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Trustee of the Multistate Environmental Response Trust
Greenfield Environmental Trust Group, Inc., Member
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July 26, 2019

By US Postal Service and E-mail—charlene.fitch@dnr.mo.gov

Charlene Fitch
Chief, Permits Section—Waste Management Program
Missouri Department of Natural Resources
1730 E. Elm Street
Jefferson City, MO 65101

Subject: **Final Greene County Highway Department Site Investigation Work Plan**
Former Tronox/Kerr-McGee Facility, 2800 West High Street, Springfield, Missouri
EPA ID No.: MOD007129406

Dear Ms. Fitch:

Pursuant to Section 3.2.6 of the Multistate Environmental Response Trust Agreement, Greenfield Environmental Multistate Trust, LLC, Trustee of the Multistate Environmental Response Trust (the Multistate Trust), hereby "seeks the prior approval of the Lead Agency . . . to perform Environmental Actions and any work plans to be undertaken by the Multistate Trust under the oversight of the Lead Agency . . . ." Accordingly, the Multistate Trust hereby submits the Final Greene County Highway Department (GCHD) Site Investigation Work Plan (GCHD Site Investigation Work Plan or Work Plan) for property located adjacent to the former Tronox/Kerr-McGee Facility located in Springfield, Missouri (Facility or Site). The Work Plan has been updated in accordance with Missouri Department of Natural Resources and comments received by stakeholders (i.e., Greene County) on the Draft Work Plan[1].

If you have questions or require additional information, please do not hesitate to contact me at (602) 312-6993 or tl@g-etg.com.

Sincerely,

Greenfield Environmental Multistate Trust LLC
Trustee of the Multistate Environmental Response Trust
By: Greenfield Environmental Trust Group, Inc., Member

Tasha Lewis

Tasha Lewis
Portfolio Manager and Project Manager

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[1] Comments on the Draft GCHD Site Investigation Work Plan were provided by Greene County and the MoDNR to the Multistate Trust on January 2 and February 7, 2019. respectively.

Enclosures: Response to MoDNR Comments on the Draft Greene County Highway Department Site Investigation Work Plan, Dated November 2, 2018

Response to MoDNR Comments on the Draft Greene County Highway Department Site Investigation Work Plan, Dated November 2, 2018

Final Greene County Highway Department Site Investigation Work Plan

cc: Lauri Gorton—Multistate Trust
Mark Hogan—Multistate Trust
Jalal El-Jayyousi—MoDNR
Bob Lanning—Environmental Works Inc.
Loren Lund—Jacobs
Craig Kaufman—Multistate Trust
Richard Nussbaum—MoDNR
Julie Schucker—Jacobs

RESPONSE TO MoDNR COMMENTS ON THE DRAFT GREENE COUNTY HIGHWAY DEPARTMENT SITE INVESTIGATION WORK PLAN, DATED NOVEMBER 2, 2018

Stakeholder	Comment No.	Document Section	Document Page Number	Comment (dated February 7, 2019)	Response
Comments					
MoDNR	1			The work plan indicates new wells will be sampled quarterly for one year and results will determine an appropriate sample frequency for the long-term monitoring program. Special Permit Section II. E. e. requires quarterly sampling and analysis for a period of time which is sufficient to establish contaminant trends in such wells. This would apply to wells in areas where the groundwater impacts appear to be facility-related. One year of quarterly monitoring may be sufficient but the need for continued quarterly monitoring will depend on the data trends from the first four quarterly sampling events.	Comment noted. The text in the second to last paragraph of Section 4.2.1 will be revised to state: "Groundwater samples collected during Phase 1 investigations will serve as the first of four consecutive quarterly monitoring events for all shallow wells established as permanent under this Work Plan. The results from these four quarterly events will be used to determine whether additional quarterly monitoring is necessary to establish a contaminant concentration trend for each well. All available data will then be used with the trend analysis evaluation to recommend to MoDNR whether each well should be included in the long-term monitoring plan for the Facility or abandoned (Tables 1 and 5). These data will also be used to inform the target analyte list and monitoring frequency for each well recommended for inclusion in the Facility's long-term monitoring program."
MoDNR	2	3	2	Investigation Objectives and Approach, the first bullet states, "Delineate the extent of impacted soil and groundwater, and DNAPL on the GCHD property attributable to the Facility." How will "attributable" be determined? Creosote like and blacktop patch materials have been handled historically at the GCHD property. How will the Trust distinguish between the sources originating from Trust property versus GCHD property for VI and other concerns? Is the use of any chemical "fingerprinting" anticipated if it proves to be necessary? While the fourth paragraph under Section 4.2.1 Shallow Monitoring Wells indicate groundwater elevation data and the chemical signature of the GCHD wells will be compared to Facility wells to evaluate whether impacts are Facility related, nothing is noted about how impacted soil will be evaluated to determine if it is Facility related.	A multiple lines of evidence approach will be used to evaluate whether detected concentrations of contaminants may be related to the Facility or a different source. Lines of evidence will include a spatial evaluation of observed conditions and concentration trends, identification of chemicals that are not Facility-related, calculation of chemical concentration ratios, and evaluation of equilibrium partitioning between soil, groundwater, and soil vapor. Spatial data analysis will consider both the horizontal and vertical distribution of contaminant concnetrations. For example, soil staining and/or elevated soil concentrations in the unsaturated zone under the Greene County Highway Department property would indicate a potential non-Facility related source. Groundwater contaminant concentrations will also be evaluated in conjuction with groundwater flow directions and gradients from the expanded monitoring network. Elevated or increasing concentrations observed in areas not directly downgradient of the Facility may be indicative of non Facility-related impacts. An additional line of evidence for a non-Facility related source would be the identification of chemicals that were not used at the Facility, such as solvents and fuel additives, in wells installed on the GCHD property. Similarly, source characterization can include a comparison of ratios of detected chemicals (e.g., benzene:napthalene; napthalene:dibenzofuran) in samples collected from the GCHD property to those from Facility samples. The use of chemical fingerprinting techniques will be added to the Work Plan.
MoDNR	3	3	3	Investigation Objectives and Approach, bullet number 4, "Assess potential risk to construction and GCHD workers associated with impacts in the subsurface soil or shallow groundwater (less than 10 feet bgs) that may be attributable to the Facility." Again, how will attribution be determined?	In general, the visual observation of contamination and/or identification of higher contaminant concentrations in shallow soil or soil vapor, relative to deeper samples, would be indicative of a non-Facility source. Refer also to response to Comment No. 1.
MoDNR	4	3	3	Investigation Objectives and Approach, bullet number 5. As this investigation focuses on impacts to the GCHD property attributed to the Facility, how would VOCs be related to the Facility operations, which have historically produced SVOCs, TPH, and BTEX contamination of soil and/or groundwater?	The available data and historical information for the Facility indicate that BTEXN are the only VOCs that can reasonably be attributed to former Facility operations. VOCs that are not BTEXN would indicate that non-Facility sources have impacted media under the GCHD property.
MoDNR	5	4	4	Phase 1 Investigation, last bullet indicates headspace (gas) samples will be collected from 17 sanitary sewer cleanouts and two manholes on the northern and eastern portions of the GCHD property to determine if the sewer is a preferential pathway for vapors present in the city sewer main. Please elaborate on the rationale for collecting samples from every sewer cleanout on the property.	The rationale for collecting headspace samples from the 17 sewer cleanouts is two-fold: (1) to characterize spatial variability; and (2) look spatially from site-wide perspective with the potential there are non-Facility source(s). This will be important to distinguish whether detected concentrations are attributable to the Facility's permitted discharge or if there are GCHD property sources contributing to the BTEXN concentrations in sewer gas. This is important because the concern that the Greene County has is that vapors from the permitted Facility discharge are migrating up the sewer pipe towards their office building. Samples collected from each cleanout will provide spatial information along with concentration gradients which will be useful in determining whether the detected concentrations are Facility-related or not.

RESPONSE TO MoDNR COMMENTS ON THE DRAFT GREENE COUNTY HIGHWAY DEPARTMENT SITE INVESTIGATION WORK PLAN, DATED NOVEMBER 2, 2018

Stakeholder	Comment No.	Document Section	Document Page Number	Comment (dated February 7, 2019)	Response
MoDNR	6		4	Paragraph regarding the previously unknown sewer, mentions the presence of dark to black material near the sewer line plug near the property boundary (377 feet upstream of Manhole No. M17NW015), and dark stains between 70 and 173 feet upstream of the manhole (see Figure 5 areas for trenching). The most north area (70 to 173 feet upstream of manhole) is located in a natural drainage way for surface water, which has appeared dark or stained in the past. Will the proposed sampling in the work plan provide adequate detail to determine if this dark material/staining in these two areas is attributable to the Trust site, or to the GCHD property?	The Work Plan will be modified to focus only near the terminus of the PVC sewer line located near the property line between the Greene County Highway Department and the former Tronox/Kerr-McGee property. This is due to concerns stated by Greene County with respect to the excavation within the detention basin and the possibility that a preferential flow path could be created causing a sinkhole collapse within the basin. Excavation near the terminus of the sewer line (both adjacent to and inside the pipe at the terminue) will provide information as to whether the black material is creosote. A combination of visual observations, odor observations and fingerprinting analysis will be used to determine if the black material is creosote. Soil located outside of the pipe will only be sampled if the soil is stained black. Together, this information will assist the Multistate Trust in consultation with both MoDNR and Greene County in determining the next steps, if any.
MoDNR	7	4.1	5	Creosote Delineation and Soil Sample Collection, the last sentence, "If creosote is observed in a boring at locations GC-01, GC-06, GC-07, or GC-12 or if soil concentrations indicate subsurface impacts above screening levels may be related to the facility, Phase 2 work will be required." Please explain the reasoning behind selecting these four sampling locations as criteria for triggering Phase 2 work.	The Phase 1 locations cited in this comment were identified following thorough review of available Facility and off-Facility data as locations needed to refine the understanding of potential impacts at the GCHD property. Step-outs from these locations would be sampled in Phase 2 if needed. Phase 2 sample locations were not proposed for Phase 1 sample locations GC-02 through GC-05 because data from proposed Phase 1 sample location GC-12 and existing monitoring wells SMW-77 and SMW-78 are expected to define the eastern extent of potential Facility-related impacts. If Facility-related impacts are observed at Phase 1 sample location GC-01 and/or GC-12, sampling at cross-gradient Phase 2 location GC-13 would be appropriate. Similarly, if Facility-related impacts are observed at Phase 1 sample location GC-06 and/or GC-07, sampling at cross-gradient Phase 2 location GC-20 would be appropriate. This rationale for Phase 2 step-out locations is currently described in the notes column of Table 2.
MoDNR	8	11	14	References and Table 7. Please ensure that the USEPA Regional Screening Levels that are used are from the most recent version, currently November 2018.	Table 7 and the references will be updated to reflect the November 2018 USEPA RSLs.
MoDNR	9	Appendix A, Section 9	9 and 10	The date of the current version of 10 CSR 23-4 is June 30, 2011, not May 2006.	Appendix A will be updated to include the most recent version of 10 CSR 23-4, dated January 29, 2019.
MoDNR	10	SOP		Standard Operating Procedure (SOP) - Analytical Method for the Determination of Volatile Organics in Soil Vapor or Air Using the HAPSITE Field GC/MS. The "Scope" statement references Table 1 of this SOP for "a list of VOCs with reporting limits (RLs) that can be analyzed with this procedure." The list of "standard analytes" in Table 1 does not include the main analytes of interest with respect to this project. Are revisions to the "Scope" statement and list of analytes needed to recognize the validity of HAPSITE use for the main analytes of interest and to ensure that reporting limits for these analytes are sufficient to ensure comparison with applicable risk-based vapor screening levels?	Table 1 of the SOP - Analytical Method for the Determination of Volatile Organics in Soil Vapor or Air Using the HAPSITE Field GC/MS will be updated to list the site-specific compounds: benzene, toluene, ethylbenzene, xylenes, and naphthalene.

