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Date: April 23, 2026, revised
Our Ref: 30321425
Subject: Fiero Off-Site VAP and SVMP Installation Work Plan
RACER Pontiac North Campus, Pontiac, Michigan

Dear Ms. Stanhope,

This scope of work (SOW) describes the methods and approach for additional investigation to address current data gaps to the west and southwest of the Former Fiero Powerhouse portion of the Revitalizing Auto Communities Environmental Response (RACER) Trust Pontiac North Campus (Site) located in Pontiac, Michigan (**Figure 1**). The SOW was prepared in response to groundwater impacts on-site near the southern former Fiero Powerhouse property boundary, and an off-site location west of the former Powerhouse, that are in excess of Michigan Department of Environment, Great Lakes, and Energy (EGLE) Fiero residential site-specific vapor intrusion criteria (SSVIAC). Details regarding current site conditions and data gaps at the former Fiero Assembly and Powerhouse properties was provided to the United States Environmental Protection Agency on September 8, 2021, as the *Vapor Intrusion Conceptual Site Model* report, on February 21, 2023, as the *2021-2022 Fiero Site Investigation Summary*, and in the *Fiero Temporary Groundwater Monitoring Plan Summary* reports provided most recently in 2024 (Arcadis 2025) as well as the monthly progress meeting that took place on December 12, 2025.

The objectives of the investigation are as follows:

1. Further assess potential vapor intrusion risk to off-site receptors downgradient of the property boundary monitoring wells, MWOS-09R (off-site) and MW-02-17 (on-site).

The proposed Scope of Work includes right-of-way permitting/access agreement, utility locating, vertical aquifer profiling (VAP), soil vapor monitoring probe (SVMP) installation and sampling and monitoring well installation.

1 SCOPE OF WORK

The Scope of Work is described in the following sections. The most current groundwater analytical data and the proposed VAP, SVMP and potential monitoring well locations are summarized in **Figure 2**.

1.1 Permitting/Access Agreement

A right-of-way (ROW) permit with the City of Pontiac will be obtained for installation of one nested pair of SVMPs within the St. Clair Street public right-of-way (ROW). An access agreement will be pursued for one VAP boring proposed to be located on private property.

1.2 Utility Locating

Prior to completing drilling activities, utility clearance will be performed using a minimum of three lines of evidence, which consists of contacting MISS DIG to clear public utilities, clearing using a hand auger to a depth of 5 feet below ground surface (bgs) and using Ground Penetrating Radar (GPR) and/or electromagnetic (EM) techniques to identify private utility lines.

1.3 Vertical Aquifer Profile Borings

A total of two VAP borings will be completed to characterize and/or delineate the off-site and property boundary volatile organic compound (VOC) impacts in groundwater. One VAP will be located off-site, to the west of the former Fiero Powerhouse property and downgradient of MWOS-09R. Another VAP will be located at the southwest corner of the former Fiero Powerhouse property boundary, downgradient of MW-02-17. The proposed VAP locations would include the following:

- At each location, complete soil borings using direct-push drilling technology to approximately 40 feet bgs or until the basal clay unit is identified. Each soil boring will be logged by an Arcadis geologist and field screened with a photoionization detector (PID) in accordance with the Arcadis technical guidance information (TGI) for soil descriptions (**Attachment 1**). The location of each VAP boring will be surveyed using a GPS system to establish its location/coordinates and elevation.
- At each location, up to three groundwater samples will be collected at nominal 5-foot intervals through the saturated thickness of the sand unit beginning at the top of the observed water table. Groundwater samples will be collected after purging for approximately 10 minutes or until the water runs clear. All VAP groundwater samples will be collected using a direct-push drill rig in accordance with the Arcadis VAP Sampling TGI (**Attachment 1**).
- Groundwater samples will be submitted to Merit Laboratories, Inc. in Lansing, Michigan for analysis of VOCs with a 24-hour turnaround using the United States Environmental Protection Agency (USEPA) Method 8260C.

1.4 Soil Vapor Monitoring Probe Installation and Sampling

Additional SVMPs will be installed off-site and at the property boundary to further assess the potential risk of vapor intrusion to nearby residential properties. One nested pair will be co-located with MWOS-09R, and the other nested pair will be located just south of MW-02-17, near the property boundary. The SVMP installation and sampling will include the following:

- At two locations, install nested pairs of SVMPs (4 total) targeting just below the silt/clay interbedded unit at the top of the sand unit and just above the seasonably high-water table. Installation will be completed in accordance with the Arcadis Installation of Soil Vapor Probes TGI (**Attachment 1**). Each SVMP will be constructed of a ½” outer diameter 6” stainless steel screen attached to ¼” outer diameter nylon lined tubing that extends to the ground surface. Filter sand material will be installed from the base of the screen to 6” above its top. Dry granular bentonite will be installed 6” above the filter sand. Hydrated bentonite will be installed from the top of the dry bentonite to within 6” of ground surface. Each SVMP will be protected by a 5” steel flush-mount well cover set in a concrete pad at the ground surface. The location of each SVMP will be surveyed by a professional surveyor to establish its location/coordinates and elevation.

- The methodology for collecting soil vapor samples will include completing a helium leak test to verify the seal of the sampling point, and a “shut-in” test completed on the sampling train to verify that a closed system is in place prior to sampling. Following a passed helium leak test and shut-in test, a SUMMA® canister, with attached pre-set flow regulator, will be used to collect the sample for laboratory analysis of the Fiero site-specific VOCs in accordance with the USEPA Method TO-15. Following sampling, an additional three volumes of air will be purged into a Tedlar® bag. Oxygen, carbon dioxide, and methane readings will be collected from the Tedlar® bag containing purged air at the sample point. All soil vapor sampling will be completed in accordance with the Arcadis Sub-Slab and Soil Vapor Sampling Using Whole Air Canisters TGI (**Attachment 1**).

Soil vapor will be collected from the newly installed locations one week after installation, and then quarterly for up to four quarterly samples.

1.5 Monitoring Well Installation and Sampling

Based on the results of the VAP borings, up to two (2) permanent monitoring wells may be installed at the location of the VAP borings during this mobilization (**Figure 2**). The downgradient water table monitoring wells would potentially be installed as delineation wells if the VAP boring locations indicate groundwater concentrations are below SSVIAC criteria. A decision matrix for potential monitoring well installation is provided below as **Exhibit 1**. If VAP sampling suggests groundwater concentrations are above SSVIAC, additional VAP step outs would be completed as part of a new scope of work in consultation with USEPA.

Monitoring well installation, if completed, would include the following:

- At each location, complete soil borings using direct-push drilling technology to the pre-determined depth based on the VAP sampling analytical results. Each soil boring will be logged by an Arcadis geologist and field screened with a photoionization detector (PID) in accordance with the Arcadis technical guidance information (TGI) for soil descriptions (**Attachment 1**).
- At each location, monitoring wells will be installed using hollow stem auger drilling techniques. Each monitoring well will be constructed of 2-inch, 5-foot stainless steel wire wrapped screens, 2-inch polyvinyl chloride (PVC) risers, and flush mount protective covers. All monitoring wells will be developed using the purge and surge method approximately 24 to 48 hours after installation. All monitoring wells will be installed and developed in accordance with the Arcadis Monitoring Wells Installation TGI (**Attachment 1**).
- Following installation, each monitoring well will be surveyed by a professional surveyor to establish its location/coordinates and reference elevation.
- Groundwater samples will be collected from each monitoring well and submitted to Merit Laboratories, Inc. in Lansing, Michigan for analysis of VOCs using the United States Environmental Protection Agency (USEPA) Method 8260C. Monitoring well samples will be collected approximately 5 business days after the development is completed.

Groundwater samples will be collected in a manner consistent with the low-flow sampling techniques in the Arcadis TGI for low-flow sample collection (**Attachment 1**), and consistent with USEPA Low-Stress (or Low-Flow) Purging and Sampling Procedure (USEPA 2017). Samples will be collected using a peristaltic pump and submitted under chain of custody protocol to the analytical laboratory. Field parameters, including dissolved oxygen, oxidation-reduction potential, pH, turbidity, and specific conductivity will be monitored for stability during sampling and recorded as a field data summary. New monitoring wells will be added to the Fiero Temporary Groundwater Monitoring Plant (TGMP).

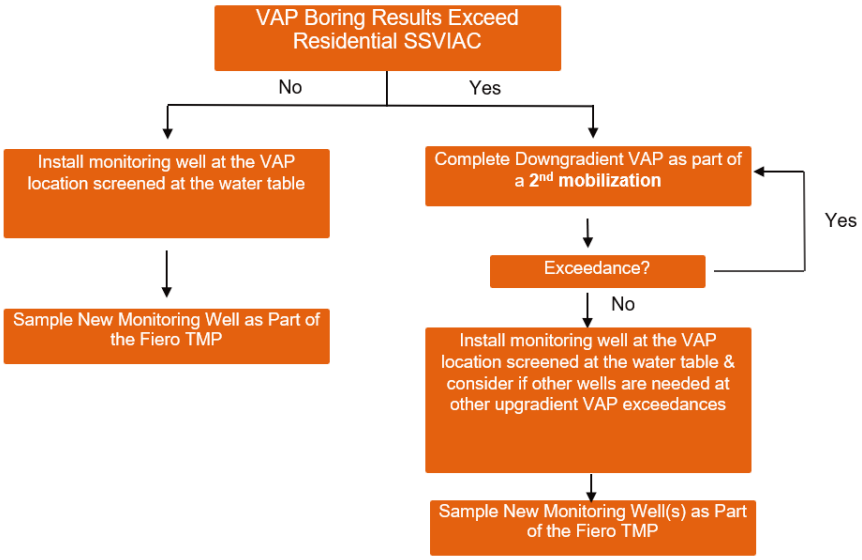

Exhibit 1. Monitoring well installation decision tree.

1.6 Analytical Methods and Quality Control

Merit Laboratories Inc. of East Lansing, Michigan will be the laboratory company supporting the environmental groundwater sample analyses and Eurofins Air Toxics, LLC/TestAmerica will be the laboratory supporting the environmental soil gas sample analyses for this project.

1.6.1 Laboratory Analytical Methods

Samples will be analyzed for the compounds identified in previous sections, including VOCs by the project laboratory by Method 8260C for groundwater and TO-15 for soil gas. Relevant laboratory Standard Operating Procedures (SOPS) are summarized below and provided in **Attachment 2.**

Index of SOPs

Laboratory SOP	Volatile Organic Compounds by Gas Chromatography/ Mass Spectrometry Method SW-846 8260C/ EPA 624.1
	Volatile Organic Compounds by Gas Chromatography/ Mass Spectrometry Method TO-15

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U.S. Environmental Protection Agency
April 23, 2026, rev.

1.6.2 Quality Assurance/Quality Control Procedures

Field Quality Assurance / Quality Control

Field Quality Assurance/Quality Control Procedures (QA/QC) samples will be collected during field sampling include:

- Field duplicate samples for groundwater and soil gas will be collected at a minimum frequency of 1 per 10 or fewer investigative samples. Field duplicate samples will be analyzed to assess the precision of the field sample collection procedures.
- Sufficient sample volume will be provided to the laboratory (as necessary) for matrix spike and spike duplicate (MS/MSD) analyses for groundwater. The data from MS/MSD analyses provides an indication of the precision and accuracy of the analytical method relative to the sample matrix. Samples for MS/MSD analysis will be designated at a minimum frequency of 1 per 20 or fewer samples.

Groundwater samples will be collected in laboratory supplied bottles and soil gas samples will be collected in laboratory provided SUMMA® canisters, packed in laboratory supplied shipping containers, and transported in accordance with the laboratory container, preservation, shipping, and packaging requirements.

Laboratory Quality Assurance / Quality Control

Laboratory QA/QC requirements for the analysis of groundwater and soil gas samples include analyzing method blanks, initial calibration verification standards, continuing calibration verification standards, MS/MSD samples, and laboratory Control Samples (LCS). The analysis frequency for these QA/QC samples is identified in the applicable laboratory SOP provided in **Attachment 2**. The acceptance criteria for these QC checks will be consistent with the analytical methods and laboratory SOP.

Laboratory Report Deliverables

Laboratory reports for samples collected will consist of the following data deliverables:

1. Case Narrative:
    a. Date of issuance
    b. Project name and number
    c. Any deviations from intended analytical strategy
    d. Condition of samples "as received"
    e. Discussion of whether sample holding times were met
    f. Discussion of technical problems or other observations that may have created analytical difficulties
    g. Discussion of any laboratory quality control checks that failed to meet project criteria
2. Chemistry Data Package:
    a. Dates of sample collection, receipt, preparation, and analysis
    b. Cross-reference of laboratory to project sample identification numbers
    c. Description of data qualifiers used
    d. Methods of sample preparation and analysis
    e. Sample results in tabular format
    f. Method blank data, surrogate data, LCS data, duplicate sample data, MS/MSD data,
    g. Fully executed chain-of-custody document

1.6.3 Data Review and Validation

Upon receipt of the final data packages from the laboratory the data will be reviewed and validated by Arcadis staff not associated with the sample collection. The data review will evaluate the final analytical results, holding time period compliance, equipment blank sample data, field duplicate sample data, method blank data, LCS data, laboratory duplicate data, surrogate compound spike data, and MS/MSD sample data. Validation of the data will consist of a Level 2 review evaluating the QA/QC data (duplicates, blanks, etc.) based on the applicable review criteria specified in " USEPA National Functional Guidelines for Organic Superfund Methods Data Review, EPA 540-R-20-005, November 2020 (with reference to the historical USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review, OSWER 9240.1-05A-P, October 1999 as appropriate)". During the data validation process the following items are checked: blanks, holding times, surrogate recoveries (when applicable), LCS/LCSD recoveries and RPDs, MS/MSD recoveries and RPDs, and field duplicate RPDs (when applicable). The results of the data review and validation process will be documented in memoranda that identify all limitations on the usability of the analytical data.

1.7 Completion Reporting

Upon completion of field activities, a completion report will be prepared and submitted in the second or third quarter of 2026 (depending on timing of installation). The completion report will include a summary of the following:

- Brief description of the field activities performed
- Boring and SVMP Construction logs
- Analytical results from the initial sampling event
- Discussion of results and path forward, including discussion of potential follow-up work required for delineation, as necessary

All quarterly follow-up sampling results for samples collected in 2026 will be summarized as part of the 2026 Fiero Annual Report.

1.8 Schedule

Subcontractor procurement for the investigation is in progress. A ROW permit application will be prepared following receipt of USEPA approval of this SOW. It is uncertain how long it will take to obtain the needed access agreement. The field activities will be implemented as soon as practical after USEPA approval, receipt of the ROW permits, an access agreement, and weather permitting. Most field activities are anticipated to be completed within four business days. Sampling of the SVMPs will occur a minimum of one week after their installation.

2 REFERENCES

Arcadis 2021. Conceptual Site Model, Pontiac North Campus Former Fiero Properties, RACER Trust, Pontiac, Michigan, August 13.

Arcadis 2023a. 2021-2022 Fiero Site Investigation Summary, Pontiac North Campus Former Fiero Properties, RACER Trust, Pontiac, Michigan, February 21.

Arcadis 2023b. 2022 Fiero Temporary Groundwater Monitoring Plan Summary, Pontiac North Campus, Pontiac, Michigan, April 21.

Arcadis 2024. 2023 Fiero Temporary Groundwater Monitoring Plan Summary, Pontiac North Campus, Pontiac, Michigan, August 14.

Arcadis 2025. 2024 Fiero Temporary Groundwater Monitoring Plan Summary, Pontiac North Campus, Pontiac, Michigan, August 08.

Sincerely,
Arcadis of Michigan, LLC

Patrick Curry
Technical Expert

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Direct Line: 810-225-1926
Mobile: 734-355-2809

Enclosures:

Figure 1 – Site Layout Map

Figure 2 – Fiero Proposed Scope of Work Locations

Attachment 1 – Arcadis TGIs

Attachment 2 – Laboratory SOPs

Figures

RAIL PARCEL
M-27
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FORMER FIERO ASSEMBLY PLANT 17
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FORMER PLANT 14S
M-18
M-10
M-20
M-34
M-19
M-7
F-9
F-10
F-15
F-14
F-11
F-1
FORMER FIERO POWERHOUSE
F-7
F-3
W-3
W-7
W-5
W-4
F-5
W-6
F-12
W-8
F-4
W-13
W-11
USPS PROPERTY
W-2
W-9
W-1
W-10
MONTCALM STREET SEEP AREA
OFF-SITE GROUNDWATER (FIERO)
HARRIS LAKE
SWDF
DUCK POND
OFF-SITE GROUNDWATER (MFD)
0
600
1,200
SCALE IN FEET

LEGEND

- CURRENT OR FORMER RACER PROPERTY BOUNDARIES
- AREAS OF INTEREST
- APPROXIMATE OFF-SITE GROUNDWATER ORDINANCE EXTENT

Service Layer Credits: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA Aerial Date: July 29, 2022

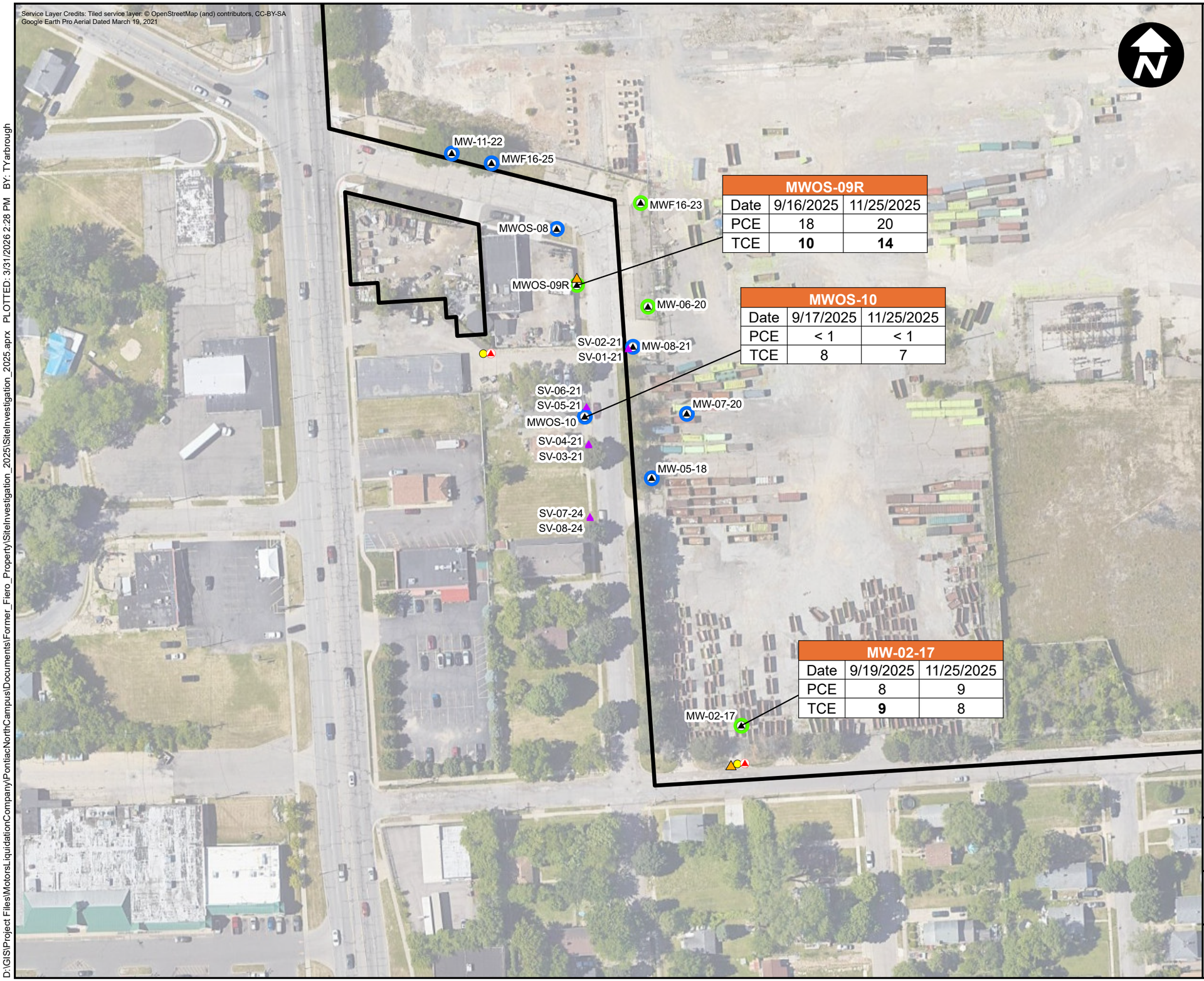
RACER TRUST
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

SITE LAYOUT MAP

ARCADIS

FIGURE
1

CITY: NOVI, MI DIV: ENV DB: TRY PIC: J. BARRETT PM: T. LINDER TM: L. NICKERSON TR: PROJECT NUMBER: COORDINATE SYSTEM: NAD 1983 StatePlane Michigan South FIPS 2113 Feet Intl
D:\GIS\Project Files\MotorsLiquidationCompany\PontiacNorthCampus\Documents\Former_Fiero_Property\FTMP_Summary2024.aprx PLOTTED: 12/18/2024 1:20 PM BY: TYarbrough



LEGEND

- PROPOSED NESTED SVMP LOCATION
- PROPOSED VAP LOCATION
- POTENTIAL PROPOSED MONITORING WELL LOCATION
- POTENTIAL PROPOSED VAP LOCATION
- EXISTING MONITORING WELL
- EXISTING SOIL VAPOR MONITORING POINT
- EXCEEDS RESIDENTIAL SSVIAC
- DOES NOT EXCEED RESIDENTIAL SSVIAC
- CURRENT OR FORMER RACER PROPERTY

VOCs	Residential SSVIAC	Nonresidential SSVIAC
PCE	**130**	*3,400*
TCE	**8.1**	*210*

NOTES:

ALL POSTED RESULTS ARE IN MICROGRAMS PER LITER (µg/L)

< - NOT DETECTED ABOVE THE LABORATORY DETECTION LIMIT

PCE - TETRACHLOROETHENE

SSVIAC - SITE-SPECIFIC VOLATILIZATION TO INDOOR AIR CRITERIA

SVMP - SOIL VAPOR MONITORING PROBE

TCE - TRICHLOROETHENE

VAP - VERTICAL AQUIFER PROFILE

VOC - VOLATILE ORGANIC CARBON

0 100 200

SCALE IN FEET

RACER TRUST
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

FIERO PROPOSED SCOPE OF WORK LOCATIONS

ARCADIS

FIGURE 2

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Attachment 1

Arcadis TGI's

TGI – Soil Description

Rev: 7

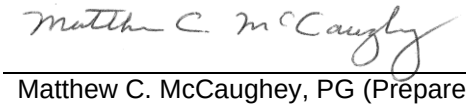
Rev Date: April 14, 2025

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	May 20, 2008	17	Original SOP	Joe Quinnan Joel Hunt
	1	September 2016	15	Updated to TGI	Nick Welty Patrick Curry
	2	February 16, 2018	15	Updated descriptions, attachments and references in text	Nick Welty Patrick Curry
	3	April 15, 2022		Minor description edits, intro of grain-size K analysis, revised boring log template	Matt McCaughey Patrick Curry
	4	June 5, 2023	All	Annual review completed by SME.	Patrick Curry
	5	June 20, 2024	All	Annual review completed/approved by Patrick Curry	Patrick Curry
	6	Mar 31, 2025	All	Annual review completed/approved by Patrick Curry	Patrick Curry
	7	April 14, 2025	All	Edits to description of plasticity	Patrick Curry

Approval Signatures

Prepared by: 4/14/2025



Matthew C. McCaughey, PG (Preparer) Date

Reviewed by: 4/14/2025

Patrick Curry, PG (Subject Matter Expert) Date

1 Introduction

This Arcadis Technical Guidance Instruction (TGI) describes proper soil description procedures based on visual inspection and testing of soil cores and samples. This document has been developed to emphasize field observation and documentation of details required to:

- Make hydrostratigraphic interpretations guided by depositional environment/geologic settings
- Provide information needed to understand the distribution of constituents of concern; properly design wells, piezometers, and/or additional field investigations; and develop appropriate remedial strategies.

2 Intended Use and Responsibilities

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.

3 Scope and Application

This TGI should be followed for unconsolidated material unless there is an established client-required specific procedure or regulatory-required specific procedure. In cases where there is a required specific procedure, it should be followed and should be referenced and/or provided as an appendix to reports that include soil classifications and/or boring logs. When following a required non-Arcadis procedure, additional information required by this TGI should be included in field notes with client approval.

This TGI incorporates elements from various standard systems such as ASTM D2488-06, Unified Soil Classification System, Burmister and Udden Wentworth. However, none of these standard systems focus specifically on contaminant hydrogeology and remedial design. Therefore, although each of these systems contain valuable guidance and information related to correct descriptions, strict application of these systems can omit information critical to our clients and the projects that we perform.

This TGI includes the following attachments:

- **Attachment A –** Field Soil Description Guide
- **Attachment B –** Particle Size System Comparison
- **Attachment C –** Description of Logging Terms
- **Attachment D –** Blank Boring Log
- **Attachment E –** Completed Boring Log

This TGI does not address details of health and safety; drilling method selection; boring log preparation; sample collection; or laboratory analysis. Refer to other Arcadis procedure, guidance, and instructional documents, the project work plans including the quality assurance project plan, sampling plan, and health and safety plan (HASP), as appropriate.

4 Personnel Qualifications

Soil descriptions should only be performed by Arcadis personnel or authorized sub-contractors with a degree in geology or a geology-related discipline. Field personnel will complete training on the Arcadis soil description TGI in the office and/or in the field under the guidance of an experienced field geologist with at least 2 years of prior experience applying the Arcadis soil description method.

5 Equipment List

The following equipment should be taken to the field to facilitate soil descriptions:

- Field book, field forms or digital devices to record soil descriptions
- Field book for supplemental notes
- This TGI for Soil Descriptions and any project-specific procedure, guidance, and/or instructional documents (if required)
- Field card showing Wentworth scale
- Munsell® soil color chart
- Tape measure divided into tenths of a foot
- Stainless steel knife or spatula
- Hand lens
- Water squirt bottle
- 4-ounce glass jars with lids (for collecting soil core samples)
- Personal protective equipment (PPE), as required by the HASP
- Digital camera

- Folding table

6 Cautions

Drilling and drilling-related hazards including subsurface utilities are discussed in other procedure documents and site-specific HASPs and are not discussed herein.

Soil samples may contain hazardous substances that can result in exposure to persons describing soils. Routes for exposure may include dermal contact, inhalation and ingestion. Refer to the project specific HASP for guidance in these situations.

7 Health and Safety Considerations

Field activities associated with soil sampling and description will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities. Know what hazardous substances may be present in the soil and understand their hazards. Always avoid the temptation to touch soils with bare hands, detect odors by placing soils close to your nose, or tasting soils.

8 Procedure

8.1 General Procedures

- Select the appropriate sampling method to obtain representative samples in accordance with the selected sub-surface exploration method, e.g., split-spoon or Shelby sample for hollow-stem drilling, acetate sleeves for direct push, bagged core for sonic drilling, etc.
- Proceed with field activities in required sequence. Although completion of soil descriptions is often not the first activity after opening sampler, identification of stratigraphic changes is often necessary to select appropriate intervals for field screening and/or selection of laboratory samples.
- Set up boring log field sheet.
    - Determine the proper units of measure. Drillers in both the US and Canada generally work in feet due to equipment specifications. Field geologists typically record drilling depths, core recovery, and sample intervals in feet and grain size in millimeters
    - Use the Arcadis standard boring log form (**Attachment D**). *Note that as of April 2022, several digital logging applications are available through the FieldNow™ program and the Fulcrum app. A future revision of this TGI, likely in early 2023, will emphasize digital logging methods and field boring log forms will no longer be acceptable. FieldNow is discussed further in Section 10.*
    - The boring log template includes a graphic log of the primary soil texture to support quick visual evaluation of grain size. The purpose of the graphic log is to quickly assess relative soil permeability. Note, for poorly sorted soils (e.g., glacial till), the principal component may not correlate to permeability of the sample. In this case, the geologist should use best judgement to graph overall soil type consistent with relative soil permeability. For example, for a dense sand/silt/clay till, the graphic log would reflect the silt/clay, rather than sand.

    - Record depths along the left-hand side at a standard scale to aid in the use of this tool.
- Examine each soil core (this is different than examining each sample selected for laboratory analysis) and record the soil conditions in accordance with guidelines provided in Section 8.2.
- At the end of the boring, record the amount of drilling fluid used (if applicable) and the total depth logged.
- At a minimum, a written or digital boring log should be prepared with the following information:
    - Describe type of surface material (asphalt, grass, topsoil, gravel, etc.)
    - Describe the type of fill or non-native soils and estimated depth to native soils
    - Record sample intervals (soil cores, environmental and/or geotechnical samples)
    - Describe soil conditions in accordance with this TGI
    - Record moisture content and estimated depth to water table or saturated zone
    - Record the total depth and document why drilling was stopped (refusal, target depth achieved, etc.)

8.2 Soil Description Procedures

The standard soil description order is presented below.

- Depth
- PRIMARY TEXTURE
- Principal and Minor Components with Descriptors
    - % Modifiers and grain size fraction
    - Angularity for very coarse sand and larger particles
    - Consistency or Density
    - Plasticity for clay and clay mixtures
    - Dilatancy for silt and silt-sand mixtures
- Sorting
- Moisture Content
- Color
- Notes

Depth. To measure and record the depth below ground surface (bgs) of top and bottom of each stratum, the following information should be recorded.

- Measured depth to the top and bottom of sampled interval. Use starting depth of sample based upon measured tool length information and the length of sample interval.
- Length of sample recovered, not including slough (material that has fallen into hole from previous interval), expressed as fraction with length of recovered sample as numerator over length of sampled interval as denominator (e.g., 36/60 for 36 inches recovered from 5-ft [60-inch] sampling interval).
- Thickness of each stratum measured sequentially from the top of recovery to the bottom of recovery.
- Any observations of sample condition or drilling activity that would help identify whether there was loss from the top of the sampling interval, loss from the bottom of the sampling interval, or compression of the sampling interval. Examples: 14/24, gravel in nose of spoon; or 36/60 bottom 12 inches of core empty.

Determination of Components. Obtain a representative sample of soil from a single stratum. If multiple strata are present in a single sample interval, each stratum should be described separately. More specifically, if the sample is from a 2-foot-long split-spoon where strata of coarse sand, fine sand and clay are present, then the resultant description should be of the three individual strata unless a combined description can clearly describe the interbedded nature of the three strata. Example: SAND, fine; with interbedded lenses of Silt and Clay, ranging between 1 and 3 inches thick.

Identify principal component and express volume estimates for minor components on logs using the following standard modifiers.

Modifier	Percent of Total Sample (by volume)
and	36 – 50
some	21 - 35
little	10 - 20
trace	<10

Determination of components is based on using the Udden-Wentworth particle size classification (see below) and measurement of the average grain size diameter. Each size class differs from the next larger class by a constant ratio of ½. Due to visual limitations, the finer classifications of Wentworth's scale cannot be distinguished in the field and the subgroups are not included. Visual determinations in the field should be made carefully by comparing the sample to the Soil Description Field Guide (**Attachment A**) that shows Udden-Wentworth scale or by measuring with a ruler.

The following table summarized the modified Udden-Wentworth Scale for grain size classification. Note that gravel is a size category encompassing the granule, pebble, cobble, and boulder size classes.

Udden-Wentworth Scale (Modified by Arcadis, 2008)				
Size Category	**Size Class**	**Millimeters**	**Inches**	**Standard Sieve #**
Gravel (Cobble)	Boulder	256 – 4096	10.08+	
	Large cobble	128 - 256	5.04 -10.08	
	Small cobble	64 - 128	2.52 – 5.04	
Gravel (Pebble)	Very large pebble	32 – 64	0.16 - 2.52	
	Large pebble	16 – 32	0.63 – 1.26	
	Medium pebble	8 – 16	0.31 – 0.63	
	Small pebble	4 – 8	0.16 – 0.31	No. 5 +
	Granule	2 – 4	0.08 – 0.16	No.5 – No.10

Sand	Very coarse sand	1 -2	0.04 – 0.08	No.10 – No.18
	Coarse sand	½ - 1	0.02 – 0.04	No.18 - No.35
	Medium sand	¼ - ½	0.01 – 0.02	No.35 - No.60
	Fine sand	1/8 -¼	0.005 – 0.1	No.60 - No.120
	Very fine sand	1/16 – 1/8	0.002 – 0.005	No. 120 – No. 230
Fines	Silt (subgroups not included)	1/256 – 1/16	0.0002 – 0.002	Not applicable (analyze by pipette or hydrometer)
	Clay (subgroups not included	1/2048 – 1/256	0.00002 – 0.0002	

Identify components as follows. Remove particles greater than very large pebbles (64-mm diameter) from the soil sample. Record the volume estimate of the greater than very large pebbles. Examine the sample fraction of very large pebbles and smaller particles and estimate the volume percentage of the pebbles, granules, sand, silt and clay. Use the jar method, visual method, and/or wash method (Appendix X4 of ASTM D2488) to estimate the volume percentages of each category.

Sieve and hydrometer grain-size analysis can be used to vet the visual description, as well as used to estimate hydraulic conductivity. Lab or field sieve analysis is advisable to characterize the variability and facies trends within each hydrostratigraphic unit. It is recommended that sieve-hydrometer analysis be performed on representative samples from each soil type to estimate the fraction of each grain size category using ASTM D422 Standard Test Method for Particle-Size Analysis of Soils. If desired sieve sizes can be specified to follow the Udden-Wentworth classification (U.S. Standard sieve sizes 6; 12; 20; 40; 70; 140; and 270) to retain pebbles; granules; very coarse sand; coarse sand; medium sand; fine sand; and very fine sand, respectively.

Several empirical formulas provide a reliable means of estimating hydraulic conductivity (K) from grain-size distribution data, provided that the formation does not contain abundant fines that result in cohesive or plastic behavior or include cobble-sized grains (Payne et al. 2008). Grain-size analysis can help bracket the permeability of hydrostratigraphic units (HSUs) and identify order-of-magnitude spatial variations in K. Arcadis has completed modifications to the Excel-based program HydroGeoSieveXL (Devlin 2015) to process sieve data quickly and estimate K. The tool calculates estimated K values from grain-size data using 15 different empirical formulas. A decision matrix then selects which of the formulas is relevant for the soil type and calculates an average K.

Principal Component. The principal component is the size fraction or range of size fractions containing the majority of the volume. Examples: the principal component in a sample that contained 55% small to medium pebbles would be “PEBBLES, small to medium”; or the principal component in a sample that was 20% fine sand, 30% medium sand and 25% coarse sand would be “SAND, fine to coarse” or for a sample that was 40% silt and 45% clay the principal component would be “CLAY and SILT”.

The boring log form (**Appendix D**) includes a graphic log to visually illustrate a relative estimate of soil permeability. To use the graphic log, place an ‘X’ or shade the appropriate column for the primary soil texture. If the soils have a high percentage of a secondary soil texture (i.e., when the ‘and’ modifier’ is used), it’s acceptable to mark off the appropriate column for the secondary soil texture in this instance. However, care should be used to avoid marking off the columns for other minor soil textures because doing so will make it difficult to determine the relative soil permeability of the poorly sorted soils.

As noted above, for poorly sorted soils such as glacial till, the principal component may not correlate to permeability of the sample. In this case, the geologist should use best judgement to graph overall soil type consistent with relative soil permeability.

Minor Component(s). The minor component(s) are the size fraction(s) containing less than 50% volume. Example: the identified components are estimated to be 60% medium sand to granules, 25% silt and clay; 15% pebbles – there are two identified minor components: silt and clay; and pebbles.

Include a standard modifier to indicate percentage of minor components (see particle size table) and the same descriptors that would be used for a principal component. An example of minor constituents with modifiers include: some silt and clay, low plasticity; little medium to large pebbles, sub-round.

8.2.1 Secondary Descriptors

The following are the descriptors used outside of the principal and minor components. Note that plasticity should be provided as a descriptor for clay and clay mixtures. Dilatancy should be provided for silt and silt mixtures. Angularity should be provided as a descriptor for pebbles and coarse sand.

Angularity. Describe the angularity for very coarse sand and larger particles in accordance with the table below (ASTM D-2488-06). Figures showing examples of angularity are available in ASTM D-2488-06 and the Arcadis Soil Description Field Guide (**Appendix B**).

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Sub-Angular	Particles are like angular description but have rounded edges
Sub-Rounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges.

Plasticity. Describe the plasticity for clay and clay mixtures based on observations made during the following test method (ASTM D-2488-06).

- As in the dilatancy test (described below), select enough material to mold into a ball about ½ inch (12 mm) in diameter. Mold the material, adding water, if necessary, until it has a soft, but not sticky, consistency.
- Shape the test specimen into an elongated pat and roll by hand on a smooth surface or between the palms into a thread about 1/8 inch (3 mm) in diameter. If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation. Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about 1/8 inch. The thread will crumble when the soil is near the plastic limit.

Description	Criteria
Non-plastic	A 1/8-inch (3 mm) thread cannot be rolled at any water content.
Low	The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Dilatancy. Describe the dilatancy for silt and silt-sand mixtures using the following field test method (ASTM D-2488-06).

- From the specimen, select enough material to mold into a ball about ½ inch (12 mm) in diameter. Mold the material adding water, if necessary, until it has a soft, but not sticky, consistency.
- Smooth the ball in the palm of one hand with a small spatula.
- Shake horizontally, striking the side of the hand vigorously with the other hand several times.
- Note the reaction of water appearing on the surface of the soil.
- Squeeze the sample by closing the hand or pinching the soil between the fingers, and not the reaction as none, slow, or rapid in accordance with the table below. The reaction is the speed with which water appears while shaking and disappears while squeezing.

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

Note that silt and silt-sand mixtures will be non-plastic and display dilatancy. Clay mixtures will have some degree of plasticity but do not typically react to dilatancy testing. Therefore, the tests outlined above can be used to differentiate between silt-dominated and clay-dominated soils.

Sorting. Sorting is the opposite of grading, which is a commonly used term in the USCS or ASTM methods to describe the uniformity of the particle size distribution in a sample. Well-sorted samples are poorly graded and poorly sorted samples are well graded. Arcadis prefers the use of sorting for particle size distributions and grading to describe particle size distribution trends in the vertical profile of a sample or hydrostratigraphic unit because of

the relationship between sorting and the energy of the depositional process. For soils with sand-sized or larger particles, sorting should be determined as follows:

Description	Criteria
Well Sorted	the range of particle sizes is limited (e.g., the sample is comprised of predominantly one or two grain sizes)
Poorly Sorted	A wide range of particle sizes are present

You can also use sieve analysis to estimate sorting from a sedimentological perspective; sorting is the statistical equivalent of standard deviation. Smaller standard deviations correspond to higher degree of sorting (see Remediation Hydraulics, 2008).

Consistency or Density. This can be determined by standard penetration test (SPT) blow counts (ASTM D-1586) obtained when using hollow-stem auger drilling methods and a split spoon sampling device. Otherwise, some field tests are available as outlined below. When drilling with hollow-stem augers and split-spoon sampling, the SPT blow counts and N-value is used to estimate density. The N-value is the blows per foot for the 6" to 18" interval. For example, for a 24-inch split spoon soil core, the recorded blows per 6-inch interval are: 4/6/9/22. Since the second interval is 6" to 12", the third interval is 12" to 18", the N value is 6+9, or 15. Fifty blow counts for less than 6 inches is considered refusal. In recent years, more common drilling methods include rotary-sonic or direct push. When blow counts are not available, density is determined using a thumb test. Note however, the thumb test only applies to fine-grained soils.

Fine-grained soil – Consistency

Description	Criteria	Blow Counts (6-12 to 12-18-inch split spoon interval)
Very soft	Easily penetrated several inches by thumb	N-value < 2
Soft	Easily penetrated one inch by thumb	N-value 2-4
Medium Stiff	Indented about ½ inch with much effort	N-value 5-8
Stiff	Indented with ¼ inch with great effort	N-value 9-15
Very Stiff	Readily indented by thumbnail	N-value 16-30
Hard	Indented by thumbnail with difficulty	N-value > than 30

Coarse-grained soil – Density

Description	Criteria	Blow Counts (6-12 to 12-18-inch split spoon interval)
Very loose	Density classification of coarse-grained soils is only required when blow counts from standard penetration tests are performed during hollow-stem auger drilling	N-value 1- 4
Loose		N-value 5-10
Medium dense		N-value 11-30
Dense		N-value 31- 50
Very dense		N-value >50

Moisture Content. Moisture content should be described for each soil sample in accordance with the table below (percentages should not be used unless determined in the laboratory). *Note that some drilling methods (e.g., sonic) can compress and dry out the sample during drilling. Therefore, it can be difficult to determine if a sample is saturated, or merely moist. In this case, care should be taken to try and determine a static water level within the borehole by measuring depth to water through the drill casing, if possible.*

Description	Criteria
Dry	Absence of moisture, dry to touch, dusty
Moist	Damp but no visible water
Wet	Visibly free water

Color. Color should be described using simple basic terminology and modifiers based on the Munsell system. Munsell alpha-numeric codes are required for all samples. If the sample contains layers or patches of varying colors this should be noted, and all representative colors should be described. The colors should be described for moist samples. If the sample is dry, it should be wetted prior to comparing the sample to the Munsell chart.

Notes. Additional comments should be made where observed and should be presented as notes with reference to a specific depth interval(s) to which they apply. Some of the significant information that may be observed includes the following.

- Odor - You should not make an effort to smell samples by placing near your nose since this can result in unnecessary exposure to hazardous materials. However, odors should be noted if they are detected during the normal sampling procedures. Odors should be based upon descriptors such as those used in NIOSH “Pocket Guide to Chemical Hazards”, e.g., “pungent” or “sweet” and should not indicate specific chemicals such as “phenol-like” odor or “BTEX” odor.
- Structure
- Bedding planes (laminated, banded, geologic contacts).
- Presence of roots, root holes, organic material, man-made materials, minerals, etc.
- Mineralogy

- Cementation
- NAPL presence/characteristics, including sheen (based on client-specific guidance).
- Reaction with HCl - typically only used for special soil conditions, such as caliche environments.
- Origin, if known (Lacustrine; Fill; etc.).

8.3 Example of Soil Descriptions

The standard generic description order is presented below.

- Depth
- PRIMARY TEXTURE
- Principal and Minor Components with Descriptors
    - % Modifiers and grain size fraction
    - Angularity for very coarse sand and larger particles
    - Consistency or Density
    - Plasticity for clay or clay mixtures
    - Dilatancy for silt and silt-sand mixtures
- Sorting
- Moisture Content
- Color
- Notes

10-15 feet CLAY, trace silt, trace small to very large pebbles, subround to subangular up to 2" diameter; medium to high plasticity, stiff, moist, dark grayish brown (10YR 4/2). NOTE: Lacustrine; laminated 0.1 to 0.2" thick, laminations brownish yellow (10YR 4/3).

10 -15 feet SAND, medium to very coarse, little granules to medium pebbles, subround to subangular, trace silt; poorly sorted, wet, grayish brown (10YR5/2).

Unlike the first example where a density of cohesive soils could be estimated, this rotary-sonic sand and pebble sample was disturbed during drilling (due to vibrations in a loose sand and pebble matrix) so no density description could be provided. Neither sample had noticeable odor so odor comments were not included.

9 Waste Management

Project-specific requirements should be identified and followed. The following procedures, or similar waste management procedures are generally required.

Water generated during cleaning procedures will be collected and contained onsite in appropriate containers for future analysis and appropriate disposal. PPE (such as gloves, disposable clothing, and other disposable equipment) resulting from personnel cleaning procedures and soil sampling/handling activities will be placed in plastic bags. These bags will be transferred into appropriately labeled 55-gallon drums or a covered roll-off box for appropriate disposal.

Soil materials will be placed in sealed 55-gallon steel drums or covered roll-off boxes and stored in a secured area. Once full, the material will be analyzed to determine the appropriate disposal method.

10 Data Recording and Management

10.1 Digital Data Collection Process Overview

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

10.2 Digital Data Collection Tools for Soil Descriptions

Arcadis is transitioning from the use of paper forms to a digital soil description logging process using web-based FieldNow applications accessible on field tablets and smart phones. Company-wide roll out of a FieldNow application for soil descriptions is targeted by the end of 2022.

Paper forms are included in Revision 3 (April 2022) of this Soil Description TGI. Specifically, a blank boring log and completed boring log are provided in **Attachment D** and **Attachment E**. Additional guidance and examples of the digital data collection tools for soil descriptions will be provided in the next revision to this TGI.

10.3 Additional Guidance

The general logging scheme for soil descriptions is described in this document. Depending on project data quality objectives, specific soil description parameters that are not applicable to project goals may be omitted at the project manager's discretion. In any case, use of consistent procedures is required.

Completed logs and/or logbook will be maintained in the task/project field records file. Digital photographs of typical soil types observed at the site and any unusual features should be obtained whenever possible. Photographs should include a ruler or common object for scale. Photo location, depth and orientation must be recorded in the daily log or logbook and a label showing this information in the photo is useful.

For projects involving soil logging and soil sampling, the soil sample should be recorded on the Arcadis boring log form and the field logbook based on Data Quality Objectives for the task/project.

11 Quality Assurance

Soil descriptions should be completed only by appropriately trained personnel. Descriptions should be reviewed by an experienced field geologist for content, format and consistency. Edited boring logs should be reviewed by the original author to assure that content has not changed.

12 References

ASTM D-1586, Test Method for Penetration Test and Split-Barrel Sampling of Soils.

ASTM D-2488-00, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)

ASTM D422, 63rd Edition, 1972 - Standard Test Method for Particle-Size Analysis of Soils.

Devlin, J.F. 2015. HydroGeoSieve XL: an Excel-based tool to estimate hydraulic conductivity from grain-size analysis. Hydrogeology Journal, DOI 10.1007/s10040-015-1255-0.

Folk, Robert L. 1980. Petrology of Sedimentary Rocks, p. 1-48.

Payne, F. C., Quinnan, J. A., & Potter, S. T. 2008. Remediation Hydraulics. Boca Raton: FL: CRC Press.

United States Bureau of Reclamation. Engineering Geology Field Manual. United States Department of Interior, Bureau of Reclamation. http://www.usbr.gov/pmts/geology/fieldmap.htm.

Munsell® Color Chart – available from Forestry Suppliers, Inc.- Item 77341 “Munsell® Color Soil Color Charts.

Field Gauge Card that Shows Udden-Wentworth scale – available from Forestry Suppliers, Inc. – Item 77332 “Sand Grain Sizing Folder.”

NIOSH Pocket Guide to Chemical Hazards.

Attachment A

Soil Field Reference Guide

The purpose of this attachment is to present a field reference guide for use during soil logging. Field staff are encouraged to bring a laminated copy of this reference guide into the job site.

SOIL DESCRIPTION FIELD GUIDE (APRIL, 2022; REV. 3.0)

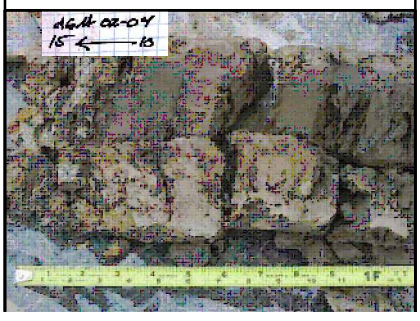
ARCADIS Design & Consultancy for natural and built assets

FINE-GRAINED SOILS

Description	Criteria
	Descriptor - Plasticity
Nonplastic	A 1/8-inch (3 mm) thread cannot be rolled at any water content.
Low	The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.
	Descriptor - Dilatancy
No Dilatancy	No visible change when shaken or squeezed.
Slow	Water appears slowly on the surface of soil during shaking and does not disappear or disappears slowly when squeezed.
Rapid	Water appears quickly on surface of soil during shaking and disappears quickly when squeezed.
Minor Components with Descriptors	
	Moisture
Dry	Absence of moisture, dry to touch, dusty.
Moist	Damp but no visible water.
Wet	Visible free water; soil is usually below the water table. (Saturated)
	Consistency
Very soft	N-value < 2 or easily penetrated several inches by thumb.
Soft	N-value 2-4 or easily penetrated 1 inch by thumb.
Medium stiff	N-value 5-8 or indented about 1/2 inch by thumb with great effort.
Stiff	N-value 9-15 or indented about 1/4 inch by thumb with great effort.
Very stiff	N-value 16-30 or readily indented by thumb nail.
Hard	N-value > than 30 or indented by thumbnail with difficulty.
Color using Munsell	
Geologic Origin (if known)	
Other	

EXAMPLE OF SOIL DESCRIPTION AND PHOTO

10-15 feet CLAY, trace silt, trace small to very large pebbles, subround to subangular up to 2" diameter; medium to high plasticity, stiff, moist, dark grayish brown (10YR 4/2). NOTE: Lacustrine; laminated 0.1 to 0.2" thick, laminations brownish yellow (10YR 4/3).



DESCRIPTION ORDER

Depth Interval
PRIMARY TEXTURE (e.g., SAND)
Principal and Minor Components with Descriptors:
- % Modifiers and grain size fraction
- Angularity coarse sand and larger
- Consistency or Density
- Plasticity for silt and clay
- Dilatancy for silt and silt-sand

Sorting for granular sediments
Moisture Content
Color
Other NOTES

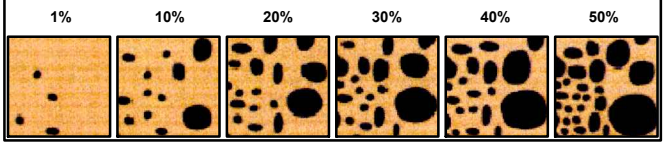
MINOR COMPONENTS % MODIFIERS

Modifier	Percent of Total Sample (by volume)
and	36 - 50
some	21 - 35
little	10 - 20
trace	<10

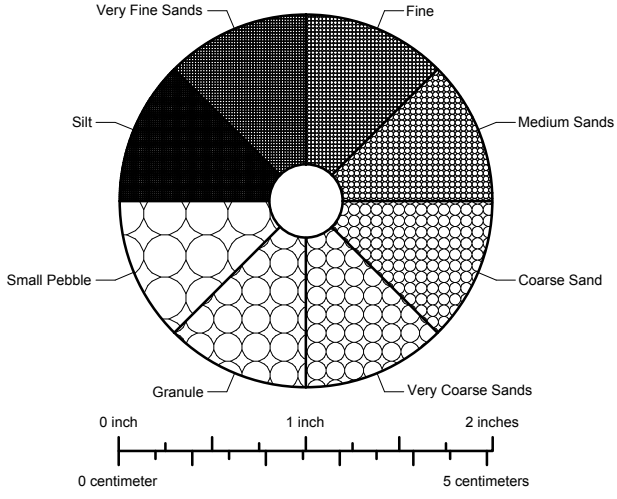
UDDEN-WENTWORTH SCALE

Fraction	Sieve Size	Grain Size	Approximate Scale
Boulder		256 - 4096 mm	Larger than volleyball
Large Cobble		128 - 256 mm	Softball to volleyball
Small Cobble		64 - 128 mm	Pool ball to softball
Very Large Pebble		32 - 64 mm	Pinball to pool ball
Large Pebble		16 - 32 mm	Dime size to pinball
Medium Pebble		8 - 16 mm	Pencil eraser to dime size
Small Pebble	No. 5+	4 - 8 mm	Pea size to pencil eraser
Granule	No. 10 - 5	2 - 4 mm	Rock salt to pea size
Very Coarse Sand	No. 18 - 10	1 - 2 mm	See field gauge card
Coarse Sand	No. 35 -18	0.5 - 1 mm	See field gauge card
Medium Sand	No. 60 - 35	0.25 - 0.5 mm	See field gauge card
Fine Sand	No. 120 - 60	0.125 - 0.25 mm	See field gauge card
Very Fine Sand	No. 230 - 120	0.0625 - 0.125 mm	See field gauge card
Silt and Clay. See SOP for description of fines	Not Applicable	<0.0625 mm	Analyze by pipette or hydrometer

PARTICLE PERCENT COMPOSITION ESTIMATION



GRAPH FOR DETERMINING SIZE OF PARTICLES



FOR COARSE-GRAINED SOILS

Description	Criteria
	Descriptor - Angularity
Angular	Particles have sharp edges and relatively planar sides withunpolished surfaces.
Subangular	Particles are similar to angular but have rounded edges.
Subround	Particles have nearly planar sides but have well-roundedcorners and edges.
Round	Particles have smoothly curved sides and no edges.
Minor Components with Descriptors	
	Sorting Cu= d60/d10
Well Sorted	Near uniform grain-size distribution Cu= 1 to 3.
Poorly Sorted	Wide range of grain size Cu= 4 to 6.
	Moisture
Dry	Absence of moisture, dry to touch, dusty.
Moist	Damp but no visible water.
Wet	Visible free water; soil is usually below the water table. (Saturated)
	Density
Very loose	N-value 1 - 4
Loose	N-value 5 - 10
Medium Dense	N-value 11 - 30
Dense	N-value 31 - 50
Very dense	N-value >50
Color using Munsell	
Geologic Origin (if known)	
Other	
	Cementation
Weak Cementation	Crumbles or breaks with handling or little finger pressure.
Moderate Cementation	Crumbles or breaks with considerable finger pressure.
Strong Cementation	Will not crumble with finger pressure.
	Reaction with Dilute HCl Solution (10%)
No Reaction	No visible reaction.
Weak Reaction	Some reaction, with bubbles forming slowly.
Strong Reaction	Violent reaction, with bubbles forming immediately.

EXAMPLE OF SOIL DESCRIPTION AND PHOTO

10 -15 feet SAND, medium to very coarse, little granules to medium pebbles, subround to subangular, trace silt; poorly sorted, wet, grayish brown (10YR 5/2).