RESPONSE TO GREENE COUNTY COMMENTS ON THE DRAFT GREENE COUNTY HIGHWAY DEPARTMENT SITE INVESTIGATION WORK PLAN, DATED NOVEMBER 2, 2018

Stakeholder	Comment No.	Document Section	Document Page Number	Comment (dated January 2, 2019)	Response
General Comments					
Greene County	1			It's a little unclear exactly how many permanent wells are proposed on the Highway Department Property. There are several places the document refers to permanent shallow monitoring wells at locations GC-10 and GC-12, but then refers to permanent bedrock monitoring wells at locations GC-01, GC-04, and CG-12.	The total number of permanent wells on the Highway Department Property is currently unknown because, at some locations, the presence/absence of NAPL and groundwater, as well as the chemical concentrations measured in soil and groundwater, will be used to determine which temporary well locations are appropriate for conversion to permanent monitoring wells. As proposed, there may be up to eight permanent monitoring wells installed on the Highway Department property. Please see response to Comment No. 2 for additional clarification. Please note that there is not a permanent shallow well planned for GC-10 (the comment might be referring to GC-01).
Specific Comments					
Greene County	1	4.2.1		The document also states in the 4th paragraph under 4.2.1 that up to three total wells should be permanent, however this same paragraph discusses criteria for deciding which of wells GC-02 to GC-07 (including GC-04, which is addressed in Section 4.2.2 as a permanent bedrock monitoring well) should be temporary vs. permanent. It looks like there could be two permanent wells (GC-01, GC-12), three permanent wells (GC-01, GC-04, and GC- 12), or up to eight (GC-01, GC-04, GC-12, and any of GC-02 through GC-07 that have groundwater impacts above the groundwater protection standard screening levels or vapor intrusion screening levels).	During the Phase 1 investigation, up to eight permanent monitoring wells are proposed for installation on the Highway Department Property, as follows: ● Two permanent shallow monitoring wells at locations GC-01 and GC-12 if groundwater is present. ● Three permanent bedrock monitoring wells at locations GC-01, GC-04, and GC-12. ● Up to three permanent shallow monitoring wells at locations GC-02 through GC-07, with a determination on which locations to install permanent wells, if any, based on field observation of presence/absence of groundwater, field observation of the presence/absence of creosote, and laboratory analysis of chemical concentrations in groundwater samples. While not on the Highway Department Property, two permanent bedrock wells will be installed in the former Black Tie Storage Area of the Facility (GC-08, GC-09). Results from the above Phase 1 investigation will subsequently be used to determine if Phase 2 is necessary and if installation of one or more additional wells at the Phase 2 step-out locations is necessary. The "up to three" text is referring to temporary wells at GC-02 through 07 that can be made permanent. The Section 4 text, Table 2, and the decision flow chart for Phase 1 will be modified to provide clarity.
Greene County	1			We do not necessarily have an objection to the idea of having permanent wells, but with the potential for that many wells we'd appreciate a clearer understanding of the long-term sampling plan for permanent wells. How often and for how long will those permanent wells be sampled? Will sampling occur indefinitely, until the former Tronox/Kerr-McGee facility is transferred to a new owner, or until sample data indicate contamination has decreased below levels of concern?	As described in the Work Plan, quarterly sampling of permanent wells is anticipated for the first year following installation, in accordance with MoDNR policies. The groundwater flow direction and chemical concentrations results from the first year of sampling will then be used with additional data from the former Tronox/Kerr-McGee Facility (Facility) to determine what additional actions, including long-term monitoring, are necessary for permanent monitoring wells installed on the Highway Department Property. For context, the frequency of current long-term monitoring program for the Facility is semi-annual, with an expectation that long-term monitoring of specific downgradient wells will continue until groundwater concentrations at point of compliance wells located at the Facility are less than the groundwater protection standards specified in the Facility's RCRA Permit. The decision to include or exclude specific permanent wells installed at the Highway Department Property as part of the long-term monitoring program will necessarily depend on the interpretation of the results obtained relative to applicable standards, MoDNR approval to abandon the well and is therefore currently uncertain.
Greene County	2	4	4	The last paragraph in section 4.0 gives a brief description of the proposed investigation of the abandoned 8-inch PVC sewer line on Greene County property that the City of Springfield found and cctv'd. The document describes excavating in two areas to determine presence or absence of creosote, but does not specify if the determination of presence or absence of creosote is to be made for material outside the pipe, or inside the pipe. From the description of excavation, we are left to infer that observations will be made outside the pipe. We feel that characterization of the black tar-like material inside the pipe is critically important to determine if the material is creosote, and that the work plan needs to specify that samples of the tar-like material will be taken from inside the pipe and analyzed for creosote compounds. If the sewer line used to run onto the Kerr-McGee property (which is our presumption) and if the black tar-like material inside the line originated further on the Kerr-McGee property it is entirely possible that there could be product that traveled inside the pipe, but would not be visible outside the pipe on Greene County's property.	Please see response to Comment No. 3.
Greene County	3	4	4	We fully support the excavation of the abandoned 8-inch PVC sewer line at the terminus near the property line between the Greene County Highway Department and the former Tronox/Kerr-McGee property. However, we have some serious concern with the proposed excavation around the abandoned 8-inch sewer line between 70 and 170 feet upstream of the City's sewer manhole Ml 7NW015. Between approximately 90 and 180 feet upstream of sewer manhole Ml 7NW015 the abandoned sewer line runs underneath the detention basin in the northwest corner of the County's facility. As measured by the City, the flow line of the abandoned sewer line in question is approximately seven feet deep. Excavating to this depth within a detention basin will create a preferential flow path which has a high potential for causing a sinkhole collapse within the basin. Detention basins in general have a high potential for sinkhole collapses due to increased water movement through the soil. Destabilizing the area within the detention basin and increasing the collapse potential is something we'd like to avoid. If the excavation close to the property line indicates the presence of creosote product moving along the sewer trench toward the County's detention basin we would certainly consider further excavation. However, due to the risk of increasing the collapse potential, we can support the proposed excavation within the detention basin only if there is clear evidence it is absolutely necessary.	The Multistate Trust agrees with the Greene County and appreciates Greene County's comment. The Work Plan will be modified to focus only near the terminus of the PVC sewer line located near the property line between the Greene County Highway Department and the former Tronox/Kerr-McGee property. Excavation near the terminus of the sewer line (both adjacent to and inside the pipe at the terminue) will provide information as to whether the black material is creosote. A combination of visual observations, odor observations and fingerprinting analysis will be used to determine if the black material is creosote. Soil located outside of the pipe will only be sampled if the soil is stained black. A sample of the black material in the pipe will be collected and submitted for fingerprinting analysis. Together, this information will assist the Multistate Trust in consultation with both MoDNR and Greene County in determining the next steps, if any.
Tables and Figures					
Greene County	1	Table 2			Table 2 will be modified to clarify Phase 1 wells and to address editorial items.
Greene County	3	Figure 5			Figure 5 will be modified to clarify permanent vs. possibly temporary wells.
Greene County	4	Figure 6		If the data from phase one meets the criteria to begin phase 2 monitoring, proposed well GC-16 would need to be relocated to ensure it is outside of the area where the County's previous fuel tanks were located. The previous tanks were removed when it was discovered they were leaking petroleum product into the surrounding soil. Although all the area was remediated by removal of all contaminated soil down to bedrock, there may still be detectable diesel and gas range organics that could confound the objective of finding material attributable to the Kerr-McGee facility. Constructability of a well in this area may also be problematic. When the contaminated soil was removed, it was replaced with quarried rock and gravel. This could potentially be difficult material to drill a shallow well through. Given the presumed predominant groundwater flow direction, moving it north or west could potentially also result in detection of organic compounds from past gasoline and/or diesel leaks.	Proposed monitoring well GC-16 will be relocated downgradient from the former tank cavity based on Greene County-provided information. There are no changes to the proposed sampling approach at monitoring well GC-16 in this phase of the investigation.

FINAL
GREENE COUNTY HIGHWAY DEPARTMENT SITE INVESTIGATION WORK PLAN

Former Tronox/Kerr-McGee Facility
2800 West High Street, Springfield, Missouri
EPA ID Number MOD007129406

Submitted by:

Greenfield Environmental Multistate Trust LLC,
Trustee of the Multistate Environmental Response Trust

Prepared by:

JACOBS®

July 26, 2019

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Acronyms and Abbreviations

µg/L	micrograms per liter
bgs	below ground surface
BTEXN	benzene, toluene, ethylbenzene, xylene, naphthalene
COC	chemicals of concern
DNAPL	dense nonaqueous phase liquid
DPT	direct-push technology
DQO	data quality objective
DRO	diesel-range organics
EPA	U.S. Environmental Protection Agency
Facility	former Tronox/Kerr-McGee Facility
GC/MS	gas chromatography–mass spectrometry
GCHD	Greene County Highway Department
GRO	gasoline-range organics
HVAC	heating, ventilation, and air conditioning
Jacobs	Jacobs Engineering Group Inc.
L	liter
MHWMF	Missouri Hazardous Waste Management Facility
mL/min	milliliter per minute
MLE	multiple-lines-of-evidence
MoDNR	Missouri Department of Natural Resources
Multistate Trust	Greenfield Environmental Multistate Trust, LLC, Trustee of the Multistate Environmental Response Trust
MWCR	Missouri Well Construction Rules
NAVD88	North American Vertical Datum 1988
PAHs	polyaromatic hydrocarbons
Permit	Missouri Hazardous Waste Management Facility Part I Permit
PID	photoionization detector
PVC	polyvinyl chloride
QC	quality control
RCRA	Resource Conservation and Recovery Act
Trust Agreement	Multistate Environmental Response Trust Agreement
SIM	selected ion monitoring
SOP	standard operating procedure
SVOCs	semivolatile organic compounds
TPH	total petroleum hydrocarbons
UFZ	uppermost flow zone
VI	vapor intrusion

VISL	vapor intrusion screening level
VOC	volatile organic compound

1. Introduction

This work plan outlines the technical procedures for conducting a site investigation of the Greene County Highway Department (GCHD) property immediately east of and adjacent to the former Tronox/Kerr-McGee Facility[1] (Facility). This work plan was prepared by Jacobs Engineering Group Inc. (Jacobs) on behalf of Greenfield Environmental Multistate Trust, LLC, not individually, but solely in its representative capacity as Trustee of the Multistate Environmental Response Trust (Multistate Trust) for the Facility located at 2800 West High Street in Springfield, Missouri with U.S. Environmental Protection Agency (EPA) ID No. MOD007129406 (Figure 1). This work plan describes the rationale, procedures, and methodologies necessary to:

1) characterize the nature and extent of potential Facility-related impacts on GCHD's property
2) assess risks to construction and GCHD workers from potentially impacted soil, groundwater
3) evaluate the potential for complete vapor intrusion (VI) pathways into currently occupied buildings on the GCHD property

By accomplishing the above objectives, this work plan will respond to GCHD's concerns, as expressed by the City of Springfield in its March 8, 2018, letter to the Multistate Trust (City of Springfield, 2018), and support assessment of on-going environmental actions[2] performed by the Multistate Trust as approved by and under the oversight of the Missouri Department of Natural Resources (MoDNR), as Lead Agency.

2. Background

The Multistate Trust implemented a corrective action program after assuming responsibility for the Facility on February 14, 2011, as a result of the Tronox LLC bankruptcy settlement approved by the U.S. Bankruptcy Court (New York). Under terms of the Multistate Environmental Response Trust Agreement (Trust Agreement), Multistate Trust's responsibilities include performing Environmental Actions as approved by and under the oversight of the Lead Agency (MoDNR). Therefore, the Multistate Trust's overarching objectives for the Facility are to:

- Perform environmental actions that are protective of human health and the environment, are sustainable, comply with all applicable regulations, and will satisfy the requirements of the Missouri Hazardous Waste Management Facility (MHWMF) Part I Permit with EPA ID No. MOD007129406 (Permit) and the Resource Conservation and Recovery Act (RCRA). The environmental actions would result in a final decision from MoDNR in the form of a "Corrective Action Complete" determination for the Facility.
- Transfer ownership and future stewardship of the Facility to a new owner(s) for a future beneficial use that is consistent with site conditions.

Previous investigations have identified benzene, toluene, ethylbenzene, xylene, naphthalene (BTEXN); semivolatile organic compounds (SVOCs), including polyaromatic hydrocarbons (PAHs); and dense nonaqueous phase liquid (DNAPL) in soil and groundwater near the boundary between the Facility and the GCHD property (Environmental Works, Inc., 2016, 2017; CH2M 2018; Jacobs 2018a, 2018b, 2018c).

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[1] The Site is referred to as the Former Tronox Facility, Former Tronox/Kerr-McGee Facility, Former Kerr-McGee Facility, Former Tronox/Kerr-McGee Wood Treatment Facility, and/or the Kerr-McGee Chemical Corporation (KMCC) Forest Products Division (FPD), Springfield, Missouri Facility.

[2] Pursuant to Section 1.1.11 of the Multistate Environmental Response Trust Agreement, "'Environmental Actions' means any and all environmental activities authorized or required under Environmental Law that occur after the Effective Date and that are related to any of the Multistate Owned Sites and certain Non-Owned Sites (for which the Multistate Trust will be performing environmental activities as provided herein), including but not limited to response or remedial actions, removal actions, corrective action, closure, or post-closure care, reclamation, investigations, studies, remediation, interim actions, final actions, emergency actions, water treatment, implementation of engineered structures and controls, monitoring, repair and replacement of engineered structures, monitoring equipment and controls, operation and maintenance, implementation, operation and maintenance of institutional controls, coordination and integration of reuse and remedial efforts and initiatives (including, without limitation, multi-stakeholder communications), and, if required, long-term stewardship and perpetual custodial care activities. 'Environmental Actions' also include the above environmental activities relating to the migration of hazardous substances emanating from the Multistate Owned Sites and certain Non-Owned Sites. For the avoidance of doubt, 'Environmental Actions' shall not include natural resource assessment or restoration."

Groundwater results and DNAPL observations from the 2017 groundwater sampling events conducted in accordance with the Permit are depicted on Figures 2 and 3 (Environmental Works, Inc., 2018). DNAPL was observed in several wells on the Facility, west of GCHD Building G (SMW-12C, PW-10, OP-1, OP-2, and OP-3), in the northeastern portion of the Facility (RW-04, RW-03, RW-06, and RW-02), and in SMW-80, which is located in the City of Springfield right-of-way just north of the GCHD property. Naphthalene concentrations in groundwater samples collected from monitoring wells SMW-80 (9,700 micrograms per liter [µg/L]) and SMW-15 (470 µg/L) exceeded the applicable groundwater protection standard (GWPS) of 20 µg/L. A new monitoring well, SMW-88, was installed in September 2018 at the northeast corner of the Facility. Although no DNAPL was observed during drilling, the initial sample collected from SMW-88 on September 27, 2018 contained 4,500 ug/L of naphthalene. Although not depicted on the figure, the most recent groundwater sample collected from SMW-88 on April 24, 2019 contained 600 ug/L of naphthalene.

The largest lateral extent of Facility-related DNAPL and chemicals of concern (COCs) is in the shallowest water-bearing zone, designated the uppermost flow zone (UFZ). The majority of DNAPL observations have been reported in weathered bedrock and karst/fracture features of the underlying limestone that are present under the residuum (that is, the silty clay soil that is on top of bedrock). These observations include those from multiple borings adjacent to the western border of the GCHD property (Figures 2 and 3). The potentiometric surface of the UFZ varies and generally follows the surface of the underlying bedrock. Groundwater flow in the UFZ near the GCHD property is generally northeasterly and mirrors the alignment of Clifton Drainage.

Based on the presence of soil and groundwater impacts and DNAPL near the western portion of the GCHD property, there is the potential that construction and/or GCHD workers could come into contact with Facility-related contaminants through exposure pathways such as inhalation, ingestion, or direct contact. The EPA defines an exposure pathway as the way a person may encounter a hazardous substance. For example, construction workers could become exposed to impacted soil and/or groundwater during intrusive activities up to an assumed depth of 10 feet below ground surface (bgs). GCHD workers who spend portions of their workday in enclosed buildings could be exposed through inhalation of volatile organic compounds (VOCs), specifically BTEXN, if vapors from impacted soil and/or groundwater migrate from the subsurface into the buildings (VI exposure pathway). The conceptual site exposure model depicting potential exposure scenarios to Facility-related COCs in soil, shallow groundwater, and air is depicted on Figure 4, with the specific exposure pathways and potential receptors addressed in this work plan highlighted in yellow.

Data collected during the GCHD property investigation will be used to further delineate the nature and extent of impacts, understand local groundwater flow direction, assess potential risks to construction and/or GCHD workers (via a human health risk assessment), and evaluate whether additional environmental actions are needed to protect human health and the environment in accordance with the requirements of the Permit. EPA defines a human health risk assessment as the process used to estimate the nature of and potential for adverse health effects in humans who may be exposed to chemicals in contaminated environmental media. Risk depends on how much of a chemical is present in the environmental medium, how much contact (exposure) a person has with the impacted medium, and the inherent toxicity of the chemical.

3. Investigation Objectives and Approach

The investigation will be conducted in a phased approach with up to four separate phases. The data quality objectives (DQOs) for each investigation phase are presented in Table 1. Phases 2, 3, and 4 will be conducted only if data collected during a previous phase indicate further delineation or risk assessment associated with the Facility is necessary.

A multiple lines of evidence approach will be used to evaluate whether detected concentrations of contaminants may be related to the Facility or a different source. Lines of evidence will include a spatial evaluation of observed conditions and concentration trends, identification of chemicals that are not Facility-related, calculation of chemical concentration ratios, use of chemical fingerprinting techniques, and evaluation of equilibrium partitioning between soil, groundwater, and soil vapor. Spatial data analysis will consider both the horizontal and vertical distribution of contaminant concentrations. For example, soil staining and/or elevated soil concentrations in the unsaturated zone under the GCHD property may indicate a potential non-Facility related source. Groundwater contaminant concentrations will also be evaluated in conjunction with groundwater flow directions and gradients from the expanded monitoring network. Elevated or increasing concentrations observed in areas not directly downgradient of the Facility may be indicative of non-Facility related impacts. An additional line of evidence for a non-Facility related source would be the identification of chemicals that were not used at the Facility, such as solvents and fuel additives, in wells installed on the GCHD property. Similarly, source characterization can include a comparison of ratios of detected chemicals (e.g., benzene:naphthalene; naphthalene:dibenzofuran) in samples collected from the GCHD property to those from Facility samples.

The proposed sample number, types, and locations for each phase are summarized in Tables 2 and 3 and depicted on Figures 5 through 8.

The primary objectives of the investigation are to:

- Delineate the extent of impacted soil and groundwater, and DNAPL on the GCHD property attributable to the Facility, where multiple lines of evidence will be used to distinguish detected concentrations of contaminants related to the Facility or a different source.
- Define the edge of the UFZ plume originating on the Facility property through the northern portion of the GCHD property
- Assess shallow bedrock groundwater flow direction in the upper portion of the UFZ near the unconsolidated soil/weathered limestone interface under the GCHD property and former Black Tie Storage Area of the Facility, which is south of the GCHD property (Figure 2)
- Assess potential risk to construction and GCHD workers associated with impacts in subsurface soil or shallow groundwater (less than 10 feet bgs) that may be attributable to the Facility
- Assess the potential for VI from Facility-related volatile COCs (BTEXN) into currently occupied buildings on the GCHD property, where VOCs that are not BTEXN would indicate they originate from non-Facility sources.

Decision flow charts (Figures 9 through 13) depict the process used to determine whether subsequent phases of investigation are necessary to meet the investigation DQOs.

4. Phase 1 Investigation

The Phase 1 investigation DQOs are as follows:

- Delineate the extent of both impacted soil and groundwater, and DNAPL on the western and northern parts of the GCHD property attributable to the Facility, using multiple lines of evidence to include chemical fingerprinting.
- Confirm the groundwater flow direction within the UFZ under the GCHD property and Black Tie Storage Area of the Facility.
- Assess human health risks to construction and GCHD workers associated with exposure to BTEXN and SVOCs attributable to the Facility in shallow soil and groundwater (less than 10 feet bgs) on the western portion of the GCHD property
- Assess the potential for VI attributable to the Facility for future buildings potentially located on the western portion of the GCHD property and for currently occupied buildings from vapors potentially migrating through the subsurface and/or the sanitary sewer lines located on the northern and eastern portions of the GCHD property

Phase 1 sample locations are depicted in blue on Figure 5. The following fieldwork will be conducted, and media will be analyzed to meet the Phase 1 investigation DQOs:

- Continuous soil cores will be collected from eight GCHD locations (GC-01 through GC-07, and GC-12). Up to three soil samples will be collected from each location for analysis of VOCs (full list of analytes), SVOCs, and total petroleum hydrocarbons (TPH; gasoline-range organics [GRO] and diesel-range organics [DRO]) to assess the potential for construction and GCHD worker exposure to impacted soil, to assess the potential source(s) of potential groundwater impacts, and/or to determine if soil may be a source of BTEXN for VI. Note that borings at locations GC-04 through GC-06 will be advanced as close as practicable to the adjacent building but cannot be installed under the building due to insufficient overhead clearance for the drill rig.

- At boring locations GC-02 through GC-07, a temporary shallow well will be constructed if there are no signs of creosote impacts in the soil core and sufficient water accumulation occurs within 24 hours of completing the soil boring. Groundwater samples will be collected from each temporary well for analysis of VOCs, SVOCs, TPH-GRO, and TPH-DRO to assess construction and GCHD worker exposure to impacted shallow groundwater and, to assess the potential for shallow groundwater to be a source of BTEXN for VI. Results from groundwater samples collected at temporary wells will be evaluated spatially and compared with GWPS and vapor intrusion screening levels (VISLs) to decide whether to designate the well as a permanent location or abandon the well. Each temporary well will be evaluated based on whether NAPL is present or absent in soil and/or groundwater, as well as the chemical concentrations measured in soil and groundwater, to determine if will be converted to a permanent monitoring well or abandoned within 30 days of installation. Permanent shallow monitoring wells will be installed at GC-01 and GC-12 if they accumulate enough water. The purpose of these wells is to support the long-term monitoring program for the Facility.
- Multi-depth soil gas samples will be collected from 10 locations (GC-01 through GC-09 and GC-12). Up to three soil gas samples will be collected from each location, depending on the depth to water (see Table 2). Samples will be collected at up to three depths based on depth to top of water column and separated by a minimum vertical distance of 4 to 5 feet. If there is sufficient depth to water, the first sample will be collected at approximately 5 feet bgs, the second between 5 feet bgs and the water column, and the third at 1 foot above the water column. If groundwater is within 8 feet of ground surface, then only one sample will be collected, at approximately 1 foot above the water table. Soil gas samples will be analyzed for VOCs and biodegradation parameters (O_2, CO_2, and methane) to assess whether vapors from groundwater or soil could pose a VI risk to buildings constructed on the western portion of the GCHD property in the future.
- Continuous soil cores will be collected from two locations (GC-08 and GC-09) in the Black Tie Storage Area of the Facility. Up to three soil samples will be collected from each location for analysis of VOCs, SVOCs, TPH-GRO, and TPH-DRO. Groundwater and/or soil gas results will also be used to assess the potential for future VI and if additional investigation is needed on the southern portion of the GCHD property. The permanent shallow bedrock monitoring wells installed at the Black Tie Storage Area are intended to confirm historical results from abandoned well SMW-23, which showed no impact to groundwater in this area. Groundwater samples will be analyzed for VOCs, SVOCs, TPH-GRO, and TPH-DRO. Analytical results will be used to assess future construction and future site worker exposure to impacted soil or groundwater and, to assess the potential for shallow groundwater to be a source of BTEXN for VI. These two new wells will also be used with new wells installed on the GCHD property to determine the current groundwater flow direction in the shallow UFZ.
- Three permanent bedrock monitoring wells will be installed at locations GC-01, GC-04, and GC-12 to further delineate the extent of impacted groundwater within the karst/fractured portion of the UFZ bedrock to define the edge of the UFZ groundwater plume below the northern part of the GCHD property. Groundwater samples will be analyzed for VOCs, SVOCs, TPH-GRO, and TPH-DRO.
- Headspace (gas) samples will be collected from 17 sanitary sewer cleanouts and two manholes on the northern and eastern portions of the GCHD property. The sanitary sewer headspace samples will be analyzed for VOCs to assess whether the sanitary sewer lateral under the GCHD property is acting as a preferential pathway for vapors present in the City sewer main, located under West High Street, to migrate into the occupied buildings on GCHD property. The rationale for collecting headspace samples from the 17 sewer cleanouts is two-fold: (1) to characterize spatial variability; and (2) look spatially from site-wide perspective with the potential there are non-Facility source(s). This will be important to distinguish whether detected concentrations are attributable to the Facility's permitted discharge or if there are GCHD property sources contributing to the BTEXN concentrations in sewer gas. This is important because the concern that the Greene County has is that vapors from the permitted Facility discharge are migrating up the sewer pipe towards their office building. Samples

collected from each cleanout will provide spatial information along with concentration gradients which will be useful in assessing whether the detected concentrations are Facility-related or not.