SOIL DESCRIPTION FIELD GUIDE (APRIL, 2022; REV. 3.0)

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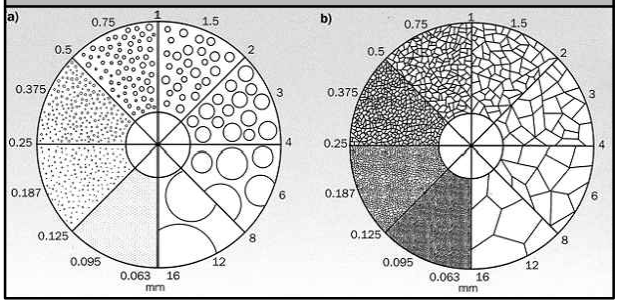
VARIATIONS IN SOIL STRATIGRAPHY

Term	Thickness of Configuration
Parting	0 - to 1/16-inch thickness.
Seam	1/16 - to 1/2-inch thickness.
Layer	1/2 - to 12-inch thickness.
Stratum	> 12-inch thickness.
Pocket	Small erratic deposit, usually less than 1 foot in size.
Varved Clay	Alternating seams or layers of sand, silt, and clay (laminated).
Occasional	≤ 1 foot thick.
Frequent	> 1 foot thick.

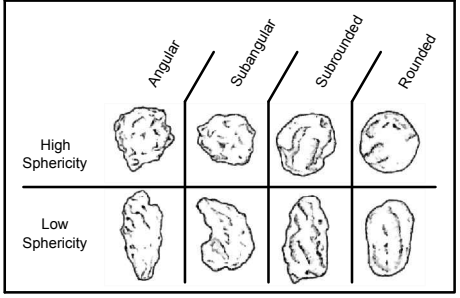
SOIL STRUCTURE DESCRIPTIONS

Term	Description
Homogeneous	Same color and appearance throughout.
Laminated	Alternating layers < 1/4 inch thick.
Stratified	Alternating layers ≥ 1/4 inch thick.
Lensed	Inclusions of small pockets of different materials, such as lenses of sand scattered through a mass of clay; note thickness.
Blocky	Cohesive soil can be broken down into small angular lumps, which resist further breakdown.
Fissured	Breaks along definite planes of fracture with little resistance to fracturing.
Slickensided	Fracture planes appear to be polished or glossy, sometimes striated.

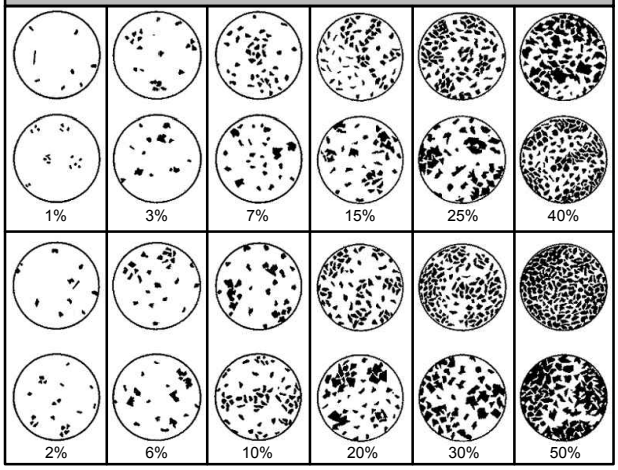
GRAPH FOR DETERMINING SIZE OF PARTICLES



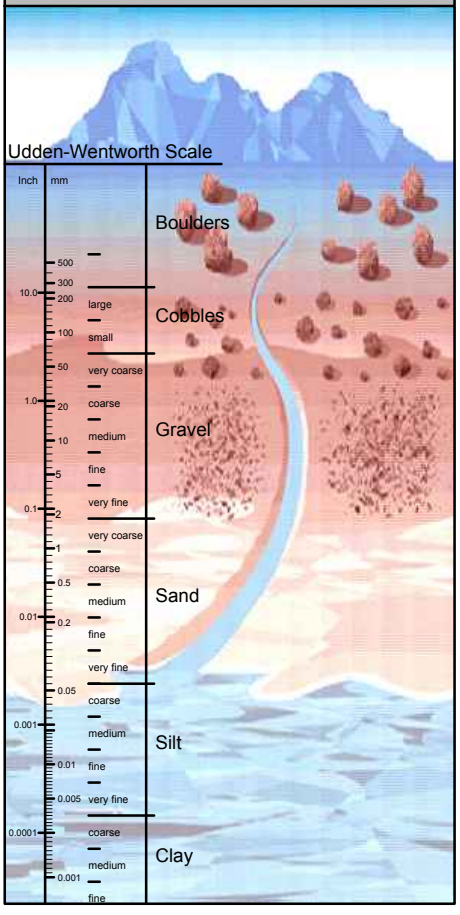
ANGULARITY CHART



PARTICLE PERCENT COMPOSITION ESTIMATION



SORTING



SETTLING TABLE (SILT/CLAY)

Diameter of Particle (mm)	<0.625	<0.031	<0.016	<0.008	<0.004	<0.002	<0.0005
Depth of Withdrawal (cm)	10	10	10	10	5	5	3
Time of Withdrawal	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec	hr:min:sec
Temperature (Celsius)							
20	00:00:29	00:01:55	00:07:40	00:30:40	00:61:19	04:05:00	37:21:00
21	00:00:28	00:01:52	00:07:29	00:29:58	00:59:50	04:00:00	
22	00:00:27	00:01:50	00:07:18	00:29:13	00:58:22	03:54:00	
23	00:00:27	00:01:47	00:07:08	00:28:34	00:57:05	03:48:00	
24	00:00:26	00:01:45	00:06:58	00:27:52	00:55:41	03:43:00	33:56:00
25	00:00:25	00:01:42	00:06:48	00:27:14	00:54:25	03:38:00	
26	00:00:25	00:01:40	00:06:39	00:26:38	00:53:12	03:33:00	
27	00:00:24	00:01:38	00:06:31	00:26:02	00:52:02	03:28:00	
28	00:00:24	00:01:35	00:06:22	00:25:28	00:50:52	03:24:00	31:00:00
29	00:00:23	00:01:33	00:06:13	00:24:53	00:49:42	03:10:00	
30	00:00:23	00:01:31	00:06:06	00:24:22	00:48:42	03:05:00	

Attachment B

Particle Size System Comparison

The purpose of this attachment is to illustrate how the Udden-Wentworth particle sizes and descriptive terms compares to other particle size systems.

When in the field, it is a customary practice to compare current soil descriptions to historical soil boring logs for reference purposes. When reviewing boring logs prepared by others, field staff should first note the particle size system used and recognize these particle size systems may differ. This will avoid confusion when cross referencing between historical and new boring logs and when reviewing existing geologic cross-sections.

For example, a well-sorted sand with grain sizes ranging from 1 to 2 mm should be classified as a very coarse sand by the Udden-Wentworth system. As shown in this attachment, the same particle size would be classified as a medium sand by the United Soil Classification System. The later system has fewer particle size grades and in general, is less descriptive than the Udden-Wentworth system.

PARTICLE SIZE SYSTEM COMPARISON

Grain size distribution in millimeters (mm)

Udden-Wentworth — Remediation Geologists and Engineers

		V. Fine	Fine	Medium	Coarse	V. Coarse	Granule	Pebbles				Cobbles		
								Small	Medium	Large	V. Large	Small	Large	
CLAY	SILT	SAND					GRAVEL							
0.039	0.065	0.125	0.25	0.5	1	2	4	8	16	32	64	128	256	
	1/16	1/8	1/4	1/2										

United Soil Classification System — Geotechnical Engineers

		Fine	Medium	Coarse	Fine	Coarse	
CLAY	SILT	SAND			GRAVEL		COBBLE
	0.074	0.42		2	4.75	19	75	300

U.S. Dept. of Agriculture — Soil Scientists

		V. Fine	Fine	Medium	Coarse	V. Coarse	
CLAY	SILT	SAND					GRAVEL
0.002	0.05	0.10	0.25	0.5	1	2	75

Remediation Hydraulics 2008, page 195): The Udden-Wentworth scale is preferred "...because the geometric progression of grain-size diameter also reflects relationships that are important when considering the erosion and deposition of sediments during the depositional process. The correlation between increasing grain size and degree of sorting and permeability is the most important, as permeability structure is responsible for the mobile and immobile porosity within aquifer systems. "

Attachment C

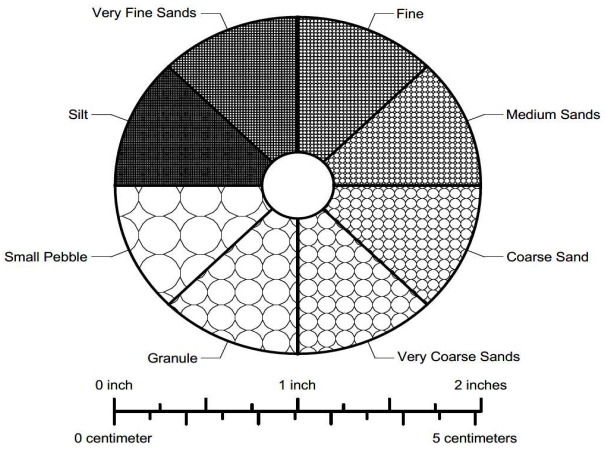
Description of Soil Logging Terms

The purpose of this attachment is to concisely define the soil logging terms used when filling out boring logs. During report preparation, project staff could use this sheet as an index placed in front of the completed boring logs. Also, it can serve as a supplemental reference sheet during field activities.

Description of Logging Terms

Note: Soil descriptions based on Arcadis Technical Guidance and Instructions (TGI) procedures. Key terms defined below.

GRAPH FOR DETERMINING SIZE OF PARTICLES



Udden Wentworth Soil Sizes

Boulder	> 256 mm
Large Cobble	128 to 256 mm
Small Cobble	64 to 128 mm
Very Large Pebble	32 to 64 mm
Large Pebble	16 to 32 mm
Medium Pebble	8 to 16 mm
Small Pebble	4 to 8 mm
Granule	2 to 4 mm
Very Coarse Sand	1 to 2 mm
Coarse Sand	0.5 to 1 mm
Medium Sand	0.25 to 0.5 mm
Fine Sand	0.125 to 0.25 mm
Very Fine Sand	0.062 to 0.12 mm
Silt/Clay	<0.065 mm

Primary Texture *(e.g. CLAY, SILT, SAND, GRANULE, PEAT, MUCK, FILL, etc.)*
List particle size with the highest percentage per sample interval (e.g. SAND)
Always CAPITALIZE the primary texture
Follow primary texture with a comma followed by grain-size descriptors, etc.

Minor Texture

And	(36 to 50%)
Some	(21 to 35%)
Little	(10 to 20%)
Trace	(>10%)

Angularity

Angular	Sharp edges
Sub-Angular	Rounded edges
Sub-Rounded	Well-rounded
Rounded	Smooth curved edges

Sand Density (Blow Counts/ft)

Very Loose	0-4
Loose	5-10
Medium Dense	11-30
Dense	31-50
Very Dense	<50

Silt/Clay Consistency (Blow Counts/ft)

Very Soft	0-2,	thumb easily penetrates several inches
Soft	3-4,	thumb easily penetrates one inch
Medium Stiff	5-8,	thumb indents 0.5 in. with much effort
Stiff	9-15,	thumb indents 0.25 in. with great effort
Very Stiff	16-30,	thumbnail is readily intended

Sorting

Well Sorted	1 to 3 Particle Sizes
Poorly Sorted	4+ Particle Sizes

Moisture Content

Dry	Dry to touch
Moist	No visible water
Wet	Visible free water

Plasticity (for silts and clays)

Non-Plastic	3 mm thread can not be rolled
Low Plasticity	3 mm thread can barely be rolled
Medium Plasticity	3 mm thread can easily and quickly rolled, but not rerolled
High Plasticity	3 mm thread can be rolled slowly, but can be rerolled

Dilatancy (for silts and silt-sand mixtures)

None	No visible change in the specimen
Slow	Water appears slowly during shaking / disappears slowly or not at all upon squeezing
Rapid	Water appears quickly during shaking / disappears quickly upon squeezing

Example Description

10 -15 feet SAND, medium to very coarse, little granules to medium pebbles, subround to subangular, trace silt; poorly sorted, wet, grayish brown (10YR5/2).

Attachment D

Blank Boring Log

The purpose of this attachment is to present a blank field form for use during soil logging. A digital version (Microsoft Excel) of this field form is available from the authors (upon request). If project specific modifications to this boring log template are warranted, please contact the Site Investigation Community of Practice leader for further assistance.

BORING LOG

ARCADIS

Boring ID:		**Project Name:**		**Page:**	/
Permit ID:		**Date Started:**		**Ground Elevation:**	
Site Address:		**Date Completed:**		**Vertical Datum:**	
City, State:		**Total Depth:**		**Northing:**	
Drilling Co:		**Depth to Water:**		**Easting:**	
Driller:		**Hole Diameter:**		**Horizontal Datum:**	
Drilling Method:		**Core Device:**		**Prepared by:**	
Boring Status:		**Drilling Fluid:**		**Reviewed by:**	

Drilling Information				Graphical Log for Primary Texture									Soil Description (Udden-Wentworth System)	Field Notes
				Fines		Sand					Gravel			
Drilling Depth (ft bgs)	Core Interval (ft)	Core Recovery (inches)	Vapor Reading (ppm)	clay	silt	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble	boulder	Depth Interval (ft), PRIMARY TEXTURE, Principal and Minor Components with Descriptors (% modifiers and grain size fraction, angularity for coarse sand and larger); Consistency/Density, Plasticity (clay or clay mix) or Dilatancy (silt/silt-sand), Sorting, Moisture Content, Color. NOTES: *Texture Modifiers: Trace (<10%), Little (10 to 20%), Some (21 to 35%), And (36 to 50%)*	Driller's Observations, Geologic Formation, Field Screening Results, Sample Interval etc.

BORING LOG

Boring ID: _____ **Project Name:** _____ **Page:** / _____

Drilling Information				Graphical Log for Primary Texture										Soil Description (Udden-Wentworth System)	Field Notes
				Fines		Sand					Gravel				
Drilling Depth (ft bgs)	Core Interval (ft)	Core Recovery (inches)	Vapor Reading (ppm)	clay	silt	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble	boulder	Depth Interval (ft), PRIMARY TEXTURE, Principal and Minor Components with Descriptors (% modifiers and grain size fraction, angularity for coarse sand and larger); Consistency/Density, Plasticity (clay or clay mix) or Dilatancy (silt/silt-sand), Sorting, Moisture Content, Color. NOTES: *Texture Modifiers: Trace (<10%), Little (10 to 20%), Some (21 to 35%), And (36 to 50%)*	Driller's Observations, Geologic Formation, Field Screening Results, Sample Interval etc.

Attachment E

Completed Boring Log

The purpose of this attachment is to provide an example of a completed boring log for reference purposes to field staff. The example provided is for a soil boring completed outside the waste mass of a closed municipal landfill near Baltimore, Maryland. The objective of the drilling program was to determine the depth to groundwater to determine the appropriate depth interval to install a soil gas monitoring well and groundwater monitoring well across the first water-bearing zone. The site geology consists of unconsolidated sediments of the Mid-Atlantic Coastal Plain, specifically the Upper Patapsco formation. These sediments were deposited in a moderate gradient fluvial environment during the Cretaceous period. The landfill was constructed into a regional clay confining unit.

BORING LOG

ARCADIS

Boring ID:	MW-08	**Project Name:**	Acme Landfill	**Page:**	1 / 1
Permit ID:	MD-PG-100	**Date Started:**	7/18/2018	**Ground Elevation:**	50.5 ft
Site Address:	100 Landfill Road	**Date Completed:**	7/18/2018	**Vertical Datum:**	NAVD 88, feet
City, State:	Baltimore, Maryland	**Total Depth:**	35 ft below ground	**Northing:**	123456.79
Drilling Co:	Earth Matters	**Depth to Water:**	19 ft below ground	**Easting:**	123456.79
Driller:	Rod E. Piper	**Hole Diameter:**	2-inch	**Horizontal Datum:**	NAD 83 feet, MD State
Drilling Method:	Direct-push/hollow-stem	**Core Device:**	5-foot macrocore sampler	**Prepared by:**	Sandy Pebbles
Boring Status:	completed as well	**Drilling Fluid:**	none	**Reviewed by:**	Clay Brown

Drilling Information				Graphical Log for Primary Texture											Soil Description (Udden-Wentworth System)	Field Notes
				Fines		Sand					Gravel					
Drilling Depth (ft bgs)	Core Interval (ft)	Core Recovery (inches)	VOC Vapor Reading (ppm)	clay	silt	very fine	fine	medium	coarse	very coarse	granule	pebble	cobble	boulder	Depth Interval (ft), PRIMARY TEXTURE, Principal and Minor Components with Descriptors (% modifiers and grain size fraction, angularity for coarse sand and larger); Consistency/Density, Plasticity (clay or clay mix) or Dilatancy (silt/silt-sand), Sorting, Moisture Content, Color. NOTES: *Texture Modifiers: Trace (<10%), Little (10 to 20%), Some (21 to 35%), And (36 to 50%)*	Driller's Observations, Geologic Formation, Field Screening Results, Sample Interval etc.
0 to 1			< 1												0-0.5 ft, topsoil with organics	Grass covered area
1 to 2			< 1				X								0.5-5 ft, SAND, fine, trace silt, trace pebble, round; poorly sorted, moist, yellowish brown (7.5 YR 5/8). NOTE: some cementation, does not react with HCl	continuous macro-core logging
2 to 3	0-5	43.2/60	< 1				X									
3 to 4			< 1				X									cemented sand @3.6-4 ft
4 to 5			< 1				X									
5 to 6			< 1				X	X	X						5-10 ft, SAND, fine to coarse, round to subround; well sorted, moist, light to strong brown (7.5 YR 6/4 to 7.5 YR 5/6).	
6 to 7			< 1				X	X	X							
7 to 8	5-10	40.8/60	< 1				X	X	X							
8 to 9			< 1				X	X	X							
9 to 10			< 1				X	X	X							
10 to 11			< 1				X	X	X						10-12.5 ft, same as above with trace silt	
11 to 12			< 1				X	X	X							
12 to 13	10-15	36/60	< 1				X	X	X							
13 to 14			< 1				X	X	X						12.5 to 15 ft, same as above, color change to pink (7.5 YR 7/3) and reddish yellow (7.5YR 6/8)	
14 to 15			< 1				X	X	X							
15 to 16			< 1						X	X					15-18.9 ft, SAND, coarse to very coarse, round to subround; well sorted, moist, strong brown (7.5YR 5/6) to reddish yellow (7.5YR 6/6)	
16 to 17			< 1						X	X						
17 to 18	15-20	55.2/60	< 1						X	X						
18 to 19			< 1		X	X	X								18.9-22.7 ft, SAND, very fine to fine, and SILT, coarse to very coarse, poorly sorted, wet, light gray (7.5YR 7/1)	water table encountered @ 18.9 ft
19 to 20			< 1		X	X	X									
20 to 21			< 1		X	X	X									
21 to 22			< 1		X	X	X									
21 to 23	20-25	36/60	< 1		X	X	X									
23 to 24			< 1	X	X										22.7-25 ft, CLAY and SILT; high plasticity, soft to stiff at 25 ft, dry to moist, light gray (2/5YR 7/1) w/ red mottling (2.5YR 4/6)	Middle Patapsco Confining Unit
24 to 25			< 1	X	X											
25 to 26			< 1	X	X										25-31.1 ft, CLAY and SILT; high plasticity, stiff; dry to moist, light gray (2/5YR 7/1) with red mottling (2.5YR 4/6)	
26 to 27			< 1	X	X											
27 to 28	25-30	30/60	< 1	X	X											
28 to 29			< 1	X	X											
29 to 30			< 1	X	X											
30 to 31			< 1	X	X											
31 to 32			< 1		X											
32 to 33	30-35 ft	60/60	< 1		X											
33 to 34			< 1		X										31.1-35 ft, SILT; high dilatancy; wet, gray (7.5YR 7/1)	End of direct-push boring @ 35 ft
34 to 35			< 1		X											

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TGI – Vertical Aquifer Profile (VAP) Sampling

Rev: 3.1

Rev Date: March 25, 2025

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
1	0	June 22, 2018	All	Original SOP	Joe Quinnan
2	1	May 11, 2020	Multiple	Added content to Personnel Qualifications, references to Geoprobe SP-16 and SP-22, Attachment 3, and updated references /formatting	Marc Killingstad
3	2	June 15, 2022	Multiple	Combined with PFAS-specific VAP TGI and dye/tracer procedures.	Patrick Curry
4	3	June 18, 2024	All	Annual review by SME completed.	Patrick Curry
5	3.1	March 25, 2025	All	Annual review completed, editorial changes only	Patrick Curry

Approval Signatures

Prepared by:		6/18/2024
	Patrick Curry (Preparer)	Date
Reviewed by:		3/25/2025
	Marc Killingstad (Subject Matter Expert)	Date

1 Introduction

This Arcadis Technical Guidance Instruction (TGI) describes proper vertical aquifer profile (VAP) sampling procedures using a variety of methods and approaches. This document has been developed to emphasize drilling and sampling procedures used to collect groundwater samples from boreholes installed via direct push technology (DPT), hollow stem auger (HSA), and rotary-sonic (sonic) methods and includes the use of visible tracer in drilling fluid to obtain representative samples during vertical profiling.

2 Intended Use and Responsibilities

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.

3 Scope and Application

Vertical aquifer profile (VAP) borings are typically advanced via DPT, HSA, or sonic drilling techniques to collect single or multiple depth-discrete groundwater samples using low-flow or grab sampling methodologies. This can be combined with retrieval of continuous soil cores and lithologic logging, as well as collection of single or multiple depth-discrete dry and saturated soil samples.

When possible, co-locate or bias VAP groundwater sampling intervals towards potential discrete transport zones (and target slow advection zones when feasible) as indicated by soil logging observations or permeability measurements (e.g., point slug tests, Geoprobe® hydraulic profiling tool [HPT] [preferred],

Waterloo APS™ [alternate]). Permeability measurements coupled with contaminant concentration allows estimation of relative flux and mass discharge to evaluate potential risk to downgradient receptors. In the absence of permeability measurements, field soil lithological logging observations may be used to interpret hydrostratigraphy and select sampling intervals.

The intent of this TGI is to provide VAP instructions including specific considerations for per- and polyfluoroalkyl substances (PFAS) due to their unique chemical and physical properties, low detection limits, and regulatory standards. It also covers field procedures for using nontoxic fluorescent tracer (e.g., fluorescein dye) in drilling fluid during drilling to assist in determining when sufficient purging has been performed prior to collecting screening-level groundwater samples during the drilling process. Screening level groundwater samples may be obtained by evacuating water from the drill casing or from intervals of geologic formations isolated by inflatable packers. This procedure improves the quality of screening-level groundwater samples by providing a technical basis to determine when purging has sufficiently removed drill water prior to collecting screening-level groundwater samples.

Multiple VAP samples can be collected through temporary wells, drilling rod tooling (e.g., Geoprobe® Screen Point 16 [SP-16]/Screen Point 22 [SP-22] Groundwater Samplers or SP-60 Sonic Groundwater Sampler or Cascade's Sonic Push-Ahead or Packer Isolation Groundwater Profilers) or via combined hydraulic profiling and sampling tools (e.g., Geoprobe® HPT-Groundwater Sampling System [HPT-GWS] or Waterloo APS™). They can be analyzed quickly via on-site mobile lab or expedited off-site fixed lab analysis to provide adaptive high-resolution quantitative groundwater concentration data. The vertical frequency of groundwater sampling within a formation will be determined relative to the scale of variability demonstrated in site hydrostratigraphy and outlined in the FIP/Work Plan. Thin aquifers with transport zones only tens of feet thick (or less) can be sampled at intervals as close as 3 to 5 feet. In aquifers with transport zones substantially thicker (e.g., more than 50 feet), sample spacing of 5 to 20 feet may be adequate. It is important to note that field data be evaluated to verify that sampling intervals provide sufficient resolution to meet data quality objectives (DQOs) (See **Section 7**).

4 Personnel Qualifications

In general, VAP activities will be performed by persons who have been trained in proper drilling and sampling procedures under the guidance of an experienced field geologist, engineer, or technician. Arcadis personnel overseeing, directing, or supervising VAP activities shall have previous related experience (minimum of 2 years) in drilling and groundwater sampling. Drilling subcontractors will need current applicable drilling licenses.

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 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 mobilization, the field team 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)/field sampling plan, Quality Assurance Project Plan (QAPP), HASP, historical information, and other relevant site documents.

Arcadis field sampling 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. Additionally, the 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.

5 Equipment List

The following equipment and materials must be available for VAP sampling

- Site plan with proposed sampling locations
- Relevant work plan (or equivalent)
- Health and Safety Plan (HASP)
- Field Tablet with appropriate Fulcrum app for logging groundwater sampling.
- NOTE: *As of June 2022, several digital logging applications are available through the FieldNow™ program and the Fulcrum app. A future revision of this TGI, likely in early 2023, will emphasize digital logging methods and groundwater sampling. FieldNow™ is discussed further in Section 10.*
- Appropriate health and safety equipment, as specified in the site HASP
    - Drilling Equipment
    - Drill rig (to be provided by drilling subcontractor). Type (e.g., roto-sonic, direct push) to be determined based on site-specific details
    - Traffic cones, delineators, caution tape, and/or fencing as appropriate for securing the work area, if not provided by the drillers

      NOTE: *Prior to mobilizing to the site, Arcadis personnel will contact the drilling subcontractor or in-house driller (as appropriate) to confirm that appropriate sampling equipment will be provided in quantities capable of achieving estimated target depths. Typical equipment/materials provided by the driller could include*

        - Acetate or plastic liners
        - Appropriate length of drilling rods and tooling
        - Drilling and sampling equipment decontamination materials,
        - Decontamination pad materials, if required. See **Section 6.3** below for more information
- Sampling Equipment
    - Appropriate groundwater sampling equipment (e.g., disposable bailers for volumetric sampling, peristaltic pump for shallow groundwater sampling, submersible bladder pump for deeper sampling). Refer to *the TGI – Low-Flow Groundwater Purging and Sampling Procedures for Monitoring Wells* (Arcadis 2020a) for necessary equipment
    - Direct push groundwater samplers (e.g., Geoprobe® SP-22) or roto-sonic sampling devices (e.g., Cascade Push Ahead/Packer Isolation Groundwater Profiler or Geoprobe® SP-60 Sonic Groundwater Sampler) (to be provided by drilling subcontractor)
    - Appropriate soil sampling equipment (e.g., stainless steel spatulas, knife, metal trowel)

- Dedicated plastic sheeting (preferably high-density polyethylene [HDPE]) or other clean surface to prevent sample contact with the ground
- Multi-parameter water quality probe (e.g., conductivity, temperature, pH, dissolved oxygen, oxidation reduction potential, and turbidity meter)
- Water level meter
- Appropriate sample containers and labels
  - Labeled sample bottles: see the *TGI – Poly- and Perfluorinated Alkyl Substances (PFAS)Field Sampling Guidance* (Arcadis 2017a) for PFAS-specific considerations
  - Ziplock-style bags to hold ice and samples
  - Appropriate blanks (field reagent blanks supplied by the laboratory)
  - Packing and shipping materials
  - Chain-of-Custody (COC) Forms; see the *Sample Chain of Custody* for reference (Arcadis2017b)
  - Appropriate transport bottles (coolers) with ice and appropriate labeling, no blue ice

- Decontamination Equipment
  - Equipment cleaning materials: see the *TGI – Poly- and Perfluorinated Alkyl Substances (PFAS)Field Sampling Guidance* (Arcadis 2017a) or the *TGI – Groundwater and Soil Sampling Equipment Decontamination* (Arcadis 2020b) as applicable
  - Drum labels as required for investigation derived waste handling: see the *TGI – Investigation-Derived Waste Handling and Storage* for details (Arcadis 2017c)
- Documentation/Field Notes
  - Electronic data collection device (smart phone or tablet) as applicable
  - Pens, pencils, and/or Sharpie® brand pens for writing
  - Digital camera
  - Any other appropriate field forms
- Tracer Equipment (as needed)
  - Sodium fluorescein (also known as fluorescein or uranine dye) tracer (to be added to drilling water to produce a vibrant yellow-green color); 38 grams of dye will be added to each 500 gallons of drilling water (potable water) to achieve target applied tracer concentration of 20 milligrams per liter (mg/L)
  - Bottles for retaining dyed drilling water samples and preparing visual dye standards (clear, colorless, 40 mL unpreserved VOA bottles or equivalent)
  - Graduated cylinders (50 mL and 1 L)
  - Scale for measuring mass of dye to the nearest 1 gram
  - Bottles for groundwater samples to be analyzed for tracer dye (if necessary) and chemicals of concern (COCs)

- Poly storage tank (typically 550-to-1,000-gallon capacity)
- Potable water source
- Generator
- Utility pump for mixing dye
- Pump for groundwater purging and sampling
- Flashlight or other portable lighting device
- Blue ice (for tracer dye samples)

6 Cautions

Field activities associated with borehole advancement and VAP groundwater sampling will be performed in accordance with the HASP, a copy of which will be present on site during such activities. Field staff (including subcontractors) will be aware of and understand the associated physical and health hazards.

6.1 Utility Clearance

The appropriate drilling authorities will be contacted and a site visit for public utility line clearance at the proposed boring locations will be conducted at least 72 hours prior to work commencing. As applicable, utility maps will be reviewed during field reconnaissance of the proposed investigation locations to determine if any are co-located with public utility lines. Arcadis will also contract an independent geophysical survey company to verify that proposed boring locations are not co-located with existing underground utility/substructure features, as necessary. Arcadis will clear locations with soft dig methods to assess the presence of underground utilities as necessary.

See the *Utility Location and Clearance Arcadis Health and Safety Standard* (Arcadis 2020c) for reference.

6.2 PFAS-Specific General Sampling Considerations

This section provides a summary of methods and procedures applicable to the collection of environmental samples for field screening or laboratory analysis during PFAS site characterization activities. In general, sampling techniques used for PFAS site characterization are consistent with conventional sampling techniques used in the environmental industry, but special consideration is made regarding PFAS-containing materials and cross-contamination potential. For example, Teflon™ and other fluoropolymer containing materials are found in pumps, tubing, and sample storage containers and, therefore, will be avoided if possible (Department of Environment Regulation [DER], Western Australia 2016; New Hampshire Department of Environmental Services [NHDES] 2016). Certain field documentation materials such as waterproof paper or field books, adhesive paper products, and some writing utensils (grouped as non-Sharpie® markers) are also prohibited items during PFAS sampling (DER 2016; NHDES 2016).

Attachment 1 (Tables 1 and 2) provides recommendations for PFAS Site Investigation equipment. Table 1 provides a summary of materials that have been approved for site investigation; this list is expected to grow longer as industry experience increases. Table 2 provides a summary of field equipment and materials that have available testing information and/or industry knowledge regarding PFAS cross-

contamination potential, and it is recommended that these materials be prohibited for sample collection. For materials that are suspected of containing and/or retaining PFAS, these recommendations are considered preliminary and subject to change.

Given the extremely low detection limits associated with PFAS analysis and the many potential sources of trace levels of PFAS, field personnel are typically advised to err on the side of caution by strictly following field wear guidelines and decontamination procedures as specified in the *TGI - Poly- and Perfluorinated Alkyl Substances (PFAS) Field Sampling Guidance* (Arcadis 2022).The most important consideration during PFAS related VAP sampling is to prevent contact between sample media and suspect PFAS sources.

6.3 PFAS-Specific Groundwater Sampling

The potential presence of material containing PFAS in equipment that may come into contact with the target water sample must be evaluated as part of the sample planning process to maintain sample integrity. For example, low-flow sampling with a peristaltic pump will be conducted using silicone or HDPE tubing; Teflon™ tubing is prohibited (DER 2016). If a bladder pump is used to collect samples, the bladder and other internal parts (e.g., check balls, O-rings, compression fittings) will not contain Teflon™, and bladder and O-rings will be changed between samples (DER 2016).

Note that if high concentrations of PFAS related to Class B firefighting foams are expected in a groundwater sample, it has been recommended to collect and shake a small portion of the sample at the time of sample collection (USACE 2016; Arcadis 2017a). If foaming is noted within the sample, it indicates elevated concentrations of PFAS may be present and the sample will be proactively diluted at the laboratory prior to analysis, and the foaming will be noted on the sample COC form. It is recommended to collect sampling equipment blanks following foam observation to confirm the effectiveness of decontamination procedures.

6.4 Use of Tracer in Drilling Fluid

Field staff (including subcontractors) will be aware of tracer hazards and understand the associated health hazards. Please be sure to read the SDS (included as Attachment 2) for fluorescein dye. Note that some individuals can experience a mild allergic reaction to skin contact with fluorescein. Protective gloves will be worn during dye handling and mixing activities, and rinse bottles will be readily available for washing affected areas in case of accidental contact.

7 Health and Safety Considerations

To ensure the safety of the field personnel, field activities associated with VAP will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities. Review all site-specific and procedural hazards as they are provided in the HASP and review relevant Job SafetyAnalysis (JSA) documents in the field each day prior to beginning work.

Appropriate personal protective equipment (PPE) will be always worn in line with the task and the site-specific HASP. Verify staff has required health and safety training and personal protection

equipment in accordance with the HASP and JSAs. At a minimum, all staff will have level D PPE with chemical resistant gloves.

8 Procedure

The specific procedure for advancing VAP borings will be developed after careful review and consideration of project DQOs and clearly detailed in the FIP/Work Plan. Typically, VAP borings are conducted in boreholes adjacent to soil borings previously completed to develop stratigraphic and relative permeability profiles of the aquifer to determine sampling depth intervals that target transport zones. Prior boreholes typically consist of soil borings with detailed soil descriptions or Geoprobe® HPT borings. The primary advantage of completing stratigraphic/permeability profiles in advance of VAP sampling is to gain an understanding of hydrofacies trends to ensure that the most appropriate intervals and sampling methods are used. For sonic or HSA drilling, VAP samples are typically collected from the same borehole as soil samples. In the absence of a co-located boring, sample depth intervals can be determined based upon lithologic logging of soil cores, either from a separate adjacent borehole or from the same borehole. HPT drilling will be completed consistent with the *TGI – Geoprobe Hydraulic Profiling Tool (HPT)* (Arcadis 2022a), and soil lithologic logging will be performed in accordance with *TGI – Soil Description* (Arcadis 2022b).

NOTE: *Waterloo APS™ can be utilized as an alternative to HPT to provide permeability profiles, but it is more time consuming than HPT; therefore, it is not considered the preferred tool for permeability profiling.*

8.1 Direct Push Vertical Aquifer Profile Sampling

Direct push tooling is ideal for shallow unconsolidated aquifers and requires minimal water for drilling, reducing the potential for sample dilution/cross-contamination. For sites with shallow groundwater in unconsolidated formations (e.g., at less than 100 feet bgs), the typical approach is to collect VAP groundwater samples nominally every 5 to 10 feet with a bias to the more permeable transport zones.

When a zone of interest is identified, either by using permeability measurements (preferred) or logging soil, a screen point sampling device such as Geoprobe® SP-16 or SP-22 (see **Attachment 3**) can be driven to the target interval and the screen opened to collect a groundwater sample. In poorly sorted aquifers with appreciable amounts of silt, VAP sampling from an adjacent borehole after completing initial permeability profiling (e.g., Geoprobe® HPT or point slug tests) is typically more efficient and cost effective. In the absence of permeability profiling tools (e.g., HPT), VAP sampling can be performed based on soil lithological observations alone, either from a separate borehole or in the same borehole. However, VAP sample collection can be more efficient when conducted from an adjacent borehole, particularly if a bottom-up sampling approach is used. See Section 8.1.1.

Combined permeability profiling and sampling tools such as the Geoprobe® HPT-GWS (or Waterloo APS™ as an alternate) can be used to collect groundwater samples based on permeability measurements from the same borehole at deeper depths where the process is more cost-effective; otherwise at shallower depths, separate permeability profiling prior to VAP sampling is preferred. This is most effective in well-sorted sand and gravel when small volumes are required for analysis, since these tools provide limited volumes for purging and sample collection. Use of these combined tools (HPT-GWS or Waterloo APS™) for PFAS sites is not recommended because low detection and regulatory thresholds for PFASs require more extensive purging to decontaminate the sampling equipment (i.e., insufficient data are available to confirm the volume of purging required to eliminate cross-contamination with PFAS).

It is recommended that DPT drilling for VAP sampling be completed using a dual-tube drilling approach. An outer casing is advanced with the screen point sampling device to limit the potential for cross-contamination between sampling intervals. Pre-calculated volume purging and monitoring for water quality parameter stabilization can be performed consistent with low-flow sampling to help determine when purge water is representative of the groundwater formation.

There are two general methods for completing VAP sampling: bottom-up and top-down. With bottom-up sampling, a greater purge volume is required to ensure a representative groundwater sample; however, the overall time savings is significant relative to top-down sampling, where more time is required per borehole to lower the tooling, retract it, and decontaminate it between subsequent sampling intervals. However, the top-down method minimizes any potential for cross-contamination and is the preferred approach for PFAS projects due to the low detection limits and regulatory levels associated with PFASs.

8.1.1 Bottom-Up VAP Sampling

Bottom-up VAP sampling involves advancing dual-tube direct push casing to the deepest target depth with either a solid drive tip (without collecting soil cores) or acetate liners for collection of continuous soil cores to provide a lithological log for the entire boring. This is followed by lowering the groundwater sampling screen through the outer casing to the bottom of the borehole and collecting multiple VAP groundwater samples at different depths as the casing and screen is retracted up the borehole.

Using this approach, the external casing is retracted to allow borehole collapse around the sampling screen while isolating it from the section above that is still covered by the external casing.

NOTE: *Bottom-up VAP sampling is not recommended when there is a potential for dense non-aqueous phase liquid (DNAPL), the highest concentrations are expected to be at the bottom of the formation, or the borehole goes through multiple confining units. Bottom-up is not recommended for PFAS sampling due to potential cross-contamination concerns associated with lack of decontamination between sample intervals.*

The advantages of this approach are: (1) when combined with soil core collection, groundwater sampling depth intervals can be pre-selected based on lithologic observations to target the transport zones, especially in the absence of any co-located permeability measurements, and (2) the entire process is much more time-efficient per borehole as the sampling equipment is not pulled, decontaminated, and then drilled to the next interval. However, additional purging (i.e., 3to 5 casing volumes) is required to assure a representative groundwater sample. Bottom-up sampling also does not allow for post-grouting of the borehole since when the groundwater sampling device is pulled up to the next VAP sampling interval, the sidewalls of the open borehole below collapse.

8.1.2 Top-Down VAP Sampling

Top-down VAP sampling involves advancing dual-tube direct push casing with either a solid drive tip (without collecting soil cores) or a plastic liner for soil core retrieval from target depth interval followed by lowering the screen point sampling screen to target depth and pulling up the outer casing to expose the screen. After purging and sample collection, the screen point device is pulled back up and decontaminated. A solid drive tip or plastic liner is lowered back into the borehole and the entire assembly is then advanced to the next depth interval. Thus, top-down sampling requires pulling the tooling after each sample interval, decontaminating the tooling, re-setting the groundwater sampler, and advancing the tooling to the next planned interval.

The advantages of this approach are that it allows grouting of the borehole from the bottom of the borehole and

reduces the potential for cross-contamination from adjacent sampling intervals.

The primary disadvantage is that the entire process is much less time-efficient per borehole since the tooling must be retracted and re-advanced every time.

NOTE: *Top-down is the preferred method for PFAS VAP sampling.*

8.2 Sonic Drilling VAP Sampling

For sites with deep unconsolidated aquifers, bedrock/weathered bedrock, or otherwise challenging drilling conditions (e.g., presence of dense tills, caliche, cobbles), sonic drilling will be necessary to complete VAP. Like direct push, groundwater profilers can be used with sonic rigs to collect multiple depth-discrete groundwater samples biased towards transport zones based on soil lithological cores. The configuration of individual samplers varies based on their manufacturer by different drilling contractors (e.g., Cascade Push Ahead/Packer Isolation Groundwater Profiler or Geoprobe® SP-60).

The overall strategy of sonic drilling VAP sampling is consistent with direct push VAP sampling; however, drilling with sonic or some rotary methods can require the introduction of drilling fluid/water that can potentially affect the integrity of the groundwater sample. If possible, sonic drilling for VAP borings will be conducted without the use of drilling water. If, for example, the geology is known for flowing sands or VAP is required deep below the water table, drilling water will be used to keep the core barrel free inside the outer drill casing. In this case it is recommended that a visible dye be used to spike the drilling water to assist with purging of the VAP interval. The VAP interval is then purged until the visible dye is no longer visible, or less the 10% of the starting concentration. For more on drilling with visible dye, see Section 8.2.3. Sonic VAP sampling is typically performed in a top-down manner using either a push ahead sampling device or a packer system.

8.2.1 Push-Ahead Groundwater Profiler

Push-ahead groundwater sampling devices are available through Cascade Drilling and other sonic drillers and consists of a stainless-steel sheathed “screen” threaded to the base of the sonic drill rod. The device is driven ahead of the sonic casing into the undisturbed formation to the prescribed sample depth interval. Once the point is at the specified interval, the threaded portion between the profiler and rod is partially unthreaded to expose the water ports to allow native formation water to enter the profiler. A groundwater sample is then obtained using either a stainless-steel bailer or pump with tubing depending on the DQOs. The interval is typically purged until relatively free of fine-grained material.

The disadvantage of using this device is that groundwater samples are obtained from undisturbed native formation with unknown soil lithology, so sampling is conducted “blind”. Therefore, it is recommended that a pre-existing lithological log from an adjacent borehole is used to determine sampling depth intervals.

8.2.2 Packer Isolation Groundwater Profiler

Packer Isolation groundwater profilers (e.g., Packer Isolation groundwater profiler from Cascade, Geoprobe ® SP-60 Sonic Groundwater Profiler) work by driving the casing over the soil core, retrieving the soil core barrel, and then lowering a stainless screen and packer assembly to the base of the sonic casing. The sonic outer casing is then extracted to expose the screen to the formation, and the packer is inflated within the casing above the screen to isolate the screened interval from any water that might be above the packer in the sonic casing. A groundwater sample can then be collected from the screen.

The biggest advantage of this device is that groundwater sampling depth intervals can be determined based on lithological logs obtained from the same borehole.

A disadvantage is that a large volume of purge water may need to be removed to clear the borehole of water introduced from above.

8.2.3 Drilling with Visible Dye

Potable water is commonly used as a drilling fluid during drilling to remove cuttings of geologic materials from the borehole (e.g., coring or roller-bit rotary drilling), cool the drill bit (e.g., sonic drilling), and/or maintain sufficient hydraulic pressure within the drilling tools to prevent heaving of aquifer solids into the drill casing(s).

Typically, if groundwater sampling is performed during drilling, the purge volume to be removed is at least as much as was lost during drilling. However, accurately determining the volume of water lost to the formation, or to specific intervals of the borehole, is not always feasible or possible.

To ensure that groundwater samples accurately represent groundwater quality of the surrounding formation and are not significantly influenced by unrecovered drilling fluid, fluorescein dye can be added to the drilling water to visually confirm when unimpacted native groundwater enters the borehole and can be sampled.

The target concentration of dye is approximately 20 mg/L, which is greater than two (2) orders of magnitude above its visual threshold (approximately 0.1 mg/L) and over five (5) orders of magnitude above its typical laboratory detection limit (less than 0.001 mg/L). Once the drilling tool has been advanced to the prescribed depth for groundwater sampling, water will be pumped from the borehole until the discharge water is relatively clear of fluorescein. The goal of purging is to reach the clarity of a prepared visual standard, indicating that the discharge water is comprised of at least 95 percent formation water and less than 5 percent drilling water. Groundwater samples will then be collected for COC analysis.

If the visual standard is still not reached after a reasonable period and volume of purging, then COC sampling can still be performed, provided that samples of the dyed drilling water and groundwater are also sent for fluorescein analysis. The fluorescein data can then be used to calculate a correction factor to be applied to COC analytical results.

8.2.3.1 Set-Up Procedures

a. Dye Batch Preparation

- Prior to initiating drilling activities, measure the proper mass of powdered dye for mixing with drilling water - 38 grams of fluorescein (provided by Ozark Underground Laboratory) will be added to every 500 gallons of water to yield an average tracer concentration of approximately 20 mg/L.
- If the drilling water “batch” is larger or smaller than 500 gallons, the same ratio of dye to drilling water will be used.
- Measure the mass of dye using a scale with an accuracy of +/- 1 gram.
- Add the dye to the drilling water batch tank while also adding the potable water to provide agitation to assist in mixing the dye.
- A utility pump is also recommended to mix the tracer with the drilling water by recirculating water in the tank for at least 15 minutes.

- Place 40 mL of the dyed drilling water into a 50 mL graduated cylinder for use in preparing the visual standard discussed below.
- Collect four (4) additional 40 ml unpreserved VOA vials of drilling water from each batch of drilling water – label all four of these vials “DW1” for the first batch of drilling water, “DW2” for the second batch, etc. These samples will be archived for potential use in preparing other standards with other dilutions (optional) or for submittal for laboratory analysis, if necessary.

b. Preparation of Visual Standard: A visual standard will be prepared for each batch of dyed drilling water, as follows.

- Pour the 40 mL volume of dyed drilling water from the 50 mL graduated cylinder into a 1 L graduated cylinder.
- Add 760 mL of un-dyed potable water (from the same potable water source used to prepare the dyed drilling water) to the 1 L graduated cylinder to produce 800 mL of “visual standard”.
- Fill one 40-mL unpreserved VOA vial with visual standard solution and label this “VS1” for the visual standard from the first batch of drilling water, “VS2” for the visual standard from the second batch of drilling water, etc.
- These visual standards represent a 95% dilution of the drill water and will provide a visual standard to verify that sufficient purging has been performed to remove at least 95% of the drilling water from a given interval, indicating that the purge water consists of at least 95% formation water.
- Discard the remaining fluid within the graduated cylinder using an appropriate container.
- Photograph the “DW” samples and the “VS” sample from each batch of drilling water with adequate, consistent light, against a white background.
- Keep all the dyed drilling water (“DW”) samples and visual standard (“VS”) samples in a cooler to keep them dark as the dye will degrade with exposure to light.

8.2.3.2 Drilling Procedures

- Fresh drilling water from the dyed drilling water batch tank will be used during drilling operations. In general, a positive head will be maintained during drilling, which should prevent dilution of the drilling water by formation water. However, any water upwelling from the casing during drilling will be contained in a tub positioned over the borehole. As needed, recovered water in the tub will be pumped to a frac tank.
- The drilling water source will be sampled for chlorine and pH at the start of the project. Chlorine, if present in detectable quantities, will consume fluorescein; therefore, wait a period of at least four (4) hours between dye addition and sampling (and use) of the drilling fluid. Below pH values of about 5, fluorescein will have reduced fluorescence. Depending on the source of the drilling fluid and project objectives, the source water may also be sampled for COCs and fluorescein.
- In open sunlight, fluorescein photodegrades rapidly. If the tracer batch tank is translucent, use 1-millimeter (mm) thick black plastic to cover the tank during the day to minimize photodegradation of the tracer batch water.
- After tracer addition, each batch of drilling fluid will be sampled at least once for fluorescein.
- At the end of the day, any excess tracer batch water can be stored for use on the following day, or it may be disposed of as investigation derived waste. Alternatively, fluorescein concentrations can be reduced to below

visible concentrations with granular activated carbon, UV-oxidation, chemical oxidants, or direct exposure to sunlight for several days.

- The field geologist will record the amount of drilling water lost to the formation during drilling of each sampling depth interval.
- At the end of the project, any excess tracer batch water can be disposed of as investigation derived waste. Alternatively, fluorescein concentrations can be reduced to below visible concentrations with granular activated carbon, UV-oxidation, chemical oxidants, or direct exposure to sunlight for several days. Depending on project and regulatory requirements, excess batch water with fluorescein concentrations below the visible limit could be discharged to a sanitary sewer or other discharge location.

8.2.3.3 Purging and Sampling Procedures

- After a groundwater sampling interval is reached, purging and screening-level groundwater sampling will be performed.
- The target sample interval will be purged using a pump, and during purging, purge water will be periodically collected in a 40-mL unpreserved VOA vial and compared to the visual standard ("VS" sample) prepared from the drilling water used to drill that depth interval.
- If the purge water contains significant suspended particulates/turbidity, it may be necessary to allow particulates to settle before comparing the purge water sample to the visual standard.
- Purging will continue until *one* of the following two conditions is met:

    1) Purge water clarity (in terms of remaining dye content) matches or exceeds the clarity of the visual standard, indicating that the purge water consists of at least 95% formation water.

        a. In this case, the purge water sample and the associated visual standard will be photographed against a white background to document that the purging goal has been reached.

OR

    2) A different practical purging limit has been reached, based on purge volume or time

        a. In this case, the purge water sample and the associated visual standard will be photographed against a white background to document the degree of purge water visual clarity that was attained

        b. Also, a sample of the purge water will be collected in a 40 mL unpreserved VOA; this sample and one of the vials of dyed drilling water will be submitted to Ozark Underground Laboratories for quantitative analysis of fluorescein. These samples will be shipped in a cooler with reusable "Blue Ice" rather than wet ice. The analytical results for fluorescein will be used to calculate a COC correction factor, as discussed below (see Section 8.2.3.4).

- After purging has been completed, screening-level groundwater samples will be collected from the discharge end of the pump tubing for COC analysis in accordance with the approved work plan.

8.2.3.4 Calculation of Correction Factor

- If the purge water does not reach the goal indicated by the visual standard ("VS" sample), a sample of the drilling water and a sample of the purge water (obtained immediately prior to sampling for COC analysis) will be sent for laboratory analysis of fluorescein.
- Representative COC concentrations in groundwater (C_{gw}) can then be calculated as:

$$C_{gw} = C_m [F_d / (F_d – F_s)]$$

where: C_m = measured COC concentration, as reported by the lab

F_d = fluorescein concentration in drilling water

F_s = fluorescein concentration in groundwater sample

- The term $[F_d / (F_d – F_s)]$ is the COC correction factor.

8.3 Boring Abandonment

Upon completion, each top-down borehole is backfilled with bentonite grout from the terminal end of the boring upward. The top portion of each boring is sealed with asphalt or concrete to match the existing grade. Each bottom-up borehole is typically abandoned by the collapse as the rods are retraced.

Borehole abandonment requirements in some geographies dictate top-down sampling; this should be verified in advance of work and outlined in the FIP/Work Plan. See also *TGI for Monitoring Well and Borehole Decommissioning.*

9 Waste Management

Investigation derived waste (IDW) (e.g., soil cuttings and decontamination water generated during cleaning procedures) will be collected and contained on site in appropriate containers: see the *TGI – Investigation- Derived Waste Handling and Storage* for details (Arcadis 2020d). All IDW generated during field activities will be placed in Department of Transportation approved containers, sealed, and labeled. Containerized IDW will be stored on site until it is profiled and subsequently transported to an approved facility for disposal or recycling.

Personal protective equipment (e.g., gloves, disposable clothing, disposable equipment) resulting from personnel cleaning procedures and soil sampling activities will be placed in plastic bags. These bags will be transferred into appropriately labeled containers for appropriate disposal.

Waste manifests for all IDW suspected to have come into contact with PFAS will clearly note the potential presence of PFAS.

Additional IDW sampling and management details will be provided in the site-specific FIP/Work Plan/QAPP addendum and will be consistent with applicable client and state requirements.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

The supervising field lead will be responsible for documenting drilling events and for recording all relevant information in a clear and concise format. The record of drilling events will include (at a minimum):

- Start and finish drilling dates
- Project name and location
- Project number, client, and site location
- VAP boring number and depths
- Depth to water
- Type of VAP performed and associated tools
- Core barrel size
- Names of contractor's drillers, inspectors, or other people onsite
- Weather conditions

Field staff will ensure COC Forms are properly completed and will verify which analytes (including PFAS analytes) are required for analysis and note on the COC.

Waterproof field books must not be used for field notes. Instead, it's recommended that field notes be on loose paper on Masonite, plastic, or aluminum clip boards and/or electronic data collection tablets (as required). Other requirements for field notes include:

- Keep field notes, writing implements, and electronic data collection tablets away from samples and sampling materials; and,
- Do not write on sampling bottles unless they are closed.

11 Quality Assurance

In general, the following quality assurance and quality control (QA/QC) samples will be collected:

- Equipment blanks
- Field duplicates
- Field (i.e., reagent) blanks

- Matrix spike/matrix spike duplicate

Details on QC sampling requirements (e.g., frequency of collection, types of QA/QC samples) are provided in the QAPP and/or FIP/Work Plan. Additionally, detailed procedures related to equipment and field (i.e., reagent) blank sample collection are outlined in the *TGI for Equipment and Reagent Blank Sample Collection for PFAS Analysis*.

In general, equipment blanks should be collected from every piece of downhole equipment that could come into contact with soil or groundwater during sample collection. This includes the profiling tools (e.g., Geoprobe® SP-16, Geoprobe® SP-22, Geoprobe® SP-60, Cascade Packer Isolation Groundwater Profiler).

To avoid cross-contamination during drilling and sampling, reusable equipment such as hand tools will be cleaned using a non-phosphate soap free of VOCs, double-rinsed in potable water, and allowed to air dry prior to re-use. Drive casings and other drilling equipment will be steam cleaned or replaced with new equipment between boreholes. The drilling equipment will be cleaned in an area designated by the supervising engineer or geologist that is located outside of the work zone.

Prior to initiating field activities, water sources to be used during drilling activities will be sampled to verify those sources are PFAS-free to the extent possible.