During the August 22, 2018 site walk, GCHD indicated that they had found a previously unknown sewer line on their property, and that this sewer line appeared to run from City of Springfield Manhole No. M17NW015 (identified as GC-MH-01 on Figure 5) southwest towards the Facility and GCHD property boundary. Figure 5 shows the approximate location of this previously unknown sewer line. The previously unknown sewer line was videoed by the City of Springfield and GCHD. This video showed the presence of dark to black material near where the sewer line was plugged (approximately 377 feet upstream of M17NW015). Additionally, dark stains were present around the circumference of the pipe near pipe joints of each 20-foot length of pipe between 70 and 170 feet upstream of M17NW015. The video also showed a broken, factory-made tap that was full of rocks at approximately 173 feet upstream of M17NW015,

During Phase 1, a utility locate and a backhoe will be used to perform an excavation near the terminus[3] of the previously unknown sewer line (both adjacent to and inside the pipe at the terminus) will provide information as to whether the dark to black material is creosote. A combination of visual observations, odor observations and fingerprinting analysis will be used to determine if the dark to black material is creosote. Soil located outside of the pipe will only be sampled and analyzed for VOCs (full list of analytes), SVOCs, TPH-GRO and TPH-DRO if the soil is stained black. Together, this information will assist the Multistate Trust in consultation with both MoDNR and Greene County in determining the next steps, if any.

4.1 Phase 1 Creosote Delineation and Soil Sample Collection

Continuous soil cores will be collected from ground surface to refusal, with an attempt to enter at least 1 foot into the weathered bedrock at locations GC-01 through GC-09 and GC-12 using a hydraulic direct-push technology (DPT) drill rig (Geoprobe). Table 4 provides details of the soil boring investigation, sampling, and key factors. Soil cores will be visually inspected to identify the presence of impacted material (staining, sheens) or free-phase creosote (oil globules), field-screened with a photoionization detector and ultraviolet light, and visually inspected for indications of moisture level and water production. (Borings may be temporarily left open to check for water accumulation—see Table 4.) Desired horizons for soil samples to evaluate various risk pathways are near surface (0 to 2 feet bgs) for VI evaluation, dermal and ingestion exposure, mid-depth (5 to 6 feet bgs) for VI evaluation and construction worker exposure, and 9 to 10 feet bgs for VI evaluation and construction worker exposure. Samples for VI evaluation need to be collected from dry (unsaturated) horizons.

Soil samples will be analyzed for VOCs by EPA Method SW8260B, TPH-GRO and TPH-DRO by EPA Method 8015C, and SVOCs by EPA Method SW8270D. Soil boring locations will be surveyed for location (*x*,*y* coordinates) to the nearest 0.1 foot relative to the Missouri State Plane Coordinate System. Elevations (ground surface) will be surveyed to the nearest 0.01 foot and tied into the North American Vertical Datum 1988 (NAVD88) vertical datum.

If creosote is observed in a boring at locations GC-01, GC-06, GC-07, or GC-12 or if soil concentrations indicate subsurface impacts above screening levels may be related to the facility, Phase 2 work will be required.

Locations GC-01, GC-06, GC-07, and GC-12 were identified following thorough review of available Facility and off-Facility data as locations needed to refine the understanding of potential impacts at the GCHD property. Step-outs from these locations would be sampled in Phase 2, if needed. Phase 2 sample locations were not proposed for Phase 1 sample locations GC-02 through GC-05 because data from proposed Phase 1 sample location GC-12 and existing monitoring wells SMW-77 and SMW-78 are expected to define the eastern extent of potential Facility-related impacts. If, however, Facility-related impacts are observed at Phase 1 sample location GC-01 and/or GC-12, Phase 2 sampling at cross-gradient location GC-13 would be appropriate. Similarly, if Facility-related impacts are observed at Phase 1 sample location GC-06 and/or GC-07, Phase 2 sampling at cross-gradient location GC-20 would be

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[3] The trenching will occur only at the terminus of the sewer line located near the property line between the GCHD and the Facility due to concerns that a preferential flow path could be created causing a sinkhole collapse within the nearby retention basin.

appropriate. This rationale for Phase 2 step-out locations is currently described in the notes column of Table 2.

4.2 Phase 1 Groundwater Sample Collection

Groundwater samples will be collected from a combination of temporary and permanent shallow and deeper monitoring wells installed during Phase 1 investigation activities. Up to eight permanent monitoring wells are proposed for installation on the Highway Department Property, as follows:

- Two permanent shallow monitoring wells at locations GC-01 and GC-12 if groundwater is present.
- Three permanent bedrock monitoring wells at locations GC-01, GC-04, and GC-12.
- Up to three permanent shallow monitoring wells at locations GC-02 through GC-07, with a determination on which locations to install permanent wells, if any, based on field observation of presence/absence of groundwater, field observation of the presence/absence of creosote, and laboratory analysis of chemical concentrations in groundwater samples.

While not on the Highway Department Property, two permanent bedrock wells will be installed in the former Black Tie Storage Area of the Facility (GC-08 and GC-09).

4.2.1 Shallow Monitoring Wells

As described in Section 4.1, DPT borings for soil sample collection will be advanced to refusal at GC-01 through GC-07 and GC-12. At each of the GC-02 through GC-07 locations where creosote impacts are not observed, and at locations GC-01 and GC-12, a 1-inch-diameter polyvinyl chloride (PVC) screen and riser pipe will be inserted to determine if groundwater is present. If groundwater is not present initially, the 1-inch temporary piezometers may remain in place within the open borehole for up to 24 hours to check for water accumulation. If groundwater does not accumulate, the temporary piezometer will be removed, and the borehole abandoned in accordance with Missouri Well Construction Rules (MWCR) and the standard operating procedures (SOPs) in Appendix A or used for soil vapor well installation (as described in Section 4.3).

If groundwater accumulates and sufficient water is present, a shallow monitoring well will be installed by overdrilling the location with augers such that the bottom of the boring extends 1 to 2 feet into weathered bedrock. A monitoring well will be constructed in the boring using 2-inch-diameter PVC casing and riser pipe. The screened interval for each well will be from the bottom of the boring, including the soil/weathered bedrock interface, to 1 foot above the highest historical water level in existing wells near that location. Wells at GC-01 and GC-12, if installed, will be completed as permanent shallow wells, which will be in addition to the bedrock monitoring wells described for these locations in the following section. Shallow monitoring wells at GC-02 through GC-07, if installed, will be designated as temporary wells. The well head for each temporary well will be protected using steel plates or other means until a decision is made to abandon the well or complete as a permanent well location. All wells will be constructed in accordance with MWCR and the SOPs in Appendix A. Permanent wells with be completed in traffic-rated vaults that match the surrounding pavement to prevent damage due to heavy vehicles including snow removal equipment.

All temporary and permanent wells will be developed in accordance with the SOP in Appendix A. Following development, each well will undergo a 3-day equilibration period to allow for recovery of formation groundwater within the screened interval. After the equilibrium period, groundwater samples will be collected using either low-flow sampling techniques or standard purge and sample, in accordance with the SOPs included in Appendix A and/or in consultation with MoDNR based on the borehole information. Groundwater samples from locations GC-02 through GC-07 will be sent for “rush” analysis of VOCs by EPA Method SW8260B, TPH-GRO and TPH-DRO by EPA Method 8015C, and SVOCs by EPA Method SW8270D and compared to GWPS.

Groundwater concentrations measured in samples from temporary wells installed at GC-02 through GC-07 will be used with groundwater elevation data and the chemical signature of wells located on the Facility to evaluate whether impacts are Facility-related. Observed groundwater impacts that are Facility-related will further be compared with GWPS RSLs and VISLs to evaluate the significance of observed impacts. These assessments will be used to determine which temporary wells should be completed as permanent monitoring wells (up to three total) or should be abandoned, while also supporting the evaluation of whether investigations at Phase 2 step-out locations are warranted (see Figure 9). Per Missouri regulations, temporary wells deeper than 10 feet that are not completed as permanent wells will be properly abandoned within 30 days of installation.

Similarly, groundwater concentrations in samples from permanent shallow wells at GC-01 and GC-12 will also be used to evaluate whether investigations at Phase 2 step-out locations are warranted (see Figure 9).

Groundwater samples collected during Phase 1 investigations will serve as the first of four consecutive quarterly monitoring events for all shallow wells established as permanent under this Work Plan. The results from these four quarterly events will be used to determine whether additional quarterly monitoring is necessary to establish a contaminant concentrations trend for each well . The available data will then be used with the trend analysis evaluation to recommend to MoDNR whether each well should be included in the long-term monitoring plan for the Facility or abandoned (Tables 1 and 5). These data will also be used to inform the target analyte list and monitoring frequency for each well recommended for inclusion in the Facility's long-term monitoring program.

All permanent wells installed on the GCHD property will be completed within traffic-rated vaults that match the surrounding pavement to prevent damage from heavy vehicles including snow removal equipment. The two wells installed in the Black Tie Storage Area will have aboveground pedestal completions. Well installations and borehole abandonment will be implemented in accordance with MWCR and the SOPs in Appendix A. Wells will be surveyed for location (*x*,*y* coordinates) to the nearest 0.1 foot relative to the Missouri State Plane Coordinate System. Elevations (ground surface and top of casing) will be surveyed to the nearest 0.01 foot and tied into the NAVD88 vertical datum.

4.2.2 Bedrock Monitoring Wells

Groundwater samples will be collected from permanent bedrock monitoring wells installed in the UFZ at locations GC-01, GC-04, and GC-12, as well as at shallow bedrock locations GC-08 and GC-09 in the Black Tie Storage Area as detailed in Table 6. Wells at these locations are intended to delineate the UFZ groundwater plume underlying the GCHD property. Wells at GC-01, GC-04, and GC-12 will also serve to delineate any DNAPL impacts to the deeper bedrock interval of the UFZ.

Based on existing well data, the target depth for wells at GC-01, GC-04, and GC-12 will be 30 feet bgs, but may be installed as deep as 40 feet bgs if no indication of fractures/voids, impact, or water production are observed. Wells will be screened to monitor horizons exhibiting these features, with screen top adjusted based on depth of bedrock. These wells will be subsurface flush-mount completions with traffic-rated vaults.

Field observations and groundwater concentration data for bedrock wells GC-01 or GC-12 will be used to determine if a Phase 2 step-out bedrock well will be installed near location GC-13 (Figures 6 and 9). Note that a Phase 2 step-out location for GC-04 will not be necessary because existing bedrock well SMW-77 (which had no creosote impacts observed during drilling and installation, and currently does not have groundwater concentrations exceeding GWPS) provides an eastern bound on Facility-related impacts in this area.

The wells at locations GC-08 and GC-09 in the Black Tie Storage Area are designed to confirm the groundwater flow direction within the UFZ south of the GCHD property in addition to verifying plume delineation, screening shallow bedrock groundwater concentrations against VISLs, and determining if Phase 2 sampling is needed. These two wells will be constructed similarly to other existing and abandoned wells near this area. Initial target drilling depth will be 5 feet below top of bedrock, with a check for water production. Lacking water, the well bore will be drilled an additional 1 foot and rechecked for water. This will continue to a maximum depth of 20 feet, to match the maximum depth of other wells installed at the Facility near this area. Wells will be screened to monitor horizons with voids, fractures, and/or water production, with screen top set one foot above the expected highest water level estimated for that location based on water levels in existing wells in the area. Both monitoring wells in the Black Tie Storage Area will have aboveground pedestal completions.

All monitoring wells will be installed in accordance with MWCR, with installation and development per SOPs in Appendix A and/or in consultation with MoDNR based on the borehole information. The new wells will be surveyed for location (*x*,*y* coordinates) to the nearest 0.1 foot relative to the Missouri State Plane Coordinate System. Elevations (ground surface and top of casing) will be surveyed to the nearest 0.01 foot and tied into the NAVD88 vertical datum.

Groundwater samples will be collected from the wells no sooner than 3 days after development to allow time for groundwater conditions to equilibrate from the installation activities. Samples will be collected using either low-flow sampling techniques or standard purge and sample, depending on the amount of groundwater recharge, in accordance with the SOPs included in Appendix A. Samples will be analyzed for VOCs by EPA Method SW8260B, TPH-GRO and TPH-DRO by EPA Method 8015C, and SVOCs by EPA Method SW8270D.

4.3 Phase 1 Soil Gas Sample Collection

Multi-depth soil gas samples will be collected at locations GC-01 through GC-09 and GC-12. After the depth to water has been determined based on the soil cores, soil gas probes will be installed within 5 feet from the corresponding soil boring location and 5 feet from each other. The soil gas probes will be installed using a DPT drilling rig in accordance with the SOP for exterior soil vapor sampling (Appendix A). The following summarizes the temporary shallow soil gas probe installations:

- A 6-inch stainless steel soil gas probe attached to 0.25-inch Teflon tubing will be lowered into the DPT boring. Filter pack sand will be poured into the borehole around the screen to create a 1-foot sand pack column around the soil gas probe.
- The remainder of the borehole will be filled with bentonite that is hydrated with distilled water in 1-foot lifts to the ground surface.
- A Swagelok cap will be placed on the tubing extending above the ground surface, and a traffic cone or similar traffic control device will be placed over the temporary soil gas probe.
- The probe will be allowed to equilibrate for a minimum of 2 hours (preferably 24 hours), per MoDNR (2006), after installation is completed before the soil gas probe is purged, leak tested, and sampled.

The deep soil gas probe installation will be performed in accordance with the SOP for exterior soil vapor sampling (Appendix A). The temporary deep soil gas probe installation is summarized as follows.

- A DPT drilling rig will be used to advance a temporary soil gas probe with a Geoprobe Post Run Tubing (PRT) system.
- The DPT rods will be pushed to the probe bottom depth (determined from the associated soil boring), with the expendable point at the bottom.
- The rod will be retracted approximately 12 inches to create a void space.
- The tubing attached to a PRT adapter will be lowered into the rods and screwed (counterclockwise) into the expendable point holder.
- The temporary probe will be allowed to equilibrate for a minimum of 2 hours (preferably 24 hours), per MoDNR (2006), after installation is completed.

Soil gas sample collection will be conducted in accordance with the SOP for exterior soil vapor sampling (Appendix A). The soil gas sample collection technique is summarized as follows:

- Measure the initial passivated steel sample canister pressure with a digital vacuum gauge and record the result. Attach the flow controller and dedicated analog gauge to the canister. Attach the canister, via the flow controller, to the sampling manifold.
- Place the helium enclosure around the probe, manifold, flow controller, and canister. Connect the probe tubing and the vacuum pump to the sampling manifold. Connections are made with Swagelok nut and ferrule sets.
- Perform a physical leak check of the sampling train (evacuate to approximately -10 inches mercury and verify the sampling train holds the vacuum for at least 1 minute).
- Flood the helium enclosure with helium (minimum 10 percent) and maintain the concentration during purging.
- Purge three dead volumes into a Tedlar bag at 200 milliliters per minute (mL/min). The dead volumes and purge times are as follows:
  - Shallow soil gas probes: 1.17 liter (L), 5.8 minutes at 200 mL/min
  - Deep soil gas probes (temporary probe): 1.98 L, 9.8 minutes at 200 mL/min
  - Deep soil gas probes (semi-permanent probe): 1.68 L, 8.4 minutes at 200 mL/min
- Measure helium in the Tedlar bag with an MGD Dielectric helium detector to determine whether the probe passed the leak test. The helium concentration in the purged soil gas must be less than 1 percent of the helium enclosure concentration during purging to pass the leak test (10,000 parts per million by volume if the helium concentration was 100 percent).
  - If the connections do not pass the leak test, take corrective measures such as tightening sampling train connections and determining whether helium detections may be caused by methane interference.
  - If methane in the soil gas causes elevated helium detector readings, collect the soil gas sample with helium flowing in the helium shroud and analyze the sample in the laboratory for helium to identify potential leaks during sampling.
  - If the soil gas probe fails the leak test, do not sample. Continue corrective measures until leak test passes check criteria.
- Perform field measurements with the LandTec GEM5000 Landfill Gas Meter and MultiRae PID.
- Collect the passivated stainless-steel canister sample by closing the sampling manifold valve to the pump, opening the valve to the canister, and opening the canister valve. Record the sample start and end times and sampling vacuum. The critical orifice flow controller will regulate the sample collection rate at 200 mL/min or less.
- Duplicate samples should be collected with a T connector and one shared flow controller.
- Measure the final canister pressure with a digital vacuum gauge and fill out the tag.

4.4 Phase 1 Sanitary Sewer Cleanout and Manhole Headspace Sample Collection

Headspace (gas) samples will be collected from 17 cleanouts and two manholes at locations GC-SC-01 through GC-SC-15 and GC-MH-01 and GC-MH-03, depicted on Figure 5. Headspace samples will be collected for approximately 24 hours using passivated stainless-steel canisters. Headspace samples will be analyzed for VOCs by EPA Method TO-15. Sewer cleanout and manhole headspace samples will be collected using the ambient (outdoor) air sampling procedures outlined the SOP for indoor, outdoor, and crawl space air sampling for VOCs using canisters (Appendix A).

- Temporary fencing, barricades, or other traffic control devices will be used to establish a sample collection zone at each cleanout or manhole. The type and schedule for deployment of these traffic control devices will be closely coordinated with GCHD personnel to minimize disruption of GCHD operations.

- Tubing connected to a 6-L passivated evacuated stainless-steel canister will be advanced into each cleanout.
- The 6-L passivated stainless-steel canisters will be placed directly within the two manholes, and the manhole lids will be replaced. The canisters will be secured high enough above the base of the manhole to avoid rising water that may occur due to precipitation or other factors.
- A sign stating DO NOT DISTURB—AIR SAMPLING IN PROGRESS will be placed at each sample zone location.
- The 6-L passivated evacuated stainless-steel canisters will be equipped with flow controllers set to collect a 24-hour sample.
- Pressure gauge checks will be conducted at a minimum of every 8 hours during the sample collection to verify the flow controllers are operating properly.

4.5 Phase 1 Data Evaluation

If soil, groundwater, or air impacts are present in the Phase 1 samples, a comprehensive assessment of the data will be conducted to determine whether the impacts appear attributable to the Facility. This assessment will use multiple lines of evidence approach to evaluate whether detected concentrations of contaminants may be related to the Facility or a different source. Lines of evidence will include a spatial evaluation of observed conditions and concentration trends, identification of chemicals that are not Facility-related, calculation of chemical concentration ratios, and evaluation of equilibrium partitioning between soil, groundwater, and soil vapor. Spatial data analysis will consider both the horizontal and vertical distribution of contaminant concentrations. For example, soil staining and/or elevated soil concentrations in the unsaturated zone under the GCHD property could indicate a potential non-Facility related source. Groundwater contaminant concentrations will also be evaluated in conjunction with groundwater flow directions and gradients from the expanded monitoring network. Elevated or increasing concentrations observed in areas not directly downgradient of the Facility may be indicative of non-Facility-related impacts. An additional line of evidence for a non-Facility-related source would be the identification of chemicals that were not used at the Facility, such as solvents and fuel additives, in wells installed on the GCHD property. Similarly, source characterization can include a comparison of ratios of detected chemicals (e.g., benzene:naphthalene; naphthalene:dibenzofuran) in samples collected from the GCHD property to those from Facility samples. Chemical fingerprinting will also be conducted for soil and groundwater samples to assess the age and distribution of petroleum compounds and the presence biomarkers. Chemical fingerprinting will involve the collection of additional groundwater and soil samples from a subset of the existing sampling locations. The locations where the samples will be collected will be based on the conditions observed in the field (presence of staining, oil globules, etc.). It is assumed that chemical fingerprinting samples will be collected at approximately 50 percent of the groundwater and soil sampling locations. These samples will be sent to a laboratory for petroleum fingerprinting analysis. The lighter petroleum fraction (i.e. gasoline range) fingerprint analysis will be conducted using a C3-C12 Quantitative Petroleum Characterization (EPA 8260 Modified) or equivalent method. The heavier petroleum fraction (diesel and motor oil range) fingerprinting analysis will be conducted using the following methods: 1) C8-C40 Full Scan Semi-Quantitative Characterization (Modified ASTM D5739) and 2) Parent and Alkylated PAHs (Modified EPA 8270).”

If it appears the impacts are attributable to the Facility, the data will be compared to the following criteria to determine whether Phase 2 sample collection is necessary:

- If DNAPL (noncriteria basis) is present in groundwater samples or is observed in soil cuttings during installation of temporary or permanent wells, Phase 2 borings and groundwater sample collection will be required.
- Soil analytical data will be compared to EPA regional screening levels for industrial workers (EPA, 2018a) that are listed in Table 7. If concentrations of Facility-related COCs in soil samples exceed the EPA regional screening levels for industrial workers, risk-based screening levels for a construction worker exposure scenario will be derived to further evaluate the significance of soil concentration data. If one or more screening levels for the construction worker scenario is exceeded, Phase 2 soil borings will be installed to further delineate the extent of soil impacts. The vertical concentration

profile and concentration ratios will also be evaluated to determine the potential source of groundwater or soil gas impacts as a line of evidence to determine whether Phase 2 sampling is required.

- Groundwater analytical data will be compared to the GWPS for Facility-related COCs. If one or more concentrations of Facility-related COCs exceed a corresponding GWPS, Phase 2 permanent monitoring wells will be installed to delineate the extent of groundwater impacts. Groundwater data also will be compared to EPA VISLs in conjunction with soil gas data to assess the potential for VI.
- Soil gas analytical data will be compared to current EPA VISLs (EPA, 2018b). If concentrations in soil gas samples exceed EPA VISLs and the soil gas concentrations are attributable to the Facility, Phase 2 soil, groundwater, and soil gas data will be collected to assess VI.
- If concentrations in sanitary sewer headspace samples from locations GC-SC-01, GC-SC-02, GC-SC-11, GC-SC-12, or GC-SC-13 contain Facility-related COCs, Phase 2 sanitary sewer headspace samples will be collected. If sanitary sewer headspace samples from locations GC-SC-03 through GC-SC-10 contain Facility-related COCs near occupied buildings, Phase 4 (indoor air investigation activities) will be initiated with spatial pattern of detections and constituent ratios/patterns to assess potential for background contributions.

The decision logic used to assess the need for Phase 2 investigations is presented on Figures 9 and 10.

5. Phase 2 and 3 Investigations

If DNAPL is present, or Facility-related COC concentrations in soil, groundwater, or soil gas exceed any of the Phase 1 data evaluation criteria and the impacted media is attributable to the Facility, Phase 2 and, if necessary, subsequent Phase 3 investigation (building exterior sampling) activities will be initiated. Phase 2 and 3 sample locations are depicted in green on Figure 6 and orange on Figure 7, respectively. Soil, groundwater, and soil gas samples will be collected using the same techniques described for the Phase 1 investigation. Groundwater samples will be analyzed using a “rush” 2-day laboratory turnaround time. Soil and soil gas samples will be “held” pending receipt of the groundwater results. Soil and soil gas samples will only be analyzed if the groundwater samples exceed groundwater VISLs.

If soil, groundwater, or air impacts are present in the Phase 2 or Phase 3 samples, a comprehensive evaluation of the data will be conducted using a multiple-lines-of-evidence (MLE) evaluation to assess whether the impacts appear attributable to the Facility. The decision logic used to assess the need for Phase 3 or Phase 4 investigations is presented on Figures 12 and 13.

Data collected during the Phase 2 investigation for soil and groundwater (non-VI) characterization will be evaluated against the criteria identified in Section 4.5. If it appears the impacts associated with VI characterization collected during Phase 2 are attributable to the Facility, the data will be evaluated to determine if Phase 3 (exterior building sampling) sample collection is necessary. Groundwater, soil, and soil gas data will be compared to EPA VISLs (EPA, 2018b), to assess the potential source(s) of subsurface impacts, to assess the potential for VI, and to conduct an MLE evaluation. If the soil gas concentrations during Phase 2 exceed EPA VISLs and the MLE evaluation indicates VI may be attributable to the Facility, then Phase 3 soil, groundwater, and soil gas data will be collected to further assess the potential for VI.