Refer to quality control requirements for the project to ensure that appropriate quality assurance and quality control (QA/QC) samples are collected. When collecting QA/QC samples, the same guidelines apply as when collecting regular samples – specifically that:

- Samples will be collected in laboratory-supplied HDPE bottles
- Bottle caps must remain in the hand of the sampler until replaced on the bottle
- Labels must be completed after the caps have been placed back on each bottle
- Samples must be stored in appropriate transport bottles (coolers) with ice (Ziplock-type bags for use as ice containers) with appropriate labeling
- Do not use blue ice except for shipping fluorescein samples
- Store PFAS samples in a separate cooler from other types of samples

11.1 Equipment Blanks (if relevant)

QA/QC sampling typically includes daily collection of equipment blanks using the laboratory-supplied water, or in the case of PFAS sampling, “PFAS-free” water. For peristaltic pump tubing, laboratory supplied water will be poured into a clean HDPE sample bottle and then pumped through new HDPE tubing using the peristaltic pump (with new silicone tubing). Equipment blanks will also be collected from the water used by drillers, as well as any downhole tooling to ensure absence of any cross-contamination. Drilling water sources must be submitted for analysis of all COCs before work commences for VAP as discussed above. See *also TGI for Poly- and Perfluorinated Alkyl Substances (PFAS) Potable Water Sampling Guidance*.

11.2 Field Duplicates

QA/QC sampling typically includes the collection of one field duplicate for every 10 or 20 samples collected. Each duplicate sample will be collected immediately after the initial sample of which it is a duplicate into a separate laboratory-provided sample bottle. Do not indicate to the laboratory which sample the duplicate replicates (i.e., it will be given a blind reference on the COC and sample name such as “Dup 1”).

11.3 Field Blanks

QA/QC sampling for typically includes the submission of one laboratory supplied field blank per day. The reagent field blank sample is brought to the site in a laboratory-supplied sample bottle. Field staff transfer the laboratory-supplied reagent blank to an empty sample bottle. This reagent field blank will be placed in the same cooler as the other PFAS samples.

11.4 Matrix Spikes (optional in some cases)

QA/QC sampling includes submitting a sample to be used as a matrix spike if the project requires it. If a separate sample bottle is required, an additional sample will be collected immediately after the initial sample of which it is a duplicate into a separate laboratory-supplied sample bottle.

11.5 Laboratory Analytical QA/QC

- Internal laboratory QA/QC will consist of one laboratory blank and one laboratory control sample (or blank spike) per batch of samples, and additional QA/QCs as indicated by the laboratory QA/QC procedures. Isotope dilution will be used for quantification with isotope-labeled surrogate standards, as available.
- For groundwater and surface water samples, extract the entire groundwater and surface water sample and at least two sampling bottle solvent rinsates for analysis to increase sample accuracy. Avoid sub-sampling an aliquot of the sample bottle.
- Soil samples will be analyzed in their entirety or thoroughly homogenized before extraction and analysis.
- As part of the internal QA/QC, relative percent difference will be calculated between samples and corresponding field or laboratory duplicates. The laboratory quality assurance portion of the laboratory certificates will be reviewed to verify that all calculations/recoveries were within acceptable limits as established by the laboratory method.
- In January 2017, the U.S. Department of Defense and U.S. Department of Energy Quality Systems Manual (QSM) 5.1 (U.S. Department of Defense 2017) was finalized and introduced laboratory guidance for the measurement of PFAS in matrices other than drinking water. This guidance is not a detailed procedural method such as an U.S. Environmental Protection Agency method, but it does recommend best practices around the analysis of PFAS. Laboratories are not required to comply with QSM 5.1 until 2019, although the recommendations around PFAS analysis are similar to what most laboratories are already implementing. Arcadis recommends that any request for PFAS analysis in

groundwater or soil should specifically reference the need to comply with Table B-15 in the QSM 5.1 (i.e., Per- and Polyfluoroalkyl Substances (PFAS) Using Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS) With Isotope Dilution or Internal Standard Quantification in Matrices Other Than Drinking Water); however, this list can be modified to support project specific deliverables.

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United Nations Environment Programme (UNEP). 2015. PFAS analysis in water for the Global Monitoring Plan of the Stockholm Convention, Set-up and guidelines for monitoring. Jana Weiss, Jacob de Boer,Urs Berger, Derek Muir, Ting Ruan, Alejandra Torre, Foppe Smedes, Branislav Vrana, Fabrice Clavient, and Heidelore Fiedler. Division of Technology, Industry and Economics. Geneva. April.

ATTACHMENT 1

Table 1 and Table 2: PFAS Investigation Material Recommendations

Table 1: Summary of Acceptable Sampling Equipment and Materials for PFAS Site Investigations

Sampling Materials	Additional Considerations	References
Water Sampling Materials		
High density polyethylene (HDPE) or silicone tubing materials	--	DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
HDPE HydraSleeves™	Low density polyethylene (LDPE) HydraSleeves™ are not recommended	USACE 2016; MassDEP 2017
Drilling and Soil Sampling Materials		
PFAS-free drilling fluids	--	DER 2016
PFAS-free makeup water	Confirm PFAS-free water source via laboratory analysis prior to investigation	--
Acetate liners	For use in soil sampling	USACE 2016
Sample Containers and Storage		
HDPE sample containers with HDPE lined lids for soil and water samples	Laboratory should provide; whole bottle analysis of aqueous samples combined with a solvent rinse of bottle is recommended	DER 2016, MassDEP 2017
Ice contained in plastic (polyethylene) bags (double bagged)	--	DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Field Documentation		
Sharpie®	--	NHDES 2016; USACE 2016; MassDEP 2017
Ball point pens	--	MassDEP 2017
Standard paper and paper labels	--	DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Decontamination		
Water-only decontamination	Confirm PFAS-free water source via laboratory analysis prior to investigation	DER 2016
Alconox®, Liquinox® or Citranox® followed by deionized water or PFAS-free water rinse	Alconox® known to contain trace levels of 1,4-dioxane	NHDES 2016; USACE 2016; MassDEP 2017
Methanol, isopropanol, or acetone	Special health and safety precautions are necessary	UNEP 2015; USACE 2016

Note: This list is considered preliminary and additional materials may be added as additional information becomes available. Project teams are expected to follow a methodical evaluation process of materials to be used and confirm acceptance prior to implementation of field activities.

Table 2: Summary of Equipment and Materials Not Recommended for PFAS Site Investigations.

Sampling Materials	Known PFAS-Containing Materials	Suspected PFAS-Containing Materials	Materials with Potential to Retain PFASs	References
Water Sampling Materials				
Teflon® or polytetrafluoroethylene (PTFE)-containing or coated field equipment (e.g., tubing, bailers, tape, plumbing paste)	x			DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Passive diffusion bags			x	MassDEP 2017
LDPE HydraSleeves ™			x	USACE 2016; MassDEP 2017
Water particle filters			x	MassDEP 2017
Drilling and Soil Sampling Materials				
Aluminum foil			x	DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Drilling fluid containing PFASs	x	x		DER 2016
Sample Containers and Storage				
Glass sample containers with lined lids			x	DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
LDPE containers and lined lids			x	USACE 2016
Teflon® or PTFE- lined lids on containers (e.g., sample containers, rinsate water storage containers)	x			DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Reusable chemical or gel ice packs (e.g., BlueIce®)		x		DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Field Documentation				
Self-sticking notes and similar office products (e.g., 3M Post-it-notes)		x		DER 2016; USACE 2016; NHDES 2016; MassDEP 2017
Waterproof paper, notebooks, and labels	x			DER 2016, MassDEP 2017
Non-Sharpie® markers		x		NHDES 2016
Decontamination				
Some detergents and decontamination solutions (e.g., Decon 90® Decontamination Solution)	x	x		DER 2016; NHDES 2016; MassDEP 2017

N**ote**: For materials that are suspected of containing PFASs, or have the potential to retain PFASs, project specific considerations may provide adequate justification for use during the field event. For example, further evaluation may be conducted in the form of pre-field equipment blank sample analysis.

ATTACHMENT 2

Safety Data Sheet (SDS) Fluorescein

SAFETY DATA SHEET (SDS)
REVISION DATE: 03/03/2016

HUE CORPORATION

Color your everything, may your Hue come true

SECTION I. IDENTIFICATION OF THE SUBSTANCE/MIXTURE AND OF THE COMPANY/UNDERTAKING

PRODUCT IDENTIFIER:

PRODUCT NAME	**HUE URANINE CONC** (Also known as Fluorescein)
PRODUCT NUMBER	1-C8-073PC
COLOR INDEX NAME	ACID YELLOW 073
COLOR INDEX NO	45350
C. A. S. #	518-47-8
CHEMICAL FAMILY.....	XANTHENE

INTENDED USE OF THE PRODUCT:

FELT TIP, MARKER INKS, WATER BASED COATINGS AND LEAK DETECTION

NAME, ADDRESS AND TELEPHONE OF RESPONSIBLE PARTY:

HUE CORPORATION	TELEPHONE	714-389-3130
P.O. BOX 509	FAX	714-389-9731
TUSTIN, CA 92781	EMAIL	SUPPORT@HUECORPORATION.COM

EMERGENCY TELEPHONE NUMBER:

CHEMTREC (USA)	1-800-424-9300
CHEMTREC (OUTSIDE USA)	1-703-527-3887

SECTION 2. HAZARD(S) IDENTIFICATION

CLASSIFICATION OF THE SUBSTANCE OR MIXTURE:

GHS-US
ACUTE TOX. - INHALATION (CATEGORY 5)
EYE DAM./IRRITATION (CATEGORY 2B)
SKIN CORR./IRRITATION (CATEGORY 3)

GHS LABELING:

HAZARD PICTOGRAMS (GHS-US):	NO SYMBOL
SIGNAL WORD	WARNING
HAZARD STATEMENT(S)	H333 - MAY BE HARMFUL IF INHALED H320 - CAUSES EYE IRRITATION H316 - CAUSES MILD SKIN IRRITATION
PRECAUTIONARY STATEMENTS	P305 + 351 + P338 - IF IN EYES: RINSE CAUTIOUSLY WITH WATER FOR SEVERAL MINUTES. REMOVE CONTACT LENSES IF PRESENT AND EASY

TO DO. CONTINUE RINSING.
P337 + P313 - IF EYE IRRITATION OCCURS/PERSISTS:
GET MEDICAL ADVICE AND ATTENTION.
P261 - AVOID BREATHING DUST/FUMES/GAS/MIST/VAPORS/SPRAY
P264 - WASH FACE THOROUGHLY AFTER HANDLING.
P322 + P313 - IF SKIN IRRITATION OCCURS: GET MEDICAL ADVICE/ ATTENTION.
P304 + 312 - IF INHALED: CALL A POISON CENTER/DOCTOR/PHYSICIAN IF YOU FEEL UNWELL

OTHER HAZARDS NO DATA AVAILABLE
UNKNOWN ACUTE TOXICITY NO DATA AVAILABLE

SECTION 3. COMPOSITION / INFORMATION ON INGREDIENTS

DESCRIPTION OF MIXTURE: PROPRIETARY MIXTURE OF DYES.

SUBSTANCE:

NAME	C.A.S.#	WEIGHT 100%	GHS-US CLASSIFICATION
ACID YELLOW 073	518-47-8	100%	ACUTE TOX. - INHALATION (CATEGORY 5) EYE DAM./IRRITATION (CATEGORY 2B) SKIN CORR./IRRITATION (CATEGORY 3)

SECTION 4. FIRST AID MEASURES

FIRST AID MEASURES GENERAL:

INHALATION: REMOVE TO FRESH AIR. IF BREATHING IS DIFFICULT, GIVE OXYGEN AND GET IMMEDIATE MEDICAL ATTENTION.

SKIN: WASH WITH MILD SOAP AND WATER. IF IRRITATION OCCURS GET MEDICAL ATTENTION. IF CLOTHING IS CONTAMINATED, RE-MOVE AND WASH BEFORE REUSE.

EYES: FLUSH EYES WITH WATER FOR AT LEAST 15 MINUTES, HOLDING EYELIDS APART FOR THOROUGH IRRIGATION. GET IMMEDIATE MEDICAL ATTENTION.

INGESTION: INDUCE VOMITING - SEEK IMMEDIATE MEDICAL ATTENTION.

MOST IMPORTANT SYMPTOMS AND EFFECTS, ACUTE AND DELAYED:

THIS PRODUCT IS NOT HAZARDOUS AS DEFINED BY HAZARDOUS COMMUNICATION STANDARD. HOWEVER, AS WITH ALL CHEMICAL; HANDLE WITH CARE, AVOID EYE AND SKIN CONTACT, AVOID INHALATION OF DUSTS OR VAPORS. WASH THOROUGHLY AFTER HANDLING. KEEP CONTAINERS CLOSED.

SECTION 5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA:

WATER, DRY CHEMICAL, CARBON DIOXIDE, FOAM.

SPECIAL HAZARDS ARISING FROM SUBSTANCE OR MEDIA:

FIREFIGHTERS SHOULD BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS TO GUARD AGAINST POTENTIALLY TOXIC AND IRRITATING FUMES. AVOID DUSTING. DUST CAN FORM EXPLOSIVE MIXTURES WITH AIR.

PROTECTION/ADVICE FOR FIREFIGHTER(S):

BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS AND PROTECTIVE CLOTHING.

SECTION 6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS:

REMOVE PERSONS FROM DANGER AREA.

ENVIROMENTAL PRECAUTIONS:

AVOID ANY UNCONTROLLED RELEASE OF MATERIAL. DO NOT EMPTY INTO DRAINS OR THE AQUATIC ENVIRONMENT.

EMERGENCY PROCEDURES:

NO ADDITIONAL INFORMATION

METHODS AND MATERIALS FOR CONTAMINENT AND CLEANING UP:

WHERE SPILLS ARE POSSIBLE, A COMPREHENSIVE SPILL RESPONSE PLAN SHOULD BE DEVELOPED AND IMPLEMENTED. AVOID ANY UNCONTROLLED RELEASE OF MATERIAL.

UTILIZE RECOMMENDED PROTECTIVE CLOTHING AND EQUIPMENT (SEE SECTION 8).
SPILLS SHOULD BE SWEPT UP USING AN ABSORBENT DUST CONTROL PRODUCT AND PLACED IN CONTAINERS. SPILL AREA CAN BE WASHED WITH WATER. COLLECT WATER FOR APPROVED DISPOSAL.
IN THE EVENT OF UNCONTROLLED RELEASE OF THIS MATERIAL, THE USER SHOULD DETERMINE IF THE RELEASE IS REPORTABLE UNDER APPLICABLE LAWS AND REGULATIONS.

SECTION 7. HANDLING AND STORAGE

PRECAUTIONS FOR SAFE HANDLING:

HANDLE WITH CARE. AVOID OVER EXPOSURE. USE NIOSH/OSHA APPROVED RESPIRATOR, WORK GLOVES, AND CLOTHING. WASH AFTER HANDLING. SENSITIVE INDIVIDUALS MAY EXPERIENCE RESPIRATORY ALLERGIES. MAY CAUSE SKIN IRRITATION. USE WITH LOCAL VENTILATION.

CONDITIONS FOR SAFE STORAGE, INCLUDING ANY INCOMPATIBILITIES:

USE PROCESS ENCLOSURES, LOCAL EXHAUST VENTILATION OR OTHER ENGINEERING CONTROLS TO KEEP AIRBORNE LEVELS BELOW RECOMMENDED EXPOSURE LIMITS.

KEEP AWAY FROM HEAT. KEEP AWAY FROM SOURCES OF IGNITION.

KEEP AWAY FROM STRONG OXIDIZING AND REDUSING AGENTS.

SPECIFIC END USES:

FELT TIP, MARKER INKS, WATER BASED COATINGS AND LEAK DETECTION

SECTION 8. EXPOSURE CONTROLS /PERSONAL PROTECTION

CONTROL PARAMETERS:

INGREDIENTS WITH LIMIT VALUES THAT REQUIRE MONITORING AT THE WORKPLACE - NOT REQUIRED

EXPOSURE CONTROLS:

APPROPRIATE ENGINEERING CONTROLS - THE USUAL PRECAUTIONARY MEASURES ARE TO BE ADHERED TO WHEN HANDLING CHEMICALS.

PERSONAL PROTECTIVE EQUIPMENT:

HAND PROTECTION	WEAR IMPERMEABLE RUBBER OR PLASTIC GLOVES
EYE PROTECTION	TIGHTLY SEALED SAFETY GOGGLES OR FULL FACE SIDE SHIELDS.
SKIN AND BODY	APRON, COVERALLS AND NON-LEATHER SOLED WORK SHOES. WASH DYE CONTAMINATED CLOTHES AND SKIN WITH MILD SOAP AND DETERGENTS.
RESPIRATORY	WEAR OSHA/NIOSH APPROVED DUST MASK/RESPIRATOR
HYGIENE MEASURES	HANDLE IN ACCORDANCE WITH GOOD INDUSTRIAL HYGIENE AND SAFETY PRACTICES. WASH HANDS AFTER HANDLING MATERIAL.
OTHER PROTECTION	DELUGE SAFETY SHOWER AND EYE WASH STATION SHOULD BE LOCATED NEAR WORK AREA.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

INFORMATION ON BASIC PHYSICAL AND CHEMICAL PROPERTIES :

APPEARANCE, COLOR, ODOR	YELLOW POWDER, NO ODOR
pH	8.0 - 9.0
MELTING POINT/FREEZING POINT	ND
INITIAL BOILING POINT/BOILING RANGE	0.00
FLASHPOINT	NORMALLY STABLE, NOT COMBUSTIBLE NOR FLAMMABLE
EVAPORATION RATE	NO DATA
FLAMMABILITY (SOLID,GAS)	NORMALLY STABLE, NOT COMBUSTIBLE NOR FLAMMABLE
UPPER EXPLOSIVE LIMITS	NA
LOWER EXPLOSIVE LIMITS	NA
VAPOR PRESSURE	NA
VAPOR DENSITY	NA
RELATIVE DENSITY	NA
SOLUBILITY IN WATER	SOLUBLE
PARTITION COEFFICIENT N-OCTANOL/WATER	NO DATA

AUTO-IGNITION TEMPERATURE	NO DATA
DECOMPOSITION TEMPERATURE	NO DATA
VISCOSITY, DYNAMIC	NO DATA
VISCOSITY, CINEMATIC	NO DATA
EXPLOSIVE PROPERTIES	N/A
OXIDIZING PROPERTIES	NA
OTHER INFORMATION	NA

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY	STABLE UNDER NORMAL STORAGE AND HANDLING CONDITIONS.
CONDITIONS TO AVOID	OXIDIZING & REDUCING AGENTS MAY DESTROY COLOR.
INCOMPATIBLE MATERIALS	OXIDIZING & REDUCING AGENTS MAY DESTROY COLOR.

HAZARDOUS DECOMPOSITION PRODUCTS - CO, CO2, OXIDES OF NITROGEN AND OTHER POTENTIALLY TOXIC FUMES.

SECTION 11. TOXICOLOGICAL INFORMATION

TOXICOLOGICAL EFFECTS :

ORAL (ANIMAL	GREATER THAN 7,000 MG/KG - RAT
DERMAL (ANIMAL)	NA
EFFECTS TO EYES (ANIMAL)	EYES - RABBIT, NOT IRRITATING
SKIN IRRITATION (ANIMAL)	SKIN - RABBIT, SLIGHT IRRITANT

SKIN CORROSION/IRRITATION	NOT CLASSIFIED
SERIOUS EYE DAMAGE/IRRITATION	CAUSES EYE IRRITATION
RESPIRATORY OR SKIN SENSITIZATION	NOT CLASSIFIED
GERM CELL MUTAGENICITY	NOT CLASSIFIED
CARCINOGENICITY	NOT CLASSIFIED
REPRODUCTIVE TOXICITY	NOT CLASSIFIED
SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE)	MAY CAUSE DROWSINESS OR DIZZINESS.
ASPIRATION HAZARD	NOT CLASSIFIED
INHALATION	MAY CAUSE DROWSINESS OR DIZZINESS.
EYE CONTACT	CAUSES SERIOUS EYE IRRITATION.
INGESTION	INGESTION MAY CAUSE NAUSEA, VOMITING AND DIARRHEA

SECTION 12. ECOLOGICAL INFORMATION

TOXICITY	NA
PERSISTENCE AND DEGRADABILITY	NA
BIOACCUMULATIVE POTENTIAL	NA
MOBILITY IN SOIL	LC-50 (LETHAL CONCENTRATION) UG = MICROGRAMS/LITER CHANNEL CATFISH - 2,267,000 UG/LITER RAINBOW TROUT - 1,372,000 UG/LITER BLUEGILL - 3,433,000 UG/LITER
OTHER ADVERSE EFFECTS	NA

SECTION 13. DISPOSAL CONSIDERATION

WASTE DISPOSAL RECOMMENDATION :

EMPTY BAGS THOROUGHLY. CARRY OUT THE PROPER RECYLING, REUSAGE OR DISPOSAL.
PLEASE REFER TO THE RELEVANT EU REGULATIONS, IN PARTICULAR THE GUIDELINES/DECISIONS OF THE COUNCIL REGARDING HANDLING OF WASTES (E.G. 75/442/EEC, 91/689/EEC, 94/67/EC, 94/904/EC) AS IMPLEMENTED IN NATIONAL REGULATIONS.

REGIONAL RECOMMENDATION :

BURY OR INCINERATE ACCORDANCE WITH FEDERAL, STATE AND LOCAL REGULATIONS.

CONTAINERS SHOULD NOT BE REUSED WITHOUT PROFESSIONAL CLEANING AND RECONDITIONING.
OBSERVE ALL LABELED SAFEGUARDS UNTIL CLEANED, RECONDITIONED OR DESTROYED.

PLEASE REFER TO SECTION 8 (EXPOSURE CONTROLS /PERSONAL PROTECTION) OF THIS SDS.

SECTION 14. TRANSPORTATION INFORMATION

UN NUMBER	NONE
UN PROPER SHIPPING NAME	NONE

DEPARTMENT OF TRANSPORTATION (DOT) : NOT HAZARDOUS FOR TRANSPORTATION

TRANSPORT HAZARD CLASS(ES)

HAZARD LABLES (DOT) :

PACKING GROUP (DOT)	NA
DOT SPECIAL PROVISIONS	NA

ADDITIONAL INFORMATION:

OVERLAND TRANSPORT	NONE
TRANSPORT BY SEA	NONE
AIR TRANSPORT	NONE
DOT QUANTITY LIMITATIONS PASSENGER AIRCRAFT	NA
DOT QUANTITY LIMITATIONS CARGO AIRCRAFT	NA

SECTION 15. REGULATORY INFORMATION

US FEDERAL REGULATIONS:

THE SUBSTANCES IS LISTED ON UNITED STATES TSCA (TOXIC SUBSTANCE CONTROL ACT) INVENTORY.

US STATE REGULATIONS:

NONE

CHEMICAL IDENTITY:

518-47-8	TSCA	DSL	NDSL	EINECS	ELINCS	ENCS	CHINA	KECL	PICCS	AICS
	X	-	-	-	-	-	-	-	-	-

TSCA STATUS	IN COMPLIANCE
E C CLASSIFICATION	(67/548/EEC - 88/379/EEC) N/A
EINECS NUMBER	
REACH CLASSIFICATION	
R PHRASES	
ADDITIONAL REGULATORY INFORMATION	

SECTION 16. OTHER INFORMATION

INDICATION OF CHANGES:

NA

OTHER INFORMATION:

NA

GHS FULL TEXT PHRASES:

MAY BE HARMFUL IF INHALED	H333
CAUSES EYE IRRITATION	H320
CASUES MILD SKIN IRRITATION	H316

	HEALTH	FLAMMABILITY	REACTIVITY	PERSONAL PROT
H. M. I. S. CLASSIFICATION:	1	0	0	D

HMIS CODE: **4** - SEVERE HAZARD, **3** - SERIOUS HAZARD, **2** - MODERATE HAZARD, **1** - SLIGHT HAZARD, **0** - MINIMAL HAZARD

SAFETY DATA SHEET (SDS)
REVISION DATE: 03/03/2016

ATTACHMENT 3

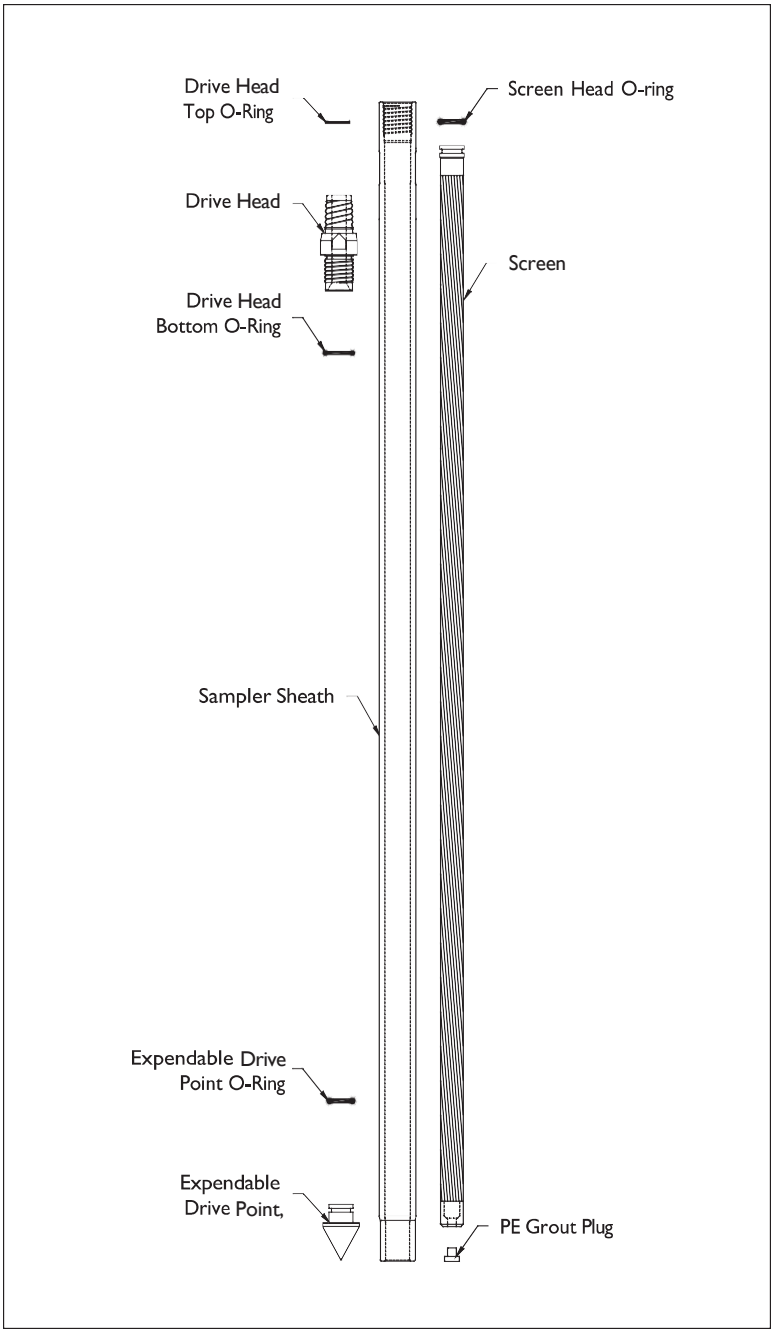
SOPs Geoprobe® Screen Point 16 and Screen Point 22 Groundwater Samplers

Geoprobe® Screen point 16 Groundwater Sampler

Standard OperatinG Procedure

Technical Bulletin No. MK3142

PREPARED: November, 2006



GEOPROBE® SCREEN POINT 16 GROUNDWATER SAMPLER PARTS

Geoprobe® and Geoprobe Systems®, Macro-Core® and Direct Image® are Registered Trademarks of Kejr, Inc., Salina, Kansas

Screen Point 16 Groundwater Sampler is manufactured under U.S. Patent 5,612,498

1.0 OBJECTIVE

The objective of this procedure is to drive a sealed stainless steel or PVC screen to depth, deploy the screen, obtain a representative water sample from the screen interval, and grout the probe hole during abandonment. The Screen Point 16 Groundwater Sampler enables the operator to conduct abandonment grouting that meets American Society for Testing and Materials (ASTM) Method D 5299 requirements for decommissioning wells and borings for environmental activities (ASTM 1993).

2.0 BACKGROUND

2.1 Definitions

Geoprobe®: A brand name of high quality, hydraulically powered machines that utilize both static force and percussion to advance sampling and logging tools into the subsurface. The Geoprobe® brand name refers to both machines and tools manufactured by Geoprobe Systems®, Salina, Kansas. Geoprobe® tools are used to perform soil core and soil gas sampling, groundwater sampling and monitoring, soil conductivity and contaminant logging, grouting, and materials injection.

Screen Point 16 (SP16) Groundwater Sampler: A direct push device consisting of a PVC or stainless steel screen that is driven to depth within a sealed, steel sheath and then deployed for the collection of representative groundwater samples. The assembled SP16 Sampler is approximately 51.5 inches (1308 mm) long with an OD of 1.625 inches (41 mm). Upon deployment, up to 41 inches (1041 mm) of screen can be exposed to the formation. The Screen Point 16 Groundwater Sampler is designed for use with 1.5-inch probe rods and machines equipped with the more powerful GH60 Hydraulic Hammer. Operators with GH40 Series hammers may chose to use this sampler in soils where driving is difficult.

Rod Grip Pull System: An attachment mounted on the hydraulic hammer of a direct push machine which makes it possible to retract the tool string with extension rods or flexible tubing protruding from the top of the probe rods. The Rod Grip Pull System includes a pull block with rod grip jaws that are bolted directly to the machine. A removable handle assembly straddles the tool string while hooking onto the pull block to effectively grip the probe rods as the hammer is raised. A separate handle assembly is required for each probe rod diameter.

2.2 Discussion

In this procedure, the assembled Screen Point 16 Groundwater Sampler (Fig. 2.1A) is threaded onto the leading end of a Geoprobe® probe rod and advanced into the subsurface with a Geoprobe® direct push machine. Additional probe rods are added incrementally and advanced until the desired sampling interval is reached. While the sampler is advanced to depth, O-ring seals at each rod joint, the drive head, and the expendable drive point provide a watertight system. This system eliminates the threat of formation fluids entering the screen before deployment and assures sample integrity.

Once at the desired sampling interval, extension rods are sent downhole until the leading rod contacts the bottom of the sampler screen. The tool string is then retracted approximately 44 inches (1118 mm) while the screen is held in place with the extension rods (Fig. 2.1B). As the tool string is retracted, the expendable point is released from the sampler sheath. The tool string and sheath may be retracted the full length of the screen or as little as a few inches if a small sampling interval is desired.

There are three types of screens that can be used in the Screen Point 16 Groundwater Sampler. Two of the these, a stainless steel screen with a standard slot size of 0.004 inches (0.10 mm) and a PVC screen with a standard slot size of 0.010 inches (0.25 mm), are recovered with the tool string after sampling. The third screen is also manufactured from PVC with a standard slot size of 0.010 inches (0.25 mm), but is designed to be left downhole when sampling is complete. This disposable screen has an exposed screen length of approximately 43 inches (1092 mm). The two screens that are recovered with the sampler both have an exposed screen length of approximately 41 inches (1041 mm).

(continued on following page)

An O-ring on the head of the stainless steel screens maintains a seal at the top of the screen. As a result, any liquid entering the sampler during screen deployment must first pass through the screen. PVC screens do not require an O-ring because the tolerance between the screen head and sampler sheath is near that of the screen slot size.

The screens are constructed such that flexible tubing, a mini-bailer, or a small-diameter bladder pump can be inserted into the screen cavity. This makes direct sampling possible from anywhere within the saturated zone. A removable plug in the lower end of the screens allows the user to grout as the sampler is extracted for further use.

Groundwater samples can be obtained in a number of ways. A common method utilizes polyethylene (TB25L) or Teflon® (TB25T) tubing and a Check Valve Assembly (GW4210). The check valve (with check ball) is attached to one end of the tubing and inserted down the casing until it is immersed in groundwater. Water is pumped through the tubing and to the ground surface by oscillating the tubing up and down.

An alternative means of collecting groundwater samples is to attach a peristaltic or vacuum pump to the tubing. This method is limited in that water can be pumped to the surface from a maximum depth of approximately 26 feet (8 m). Another technique for groundwater sampling is to use a stainless steel Mini-Bailer Assembly (GW41). The mini-bailer is lowered down the inside of the casing below the water level where it fills with water and is then retrieved from the casing.

The latest option for collecting groundwater from the SP16 sampler is to utilize a Geoprobe® MB470 Series Mechanical Bladder Pump (MBP)*. The MBP may be used to meet requirements of the low-flow sampling protocol (Puls and Barcelona 1996, ASTM 2003). Through participation in a U.S. EPA Environmental Technology Verification study, it was confirmed that the MB470 can provide representative samples (EPA 2003).

**The Mechanical Bladder Pump is manufactured under U.S. Patent No. 6,877,965 issued April 12, 2005.*

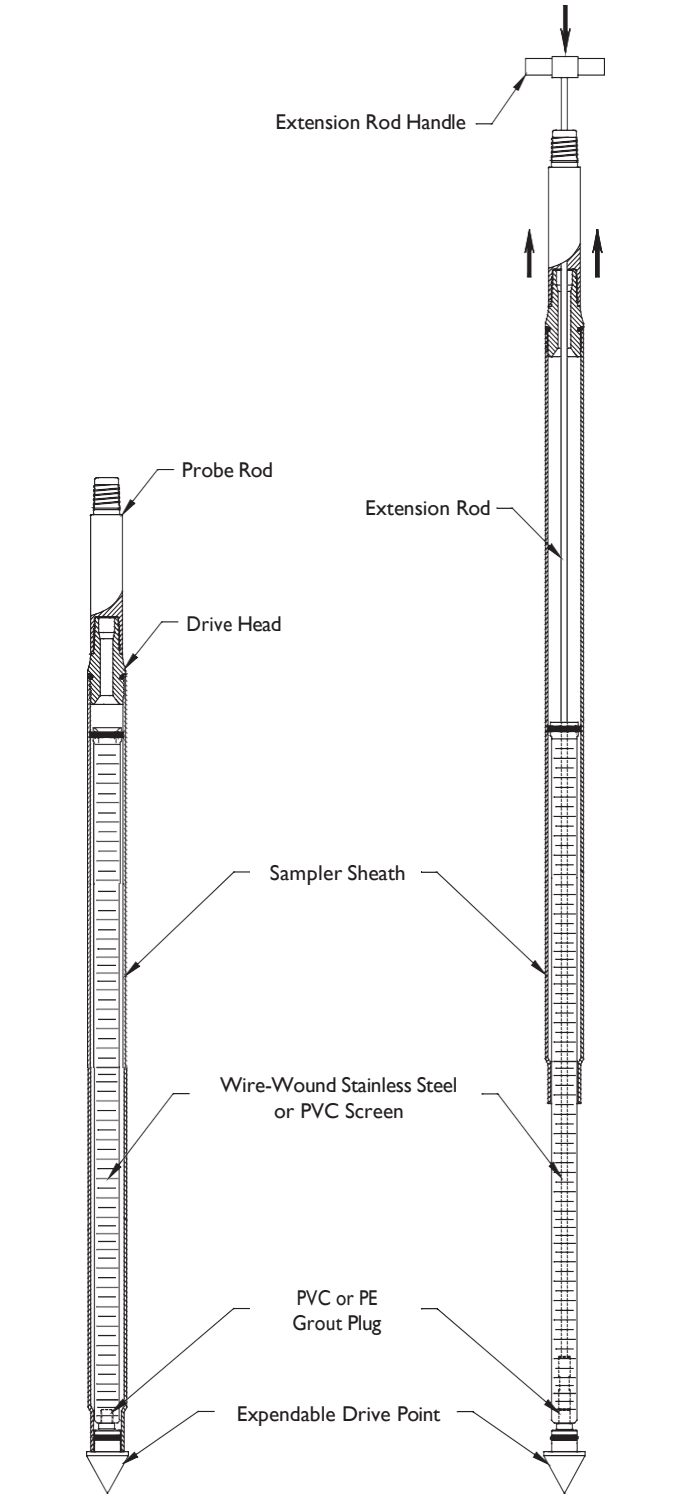


FIGURE 2.1
Screen Point 16 Groundwater Sampler

3.0 TOOLS AND EQUIPMENT

The following tools and equipment can be used to successfully recover representative groundwater samples with the Geoprobe® Screen Point 16 Groundwater Sampler. Refer to Figures 3.1 and 3.2 for identification of the specified parts. Tools are listed below for the most common SP16 / 1.5-inch probe rod configurations. Additional parts for optional rod sizes and accessories are listed in Appendix A.

SP16 Sampler Parts	**Part Number**
SP16 Sampler Sheath	15187
SP16 Drive Head, 0.5-inch bore, 1.5-inch rods*	18307
SP16 O-ring Service Kit, 1.5-inch rods *(includes 4 each of the O-ring packets below)*	15844
O-rings for Top of SP16 Drive Head, 1.5-inch rods only (Pkt. of 25)	*15389*
O-rings for Bottom of SP16 Drive Head (Pkt. of 25)	*13196*
O-rings for GW1520 Screen Head (Pkt. of 25)	*GW1520R*
O-rings for SP16 Expendable Drive Point (Pkt. of 25)	*GW1555R*
Screen, Wire-Wound Stainless Steel, 4-Slot*	GW1520
Grout Plugs, PE (Pkg. of 25)	GW1552K
Expendable Drive Points, steel, 1.625-inch OD (Pkg. of 25)*	GW1555K
Screen Point 16 Groundwater Sampler Kit, 1.5-inch Probe Rods *(includes 1 each of: 15187, 18307, 15844, GW1520, GW1535, GW1540, GW1555K, and GW1552K)*	15770

Probe Rods and Probe Rod Accessories	**Part Number**
Drive Cap, 1.5-inch probe rods, threadless, (for GH60 Hammer)	12787
Pull Cap, 1.5-inch probe rods	15090
Probe Rod, 1.5-inch x 60-inch*	11121

Extension Rods and Extension Rod Accessories	**Part Number**
Screen Push Adapter	GW1535
Grout Plug Push Adapter	GW1540
Extension Rod, 60-inch*	10073
Extension Rod Coupler	AT68
Extension Rod Handle	AT69
Extension Rod Jig	AT690
Extension Rod Quick Link Coupler, pin	AT695
Extension Rod Quick Link Coupler, box	AT696

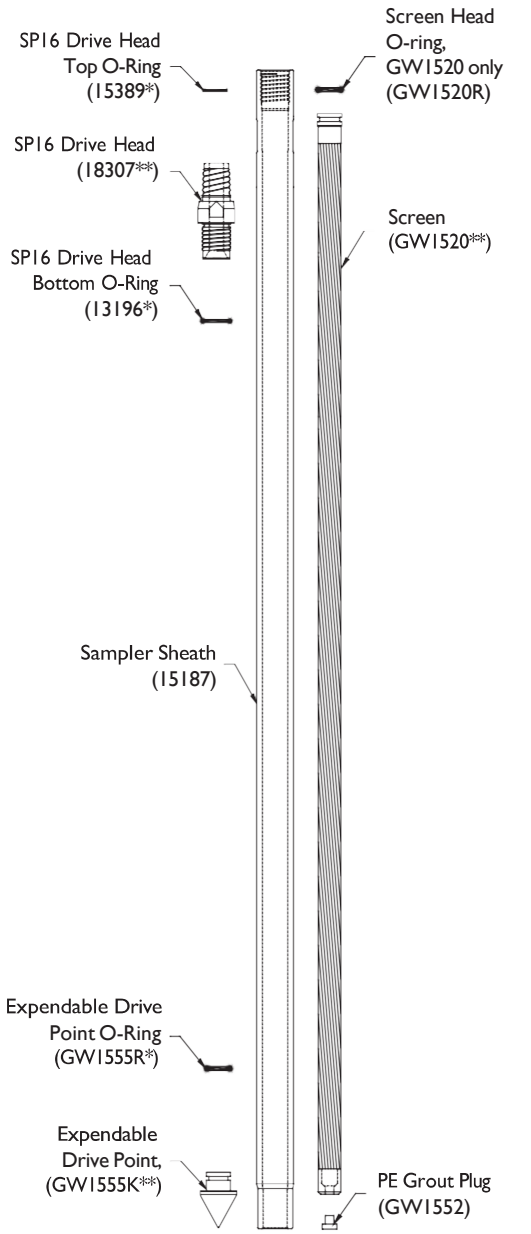
Grout Accessories	**Part Number**
Grout Nozzle, for 0.375-inch OD tubing	GW1545
High-Pressure Nylon Tubing, 0.375-inch OD / 0.25-inch ID, 100-ft. (30 m)	11633
Grout Machine, self-contained*	GS1000
Grout System Accossories Package, 1.5-inch rods	GS1015

Groundwater Purging and Sampling Accessories	**Part Number**
Polyethylene Tubing, 0.375-inch OD, 500 ft.*	TB25L
Check Valve Assembly, 0.375-inch OD Tubing*	GW4210
Water Level Meter, 0.438-inch OD Probe, 100 ft. cable*	GW2000
Mechanical Bladder Pump**	MB470
Mini Bailer Assembly, stainless steel	GW41

Additional Tools	**Part Number**
Adjustable Wrench, 6.0-inch	FA200
Adjustable Wrench, 10.0-inch	FA201
Pipe Wrenches	NA

* See Appendix A for additional tooling options.

** Refer to the Standard Operating Procedure (SOP) for the Mechanical Bladder Pump (Technical Bulletin No. MK3013) for additional tooling needs.



* Included in the SP16 O-ring Service Kit (15844)
** Part numbers show most common tool configuration. See Appendix A for alternative parts.

FIGURE 3.1
SP16 Sampler Parts

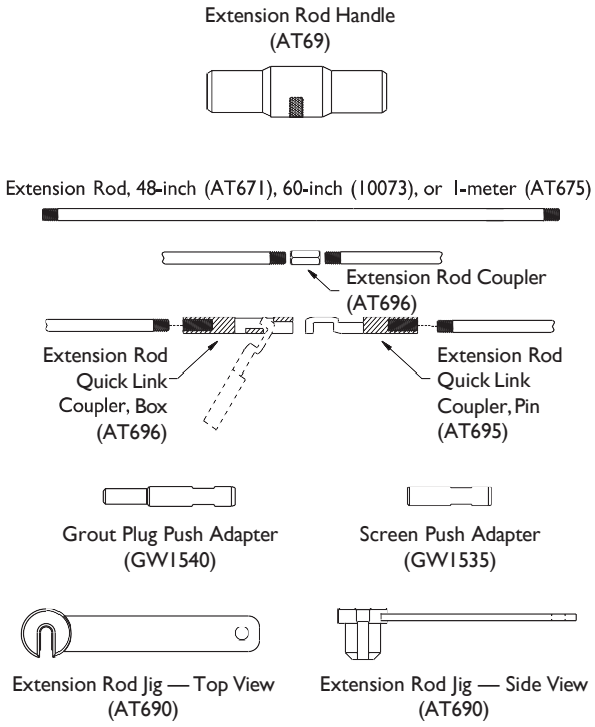


FIGURE 3.2
Geoprobe® Extension Rods and Accessories

4.0 OPERATION

4.1 Basic Operation

The SP16 sampler utilize a stainless steel or PVC screen which is encased in an alloy steel sampler sheath. An expendable drive point is placed in the lower end of the sheath while a drive head is attached to the top. O-rings on the drive head and expendable point provide a watertight sheath which keeps contaminants out of the system as the sampler is driven to depth.

Once the sampling interval is reached, extension rods equipped with a screen push adapter are inserted down the ID of the probe rods. The tool string is then retracted up to 44 inches (1118 mm) while the screen is held in place with the extension rods. The system is now ready for groundwater sampling. When sampling is complete, a removable plug in the bottom of the screen allows for grouting below the sampler as the tool string is retrieved.

4.2 Sampler Options

The Screen Point 15 and Screen Point 16 Groundwater Samplers are nearly identical. Subtle differences in the design of the SP16 sampler make it more durable than the earlier SP15 system. Operators of GH60-equipped machines should always utilize SP16 tooling. Operators of machines equipped with GH40 Series hammers may also choose SP16 tooling when sampling in difficult probing conditions.

A 1.75-inch OD Expendable Drive Point (17066K) and Disposable PVC Screen (16089) provide two useful options for the SP16 sampler. The 1.75-inch drive point may be used when soil conditions make it difficult to remove the sampler after driving to depth. The disposable PVC screen may be left downhole after sampling (when regulations permit) to eliminate the time required for screen decontamination.

4.3 Decontamination

In order to collect representative groundwater samples, all sampler parts must be thoroughly cleaned before and after each use. Scrub all metal parts using a stiff brush and a nonphosphate soap solution. Steam cleaning may be substituted for hand-washing if available. Rinse with distilled water and allow to air-dry before assembly.

4.4 SP16 Sampler Assembly (Figure 4.1)

Part numbers are listed for a standard SP16 sampler using 1.5-inch probe rods. Refer to Page 6 for screen and drive head alternatives.

1. Place an O-ring on a steel expendable drive point (GW1555K). Firmly seat the expendable point in the necked end of a sampler sheath (15187).

2. Install a PE Grout Plug (GW1552) in the bottom end of a Wire-wound Stainless Steel Screen (GW1520). Place a GW1520R O-ring in the groove on the top end of the screen.

3. Slide the screen inside of the sampler sheath with the grout plug toward the bottom of the sampler. Ensure that the expendable point was not displaced by the screen.

4. Install a bottom O-ring (13196) on a Drive Head (18307 or 15188). Thread the drive head into the sampler sheath using an adjustable wrench if necessary to ensure complete engagement of the threads. Attach a Drive Cap (12787 or 15590) to the top of the drive head.

   NOTE: The 18307 drive head should be used whenever possible as the smaller 0.5-inch ID provides a greater material cross-section for increased durability.

Sampler assembly is complete.

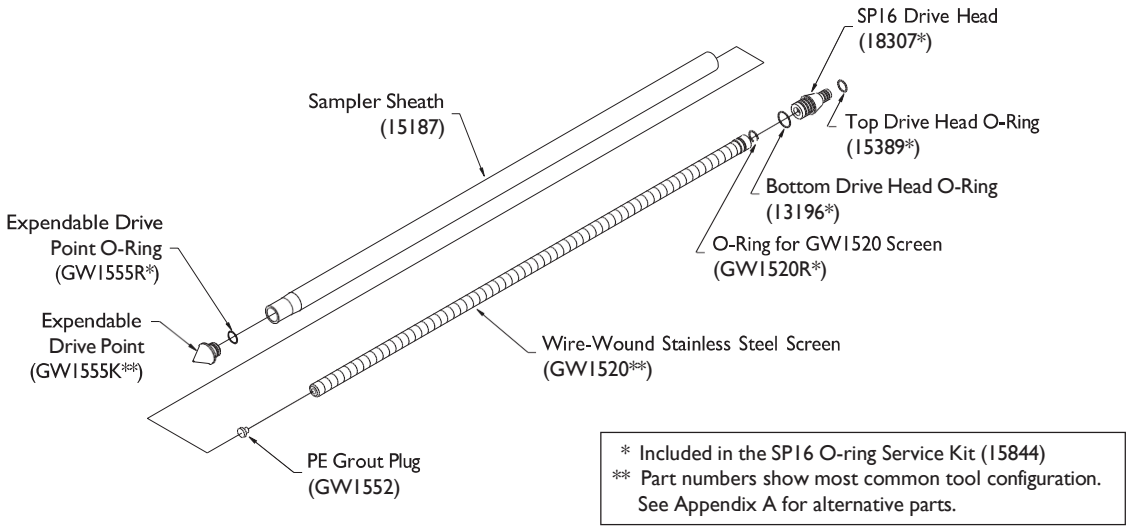


FIGURE 4.1
Screen Point 16 Groundwater Sampler Assembly

4.5 Advancing the SP16 Sampler

To provide adequate room for screen deployment with the Rod Grip Pull System, the probe derrick should be extended a little over halfway out of the carrier vehicle when positioning for operation.

1. Begin by placing the assembled sampler (Fig. 2.1.A) in the driving position beneath the hydraulic hammer of the direct push machine as shown in Figure 4.2.

2. Advance the sampler with the throttle control at slow speed for the first few feet to ensure that the sampler is aligned properly. Switch to fast speed for the remainder of the probe stroke.

3. Completely raise the hammer assembly. Remove the drive cap and place an O-ring in the top groove of the drive head. Distilled water may be used to lubricate the O-ring if needed.

   Add a probe rod (length to be determined by operator) and reattach the drive cap to the rod string. Drive the sampler the entire length of the new rod with the throttle control at fast speed.

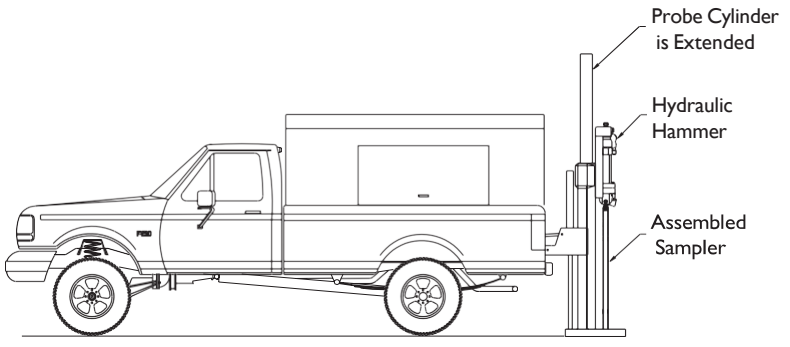


FIGURE 4.2
Screen Point 16 Groundwater Sampler in Driving Position

4. Repeat Step 3 until the desired sampling interval is reached. Approximately 12 inches (305 mm) of the last probe rod must extend above the ground surface to allow attachment of the puller assembly. A 12-inch (305 mm) rod may be added if the tool string is over-driven.

5. Remove the drive cap and retract the probe derrick away from the tool string.

4.6 Screen Deployment

1. Thread a screen push adapter (GW1535) on an extension rod of suitable length (AT671, 10073, or AT675). Attach a threaded coupler (AT68) to the other end of the extension rod. Lower the extension rod inside of the probe rod taking care not to drop it down the tool string. An extension rod jig (AT690) may be used to hold the rods.

2. Add extension rods until the adapter contacts the bottom of the screen. To speed up this step,it is recommended that Extension Rod Quick Links (AT695 and AT696) are used at every other rod joint.

3. Ensure that at least 48 inches (1219 mm) of extension rod protrudes from the probe rod. Thread an extension rod handle (AT69) on the top extension rod.

4. Maneuver the probe assembly into position for pulling.

5. Raise (pull) the tool string while physically holding the screen in place with the extension rods (Fig. 4.3.B). A slight knock with the extension rod string will help to dislodge the expendable point and start the screen moving inside the sheath.

   Raise the hammer and tool string about 44 inches (1118 cm) if using a GW1520 or GW1530 screen. At this point the screen head will contact the necked portion of the sampler sheath (Fig. 4.3.C.) and the extension rods will rise with the probe rods. Use care when deploying a PVC screen so as not to break the screen when it contacts the bottom of the sampler sheath.

   The Disposable Screen (16089) will extend completely out of the sheath if the tool string is raised more than 45 inches (1143 mm). Measure and mark this distance on the top extension rod to avoid losing the screen during deployment.

6. Remove the rod grip handle, lower the hammer assembly, and retract the probe derrick. Remove the top extension rod (with handle) and top probe rod. Finally, extract all extension rods.

7. Groundwater samples can now be collected with a mini-bailer, peristaltic or vacuum pump, tubing bottom check valve assembly, bladder pump, or other acceptable small diameter sampling device.

   When inserting tubing or a bladder pump down the rod string, ensure that it enters the screen interval. The leading end of the tubing or bladder pump will sometimes catch at the screen head giving the illusion that the bottom of the screen has been reached. An up-and-down motion combined with rotation helps move the tubing or bladder pump past the lip and into the screen.

4.7 Abandonment Grouting for GW1520 and GW1530 Screens

The SP16 Sampler can meet ASTM D 5299 requirements for abandoning environmental wells or borings when grouting is conducted properly. A removable grout plug makes it possible to deploy tubing through the bottom of GW1520 and GW1530 screens. A GS500 or GS1000 Grout Machine is then used to pump grout into the open probe hole as the sampler is withdrawn. The following procedure is presented as an example only and should be modified to satisfy local abandonment grouting regulations.

1. Maneuver the probe assembly into position for pulling. Attach the rod grip puller to the top probe rod. Raise the tool string approximately 4 to 6 inches (102 to 152 cm) to allow removal of the grout plug.

2. Thread the Grout Plug Push Adapter (GW1540) onto an extension rod. Insert the adapter and extension rod inside the probe rod string. Add extension rods until the adapter contacts the grout plug at the bottom of the screen. Attach the handle to the top extension rod. When the extension rods are slightly raised and lowered, a relatively soft rebound should be felt as the adapter contacts the grout plug. This is especially true when using a PVC screen.

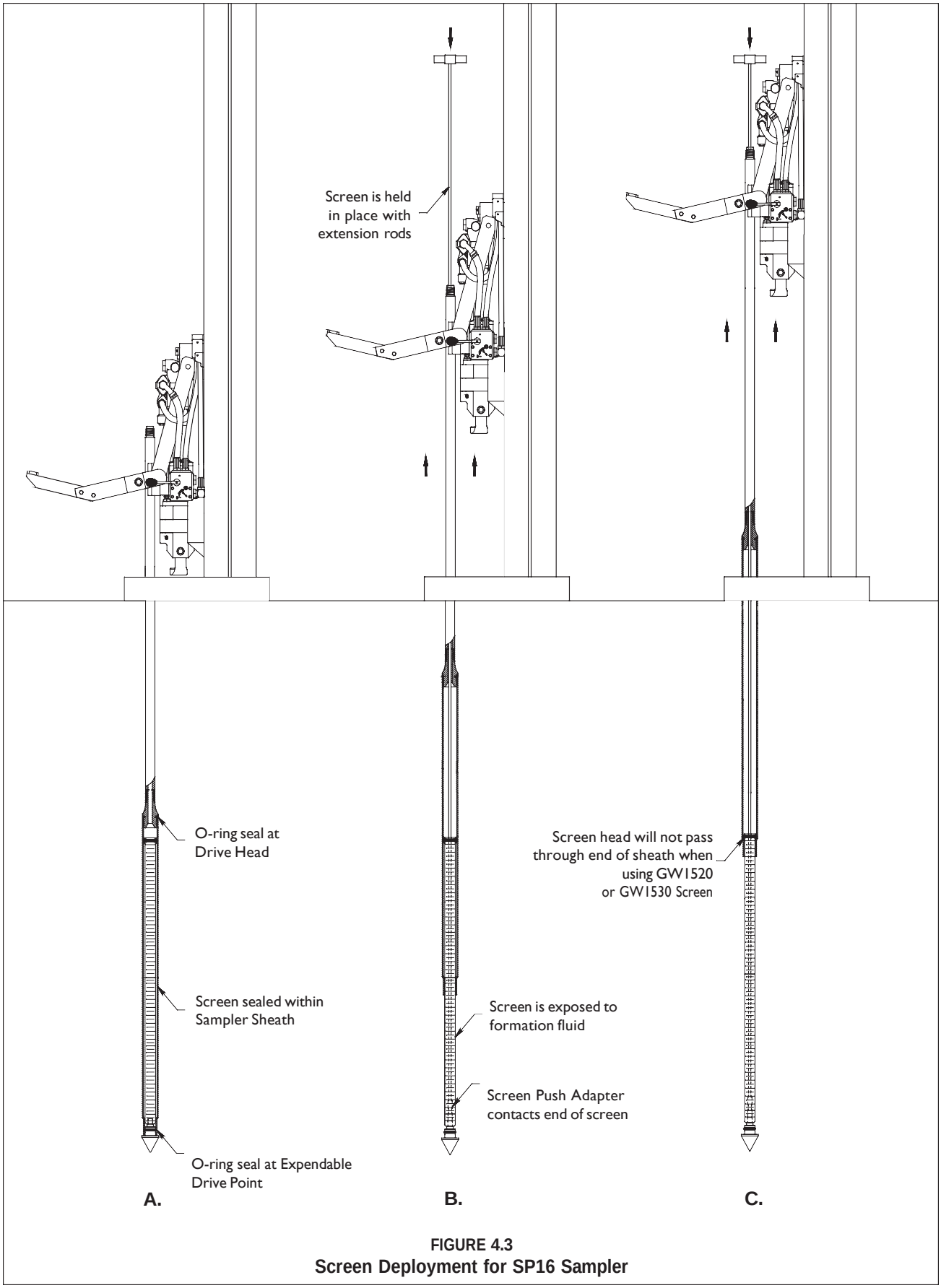


FIGURE 4.3
Screen Deployment for SP16 Sampler

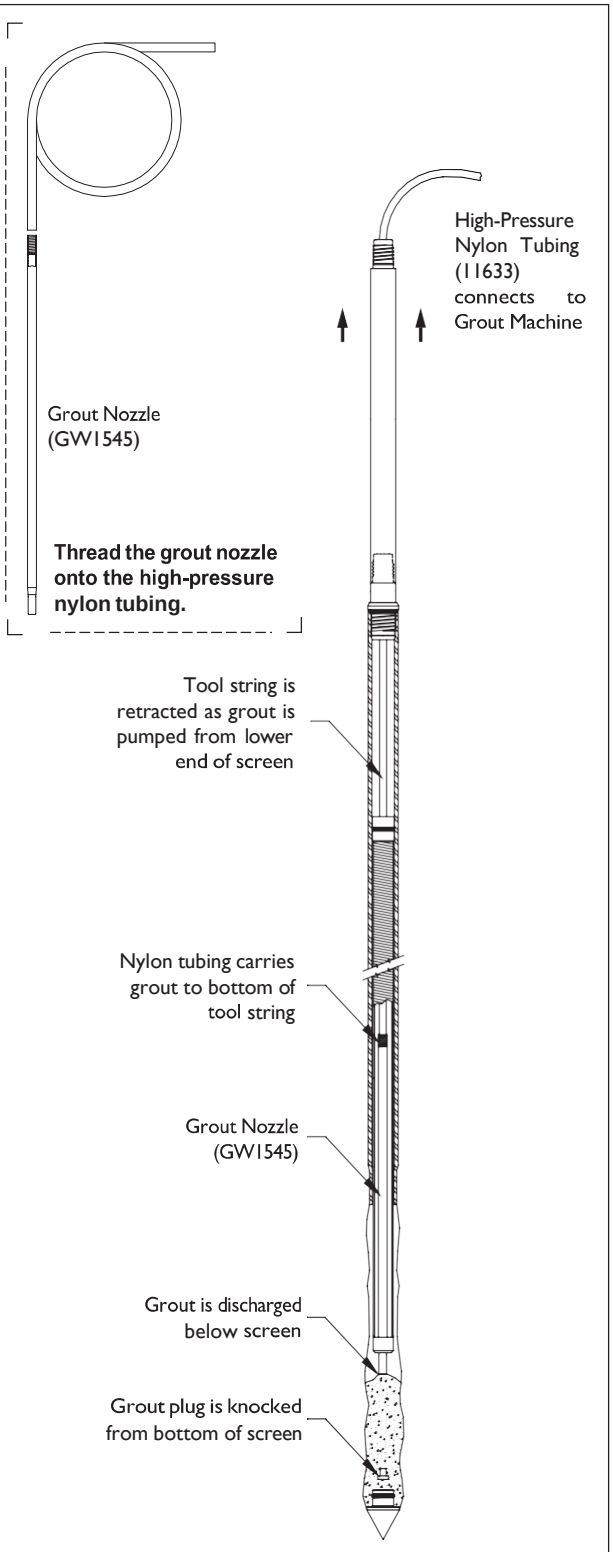


FIGURE 4.4
Grouting the SP16 Sampler With a GW1520 or GW1530 Screen

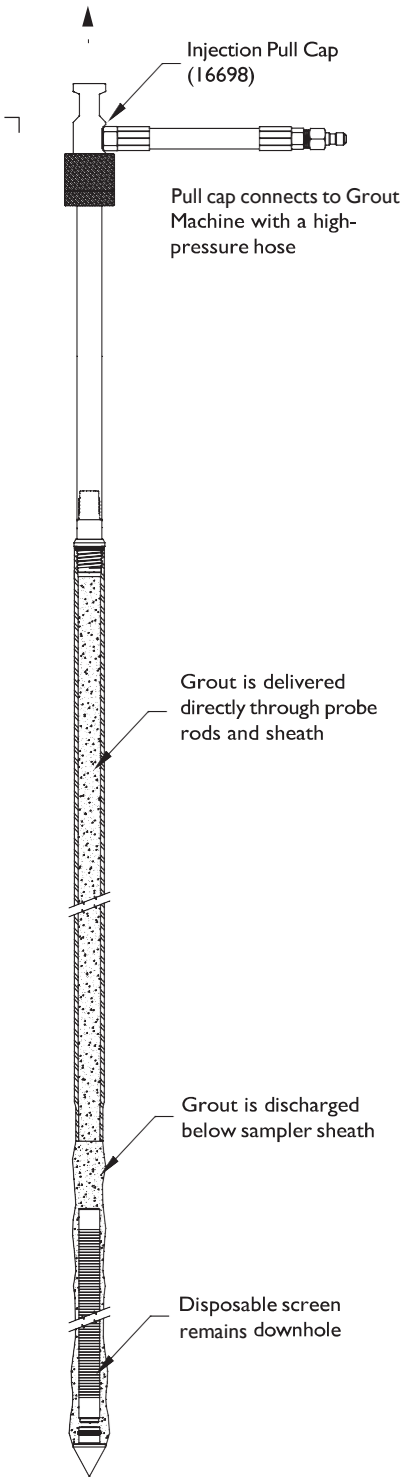


FIGURE 4.5
Grouting the SP16 Sampler With a 16089 Disposable Screen

3. Place a mark on the extension rod even with the top of the probe rod. Apply downward pressure on the extension rods and push the grout plug out of the screen. The mark placed on the extension rod should now be below the top of the probe rod. Remove all extension rods.

   Note: When working with a stainless steel screen, it may be necessary to raise and quickly lower the extension rods to jar the grout plug free. When the plug is successfully removed, a metal-on-metal sensation may be noted as the extension rods are gently "bounced" within the probe rods.

4. A Grout Nozzle (GW1545) is now connected to High-Pressure Nylon Tubing (11633) and inserted down through the probe rods to the bottom of the screen (Fig. 4.4). It may be necessary to pump a small amount of clean water through the tubing during deployment to jet out sediments that settled in the bottom of the screen. Resistance will sometimes be felt as the grout nozzle passes through the drive head. Rotate the tubing while moving it up-and-down to ensure that the nozzle has reached the bottom of the screen and is not hung up on the drive head.

   Note: *All probe rods remain strung on the tubing as the tool string is pulled. Provide extra tubing length to allow sufficient room to lay the rods on the ground as they are removed. An additional 20 feet is generally enough.*

5. Operate the grout pump while pulling the first rod with the rod grip pull system. Coordinate pumping and pulling rates so that grout fills the void left by the sampler. After pulling the first rod, release the rod grip handle, fully lower the hammer, and regrip the tool string. Unthread the top probe and slide it over the tubing placing it on the ground near the end of the tubing.

6. Repeat Step 5 until the sampler is retrieved. Do not bend or kink the tubing when pulling and laying out the probe rods. Sharp bends create weak spots in the tubing which may burst when pumping grout. Remember to operate the grout pump only when pulling the rod string. The probe hole is thus filled with grout from the bottom up as the rods are extracted.

7. Promptly clean all probe rods and sampler parts before the grout sets up and clogs the equipment.

4.8 Abandonment Grouting for the 16089 Disposable Screen

ASTM D 5299 requirements can also be met for the SP16 samplers when using the 16089 disposable screen. Because the screen remains downhole after sampling, the operator may choose either to deliver grout to the bottom of the tool string with nylon tubing or pump grout directly through the probe rods using an Injection Pull Cap (16698). A GS500 or GS1000 Grout Machine is needed to pump grout into the open probe hole as the sampler is withdrawn. The following procedure is presented as an example only and should be modified to satisfy local abandonment grouting regulations.

1. Maneuver the probe assembly into position for pulling with the rod grip puller.

2. Thread the screen push adapter onto an extension rod. Insert the adapter and extension rod inside the probe rod string. Add extension rods until the adapter contacts the bottom of the screen. Attach the handle to the top extension rod.

3. The disposable screen must be extended at least 46 inches (1168 mm) to clear the bottom of the sampler sheath. Considering the length of screen deployed in Section 4.7, determine the remaining distance required to fully extend the screen from the sheath. Mark this distance on the top extension rod.

4. Pull the tool string up to the mark on the top extension rod while holding the disposable screen in place.

   The screen is now fully deployed and the sampler is ready for abandonment grouting. Apply grout to the bottom of the tool string during retrieval using either flexible tubing (as described in Section 4.7) or an injection pull cap (Fig. 4.5). This section continues with a description of grouting with a pull cap.

5. Remove the rod grip handle and maneuver the probe assembly directly over the tool string. Thread an Injection Pull Cap (16698) onto the top probe rod and close the hammer pull latch over the top of the pull cap.

6. Connect the pull cap to a Geoprobe® grout machine using a high-pressure grout hose.

7. Operate the pump to fill the entire tool string with grout. When a sufficient volume has been pumped to fill the tool string, begin pulling the rods and sampler while continuing to operate the grout pump. Considering the known pump volume and sampler cross-section, time tooling withdrawal to slightly "overpump" grout into the subsurface. This will ensure that all voids are filled during sampler retrieval.

   The grouting process can lubricate the probe hole sufficiently to cause the tool string to slide back downhole when disconnected from the pull cap. Prevent this by withdrawing the tool string with the rod grip puller while maintaining a connection to the grout machine with the pull cap.

4.9 Retrieving the Screen Point 16 Sampler

If grouting is not required, the Screen Point 16 Sampler can be retrieved by pulling the probe rods as with most other Geoprobe® applications. The Rod Grip Pull System should be used for this process as it allows the operator to remove rods without completely releasing the tool string. This avoids having the probe rods fall back downhole when released during the pulling procedure. A standard Pull Cap (15164) may still be used if preferred. Refer to the Owner's Manual for your Geoprobe® direct push machine for specific instructions on pulling the tool string.

5.0 REFERENCES

American Society of Testing and Materials (ASTM), 2003. D6771-02 Standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations. ASTM, West Conshocken, PA. (www.astm.org)

American Society of Testing and Materials (ASTM), 1993. ASTM 5299 *Standard Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities.* ASTM West Conshohocken, PA. (www.astm.org)

Geoprobe Systems®, 2003, *Tools Catalog, V.6.*

Geoprobe Systems®, 2006, *Model MB470 Mechanical Bladder Pump Standard Operating Procedure (SOP), Technical Bulletin No. MK3013.*

Puls, Robert W., and Michael J. Barcelona, 1996. Ground Water Issue: Low-Flow (Minimal Drawdown) Ground Water Sampling Procedures. EPA/540/S-95/504. April.

U.S. Environmental Protection Agency (EPA), 2003. Environmental Technology Verification Report: Geoprobe Inc., Mechanical Bladder Pump Model MB470. Office of Research and Development, Washington, D.C. EPA/600R-03/086. August.

Appendix A
ALTERNATIVE PARTS

The following parts are available to meet unique soil conditions. See section 3.0 for a complete listing of the common tool configurations for the Geoprobe® Screen Point 16 Groundwater Sampler.

SP16 Sampler Parts and Accessories	Part Number
SP16 Drive Head, 0.625-inch bore, 1.5-inch rods	15188
Expendable Drive Points, aluminum, 1.625-inch OD (Pkg. of 25)	GW1555ALK
Expendable Drive Points, steel, 1.75-inch OD (Pkg. of 25)	17066K
Screen, PVC, 10-Slot	GW1530
Screen, Disposable, PVC, 10-Slot	16089

Groundwater Purging and Sampling Accessories	Part Number
Polyethylene Tubing, 0.25-inch OD, 500 ft.	TB17L
Polyethylene Tubing, 0.5-inch OD, 500 ft.	TB37L
Polyethylene Tubing, 0.625-inch OD, 50 ft.	TB50L
Check Valve Assembly, 0.25-inch OD Tubing	GW4240
Check Valve Assembly, 0.5-inch OD Tubing	GW4220
Check Valve Assembly, 0.625-inch OD Tubing	GW4230
Water Level Meter, 0.375-inch OD Probe, 100-ft. cable	GW2001
Water Level Meter, 0.438-inch OD Probe, 200-ft. cable	GW2002
Water Level Meter, 0.375-inch OD Probe, 200-ft. cable	GW2003
Water Level Meter, 0.438-inch OD Probe, 30-m cable	GW2005
Water Level Meter, 0.438-inch OD Probe, 60-m cable	GW2007
Water Level Meter, 0.375-inch OD Probe, 60-m cable	GE2008

Grouting Accessories	Part Number
Grout Machine, auxiliary-powered	GS500

Probe Rods, Extension Rods, and Accessories	Part Number
Probe Rod, 1.5-inch x 1-meter	17899
Probe Rod, 1.5-inch x 48-inch	13359
Drive Cap, 1.5-inch rods (for GH40 Series Hammer)	15590
Rod Grip Pull Handle, 1.5-inch Probe Rods (for GH40 Series Hammer)	GH1555
Extension Rod, 48-inch	AT671
Extension Rod, 1-meter	AT675

Equipment and tool specifications, including weights, dimensions, materials, and operating specifications included in this brochure are subject to change without notice. Where specifications are critical to your application, please consult Geoprobe Systems®.

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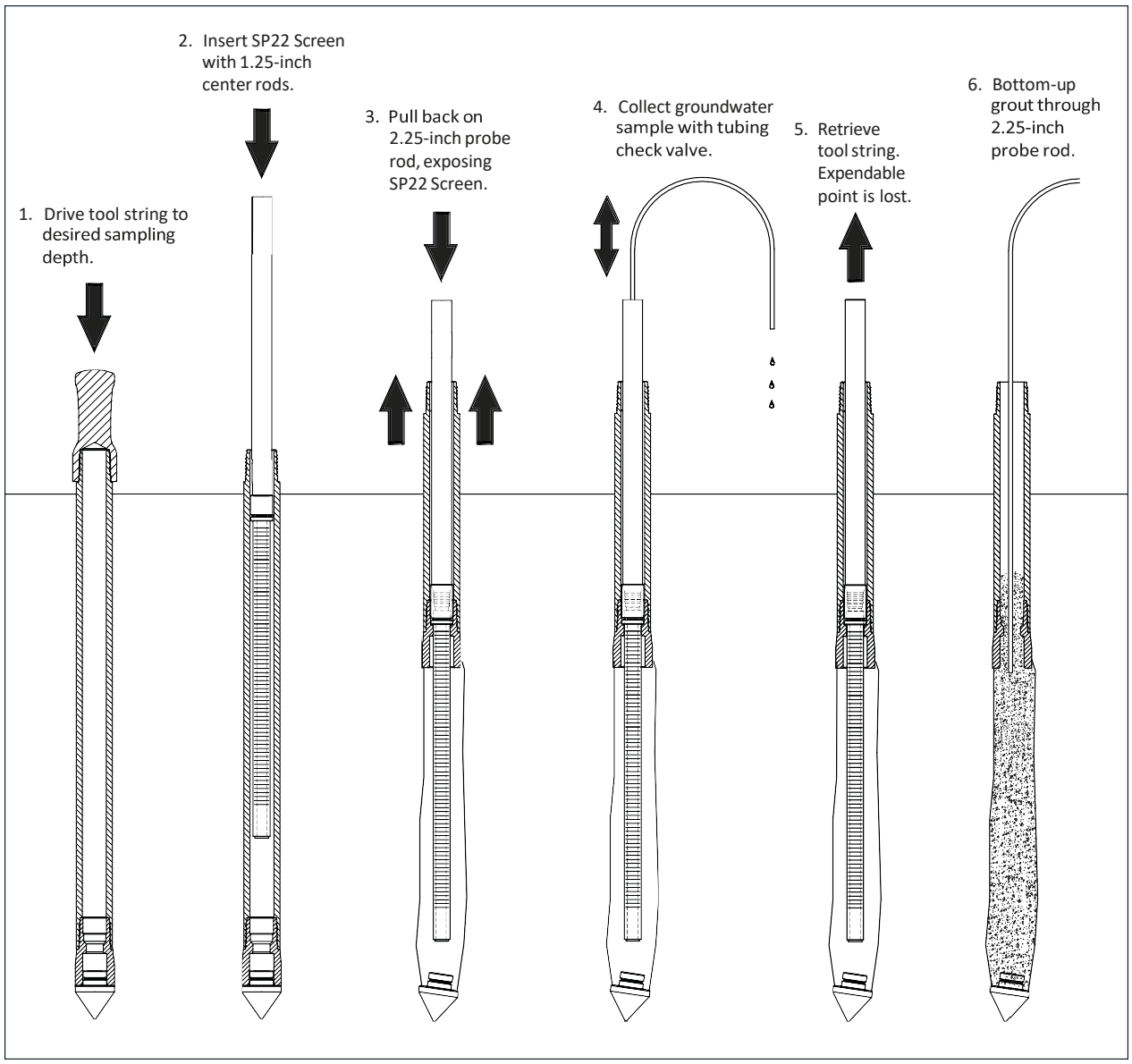
Geoprobe® Screen point 22 Groundwater Sampler

Standard operating procedure

Technical Bulletin No. MK3173

PREPARED: April 2010



OPERATION OF THE GEOPROBE® SCREEN POINT 22 GROUNDWATER SAMPLER

Geoprobe® and Geoprobe Systems®, Macro-Core® and Direct Image® are Registered Trademarks of Kejr, Inc., Salina, Kansas

Screen Point 22 Groundwater Sampler is manufactured under U.S. Patent 5,612,498

1.0 OBJECTIVE

The objective of this procedure is to deploy a stainless steel or PVC screen at depth, obtain a representative water sample from the screen interval, and grout the probe hole during abandonment. The Screen Point 22 Groundwater Sampler enables the operator to conduct abandonment grouting that meets American Society for Testing and Materials (ASTM) Method D 5299 requirements for decommissioning wells and borings for environmental activities (ASTM 1993).

2.0 BACKGROUND

2.1 De!nitions

Geoprobe®: A brand name of high quality, hydraulically powered machines that utilize static force and percussion or rotation to advance sampling and logging tools into the subsurface. The Geoprobe® brand name refers to both machines and tools manufactured by Geoprobe Systems®, Salina, Kansas. Geoprobe® tools are used to perform activities such as soil core and soil gas sampling, groundwater sampling and monitoring, soil conductivity and contaminant logging, grouting, and materials injection.

Screen Point 22 (SP22) Groundwater Sampler: A direct push device consisting of a PVC or stainless steel screen that is lowered (post-run) to depth within a sealed string of steel probe rods and then deployed for the collection of representative groundwater samples. Upon deployment, up to 48 inches (1219 mm) of screen can be exposed to the formation. There is also an optional 12-inch screen that can be used. The Screen Point 22 Groundwater Sampler is designed for use with 2.25-inch probe rods and machines equipped with the more powerful GH60 and GH80 series hydraulic hammers. Operators with GH40 series hammers may choose to use this sampler in soils where driving is easier.

Rod Grip Pull System: An attachment mounted on the hydraulic hammer of a direct push machine which makes it possible to retract the tool string with probe rods or !exible tubing protruding from the top of the probe rods. The Rod Grip Pull System includes a pull block with rod grip jaws that are bolted directly to the machine. A removable handle assembly straddles the tool string while hooking onto the pull block to effectively grip the probe rods as the hammer is raised. A separate handle assembly is required for each probe rod diameter.

2.2 Discussion (Fig. 2.1)

In this procedure, 2.25-inch probe rods are advanced into the subsurface with a Geoprobe® subsurface machine (Fig. 2.1, Step 1). While the tool string is advanced to depth, O-ring seals at each rod joint, the expendable point holder, and the expendable drive point provide a watertight system. This eliminates the threat of formation !uids entering the screen before deployment and assures sample integrity.

Once the leading end of the 2.25-inch probe rods reaches the desired sampling interval, an SP22 screen is lowered to the bottom of the rods using a string of either 1.25-inch outside diameter (OD) light-weight center rods, 1.25-inch probe rods, or 0.75-inch schedule 40 !ush-thread PVC riser (Fig. 2.1, Step 2). The 2.25-inch rods are then retracted while the SP22 screen is held in place with the 1.25-inch rods or PVC riser (Fig 2.1, Step 3). As the 2.25-inch tool string is retracted, the expendable point is released from the expendable point holder. The tool string and expendable point holder may be retracted the full length of the screen or as little as a few inches if a small sampling interval is desired.

The SP22 Sampler can also be used with the Geoprobe® DT22 system. (Fig. 2.2)

(continued on following page)

Expendable Drive Points

The SP22 system utilizes an SP22 Expendable Point Holder (33764) and standard 2.45-inch (62-mm) OD steel Expendable Drive Points for 2.25-inch probe rods (AT2015K). Extended Shank Expendable Drive Points (19442) are available for soft soil conditions where standard points may be advanced out of the point holder during percussion. A third option is to use a part number 43128 SP22 Expendable Point Holder along with 1.625-inch (41-mm) steel Expendable Drive Points (GW1555K). These smaller drive points are more economical to purchase and ship, but must not be used with GH80 Series Hydraulic Hammers as they may not stay seated during percussion.

Screens

Two types of screens have been developed for use in the Screen Point 22 Groundwater Sampler - a stainless steel screen with a standard slot size of 0.004 inches (0.10 mm) and a PVC screen with a standard slot size of 0.010 inches (0.25 mm). These screens are available in nominal 48- and 12-inch lengths. Effective screen lengths for the 48- and 12-inch PVC screens are 48 inches (1219 mm) and 12 inches (305 mm), while 48- and 12-inch stainless steel screens have effective screen lengths of 43 inches (1092 mm) and 14 inches (356 mm) respectively. Both types of screens are recovered with the tool string after sampling.

The SP22 PVC Screen Head Adapter (37871) provides yet another screen option for the SP22 sampler. Using this adapter, a section of slotted 0.75-inch Schedule 40 PVC pipe may be lowered through the 2.25-inch probe rods using a string of !ush-threaded 0.75-inch Schedule 40 PVC Riser. An SP22 PVC Screen Plug (38968) is installed in the leading end of the slotted pipe prior to use. The slotted pipe may be cut and the screen plug installed to provide custom screen lengths .

An O-ring is located at the top of each stainless screen and on the screen adapters. When a screen is deployed, this O-ring maintains a seal between the top of the screen and the inner wall of the probe rods or expendable point holder as indicated in Figure 2.1. As a result, any liquid entering the tool string must !rst pass through the screen.

Screens are constructed such that equipment can be inserted into the screen cavity for sample collection as noted in the following section and illustrated in Figure 2.1, Step 4. This makes direct sampling possible from anywhere within the saturated zone.

The inner rod string and screen are generally removed prior to grouting through the 2.25-inch rod string as shown in Figure 2.1, Steps 5-6. However, a removable plug in the lower end of the screens allows for grouting through !exible tubing extending out the bottom of the screen as with the Geoprobe® SP15/16 Groundwater Samplers if desired.

Sample Collection

Groundwater samples can be obtained from the SP22 screen in a number of ways. A common method utilizes 0.375-inch OD polyethylene (TB25L) or Te!on® (TB25T) tubing and a check valve assembly. The check valve (with check ball) is attached to one end of the tubing and inserted down the casing until it is immersed in groundwater. Water is then pumped through the tubing and to the ground surface by oscillating the tubing up and down.

An SP22 Check Valve Assembly (37893) is recommended if sampling through 1.25-inch light-weight center rods. The SP22 Check Valve Assembly is approximately 20 inches long to enable it to pass through the stepped diameters at each rod joint that may cause problems for other, shorter check valves.

An alternative means of collecting groundwater samples is to attach a peristaltic or vacuum pump to tubing that is inserted through the inner rods to within the SP22 screen. This method is limited in that water can be pumped to the surface from a maximum depth of approximately 26 feet (8 m). Another technique for groundwater sampling is to use a stainless steel Mini-Bailer Assembly (GW41). The mini-bailer is lowered down the inside of the casing below the water level where it !lls with water and is then retrieved from the casing.

The latest option for collecting groundwater from the SP22 Sampler is to utilize a Geoprobe® MB470 Series Mechanical Bladder Pump (MBP)*. The MBP may be used to meet requirements of the low-!ow sampling protocol (Puls and Barcelona 1996, ASTM 2003). Through participation in a U.S. EPA Environmental Technology Veri!cation study, it was con!rmed that the MB470 can provide representative samples (EPA 2003).

**The Mechanical Bladder Pump is manufactured under U.S. Patent No. 6,877,965 issued April 12, 2005.*

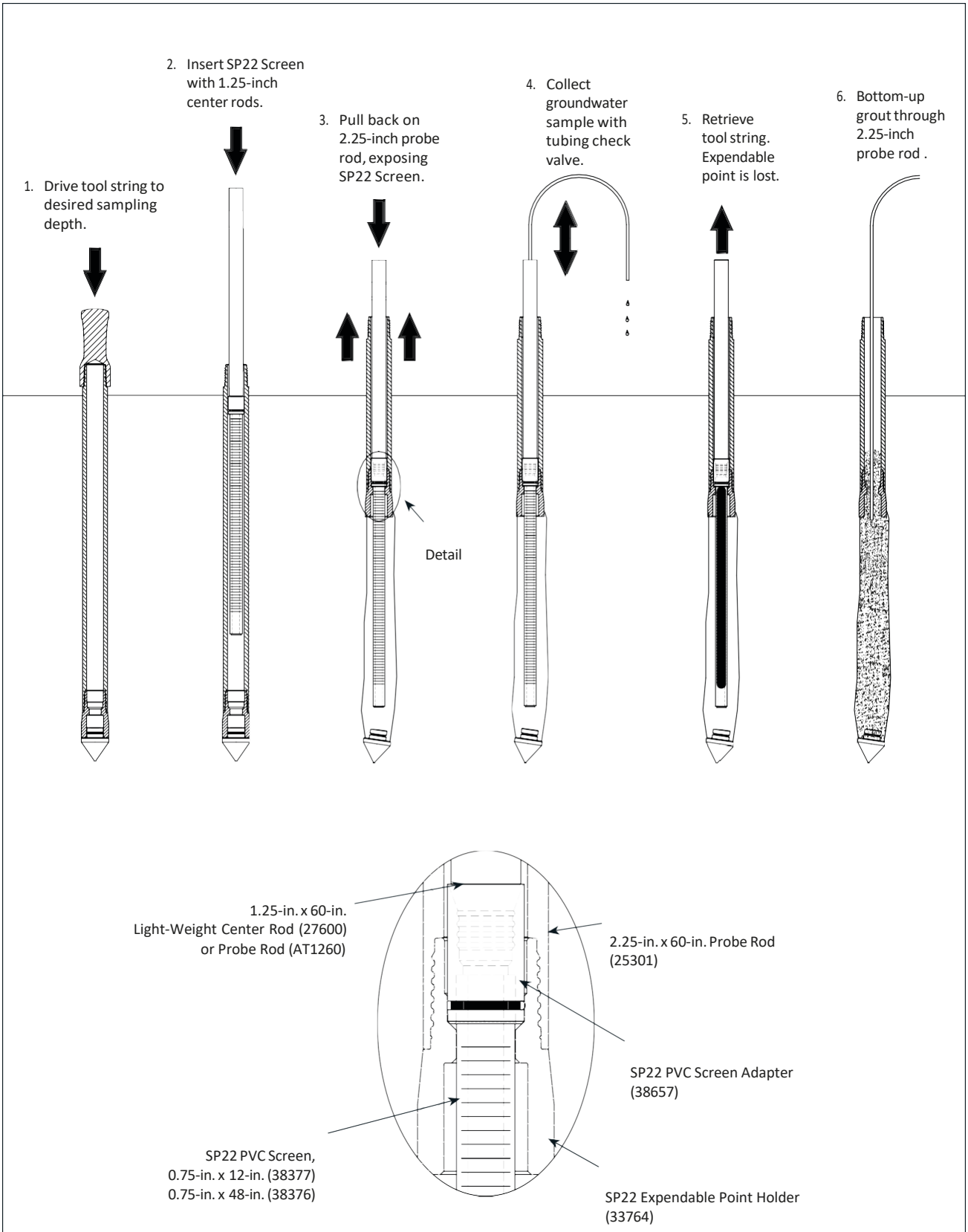


FIGURE 2.1
Screen Point 22 Groundwater Sampler - 0.75-inch PVC Screen Option

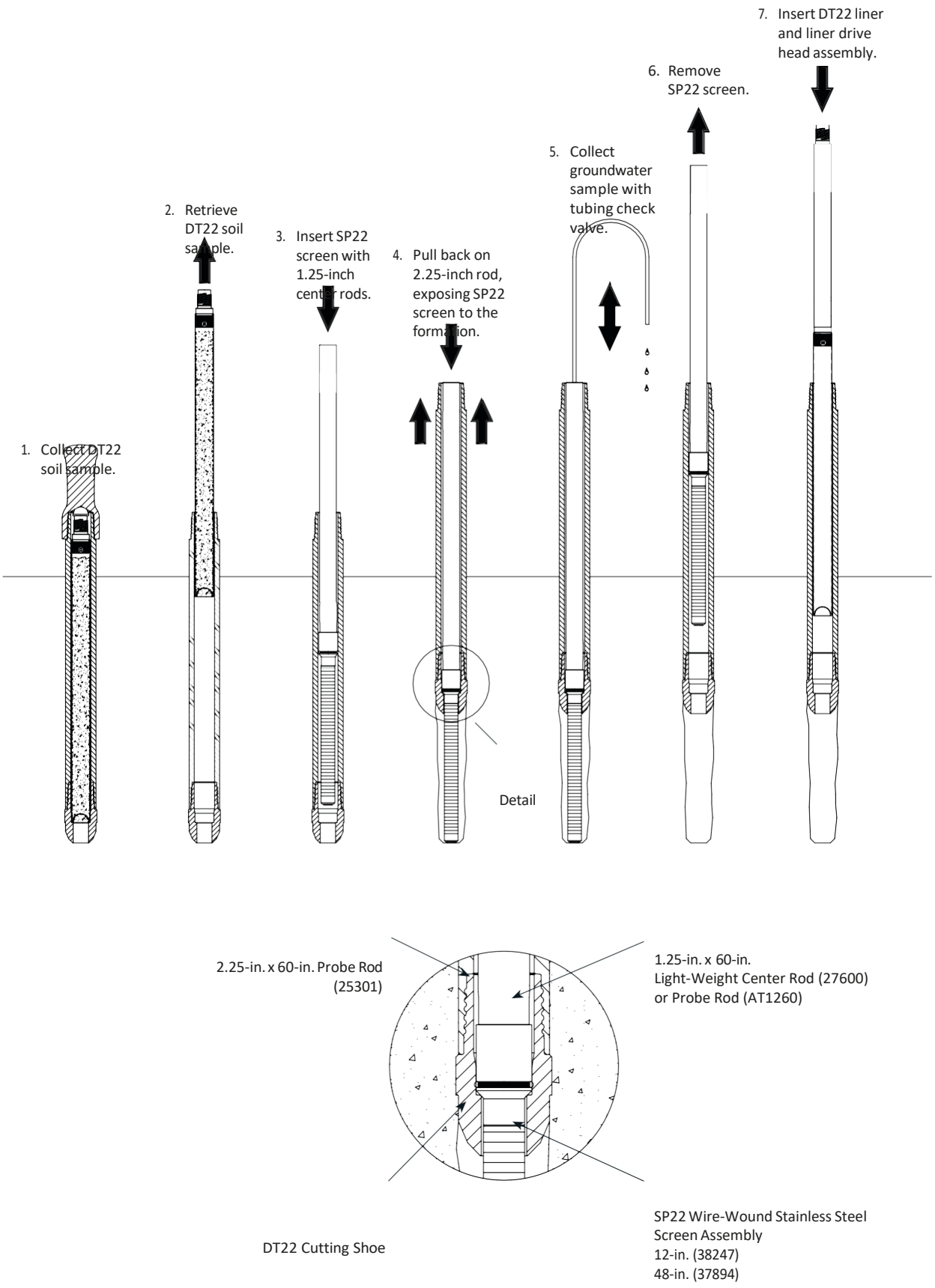


FIGURE 2.2

Screen Point 22 Groundwater Sampler Operation with DT22 Sampling System

3.0 TOOLS AND EQUIPMENT

The following tools and equipment can be used to successfully recover representative groundwater samples with the Geoprobe® Screen Point 22 Groundwater Sampler. Refer to Figures 3.1 and 3.2 for identi!cation of the speci!ed parts. Tools are listed below for the most common SP22 / 2.25-inch probe rod con!gurations. Additional rod sizes and accessories are available. Contact Geoprobe Systems® for information regarding tools and equipment options.

SP22 Sampler Parts	Part Number
SP22 Screen, Wire-Wound Stainless Steel, 4-Slot (48-in.)	37894
SP22 Screen, Wire-Wound Stainless Steel, 4-Slot (12-in.)	38247
Grout Plugs, PE (Pkg. of 25)	GW1552K
SP22 Screen, PVC, 10-Slot, 0.75-in. x 48-in	38376
SP22 Screen, PVC, 10-Slot, 0.75-in. x 48-inch, Kit (includes 2 each of 38376 and 38429)	*38664*
SP22 Screen, PVC, 10-Slot, 0.75-in. x 12-in.	38377
SP22 Screen, PVC, 10-Slot 0.75-in. x 12-in., Kit (includes 2 each of 38377 and 38429)	*38667*
SP22 PVC Screen Plug	38968
SP22 PVC Screen Plug Kit (includes 10 of 38968)	*38530*
SP22 PVC Screen Adapter, 0.75-in. PVC x 1.25-in. Probe Rod Box	38657
SP22 PVC Screen Head Adapter, 0.75-in. (for !ush-threaded 0.75-in. Schedule 40 PVC)	37871
SP22 O-ring Kit (Pkg. of 10 O-rings for SP22 PVC screen adapters and stainless steel screens)	37853
O-rings, 0.75-in. PVC Riser (Pkg. of 25)	GW4401R
SP22 Expendable Point Holder, 2.25-in. Probe Rods, AT2045K and 19442 Points	33764
SP22 Expendable Point Holder, 2.25-in. Probe Rods, GW1555 Points*	43128

Outer Casing (2.125-inch Probe Rods) and Inner Rod String	Part Number
Probe Rod, 2.25-in. x 60-in.	25301
Expendable Drive Points, Steel, 2.45-in. OD (Pkg. of 25)	AT2015K
Expendable Drive Points, Steel, 2.45-in. OD, extended shank	19442
Expendable Points, steel, 1.625-in. OD (Pkg. of 25)*	GW1555K
Drive Cap, 2.25-in. Probe Rods, Threadless, (for GH60 and GH80 Series Hammers)	31530
O-Rings, 2.25-in. Probe Rods (Pkg. of 25)	AT2100R
Rod Grip Handle, 2.25-in. Probe Rods, (for GH60 and GH80 Series Hammers)	29385
Light-Weight Center Rod, 1.25-in. x 60-in.	27600
Probe Rod, 1.25-in. x 60-in.	AT1260
O-ring, 1.25-in. rods (Pkg. of 25)	AT1250R
Rod Grip Handle, 1.25/1.5-in. Rods, (for GH60 and GH80 Series Hammers)	15554
PVC Riser, 0.75-in. Schedule 40 x 60-inch	11747
PVC Pipe, 0.75-in. Schedule 40 x 60-inch, 10-Slot	17474

Grout Accessories	Part Number
High-Pressure Nylon Tubing, 0.375-in. OD / 0.25-in. ID, 100-ft. (30 m)	11633
Grout Machine, Auxiliary-Powered	GS2200
Grout System Accessories Package, 2.25-in. rods	GS1015

Groundwater Purging and Sampling Accessories	Part Number
Polyethylene Tubing, 0.375-in. OD, 500 ft	TB25L
Check Valve Assembly, 0.375-in. OD Tubing x 20 in. Long	37893
Water Level Meter, 0.438-in. OD Probe, 100 ft. cable	GW2000
Mechanical Bladder Pump**	MB470
Mini Bailer Assembly, Stainless Steel	GW41

* Not for use with GH80 Series Hydraulic Hammers

** Refer to the Standard Operating Procedure (SOP) for the Mechanical Bladder Pump (Technical Bulletin No. MK3013) for additional tooling needs.

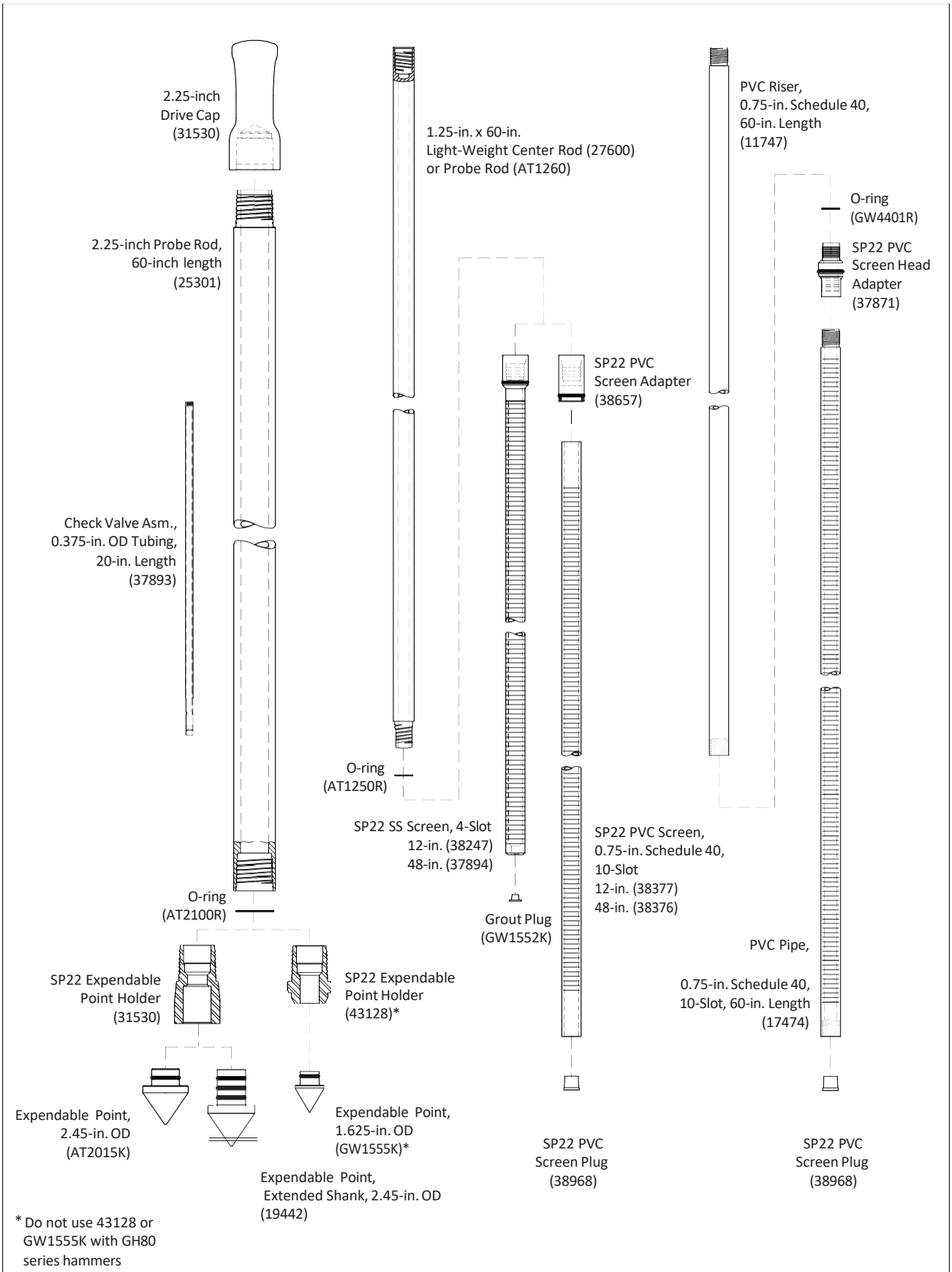


FIGURE 3.1

SP22 Sampler Parts

4.0 OPERATION

4.1 Basic Operation

The SP22 Sampler utilizes a stainless steel or PVC screen which is lowered (post-run) through an alloy steel 2.25-inch OD probe rod tool string. An expendable drive point is placed in an expendable point holder on the leading 2.25-inch probe rod prior to advancement (Fig. 4.1). This expendable point is removed and stays in the subsurface as the rods are pulled back to exposes the SP22 screen. O-rings on the probe rods , the expendable point holder, and the expendable drive point provide a watertight tool string which keeps contaminants out of the system as the 2.25-inch rods are driven to depth in preparation for installation of the SP22 screen.

Once the sampling interval is reached with the 2.25-inch probe rods, the stainless steel or PVC screen is lowered through the rods using 1.25-inch probe rods, 1.25-inch light-weight center rods, or 0.75-inch PVC riser pipe. The 2.25-inch tool string is then retracted while the screen is held in place with the inner rods or riser. The system is now ready for groundwater sampling. When sampling is complete, the inner rods and screen are removed for grouting during retrieval or the 2.25-inch rods. Alternatively, a removable plug is located in the bottom of the screens to allow grouting directly through the inner tool string with high-pressure tubing during retrieval.

4.2 Decontamination

In order to collect representative groundwater samples, all sampler parts must be thoroughly cleaned before and after each use. Scrub all metal parts using a stiff brush and a nonphosphate soap solution. Steam cleaning may be substituted for hand-washing if available. Rinse with distilled water and allow to air-dry before assembly.

4.3 Lead Rod Assembly (Fig. 4.1)

1. Place an O-ring on the expendable point holder.
2. Thread expendable point holder into the 2.25-inch probe rod.
3. Place an O-ring on a steel expendable drive point.
4. Firmly seat the expendable point in the expendable point holder.
5. Place 2.25-inch Drive Cap (31530) on the top of the 2.25-inch probe rod. The lead rod assembly is now ready to be driven to depth.

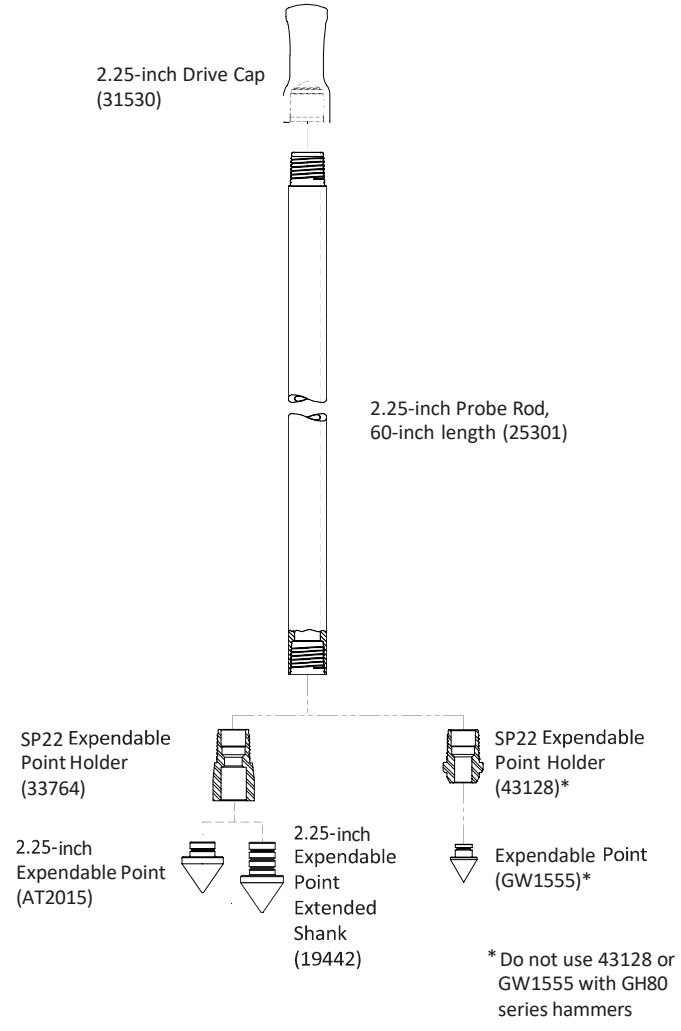


FIGURE 4.1
Lead Rod Assembly for the SP22 Groundwater Sampler

4.4 Advancing the Tool String (Fig. 4.2, step 1)

To provide adequate room for screen deployment with the Rod Grip Pull System, the probe derrick should be extended a little over halfway out of the carrier vehicle when positioning for operation.

1. Drive !rst 2.25-inch probe rod (as assembled in section 4.3).

2. Advance the tool string at a slow speed for the !rst few feet to ensure that the string is aligned properly.

3. Completely raise the hammer assembly. Remove the drive cap and place an O-ring in the top groove of the driven probe rod. Distilled water may be used to lubricate the O-ring if needed.

   Add a probe rod (length to be determined by operator) and reattach the drive cap to the rod string. Drive the tool string the entire length of the new rod.

4. Repeat Step 3 until the desired sampling interval is reached. Approximately 12 inches (305 mm) of the last probe rod must extend above the ground surface to allow attachment of the puller assembly. A 12-inch (305 mm) rod may be added if the tool string is over-driven.

5. Remove the drive cap and retract the probe derrick away from the tool string.

4.5 Screen Deployment (Fig 4.2, step 2 - 4)

1. Attach an SP22 stainless steel or PVC screen to a 1.25-inch probe rod, 1.25-inch light-weight center rod, or 0.75-inch !ush-thread PVC riser using an SP22 PVC Screen Adapter (38657) or SP22 PVC Screen Head Adapter (37871) as shown in Figure 3.1. Note that the 38657 screen adapter is connected to the SP22 PVC screen using the setscrews provided with the adapter.

and lower it into the driven casing.

2. Lower the screen into the 2.25-inch probe rod casing and add rods or riser until the screen head contacts the bottom of the tool string.

3. Ensure that at least 48 inches (1219 mm) of rods or riser protrudes from the top 2.25-inch probe rod.

4. Maneuver the probe assembly into position for pulling.

5. Raise (pull) the outer 2.25-inch tool string while physically holding the screen in place with the inner 1.25-inch rods or 0.75-inch riser. A slight knock with the inner tool string will help to dislodge the expendable point and start the screen moving inside the probe rod.

   Raise the hammer and outer tool string to expose the desired length of screen. The inner rods will begin raising with the outer rods when the screen adapter contacts the necked portion of the expendable point holder or DT22 Cutting Shoe. Use care when deploying a PVC screen so as not to break the screen when it contacts the expendable point.

6. Remove the rod grip handle, lower the hammer assembly, and retract the probe derrick. Remove the top 2.25-inch probe rod.

7. Groundwater samples can now be collected with a mini-bailer, peristaltic or vacuum pump, tubing bottom check valve assembly, bladder pump, or other acceptable small diameter sampling device.

   When inserting tubing or a bladder pump down the rod string, ensure that it enters the screen interval. The leading end of the tubing or bladder pump will sometimes catch at the screen head giving the illusion that the bottom of the screen has been reached. An up-and-down motion combined with rotation helps move the tubing or bladder pump past the lip and into the screen.

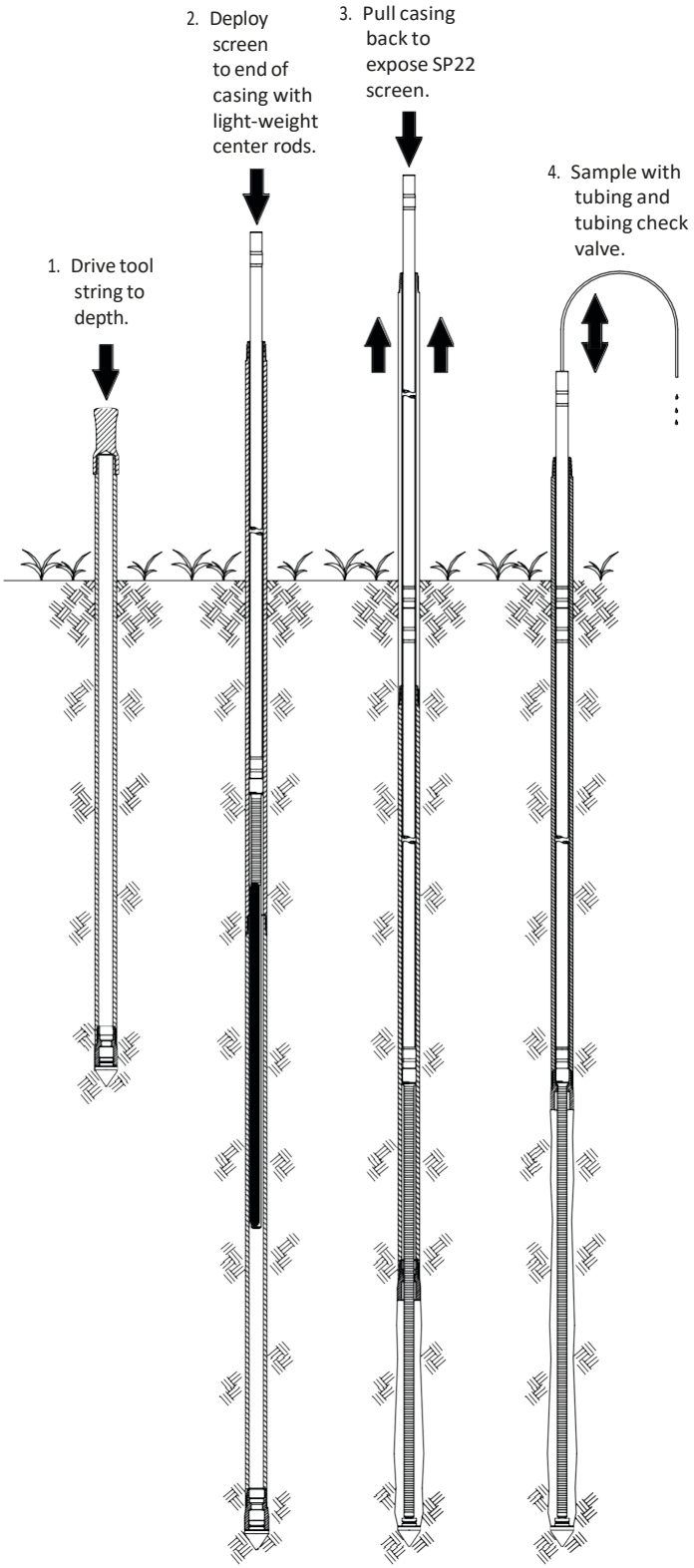


FIGURE 4.2
Screen Deployment for SP22 Sampler

4.6 Abandonment Grouting for SP22 Screens

The SP22 Sampler can meet ASTM D 5299 requirements for abandoning environmental wells or borings when grouting is conducted properly. A removable grout plug makes it possible to deploy tubing through the bottom of the SP22 screens, but the easiest method is to remove the inner string of rods; including the SP22 screen. A Grout Machine is then used to pump grout into the open probe hole as the outer casing is withdrawn. The following procedure is presented as an example only and should be modi!ed to satisfy local abandonment grouting regulations. (Figure 4.3)

1. Maneuver the probe assembly into position for pulling.

2. High-Pressure Nylon Tubing (11633) is inserted down through the probe rods through the bottom of the expendable point holder (Fig. 4.3).