Phase 3 data will be evaluated to assess only the VI pathway. If Phase 3 groundwater or soil gas data indicate impacts are attributable to the Facility (via the MLE evaluation) and the concentrations exceed the applicable VISLs, then Phase 4 (indoor air investigation activities) will be conducted.

6. Phase 4 Investigation

Phase 4 investigation activities will be conducted to assess indoor air in the occupied office buildings on the eastern side of the GCHD property. Phase 4 will be conducted only if either of the following is the case:

- Phase 3 soil gas results indicate that a potential vapor source attributable to the Facility is near the buildings and could pose a VI concern
- Phase 1 samples collected within the sanitary sewer in the northern end of the GCHD property appear to pose a preferential pathway for vapors attributable to the Facility in the sewer system to enter the buildings

Phase 4 investigation activities will include conducting a detailed building survey; conducting a HAPSITE survey; collecting subslab, indoor, and outdoor air samples; and conducting a pressure cycling test (if possible) within the footprints of Buildings GC-B1 and GC-B2 to assess the potential for indoor air to be impacted by VI from an outside source (soil or shallow groundwater impacts) attributable to the Facility. Phase 4 sample locations depicted in purple on Figure 8. Sample collection procedures for the Phase 4 investigation are described in the following subsections.

6.1 Subslab Vapor Sampling Activities

Subslab vapor sampling will be performed in the two occupied structures identified for Phase 4 sample collection on Figure 8. Subslab vapor pin installation and sampling will be performed in accordance with the SOP for subslab soil gas sampling (Appendix A), summarized as follows:

- The area for probe installation will be checked with ground penetrating radar or other device for subsurface utilities and rebar. During drilling, a four-gas meter will be used to monitor for methane (as the lower explosive limit), and a PID will be used to monitor for VOCs. Flush-type vapor pins will be installed and leak-checked with a water dam to verify a good seal prior to sampling.
- Locations will be selected near the center of the lowest room in a low-traffic area, avoiding garages; rooms with operating wood-burning stoves; natural gas water heaters; heating, ventilation, and air conditioning (HVAC) systems; or areas containing potential VOC sources that have not or cannot be removed. Samples will not be collected near foundation walls or near cracks or other openings. To avoid creating an opening for water entry into the structure, subslab samples will not be collected in locations where groundwater is, or is suspected to be, in contact with the foundation.
- Before sampling, the vapor probe will be purged at a flow rate of 200 mL/min, and the purged soil vapor will be screened using a PID for VOCs and a gas meter to measure carbon dioxide, methane, and oxygen levels before sampling. Also, before collecting samples, a leak detection test will be conducted using a helium shroud.
- Sampling will be performed using one 1-L passivated evacuated stainless-steel canister, batch-certified clean, with its flow controller set for 5-minute collection and a 6-L passivated evacuated stainless-steel canister, individually selected ion monitoring (SIM)–certified clean, with a flow controller set for 20 minutes. Before sampling, both canisters will be connected to the subslab probe using a stainless-steel tee to allow fittings to remain connected from sample probe purge through sample collection. It is important that both canisters are not filled simultaneously, because of the differential fill rates and inability to monitor residual vacuums accurately while sampling.
- The 1-L air sample will be analyzed by EPA Method TO-15 scan mode. The laboratory will analyze only the 6-L canister if the EPA Method TO-15 scan mode results indicate the VOC levels are low enough to not damage their equipment during analysis of the 6-L sample using EPA Method TO-15 SIM.
- Following sample collection, the canisters will be labeled and shipped under chain-of-custody to the approved laboratory for VOC analysis by EPA Method TO-15 SIM plus helium.
- Vapor pin caps will be placed in the barbed fittings of the vapor pins to secure the probes for future sampling.

Following probe installation, the sampling area will be cleaned up and furnishings replaced. The vapor pin probes will remain in place until after indoor air sampling activities (discussed below) are complete. The probes will be removed following completion of all indoor air sampling activities, and the concrete slab will be carefully patched.

6.2 Indoor Air Sampling Activities

Indoor air sampling also will be conducted in the two buildings identified on Figure 8. Before initiating the indoor air sample collection activities, a building survey will be performed. The following information will be collected during the building survey:

- Building use and occupancy
- Condition of the building envelope
- Presence of a basement or crawlspace
- Presence of preferential pathways for VI
- Dimensions of the building and interior compartments
- Condition of the slab and basement walls and presence of potential VI pathways
- Type, zoning, and typical operational settings of the HVAC system
- Presence of potential indoor sources of VOCs
- Evidence of groundwater infiltration into the structure

The SOP for conducting a building survey is included in Appendix A.

Up to 14 indoor air samples will be collected at each of the two occupied buildings of interest. A HAPSITE portable gas chromatography–mass spectrometry (GC/MS) unit will be used to screen VOC concentrations before the 6-L passivated stainless-steel canisters are deployed to identify potential background sources that can be removed before sampling (to the extent feasible). The HAPSITE GC/MS field methods will be conducted in accordance with the SOP *Analytical Method for the Determination of Volatile Organics in Soil Vapor or Air Using the HAPSITE Field GC/MS* (Appendix A).

Indoor air sampling with the passivated stainless-steel canisters will be conducted using the procedures outlined in the SOP for sampling indoor air (Appendix A). The sampling procedures are summarized as follows:

- One location will be selected near the center of the main level of each structure. In structures with basements, an indoor air sample will be collected from the basement as well and will be located as close as practicable to where a subslab sample was collected.
- A 6-L passivated evacuated stainless-steel canister will be used at each location, with a flow control set for 10-hour collection used to encompass the full 10-hour indoor air sampling period. The canister will be positioned 3 to 5 feet off the floor. A digital vacuum gauge will be used to measure the pressure in the canisters before and after sampling.
- The requirement for not touching, moving, or otherwise interfering with the placed canister will be clearly explained to the building occupants. A sign stating DO NOT DISTURB—AIR SAMPLING IN PROGRESS will be placed with the canister during the sample collection period. If the canister is in a closed room, a second, similar sign will be placed on the closed door.

6.3 Pressure-enhanced Indoor Air Sampling (Pressure Cycling)

Pressure-enhanced indoor air sampling (pressure cycling) will also be used, if applicable, as an additional line of evidence during the Phase 4 investigation activities. Pressure cycling may not be applicable to all buildings based on the configuration of the area being investigated. The strategy of pressure cycling is based on onsite analytical methods presented in Mosley (2008, 2010), McHugh et al. (2012a, 2012b), and Air Force Civil Engineer Center (2013) and will be used to evaluate the potential for VI impacts in a building with the goal to induce near worst-case conditions. The pressure cycling approach uses a blower door fan or other fan to create negative pressure conditions indoors that are favorable to VI, or positive pressure conditions that are unfavorable to VI. The method also is referred to as the controlled pressure method (Holton et al., 2015).

The intent of the pressure cycling method is to measure indoor air concentrations under known and uniform negative or positive pressure conditions. The manipulation of VI conditions in this controlled manner reduces the uncertainty in indoor air concentrations created by natural temporal variability, reducing the multiple sampling events required to assess variability by conventional VI investigation methods. It can also help determine whether background sources are contributing to indoor air VOC concentrations. If VI is occurring, this approach also can be used to aid in determining mitigation strategies by understanding vapor entry points into the building, including vapor transport through atypical preferential VI pathways.

The HAPSITE GC/MS will be used during the investigation to provide near-real-time analysis of indoor VOC concentrations during the pressure cycling event.

6.4 Outdoor Sampling Activities

Outdoor air sampling will be performed during the Phase 4 sampling event to assess potential outdoor air sources that may impact indoor air. Four outdoor ambient air samples will be collected during the period of interior vapor sampling to assess the contribution of outdoor, background VOC sources compared to the measured indoor air VOC concentrations. Procedures for placement, setup, and sampling of ambient air will be performed in accordance with the air sampling SOP and involves the following:

- Outdoor air samples will be collected from each of the four property boundaries (see approximate proposed locations on Figure 8.) Actual prevailing wind at the time of sampling will be used to select the final locations along the boundaries.
- Sample canisters will be placed away from busy roads to the extent practicable and set at a height of 3 to 5 feet. For security, the canisters will be secured to immovable objects if possible. A sign stating DO NOT DISTURB—AIR SAMPLING IN PROGRESS will be placed on or near the canister during the sample collection period.
- Four 6-L canisters will be placed along the property boundaries. Canister flow controllers will be set for 10- to 12-hour collection to encompass the full 10-hour indoor door air sampling period. A digital vacuum gauge will be used to measure the pressure in the canisters before and after sampling.
- One outside ambient air duplicate sample will be collected at a location to be determined by the field team leader.
- Following sample collection, the canisters will be labeled and shipped under chain of custody to the approved laboratory for VOC analysis by EPA Method TO-15 SIM.

6.5 Meteorological Data

Meteorological data will be collected in conjunction with the Phase 4 indoor air sample collection. The sampling approach for collecting meteorological data from three weather stations positioned at the site includes:

- Establish weather station location based on existing information related to site features and initial weather data
- Collect prevailing wind direction, wind speed, temperature, and relative humidity data; operate the weather station continuously for 1 week before and simultaneously with Phase 4 investigation activities
- To the extent possible, take measures to protect and secure weather stations and sampling equipment located in public settings against tampering, theft, and potential weather hazards

Predominant wind direction from the prior week's meteorological data will be calculated in the field before air samples are collected using canisters. The predominant wind direction the day of sample collection will be used to adjust the sample locations, as needed, to best assess potential sources. The meteorological and analytical air data may also be used to adjust the final outdoor air sample locations and provide an additional line of evidence when assessing potential outdoor air sources.

6.6 Phase 4 Data Evaluation

If impacts are present in the Phase 4 indoor air samples, a comprehensive evaluation of the data will be conducted to assess whether the impacts appear attributable to the Facility, from background sources located outside, and/or sources inside the building(s).

If it appears impacts associated with Phase 4 indoor air sampling are potentially attributable to the Facility, based on an MLE evaluation, the subslab soil vapor data will be compared to VISLs and the indoor air data will be compared with outdoor air concentrations and with EPA indoor air action levels to determine whether additional investigation or mitigation of indoor air vapors is necessary.

The decision logic used to assess the need for additional investigation or mitigation of indoor air vapors is outlined on Figure 13.

7. Quality Assurance and Quality Control Samples

Tables 3, 7, and 8 summarize the sample quantities, quality control (QC) sample quantities, laboratory methods, screening levels, detection and reporting limits, sample containers, and holding times.

8. Data Validation

Jacobs will validate the analytical results from each phase of investigation. The project chemist will have responsibility for overseeing the data validation effort. Data validation will be carried out when the data packages are received from the laboratory. It will be performed on an analytical batch basis using the summary results of calibration and laboratory QC, as well as those of the associated field samples.

Level 3 data validation of all analytical data will be performed with Level 4 data validation being performed on 10 percent of the analytical data. The Level 3 data validation will include the following:

- Review the data set narrative to identify any issues that the laboratory reported in the data deliverable
- Check sample integrity (sample collection and holding times, canister pressures, etc.)
- Evaluate basic QC measurements used to assess the accuracy, precision, and representativeness of data, including QC blanks, laboratory control samples, matrix spike/matrix spike duplicate, surrogate recovery when applicable, and field or laboratory duplicate results
- Review sample results, target compound lists, and detection limits to verify project analytical requirements were met
- Initiate corrective actions, as necessary, based on the data review findings
- Qualify the data using appropriate qualifier flags, as necessary, to reflect data usability limitations
- Evaluate calibration and QC summary results against the project requirements
- Undertake other method-specific QC requirements

Level 4 data validation includes a review of sample chromatograms and verification of analyte identification and calculations for at least 10 percent of the data for the sampling event chosen for Level 4 validation. The results of the data validation will be provided in a data quality evaluation (DQE) technical memorandum.

9. Reporting

Jacobs will prepare a technical memorandum after each investigation phase is completed. Each technical memorandum will include a summary of the sample collection and analysis completed; an updated conceptual site model and conceptual site exposure model (as needed); a tabular summary of sampling results, including comparison to applicable risk-based screening levels or action levels; figures depicting the analytical results; and a DQE report. The technical memorandum also will include an assessment of whether project DQOs have been achieved or whether additional investigation is required.