   Note: All probe rods remain strung on the tubing as the tool string is pulled. Provide extra tubing length to allow suf!cient room to lay the rods on the ground as they are removed. An additional 20 feet is generally enough.

3. Operate the grout pump while pulling the !rst rod with the rod grip pull system. Coordinate pumping and pulling rates so that grout !lls the void left by the sampler. After pulling the !rst rod, release the rod grip handle, fully lower the hammer, and regrip the tool string. Unthread the top probe and slide it over the tubing placing it on the ground near the end of the tubing.

4. Repeat Step 5 until the tool string is retrieved. Do not bend or kink the tubing when pulling and laying out the probe rods. Sharp bends create weak spots in the tubing which may burst when pumping grout. Remember to operate the grout pump only when pulling the rod string. The probe hole is thus !lled with grout from the bottom up as the rods are extracted.

5. Promptly clean all probe rods and sampler parts before the grout sets up and clogs the equipment.

4.7 Retrieving the Screen Point 22 Sampler

If grouting is not required, the Screen Point 22 Sampler can be retrieved by pulling the probe rods as with most other Geoprobe® applications. The Rod Grip Pull System should be used for this process as it allows the operator to remove rods without completely releasing the tool string. This avoids having the probe rods fall back downhole when released during the pulling procedure. A standard Pull Cap (33622) may still be used if preferred. Refer to the Owner's Manual for your Geoprobe® direct push machine for speci!c instructions on pulling the tool string.

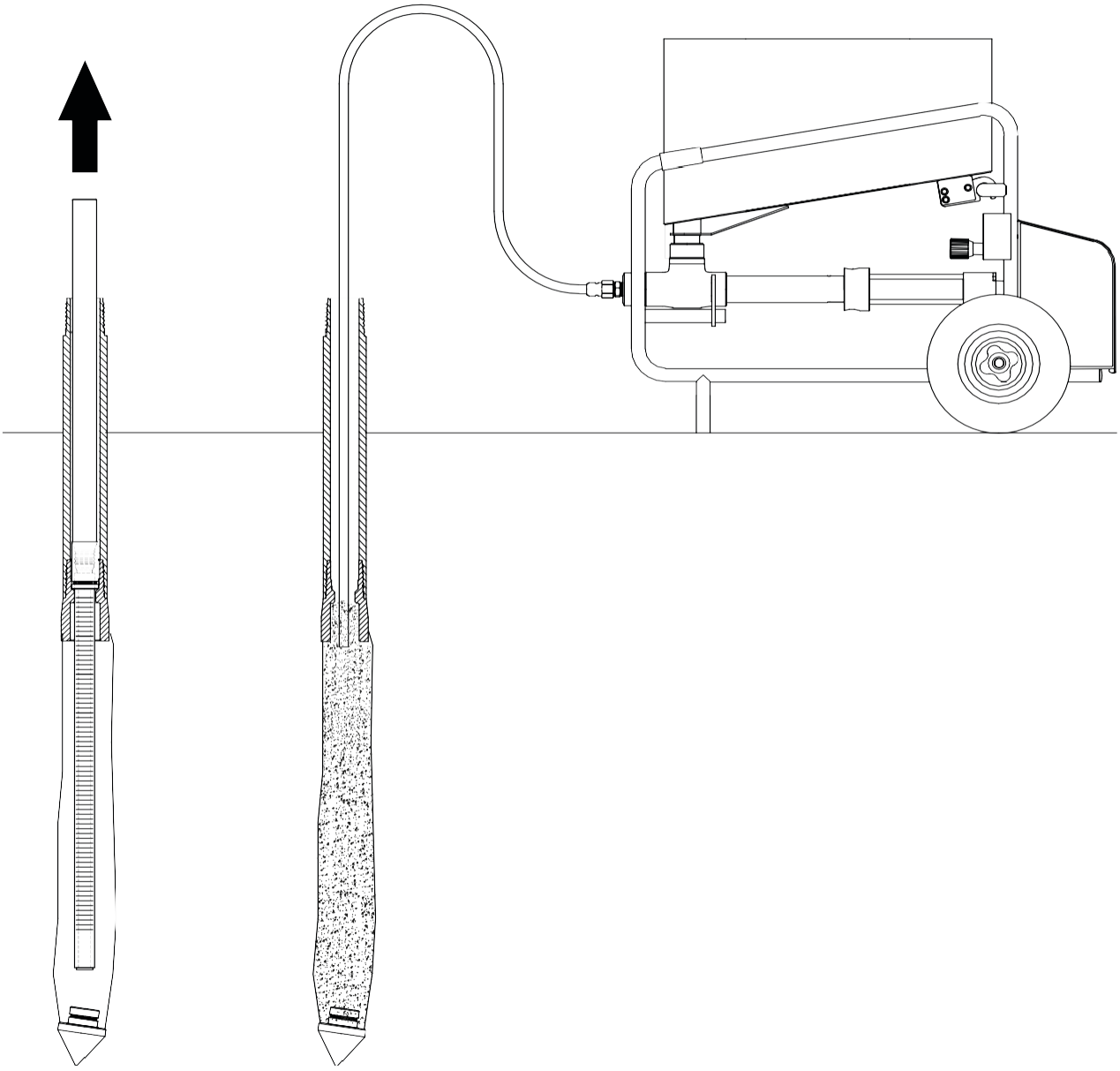


FIGURE 4.3
Abandonment Grouting for the SP22 Sampler

5.0 REFERENCES

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Equipment and tool speci!cations, including weights, dimensions, materials, and operating speci!cations included in this brochure are subject to change without notice. Where speci!cations are critical to your application, please consult Geoprobe Systems®.

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TGI - Installation of Soil Vapor Probes

Rev: 4

Rev Date: April 30, 2025

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
1	1	12/12/2017	All	Initial TGI Development	Eric Epple Daniel Zuck Mitch Wacksman
2	2	1/3/2022	All	Revisions, Update to new format for QMS	Lindsey Deschenes Robert Uppencamp
3	3	1/25/2023	All	Annual review completed by Sarah Jonker Updated revision number and revision date; updated version control page as requested by Sarah Jonker on 1/25/2023.	Sarah Jonker
4	4	4/30/2025	All	Annual review; Several revisions throughout / complete rewrite	Sarah Jonker Brittany Fagin Eric Epple Lindsey Deschenes

Approval Signatures

Prepared by:		4/16/2025
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1 Introduction

This Technical Guidance Instruction (TGI) provides the methods and procedures for installing soil vapor probes. Additional TGIs should be reviewed for procedures specific to soil vapor probe sampling. 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 *TGI: Soil Vapor Sampling and Analysis using Sorbent Tubes for USEPA Method TO-17*. Check the QMS library for state specific TGIs according to your project location.

2 Intended Use and Responsibilities

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.

3 Scope and Application

This TGI is recommended as a practical approach for the installation of soil vapor sampling probes where the intent is to collect soil vapor samples over one or more sampling events. Nested soil vapor probes (i.e., multiple sample depths inside a single boring) can also be installed using these methods. Drilling methods that can be used to advance borings for the installation of soil vapor probes includes hand auger, direct push, and hollow stem auger. Rotary sonic drilling and air-knife clearance is discouraged but may be necessary in certain circumstances. If rotary sonic drilling or air-knife clearance is necessary, discuss extended equilibration time

considerations. Soil vapor samples are often collected as part of vapor intrusion investigations associated with subsurface impacts. 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.

4 Personnel Qualifications

Soil vapor probe installation activities will be performed by staff who have been trained on 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 Technical Guidance Instructions (TGI)s for those activities.

5 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 (JSAs).
- 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 outer diameter (OD) inert tubing (typically Teflon, Teflon-lined, or Nylon). Be aware that some regulatory agencies have requirements on the type of tubing to be used.
- Probe compression cap (to seal the tubing during equilibration).
- Probe screen and anchor point – ½-inch OD stainless steel screen, such as the Geoprobe Systems® implant, or similar. Several screen lengths are available 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 (IDW) handling.
- Labels for sample soil vapor probe tubing. Stamped metal tags affixed with zip ties are recommended. Do not use tape.
- MultiRae® four or five-gas meter (or equivalent) for health and safety air monitoring during drilling.
- A photoionization detector (PID) capable of parts per million (ppm) readings.
- Landtec® GEM 5000 landfill gas meter (or equivalent).
- Decontamination equipment including bucket, distilled or deionized water, cleansers (Alconox®, TSP, or similar) appropriate for removing expected chemicals of concern and paper towels.

- Engineer's tape/measuring wheel.
- Weighted tape.
- Digital camera or phone with camera (confirm client approval).
- Field notebook and/or FieldNow® digital app (preferred).
- 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, probes, and fittings and not the 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;
- Boring equipment: hand auger and/or drill rig equipped with direct push or rotary auger capability;
- Clean filter silica sand (#2 or larger);
- Granular bentonite or bentonite powder (bentonite chips are discouraged);
- Hydraulic or non-shrink cement grout;
- Tremie pipe with funnel or manual grout pump (1-inch OD PVC Pipe);
- Applicable materials to install watertight protective casing (flush traffic rated well box or stand-pipe) to be discussed with drilling contractor prior to mobilization.

6 Cautions

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 Arcadis Utility Clearance HS Standard and HASP for detail. An Arcadis 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 quality 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 is not recommended 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, hand sanitizers, fuels and solvents or oils prior to handling soil vapor construction materials. Clean nitrile gloves should be used when handling any probe components (this includes the drilling contractor). Field personnel should **not use sharpie markers** during installation or note taking.
- Gravel or dense clay may make direct push drilling methods 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 detergent (Alconox®, TSP, or similar), then a final rinse with distilled water. The equipment should be allowed to air dry before use. When 1,4-dioxane is a site-specific constituent of concern, TSP (trisodium phosphate) should be used. Refer to the Arcadis *TGI – Decontamination of Components for Vapor Intrusion Sampling* for further guidance.

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, typically 2-feet above groundwater depth, if feasible. Depths of perched water zones should also be considered. Review historical groundwater data for seasonal high groundwater depths to support installation depth and considering gauging nearby monitoring wells if accessible.
- Use of an air knife or vacuum truck is not recommended. Some jurisdictions explicitly prohibit the use of an air knife for soil vapor probe installation. However, if manual (hand auger) soil boring clearance is impractical based on soil lithology, use of an air knife or vacuum truck should be discussed as an alternative with the project team and used sparingly. Significant equilibration time will be required prior to sampling when an air knife or vacuum truck is used.
- Vapor probes can be finished at the ground surface with a flush mount traffic rated road box or vault (preferred) or with a standpipe 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.

7 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.

8 Procedure

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-feet below ground surface (bgs). Soil vapor probe placement is project specific and based on site objectives, however as a general consideration soil vapor probes must be installed in dry conditions approximately 2-feet above the water table or perched soil moisture.

All drilling equipment must be decontaminated prior to use and between each boring/installation. Handle and store decontaminated soil vapor probes in a manner that prevents contamination, such as in a Ziploc® bag prior to use. Record the outer diameter of the drilling equipment for an accurate borehole diameter.

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. 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 tooling.
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 and hydrate to properly seal.
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 screen/sand interval.
5. Withdraw the drill pipe 6 inches and place 6 inches of dry granulated bentonite on top of the clean sand layer.

   Add hydrated granular bentonite or bentonite slurry to 12-inches below the ground surface, or bottom of next sample interval (for nested installations). Install appropriate surface finish (i.e., bolting watertight 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. For temporary probes, to be destroyed shortly after sampling, only use hydrated bentonite up to 12-inches below ground surface.

   a. For permanent probe installation at California sites (subject to DTSC VI Guidance), add 6-inches of hydrated granular bentonite and let it set for a minimum of 30 minutes. After the bentonite is set, pour Portland Neat Cement Type I/II up to 12-inches below ground surface as the annular seal.

6. The remaining annulus within the road box may be filled with non-shrink grout cement or hydrated granular bentonite to approximately 0.5-foot below ground surface, or enough to seal the tubing to the protective casing. Place 2 to 3 inches of sand on top of the cement to ensure that the tubing and fittings do not make contact with the cement during curing or hydrated granular bentonite.
7. Cut sample tubing long enough to allow enough length to sample in the future. For flush mounted casings, 2 to 3 feet of tubing is recommended. For stand-pipe casing, make sure there is at least 6 to 7-feet of tubing extending above grade. Terminate sample tubing using an airtight plug or valve with compression fittings (stainless steel is recommended).
8. Clearly label sample probe and protective casing with ID and depth. Stamped metal tags affixed with stainless zip ties are recommended.
9. Allow at least 24-hours for soil vapor probe equilibration and cement curing prior to leak testing and sampling. See applicable TGIs and applicable state guidance for specifically required equilibration times typically determined based on drilling methods used.

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

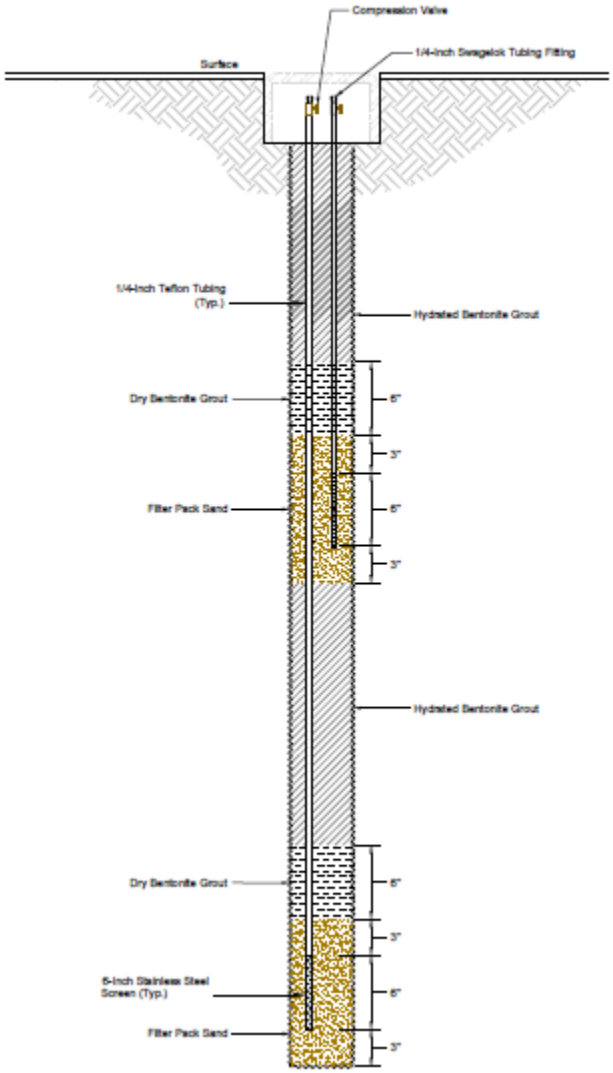

Figure 1. Nested soil vapor probe construction schematic.

9 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.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

Drilling activities should be documented on appropriate field/log forms (see Attachment A) as well as in a proper field notebook. 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).

11 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 TGI. New tubing should be used for every installation. Soil vapor probe materials will also be cleaned prior to well installation. Refer to the Arcadis *TGI – Decontamination of Components for Vapor Intrusion Sampling* for further guidance.

12 References

California Environmental Protection Agency (CalEPA) – Department of Toxic Substances Control (DTSC). 2015. Advisory – Active Soil Gas Investigations (https://dtsc.ca.gov/wp-content/uploads/sites/31/2021/11/VI_ActiveSoilGasAdvisory_FINAL_a.pdf). July.

Interstate Technology Regulatory Council (ITRC). 2007. Technical and Regulatory Guidance. Vapor Intrusion Pathway: A Practical Guideline (https://itrcweb.org/wp-content/uploads/2024/09/VI-1.pdf). January.

New Jersey Department of Environmental Protection (NJDEP) – Site Remediation and Waste Management Program. 2016. Vapor Intrusion Technical Guidance (https://dep.nj.gov/wp-content/uploads/srp/vig_main_4.0.pdf). 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.

Attachment A

Single Soil Vapor Probe Construction Diagram

Nested Soil Vapor Probe Construction Diagram

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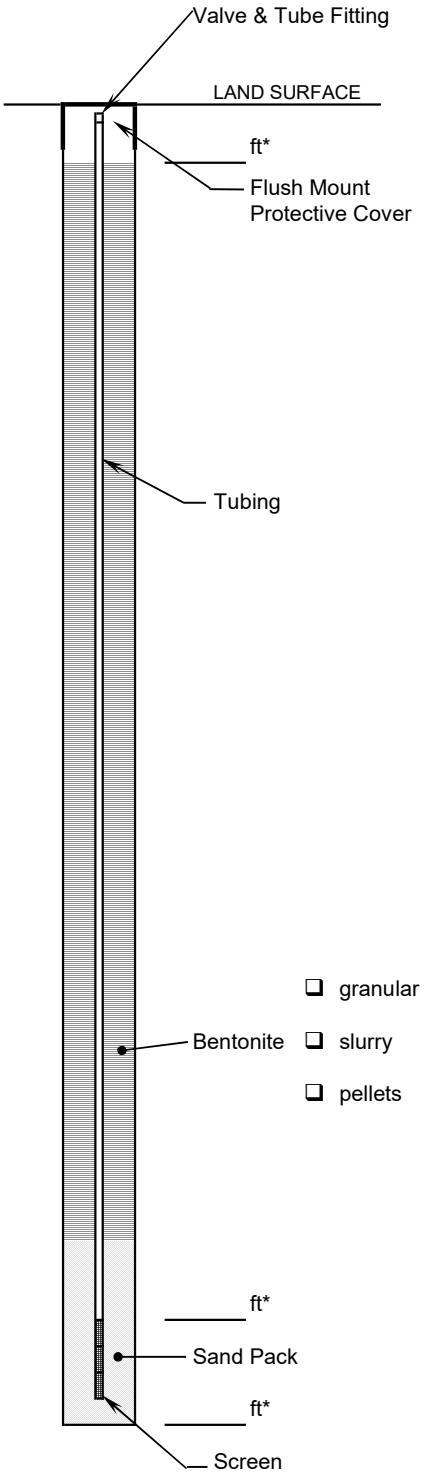
SINGLE SOIL VAPOR PROBE CONSTRUCTION DIAGRAM



* Depth Below Land Surface

Project: _____ Port: _____

City: _____

County: _____ State: _____

GPS Coordinates:

Latitude: _____

Longitude: _____

Land-Surface Elevation and Datum:

_____ feet

❑ Surveyed

❑ Estimated

Installation Date: _____

Weather Conditions at Installation: _____

_____

Drilling Contractor: _____

Driller: _____

Drilling Method: _____

Screen:

Construction: _____

Length: _____

Tubing:

Construction: _____

Diameter: _____

End Valve:

Type/Construction: _____

End Connection: _____

Remarks: _____

_____

_____

_____

_____

_____

_____

_____

Prepared by: _____

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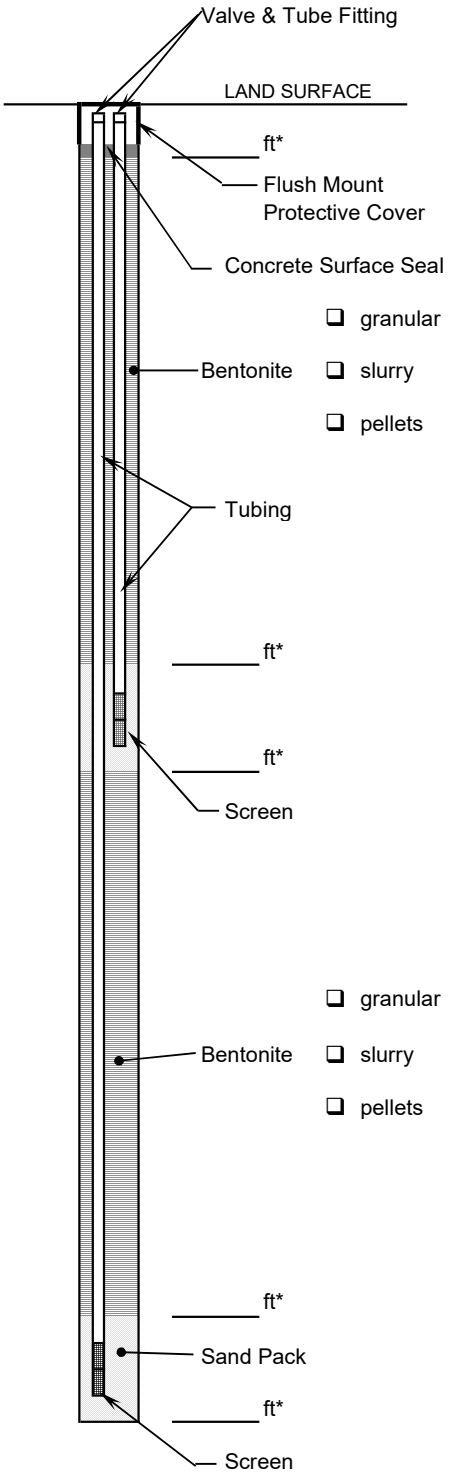
NESTED SOIL VAPOR PROBE CONSTRUCTION DIAGRAM



* Depth Below Land Surface

Project: _____ Port: _____

City: _____

County: _____ State: _____

GPS Coordinates:

Latitude: _____

Longitude: _____

Land-Surface Elevation and Datum:

_____ feet

❑ Surveyed

❑ Estimated

Installation Date: _____

Weather Conditions at Installation: _____

_____

Drilling Contractor: _____

Driller: _____

Drilling Method: _____

Screen:

Construction: _____

Length: _____

Tubing:

Construction: _____

Diameter: _____

End Valve:

Type/Construction: _____

End Connection: _____

Remarks: _____

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TGI - Sub-Slab Vapor and Soil Vapor Sampling Using Whole Air Canisters

Rev: 3

Rev Date: July 22, 2025

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
1	1	9/18/2016	All	Updated Rev0	Mitch Wacksman
2	2	8/4/2023	All	Updated Rev1	Sarah Jonker Christina Weaver Robert Uppencamp
3	3	7/22/2025	All	Complete re-write to all sections.	Sarah Jonker Margaret Bartee

Approval Signatures

Prepared by:		7/22/2025
	Sarah Jonker	Date
Reviewed by:		7/22/2025
	Margaret Bartee	Date

1 Introduction

This Technical Guidance Instruction (TGI) provides the methods and procedures for collecting whole air samples via USEPA Method TO-15 from sub-slab vapor or exterior soil vapor using whole air stainless-steel canisters. It is advisable to consult with a vapor intrusion subject matter expert (SME) when planning and executing the procedures detailed in this TGI.

2 Intended Use and Responsibilities

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.

3 Scope and Application

This Technical Guidance Instruction (TGI) has been updated to reflect United States Environmental Protection Agency (USEPA) criteria (USEPA 2015) and best practices.

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 stainless-steel canisters for the analysis of volatile organic compounds (VOCs) by USEPA Method TO-15 (TO-15). This document assumes a sample port (either sub-slab port or exterior soil vapor probe) has already been installed. This document covers the above ground assembly and sampling methods.

Separate TGIs are available in the TGI library for the installation of sub-slab ports and exterior soil vapor probes. Sampling is typically able to commence a minimum of 2 hours after installation of a sub-slab port (VaporPin®) and a minimum of 24 hours after installation of a soil vapor probe. Confirm equilibration times with the project's regulatory jurisdiction.

Method TO-15 typically uses a 1-liter, 3-liter, or 6-liter stainless-steel canisters 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, materials, and detailed instructions for collecting soil vapor samples for VOC analysis.

4 Personnel Qualifications

Arcadis field sampling personnel will have current health and safety training, including 40-hour HAZWOPER training, site supervisor training, Department of Transportation (DOT)/International Air Transport Association HazMat #1, 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.

5 Equipment List

The equipment required for soil vapor sample collection is presented below. All stainless-steel supplies must be cleaned/decontaminated prior to use.

5.1 Laboratory

- 1, 3, or 6-liter whole air stainless-steel canisters. Order either batch certified canisters or individually certified canisters as required by the project. Order at least one extra whole air stainless-steel canister per 20 samples to account for a potential loss of vacuum malfunction in shipping, if feasible. A 1-liter whole air stainless-steel canister is typical for soil vapor sampling and will achieve most reporting limit requirements. Confirm the applicable screening levels for the project will be met by the laboratory reporting limits.
- Flow controllers must be ordered for each whole air stainless-steel canister ordered. Flow controllers will come 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., between 80-200 milliliters per minute [mL/min]). Confirm with the laboratory that the flow controller comes with a particulate filter and vacuum gauge.
- Order a stainless-steel duplicate tee as needed. Projects typically require 1 duplicate per 10 samples or 20 samples. Confirm the project QA/QC requirements.

5.2 Supplies

Soil vapor probes are typically completed with all sample assembly components permanently connected and contained within the manway vault. Purging materials and sampling media are required.

Supplies to build one sub-slab port assembly are listed below. Clean/decontaminate all stainless-steel supplies prior to use. Tubing and ferrules cannot be reused. Stainless-steel supplies should be Swagelok® or Parker A-Lok compatible compression fittings. Supplies can be purchased at companies such as Swagelok® www.swagelok.com, McMaster Carr www.mcmaster.com, or ESP Supply www.shop-esp.com.

Two sub-slab sample assembly types are detailed in Section 8. Materials to build each type of sample assembly are listed below.

Sub-Slab Port Assembly for Vapor Pin™ with Barb Fitting using the Sample Configuration with Purge Isolation

- 1: 1/4-inch stainless-steel valve with compression fittings.
- 6: 1/4-inch stainless-steel compression nuts.
- 6: 1/4-inch stainless-steel front and back compression ferrules.
- 1: 1/4-inch stainless steel union tee. Some labs have flow controllers with a purge port and valve built in. Confirm with the lab flow controller setup (request a diagram or photo). A Luer-Lok™ 3-way valve can be used at the tee fitting as well (single use).
- 36-inches: 1/4-inch outer diameter (OD) Teflon®, Teflon® lined, or Nylaflow tubing.
- 8-inches: 1/4-inch inner diameter (ID) silicone tubing.
- 50 or 60-mL syringe equipped with a three-way Luer-Lok™ valve. Alternately, a low-flow air pump may be used.
- 1-liter Tedlar® bag to collect purge air for the leak detection test, field parameter measurements, and venting outside a structure if working inside.

Sub-Slab Port Assembly for Vapor Pin™ with Barb Fitting using Separate Purge and Sample Configuration

- 1: 1/4-inch stainless-steel ball with compression fittings.
- 3: 1/4-inch stainless-steel compression nuts.
- 3: 1/4-inch stainless-steel front and back compression ferrules.
- 24-inches: 1/4-inch OD Teflon®, Teflon® lined, or Nylaflow tubing.
- 8-inches: 1/4-inch ID silicone tubing.
- 60-mL syringe equipped with a three-way Luer-Lok™ valve. Alternately, a low-flow air pump may be used.
- 1-liter Tedlar® bag to collect purge air for the leak detection test, field parameter measurements, and venting outside a structure if working inside.

5.3 Rental Equipment/Supplies

Appropriate equipment and materials for quality assurance testing are detailed in the respective quality assurance TGIs (i.e., helium leak testing, water dam testing, methane testing).

- 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).
- Low-flow air pump with time-elapse clock (GilAir or equivalent) capable of a flow rate between 100 ≤ to ≤ 200 mL/min for purging. This may require a low-flow module. Alternately, a 60-mL syringe with a three-way Luer-Lok™ valve may be used.

- Air pump calibration instrument such as a DryCal® Defender (or equivalent), as needed.
- Photoionization detector (PID) with calibration kit, as needed.
- Multi-gas monitor (LANDTEC® GEM™ 2000 PLUS/5000 or similar) capable of detecting percentage of carbon dioxide, methane, and oxygen with calibration kit, as needed.
- Helium detector (Dielectric MGD-2002 or similar).
- Ultra-high purity (UHP) helium tank with compatible regulator.
- Portable weather meter, as needed. Alternately, weather applications or weather websites can be used.

5.4 Personal Gear and Documents

- Appropriate-sized open-end wrench (typically 9/16-inch and 1/4-inch, #14 spanner for Vapor Pins®).
- 1/4-inch adjustable wrench.
- Channel locking plier with 1.5-inch or larger opening (helium tank manifold and 2-way valves).
- Non-VOC containing modelling clay to mitigate leaks such as Craft Smart Natural Clay (air-dry) or Pepy Plasticine (non-drying). Clay should have no color added and meet ASTM D-4236 standards for required clear labeling (This means they must include general VOCs or harmful ingredients in the label).
- Shroud (plastic bucket, garbage can, plastic bag, plastic drop cloth, laboratory provided helium leak detection kit, etc.).
- Sand filled socks, weighted chain, or equivalent to seal helium shroud when using a plastic bag or drop cloth.
- Chain-of-custody (COC) form(s) – lab supplied preferred.
- Nitrile gloves.
- Work gloves.
- Sample collection log, field notebook/tablet, or current Standard Vapor Intrusion Sampling FieldNow® application.

6 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 (e.g., Sharpie®), wear/apply fragrances including sunscreens, hand sanitizer, or alcohol-based cleaning products. Do not smoke cigarettes/cigars before and/or during the sampling event.
- Soil vapor sampling equipment and tools should be stored separately from adhesives with VOCs such as duct tape. Field staff should take note of any sanitation stations or recent use of chemicals within proximity of their sample locations.
- Tubing and piping materials commonly used for other types of sampling such as HDPE, LDPE, and PVC should not be used in soil vapor sampling. These materials can either absorb constituents of potential concern present in soil vapor or introduce VOCs via off gassing. Refer to Section 5 for the list of approved soil vapor sampling materials.

- Ensure the flow controller is pre-calibrated to the proper sample collection duration (confirm with laboratory) by checking equipment inventory enclosed with equipment packaging and flow controller tags. Discuss discrepancies with project team prior to final mobilization for sampling. 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., 2 to 10 inches of mercury [in Hg]) remains in the canister when sample collection is terminated.
- The helium detector will function correctly at high relative humidity levels of 50% or greater, but its accuracy and sensitivity may be reduced. In addition, high concentrations of methane can cause false readings. Use a multi-gas monitor to screen purged air during leak check if methane interference is anticipated. Review the TGI for *Administering Helium Tracer Gas Leak Test* for further details on helium leak testing.
- The integrity of the sample train and sample port 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 testing.
- When conducting a shut-in test, pull the syringe slowly at a rate no faster than 1 to 2 mL/second (approximately 60 to 120 mL/min, the lower the better) to avoid damage to the flow controller, and stop pulling once you have achieved a vacuum. Most flow controllers are not constructed to withstand vacuum from the outlet side of the device, and therefore, rapid application of strong vacuum from a quick, full pull of a syringe can damage the internal components.
- It is important to record the canister vacuum, start and stop times, and sample identification on a proper field sampling form or current Standard Vapor Intrusion Sampling FieldNow® application. You should observe and record the time/ vacuum at the start, and then again one or two minutes after starting the sample collection. It is a good practice to lightly tap the vacuum gauge with your finger before reading it to make sure the needle is not stuck. If the canister is filling as expected, the sampling rate should match the rate of the flow controller set point. Consult your project manager, risk assessor, or air sampling expert by phone if the canister does not appear to be working properly due to insufficient or rapid pressure changes.
- Ensure that there is still measurable vacuum in the canister after sampling. The target residual vacuum is -5 inches Hg, however the acceptable range is between -2 in Hg and -10 in Hg. Sometimes the gauges sent from labs have off-set errors, or they stick.
- When sampling, carefully consider elevation. If your site is over 2,000 feet above sea level, or the difference in elevation between your site and your lab is more than 2,000 feet, then pressure effects will be significant. If you take samples at a higher elevation, they will contain less air for a given ending vacuum 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 received by a laboratory at high elevation may appear to not have much vacuum left in them. Pressure at sea level is 1 atm which corresponds to 29.92 inches Hg. Enter the sample location (city/town) atmosphere (atm) into the Pressure Conversions Calculator to determine the difference in the corresponding pressure in inches of Hg: http://www.uigi.com/Atmos_pressure.html. For instance, the atmosphere in Denver, Colorado is 0.830 atm which corresponds to 24.83 in Hg. This indicates approximately 5 inches Hg difference from sea level.
- If possible, have equipment shipped two to three days before the scheduled start of the sampling event so that all materials can be checked. Check the vacuum in each canister as soon as they arrive. The preference is a starting vacuum of -28 inches of Hg or more, but some canisters may be used in certain jurisdictions with lower starting vacuum. However, ff the initial vacuum registers less than -25 inches of Hg, then the canister is not appropriate for use and another canister should be used. The initial vacuum required varies by

jurisdiction; confirm with the project regulatory authority and project team prior to sampling. If an analog or digital gauge is available when conducting inventory, ensure the vacuum is similar to the laboratory recorded vacuum on the sample tag. 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, especially at remote sites.
- When taking field measurement readings of the soil vapor conditions, it is best practice to collect reading from a Tedlar® bag instead of directly from sample port. This is due to field instruments having a flow rate of greater than 200 ml/min, which can cause partitioning of contaminants during sampling. In addition, for health and safety reasons, when there are elevated concentrations of site contaminants it is best not to purge into the sampler's breathing zone.
- Considering laying out a new trash bag or tarp on the ground next to the sample port to prevent sampling equipment from touching potentially impacted ground (i.e., asphalt parking lot with car oil stains).
- Shallow exterior soil-gas sampling normally should not proceed immediately following a significant rain event. Consult applicable regulations and guidance for recommended wait times following precipitation events before sampling can proceed.
- This TGI is not a substitute for a Work Plan. Staff involved with a soil vapor sampling event must review the Work Plan prior to pre-field planning activities.

7 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.

Soil vapor sampling is often done on the ground with workers on their knees. Low stools, knee pads, or a large pad can be used under the entire sample area (i.e., a large, folded box). This will protect the worker's knees. Ensure proper hand protection is worn while working with hand tools during sample train assembly. The metal-on-metal fittings often create small metal splinters, so always use gloves when handling thecanisters, fittings, valves, etc. Do not blow the splinters off towards other workers. Use outer nitrile gloves when handling all sample train components to prevent potential cross contamination.

Methane is encountered at some project sites, especially petroleum sites and in situ remediation sites. Package the canister and flow controller per DOT regulations for return shipment to the laboratory. These regulations can be found at the Transportation Safety Program's Team Site on the Source. The canister does not require preservation with ice or refrigeration during shipment. Refer to TGI – Soil Gas Methane Monitoring for Shipping Determination of Soil Gas Samples if sampling in an area with unknown or known methane conditions. A shipping determination form is required for shipment of any type of samples prior to field mobilization.

8 Procedure

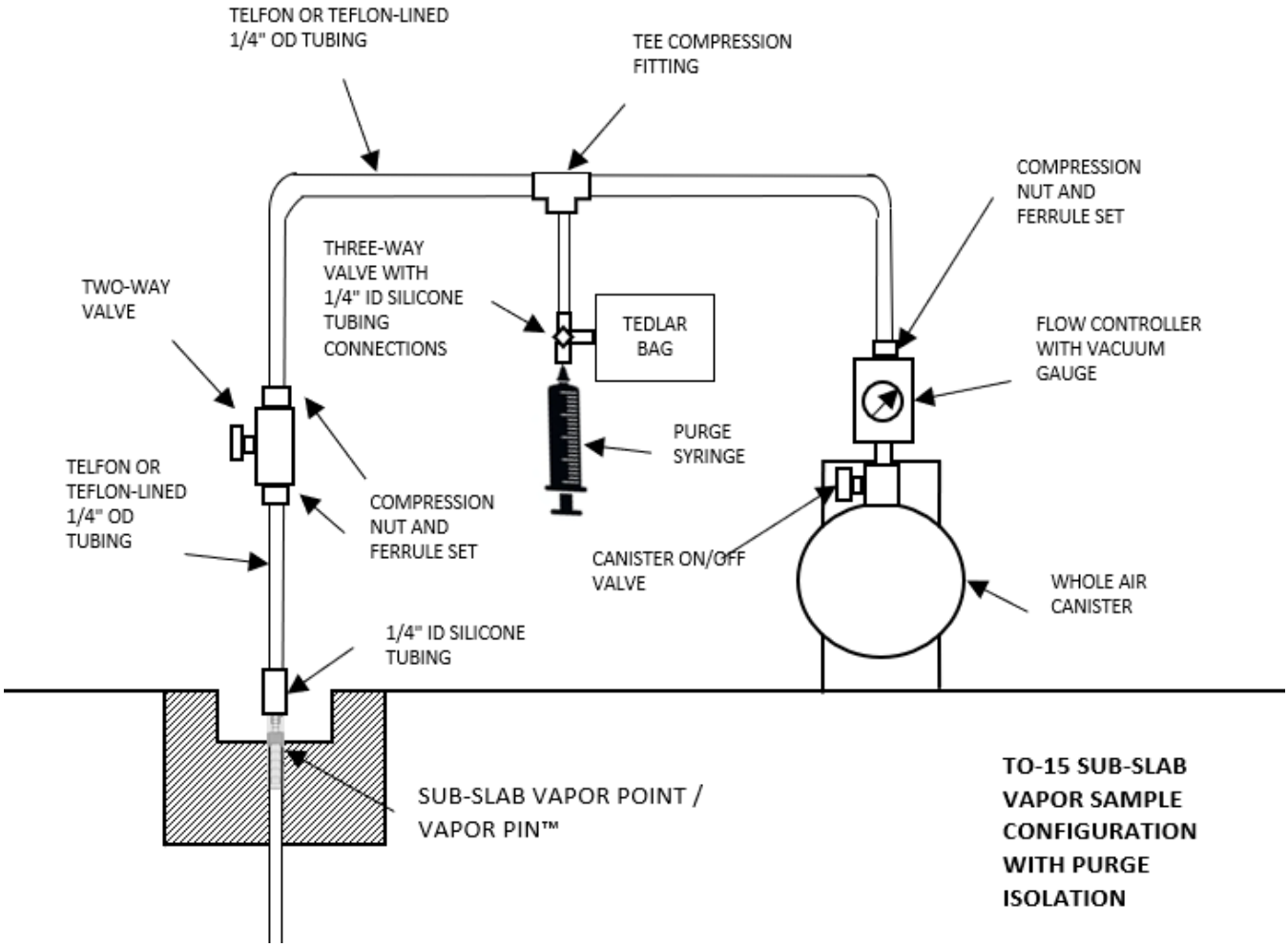
8.1 Sample Train Assembly

The following procedures should be used to collect a soil vapor sample using a whole air stainless-steel canister. These methods can be used for both soil vapor probe samples and interior sub-slab soil vapor samples collected from both permanent and temporary sample point installations. Two configurations of the sample train are acceptable in most jurisdictions; confirm with the project regulatory authority.

Sub-Slab Port Assembly for Vapor Pin™ with Barb Fitting using the Sample Configuration with Purge Isolation

1. Pre-assemble the sample train for each sub-slab port to be sampled (Vapor Pin® with barb fitting). Cut three ~10-inch pieces of 1/4- inch OD Teflon®, Teflon® lined, or Nylaflow tubing and 1 ~6-inch piece of the same tubing.
2. Connect one piece of the 10-inch tubing to the two opposite sides of the stainless-steel tee with compression nuts and ferrule sets. Install a compression nut and ferrule set to the other side of each tubing piece.
3. Remove the cap from the canister and connect the flow controller with in-line particulate filter and vacuum gauge. The flow controller attaches directly to the canister and the pre-set rate dictates the sample duration. The laboratory may have connected the canister and flow controller prior to shipping. Attach the canister and flow controller assembly to the tubing from one side of the stainless-steel tee.
4. Unless the flow controller manifold came with a purge port and valve, one will need to be added. Cut a short length (~6-inches) of 1/4- inch OD Teflon®, Teflon® lined, or Nylaflow tubing. Connect to the open end of the tee fitting using a compression nut and ferrule set. This tee adds a leg to the sample train that will be used to purge “dead” air from the sample train.
5. Connect the purge syringe with three-way valve and/or air pump to the free end tubing from the tee using a length short piece of 1/4-inch ID silicone tubing.
6. Attach a two-way compression valve to the remaining free end of the tee tubing. Cut another 6-inch piece of 1/4-inch OD Teflon tubing and connect to the other side of the two-way valve with a compression nut and ferrule set. 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. See Section 8.3 for purging details.
7. When collecting duplicate or other quality assurance/quality control (QA/QC) samples as required by applicable regulations and guidance, couple two canisters using a stainless-steel compression duplicate sample tee-fitting supplied by the laboratory. Attach flow controller with in-line particulate filter and vacuum gauge to duplicate sample tee.
8. Attach the terminal end of the two-way compression valve to the sample port as appropriate. This may be done using the options below:
    a. Use a section of silicone tube to connect the Teflon sample tubing to the barbed fitting of a Vapor Pin® port.
    b. Use Swagelok® or equivalent compression fittings to connect Teflon tubing to the sample port. Teflon tape should never be used on Swagelok® or equivalent compression fittings.

A schematic of the first suggested sample train setup isolating the purge line is illustrated below:

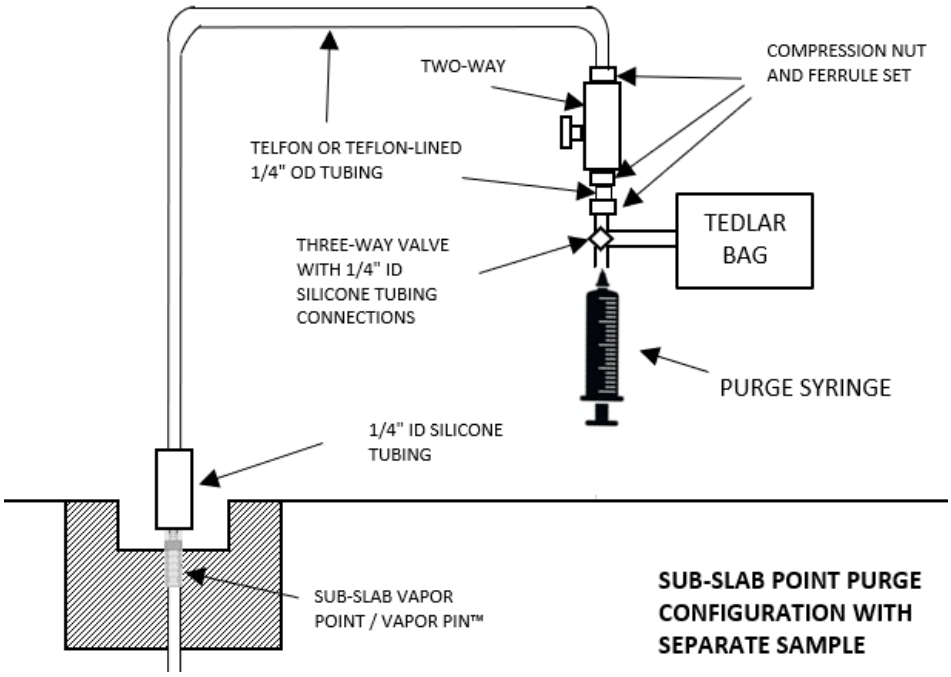


Sub-Slab Port Assembly for Vapor Pin™ with Barb Fitting using Separate Purge and Sample Configuration

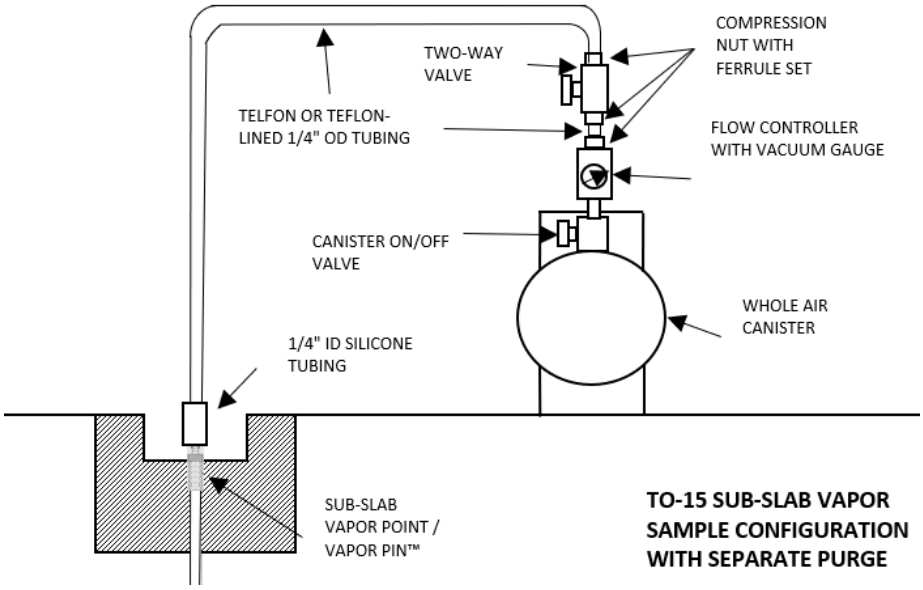
1. Pre-assemble the sample train for each sub-slab port to be sampled (Vapor Pin® with barb fitting). Cut an approximate 18-inch length and a 1-inch length of Teflon or Teflon-lined 1/4-inch OD tubing. Cut a 2-inch piece of 1/4-inch ID silicone tubing. Connect the silicone tubing to one end of the 18-inch length of tubing. Connect a stainless-steel two-way valve with compression fittings to the other side of the Teflon tubing. Connect the 1-inch piece of Teflon tubing to the other side of the two-way valve. Connect a compression nut and ferrule set to the other end of the 1-inch piece of Teflon tubing for the connection to the canister. This sample train is found within the well vault at permanent soil vapor probes.
2. Assemble the sample train by removing the cap from the canister and connecting the flow controller with in-line particulate filter and vacuum gauge. The flow controller attaches directly to the canister and the pre-set rate dictates the sample duration. The laboratory may have connected the canister and flow controller prior to shipping.

3. At sub-slab ports, connect the silicone end of the sample train to the barb fitting of the Vapor Pin®. For both sub-slab ports and soil vapor wells, connect a three-way valve to a syringe using the Lok-Lur tip. Connect one end of the sample train to the three-way valve with a 1-inch piece of silicone tubing and the last end to a Tedlar bag with a 1-inch piece of silicone tubing. A personal air pump capable of 200 milliliters per minute (mL/min) can be substituted for the syringe. See Section 8.3 for purging details.

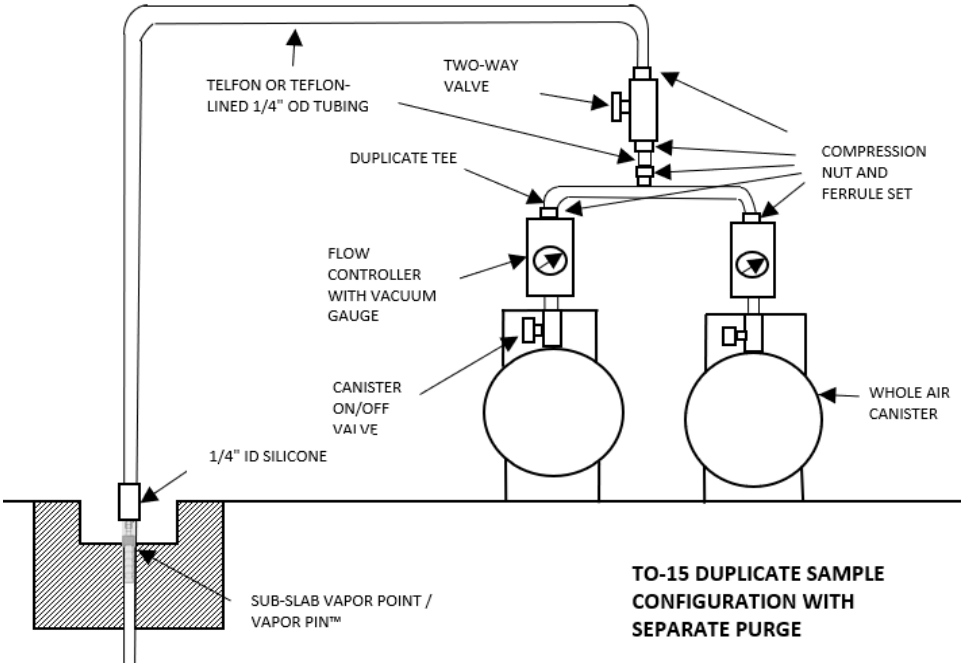
A schematic of the suggested second type of sample train setup is illustrated below:



4. Once purging is complete, close the two-way valve, then disconnect the silicon tubing next to the two-way compression valve from the sample assembly. Connect the canister and flow controller using the installed compression nut.



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



8.2 Sample Documentation

Record weather information at the beginning of each day of the sampling event at a minimum. If appropriate record weather information during the middle and end of each day of the sampling event. Use the weather function in the FieldNow® Standard – Vapor Intrusion Sampling Log application. If using a field sampling form contact the local airport or other suitable information source (e.g., weatherunderground.com, or NOAA) to obtain the following information:

- Wind speed and direction;
- Ambient temperature;
- Barometric pressure; and
- Relative humidity.

Record information on sample label tags on canister, on field sample log or in the FieldNow® Standard – Vapor Intrusion Sampling Log application, and COC. This includes:

- Canister number;
- Flow controller number;
- Sample ID;
- Start and end times; and
- Canister initial and final vacuum.

Take a photograph of the canister, completed canister tag, and surrounding area.

8.3 Sample Collection

At sub-slab ports, connect the sample train to the sub-slab port barb fitting with 1/4-inch ID silicone tubing. The two-way compression valve should be closed. Soil vapor probes are typically completed with all sample train components permanently connected and contained within the manway vault.

Sample collection consists of pre-sampling (i.e., shut-in test, 3-volume purge, and leak check) as well as sampling activities, discussed below. The procedures listed below for the 3-volume purge may also be used to conduct the post-installation purge of the soil vapor sampling point, which should be conducted within 24 to 48 hours following soil vapor sampling point installation, but includes additional calculated volume.

8.3.1 Shut-in Test and 3-Volume Purge

Conduct a shut-in test, 3-volume purge, and leak check prior to sampling. The shut-in test is conducted first, and then the 3-volume purge is completed concurrently with the leak check. The pre-sampling purge volume conducted immediately prior to sampling includes the internal volume of the tubing and sub-slab port or probe tip. The post-installation purge volume conducted immediately after installation includes the following:

- The internal volume of the tubing and probe;
- The void space of the sand pack around the probe; and
- The void space of the dry bentonite in the annular space.

Sample Train Purge Isolation Setup with Syringe

1. Set-up the helium leak test shroud or water dam test in accordance with applicable TGI, when necessary. Note, the water dam test can only be performed on sub-slab ports not soil vapor probes.
2. Perform a shut-in test or leak-down-test with the two-way compression valve closed to the sample port. Open the three-way valve to the syringe and slowly pull a vacuum at a rate no faster than 1 to 2 mL/second (approximately 60 to 120 mL/min). Quickly close the three-way valve and record the pressure indicated on the gauge.
3. Open the canister valve but do not open the two-way valve on the sample assembly.
4. Record the vacuum indicated on the gauge connected to the canister. Observe the vacuum gauge for at least two minutes and no longer than 10 minutes. If there are no leaks in the system, this vacuum should be held exactly (estimate the decimal place – i.e., 29.1 inches of Hg). Tap the gauge and wait to see if pressure drops on the gauge.
5. If vacuum holds, document values and proceed with purge by opening the two-way sample assembly valve. If not, attempt to rectify the situation by tightening fittings and restart shut-in test.
6. Purge approximately three volumes of air from the sample port and tubing using the syringe or personal air pump capable of rates of <200 mL/min into the Tedlar® bag using a flow rate <200 mL/min. Purge rate should not exceed 200 mL/min or 1 to 1.5 mL per second when using a syringe. Purge volume is calculated using the equation of V = $\pi^2 h$:

$$\textit{Purge volume} = 3 \times \pi \times \textit{inner radius of tubing}^2 \times \textit{length of tubing}$$

7. Purged air will be collected into a Tedlar® bag to so VOCs are not released into interior spaces or the sampler's breathing zone. Perform quality control method tests such as helium leak testing, water dam testing, and/or field screening for VOCs concurrently per the project-specific work plan.
8. Close the three-way valve to the syringe to isolate this leg of the sample train.

Sample Train Separate Purge/Sample Setup with Canister

1. Connect the three-way valve, syringe, and Tedlar bag to the sample train. Open the two-way compression valve and purge approximately three volumes of air from the sample port and tubing using the syringe or personal air pump capable of <200 mL/min into the Tedlar® bag using a flow rate <200 mL/min. Purge rate should not exceed 200 mL/min or 1 to 1.5 mL per second when using a syringe. Purge volume is calculated using the equation above.
2. Close the two-way compression valve and disconnect the syringe purge setup.
3. Connect the canister and flow controller to the sample train. Perform a shut-in test or leak-down-test by opening the canister valve but do not open the two-way valve on the sample assembly.
4. Record the vacuum indicated on the gauge connected to the canister. Observe the vacuum gauge for at least two minutes. If there are no leaks in the system, this vacuum should be held exactly (estimate the decimal place – i.e., 29.5 inches of Hg).
5. If vacuum holds, document values and proceed with sampling by opening the two-way sample assembly valve. If not, attempt to rectify the situation by tightening fittings and restart shut-in test.

8.3.2 Sampling

1. Open the canister valve to initiate sample collection. Record the start time and the initial canister vacuum on the sample log or FieldNow® application. The preference is a starting vacuum of -28 inches of Hg or more, but some canisters may be used in certain jurisdictions with lower starting vacuum. However, ff the initial vacuum registers less than -25 inches of Hg (-27 inches of Hg in Michigan), then the canister is not appropriate for use and another canister should be used. The initial vacuum required varies by jurisdiction; confirm with the project regulatory authority.
2. Check the canister approximately halfway through the sample duration and note progress on sample logs or FieldNow® application. If the vacuum decreases greater than a rate of 200 mL/min or the vacuum stops decreasing during sample collection contact the project team.

8.3.3 Termination of Sample Collection

1. Sampling canisters should not be left unattended. For example, a 1-liter canister will typically take approximately 5 to 30 minutes, so even brief inattention or distraction can mistakenly lead to the canister reaching 0 inches of Hg or water in the tubing damaging the equipment.
2. Record the final vacuum on the sample collection log or FieldNow® Standard – Vapor Intrusion Sampling Log app. Stop collecting the sample by closing the canister valve then the sample train valve. The canister should have a minimum amount of vacuum (approximately 5 inches of Hg or slightly greater). Check with the project team on final pressure requirements as these vary by region.
3. Record the date and local time (24-hour basis) of valve closing on the canister tag, sample collection log or FieldNow® Standard – Vapor Intrusion Sampling Log application, and COC form.
4. Refill the Tedlar® bag with purged air with enough air to fill the bag via the purge to pump or syringe. Connect the Tedlar® bag to the PID and record stabilized VOC concentration on sample collection log. Disconnect the PID then connect the methane meter to the Tedlar® bag. Make sure to activate the pump on the methane meter, if not automatically started once turned on, and then allow time for vapor to flow through the meter to collect readings. Record stabilized methane concentration readings on sample collection log.
5. Disconnect sample tubing from the sample port and replace any coverings or abandon as appropriate to mitigate tripping hazards.
6. Remove the flow controller from the canister, re-install the brass plug on the canister fitting, and tighten with the appropriate wrench. If the canister and flow controller were shipped pre-assembled from the laboratory do not disassemble; simply re-install the brass plug on the flow controller fitting.
7. Verify the appropriate forms and sample labels are filled out appropriately as directed by the laboratory (e.g., affix card with a string).
8. Package the canister and flow controller per DOT regulations for return shipment to the laboratory. These regulations can be found at the Transportation Safety Program's Team Site on the Source. The canister does not require preservation with ice or refrigeration during shipment. Refer to TGI – Soil Gas Methane Monitoring for Shipping Determination of Soil Gas Samples if sampling in an area with unknown or known methane conditions. A shipping determination form is required for shipment of any type of samples prior to field mobilization.
9. Complete and verify 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) or sign COC over to courier. Consult with the project team on appropriate shipping speeds and shipment insurance.

9 Waste Management

No specific waste management procedures are required.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

11 Quality Assurance

Quality assurance and quality control (QA/QC) will be conducted following project requirements.

11.1 Duplicate Samples

Duplicate samples should be collected in the field as a quality assurance step per project requirements. Generally, one duplicate is taken per 10 or per 20 samples analyzed, but project specific requirements should take precedence. A duplicate tee is required when collecting soil vapor duplicate samples.

11.2 Equipment Blank

Equipment blank samples may be collected in the field as a quality assurance step in order to verify and evaluate the effectiveness of decontamination procedures for new, recycled, or reused materials (i.e., syringes, Swagelok® fittings, 1/4-inch tubing) per project requirements. Generally, one equipment blank sample is taken per 20 sample locations, but project specific requirements should take precedence. Equipment blank sampling steps detailed below:

1. Connect decontaminated reusable sampling supplies, in line with a clean, laboratory provided soil vapor manifold and 1-liter canister to a laboratory provided nitrogen-filled canister.
2. Conduct a shut-in test as described in section 8.3.1. Please note: a 3-volume purge and leak test are not necessary for the equipment blank.
3. Collect a sample (generally following the steps from sections 8.3.2 and 8.4.3 using the nitrogen

canister as the vapor source. Gas collection readings from a PID and methane meter are not necessary for the equipment blank.

12 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.

DiGiulio 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.

USEPA. 1999a. Compendium Method TO-15. Determination of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). Center for Environmental Research Information. Office of Research and Development. January.

USEPA. 2015. Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air. OSWER Publication 9200.2-154. June.

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

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TGI – Monitoring Well Installation

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Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	4/24/2017	All	Re-written as a TGI	Marc Killingstad Peter C. Frederick
	1	6/23/2022	All	Put into new template format, reviewed and made minor revisions	Whitney Plasket Marc Killingstad
	2	8/30/2023	All	Annual review completed by SME. Updated Rev 1.	Marc Killingstad

Approval Signatures

Prepared by:		8/30/2023
	Whitney Plasket	Date
Reviewed by:		8/30/2023
	Marc Killingstad	Date

1 Introduction

This Technical Guidance Instruction (TGI) describes methods used to install groundwater monitoring wells in unconsolidated aquifers. It is assumed that the monitoring well to be installed has been properly designed, including sizing of the filter pack and screen, the length of the screen, total depth of the well, material strength and compatibility and surface completion. Typical monitoring wells are constructed of manufactured screen and engineered filter pack and are generally suitable for formations with granular materials having a grain size distribution with up to 50% passing a #200 sieve and up to 20% clay-sized material. Monitoring wells installed in formations finer than this may not be able to produce turbidity free water.

2 Intended Use and Responsibilities

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.

3 Scope and Application

The monitoring well installation procedures set forth herein are consistent with the approach and methods presented in the American Society of Testing and Materials (ASTM) *D5092 – Standard Practice for Design and Installation of Groundwater Monitoring Wells* (ASTM D5092). As such, following this TGI in combination with proper well design (see appropriate TGI and/or consult with appropriate subject matter expert), well development (see appropriate TGI), groundwater sampling procedures (see appropriate TGI), and well maintenance and

rehabilitation (see appropriate TGI and/or consult with appropriate subject matter expert), will result in a monitoring well suitable for: (1) collection of groundwater samples representative of the surrounding formation and free of artificial turbidity; (2) measurement of accurate groundwater levels; and (3) hydraulic testing of formation sediments immediately adjacent to the open interval of the well to assess hydraulic properties (e.g., slug testing).

Monitoring well boreholes in unconsolidated (overburden) materials are often drilled using the hollow-stem auger drilling method; however, other drilling methods are also suitable for installing overburden monitoring wells and may be appropriate given site-specific geologic conditions or project objectives. These methods include drive-and-wash, spun casing, rotosonic (sonic), dual-rotary (Barber Rig), and fluid/mud rotary with core barrel or roller bit. Direct-push techniques (e.g., Geoprobe® or cone penetrometer) and driven well points may also be used in some cases within the overburden.

Monitoring wells to be installed within consolidated materials such as fractured bedrock are commonly drilled using air rotary, water-rotary (coring or tri-cone roller bit), or sonic drilling methods. For guidance when installing monitoring wells in consolidated materials, please consult the appropriate subject matter expert and, if available, the applicable guidance document.

The drilling method to be used at a given site will be selected based on site-specific consideration of anticipated drilling/well depths, site or regional geologic knowledge, type of monitoring to be conducted using the installed well, project objectives, and cost. Consultation with the appropriate subject matter expert is also strongly recommended.

No oils or grease will be used on equipment introduced into the boring (e.g., drill rod, casing, or sampling tools). No polyvinyl chloride (PVC) glue/cement will be used in constructing or retrofitting monitoring wells that will be used for water-quality monitoring.

Coated bentonite pellets are generally not recommended because of potential chemical incompatibilities between the coating material and groundwater chemistry.

Specifications of materials to be installed in the borehole will be obtained prior to mobilizing onsite. These materials generally include:

- Well casing (length, material, and diameter);
- Well screen (length, material, diameter, and slot size);
- Grout (typically neat cement grout, which is 5-6 gallons of water per 94 lb. bag of Portland Type I/II cement *with no bentonite* but, as applicable, up to 5% bentonite can be added);
- Filter pack (filter pack type and fine sand seal type, as applicable); and
- Bentonite (type, as applicable/needed, non-coated pellets or tablets are generally preferred over chips).

Well materials will be inspected and, if needed, cleaned, or replaced prior to installation. The field task manager or field team lead will communicate with the drilling company ahead of time to make sure the materials meet the required specification for well construction.

NOTE: If installing monitoring wells for per- and polyfluoroalkyl substances please refer to *TGI for Per- and Polyfluoroalkyl Substances (PFAS) Field Sampling Guide*.

4 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 field implementation plan (FIP)/task-specific work plan, 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 well installation activities will have a minimum of 1 year of previous environmental monitoring well installation experience. Field employees with less than six months of experience will be accompanied by a supervisor (as described above) to ensure that proper well installation 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 particularly the selected drilling method/rig.

Monitoring well installation activities will be performed by persons who have been trained in proper well installation procedures under the guidance of an experienced field geologist, engineer, or technician. Field sampling is typically performed for soil or bedrock characterization as part of monitoring well installation; therefore, field personnel will have undergone in-field training in soil or bedrock description and sample collection methods, as described in *TGI for Soil Drilling and Sample Collection, TGI for Bedrock Core Collection and Description, and TGI for Soil Description*.

5 Equipment List

The following materials may be required during soil boring and monitoring well installation activities:

- Site Plan with proposed soil boring/well locations;
- Field Implementation Plan (FIP)/Work Plan that includes site map with proposed well locations, well construction details (tabulated and drawings) which will include well casing material and size, well screen material and size, length of screen, target depth and screen interval, filter pack material, development methods, and previous boring logs (as available);
- Field Sampling Plan (FSP), and site-specific Health and Safety Plan (HASP);
- Personal protective equipment (PPE) as required by the HASP;

- Traffic cones, delineators, caution tape, and/or fencing as appropriate for securing the work area, if such are not provided by drillers;
- Appropriate soil sampling equipment (e.g., stainless steel spatulas, knife);
- Soil and/or bedrock logging equipment as specified in the FIP/work plan or other appropriate project documents;
- Appropriate sample containers and labels;
- Drum labels as required for investigation derived waste handling;
- Insulated coolers with ice, when collecting samples requiring preservation by chilling;
- Photoionization detector (PID) or flame ionization detector (FID);
- Ziplock style bags;
- Water level or oil/water interface meter;
- Locks and keys for securing the well after installation;
- Decontamination equipment (bucket, distilled or deionized water, cleansers appropriate for removing expected chemicals of concern, paper towels);
- Engineer's tape/measuring wheel;
- Weighted tape;
- Disposable bailers;
- Forms/notes:
    - Tablet with digital forms
    - Field notebook
    - Chain-of-custody forms
    - Digital camera (or smart phone with camera);
    - Appropriate field forms, consider including a photo of the well head and a Google Earth map showing the well location.

Prior to mobilizing to the site, Arcadis personnel will contact the drilling subcontractor or in-house driller (as appropriate) to confirm that appropriate sampling and well installation equipment will be provided. Specifications of the sampling and well 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. Equipment/materials typically provided by the driller could include:

- Drilling equipment required by the ASTM standard guidance document D1586, when performing split-spoon sampling;
- Disposable plastic liners (when drilling with direct-push equipment);
- Drums for investigation derived waste (IDW);
- Equipment to move IDW drums, if required;
- Drilling and sampling equipment decontamination materials;
- Decontamination pad materials, if required;

- Traffic cones, delineators, caution tape, and/or fencing as appropriate for securing the work area, if required; and
- Well construction materials.

6 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 Arcadis standard for proper utility clearance protocol.
- Prior to beginning field work, contact the project technical team (including Project Hydrogeologist) to ensure that all field procedures, logistics (e.g., access issues, health and safety issues, communication network, schedules, etc.), and objectives are clearly understood by all team members.
- Some regulatory agencies require a minimum annular space between the well or permanent casing and the borehole wall. When specified, the minimum clearance is typically 2 to 3 inches on all sides (e.g., a 2-inch diameter well requires a 6-inch diameter borehole). In addition, some regulatory agencies have specific requirements regarding grout mixtures and well seal materials. Determine whether the oversight agency has any such requirements prior to finalizing the drilling and well installation plan. If installing a monitoring well into consolidated sediments, refer to regulatory agency rules regarding casing.
- The maximum screen length may also be dictated by regulatory agencies. If installing a monitoring well with greater than a 10-ft screen, refer to regulatory agency rules regarding screen length.
- If dense non-aqueous phase liquids (DNAPL) are known or expected to exist at the site, refer to the project specific documents for additional details regarding drilling and well installation to reduce the potential for inadvertent DNAPL remobilization. Similarly, if light non-aqueous phase liquids (LNAPLs) are 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 and sampling of soil or bedrock, decontamination of drilling/sampling equipment, or grouting boreholes upon completion will be of a quality acceptable for project objectives. Consider testing of water supply as necessary.
- Similarly, consider the compatibility between the well materials and the surrounding environment. For example, PVC well materials are not preferred when DNAPL is present. In addition, some groundwater conditions leach metals from stainless steel or are corrosive to metal well materials, and some remedial technologies are incompatible with certain materials of construction. If questions arise, contact the CPM and Project Hydrogeologist/Technical Lead to discuss.
- Specifications of materials used for backfilling the borehole will be obtained, reviewed, and approved to meet project quality objectives. Bentonite is not recommended where DNAPLs are likely to be present or in groundwater with high salinity. In these situations, neat cement grout is preferred.
- As noted above, coated bentonite pellets are not recommended for monitoring well construction, as the coating could impact the water quality in the completed well.

- Heat of hydration during neat cement grout curing must be considered to avoid damage to PVC well materials. The annular space for a typical monitoring well is small enough that heat of hydration should not create excessive temperature increases which may damage PVC well material. However, washouts in the borehole can lead to thick accumulations of grout which can produce enough heat during curing to weaken and potentially damage PVC casing. If heat of hydration is a concern, contact the Project Hydrogeologist/Technical Lead to address the issue.
- Similarly, it is imperative that backfill volumes (filter pack and well seal) be estimated and then closely monitored to ensure that materials are not 'lost' to the formation. If estimated volumes do not reasonably match actual volumes, contact the Project Hydrogeologist/Technical Lead to address the issue.

7 Health and Safety Considerations

Field activities associated with monitoring well installation will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities. The HASP may require that the drilling company provide their own HASP and/or Job Safety Analyses (JSAs).

The HASP will be followed, as appropriate, to ensure the safety of field personnel. Review all site-specific and procedural hazards as they are provided in the HASP, and review Job SafetyAnalysis (JSA) documents in the field each day prior to beginning work.

Prior to drilling, utility clearance must be performed (see Section 6). Appropriate personal protective equipment (PPE) must always be worn in accordance with the task and the HASP.

Working outside at sites with suspected contamination may expose field personnel to hazardous materials such as contaminated groundwater or 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 useof fixed/folding-blade knives and use appropriate hand protection.

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

8 Procedure

The procedures for installing groundwater monitoring wells are presented below:

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

1. Prior to monitoring well installation, determine the expected volumes of filter pack and seal materials including grout (neat cement or cement-bentonite) and bentonite (if applicable).
2. Locate boring/well location, establish work zone, and set up sampling equipment decontamination area.
3. During well installation, record construction details, measurements, and tabulate materials used (e.g., screen and riser footages; filter pack volume; bags of cement/sand; volume of grout; etc.) in the field notebook as well as appropriate field forms.

4. Advance boring to desired depth.
    a. Collect soil and/or bedrock samples at appropriate interval(s), document, and store samples for laboratory analysis as specified in the FIP/Work Plan.
    b. Decontaminate equipment between samples in accordance with the *TGI for Groundwater and Soil Sampling Equipment Decontamination* or if installing monitoring wells for per- and polyfluoroalkyl substances please refer to *TGI for Per- and Polyfluoroalkyl Substances (PFAS) Field Sampling Guide* for both sampling and decontamination guidance.
    c. A common sampling method that produces high-quality soil samples with relatively little soil disturbance is described in *ASTM D1586 – Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils* (ASTM D1586). Split-spoon samples are obtained during drilling using hollow-stem auger, drive-and-wash, spun casing, and fluid/mud rotary.
    d. Sonic 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.
    e. Dual-rotary removes cuttings by compressed air or water/mud and allow only a general assessment of geology.
5. Describe each soil sample as outlined in *TGI for Soil Description* and document descriptions in the field notebook and/or field tablet or field forms and photo document the samples. It should be noted that electronic logs must be backed up and transferred to a location accessible to other project team members as soon as feasible to retain and protect the field data. During boring advancement, document all drilling events in field notebook or field forms, including blow counts (number of blows required to advance split-spoon sampler in 6-inch increments) and work stoppages. Blow counts will not be available if sonic, dual-rotary, or direct-push methods are used.
6. Before installing a screen, it is important to confirm that the borehole has been advanced into the targeted saturated zone. This is particularly important for wells installed to monitor the water table and/or the shallow saturated zone, as the capillary fringe may cause soils above the water table to appear saturated. If one or more previously installed monitoring wells exist nearby, use the depth to water at such well(s) to estimate the water-table depth at the new borehole location.

    NOTE: *To verify that the borehole has been advanced into the saturated zone, it is necessary to measure the water level in the borehole. For boreholes drilled without using water (e.g., hollow-stem auger, cable-tool, air rotary, air hammer), verify the presence of groundwater (and/or LNAPL, if applicable) in the borehole using an electronic water level meter, oil-water interface probe, or a new/decontaminated bailer. For boreholes drilled using water (e.g., drive and wash, spun-casing with roller-bit wash, sonic, or water rotary with core or roller bit), monitor the water level in the borehole as it re-equilibrates to the static level.*

    In low-permeability units like clay, fine-grained glacial tills, shale, and other bedrock formations, it may be necessary to wait overnight to allow the water level to equilibrate. Document depth to water in the borehole on the appropriate field forms and field notebook. If there are questions concerning the depth of the well/screen interval, consult with the project technical lead prior to finalizing well depth/screen interval. To the extent practicable, ensure that the depth of the well below the apparent water table is deep enough so that the installed well can monitor groundwater year-round, accounting for seasonal water-table fluctuations. When in doubt, err on the side of slightly deeper well installation.

7. Upon completing the borehole to the desired depth, if a screened well construction is required, install the monitoring well by lowering the screen and casing assembly through the augers or casing. Monitoring wells typically will be constructed of 2-inch-diameter (although sometimes 4-inch), flush-threaded PVC or stainless steel slotted or wire wrapped well screen and blank riser casing. Smaller diameters may be used if wells are installed using direct-push methodology or if multiple wells are to be installed in a single borehole, according to the well design as outlined in the FIP/Work Plan. The screen length and other construction details will be specified in the FIP/Work Plan based on regulatory requirements and specific monitoring objectives. Monitoring well screens are usually 5 to 10 feet long, but the screen length will depend on the purpose for the well and the objectives of the groundwater investigation and will (in most cases) be determined prior to the field mobilization.

   NOTE: *The slot size and filter pack gradation will be predetermined in the Work Plan (or equivalent) or FSP and based on site-specific grain-size analysis (sieve analysis) or other geologic considerations or monitoring objectives. Consult the Project Hydrogeologist and/or subject matter expert if there are questions/concerns regarding the filter pack and slot size specified. If the screen slot size and filter pack have not been based on site-specific grain-size analysis, consider collecting soil samples during well installation so future wells can be properly designed.*

   NOTE: *A blank sump may be attached below the well screen if the well is being installed for DNAPL recovery /monitoring purposes. If so, the annular space around the sump may be backfilled with filter pack during placement around the well screen.*

8. A blank riser will extend from the top of the screen to the level specified in the FIP/Work Plan (e.g., approximately 2.5 feet above grade if a stick up or just below grade where a flush-mounted monitoring well is specified).

   NOTE: *For wells greater than 50 feet deep, placement of centralizers may be desired to assist in centering the monitoring well in the borehole during installation. Refer to the FIP/Work Plan and/or consult with the Project Hydrogeologist/Technical Lead.*

9. When the monitoring well assembly has been set, using a tremie place the washed silica filter pack in the annular space from the bottom of the boring to a height above the top of the screen as specified in the FIP/Work Plan (typically placed to at least 2 feet above the top of the well screen). The filter pack will be placed, and drilling equipment extracted in increments until the top of the sand pack is at the appropriate depth.

   NOTE: *It is very important to verify that the expected volume of filter pack matches with the actual amount placed. There can be differences due to irregularities in the borehole geometry. Washout of the borehole will result in the need for greater than calculated well materials. If a difference of more than 10% is noted, consult with the Project Hydrogeologist/Technical Lead. The filter pack will be consistent with the screen slot size and the soil particle size in the screened interval, as specified in the FIP/Work Plan.*

10. After placement of the filter pack, preliminary well development is recommended be performed to ensure that the filter pack settles and does not bridge within the annular space and to remove any fines accumulated in the well during installation. This typically entails gently surging the entire well screen to prevent filter pack material bridging and to settle the filter pack prior to well seal installation. For recommended procedures, please refer to the *TGI for Monitoring Well Development*. Monitor the placement of the filter pack (e.g., with a weighted tape measure) and, as necessary during preliminary development (i.e., settlement), add filter pack to ensure proper thickness/height above screen is attained.

11. Depending on the project-specific requirements and applicable federal/state/local regulations, a well seal comprised of either fine sand or hydrated bentonite will then be placed in the annular space above the filter pack, typically at a minimum of 2 feet thick—follow the specifications outlined in the FIP/Work Plan). If non-hydrated bentonite is used, allow sufficient time for hydration to occur (typically a minimum of 30 minutes, but follow manufacturer's recommendations and/or specifications outlined in the FIP/Work Plan). Potable water may be added to hydrate the bentonite if the seal is above the water table. Monitor the placement of the fine sand/bentonite seal (e.g., with a weighted tape measure).

    NOTE: *Coated bentonite pellets are generally not recommended for monitoring well construction because of potential chemical incompatibilities between the coating material and groundwater chemistry.*

12. During the extraction of the augers or casing, a neat cement or cement/bentonite grout will be placed in the annular space from the well seal to a depth as specified in the FIP/Work Plan (e.g., approximately 2 ft. below groundwater surface). It is recommended that grout be placed with a tremie pipe. Ensure that seal materials are mixed at the proper ratios with water following manufacturer's recommendations.

    NOTE: *If it is necessary to install a monitor well into a permeable zone below a confining layer (i.e., confined conditions), particularly if the deeper zone is believed to have water quality that differs significantly from the zone above the confining layer, then a telescopic well construction may be considered.*

    In this case, the borehole is advanced approximately 3 to 5 feet into the top of the confining layer (depending upon the thickness of the confining layer), and a permanent casing (typically PVC or stainless steel) is installed into the socket drilled into the top of the confining layer.

    The casing is then grouted in place. The preferred methods of grouting telescoping casings include (1) pressure-injection grouting using an inflatable packer installed temporarily into the base of the casing, such that grout is injected out the bottom of the casing until it is observed at ground surface outside the casing; (2) displacement-method grouting (also known as the Halliburton method), which entails filling the casing with grout and displacing the grout out the bottom of the casing by pushing a drillable plug, typically made of wood to the bottom of the casing, following by tremie grouting the remainder of the annulus outside the casing; or (3) tremie grouting the annulus surrounding the casing using a tremie pipe installed to the base of the borehole.

    In all three cases, the casing is grouted to the ground surface, and the grout is allowed to set prior to drilling deeper through the casing. Refer to the FIP/Work Plan, Project Hydrogeologist, and/or subject matter expert for the completion of non-standard monitoring wells, including telescopic wells.

13. Install the monitoring well surface completion as specified in FIP/Work Plan. Typical completions are a locking, steel protective casing (extended at least 1.5 feet below grade and 2 feet above grade) over the riser casing and secure with a neat cement seal. Alternatively, for flush-mount completions, place a steel curb box with a bolt-down lid over the riser casing and secure with a neat cement seal. In either case, the cement seal will extend approximately 1.5 to 2.0 feet below grade and laterally at least 1 foot in all directions from the protective casing and will slope gently away from the casing to promote drainage away from the well.

14. When an above-grade completion is used, the riser will be sealed using an expandable locking plug and the top of the well will be vented by drilling a small-diameter (1/8 inch) hole near the top of the well casing or through the locking plug, or by cutting a vertical slot in the top of the well casing. When a flush-mount installation is used, the riser will be sealed using an unvented, expandable locking plug.

15. Monitoring wells will be labeled as specified in the FIP/Work Plan. If not specified, use indelible ink or paint with the appropriate designation on both the inner and outer well casings and/or inside of the curb box lid. If called for, mark a consistent measuring point by cutting a V in the PVC casing or marking the measuring point in black.
16. After completing the well installation, lock the well, clean the area, and dispose of materials in accordance with the procedures outlined in Section 9 below.
17. After completing well installation, finalize documentation and follow data management procedures outlined in Section 10 below.
18. For final well development guidance and procedures, please refer to the *TGI for Monitoring Well Development.*

Direct-Push Method

The direct-push drilling method may also be used to complete soil borings and install monitoring wells. Examples of this technique include the Diedrich ESP vibratory probe system, GeoProbe®, or AMS Power Probe® dual-tube system. 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 and 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. The outside diameter (OD) of the outer casing ranges from 1.75 to 2.4 inches and the OD of the inner sampling tube ranges from 1.1 to 1.8 inches.

The outer casing isolates shallow layers and permits the unit to continue to probe at depth. The double-rod system provides a borehole that may be tremie-grouted from the bottom up. Alternatively, the inside diameter (ID) of the steel casing provides clearance for the installation of small-diameter (e.g., 0.75- to 1-inch ID) micro-wells.

If direct-push drilling has been determined to be a viable method for site conditions and project objectives, procedures for installing monitoring wells in soil using the direct-push method are described below.

1. Locate boring/well location, establish work zone, and set up sample equipment decontamination area.
2. Advance soil boring to designated depth, collecting samples at intervals specified in the FIP/Work Plan. Samples will be collected using dedicated, disposable, plastic liners. Collect and describe samples in accordance with the procedures outlined in Steps 4 and 5 above. Collect samples for laboratory analysis as specified in the FIP/Work Plan.
3. Upon advancing the borehole to the desired depth, install the micro-well through the inner drill casing. The micro-well will consist of approximately 1-inch ID PVC or stainless-steel slotted screen and blank riser. The filter pack, well seal, and neat cement/cement-bentonite grout will be installed as described, where applicable, in Steps 9 through 12 above.
4. Install surface completion (protective steel casing or flush-mount), as appropriate and as described in Steps 13 through 15 above.
5. After completing the well installation, lock the well, clean the area, and dispose of materials in accordance with the procedures outlined in Section 9 below.
6. After completing well installation, finalize documentation and follow data management procedures outlined in Section 10 below.

Driven Well Point Installation

If specified in the FIP/Work Plan, well points installed by pushing or driving using a drilling rig or direct-push rig (or hand-driven where possible) will typically consist of a 1- to 2-inch-diameter threaded steel casing with either 0.010- or 0.020-inch slotted stainless-steel screen. The screen length will vary depending on the hydrogeologic conditions of the site. The casings will be joined together with threaded couplings and the terminal end will consist of a steel well point. Because they are driven or pushed to the desired depth, well points do not have annular backfill materials such as sand pack or grout. Refer to the FIP/Work Plan and/or consult with the Project Hydrogeologist/Technical Lead and/or subject matter expert for specific guidance on drive point installation procedures/specifications.

9 Waste Management

IDW, including soil cuttings and excess drilling fluids (if used), decontamination liquids, and disposable materials (well material packages, PPE, etc.), will be placed in clearly labeled, appropriate containers, or managed as otherwise specified in the Work Plan (or equivalent), FSP, and/or IDW management guidance document.

Investigative-Derived Waste (IDW) generated during drilling activities, including soil and excess drilling fluids (if used), and decontamination liquids, will be stored on site in appropriately labeled containers and disposed of properly. Disposable materials will be stored and disposed of separately. 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 for Investigation-Derived Waste Handling and Storage,* the procedures identified in the FIP/work plan 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.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

If not using FieldNow®, all well drilling/installations activities will be documented on appropriate field/log forms as well as in a proper field notebook and/or Personal Digital Assistant (PDA) and/or tablet. All field data will be recorded digitally or with 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. Any deviations or omissions from this TGI will be documented.

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 well installation activities, soil descriptions, well construction specifications (screen and riser material and diameter, sump length, screen length and slot size, riser length, filter pack type and volume, type of well seal (fine sand or bentonite seal) and volume, type and volume of grout (neat cement or cement-bentonite), and other materials used.

Management of the original documents from the field will be completed in accordance with the site-specific QAPP. Records generated as a result of this TGI will be controlled and maintained in the project record files in accordance with project requirements.

Initial field logs and forms will be transmitted to the Arcadis CPM and/or Technical Lead at the end of each day unless otherwise directed by the CPM. The field team leader retains copies of the field documentation.

Locations of newly installed wells will be documented photographically and/or on a site sketch. If appropriate, a measuring wheel, engineer's tape, or handheld GPS will be used to determine approximate distances from key site features or estimated coordinates.

The well location, ground surface elevation, and inner and outer casing elevations will be surveyed using the method specified in the FIP/Work Plan. Generally, a local baseline control will be set up. This local baseline control can then be tied into the appropriate vertical and horizontal datum, such as the National Geodetic Vertical Datum (NGVD)of 1929 or North American Vertical Datum (NAVD) of 1988 and the State Plane Coordinate System. At a minimum, the elevation of the top of the inner casing used for water-level measurements should be measured to the nearest 0.01 foot. Elevations will be established in relation to the NGVD of 1929 or the NAVD of 1988. A permanent mark will be placed on top of the inner casing to mark the point for water-level measurements.

11 Quality Assurance

Quality assurance procedures will be conducted in accordance with the Arcadis Quality Management System or the site-specific QAPP. Refer to the QAPP or FIP/sampling plan/work plan for specific requirements.

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. All well construction materials will be inspected and cleaned (as necessary) prior to well installation.

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.

12 References

American Society for Testing Materials (ASTM) D5092 - *Standard Practice for Design and Installation of Ground Water Monitoring Wells*. American Society for Testing Materials. West Conshohocken, Pennsylvania.

American Society of Testing and Materials (ASTM) D1586 - *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils*. American Society for Testing Materials. West Conshohocken, Pennsylvania.

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TGI – Monitoring Well Development

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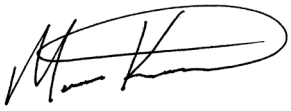
Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	4/24/2017	All	Re-written as TGI	Marc Killingstad
	1	4/12/2022	All	Updated to new format and some minor content changes	Marc Killingstad
	2	4/5/2023	All	Annual review completed by Marc Killingstad. Updated document revision number and date, version control and signature page.	Marc Killingstad

Approval Signatures

Prepared by:		4/5/2023
	Jay Erickson (Preparer)	Date
Reviewed by:		4/5/2023
	Marc Killingstad (Subject Matter Expert)	Date

1 Introduction

This Technical Guidance Instruction (TGI) covers the development of screened wells used for obtaining representative groundwater information and samples from granular aquifers (i.e., monitoring wells).

Note: This TGI only applies to monitoring well development and not remediation (injection/extraction) well development.

2 Intended Use and Responsibilities

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.

3 Scope and Application

The objectives of monitoring well development are:

1. Repair damage to the borehole wall from drilling that can include clogging, smearing or compaction of aquifer materials;
2. Remove fine-grained sediment from the formation and filter pack that may result in high turbidity levels in groundwater samples;
3. To re-sort formation and filter pack material adjacent to the well screen;

4. To recover any drilling fluids (if used) that may affect the permeability of the formation and filter pack or alter the water quality around the well; and
5. To optimize the well efficiency and hydraulic communication between the well screen and the formation.

Successful monitoring well development is dependent on the following:

1. Hydrostratigraphy – Permeable formations containing primarily sand and gravel are more easily developed due to lower percentages of silt and clay material. Water in permeable formations can be moved in and out of the screen and/or through the formation easier than in less permeable deposits.
2. Well Diameter – Development tooling including brushes, surge blocks, pumps and jetting tools are more readily available for wells 4 inches in diameter and greater.
3. Well Design – Wells with filter packs and screens designed to match the formation through the analysis of formation sieve samples are easier to develop. An important aspect to well design is to minimize the size of the annular space between the formation and well screen. Adequate room must be allowed for the proper installation of well materials, but not too large as to prevent/reduce communication with the surrounding formation.
4. Drilling Methods – Different drilling methods result in varying amount of borehole damage and, therefore, impact the degree to which development will be successful.

Well development methods for monitoring wells include the following:

1. Bailing – Use of a bailer to remove water and sediment from the well casing. This technique does little to remove fines from the filter pack and may lead to bridging of sediment since the flow is in only one direction, toward the well screen. The most effective use of bailing during monitoring well development is in conjunction with other methods (e.g., surging/swabbing) to remove fines accumulated in the monitoring well between cycles of other development methods.
2. Pumping/over pumping – Use of a pump to remove water and sediment from the well casing, over pumping involves pumping the well at a rate that exceeds the design capacity of the well. Similar to bailing, this technique does little to remove fines from the filter pack and may lead to bridging of sediment since the flow is in only one direction, toward the well screen. Small diameter monitoring wells have the additional constraint on pump size and flow rates which further limit the effectiveness of this methodology.
3. Backwashing (rawhiding) – Consists of starting and stopping a pump intermittently to produce rapid pressure changes in a well. This method can produce better results than pumping alone since the procedure involves movement of the water in and out of the screen and formation. However, in many cases the surging action is not rigorous enough to fully develop the well and might be considered the final phase of development after a more rigorous method has been used. Again, small diameter monitoring wells have the additional constraint on pump size and flow rates which further limit the effectiveness of this methodology.
4. Surging/swabbing – Use of a mechanical surge block or swabbing tool to operate like a piston with an up and down motion. The downstroke causes a backwash action that breaks up bridged sediment and the upstroke pulls the dislodged sediment into the well. This method works well for both small and large diameter monitoring wells. Care should be taken on the downstroke so as not to force fines back into the formation, frequent pumping/purging during surging help to keep fines out of the well. Double surge blocks are recommended, and this is typically the most effective method for development of monitoring wells.

5. Jetting – Use of a tool fitted with nozzles that direct streams of water horizontally into well screens at high velocity. Due to the size of the tooling, this method is better suited for wells 4 inches in diameter and larger. The method is also more effective with wire-wrapped/continuous slot screens due to the increased open area. Jetting requires specialized equipment and concurrent pumping to prevent reintroducing fines into the filter pack. Additionally, depending on the configuration of the tool, jetting may require subsequent surging/pumping to remove fines dislodged in the filter pack and formation. Typically, jetting is not a preferred option for new well development but may be effective as part of a re-development/rehabilitation effort.

For most situations, surging/swabbing coupled with bailing or pumping to remove dislodged materials is recommended.

Final well development for properly designed and constructed monitoring wells may begin after the annular seal materials have been installed and allowed to cure, since these wells are designed to retain approximately 90% of the filter pack material. This cure time is typically at least 24 to 48 hours after the sealing materials have been installed.

This TGI is meant to provide a general guide for proper development of newly installed monitoring wells.

A site-specific field implementation plan (FIP) for well installation and development detailing the specific methods and tools is strongly recommended to provide site-specific instruction and guidance.

4 Personnel Qualifications

Generally, 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, and/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 specified in the Health and Safety Plan (HASP) which may include first aid, cardiopulmonary resuscitation (CPR), Blood Borne Pathogens (BBP) as needed. In addition, Arcadis field sampling 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. The HASP and other documents will identify other training requirements and access control requirements.

The designated Field Manager is responsible for periodic observation of field activities and review of field generated documentation associated with this TGI. The Field Manager is also responsible for implementation of corrective action if problems occur (e.g., retraining personnel, additional review of work plans and TGIs, variances to QC sampling requirements, issuing non-conformances, etc.).

Prior to mobilizing to the 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)/field sampling plan/work plan, Quality Assurance Project Plan (QAPP), HASP, historical information, and other relevant site documents.

Field personnel assigned to install and develop monitoring wells are responsible for completing their tasks in accordance with the specifications outlined in this TGI and other appropriate and relevant guidelines.

Monitoring well development activities will be performed by persons who have been trained in proper well development procedures under the guidance of an experienced field geologist, engineer, or technician.

5 Equipment List

Required equipment depends on the selected method and should be detailed in the site-specific FIP; however, the following are typically required.

- Approved site-specific Health and Safety Plan (HASP)
- Approved site-specific FIP which will include site map, well construction information/borehole information, and development plan
- Personal protective equipment (PPE) and health and safety equipment, as required by the HASP
- Field notebook and/or smart device (phone or tablet)
- Cleaning/decontamination equipment
    - Non-phosphate laboratory soap (Alconox or equivalent), brushes, clean buckets or clean wash tubs—new buckets or tubs will be purchased if it cannot be determined if the presentitems are clean
    - Distilled or de-ionized water for equipment decontamination
- Monitoring well keys
- Water-level meter
- Down-hole multiparameter water quality sonde (e.g., YSI)
- Plastic sheeting (e.g., Weatherall Visqueen) to protect all down-hole sampling equipment fromcontact with potential sources of contamination
- Well development forms/logs
- Well construction logs/diagrams
- Weighted tape (of sufficient length for maximum site depth)
- Turbidity meter
- Camera
- Watch/timing device

6 Cautions

Different USEPA regions and/or state regulatory agencies may stipulate deviations from this document. It is the responsibility of the Project Team (Project Manager and Technical Lead) to be fully aware of the requirements from the applicable regulatory framework.

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/field sampling plan/work plan scope and objectives is strongly recommended prior to mobilization to ensure that the field work will be effectively and efficiently executed.

Where surging is performed to assist in removing fine-grained material from the sand pack, surging must be performed in a gentle manner. Excessive suction could promote fine-grained sediment entry into the outside of the sand pack from the formation.

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

In some cases, it may be necessary to add potable water to a well to allow surging and development, especially for new monitoring wells installed in low permeability formations. Before adding potable water to a well, the Certified Project Manager (CPM) and/or Project Hydrogeologist must be notified, and the CPM shall make the decision regarding the appropriateness and applicability of adding potable water to a well during well development procedures. If potable water is to be added to a well as part of development, the potable water source should be sampled and analyzed for constituents of concern, and the results evaluated by the CPM prior to adding the potable water to the well. If potable water is added to a well for development purposes, at the end of development the well will be purged dry to remove the potable water, or if the well no longer goes dry then the well will be purged to remove at least three times the volume of potable water that was added

7 Health and Safety Considerations

Field activities associated with monitoring well development will be performed in accordance with a site-specific HASP, a copy of which will be present on site during such activities.

Appropriate 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.

Access to well locations may expose field personnel to hazardous materials such as contaminated groundwater or NAPL (e.g., petroleum hydrocarbons, chlorinated solvents). Other potential hazards include pressurized wells, stinging insects that may inhabit well heads, other biological hazards (e.g., ticks in long grass/weeds around wellhead), and potentially the use of sharp cutting tools (scissors, knife). Open well caps slowly and keep face and body away while allowing to vent any built-up pressure to vent. 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.

Do not enter confined spaces unless following appropriate confined space entry procedures specified in the HASP.

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

8 Procedure

As indicated above, for most monitoring wells, gentle surging coupled with bailing or pumping to remove dislodged sediment is recommended.

8.1 Preliminary Well Development

After installation of the primary filter pack around the monitoring well screen, preliminary well development is recommended be performed to ensure that the filter pack settles and does not bridge within the annular space. The preliminary well development steps are as follows:

1. Measure and record depth to water, total depth of well, and depth to top of the sand pack in the annulus.
2. Use steel or weighted bailer to remove any fines that have accumulated in the bottom of the well.
3. Lower an appropriately sized double-surge block into the screened portion of the well on a rigid pipe or high-density tubing and gently cycle up and down to force water in and out of the screen slots and formation. A two-foot throw is recommended (use tape or chalk marks on the pipe or tubing); however, the entire length of well screen must be gently surged.
4. Start above the screen and gently surge over two-foot intervals while working down to the screen bottom.

NOTE: Care must be taken not to surge the well too aggressively at this point as the casing is not well-supported and damage could occur. The objective is to create enough surging action to settle the primary filter pack and provide some preliminary removal of accumulated materials before final development.

NOTE: If possible, ensure that the developer surges the block upward faster than downward to pull the fines out of the filter pack, instead of forcing them back in (and allowing for proper settlement).

5. Monitor the total depth of the well periodically during surging to ensure that we are not pulling excessive amounts of filter pack through the screen and remove any debris accumulated in the well with a weighted bailer or pump.
6. Re-measure the top of the sand in the annulus to see if more sand pack is necessary. Remove any fines that have accumulated out of the well using a submersible pump or weighted bailer.

NOTE: If the monitoring well was drilled using mud rotary drilling methodology or if significant fines were encountered during the well installation, consider adding a commercially available 'mud' dispersant (e.g., AQUA-CLEAR PFD, Nu Well 220, etc.) as part of the preliminary development. This will help to break up the 'skin' along the borehole wall created by either the drilling fluid or smearing during drilling and assist in final development. Follow manufacturer's directions for dosing, and the mixture should be worked through the entire saturated screen interval by gently surging or brushing.

8.2 Final Well Development

After sufficient time has passed to allow for proper curing of the well seal/grout (i.e., 24 to 48 hours), final well development can be performed. Final well development steps are as follows:

1. Don appropriate PPE (as required by the site-specific HASP).
2. Place plastic sheeting around the well.
3. Clean all equipment entering each monitoring well, except for new, disposable materials that have not been previously used.
4. Open the well cover while standing upwind of the well, remove well cap. Insert PID probe approximately 4 to 6 inches into the casing or the well headspace and cover with gloved hand. Record the PID reading in

the field notebook. If the well headspace reading is less than 5 PID units, proceed; if the headspace reading is greater than 5 PID units, screen the air within the breathing zone. If the PID reading in the breathing zone is below 5 PID units, proceed. If the PID reading is above 5 PID units, move upwind from well for 5 minutes to allow the volatiles to dissipate. Repeat the breathing zone test. If the reading is still above 5 PID units, don the appropriate respiratory protection in accordance with the requirements of the HASP. Record all PID readings.

5. Obtain an initial measurement of the depth to water and the total well depth from the reference point at the top of the well casing. Record these measurements in the field logbook. It is recommended to use a weighted tape for the total well depth measurement.
6. The depth to the bottom of the well should be sounded and then compared to the completion form or construction diagram for the well. Any discrepancies should be reported immediately to the CPM and/or Project Hydrogeologist. If sand or sediment is present inside the well, it should first be removed by bailing. Do not insert bailers, pumps, or surge blocks into the well if obstructions, parting of the casing, or other damage to the well is suspected. Instead report the conditions to the CPM and/or Project Hydrogeologist and obtain approval to continue or cease well development activities.

NOTE: If the monitoring well was drilled using mud rotary drilling methodology or if significant fines were encountered during the well installation, it is recommended that a commercially available 'mud' dispersant (e.g., AQUA-CLEAR PFD, Nu Well 220, etc.) be included as part of the final well development to effectively break up the 'skin' along the borehole wall created by either the drilling fluid or smearing during drilling.

Per manufacturer's instructions, the general procedure for adding dispersant is as follows:

i. Determine volume of water in screen area and double the calculated volume to account for water in gravel pack and formation interface

ii. Once the water volume is determined, calculate the required treatment volume of dispersant need per manufacturer's recommendations

iii. Mix thoroughly before introducing into well

iv. The preferable application method utilizes a tremie line with the product applied into the screened area

v. Mixture should be thoroughly blended in well, then agitated via surging/swabbing/brushing repeatedly (e.g., every two hours) for a period of up to 24 hours

vi. The dispersant should sit for at least 6 to 8 hours or overnight before continuing well development activities

7. After allowing the dispersant to sit for the required time (if dispersant is used), start the mechanical development by lowering an appropriately sized double-surge block (or similar) into the well on a rigid pipe or high-density tubing.
    i. Surging should start above the screen to reduce the possibility of "sand-locking" the surge block. Initial surging should be with a long stroke and at a slow rate (20 to 25 strokes per minute)
    ii. After surging above the screen, the well should be cleaned via bottom-loading bailer, submersible pump, or inertia pump tubing with check valve to the bottom of the well

iii. Begin surging at the lower end of the screen, gradually working upward, surging in 2-ft intervals until the entire screen has been developed.

iv. Surge the well a minimum of 10 throws per 2-ft screen interval.

v. Each interval may require several surge cycles to achieve the best development.

vi. The entire length of well screen must be surged.

vii. Ensure that the developer surges the block upward faster than downward to pull the fines out of the filter pack, instead of forcing them back in (and allowing for proper settlement)

viii. measure total depth of the well periodically during surging to ensure that excessive amounts of sediment are not being pulled through the screen. Remove any debris accumulated in the well via simultaneous airlifting (if a combined tool is available) or with bailing/pumping.

8. After completing a cycle of surging, lower a bottom-loading bailer, submersible pump, or inertia pump tubing with check valve to the bottom of the well and gently bounce on the bottom of the well to collect/remove accumulated sediment, if any. Remove and empty the bailer, if used. Repeat until the bailed/pumped water is free of excessive sediment and contact at the bottom of the well feels solid. Alternatively, measurement of the well depth with a weighted tape can be used to verify that sediment and/or silt has been removed to the extent practicable, based on a comparison with the well installation log or previous measurement of total well depth.
9. After surging the well for a minimum of two cycles and removing excess accumulated sediment from the bottom of the well, re-measure the depth-to-water and the total well depth from the reference point at the top of the well casing. Record these measurements in the field log book.
10. Remove formation water by pumping/bailing.

    i. Where pumping is used, measure and record the pre-pumping water level.

    ii. Operate the pump at a relatively constant rate

    iii. Measure the pumping rate using a calibrated container and stopwatch, and record the pumping rate in the field log book

    iv. Measure and record the water level in the well at least once every 5 minutes during pumping

    v. Record any relevant observations in terms of color, visual level of turbidity, sheen, odors, etc.

    vi. Pump or bail until termination criteria specified in the site-specific FIP are reached

    vii. Record the total volume of water purged from the well

NOTE: The FIP may also specify a maximum turbidity requirement for completion of development. Unless otherwise specified the maximum turbidity should be 50 NTUs or less

11. While developing, take periodic water level measurements (at least one every five minutes) to determine if drawdown is occurring and record the measurements on the Well Development Log.
12. While developing, calculate the rate at which water is being removed from the well. Record the volume on the Well Development Log.
13. While developing, water is also periodically collected directly from the well or bailer discharge and readings taken of the indicator parameters: pH, specific conductance, and temperature. Development is

considered complete when the indicator parameters have stabilized (i.e., three consecutive pH, specific conductance, and temperature readings are within tolerances specified in the project work plans or within 10% if not otherwise specified), the extracted water is clear and free of fine sediment and most importantly, when acceptable volume of water has been removed and/or a sufficient amount of surging has been performed.

14. In certain instances, for slow recharging wells, the parameters may not stabilize. In this case, well development is considered complete when minimal amounts of fine-grained sediments are recovered, and an acceptable volume of water has been removed.
15. If the well goes dry, stop pumping or bailing. Note the time that the well went dry. After allowing the well to recover, note the time and depth to water. Resume pumping or bailing when sufficient water has recharged the well.
16. Contain all development water in appropriate containers.
17. When complete, secure the lid back on the well.
18. Place disposable materials in plastic bags for appropriate disposal and decontaminate reusable, downhole pump components and/or bailer

9 Waste Management

Investigation-Derived Waste (IDW), including purge water and decontamination liquids, will be stored on site in appropriately labeled containers and disposed of properly. Disposable materials will be stored and disposed of separately. 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., water, PPE). Waste will be managed in accordance with the *TGI – Investigation-Derived Waste Handling and Storage*, the procedures identified in the FIP/field sampling plan/work plan 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.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

All well development activities will be documented on appropriate log forms 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 well development activities; development

method(s); observations of purge water color, turbidity, odor, sheen, etc.; purge rate; and water levels before, during, and after pumping.

Management of the original documents from the field will be completed in accordance with the site-specific QAPP. Records generated as a result of this TGI will be controlled and maintained in the project record files in accordance with project requirements.

Development activities will be documented on appropriate field logs as well as in a proper field notebook. All field data will be recorded digitally or with 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. Any deviations or omissions from this TGI should be documented.

Initial field logs and forms will be transmitted to the Arcadis CPM and/or Technical Lead at the end of each day unless otherwise directed by the CPM. The field team leader retains copies of the field documentation.

11 Quality Assurance

Quality assurance procedures will be conducted in accordance with the Arcadis Quality ManagementSystem or the site-specific QAPP. Refer to the QAPP or FIP/sampling plan/work plan for specific requirements.

12 References

American Society for Testing Materials (ASTM), Designation D5521-05. *Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers*. American Society for Testing Materials. West Conshohocken, Pennsylvania.

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TGI – Low-Flow Groundwater Purging and Sampling Procedures for Monitoring Wells

Rev: 3

Rev Date: April 5, 2023

Version Control

Issue	Revision No.	Date Issued	Page No.	Description	Reviewed By
	0	October 12, 2018	All	Updated and re-written as TGI with new branding and content	Marc Killingstad
	1	May 8, 2020	Pages 5, 10-11	Added clarification/details for equipment requirements and procedure steps based on USEPA guidance	Marc Killingstad
	2	April 5, 2022	All	Updated to new branding template and minor edits	Marc Killingstad
	3	April 5, 2023	All	Annual review completed by SME. Document version number and document date updated.	Marc Killingstad

Approval Signatures

Prepared by:	Xuan Xu	4/5/2023
	Xuan Xu (Preparer)	Date
Reviewed by:		4/5/2023
	Marc Killingstad (Subject Matter Expert)	Date

1 Introduction

Groundwater samples are collected from monitoring wells to evaluate groundwater quality. The protocol presented in this Technical Guidance Instruction (TGI) describes the procedures to purge monitoring wells and collect groundwater samples using the low flow purging/sampling methodology. This protocol has been developed in accordance with the United States Environmental Protection Agency (USEPA) Region I *Low Stress (Low Flow) Purging and Sampling Procedures for the Collection of Groundwater Samples from Monitoring Wells* (EQASOP-GW4; September 19, 2017).

2 Intended Use and Responsibilities

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.

3 Scope and Application

Both filtered and unfiltered groundwater samples may be collected using this low-flow sampling method. Filtered samples will be obtained using a 0.45-micron disposable filter. Project teams will evaluate the last time the monitoring wells were developed and determine if additional development might be necessary. Water samples will not be taken immediately following well development. Sufficient time will be allowed for the groundwater flow regime in the vicinity of the monitoring well to stabilize and to approach chemical equilibrium with the well

construction materials. This lag time will depend on site conditions and methods of installation but often exceeds one week.

4 Personnel Qualifications

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

Arcadis field sampling 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. Additionally, the groundwater sampling 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.

5 Equipment List

Specific to this activity, the following materials (or equivalent) will be used:

- Site-specific HASP and health and safety documents identified in the HASP
- Field Implementation Plan (FIP) that includes site map, well construction records, sampling plan (sample analyses, sample volume required, and sample holding time), and prior groundwater sampling records (if available)
- Field notebook and/or smart device (phone or tablet)
- Low-flow sampling field forms (**Attachment A**)
- Appropriate personal protective equipment (PPE) (e.g., latex or nitrile gloves, safety glasses, etc.)as specified in the HASP
- Well keys and other tools to remove manhole covers (manual torque wrench with 9/16” socket and flat head screwdriver typical)
- Photoionization detector (PID) or Flame ionization detector (FID) (as appropriate, depending onsite-specific constituents of concern)
- Electronic water-level indicator (e.g., Solinist Model 101) or oil/water interface probe with 0.01- foot accuracy (oil/water as appropriate, note that sampling will not be performed when sheen orlight non-aqueous phase liquid [LNAPL] is present)
- Down-hole multi-parameter water-quality sonde (temperature/pH/specific conductivity/oxidationreduction [ORP]/turbidity/dissolved oxygen) meter coupled with flow-through-cell for measurements, for example:

  - YSI 6-Series Multi-Parameter Instrument
  - Horiba U-22 Multi-Parameter Instrument.
  - Hydrolab Series 3 or Series 4a Multiprobe and Display.

  NOTE: *Transparent, small volume flow-through-cells (e.g., 250 milliliters or less) are preferred as they allow for easy detection of air bubbles and sediment buildup in the cell, which can interfere with the monitoring instrument probes. A small volume cell also allows for quick turnover of water in the cell between measurements of the indicator field parameters. It is recommended to use a flow-through-cell and monitoring probes from the same manufacturer and model to avoid incompatibility between the probes and flow-through-cell.*

- Plastic sheeting (e.g., Weatherall Visqueen) to protect all down-hole sampling equipment from contact with potential sources of contamination.
- Decontamination equipment
  - Non-phosphate laboratory soap (Alconox or equivalent), brushes, and clean buckets, and/or clean wash tubs—new buckets or tubs will be purchased if it cannot be determined if the present items are clean
  - Distilled or de-ionized water for equipment decontamination
- Indelible ink pen
- 150-foot measuring tape (or sufficient length for the maximum site depth requirement)
- Sampling pump, which may consist of one or more of the following:
  - Submersible pump (e.g., Grundfos Redi-Flo 2)
  - Peristaltic pump (e.g., ISCO Model 150)
  - Bladder pump (e.g., Marschalk System 1, QED Micropurge, Geotech)
- Appropriate controller and power source for pump:
  - Submersible and peristaltic pumps require electric power from either a generator or a deep cell battery
  - Submersible pumps such as Grundfos require a pump controller to run the pump
  - Bladder pumps require a pump controller and a gas source (e.g., air compressor or compressed N_2 or CO_2 gas cylinders)
- Teflon® tubing or Teflon®-lined polyethylene tubing of an appropriate size for the pump being used
  - For peristaltic pumps, dedicated Tygon® tubing (or other type as specified by the manufacturer) will be used through the pump apparatus
  - Teflon® will not be used when sampling for per- and polyfluoroalkyl substances (PFAS)
- Graduated cylinder and stopwatch or other device to measure time to determine pumping rate
- Appropriate water sample containers (supplied by the laboratory)
- Appropriate blanks (trip blank supplied by the laboratory)
- Sample labels and Chain-of-Custody forms (COC)
- 0.45-micron disposable filters (if field filtering is required)

- A supplemental turbidity meter (e.g., Horiba U-10, Hach 2100P, LaMotte 2020) may be required for specific projects and will be specified in the project FIP/ work plan and the kick-off notes.
    - If used, in-line 'T' and valve allows for collection of water for turbidity measurements before the pump discharge enters the flow-through cell

NOTE: *The maintenance requirements for the above equipment generally involve decontamination or periodic cleaning, battery charging, and proper storage, as specified by the manufacturer. For operational difficulties, the equipment will be serviced by a qualified technician.*

6 Cautions

Different USEPA regions and/or state regulatory agencies may stipulate deviations from this document. Itis the responsibility of the Project Team (Project Manager and Technical Lead) to be fully aware of the requirements from the applicable regulatory framework.