Upon completion of the proposed investigations, a comprehensive final report will be prepared evaluating all the phases completed. The final report will be prepared in lieu of the technical memorandum summarizing the activities of the final phase that was completed.

10. Schedule

Table 9 summarizes the anticipated schedule following MoDNR approval of this work plan.

11. References

Air Force Civil Engineer Center. 2013. *Fairchild Air Force Base OU 5, Site SS-39, TCE Orphan Plumes Vapor Intrusion Pathway Evaluation Report*. Revision 0 Draft. October.

City of Springfield. 2018. Letter to Trustee of the Multistate Environmental Response Trust. March 8.

Environmental Works, Inc. 2016. *Remedial Action Optimization Work Plan, Former Tronox Facility 2800 West High Street, Springfield, Missouri RCRA Permit Number MOD007129406*. August 16.

Environmental Works, Inc. 2017. *Indoor Air Work Plan, Former Tronox Facility 2800 West High Street, Springfield, Missouri RCRA Permit Number MOD007129406*. June 27.

Environmental Works, Inc. 2018. *2017 Annual Report, Corrective Action Effectiveness, Former Wood Treating Facility, Springfield, Missouri*. April.

Holton, Chase, Yuanming Guo, Hong Luo, Paul Dahlen, Kyle Gorder, Erik Dettenmaier, and Paul C. Johnson. 2015. "Long-Term Evaluation of the Controlled Pressure Method for Assessment of the Vapor Intrusion Pathway." *Environmental Science & Technology*. Vol. 49, no. 4. pp. 2091–2098.

CH2M. 2018. *Final Indoor Air Sampling: Warm-season Event 2017, Former Tronox/Kerr-McGee Facility, Springfield, Missouri; RCRA Permit No. MOD007129406*. July 5.

Jacobs Engineering Group Inc. (Jacobs). 2018a. *Final Additional Outdoor Air and Indoor Air Confirmatory Sampling: December 2017, Former Tronox/Kerr-McGee Facility, Springfield, Missouri; RCRA Permit No. MOD007129406* October 26.

Jacobs Engineering Group Inc. (Jacobs). 2018b. *Final Indoor Air Sampling: Heating-season Event 2018, Former Tronox/Kerr-McGee Facility, Springfield, Missouri; RCRA Permit No. MOD007129406.* November 2.

Jacobs Engineering Group Inc. (Jacobs). 2018c (in publication). *Draft Indoor Air Sampling: High-water-table Event 2018, Former Tronox Facility, Springfield, Missouri*.

McHugh, T., L. Beckley, and D. Bailey. 2012a. *Final Report, Protocol for Tier 2 Evaluation of Vapor Intrusion at Corrective Action Sites*. ESTCP Project ER-200707. http://www.serdp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-200707.

McHugh, T., L. Beckley, D. Bailey, K. Gorder, E. Dettenmaier, I. Rivera-Duarte, S. Brock, and I.C. MacGregor. 2012b. "Evaluation of Vapor Intrusion Using Controlled Building Pressure." *Environmental Science and Technology*. Vol. 46. pp. 4792–4799.

Missouri Department of Natural Resources (MoDNR). 2006. *Soil Gas Sampling Protocol: Departmental Missouri Risk-Based Corrective Action Technical Guidance*. October. 16 pp. https://dnr.mo.gov//hwp/mrbca/docs/mrbcaappendh.pdf.

Mosley, R.B., D. Greenwell, A. Lee, K. Baylor, M. Plate, and C. Lutes. 2008. Use of Integrated Indoor Radon and Volatile Organic Compounds (VOCs) to Distinguish Soil Sources from Above-Ground Sources. Presented at AWMA Symposium on Air Quality Measurement and Technology. Chapel Hill, NC. November 6.

Mosley, R.B., D. Greenwell, and C.C. Lutes. 2010. Use of Integrated Indoor Concentrations of Tracer Gases and Volatile Organic Compounds (VOCs) to Distinguish Soil Sources from Above-Ground Sources. Presented at Seventh International Remediation of Chlorinated and Recalcitrant Compounds Conference. Monterey, CA. May 24–27.

U.S. Environmental Protection Agency (EPA). 2015a. *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites.* EPA 510-R-15-001. Office of Solid Waste and Emergency Response, Office of Underground Storage Tanks.

U.S. Environmental Protection Agency (EPA). 2015b. OSWER *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Sources to Indoor Air.* OSWER Publication 9200.2-154. Office of Solid Waste and Emergency Response. http://www.epa.gov/oswer/vaporintrusion/.

U.S. Environmental Protection Agency (EPA). 2018a. *Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites*. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables.

U.S. Environmental Protection Agency (EPA). 2018b. *Vapor Intrusion Screening Level (VISL) Calculator. Office of Solid Waste and Emergency Response*. (MS Excel Spreadsheet.) https://www.epa.gov//vapor-intrusion-screening-level-calculator.

Tables

Table 1. Data Quality Objectives

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

#	Issue Statement	Data Collection Objective	Investigation Approach Summary/Scope Overview	Decision Factors/Criteria
	Remedial Action Optimization: Nature and Extent of Contamination—Groundwater, DNAPL			
1	The extent of DNAPL under the GCHD property is not fully defined and potential mobility is unclear.	Evaluate presence or absence of DNAPL in soil cuttings from alluvium/weathered bedrock through Geoprobe borings and in upper bedrock through drilling.	• Push Phase 1 Geoprobe borings (GC-01 through GC-07, and GC-12) to refusal and into weathered bedrock to evaluate the potential presence of DNAPL in shallow portion of the UFZ. • Advance air rotary borings at GC-01, GC-04, and GC-12 into bedrock to further evaluate the potential presence of DNAPL below the weathered bedrock. • Log soil core, observe water saturation level and evidence of DNAPL.	• If DNAPL is found under the Greene County property in a shallow boring (GC-01, GC-06, GC-07,or GC-12), collect additional soil samples to delineate area of DNAPL impact during Phase 2. See Figure 9 for decision criteria.
	The extent of shallow groundwater impacts under the GCHD property is not fully delineated.	Further delineate the extent of the groundwater impacts on GCHD property from the former Tronox Facility and develop a baseline to monitor effects of remedy optimization.	• Check for water accumulation in borings. • At GC-01 and GC-12, construct a permanent well with a screen interval that includes weathered bedrock interface if water is present. • At GC-02 through GC-07, construct a temporary monitoring well with a screen interval that includes weathered bedrock interface if water is present and DNAPL is absent. • Collect groundwater samples for rush turnaround analysis from all newly installed permanent and temporary wells. • Use soil boring and groundwater concentration data to determine whether to designate each temporary wells as permanent or abandon. • Sample permanent wells quarterly for one year. • Analyze water samples from GC-01 through GC-07, and GC-12 for VOCs, SVOCs, TPH-GRO, TPH-DRO to evaluate for Facility-related COCs.	• Temporary shallow wells only installed at GC-02 through GC-07 if water is present and DNAPL is absent • If groundwater concentrations in GC-01, GC-03 through GC-07, or GC-12 are Facility-related and exceed GWPS, collect additional samples to delineate area of groundwater impact during Phase 2. • Sample all permanent wells for groundwater quarterly. All available data will then be used with the trend analysis evaluation to recommend to MoDNR whether each well should be included in the long-term monitoring plan for the Facility or abandoned. See Figure 9 for decision criteria.
	The extent of UFZ bedrock groundwater plume under the GCHD property is not fully defined.	Further define the edge of the UFZ bedrock plume on Greene County property from the former Tronox Facility.	• Install bedrock UFZ wells (GC-01, GC-04, and GC-12) at the GCHD property and field screen for DNAPL impacts. • Install bedrock UFZ wells (GC-08 and GC-09) at the Black Tie Storage Area of the former Tronox Facility to monitor water quality upgradient of the GCHD property. • Sample bedrock wells quarterly for VOCs, SVOCs, TPH-GRO, and TPH-DRO to evaluate for Facility-related COCs.	• If groundwater concentrations at GC-01 or GC-12 exceed GWPS for multiple sampling events, install additional bedrock UFZ well at GC-13. • Re-evaluate sampling frequency after the first year of quarterly data has been evaluated.. See Figure 9 for decision criteria.
	Remedial Action Optimization: Hydrology/Hydrogeology			
2	The groundwater flow direction under the GCHD property and Black Tie Storage Area of the former Tronox Facility needs to be confirmed.	Determine the current groundwater flow direction and compare findings with historical data from wells previously abandoned in this area.	• Monitor depth to groundwater quarterly in wells installed at the GCHD property and Black Tie Storage area to prepare potentiometric surface maps that depict groundwater flow direction.	• When selecting screen intervals for GC-08 and GC-09, evaluate water production during drilling for final well depth, ensure screen is open across the bedrock interface, and that the screen extends to 1 ft above the expected high water level.
	Human Health Risk Assessment—Direct Contact (Construction Workers)			
3	The potential for unacceptable risk to construction workers on the GCHD property associated with subsurface soil or groundwater contamination from the former Tronox property has not been sufficiently evaluated.	Collect soil samples and shallow groundwater samples to help assess risk to potential receptors.	• Phase 1 surficial and subsurface soil, and groundwater sample collection from permanent wells (GC-01 and GC-12) and temporary wells (GC-03 through GC-07; installed only if DNAPL is absent) • Phase 2 soil sample collection as needed	If Phase 1 soil sampling does not sufficiently delineate area of subsurface soil impact related to former Tronox Facility, collect additional samples to delineate during Phase 2 and/or 3.
	Human Health Risk Assessment—Vapor Intrusion (Indoor Workers)			
4	The potential for vapor intrusion (VI) from former Tronox Facility site-related chemicals at the occupied GCHD buildings has not been sufficiently addressed.	Collect multiple lines of evidence (groundwater, soil, soil gas, preferential pathway (sewer line), subslab vapor, and indoor/ outdoor air sample), information on utility and building characteristics; and conduct pressure control testing to assess VI. Collect field measurements of CO2, CH4, and O2 and support the assessment of biodegradation potential (aerobic biodegradation parameters typically measured for petroleum hydrocarbon sites).	Phase 1: Collect and analyze groundwater (from top of water column), soil and soil gas samples for VOCs near boundary with former Tronox property to assess the potential for a vapor intrusion source associated with impacts from the former Tronox Facility operations. Collect headspace samples in the sewer line for VOCs, including one manhole, to assess the potential for the sewer line to act as a preferential VI pathway. Collect fixed-gas samples (CO2, CH4 and O2) using field instrument. Phase 2: Collect and analyze step-out groundwater samples from top of water column to assess the potential for a vapor intrusion source associated with impacts from the former Tronox Facility. Potentially (based on groundwater results) collect and analyze step-out soil and soil gas samples and analyze for VOCs. Collect fixed-gas samples (CO2, CH4, and O2) using field instrument. Phase 3: Collect and analyze step-out groundwater from top of water column samples to assess the potential for a vapor intrusion source associated with impacts from the former Tronox Facility near occupied buildings of interest. Potentially (based on groundwater results) collect and analyze step-out soil and soil gas samples and analyze for VOCs. Collect fixed-gas samples (CO2, CH4, and O2) using field instrument. Phase 4: Collect and analyzed indoor/outdoor air and subslab vapor samples, and conduct pressure control testing [if applicable]) in the occupied buildings on the GCHD property, as needed.	• Comparison to generic risk-based screening levels (applicable to soil gas, groundwater, indoor air, and subslab vapor). • Evaluate available data for source attribution (i.e., related to former Tronox Facility) based on spatial (horizontal & vertical) distribution of concentrations, chemical composition, use of chemical fingerprinting techniques, and conceptual site model (geology, groundwater flow direction, presence of DNAPL, receptors). • Evaluation of bioattenuation potential (fixed-gases, distance to contamination, soil and groundwater concentrations). • Evaluation of indoor air, outdoor air, and subslab sampling results, in conjunction with other lines of evidence (pressure control testing, building characteristics, occupancy, etc.). See Figures 9–13 for decision criteria.