Weather

- If heavy precipitation occurs, and no cover over the sampling area and monitoring well can be erected, sampling may be discontinued until adequate cover is provided. Rainwater could compromise groundwater samples.
- Avoid extreme weather situations. Be aware that thermal currents and vertical mixing of cold and warm water inside the well casing could create a convection cell within the well and compromise data collection (e.g., biological mechanisms).
    - Direct sunlight and hot ambient temperatures may cause the groundwater in the tubing orflow-through-cell to heat up and de-gas. This may result in the loss of volatile organic compounds (VOCs) and dissolved gases. Shade the equipment from direct sunlight, keep the tubing as short as possible and avoid the hottest times of the day.
    - Sampling during freezing conditions may adversely impact the data quality objectives. USEPA recommends low-flow sampling be conducted at air temperatures above 32°F (0°C) or taking special precautions to prevent groundwater from freezing in the equipment.

Cross-Contamination

- To mitigate potential cross-contamination, groundwater samples are to be collected in a pre- determined order from least impacted to impacted based on previous analytical data. If no analytical data are available, collect samples in order of up-gradient, then furthest down-gradient tosource area locations.
- Note that permanent markers could introduce volatile constituents into the samples*; therefore, indelible ink is recommended* to be used for labels on sample containers or sample coolers.
- When using a gasoline generator, this power source will be set-up at least 30 feet downwind from the well to avoid exhaust fumes to contaminate samples.

Pumps

- Preferred methods of extracting groundwater are adjustable rate, submersible pumps - such as centrifugal pumps or bladder pumps – constructed of stainless steel or polytetrafluoroethylene (PTFE, i.e., Teflon®). However, *PTFE will not be used when sampling for per- and polyfluoroalkyl substances (PFAS). PTFE could contain PFAS*.

- When using a bladder pump for collecting VOCs and dissolved gases, “best practice” is to set-up the pump to deliver sufficient water to fill a 40 mL VOC vial.
- The use of peristaltic pumps will be based on the type of data to be collected. *Because the use a peristaltic pump can result in de-gassing of VOC and / or dissolved gases from groundwater, a different type of pump will be considered if these compounds are of concern.*
- *Manual or motor driven inertial pumping devices are not recommended because they cause greater disturbance during purging and pumping than regular pumps and are less easily controlled. This could cause a higher degree of data variability.*

Tubing

- When sampling for VOCs, SVOCs, pesticides, PCBs and inorganics, use of PTFE (Teflon®) or PTFE-lined tubing is preferred. However, PTFE tubing will not be used when sampling for PFAS.
- PVC, polypropylene or polyethelene tubing may be used when sampling for metals or other inorganics.
- Tubing with inside diameters of 1/4 or 3/8 inch is recommended because this will help ensure tubing remains water filled when operating at very low pumping rates.

General Precautions

- Store and/or stage empty and full sample containers and coolers out of direct sunlight.
- It may be necessary to field filter the groundwater for some parameters (e.g., metals) during collection, depending on preservation, analytical method, and project quality objectives. The task-kick-off notes and the FIP/work plan will list the samples that require field filtering.
- Be careful not to overtighten lids with Teflon® liners or septa (e.g., 40 mL vials). Over-tightening can cause the glass to shatter or impair the integrity of the Teflon® seal.

7 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 always worn 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.

Access to wells may expose field personnel to hazardous materials such as contaminated groundwater or non-aqueous phase liquid (NAPL) (e.g., oil). Other potential hazards include pressurized wells, stinging insects that may inhabit well heads, other biologic hazards (e.g. ticks in long grass/weeds around well head), and potentially the use of sharp cutting tools (scissors, knife)—open well caps slowly and keep face and body away to allow to vent any built-up pressure; 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.

Generators and cord and plug equipment will employ an overcurrent protection device such as an integrated ground fault circuit interrupter (GFCI) cord. Grundfos pump controllers will not run properly with a GFCI, so the power source will be equipped with other overcurrent protection means.

Overtightening of lids with Teflon® liners can cause the glass to shatter and create a risk for hand injuries.

8 Procedure

Field personnel will set up and perform low-flow sampling in accordance with the following procedures.

1. Review FIP and groundwater sampling records from previous sampling events (if available) prior to mobilization to estimate the optimum pumping rate and anticipated drawdown for each well to perform sampling as efficiently as possible (i.e., reach a stabilized pumping condition).
2. Calibrate field instruments according to manufacturer procedures for calibration and record calibration procedure and results in field log.
3. All equipment will either be new or decontaminated in accordance with appropriate guidance document *(TGI – Groundwater and Soil Sampling Equipment Decontamination)* prior to use.
4. Visually inspect the well to ensure that it is undamaged, properly labeled and secured
   a. Damage or other conditions that may affect the integrity of the well will be recorded in the Field Activity Daily Log and brought to the attention of the designated Field Manager and/or Project Manager
   b. Record well construction and conditions on the Low-Flow Sampling Field Form **(Attachment A)**.
5. Place clean plastic sheeting on the ground near the well to keep monitoring and sampling equipment off the surface unless the equipment is elevated above the ground (e.g., on a table).
6. Open the well cover while standing upwind of the well. Remove the well cap and place it on the plastic sheeting. If appropriate or required for site-specific conditions, insert the photoionization detector (PID) probe approximately 4 to 6 inches into the casing or the well headspace and cover it with a gloved hand. Record the PID reading in the field log. Perform air monitoring in the breathing zone according to the HASP and/or JSA.
7. Measure and record the initial depth to groundwater prior to placing the pumps.
8. Prepare and install the pump in the well.

   NOTE: *Groundwater will be purged from the wells using an appropriate pump. If the depth to water is below the sampling range of a peristaltic pump (approximately 25 feet below ground surface), a submersible or bladder pump will be used, provided that the well is constructed with a casing diameter of at least two (2) inches (the minimum well diameter capable of accommodating such pumps). For smaller diameter wells, where the depth to water is below the sampling range of a peristaltic pump, alternative sampling methods (i.e., bailing or small diameter bladder pumps) will be used to purge and sample the groundwater. Bladder pumps are preferred over peristaltic and submersible pumps to prevent volatilization if sampling of VOCs and/or dissolved gasses is required. Purge water will be collected and containerized according to the direction of the project team.*

   a. For submersible and non-dedicated bladder pumps, decontaminate the pump according to site decontamination procedures. Non-dedicated bladder pumps will require a new bladder and attachment of an air-line, sample discharge line, and safety cable prior to placement in the well. Attach the air-line tubing to the air-port on the top of the bladder pump. Attach the sample discharge tubing to the water port on the top of the bladder pump. Take care not to reverse the air and discharge tubing lines during bladder pump setup, as this could result in bladder failure or rupture. Attach and secure a safety cable to the eyebolt on the top of pump (if present, depending on pump model used). Slowly lower the pump, safety cable, tubing, and electrical lines into the well to a depth corresponding to the approximate center of the saturated screen section of the well. Avoid twisting

and tangling of safety cable, tubing, and electrical lines while lowering the pump into the well; twisted and tangled lines could result in the pump becoming stuck in the well casing. Also, make sure to keep tubing and lines from touching the ground or other surfaces while introducing them into the well, as this could lead to unintended contamination.

b. If using a bladder pump, connect the air-line to the pump controller output port. The pump controller will be connected to a supply line from an air compressor or compressed gas cylinder using an appropriate regulator and air hose. Tighten the regulator connector onto the gas cylinder (if used) to prevent leaks. Teflon® tape may be used on the threads of the cylinder to provide a tighter seal. Once the air compressor or gas cylinder is connected to the pump controller, turn on the compressor or open the valve on the cylinder to begin the gas flow. Turn on the pump controller power (if an on/off switch is present) and verify that all batteries are charged and fully functioning before starting the pump.

c. If a peristaltic pump is being used, slowly lower the sampling tubing into the well to a depth corresponding to the approximate center of the saturated screen section of the well. The pump intake or sampling tube must be kept at least two (2) feet above the bottom of the well to prevent mobilization of any sediment present in the bottom of the well.

d. If using an in-line 'T' and valve, install between pump discharge water line and the bottom inlet port of the flow-through cell. Attach a short piece of tubing to the outlet. This set-up will be used to collect samples for turbidity readings.

9. Connect the pump discharge water line to the bottom inlet port on the flow-through cell connected to the multi-parameter water-quality sonde and make sure to record equipment/instrument identification (manufacturer and model number).

10. Before starting the pump, ensure that the water level inside the well has stabilized (i.e., measure the water level multiple times after deploying the pump in the well).

11. Start pumping the well at 200 to 500 milliliters (mL) per minute (or at lower site-specific rate if specified) and adjust the pumping rate to cause little or no water level drawdown in the well (less than 0.3 feet below the initial static depth to water measurement): the water level should stabilize, however, this is not always possible.

12. If the well diameter is of sufficient size, measure the water level every 3 to 5 minutes (or as appropriate, lower flow rates may require longer time between readings) during pumping.

13. Maintain a steady flow rate to the extent practicable and do not break pump suction or cause entrainment of air in the sample.

14. Record pumping rate adjustments and depths to water.

    If necessary, reduce pumping rates to the minimum capabilities of the pump to avoid pumping the well dry and/or to stabilize indicator parameters; if the recharge rate of the well is very low, use alternative purging techniques, which will vary based on the well construction and screen position.

    For wells screened across the water table, the well may be pumped dry, and sampling can commence as soon as the volume in the well has recovered sufficiently to permit collection of samples.

    For wells screened entirely below the water table, the well can be pumped until a stabilized level (which may be greater than the maximum displacement goal of 0.3 feet) is maintained and monitoring for stabilization of field indicator parameters can commence; if a lower stabilization level cannot be

maintained, the well may be pumped until the drawdown is at a level slightly higher than top of the well screen.

15. After water levels have stabilized and a sufficient volume has been purged (see note below), continue pumping and begin monitoring field indicator parameters using a multi-parameter water-quality sonde coupled with a flow-through-cell.

    NOTE: *The final purge volume must be greater than the stabilized drawdown volume plus the pump's tubing volume. If the drawdown has exceeded 0.3 feet and stabilizes, calculate the volume of water between the initial water level and the stabilized water level. Add the volume of the water which occupies the pump's tubing to this calculation. This combined volume of water needs to be purged from the well after the water level has stabilized before samples are collected.*

16. Use the flow to measure all indicator field parameters, except for turbidity, every 3 to 5 minutes (or after each volume of the flow-through cell has been purged or other appropriate interval); turbidity samples will be collected before the flow-through-cell using the T-valve and a clean container such as a glass beaker.

17. Record field indicator parameters on the groundwater sampling log.

18. The well is considered stabilized and ready for sample collection when three consecutive readings are within the following limits:

    - **Turbidity** within ± 10% for values greater than 5 nephelometric turbidity units [NTUs] or if three turbidity values are less than 5 NTUs, consider the values stabilized
    - **Dissolved Oxygen (DO)** within ± 10% for values greater than 0.5 mg/L or if three DO values are less than 0.5 mg/L, consider the values stabilized
    - **Specific Conductance** within ± 3%
    - **Temperature** within ± 3%
    - **pH** within ± 0.1 unit
    - **Oxidation/Reduction Potential (ORP)** within ±10 millivolts (mV)

    NOTE: *Alternate stabilization goals may exist in different geographic regions, consult the site- specific FIP/work plan for stabilization criteria).*

    NOTE: *While achieving turbidity levels less than 5 NTU and a stable drawdown of less than 0.3 feet is desirable, sample collection may still take place provided the indicator field parameter criteria in this procedure are met.*

19. If the parameters have stabilized but turbidity remains relatively high (e.g., greater than 50 NTUs), the pump flow rate may be decreased to a minimum rate of 100 mL/min to reduce turbidity levels as low as possible. If groundwater turbidity has been minimized (i.e., consecutive readings within ± 10%) and the values for all other parameters have stabilized, the well may be sampled; however, consult specifications in the FIP/work plan and/or the project technical lead prior to sampling.

20. If after one (1) hour of purging indicator field parameters have not stabilized, consult specifications in the FIP/work plan and/or the project technical lead prior to sampling.

    In general, three potential options are available if stabilization criteria are not met:

    a. Continue purging until stabilization is achieved.

    b. Discontinue purging, do not collect any samples, and record in field logbook/on the sampling form that stabilization could not be achieved (documentation must describe attempts to achieve stabilization).

c. Discontinue purging, collect samples, and provide full explanation of attempts to achieve stabilization. There is a risk that the analytical data obtained under these conditions, particularly metals and hydrophobic organic analytes, may reflect a sampling bias and, as a result, the data may not meet the data quality objectives of the sampling event.

NOTE: *DO is extremely susceptible to various external influences (including temperature or the presence of bubbles on the DO meter); therefore, great care will be taken to minimize the agitation or other disturbance of water within the flow-through cell while collecting these measurements. If air bubbles are present on the DO probe or in the discharge tubing, remove them before taking a measurement. If DO values are not within acceptable range for the temperature of groundwater, again check for and remove air bubbles on the probe before re-measuring. The table below may be used as a general guide for DO values under various temperatures; however, understand that the table corresponds to freshwater solubility and groundwater contaminants may affect oxygen solubility. If DO value is 0.00 or less, then the meter will be serviced and re-calibrated. If DO values are above possible results, then the meter will be serviced and re-calibrated.*

NOTE: *During extreme weather conditions, stabilization of field indicator parameters may be difficult to attain. Modifications to the sampling procedures to alleviate these conditions (e.g., measuring the water temperature in the well adjacent to the pump intake) will be documented in the field logbook/on the sampling form.*

NOTE: *If other field conditions are suspected of preventing stabilization of certain parameters, detailed observations will be documented in the field logbook/on the sampling form.*

Oxygen Solubility in Fresh Water

Temperature (degrees C)	Dissolved Oxygen (mg/L)
0	14.6
1	14.19
2	13.81
3	13.44
4	13.09
5	12.75
6	12.43
7	12.12
8	11.83
9	11.55
10	11.27
11	11.01
12	10.76
13	10.52
14	10.29
15	10.07
16	9.85
17	9.65
18	9.45
19	9.26
20	9.07
21	8.9
22	8.72
23	8.56
24	8.4
25	8.24
26	8.09
27	7.95
28	7.81
29	7.67
30	7.54
31	7.41
32	7.28
33	7.16
34	7.05
35	6.93

Reference: Vesilind, P.A., Introduction to Environmental Engineering, PWS Publishing Company, Boston, 468 pages (1996)

21. Complete the sample label(s) and cover the label(s) with clear packing tape to secure the label onto the container.
22. After the indicator parameters have stabilized, collect groundwater samples by diverting flow out of the unfiltered discharge tubing into the appropriate labeled sample container.
    a. If a flow-through analytical cell is being used to measure field parameters, the flow-through cell will be disconnected after stabilization of the field indicator parameters and prior to groundwater sample collection.
    b. Under no circumstances will analytical samples be collected from the discharge of the flow- through cell.
    c. If an in-line ‘T’ and valve are used, the valve needs to be removed as well.

d. Samples will be collected in the following order: VOCs, total organic carbon (TOC), semi- volatile organic compounds (SVOCs), metals and cyanide, and others (or other order as defined in the site-specific FIP/work plan).
e. When the container is full, tightly screw on the cap.

23. If sampling for total and filtered metals and/or polychlorinated biphenyls (PCBs), a filtered and unfiltered sample will be collected.
    a. Install an in-line, disposable 0.45-micron particle filter on the discharge tubing after the appropriate unfiltered groundwater sample has been collected.
    b. Continue to run the pump until an initial volume of "flush" water has been run through the filter in accordance with the manufacturer's directions (generally 100 to 300 mL).
    c. Collect the filtered groundwater sample by diverting flow out of the filter into the appropriately labeled sample container.
    d. When the container is full, tightly screw on the cap.
24. Secure with packing material and store the samples on ice in an insulated transport container provided by the laboratory and include a temperature blank in each container to be shipped.
25. Record on the Low-Flow Sampling Field Form (and bound field logbook) the time at which sampling procedures were completed, any pertinent observations of the sample (e.g., physical appearance and the presence or lack of odors or sheens), and the values of the stabilized field indicator parameters as measured during the final reading during purging **(see Attachment A)**.
26. Turn off the pump and air compressor or close the gas cylinder valve if using a bladder pump setup.
27. Slowly remove the pump, tubing, lines, and safety cable from the well.
    a. If using dedicated tubing, do not allow the tubing or lines to touch the ground or any other surfaces which could contaminate them.
    b. If using dedicated tubing, it will be folded - without pinching it - to a length that will allow the well to be capped and also facilitate retrieval of the tubing during later sampling events.
    c. Use a length of rope or string to tie the tubing to the well cap.
    d. Alternatively, if tubing and safety line are to be saved and reused for sampling the well at a later date, coil the tubing neatly and placed in a clean plastic bag that is clearly labeled with the well ID ensuring the bag is tightly sealed before placing it in storage.
28. Secure the well and properly dispose of personal protective equipment (PPE) and disposable equipment.
29. Complete the procedures for packaging, shipping, and handling with the associated Chain-of- Custody.
30. Complete decontamination for flow-through analytical cell and submersible or bladder pump, as appropriate *(TGI – Groundwater and Soil Sampling Equipment Decontamination).*
31. At the end of each day of the sampling event, perform calibration check of field instruments and record procedure and results in field log.

9 Waste Management

Materials generated during groundwater sampling activities, including disposable equipment and excess purge water, will be stored on site in appropriately labeled containers and disposed of properly. 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 logbook.

10 Data Recording and Management

Digital data collection is the Arcadis standard using available FieldNow® applications that enable real-time, paperless data collection, entry, and automated reporting. Paper forms should only be used as backup to FieldNow® digital data collection and/or as necessary to collect data not captured by available FieldNow® applications. The Field Now® digital form applications follow a standardized approach, correlate to most TGIs and are available to all projects accessible with a PC or capable mobile device. Once the digital forms are saved within FieldNow®, the data is instantly available for review on a web interface. This facilitates review by project management team members and SMEs enabling error or anomalous data detection for correction while the staff are still in the field. Continual improvements of FieldNow® applications are ongoing, and revisions are made as necessary in response to feedback from users and subject matter experts.

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

In general, forms (e.g., Low-Flow Sampling 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.

Field logs and Chain-of-Custody records will be transmitted to the Arcadis Project Manager and/or Task Manager, as appropriate, at the end of each day unless otherwise directed. Electronic data files will be sent to the project team and uploaded to the electronic project folder daily.

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

11 Quality Assurance

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

Unless described otherwise in the project-specific FIP/work plan, QAPP, or Sampling and Analysis Plan, quality assurance/quality control samples will be collected as follows:

- One duplicate for every 10 samples
- One laboratory matrix/matrix spike sample for every 20 samples
- In addition to the quality control samples to be collected in accordance with this TGI, the following quality control procedures will be observed in the field:
- Collect samples from monitoring wells, in order of increasing concentration, to the extent known based on review of historical site information if available
- Equipment blanks will include the pump and tubing (if using disposable tubing) or the pump only (if using tubing dedicated to each well)
- Collect equipment blanks after wells with higher concentrations (if known) have been sampled

- Operate all monitoring instrumentation in accordance with manufacturer's instructions and calibration procedures—calibrate instruments at the beginning of each day, verify the calibration at the end of each day, and record all calibration activities in the field notebook
- Clean all groundwater sampling equipment prior to use in the first well and after each subsequent well following the procedure for equipment decontamination

12 References

USEPA. 1986. *RCRA Groundwater Monitoring Technical Enforcement Guidance Document* (September 1986).

USEPA. 1991. *Handbook Groundwater, Volume II Methodology*, Office of Research and Development, Washington, DC. USEPN62S, /6-90/016b (July 1991).

USEPA Region I. 2017. *Low Stress (Low Flow) Purging and Sampling Procedures for the Collection of Groundwater Samples from Monitoring Wells (*EQASOP-GW4; September 19, 2017).

U.S. Geological Survey (USGS). 1977. *National Handbook of Recommended Methods for Water-Data Acquisition: USGS Office of Water Data Coordination*. Reston, Virginia.

13 Attachments

Attachment A – Low Flow Sampling Field Form

Attachment A

Low-Flow Sampling Field Form

GROUNDWATER SAMPLING FORM

Project No. _____ Well ID _____ Date _____

Project Name/Location _____ Weather _____

Measuring Pt. Description _____ Screen Setting (ft-bmp) _____ Casing Diameter (in.) _____ Well Material ____ PVC ____ SS

Static Water Level (ft-bmp) _____ Total Depth (ft-bmp) _____ Water Column (ft) _____ Gallons in Well _____

MP Elevation _____ Pump Intake (ft-bmp) _____ Purge Method: _____ Sample Method _____

Pump On/Off _____ Centrifugal _____ Submersible _____ Other _____

Sample Time: _____ Volume Purged _____

Purge Start _____ Gallons Purged _____ Sample ID _____ Sampled by _____

Purge End _____ Replicate/Code No. _____

Time	Minutes Elapsed	Rate (gpm)/(mL/min) 200mL/min +	Depth to Water (ft) -0.3	Gallons Purged	pH ± 0.1	Cond. (µMhos)/(mS/cm) ± 3%	Turbidity (NTU) ± 10%	DO (mg/L) ± 10%	Temp. (°C)/(°F) ± 3%	Redox (mV) ± 10mV	Appearance	
											Color	Odor
Stabilization Calculations (±)												
Stabilization Criteria					**± 0.1 s.u.**	**±3%**	**± 10% or within 1 NTU (1)**	**± 10%**	**±3%**	**±10 mV**		

(1) **Turbidity** < 50 NTU and ±10% or within 1 NTU of a previous reading when <10 NTU

Constituents Sampled	Container	Number	Preservative

Comments _____

Well Casing Volumes

Gallons/Foot					
	1" = 0.04	*1.5" = 0.09*	*2.5" = 0.26*	*3.5" = 0.50*	*6" = 1.47*
	1.25" = 0.06	*2" = 0.16*	*3" = 0.37*	*4" = 0.65*	

Well Information

Well Location: _____ Well Locked at Arrival: Yes / No

Condition of Well: _____ Well Locked at Departure: Yes / No

Well Completion: Flush Mount / Stick Up Key Number To Well: _____

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Attachment 2

Laboratory SOP’s

STANDARD OPERATING PROCEDURE

VOLATILE ORGANIC COMPOUNDS BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY
METHOD SW-846 8260C/ EPA 624.1

APPROVALS:

Barbara Ball

03/08/2023

QA Officer Date

Mayra Mushaly

03/08/2023

Technical Director Date

Number	Description of Change	Date
001-011	Previous revisions not documented	
0012	Updated to comply with DoD QSM and ISO 17025 standards.	6/9/11
013	Updated to method 8260C	9/4/13
014	Updated to comply with DoD QSM 5.0 standards.	04/01/16
015	Updated to comply with DoD QSM 5.1 standards.	01/17/18
016	NY NELAC Audit Finding	03/13/19
017	DOD Audit Corrective Action	09/29/2020
018	2020 Internal Audit revisions	02/16/2021
019	NY NELAC Audit Finding	05/25/2022
020	Emergency SOP Amendment Form	03/08/2023
021		
022		

1.0 SCOPE AND APPLICATION

This SOP is used to determine volatile organic compounds (VOC) in a variety of matrices, regardless of water content, including various air sampling trapping media, ground and surface water, aqueous sludges, caustic liquors, acid liquors, waste solvents, oily wastes, mousses, tars, fibrous wastes, polymeric emulsions, filter cakes, spent carbons, spent catalysts, soils, and sediments. See Table 1 for a list of compounds (along with their characteristic ions) that have been evaluated.

There are various techniques by which these compounds may be introduced into the GC/MS system. Purge-and-trap, by SW-846 Methods 5030C (aqueous samples) and 5035A (solid, waste, and oil samples), are the most commonly used technique for volatile organic analytes. SW-846 Method 5000 provides general information on the selection of other introduction methods.

The practical quantitation limit (PQL) for an individual compound is instrument dependent and also dependent on the choice of the sample preparation/introduction method. Using standard quadrapole instrumentation and the purge-and-trap technique, limits should be approximately 50 µg/kg (wet weight) for solid samples and 1 µg/L for ground water. When lower reportable detection limits (RDLs) are required, the mass spectrometer (MS) can be set to selective ion monitoring (SIM) to achieve limits approximately 20 times lower then obtainable using the full scan method. Regardless of the sample matrix, PQLs will be proportionately higher for sample extracts and samples that require dilution or when a reduced sample size is used to avoid saturation of the detector.

Method Detection Limits (MDL) and Practical Quantitation Limits (PQL) are available in Merit's LIMs system.

This SOP is restricted to use by, or under the supervision of, analysts experienced in the use of gas chromatograph/mass spectrometers, and skilled in the interpretation of mass spectra and their use as a quantitative tool.

This SOP is not for use with samples that come into the lab for OHIO VAP work.

2.0 SUMMARY OF THE METHOD

VOC are introduced into the gas chromatograph by the purge-and-trap method or by other methods. The analytes are introduced directly to a wide-bore capillary column. The column is temperature-programmed to separate the analytes, which are then detected with a mass spectrometer interfaced to the gas chromatograph.

Analytes eluted from the capillary column are introduced into the mass spectrometer via a jet separator or a direct connection. Identification of target analytes is accomplished by comparing their mass spectra

with the electron impact spectra of authentic standards. Quantitation is accomplished by comparing the response of a major (quantitation) ion relative to an internal standard using a five point (or more) calibration curve.

The method includes specific calibration and quality control steps that supersede the general requirements provided in SW-846 Method 8000.

3.0 INTERFERENCES

Major contaminant sources are volatile materials in the laboratory and impurities in the inert purging gas and in the sorbent trap. The use of non-polytetrafluoroethylene (PTFE) thread sealants, plastic tubing, or flow controllers with rubber components should be avoided, since such materials out-gas organic compounds will be concentrated in the trap during the purge operation.

Cross-contamination may occur when any sample is analyzed immediately after a sample containing high concentrations of volatile organic compounds. After the analysis of a sample containing high concentrations of volatile organic compounds, one or more blanks should be analyzed to allow the system to be cleaned as well as to demonstrate the ultimate absence of cross-contamination. Alternatively, if the sample immediately following the high concentration sample does not contain the volatile organic compounds present in the high level sample, freedom from contamination has been established.

4.0 APPARATUS AND MATERIALS

Gas chromatograph/mass spectrometer system

- Gas chromatograph - An analytical system complete with a temperature programmable gas chromatograph suitable for splitless injection and all required accessories, including syringes, analytical columns, and gases. The capillary column should be directly coupled to the source.
- 20 m × 0.18 mm ID capillary column coated with DB-624 (J&W Scientific), Rt_x-502.2 (RESTEK), or VOCOL (Supelco), 1-µm film thickness, or equivalent.
- Mass spectrometer capable of scanning from 35 to 260 amu every 2 sec or less, using 70 volts (nominal) electron energy in the electron impact ionization mode. The mass spectrometer must be capable of producing a mass spectrum for 4-bromofluorobenzene (BFB) which meets the criteria in Table 4.
- GC/MS interface - The capillary column is interfaced through a direct connection to the GC/MS system.

- Data system - A computer system is interfaced to the mass spectrometer. Hewlett-Packard Chemstation software (with environmental data analysis) is used to acquire and process GC/MS data.

Purge-and-trap device.

Microsyringes - 2 to 500-µL.

Balance - Analytical, capable of weighing 0.001 g, and top-loading, capable of weighing 0.1 g.

Glass bottles - 40-mL, with PTFE-lined screw-caps.

pH paper.

5.0 REAGENTS

Reagent grade organic chemicals shall be used in all tests. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without introducing adverse interferences.

Organic-free reagent water - All references to water in this method refer to organic-free reagent water.

Stock standard solutions.

- Certified stock standard solutions are purchased when available for the bulk of desired analytes. They are typically available at concentrations of 1000 to 2000 mg/L.
- Supplemental compounds added to calibration mixes are generally prepared gravimetrically from neat standard references (in order to create a high-concentration stock solution).
- Stock standard solutions are stored in bottles with PTFE-lined screw-caps. They are refrigerated and protected from light, as recommended by the standard manufacturer.
- Stock standard solutions are replaced prior to expiration, or sooner if comparison with quality control check samples indicate a problem.

Internal standard solutions - The internal standards used are pentafluorobenzene, 1,4-difluorobenzene, chlorobenzene-d_5, and 1,4-dichlorobenzene-d_4 (see Table 2). Internal standards are used at a working concentration of 50 mg/L and are added to samples, spikes, blanks, and calibration standards at a uniform concentration of 50 µg/L (i.e. 10µL per 5000µL purge volume). For SIM (selective ion monitoring) analysis, internal standards are the same, but with concentrations at 0.4 ppb (µg/L).

Calibration standards - A minimum of five calibration standards are prepared at different concentrations. The lowest calibration standard corresponds to a sample concentration at or below the standard reporting

limit. The remaining standards should represent the working range of the GC/MS system. Each standard should contain each analyte for quantitation by this method. For DoD projects, each standard shall contain all target compounds.

Surrogate standards - The surrogates used are toluene-d_8, 4-bromofluorobenzene, and 1,2-dichloroethane-d_4. Surrogate standards are used at a working concentration of 50 mg/L and are added to samples, spikes, blanks, and calibration standards at a uniform concentration of 50 µg/L, or less. For SIM (selective ion monitoring) analysis, surrogate standards are the same, but with concentrations at 0.4 ppb (µg/L).

Matrix spike (MS), matrix spike duplicate (MSD) and laboratory control standards (LCS) - Matrix spiking solutions are prepared using the same standards as those used for the calibration. For DoD projects, matrix spiking solutions shall contain all target compounds.

- Matrix spiking mixes for individual analytes are created at 100 mg/L and spiked into samples at 50 µg/L (*i.e.* 2.50µL per 5000µL purge volume).
- For SIM (selective ion monitoring) analysis, compounds of interest are spiked at concentrations of 0.4 ppb (µg/L).
- For 1-Dioxane, compounds of interest are spiked at concentrations of 50 ppb (µg/L).

Methanol, CH_3OH - Pesticide quality or equivalent, demonstrated to be free of analytes. Store apart from other solvents.

6.0 SAMPLE HANDLING AND PRESERVATION

Unanalyzed samples are refrigerated at 4 ± 2 degrees Celsius in sealed vials or containers.

Aqueous samples are preserved to a pH <2with HCl and/or $Na_2S_2O_3$ (unless unpreserved requested) and collected in a 40 ml. Preserved samples must be analyzed within 14 days from sample collection; unpreserved samples must be analyzed within 7 days from sample collection.

Soil samples collected Encore™ Samplers must be preserved within 48 hours and analyzed within 14 days. Soil samples collected in glass jars shall be kept refrigerated and analyzed within 14 days from sample collection. For additional information on sample collection, handling and preservation for soil samples see SOP #ORL-005.

7.0 PROCEDURE

Sample introduction.

- Direct injection - This method of introduction is used only rarely, generally when the compounds of interest exhibit poor purging efficiency. Quantitation in this case, if required, is generally subject to external standard calibration procedures (*cf*. Method 8000).

- Purge-and-trap - This is generally used for sample introduction for both soil and water samples. All samples, standards, spikes, and blanks are introduced into the GC/MS system in an identical manner (see Merit SOP# ORL-005).

GC/MS operating conditions - see Table 3 for routine operating conditions for VOC analysis.

- For SIM, the MS is put into the SIM mode. Based on compounds of interest, the time windows are set within the run (i.e. for internal standards, surrogate standards, compounds). For each time window, corresponding to a compound, a minimum of 3 ions are chosen for qualitative analysis. One ion (primary ion), generally the most abundant ion is used for quantitative analysis.

Initial calibration.

- Each GC/MS system must be hardware-tuned to meet the criteria in Table 4 for 4-bromofluorobenzene. Analysis does not begin until these criteria are met.

    - In the absence of any other manipulations, evaluate the mass spectrum of the peak apex or the scan immediately preceding or following from the total ion chromatogram for the BFB peak. This is the default approach used.

    - If the above evaluation is adversely affected by ion peak asymmetry, average the three highest intensity scans of the peak or average the mass spectrum ranging from the 10% initial peak intensity to the tailing 10% peak intensity level from the total ion chromatogram for the BFB peak.

    - If the above evaluation is adversely affected by background contamination, perform a background subtraction with a spectrum within 20 scans of the BFB peak which does not represent a target compound. Use of this procedure may be indicative of failing MS performance. The MS source should be cleaned and re-tuned.

    - The BFB mass intensity criteria in Table 4 are used as tuning acceptance criteria.

    - All subsequent standards, samples, MS/MSDs, and blanks associated with a BFB analysis must use the identical mass spectrometer instrument conditions, Exception: for SIM, tune is run using full scan acquisition and subsequent samples are acquired using SIM.

- Purge and analyze each calibration standard (containing internal standards) and tabulate the area of the primary characteristic ion against concentration for each target analyte (as indicated in Table 1). A set of at least five calibration standards is necessary. The purge volume must be the same for all standards and sample extracts. Figure 1 shows a chromatogram of a midpoint calibration standard.

- Calculate response factors (*RF*s) for each target analyte relative to one of the internal standards as follows: $RF = A_s C_i / A_i C_s$. Here, A_s and A_i are the areas of the standard compound and corresponding internal standard, respectively. Likewise, C_s and C_i are the respective concentrations (in any consistent set of units) of the standard compound and corresponding internal standard.

- Response Factor Criteria

  - It is recommended that a minimum response factor for the most common target analytes as noted in Table 2b, be demonstrated for each individual calibration level as a means to ensure that these compounds are behaving as expected. In addition, meeting the minimum response factor criteria for the lowest calibration level is important in demonstrating the desired sensitivity. Due to the large number of compounds that may be analyzed, some compounds will fail to meet this criteria. In particular, poor performers such as ketones and 1,2-dibromo-3-chloropropane are likely to fail this criteria but have been demonstrated to perform adequately overall.

  - If the minimum response factors are not met, the system must be evaluated, and corrective action must be taken before sample analysis begins. Possible problems include standard mixture degradation, contamination in the purge-and-trap system, excessively high or low purge flow rates, and active sites in the column or chromatographic system. Replacing the calibration standards, clipping and/or replacing the column will likely solve this problem.

- Evaluation of retention times - The relative retention time (RRT) of each target analyte in each calibration standard should agree within 0.06 RRT units. This is accomplished by setting the retention time extraction windows in the Chemstation software.

- Linearity of target analytes - If the %RSD of any target analytes is 20% or less, then the relative response factor may be assumed to be constant over the calibration range, and the average relative response factor may be used for quantitation.

- Refer to SW-846 Method 8000 if a least-squares regression is used to determine a linear or quadratic fit to the calibration data. Quadratic polynomials are generally fit through the origin in order to prevent the symptomatic aphysical prediction of high concentrations at very low responses. The coefficient of determination for any regression fit should be ≥0.99. In addition, 6 calibration data points are required for a calibration fit with 3 free parameters, while 5 are required for a calibration fit with 1 or 2 free parameters.
- When the RSD exceeds 20%, the plotting and visual inspection of a calibration curve can be a useful diagnostic tool. The inspection may indicate analytical problems, including errors in standard preparation, the presence of active sites in the chromatographic system, analytes that exhibit poor chromatographic behavior, *etc*.
- The method of linear regression analysis has the potential for a significant bias to the lower portion of a calibration curve, while the relative percent difference and the quadratic methods of calibration do not have this potential bias. When calculating the calibration curves using the linear regression model, a minimum quantitation check on the viability of the lowest calibration point should be performed by re-fitting the response from the low concentration calibration standard back into the curve. The recalculated concentration of the low calibration point should be within 30% of the standard's true concentration. Other recovery criteria may be applicable depending on the project's data quality objectives. For analytes which do not meet the minimum quantitation calibration re-fitting criteria reporting those analytes as estimated when the concentration is at or near the lowest calibration point may be appropriate.
- The initial calibration curve should be verified immediately after performing the standard analyses using a second source standard at a concentration near the midpoint of the calibration range. The acceptance limits are 70-130% or project specific. Analytes that fail this criteria are considered estimated values.
- The quality of the calibration fit for any particular compound is communicated to the data user via the Quality Control report for a given batch of samples. The calibration summary report includes: the concentration and RF for each standard in the calibration curve, the type of calibration fit, the calibration fit parameters (*i.e*. average RF or regression coefficients), and the appropriate calibration quality metric (*i.e*. %RSD or COD).

♦ GC/MS calibration verification - Calibration verification consists of three steps that are performed at the beginning of each 12-hour analytical shift.

- Prior to the analysis of samples or calibration standards, purge the BFB standard into the GC/MS system. The resultant mass spectrum for BFB must meet the criteria given in Table 4 before sample analysis begins. These must be *injected* within 12 hours of the injection time for the BFB.
- The initial calibration for each compound of interest should be verified once every 12 hours prior to sample analysis, using the introduction technique and conditions used for samples. This is accomplished by analyzing a calibration standard at a concentration near the midpoint concentration for the calibration range of the GC/MS (50 µg/L; this represents 2.50 µL of the 100 mg/L calibration standard solution in a 5mL purge volume). A concentration of 0.1µg/L is analyzed for SIM procedures. The results from the calibration standard analysis must meet the verification acceptance criteria provided below. In addition the internal standards should be within 10s of those in the midpoint calibration standard and the responses should be 50-200% of those in the midpoint calibration standard.
- A method blank is run every 20 samples to ensure that the total system (preparation glassware, introduction device, transfer lines, and the GC/MS system itself) is free of contaminants. A method blank/wash sample is also run after calibration check/spike samples and prior to analytical samples in order to eliminate carryover contamination from the purge-and-trap system.
- Calibration Verification
    - A calibration verification must be made during every 12-hour analytical shift.
    - Each of the most common target analytes in the calibration verification standard should meet the minimum response factors as noted in Table 2b. This is the same check that is applied during the initial calibration and exceptions are noted above.
    - If the minimum response factors are not met, the system must be evaluated, and corrective action must be taken before sample analysis begins.
    - All target compounds of interest must be evaluated using a 20% variability criterion. If the percent drift for a compound is less than or equal to 20%, then the initial calibration for that compound is assumed to be valid. Due to the large numbers of compounds that may be analyzed by this method, some compounds will fail to meet the criteria. If the criterion is not met for more than 20% of the compounds included in the initial calibration, then corrective action must be taken prior to the analysis of samples. In cases where compounds fail, they may still be reported as non-detects if it can be demonstrated that there was adequate sensitivity to detect the compound at the applicable quantitation limit. For situations when a failed compound is present, the concentration is an estimated

value. Drift is defined as the normalized deviation of the measured from the spike value of a target component: $\%D = \left|C - C_{spike}\right| / C_{spike}$.

- Problems similar to those listed under initial calibration could affect the calibration verification. If the problem cannot be corrected by other measures, a new initial calibration must be generated. The calibration verification criteria must be met before sample analysis begins.

GC/MS analysis of samples.

- Samples are screened at a diluted state via GC/MS whenever possible prior to analysis within a 12-hour QC batch. This can identify potentially low surrogate recoveries, high target compound concentrations, non-target matrix interferences. This will minimize contamination of the GC/MS system from unexpectedly high concentrations of organic compounds.
- Use a 5 mL syringe to take a 5 mL aliquot from the sample vial. Be sure to eliminate any air bubbles from within the syringe.
- Add 5 µL of 50 mg/L internal/surrogate standard mixture are introduced to each sample through the autosampler. For SIM analysis, internal and surrogate standards are spiked at 0.1µg/L.
- If the concentration for any quantitation ion exceeds the initial calibration range of the GC/MS system, the sample extract should be diluted and reanalyzed. In any event, a result based on an extrapolation of calibration curve beyond the working range is flagged on the analytical report.
- The Extracted Ion Current Profile (EICP) area for all of the internal standards in all spikes, blanks, and samples is monitored relative to the most recent calibration verification standard. Changes by more than a factor of two (*i.e.* 50% to 200%) can indicate adverse matrix effects (in the case of an isolated sample) or degrading MS performance (in the case of a systematic low bias). A single-sample matrix effect is documented either via screening or re-analysis and is noted on the analytical report (see Table 5a and 5b). Similarly, the retention times for all of the internal standards in all spikes, blanks, and samples is monitored relative to the most recent calibration verification standard. The change in retention time for any internal standard by more than 30 seconds of the most recent calibration verification standard is indicative of the same potential problems listed above and should be flagged/corrected as appropriate.

Qualitative analysis.

- The qualitative identification of compounds determined by this method is based on retention time and on comparison of the sample mass spectrum, after background correction, with characteristic

ions in a reference mass spectrum. The reference mass spectrum must be generated by the laboratory using the conditions of this method. The characteristic ions from the reference mass spectrum are given in Figures 1a and 1b. Compounds are identified when the following criteria are met.

- Initial selection of a target compound peak is performed by the Chemstation data system search routine. The search is based on the presence of a target chromatographic peak containing ions specific for the target compound at a compound specific retention time.
- The RRT of the sample component is within ± 0.06 RRT units of the RRT of the standard component. This is accomplished using retention time extraction windows within the Chemstation data system.
- The relative intensities of the characteristic ions agree within 30% of the relative intensities of these ions in the reference spectrum. (Example: For an ion with an abundance of 50% in the reference spectrum, the corresponding abundance in a sample spectrum can range between 20% and 80%.)
- Structural isomers that produce very similar mass spectra are identified as individual isomers if they have sufficiently different GC retention times. Sufficient GC resolution is achieved if the height of the valley between two isomer peaks is less than 25% of the sum of the two peak heights. Otherwise, structural isomers are identified as isomeric pairs.
- Identification is hampered when sample components are not resolved chromatographically and produce mass spectra containing ions contributed by more than one analyte. When gas chromatographic peaks obviously represent more than one sample component (*i.e.*, a broadened peak with shoulder(s) or a valley between two or more maxima), appropriate selection of analyte spectra and background spectra is important.
- Examination of extracted ion current profiles of appropriate ions can aid in the selection of spectra and in qualitative identification of compounds. When analytes coelute (*i.e.*, only one chromatographic peak is apparent), the identification criteria may be met, but each analyte spectrum will contain extraneous ions contributed by the coeluting compound.
- In the two previous cases, analyst expertise as well as knowledge of site history may be important in accepting/rejecting the identification of a compound. In the event of continued uncertainty, the analyst should preferentially make a conservative judgment and accept an identified hit, allowing the potential for a false positive.

- For samples containing components not associated with the calibration standards, a library search may be made for the purpose of tentative identification. The necessity to perform this type of identification will be determined by the purpose of the analyses being conducted. Only after visual comparison of sample spectra with the nearest library searches may the analyst assign a tentative identification. Guidelines for tentative identification are:
  - Relative intensities of major ions in the reference spectrum (ions > 10% of the most abundant ion) should be present in the sample spectrum.
  - The relative intensities of the major ions should agree within ± 20%.
  - Molecular ions present in the reference spectrum should be present in the sample spectrum.
  - Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination or presence of coeluting compounds.
  - Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting peaks. Data system library reduction programs can sometimes create these discrepancies.

Quantitative analysis.

- Once a compound has been identified, the quantitation of that compound will be based on the integrated abundance of the primary characteristic ion from the EICP.
- The curve fit applied in the initial calibration is the same as that used to compute the concentration of a target analyte in a sample. All curve fits are evaluated by the data system and are of the form: $A_s/A_i = k_0 + k_1[C_s/C_i] + k_2[C_s/C_i]^2$. Here A_s and A_i are the areas of the target and internal standard, C_s and C_i are the concentrations of the target and internal standard, and k_i is the i^{th}-order regression coefficient. Note that for a mean RF fit to the calibration data, $k_1 \equiv$ <RF>, while k_0, $k_2 \equiv 0$.
- The concentration of any non-target analytes identified in the sample may be estimated by assuming a mean RF of 1 and by using the tentatively identified compound (TIC) areas for the nearest internal standard and target compound. The resulting concentration should be reported indicating: (1) that the value is an estimate, and (2) which internal standard was used to determine concentration. Use the nearest internal standard free of interferences.

- Structural isomers that produce very similar mass spectra should be quantitated as individual isomers if they have sufficiently different GC retention times. Otherwise, structural isomers are quantitated as isomeric pairs (such as p- and m-xylene).

8.0 QUALITY CONTROL

All of the quality control items employed and evaluated are provided in Table 5a and 5b. In addition, the table indicates the frequency of each QC item along with appropriate courses of corrective action. Control limits for surrogates and internal standards are listed in Table 6. The analyst will follow SOP # QA-007 and complete the appropriate review form upon completion of the analysis.

9.0 METHOD PERFORMANCE

The precision and accuracy of the method depends upon the overall performance of the sample preparation and analysis. Laboratory specific performance data is provided for Merit's LIMs system. Each sample batch contains a method blank, laboratory control sample and matrix spike samples. Performance Evaluation samples are analyzed periodically in order to prove the performance of the method.

10.0 EQUIPMENT MAINTENANCE AND TROUBLESHOOTING

Each instrument is assigned a maintenance logbook. All maintenance performed on the instrument must be recorded. Additionally, any modifications to the instrument settings shall be noted in the specific instrument logbook. Maintenance procedures provided in the equipment manual shall be followed. Maintenance may include, cleaning the MS source, clipping/replacing the column, or replacing the calibration standard.

Computer software and firmware can be found on Merit's network at F:\data\MERIT\EQUIPMENT\Instrument-Software Version List.200818.xls.

11.0 SAFETY

Eye protection and gloves must be worn while performing the analyses. Every laboratory area has eyewash, emergency shower, and fire extinguisher. The metals lab also has dust masks available for use with dust samples. The air system throughout the laboratory area is on a 100% fresh air exchange system, this system exchanges 100% the air in the laboratory area with air from outside 6 times per hour and 30 times per hour when the emergency purge button is hit.

A reference file of material safety data sheets (MSDSs) is available to all personnel. Specific attention shall be paid (but not limited) to:

a. Methanol may react violently with acids, acid chlorides, acid anhydrides, oxidizing agents, reducing agents and alkali metals. Protect from moisture. Highly flammable.

b. Hydrochloric acid is corrosive. Extreme heat or contact with metals can release flammable hydrogen gas, stable under ordinary conditions of use and storage, and incompatible with many substances and highly reactive with strong bases, metals, metal oxides, hydroxides, amines, carbonates, cyanides, sulfides, sulfites, and formaldehyde.

12.0 WASTE DISPOSAL AND POLLUTION PREVENTION

All laboratory waste must be managed, stored, and disposed in accordance with all federal and state laws and regulations. Additional information can be found in the Sample Disposal SOP and Merit's Waste Management Plan and Handbook.

13.0 DEFINITIONS

4-Bromofluorobenzene (BFB), is used to verify that the GC/MS is properly tuned and ready for calibration and sample analyses. BFB is directly injected at 25-50 ng and precedes all other analyses. A twelve hour analysis time window is used before another BFB injection is required.

An Initial Calibration Verification standard (ICV) is analyzed before the analysis of samples as a check on the calibration curve. The ICV shall be of a second source, meaning a separate vendor and/or lot # shall be used to prepare this standard. A second source is needed to validate the integrity and concentration of the standards used for calibration.

An Initial Calibration Blank (ICB) is also analyzed before samples to confirm that the deionized water (DI H2O) used for standards, blanks, and dilutions are free from contamination. An ICB for soil samples also includes organic free sand and/or methanol used for standard and QC preparation, as well as sample dilutions and volume adjustments; the control sand and methanol must also be documented as free from contamination.

A Calibration Check Verification standard (CCV) is analyzed at the beginning of each sequence (following the BFB injection) shift and every 12 hour shift thereafter. A CCV is made up from the same standards used for calibration and is used to ensure that the calibration and retention times are stable.

An analytical batch is defined as a group of samples (not to exceed 20 samples) analyzed per sequential run. Depending on client or program requirements, an analytical batch may or may not include matrix spikes as part of the 20 samples.

Internal standards (ISTD) are added to each sample, blank, spike, and check standard. The ISTDs used are Fluorobenzene, Chlorobenzene-d_5, and 1,4-Dichlorobenzene-d_4. The ISTD is used for internal calibration as a reference peak and to check purging efficiency.

Surrogate standards (SSTD) are also added to each sample, blank, spike, and check standard. The SSTDs used are Toluene-d_4, 4-Bromofluorobenzene, 1,2-Dichloroethane-d_4, and Dibromofluoromethane. The SSTD is used as matrix interference and as a method control check.

Method Blank (MB): An analyte-free matrix to which all reagents are added in the same volumes or proportions as used in the sample processing. The method blank is carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination resulting from the analytical process.

A Continuing Calibration Blank (CCB) is analyzed every 12 hour shift after the MB has been analyzed and before sample reanalyzes to ensure the system is still free from contamination.

Instrument blanks are analyzed whenever instrument contamination is a suspected possibility. The purpose of an IB is to prevent carry over from a standard, spike, or contaminated sample into another sample or blank. The acceptance criteria for an IB is the same as for a MB or CCB (for example: if an IB contains detections above acceptance criteria and a MB and/or sample following the IB exhibit the same contamination above acceptance criteria, then the instrument shall be considered contaminated). The samples and/or MBs shall be reanalyzed after the instrument is confirmed free from contamination.

Laboratory Control Spike (LCS): Milli-Q water (for water) and Organic-Free Soil (for soil) is spiked with all target compounds and carried through the complete sample preparation and analytical procedure. The control spike is used to document the ability of an analyst to generate acceptable precision and bias to verify the analytical system performance, and to document method accuracy for each matrix.

Matrix Spike (MS): An aliquot of sample spiked with all target compounds. The spiking occurs prior to sample preparation and analysis. They are used to document the precision and bias of a method in a given sample matrix.

Matrix Spike Duplicate (MSD): Intra-laboratory split samples spiked with all target compounds. The spiking occurs prior to sample preparation and analysis. They are used to document the precision and bias of a method in a given sample matrix.

14.0 REFERENCES

Bellar, T., *Measurement of Volatile Organic Compounds in Soils Using Modified Purge-and-Trap and Capillary Gas Chromatography/Mass Spectrometry*, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Cincinnati, OH, November, 1991.

Department of Defense, Quality Systems Manual for Environmental Laboratories (DoD QSM), DoD Environmental Data Quality Workgroup, Department of Navy, Lead Service, ISO/IEC 17025:2005, ISO/IEC 17025:2017 and The NELAC Institute (TNI) Standards, Volume 1, September 2009, Version 5.3, May 7, 2019

U.S. EPA 40 CFR Part 136, *Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; Final Rule and Interim Final Rule and Proposed Rule,* October 26, 1984.

EPA SW-846, *Test Methods for Evaluation Solid Waste*, 3rd Edition, Update I dated 7/92, Update II dated 9/94, Update IIA dated 8/93, Update IIB dated 1/95, Update III dated 12/96, Update IV dated 1/08.

International Standards Organization (ISO), 2005. *General Requirements for the Competence of Testing and Calibration Laboratories.* ISO 17025.

National Environmental Laboratory Accreditation Conference (NELAC), 2003. *Standards, Chapters 1–6*, EPA/600/R-04/003.

EPA Method 624.1, December 2016

Table 1. Summary of Retention Times and Characteristic Ions for Volatile Organics

Compound List Report Ravnica

Method : F:\GCMS.DAT\RAVNICA.SN\METHODS\WR201119.M
Title : Volatile Organics, SW-846 # 8260B
Last Update : Thu Nov 19 18:19:17 2020
Response via : Initial Calibration
Total Cpnds : 88

PK#		Compound Name	QIon	Exp_RT	Rel_RT	Cal	#Qual	A/H	ID
1	I	PENTAFLUOROBENZENE (I)	168	4.04	1.000	A	2	A	B
2	S	1,2-DICHLOROETHANE-D4 (S)	65	4.19	1.039	A	2	A	B
3		1,1,2-Trichloro-1,2,2-trifluor	101	2.63	0.651	A	2	A	B
4		Diethyl ether (*)	74	2.41	0.596	A	2	A	B
5		Acetone (*)	43	2.66	0.660	A	2	A	B
6		Methyl iodide (iodomethane) (*	142	2.70	0.669	A	2	A	B
7		Carbon disulfide (*)	76	2.76	0.684	A	2	A	B
8		Methyl Acetate	43	2.91	0.721	A	2	A	B
9		tert-Methyl butyl ether (MTBE)	73	3.17	0.784	A	3	A	B
10		Acrylonitrile (*)	53	3.15	0.780	A	2	A	B
11		2-Butanone (MEK) (*)	43	3.77	0.935	A	2	A	B
12		Dichlorodifluoromethane	85	1.26	0.311	QO	2	A	B
13		Chloromethane (SPCC)	50	1.34	0.332	A	2	A	B
14		Vinyl Chloride (CCC)	62	1.47	0.365	A	2	A	B
15		Bromomethane	94	1.75	0.432	A	2	A	B
16		Chloroethane	64	1.85	0.458	A	3	A	B
17		Acrolein	56	2.52	0.623	A	2	A	B
18		Trichlorofluoromethane	101	2.17	0.538	A	3	A	B
19		1,1-Dichloroethene (CCC/MS)	61	2.58	0.639	A	3	A	B
20		Methylene Chloride	84	2.97	0.736	A	3	A	B
21		trans-1,2-Dichloroethene	61	3.16	0.782	A	3	A	B
22		Hexane	57	3.33	0.825	A	2	A	B
23		Vinyl Acetate	43	3.32	0.823	A	2	A	B
24		1,1-Dichloroethane (SPCC)	63	3.42	0.848	A	2	A	B
25		cis-1,2-Dichloroethene	96	3.76	0.932	A	2	A	B
26		2,2-Dichloropropane	77	3.76	0.932	A	2	A	B
27		Tetrahydrofuran	42	3.92	0.970	A	2	A	B
28		Chloroform (CCC)	83	3.94	0.975	A	2	A	B
29		Bromochloromethane	130	3.90	0.965	A	3	A	B
30		1,1,1-Trichloroethane	97	4.04	1.000	A	2	A	B
31		1,1-Dichloropropene	75	4.11	1.018	A	2	A	B
32		Cyclohexane	42	4.06	1.005	A	3	A	B
33	I	1,4-DIFLUOROBENZENE (I)	114	4.40	1.000	A	2	A	B
34	S	TOLUENE-D8 (S)	98	5.11	1.160	A	2	A	B
35		4-Methyl-2-pentanone (MIBK) (*	58	5.04	1.145	A	3	A	B
36		2-Hexanone (*)	58	5.43	1.232	A	3	A	B
37		2-chloroethylvinyl ether	63	4.90	1.113	A	2	A	B
38		Carbon Tetrachloride	117	4.12	0.936	A	2	A	B
39		Benzene (MS)	78	4.22	0.958	A	2	A	B
40		1,2-Dichloroethane	62	4.23	0.961	A	3	A	B
41	M	Trichloroethene (MS)	95	4.53	1.030	A	3	A	B
42		1,2-Dichloropropane (CCC)	63	4.64	1.055	A	2	A	B
43		Bromodichloromethane	83	4.77	1.083	A	3	A	B
44		Methyl Cyclohexane	55	4.63	1.051	A	3	A	B
45		Dibromomethane	174	4.71	1.069	A	3	A	B
46		cis-1,3-Dichloropropene	75	4.98	1.131	A	2	A	B
47	M	Toluene (CCC/MS)	91	5.14	1.167	A	2	A	B
48		trans-1,3-Dichloropropene	75	5.23	1.188	A	2	A	B

49	1,1,2-Trichloroethane	83	5.32	1.208	A	3	A	B
50	Tetrachloroethene	166	5.39	1.225	A	2	A	B
51 I	CHLOROBENZENE-D5 (I)	82	5.78	1.000	A	2	A	B
52 S	4-BROMOFLUOROBENZENE (S)	174	6.33	1.095	A	2	A	B
53	1,3-Dichloropropane	76	5.40	0.935	A	2	A	B
54	trans-1,4-Dichloro-2-butene	53	6.41	1.109	QO	3	A	B
55	Dibromochloromethane	129	5.51	0.954	A	2	A	B
56	1,2-Dibromoethane	107	5.57	0.965	A	2	A	B
57 M	Chlorobenzene (SPCC/MS)	112	5.79	1.003	A	2	A	B
58	1,1,1,2-Tetrachloroethane	131	5.83	1.009	A	3	A	B
59	Ethylbenzene (CCC)	91	5.84	1.010	A	2	A	B
60	p,m-Xylene	106	5.89	1.019	A	2	A	B
61	o-Xylene	91	6.08	1.052	A	2	A	B
62	Styrene	104	6.08	1.053	A	2	A	B
63	Isopropylbenzene	105	6.24	1.081	A	2	A	B
64	Bromoform (SPCC)	173	6.18	1.070	A	2	A	B
65	1,1,2,2-Tetrachloroethane (SPC	83	6.38	1.104	A	3	A	B
66	1,2,3-Trichloropropane	110	6.41	1.110	A	3	A	B
67	n-Propylbenzene	91	6.44	1.114	A	2	A	B
68	Bromobenzene	156	6.41	1.109	A	2	A	B
69	1,3,5-Trimethylbenzene	120	6.52	1.128	A	2	A	B
70	2-Chlorotoluene	91	6.49	1.123	A	2	A	B
71	4-Chlorotoluene	126	6.54	1.132	A	2	A	B
72	tert-Butylbenzene	91	6.67	1.155	A	2	A	B
73	1,2,4-Trimethylbenzene	120	6.70	1.160	A	2	A	B
74 I	1,4-DICHLOROBENZENE-D4 (I)	152	6.88	1.000	A	2	A	B
75	sec-Butylbenzene	105	6.78	0.986	A	2	A	B
76	p-Isopropyltoluene	119	6.84	0.995	A	2	A	B
77	1,3-Dichlorobenzene	146	6.85	0.995	A	2	A	B
78	1,4-Dichlorobenzene	146	6.89	1.002	A	2	A	B
79	1,2-Dichlorobenzene	146	7.07	1.028	A	2	A	B
80	1,2,3-Trimethylbenzene	105	6.90	1.004	A	2	A	B
81	n-Butylbenzene	91	7.04	1.024	A	2	A	B
82	Hexachloroethane	201	7.19	1.046	A	2	A	B
83	1,2-Dibromo-3-Chloropropane	157	7.44	1.082	A	3	A	B
84	1,2,4-Trichlorobenzene	182	7.84	1.140	A	3	A	B
85	Hexachlorobutadiene	225	7.92	1.151	A	3	A	B
86	1,2,3-Trichlorobenzene	180	8.09	1.176	A	3	A	B
87	Naphthalene	128	7.97	1.159	A	3	A	B
88	2-Methylnaphthalene	142	8.52	1.239	A	2	A	B

Cal A = Average L = Linear LO = Linear w/origin Q = Quad QO = Quad w/origin
#Qual = number of qualifiers
A/H = Area or Height
ID R = R.T. B = R.T. & Q Q = Qvalue L = Largest A = All

WR201119.M Fri Dec 18 09:41:56 2020

: For DoD projects, all target compounds will be included in the matrix spike and matrix spike duplicate

Table 2. Summary of Applicable Performance Compounds - Volatile Organics Analysis

COMPOUND	ISD	SSD
PENTAFLUOROBENZENE	✔	
1,2-DICHLOROETHANE-D4		✔
1,4-DIFLUOROBENZENE	✔	
TOLUENE-D8		✔
CHLOROBENZENE-D5	✔	
4-BROMOFLUOROBENZENE-		✔
1,4-DICHLOROBENZENE-D4	✔	

: For DoD projects, all target compounds will be included in the matrix spike and matrix spike duplicate

Key

ISD: Internal Standard Compound

SSD: Surrogate Standard Compound

Table 2b. Recommended Minimum Relative Response Factor Criteria For Initial And Continuing Calibration Verification.

Volatile Compounds	Minimum Response Factor (RF)[a]
Dichlorodifluoromethane	0.100
Chloromethane	0.100
Vinyl chloride	0.100
Bromomethane	0.100
Chloroethane	0.100
Trichlorofluoromethane	0.100
1,1-Dichloroethene	0.100
1,1,2-Trichloro-1,2,2-trifluoroethane	0.100
Acetone	0.100
Carbon disulfide	0.100
Methyl Acetate	0.100
Methylene chloride	0.100
trans-1,2-Dichloroethene	0.100
cis-1,2-Dichloroethene	0.100
Methyl tert-Butyl Ether	0.100
1,1-Dichloroethane	0.200
2-Butanone	0.100
Chloroform	0.200
1,1,1-Trichloroethane	0.100
Cyclohexane	0.100
Carbon tetrachloride	0.100
Benzene	0.500
1,2-Dichloroethane	0.100
Trichloroethene	0.200
Methylcyclohexane	0.100
1,2-Dichloropropane	0.100
Bromodichloromethane	0.200
cis-1,3-Dichloropropene	0.200
trans-1,3-Dichloropropene	0.100
4-Methyl-2-pentanone	0.100
Toluene	0.400
1,1,2-Trichloroethane	0.100
Tetrachloroethene	0.200
2-Hexanone	0.100
Dibromochloromethane	0.100
1,2-Dibromoethane	0.100
Chlorobenzene	0.500

Volatile Compounds	Minimum Response Factor (RF)[a]
Ethylbenzene	0.100
meta-/para-Xylene	0.100
ortho-Xylene	0.300
Styrene	0.300
Bromoform	0.100
Isopropylbenzene	0.100
1,1,2,2-Tetrachloroethane	0.300
1,3-Dichlorobenzene	0.600
1,4-Dichlorobenzene	0.500
1,2-Dichlorobenzene	0.400
1,2-Dibromo-3-chloropropane	0.050
1,2,4-Trichlorobenzene	0.200

[a] The Project-specific response factors obtained may be affected by the quantitation ion selected and when using possible alternate ions the actual response factors may be lower than those listed.

Table 3. GC/MS Operating Conditions - Volatile Organics Analysis

Operating Parameter	**Volatiles Analysis**
Chromatographic Column	DB 624, *L* = 20 *m*, *ID* = 0.18 *mm*
Carrier Gas	Helium (He)
Temperature Program	T_0 = 30°C, hold 2.0 *min* dT/dt_1 = 32°C/*min* T_1 = 195°C dT/dt_2 = 30°C/*min* T_2 = 235°C
Injector Temperature	150°C
Detector Temperature	300°C
Purge Volume	5 *mL*
Mass Scanning Range	35 *m/z* - 260 *m/z*
Mass Scanning Rate	2.0 *Hz*

Note: the above is subject to change based on GC and/or sample conditions.

Table 4. BFB Tune Evaluation Criteria

Target *m/z*	**Relative *m/z***	**LCL (%)**	**UCL (%)**
50	95	8	40
75	95	30	66
95	95	100	100
96	95	5.0	9.0
173	174	0	2.0
174	95	50	120
175	174	4.0	9.0
176	174	93	101
177	176	5.0	9.0

Abundance criteria are for a quadrupole mass spectrometer. Alternative tuning criteria from other published EPA reference methods may be used, provided method performance is not adversely affected. Alternative tuning criteria specified by an instrument manufacturer may also be used for another type of mass spectrometer, or for an alternative carrier gas, provided method performance is not adversely affected.

Table 5a. Quality Control Items, Frequency, and Corrective Action

QC Item	Frequency	Acceptance Criteria	Corrective Action
Initial Calibration	Prior to all analytical runs	Method-based	Examine the entire analytical system; some or all of the following: clean MS source, re-tune, clip/replace column, replace calibration standards, re-calibrate.
BFB	12-hour	Table 4	Re-attempt injection; clean MS source, re-tune; failure requires the re-analysis of all associated analytical runs.
Calibration Verification	12-hour	Table 2b	Re-attempt injection; some or all of the following: clean MS source, re-tune, clip/replace column, replace calibration standards, re-calibrate; failure requires the re-analysis of all associated analytical runs.
LCS and MS	20 samples	Laboratory in-house Control Limits with no more than 4 Marginal Exceedances	A failed LCS should be re-analyzed. A failed MS requires no action provided that the LCS is acceptable. If additional sample exists, the samples associated with a failed LCS should be re-analyzed or QC data qualified.
Duplicate or MSD	20 samples	n/a	Relative Percent Differences (RPDs) are computed and included in the QC report
Method Blank	20 samples	<RL	Method blank contamination is flagged on the analytical report for any identified target compound. Blanks indicative of contaminated analytical system (typically the purge-and-trap system) should result in a thorough cleansing of the affected system and sample/blank re-analysis.
Internal Standard	All samples	Section 7.5.5	Adverse matrix effects on areas/recoveries are demonstrated either by screening the extract of re-analyzing the sample within a 12-hour QC batch.

QC Item	Frequency	Acceptance Criteria	Corrective Action
			The resulting analytical report is flagged appropriately. A negative bias unrelated to matrix effects indicates the need to: clean the MS source, re-tune, and re-calibrate
Surrogate Standard	All samples	Table 6	Adverse matrix effects on areas/recoveries are demonstrated either by screening the extract of re-analyzing the sample within a 12-hour QC batch. The resulting analytical report is flagged appropriately. If additional sample exists, the sample should be re-extracted prior to re-analysis if a matrix effect cannot be demonstrated.
Target Compound	All samples	Method-based	Target compounds beyond the calibration range are diluted and re-analyzed and/or flagged as estimated on the analytical report.

Table 5b. Quality Control Items, Frequency, and Corrective Action for DoD Projects

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria	Comments
Tune Check	Prior to ICAL and prior to each 12-hour period of sample analysis.	Specific ion abundance criteria of BFB or DFTPP from method.	Retune instrument and verify.	Flagging is not appropriate.	No samples shall be analyzed without a valid tune.
Initial calibration (ICAL) for all analytes (including surrogates)	At instrument set-up and after ICV or CCV failure, prior to sample analysis.	Each analyte must meet one of the three options below: Option 1: RSD for each analyte ≤ 15%; Option 2: linear least squares regression for each analyte: r2 ≥ 0.99; Option 3: non-linear least squares regression (quadratic) for each analyte: r2 ≥ 0.99.	Correct problem then repeat ICAL.	Flagging is not appropriate.	Minimum 5 levels for linear and 6 levels for quadratic. No samples shall be analyzed until ICAL has passed. If the specific version of a method requires additional evaluation (e.g., RFs or low calibration standard analysis and recovery criteria) these additional requirements must also be met.
Retention Time window position establishment	Once per ICAL and at the beginning of the analytical sequence.	Position shall be set using the midpoint standard of the ICAL curve when ICAL is performed. On days when ICAL is not performed, the initial CCV is used.	NA.	NA.	Calculated for each analyte and surrogate.
Evaluation of Relative Retention Times (RRT)	With each sample.	RRT of each reported analyte within ± 0.06 RRT units.	Correct problem, then rerun ICAL.	NA.	After maintenance is performed which may affect retention times, RRTs may be updated based on the daily CCV. RRTs shall be compared with the most recently updated RRTs.
Initial	Once after	All reported	Correct problem.	Flagging is not	No samples shall be analyzed

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria	Comments
Calibration Verification (ICV)	each ICAL, analysis of a second source prior to sample analysis	analytes within ± 20% of true value.	Rerun ICV. If that fails, repeat ICAL.	appropriate.	until calibration has been verified with a second source.
Continuing calibration verification (CCV)	Daily before sample analysis; after every 12 hours of analysis time; and at the end of the analytical batch run.	All reported analytes and surrogates within ± 20% of true value. All reported analytes and surrogates within ± 50% for end of analytical batch CCV.	Immediately analyze two additional consecutive CCVs. If both pass, samples may be reported without reanalysis. If either fails or if two consecutive CCVs cannot be run, perform corrective action(s) and repeat CCV and all associated samples since the last acceptable CCV. Alternately, recalibrate if necessary; then reanalyze all associated samples since the last acceptable CCV.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply Q-flag to all results for the specific analyte(s) in all samples since last acceptable calibration verification.	Results may not be reported without a valid CCV. Flagging is only appropriate in cases where the samples cannot be reanalyzed. If the specific version of a method requires additional evaluation (e.g, average RFs) these additional requirements must also be met.
Internal standards (IS)	Every field sample, standard, and QC sample.	Retention time ± 10 seconds from retention time of the midpoint standard in the ICAL; EICP area within -50% to +100% of ICAL midpoint standard.	Inspect mass spectrometer and GC for malfunctions and correct problem. Reanalysis of samples analyzed while system was malfunctioning is	If corrective action fails in field samples, data must be qualified and explained in the case narrative. Apply Q-flag	NA

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria	Comments
		On days when ICAL is not performed, the daily initial CCV can be used.	mandatory.	to analytes associated with the non-compliant IS. Flagging criteria is not appropriate for failed standards.	
Method blank (MB)	One per preparatory batch.	No analytes detected > ½ LOQ or > 1/10th the amount measured in any sample or 1/10th the regulatory limit, whichever is greater. Common contaminants, must not be detected > LOQ.	Correct problem. If required, reprep and reanalyze MB and all QC samples and field samples processed with the contaminated blank.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply B-flag to all results for the specific analyte(s) in all samples in the associated preparatory batch.	Results may not be reported without a valid method blank. Flagging is only appropriate in cases where the samples cannot be reanalyzed.
Laboratory Control Sample (LCS)	One per preparatory batch.	A laboratory must use the QSM Appendix C Limits for batch control if project limits are not specified. If the analyte(s) are not listed, use in-house LCS limits if project limits are not specified.	Correct problem, then reprep and reanalyze the LCS and all samples in the associated preparatory batch for failed analytes, if sufficient sample material is available.	If reanalysis cannot be performed, data must be qualified and explained in the case narrative. Apply Q-flag to specific analyte(s) in all samples in the associated preparatory	Must contain all surrogates and all analytes to be reported. Results may not be reported without a valid LCS. Flagging is only appropriate in cases where the samples cannot be reanalyzed.

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria	Comments
				batch.	
Matrix Spike (MS)	One per preparatory batch.	A laboratory must use the QSM Appendix C Limits for batch control if project limits are not specified. If the analyte(s) are not listed, use in-house LCS limits if project limits are not specified.	Examine the project-specific requirements. Contact the client as to additional measures to be taken.	For the specific analyte(s) in the parent sample, apply J-flag if acceptance criteria are not met and explain in the case narrative.	Must contain all surrogates and all analytes to be reported. For matrix evaluation only. If MS results are outside the limits, the data shall be evaluated to determine the source(s) of difference, i.e., matrix effect or analytical error.
Matrix spike duplicate (MSD) or Matrix duplicate (MD)	One per preparatory batch.	A laboratory must use the QSM Appendix C Limits for batch control if project limits are not specified. If the analyte(s) are not listed, use in-house LCS limits if project limits are not specified. MSD or MD: RPD of all analytes ≤ 20% (between MS and MSD or sample and MD).	Examine the project-specific requirements. Contact the client as to additional measures to be taken.	For the specific analyte(s) in the parent sample, apply J-flag if acceptance criteria are not met and explain in the case narrative.	MSD: Must contain all surrogates and all analytes to be reported. The data shall be evaluated to determine the source of difference. For Sample/MD: RPD criteria only apply to analytes whose concentration in the sample is greater than or equal to the LOQ.
Surrogate spike	All field and QC samples.	QC acceptance criteria specified by project, if available; otherwise use QSM Appendix C limits or in-house LCS limits if analyte(s) are not listed..	Correct problem, then reprep and reanalyze all failed samples for all surrogates in the associated preparatory batch, if sufficient sample material is available. If obvious	Apply Q-flag to all associated analytes if acceptance criteria are not met and explain in the case narrative.	Alternative surrogates are recommended when there is obvious chromatographic interference.

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action	Flagging Criteria	Comments
			chromatographic interference with surrogate is present, reanalysis may not be necessary, but the client must be notified prior to reporting data and the failures must be discussed in the Case Narrative.		

DoD Appendix C LCS Limits
Method 8260 Solid Matrix

CAS ID	ANALYTE	LOWER CONTROL LIMIT (LCL)	UPPER CONTROL LIMIT (UCL)
630-20-6	1,1,1,2-Tetrachloroethane	78	125
71-55-6	1,1,1-Trichloroethane	73	130
79-34-5	1,1,2,2-Tetrachloroethane	70	124
79-00-5	1,1,2-Trichloroethane	78	121
76-13-1	1,1,2-Trifluoro-1,2,2-trichloroethane [Freon-113]	66	136
75-34-3	1,1-Dichloroethane	76	125
75-35-4	1,1-Dichloroethene	70	131
563-58-6	1,1-Dichloropropene	76	125
87-61-6	1,2,3-Trichlorobenzene	66	130
96-18-4	1,2,3-Trichloropropane	73	125
526-73-8	1,2,3-Trimethlybenzene	82	118
120-82-1	1,2,4-Trichlorobenzene	67	129
95-63-6	1,2,4-Trimethylbenzene	75	123
96-12-8	1,2-Dibromo-3-chloropropane	61	132
106-93-4	1,2-Dibromoethane	78	122
95-50-1	1,2-Dichlorobenzene	78	121
107-06-2	1,2-Dichloroethane	73	128
17060-07-0	1,2-Dichloroethane-d4	71	136
540-59-0	1,2-Dichloroethene	78	122
78-87-5	1,2-Dichloropropane	76	123
354-23-4	1,2-Dichlorotrifluoroethane [Freon 123a]	64	132
108-70-3	1,3,5-Trichlorobenzene	71	128
108-67-8	1,3,5-Trimethylbenzene	73	124
541-73-1	1,3-Dichlorobenzene	77	121
142-28-9	1,3-Dichloropropane	77	121
542-75-6	1,3-Dichloropropene	77	126
106-46-7	1,4-Dichlorobenzene	75	120
105-05-5	1,4-Diethylbenzene	79	114

123-91-1	1,4-Dioxane	55	138
544-10-5	1-Chlorohexane	71	130
594-20-7	2,2-Dichloropropane	67	133
78-93-3	2-Butanone (MEK)	51	148
126-99-8	2-Chloro-1,3-butadiene	65	133
110-75-8	2-Chloroethyl vinyl ether	43	149
95-49-8	Chlorotoluene	75	122
591-78-6	2-Hexanone	53	145
79-46-9	2-Nitropropane	47	150
67-63-0	2-Propanol [Isopropyl alcohol]	60	140
460-00-4	4-Bromofluorobenzene	79	119
106-43-4	4-Chlorotoluene	72	124
108-10-1	4-Methyl-2-pentanone [MIBK]	65	135
67-64-1	Acetone	36	164
75-05-8	Acetonitrile	54	143
107-02-8	Acrolein [Propenal]	47	155
107-13-1	Acrylonitrile	65	134
107-05-1	Allyl chloride	68	135
71-43-2	Benzene	77	121
100-44-7	Benzyl chloride	64	120
108-86-1	Bromobenzene	78	121
74-97-5	Bromochloromethane	78	125
75-27-4	Bromodichloromethane	75	127
75-25-2	Bromoform	67	132
74-83-9	Bromomethane	53	143
75-15-0	Carbon disulfide	63	132
56-23-5	Carbon tetrachloride	70	135
108-90-7	Chlorobenzene	79	120
124-48-1	Chlorodibromomethane	74	126
75-00-3	Chloroethane	59	139
67-66-3	Chloroform	78	123
74-87-3	Chloromethane	50	136
156-59-2	cis-1,2-Dichloroethene	77	123

10061-01-5	cis-1,3-Dichloropropene	74	126
1476-11-5	cis-1,4-Dichloro-2-butene	69	143
110-82-7	Cyclohexane	67	131
108-94-1	Cyclohexanone	30	156
1868-53-7	Dibromofluoromethane	78	119
74-95-3	Dibromomethane	78	125
75-71-8	Dichlorodifluoromethane [Freon-12]	29	149
75-43-4	Dichlorofluoromethane	47	155
60-29-7	Diethyl ether	71	129
108-20-3	Diisopropyl ether	69	127
64-17-5	Ethanol	45	159
141-78-6	Ethyl acetate	52	139
97-63-2	Ethyl methacrylate	69	129
637-92-3	Ethyl tert-butyl ether	72	126
100-41-4	Ethylbenzene	76	122
462-06-6	Fluorobenzene	81	114
142-82-5	Heptane	49	138
87-68-3	Hexachlorobutadiene	61	135
67-72-1	Hexachloroethane	72	133
110-54-3	Hexane	45	142
74-88-4	Iodomethane	71	131
78-83-1	Isobutyl alcohol	60	135
108-21-4	Isopropyl acetate [Acetic acid]	58	131
98-82-8	Isopropylbenzene	68	134
179601-23-1	m/p-Xylene [3/4-Xylene]	77	124
126-98-7	Methacrylonitrile	66	132
79-20-9	Methyl acetate	53	144
80-62-6	Methyl methacrylate	63	134
1634-04-4	Methyl tert-butyl ether [MTBE]	73	125
108-87-2	Methylcyclohexane	66	133
75-09-2	Methylene chloride	70	128
123-86-4	n-Butyl acetate	62	128
71-36-3	n-Butyl alcohol	55	131

104-51-8	n-Butylbenzene	70	128
103-65-1	n-Propylbenzene	73	125
91-20-3	Naphthalene	62	129
95-47-6	o-Xylene	77	123
99-87-6	p-Isopropyltoluene [p-Cymene]	73	127
76-01-7	Pentachloroethane	69	135
107-12-0	Propionitrile [Ethyl cyanide]	68	134
135-98-8	sec-Butylbenzene	73	126
100-42-5	Styrene	76	124
994-05-8	tert-Amyl methyl ether [TAME]	73	126
75-65-0	tert-Butyl alcohol	68	133
98-06-6	tert-Butylbenzene	73	125
127-18-4	Tertachloroethene	73	128
109-99-9	Tetrahydrofuran	61	135
108-88-3	Toluene	77	121
2037-26-5	Toluene-d8	85	116
156-60-5	trans-1,2-Dichloroethene	74	125
10061-02-6	trans-1,3-Dichloropropene	71	130
110-57-6	trans-1,4-Dichloro-2-butene	62	136
79-01-6	Trichloroethene	77	123
75-69-4	Trichlorofluoromethane [Freon-11]	62	140
108-05-4	Vinyl acetate	50	151
75-01-4	Vinyl chloride	56	135
1330-20-7	Xylene [total]	78	124

DoD Appendix C LCS Limits
Method 8260 Water Matrix

CAS ID	ANALYTE	LOWER CONTROL LIMIT (LCL)	UPPER CONTROL LIMIT (UCL)
630-20-6	1,1,1,2-Tetrachloroethane	78	124
71-55-6	1,1,1-Trichloroethane	74	131
79-34-5	1,1,2,2-Tetrachloroethane	71	121
79-00-5	1,1,2-Trichloroethane	80	119
76-13-1	1,1,2-Trifluoro-1,2,2-trichloroethane	70	136

	[Freon-113]		
75-34-3	1,1-Dichloroethane	77	125
75-35-4	1,1-Dichloroethene	71	131
563-58-6	1,1-Dichloropropene	79	125
87-61-6	1,2,3-Trichlorobenzene	69	129
96-18-4	1,2,3-Trichloropropane	73	122
526-73-8	1,2,3-Trimethlybenzene	82	120
120-82-1	1,2,4-Trichlorobenzene	69	130
95-63-6	1,2,4-Trimethylbenzene	76	124
96-12-8	1,2-Dibromo-3-chloropropane	62	128
106-93-4	1,2-Dibromoethane	77	121
95-50-1	1,2-Dichlorobenzene	80	119
107-06-2	1,2-Dichloroethane	73	128
17060-07-0	1,2-Dichloroethane-d4	81	118
540-59-0	1,2-Dichloroethene	79	121
78-87-5	1,2-Dichloropropane	78	122
354-23-4	1,2-Dichlorotrifluoroethane [Freon 123a]	70	136
108-70-3	1,3,5-Trichlorobenzene	75	130
108-67-8	1,3,5-Trimethylbenzene	75	124
106-99-0	1,3-Butadiene	43	158
541-73-1	1,3-Dichlorobenzene	80	119
142-28-9	1,3-Dichloropropane	80	119
542-75-6	1,3-Dichloropropene	77	123
106-46-7	1,4-Dichlorobenzene	79	118
105-05-5	1,4-Diethylbenzene	79	118
123-91-1	1,4-Dioxane	59	139
544-10-5	1-Chlorohexane	76	124
540-84-1	2,2,4-Trimethylpentane [Isooctane]	58	132
594-20-7	2,2-Dichloropropane	60	139
75-85-4	2-Butanol	66	120
78-93-3	2-Butanone (MEK)	56	143
126-99-8	2-Chloro-1,3-butadiene	65	135

110-75-8	2-Chloroethyl vinyl ether	51	139
95-49-8	Chlorotoluene	79	122
591-78-6	2-Hexanone	57	139
91-57-6	2-Methylnaphthalene	17	142
79-46-9	2-Nitropropane	49	136
67-63-0	2-Propanol [Isopropyl alcohol]	56	142
624-95-3	3,3-Dimethyl-1-butanol	49	133
460-00-4	4-Bromofluorobenzene	85	114
106-43-4	4-Chlorotoluene	78	122
108-10-1	4-Methyl-2-pentanone [MIBK]	67	130
67-64-1	Acetone	39	160
75-05-8	Acetonitrile	50	142
107-02-8	Acrolein [Propenal]	39	155
107-13-1	Acrylonitrile	63	135
107-05-1	Allyl chloride	68	130
71-43-2	Benzene	79	120
100-44-7	Benzyl chloride	42	138
108-86-1	Bromobenzene	80	120
74-97-5	Bromochloromethane	78	123
75-27-4	Bromodichloromethane	79	125
75-25-2	Bromoform	66	130
74-83-9	Bromomethane	53	141
75-15-0	Carbon disulfide	64	133
56-23-5	Carbon tetrachloride	72	136
108-90-7	Chlorobenzene	82	118
124-48-1	Chlorodibromomethane	74	126
75-45-6	Chlorodifluoromethane	40	129
75-00-3	Chloroethane	60	138
67-66-3	Chloroform	79	124
74-87-3	Chloromethane	50	139
156-59-2	cis-1,2-Dichloroethene	78	123
10061-01-5	cis-1,3-Dichloropropene	75	124
1476-11-5	cis-1,4-Dichloro-2-butene	57	146

110-82-7	Cyclohexane	71	130
1868-53-7	Dibromofluoromethane	80	119
74-95-3	Dibromomethane	79	123
75-71-8	Dichlorodifluoromethane [Freon-12]	32	152
75-43-4	Dichlorofluoromethane	72	131
60-29-7	Diethyl ether	68	129
108-20-3	Diisopropyl ether	67	128
64-17-5	Ethanol	48	151
141-78-6	Ethyl acetate	55	138
97-63-2	Ethyl methacrylate	72	126
637-92-3	Ethyl tert-butyl ether	70	127
100-41-4	Ethylbenzene	79	121
462-06-6	Fluorobenzene	80	116
142-82-5	Heptane	49	140
87-68-3	Hexachlorobutadiene	66	134
67-72-1	Hexachloroethane	72	134
110-54-3	Hexane	48	143
74-88-4	Iodomethane	69	131
78-83-1	Isobutyl alcohol	63	133
108-21-4	Isopropyl acetate [Acetic acid]	63	133
98-82-8	Isopropylbenzene	72	131
179601-23-1	m/p-Xylene [3/4-Xylene]	80	121
126-98-7	Methacrylonitrile	63	133
79-20-9	Methyl acetate	56	136
80-62-6	Methyl methacrylate	67	128
1634-04-4	Methyl tert-butyl ether [MTBE]	71	124
108-87-2	Methylcyclohexane	72	132
75-09-2	Methylene chloride	74	124
123-86-4	n-Butyl acetate	69	125
71-36-3	n-Butyl alcohol	59	131
104-51-8	n-Butylbenzene	75	128
109-60-4	n-Propyl acetate	76	126
103-65-1	n-Propylbenzene	76	126

91-20-3	Naphthalene	61	128
95-47-6	o-Xylene	78	122
99-87-6	p-Isopropyltoluene [p-Cymene]	77	127
76-01-7	Pentachloroethane	69	133
109-66-0	Pentane	16	134
107-12-0	Propionitrile [Ethyl cyanide]	64	136
135-98-8	sec-Butylbenzene	77	126
100-42-5	Styrene	78	123
994-05-8	tert-Amyl methyl ether [TAME]	68	128
75-65-0	tert-Butyl alcohol	68	129
762-75-4	tert-Butyl formate	65	132
98-06-6	tert-Butylbenzene	78	124
127-18-4	Tertachloroethene	74	129
109-99-9	Tetrahydrofuran	57	133
108-88-3	Toluene	80	121
2037-26-5	Toluene-d8	89	112
156-60-5	trans-1,2-Dichloroethene	75	124
10061-02-6	trans-1,3-Dichloropropene	73	127
110-57-6	trans-1,4-Dichloro-2-butene	43	140
79-01-6	Trichloroethene	79	123
75-69-4	Trichlorofluoromethane [Freon-11]	65	141
108-05-4	Vinyl acetate	54	146
75-01-4	Vinyl chloride	58	137
1330-20-7	Xylene [total]	79	121

LCS Limits
EPA 624.1 Water Matrix

CAS ID	ANALYTE	LOWER CONTROL LIMIT (LCL)	UPPER CONTROL LIMIT (UCL)
71-55-6	1,1,1-Trichloroethane	70	130
79-34-5	1,1,2,2-Tetrachloroethane	60	140
79-00-5	1,1,2-Trichloroethane	70	130
75-34-3	1,1-Dichloroethane	70	130
75-35-4	1,1-Dichloroethene	50	150
95-50-1	1,2-Dichlorobenzene	65	135
107-06-2	1,2-Dichloroethane	70	130
78-87-5	1,2-Dichloropropane	35	165
541-73-1	1,3-Dichlorobenzene	70	130
106-46-7	1,4-Dichlorobenzene	65	135
110-75-8	2-Chloroethyl vinyl ether	0	225
107-02-8	Acrolein [Propenal]	60	140
107-13-1	Acrylonitrile	60	140
71-43-2	Benzene	65	135
75-27-4	Bromodichloromethane	65	135
75-25-2	Bromoform	70	130
74-83-9	Bromomethane	15	185
56-23-5	Carbon tetrachloride	70	130
108-90-7	Chlorobenzene	65	135
124-48-1	Chlorodibromomethane	70	135
75-00-3	Chloroethane	40	160
67-66-3	Chloroform	70	135
74-87-3	Chloromethane	0	205
10061-01-5	cis-1,3-Dichloropropene	25	175
100-41-4	Ethylbenzene	60	140
75-09-2	Methylene chloride	60	140
127-18-4	Tetrachloroethene	70	130
108-88-3	Toluene	70	130
156-60-5	trans-1,2-Dichloroethene	70	130

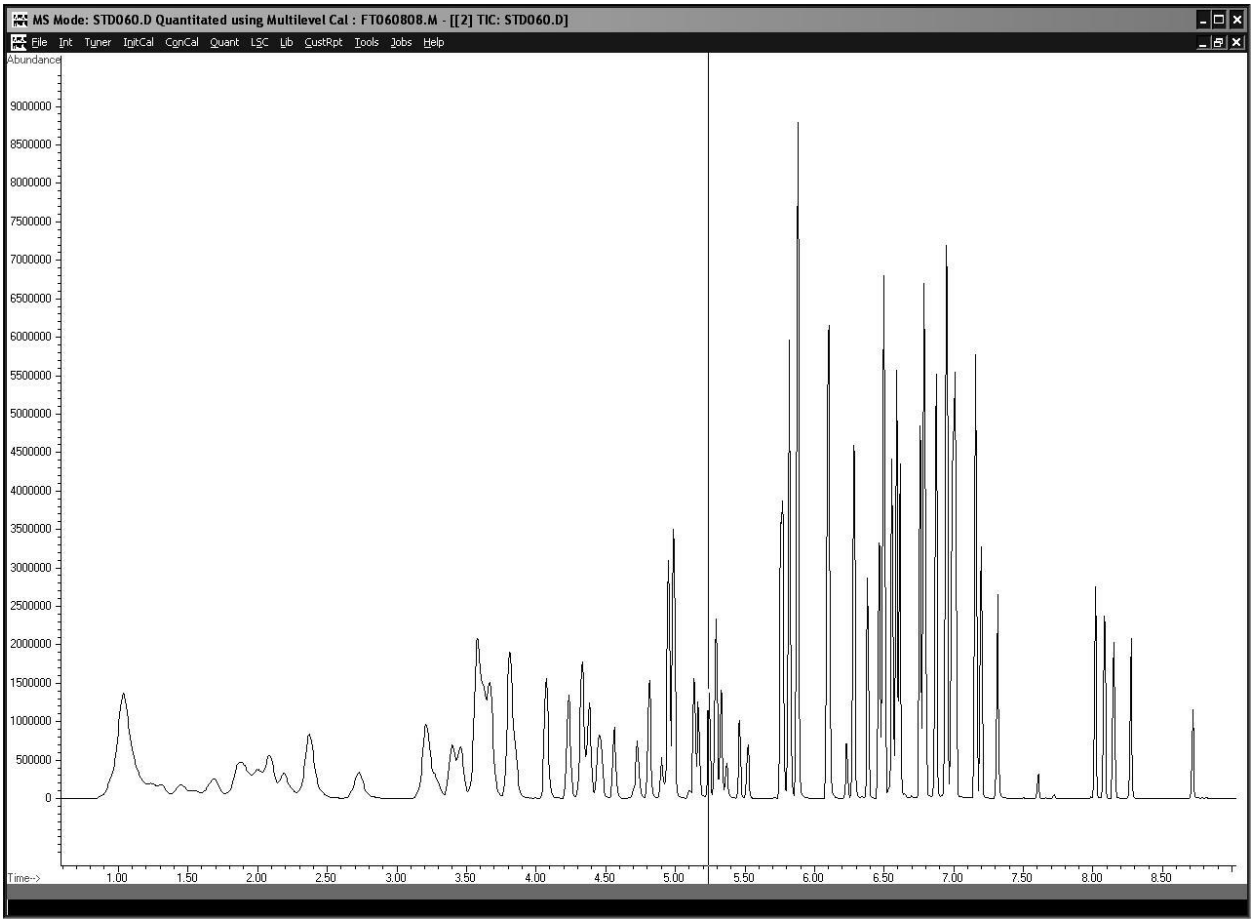
10061-02-6	trans-1,3-Dichloropropene	50	150
79-01-6	Trichloroethene	65	135
75-69-4	Trichlorofluoromethane [Freon-11]	50	150
75-01-4	Vinyl chloride	5	195

Table 6. Summary of Control Limits: Surrogate and Internal Standard Compounds Percent Recovery†

COMPOUND	Water Matrix		Solid Matrix	
	LCL (%)	UCL (%)	LCL (%)	UCL (%)
1.2-DICHLOROETHANE-D4	72.0	125.0	71.0	124.0
TOLUENE-D8	89.0	112.0	83.0	120.0
4-BROMOFLUOROBENZENE	80.0	124.0	81.0	124.0
Pentafluorobenzene	50.0	200.0	50.0	200.0
1,4-Difluorobenzene	50.0	200.0	50.0	200.0
Chlorobenzene-D5	50.0	200.0	50.0	200.0
1,4-Dichlorobenzene-D4	50.0	200.0	50.0	200.0

†: Results based on recovery data from 2020.

Figure 1. Example Total Ion Chromatogram for a Midpoint VOA Calibration Standard†



†: Data file Std060.D (60 μg/L). GC/MS acquisition parameters are given by Table 4.

ANALYTICAL METHODS

Section 9.0

Method: EPA Method TO-14A/TO-15 Volatile Organic Compounds (Standard/QUAD)			
Laboratory SOP #: 6	Revision #: 50	Effective Date: May 28, 2024	Methods Manual Summary

Description: This method involves full scan gas chromatograph/mass spectrometer (GC/MS) analysis of whole air samples collected in evacuated stainless steel canisters. Samples are analyzed for volatile organic compounds (VOCs) using EPA Method TO-14A/TO-15 protocols. An aliquot of up to 0.5 liters of air is withdrawn from the canister utilizing a volumetric loop or mass flow controller. This volume is loaded onto a hydrophobic multibed sorbent trap to remove water and carbon dioxide and to concentrate the vapor sample. The focused sample is then flash-heated to sweep adsorbed VOCs onto a secondary trap for further concentration and/or directly onto a GC/MS for separation and detection.

Eurofins Environment Testing Northern California, LLC maintains a suite of TO-14A/TO-15 methods, each optimized to efficiently meet the data objectives for a wide range of targeted concentration ranges. The methods, their reporting limits, and typical applications are summarized in the table below. This method summary describes TO-14A/TO-15 full scan (Standard or QUAD).

Eurofins Environment Testing Northern California, LLC Method	**Base Reporting Limits**	**Typical Application**
TO-14A/TO-15 Full Scan (5&20)	5 – 20 ppbv	Soil gas and ppmv range vapor matrices
TO-14A/TO-15 Full Scan (Standard or QUAD)	0.5 – 5.0 ppbv	Ambient air, soil gas, and ppbv level vapor matrices
TO-14A/TO-15 Full Scan (Low-level)	0.1 – 1.0 ppbv	Indoor and outdoor air
TO-14A/TO-15 SIM	0.01 – 0.5 ppbv	Indoor and outdoor air

Certain compounds are not included in Eurofins Environment Testing Northern California, LLC's standard target analyte list. These compounds are communicated at the time of client proposal request. Unless otherwise directed, Eurofins Environment Testing Northern California, LLC reports these non-routine compounds with partial validation. Validation may include a 3-point calibration with the lowest concentration defining the reporting limit, no second source verification analyzed, and no method detection limit study performed unless previous arrangements have been made. In addition, stability of the non-standard compound during sample storage is not validated. Full validation may be available upon request.

Eurofins Environment Testing Northern California, LLC takes no modifications of technical significance to Method TO-15 for the "QUAD" configurations. Since Eurofins Environment Testing Northern California, LLC applies TO-15 methodology to all Summa canisters regardless of whether TO-14A or TO-15 is specified by the project, the laboratory has

established modifications to method TO-14A as detailed in Table 1. Please note that Methods TO-14A and TO-15 were validated for specially treated canisters. As such, the use of Tedlar bags for sample collection is outside the scope of the method and not recommended for ambient or indoor air samples. It is the responsibility of the data user to determine the usability of TO-14A and TO-15 results generated from Tedlar bags.

Table 1. Summary of TO-14A Method Modifications

Requirement	TO-14A	Laboratory Modifications
Sample Drying System	Nafion Drier	Multibed hydrophobic sorbent.
Blank acceptance criteria	≤ 0.2 ppbv	≤ RL
BFB ion abundance criteria	Ion abundance criteria listed in Table 4 of TO-14A	Follow abundance criteria listed in TO-15.
BFB absolute abundance criteria	Within 10% when comparing to the previous daily BFB	CCV internal standard area counts are compared to ICAL; corrective action when recovery is less than 60%.
Initial Calibration	≤ 30% RSD for listed 39 VOCs	Follow TO-15 requirements of ≤ 30% RSD with 2 of Laboratory's 62 standard compounds allowed out to ≤ 40% RSD

The standard target analyte list, reporting limit (RL) also referred to as Limit of Quantitation, QC criteria, and QC summary can be found in Tables 2 through 6.

Table 2 is the standard list of accredited compounds (except where noted), reporting limits and QC acceptance criteria. Each project may be customized as needed. Additional compounds and different reporting limits may be obtainable and/or achieved upon request.

Table 2. Method TO-14A/TO-15 Analyte List (QUAD)

Analyte	RL/LOQ (ppbv)	QC Acceptance Criteria			
		ICAL (%RSD)	CCV (%R)	ICV/LCS (%R)	Precision Limits (Max. RPD)
1,1,2,2-Tetrachloroethane	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,1,2-Trichloroethane	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,1-Dichloroethane	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,1-Dichloroethene	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,2,4-Trichlorobenzene	2.0	≤ 30%	70 – 130	70 – 130	± 25
1,2,4-Trimethylbenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,2-Dibromoethane (EDB)	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,2-Dichlorobenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,2-Dichloroethane	0.5	≤ 30%	70 – 130	70 – 130	± 25

Analyte	RL/LOQ (ppbv)	QC Acceptance Criteria			
		ICAL (%RSD)	CCV (%R)	ICV/LCS (%R)	Precision Limits (Max. RPD)
1,2-Dichloropropane	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,3,5-Trimethylbenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,3-Dichlorobenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,4-Dichlorobenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Benzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Bromomethane	1.0	≤ 30%	70 – 130	70 – 130	± 25
Carbon Tetrachloride	0.5	≤ 30%	70 – 130	70 – 130	± 25
Chlorobenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Chloroethane	2.0	≤ 30%	70 – 130	70 – 130	± 25
Chloroform	0.5	≤ 30%	70 – 130	70 – 130	± 25
Chloromethane	5.0	≤ 30%	70 – 130	70 – 130	± 25
Chlorotoluene (Benzyl Chloride)	0.5	≤ 30%	70 – 130	70 – 130	± 25
cis-1,2-Dichloroethene	0.5	≤ 30%	70 – 130	70 – 130	± 25
cis-1,3-Dichloropropene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Dichloromethane (Methylene Chloride)	1.0	≤ 30%	70 – 130	70 – 130	± 25
Ethylbenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Freon 11 (Trichlorofluoromethane)	0.5	≤ 30%	70 – 130	70 – 130	± 25
Freon 113 (Trichlorotrifluoroethane)	0.5	≤ 30%	70 – 130	70 – 130	± 25
Freon 114	0.5	≤ 30%	70 – 130	70 – 130	± 25
Freon 12 (Dichlorodifluoromethane)	0.5	≤ 30%	70 – 130	70 – 130	± 25
Hexachlorobutadiene	2.0	≤ 30%	70 – 130	70 – 130	± 25
m,p-Xylene	1.0	≤ 30%	70 – 130	70 – 130	± 25
Methyl Chloroform (1,1,1-Trichloroethane)	0.5	≤ 30%	70 – 130	70 – 130	± 25
o-Xylene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Styrene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Tetrachloroethene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Toluene	1.0	≤ 30%	70 – 130	70 – 130	± 25
trans-1,3-Dichloropropene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Trichloroethene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Vinyl Chloride	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,3-Butadiene	0.5	≤ 30%	70 – 130	70 – 130	± 25
1,4-Dioxane	1.0	≤ 30%	70 – 130	70 – 130	± 25

Analyte	RL/LOQ (ppbv)	QC Acceptance Criteria			
		ICAL (%RSD)	CCV (%R)	ICV/LCS (%R)	Precision Limits (Max. RPD)
2-Butanone (Methyl Ethyl Ketone)	2.0	≤ 30%	70 – 130	70 – 130	± 25
2-Hexanone	2.0	≤ 30%	70 – 130	70 – 130	± 25
4-Ethyltoluene	0.5	≤ 30%	70 – 130	70 – 130	± 25
4-Methyl-2-Pentanone (MIBK)	0.5	≤ 30%	70 – 130	70 – 130	± 25
Acetone	5.0	≤ 30%	70 – 130	70 – 130	± 25
Bromodichloromethane	0.5	≤ 30%	70 – 130	70 – 130	± 25
Bromoform	0.5	≤ 30%	70 – 130	70 – 130	± 25
Carbon Disulfide	2.0	≤ 30%	70 – 130	70 – 130	± 25
Cyclohexane	0.5	≤ 30%	70 – 130	70 – 130	± 25
Dibromochloromethane	0.5	≤ 30%	70 – 130	70 – 130	± 25
Ethanol	5.0	≤ 30%	70 – 130	70 – 130	± 25
Heptane	0.5	≤ 30%	70 – 130	70 – 130	± 25
Hexane	0.5	≤ 30%	70 – 130	70 – 130	± 25
Isopropanol	2.0	≤ 30%	70 – 130	70 – 130	± 25
Methyl t-Butyl Ether (MTBE)	2.0	≤ 30%	70 – 130	70 – 130	± 25
Tetrahydrofuran	0.5	≤ 30%	70 – 130	70 – 130	± 25
trans-1,2-Dichloroethene	0.5	≤ 30%	70 – 130	70 – 130	± 25
2,2,4-Trimethylpentane	0.5	≤ 30%	70 – 130	70 – 130	± 25
Cumene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Propylbenzene	0.5	≤ 30%	70 – 130	70 – 130	± 25
3-Chloropropene	0.5	≤ 30%	70 – 130	70 – 130	± 25
Naphthalene*	1.0	≤40%	60 – 140	60 – 140	± 25
TPH (Gasoline) **	50	1-Point Calibration	N/A	ICV only; 60 – 140	± 25
NMOC (Hexane/Heptane)**	10	1-Point Calibration	N/A	NA	± 25

*Due to its low vapor pressure, Naphthalene may exceed TO-15 performance requirements. The wider QC limits reflect typical performance. Although Naphthalene is not on Eurofins Environment Testing Northern California, LLC's "standard" TO-15 list, it is commonly requested and included in Table 2.

**TPH and NMOC are not on Eurofins Environment Testing Northern California, LLC's "standard" TO-15 list, but are included in Table 2 due to common requests. These are semi-quantitative non-accredited parameters.

Table 3 is the list of non-standard NELAP accredited Method TO-15 compounds that may be requested.

Table 3. Method TO-15 Additional Analyte List (QUAD)

Analyte	RL/LOQ (ppbv)	QA Acceptance Criteria			
		ICAL (%RSD)	CCV (%R)	ICV/LCS (%R)	Precision Limits (Max. RPD)
1,1,1,2-Tetrachloroethane	0.5	≤30%	70 – 130	70 – 130	± 25
1,2,3-Trichloropropane	0.5	≤30%	70 – 130	70 – 130	± 25
1,2-Dibromo-3-chloropropane	2.0	≤30%	70 – 130	70 – 130	± 25
1,3-Dichloropropane	0.5	≤30%	70 – 130	70 – 130	± 25
2-Chlorotoluene	2.0	≤30%	70 – 130	70 – 130	± 25
Acrylonitrile	0.5	≤30%	70 – 130	70 – 130	± 25
alpha-methyl-styrene	2.0	≤30%	70 – 130	70 – 130	± 25
4-Isopropyltoluene (p-Cymene)	2.0	≤30%	70 – 130	70 – 130	± 25
Bromobenzene	2.0	≤30%	70 – 130	70 – 130	± 25
Butane	2.0	≤30%	70 – 130	70 – 130	± 25
Butyl Benzene	0.5	≤30%	70 – 130	70 – 130	± 25
Dibromomethane	0.5	≤30%	70 – 130	70 – 130	± 25
Ethyl Acetate	2.0	≤30%	70 – 130	70 – 130	± 25
Freon 21 (Dichlorofluoromethane)	2.0	≤30%	70 – 130	70 – 130	± 25
Freon 22 (Chlorodifluoromethane)	2.0	≤30%	70 – 130	70 – 130	± 25
Isobutane	2.0	≤30%	70 – 130	70 – 130	± 25
Isopentane	2.0	≤30%	70 – 130	70 – 130	± 25
Methyl Methacrylate	2.0	≤30%	70 – 130	70 – 130	± 25
Methylcyclohexane	2.0	≤30%	70 – 130	70 – 130	± 25
Nonane	2.0	≤30%	70 – 130	70 – 130	± 25
n-Pentane	2.0	≤30%	70 – 130	70 – 130	± 25
Propylene	2.0	≤30%	70 – 130	70 – 130	± 25
Octane	2.0	≤30%	70 – 130	70 – 130	± 25
sec-Butylbenzene	0.5	≤30%	70 – 130	70 – 130	± 25
tert-Butyl Alcohol	2.0	≤30%	70 – 130	70 – 130	± 25
tert-Butyl Benzene	2.0	≤30%	70 – 130	70 – 130	± 25
Vinyl Acetate	2.0	≤30%	70 – 130	70 – 130	± 25
Vinyl Bromide	0.5	≤30%	70 – 130	70 – 130	± 25

Table 4. Internal Standards

Analyte	Accuracy (% R)
Bromochloromethane	60 – 140
1,4-Difluorobenzene	60 – 140
Chlorobenzene-d_5	60 – 140

Table 5. Surrogates

Analyte	Accuracy (% R)
1,2-Dichloroethane-d_4	70 – 130
Toluene-d_8	70 – 130
4-Bromofluorobenzene	70 – 130

Table 6. Summary of Calibration and QC Procedures for Methods TO-14A/TO-15

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action
Tuning Criteria	Every 24 hours	TO-15 ion abundance criteria	Correct problem then repeat tune.
Minimum 5-Point Initial Calibration (ICAL)	Prior to sample analysis	% RSD ≤ 30 with 2 compounds allowed out to ≤ 40% RSD	Correct problem then repeat Initial Calibration curve.
Initial Calibration Verification and Laboratory Control Sample (ICV and LCS)	After each Initial Calibration curve, and daily prior to sample analysis	Recoveries for 85% of "Standard" compounds must be 70–130%. No recovery may be < 50%. ICV evaluated on a full list basis at the time of calibration. If specified by the project, in-house generated control limits may be used.	Check the system and reanalyze the standard. Re-prepare the standard if necessary to determine the source of error. Re-calibrate the instrument if the primary standard is found to be in error.
Continuing Calibration Verification (CCV) for Standard compounds	At the start of each analytical clock after the tune check	70–130%	Compounds exceeding this criterion and associated data will be flagged and narrated with the exception of high bias associated with non-detects. If more than two compounds from the standard list recover outside of 70–130% or > 10% of VOCs if short list is used (20 compounds or less), corrective action will be taken. If any compound exceeds 60–140%, samples are not analyzed unless data meets project needs. Check the system and reanalyze the standard. Re-prepare the standard if necessary. Re-calibrate the instrument if the criteria cannot be met.
Laboratory Blank	After analysis of standards and prior to sample analysis, or when contamination is present.	Results less than the laboratory reporting limit	Inspect the system and re-analyze the blank. "B"-flag data for common contaminants.

QC Check	Minimum Frequency	Acceptance Criteria	Corrective Action
Internal Standard (IS)	As each standard, blank, and sample is being loaded	Retention time (RT) for blanks and samples must be within ±0.33 min of the RT in the CCV and within ±40% of the area counts of the daily CCV internal standards.	**For blanks:** Inspect the system and reanalyze the blank. **For samples:** Re-analyze the sample. If the ISs are within limits in the re-analysis, report the second analysis. If ISs are out-of-limits a second time, dilute the sample until ISs are within acceptance limits and narrate.
Surrogates	As each standard, blank, and sample is being loaded	70–130% If specified by the project, in-house generated control limits may be used.	**For blanks:** Inspect the system and reanalyze the blank. **For samples:** Re-analyze the sample unless obvious matrix interference is documented. If the %Rs are within limits in the re-analysis, report the second analysis. If %Rs are out-of-limits a second time, report data from first analysis and narrate.
Laboratory Duplicates – Laboratory Control Sample Duplicates (LCSD)	One per analytical batch	RPD ≤25%	Narrate exceedances. If more than 5% of compound list is outside criteria or if compound has >40%RPD, investigate the cause and perform maintenance as required. If instrument maintenance is required, calibrate as needed.