Table 2. Proposed Sampling Locations

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Investigation Phase^{a}	Sample Matrix	No.	Sample Type	Location^{a}	Sample Location Identifier^{a}	Investigation Objective^{b}	Analytes	Notes, including Sample Depth Interval (feet bgs)	Rationale	Decision Logic
1	**Groundwater**	1	Monitoring Well	GC-01	GC-MW-01-S	1, 2, 3, 4	VOCs^{c}, SVOCs^{c}, TPHg, TPHd	Single screen across soil and into top of weathered bedrock. Permanent well.	• Only install wells at GC-02 through GC-07 locations if water present and DNAPL is absent in boring. • Assess the extent of impacted groundwater within the unconsolidated zone and within the uppermost flow zone of the bedrock aquifer. • Assess potential vapor intrusion source. • Confirm groundwater flow direction.	See Figure 9.
		2		GC-01	GC-MW-01-D	1,2		Bottom of screen will be between 30 and 40 ft bgs, based on field observations. Permanent well.		
		3		GC-02	GC-MW-02	1, 2, 3, 4		Temporary (potentially permanent) well screened to just below soil.weathered bedrock interface.		
		4		GC-03	GC-MW-03	1, 2, 3, 4		Temporary (potentially permanent) well screened to just below soil.weathered bedrock interface.		
		5		GC-04	GC-MW-04-S	1, 2, 3, 4		Temporary (potentially permanent) well screened to just below soil.weathered bedrock interface.		
		6			GC-MW-04-D	1,2		Bottom of screen to be located between 30 and 40 ft bgs using field observations.		
		7		GC-05	GC-MW-05	1, 2, 3, 4		Temporary (potentially permanent) well screened to just below soil.weathered bedrock interface.		
		8		GC-06	GC-MW-06	1, 2, 3, 4		Temporary (potentially permanent) well screened to just below soil.weathered bedrock interface.		
		9		GC-07	GC-MW-07	1, 2, 3, 4		Temporary (potentially permanent) well screened to just below soil.weathered bedrock interface.		
		10		GC-08	GC-MW-08	1, 2,3		Single screen crossing bedrock interface and into upper bedrock. Permanent well.		
		11		GC-09	GC-MW-09	1, 2,3		Single screen crossing bedrock interface and into upper bedrock. Permanent well.		
		12		GC-12	GC-MW-12-S	1, 2, 3, 4		Single screen across soil and into top of weathered bedrock. Permanent well.		
		13		GC-12	GC-MW-12-D	1,2		Bottom of screen will be between 30 and 40 ft bgs, based on field observations. Permanent well.		
	Soil	1	Soil Boring	GC-01	GC-SO-01	1, 3, 4	VOCs^{c}, SVOCs^{c}, TPHg, TPHd	Collect samples up to 3 depths targeting 0-2 ft, 5 to 6 ft, and 9 to 10 ft; depths may vary pending water table □	• Assess potential vapor intrusion source. • Assess presence of DNAPL/NAPL (globules). • Assess potential risk to current and future construction workers • Determine presence of groundwater • Phase 2 step-out locations will be advanced immediately if creosote is present	
		2		GC-02	GC-SO-02	1, 3, 4				
		3		GC-03	GC-SO-03	1, 3, 4				
		4		GC-04	GC-SO-04	1, 3, 4				
		5		GC-05	GC-SO-05	1, 3, 4				
		6		GC-06	GC-SO-06	1, 3, 4				
		7		GC-07	GC-SO-07	1, 3, 4				
		8		GC-08	GC-SO-08	1, 3, 4				
		9		GC-09	GC-SO-09	1, 3, 4				
		10		GC-12	GC-SO-12	4				
	Soil Gas (Exterior)	1	Air (Canister)	GC-01	GC-SG-01	4	VOCs^{c}	Up to 3 depths based on depth to top of water column and separated by a minimum of 4 to 5 feet. The first sample is at ~5 feet bgs: 1) 5 feet bgs; 2) between 5 and top of water column; and 3) 1 foot above top of water column .	• Assess potential vapor intrusion source. • Assess potential vapor intrusion risk to future workers	
		2		GC-02	GC-SG-02	4				
		2		GC-03	GC-SG-03	4				
		3		GC-04	GC-SG-04	4				
		4		GC-05	GC-SG-05	4				
		5		GC-06	GC-SG-06	4				
		6		GC-07	GC-SG-07	4				
		7		GC-08	GC-SG-08	4				
		8		GC-09	GC-SG-09	4				
		9		GC-12	GC-SG-12	4				
	Sewer Line Clean-Out Headspace	1	Air (Canister)	GC-SC-01	GC-SC-01	4	VOCs^{c}	Sewer pipeline cleanout from northern portion of GCHD property to GC-B1 and GC-B2. Including cleanout directly at buildings (GC-SC-14 and GC-SC-15).	• Assess potential vapor intrusion source. • Assess potential vapor intrusion preferential pathway and need for further investigation.	See Figure 10.
		2		GC-SC-02	GC-SC-02	4				
		3		GC-SC-03	GC-SC-03	4				
		4		GC-SC-04	GC-SC-04	4				
		5		GC-SC-05	GC-SC-05	4				
		6		GC-SC-06	GC-SC-06	4				
		7		GC-SC-07	GC-SC-07	4				
		8		GC-SC-08	GC-SC-08	4				
		9		GC-SC-09	GC-SC-09	4				
		10		GC-SC-10	GC-SC-10	4				
		11		GC-SC-11	GC-SC-11	4				
		12		GC-SC-12	GC-SC-12	4				
		13		GC-SC-13	GC-SC-13	4				
		14		GC-SC-14	GC-SC-14	4				
		15		GC-SC-15	GC-SC-15	4				
		16		GC-SC-16	GC-SC-16	4				
		17		GC-SC-17	GC-SC-17	4				
	Manhole Headspace	1	Air (Canister)	GC-MH-01	GC-MH-01 (SW-15)	4	VOCs^{c}	Manhole (re-sample, sample [SW-15] collected on August 22, 2018)		
		2		GC-MH-02	GC-MH-02	4		Manhole (O/W Separator)		
		3		GC-MH-03	GC-MH-03	4		Manhole (wash-down pad)		

Table 2. Proposed Sampling Locations

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Investigation Phase[a]	Sample Matrix	No.	Sample Type	Location[a]	Sample Location Identifier[a]	Investigation Objective[b]	Analytes	Notes, including Sample Depth Interval (feet bgs)	Rationale	Decision Logic
2	**Groundwater**	1	Monitoring Well	GC-11	GC-MW-11	1, 2, 3, 4	VOCs[c], SVOCs[c], TPHg, TPHd	Contingency for shallow impact at GC-04 or GC-05. Screened across soil and into weathered bedrock	Step-out location to assess the extent of impacted groundwater within the unconsolidated zone.	See Figures 9, 10 and 11.
		2		GC-12	GC-MW-12	1, 2, 3, 4		Resample GC-MW-12		
		3		GC-13	GC-MW-13-S	1, 2, 3, 4		Contingency for shallow impact at GC-01 or GC-12. Screened across soil and into weathered bedrock		
		4		GC-13	GC-MW-13-D	1,2		Contingency for bedrock impact at GC-01 or GC-12. Bottom of screen to be located between 30 and 40 ft bgs using field observations.	Step-out location to assess the extent of impacted groundwater within bedock of the upper flow zone.	
		5		GC-19	GC-MW-19	1, 2, 3, 4		Contingency for shallow impact at GC-06 or GC-07. Screened across soil and into weathered bedrock	Step-out locations to assess the extent of impacted groundwater within the unconsolidated zone.	
		6	Discrete (Grab) Sample	GC-10	GC-GW-10	4		Top of water column	Step-out locations to characterize potential vapor intrusion source in proximity to occupied buildings.	
		7		GC-11	GC-GW-11	4				
		8		GC-13	GC-GW-13	4				
		9		GC-14	GC-GW-14	4				
		10		GC-15	GC-GW-15	4				
		11		GC-16	GC-GW-16	4				
	Soil	1	Soil Boring	GC-10	GC-SO-10	4	VOCs[c], SVOCs[c], TPHg, TPHd (Hold for analysis pending groundwater sampling results)	Up to 3 depths down to 10 feet bgs based on depth to water table and separated by a minimum of 4 feet. The first sample is 1 foot below the asphalt layer. For example, 1) 1 to 2 ; 2) 5 to 6; and 3) 9 to 10 feet bgs.	Step-out locations to characterize potential vapor intrusion source in proximity to occupied buildings and DNAPL impacts (GC-10, GC-13, GC-20 step-outs for DNAPL)	
		2		GC-11	GC-SO-11	1,4				
		3		GC-13	GC-SO-13	1,4				
		4		GC-14	GC-SO-14	4				
		5		GC-15	GC-SO-15	4				
		6		GC-16	GC-SO-16	4				
		7		GC-19	GC-SO-19	1,4				
		8 to 12		TBD	TBD	1, 2, 3, 4		Location and number of samples and the sample depth intervals to be based on field observations during trenching activities.	Locations to characterize terminus of the previously unknown sewer line.	
2	**Soil Gas (Exterior)**	1	Air (Canister)	GC-10	GC-SG-10	4	VOCs[c]	Up to 3 depths based on depth to top of water column and separated by a minimum of 4 to 5 feet. The first sample is at ~5 feet bgs: 1) 5 feet bgs; 2) btw. 5 and top of water column; and 3) 1 foot above top of water column	• Step-out locations to characterize potential vapor intrusion source in proximity to occupied buildings. • Assess potential vapor intrusion risk to future workers	See Figure 12.
		2		GC-11	GC-SG-11	4				
		3		GC-13	GC-SG-13	4				
		4		GC-14	GC-SG-14					
		5		GC-15	GC-SG-15	4				
		6		GC-16	GC-SG-16	4				
3	**Groundwater**	1	Monitoring Well	GC-17	GC-GW-17	4	VOCs[c], SVOCs[c], TPHg, TPHd	Top of water table	Step-out locations to characterize potential vapor intrusion source in proximity to occupied buildings.	See Figure 12.
		2		GC-18	GC-GW-18	4				
	Soil	1	Soil Boring	GC-17	GC-SO-17	4	VOCs[c], SVOCs[c], TPHg, TPHd (Hold for analysis pending groundwater sampling results)	Up to 3 depths based on depth to water table and separated by a minimum of 4 feet. The first sample is 1 foot below the asphalt layer. For example, 1) 1 to 2 feet; 2) 5 to 6; and 3) 9 to 10 feet (if applicable).	Step-out locations to characterize potential vapor intrusion source in proximity to occupied buildings.	
		2		GC-18	GC-SO-18	4				
	Soil Gas (Exterior)	1	Air (Canister)	GC-17	GC-SG-17	4	VOCs[c]	Up to 3 depths based on depth to top of water column and separated by a minimum of 4 to 5 feet. The first sample is at ~5 feet bgs: 1) 5 feet bgs; 2) btw. 5 and top of water column; and 3) 1 foot above top of water column.	• Step-out locations to characterize potential vapor intrusion source in proximity to occupied buildings. • Assess potential vapor intrusion risk to future workers	
		2		GC-18	GC-SG-18	4				
4	**Subslab Vapor**	1	Air (Canister)	GC-B1	GC-B1-SSV-01	4	VOCs[c]	Beneath foundation	• Assess vapor intrusion potential (source characterization) beneath occupied buildings. • Assess vapor intrusion risk for future workers.	See Figure 13.
		2	Air (Canister)	GC-B1	GC-B1-SSV-02	4				
		3	Air (Canister)	GC-B1	GC-B1-SSV-03	4				
		4	Air (Canister)	GC-B1	GC-B1-SSV-04	4				
		5	Air (Canister)	GC-B1	GC-B1-SSV-05	4				
		6	Air (Canister)	GC-B1	GC-B1-SSV-06	4				
		7	Air (Canister)	GC-B1	GC-B1-SSV-07	4				
		8	Air (Canister)	GC-B1	GC-B1-SSV-08	4				
		9	Air (Canister)	GC-B2	GC-B2-SSV-01	4				
		10	Air (Canister)	GC-B2	GC-B2-SSV-02	4				
		11	Air (Canister)	GC-B2	GC-B2-SSV-03	4				
		12	Air (Canister)	GC-B2	GC-B2-SSV-04	4				
		13	Air (Canister)	GC-B2	GC-B2-SSV-05	4				
		14	Air (Canister)	GC-B2	GC-B2-SSV-06	4				
	Indoor Air	1	Air (Canister)	GC-B1	GC-B1-IA-01	4	VOCs[c]	Breathing zone	Assess vapor intrusion risk within occupied buildings for current workers.	
		2		GC-B1	GC-B1-IA-02	4				
		3		GC-B1	GC-B1-IA-03	4				
		4		GC-B1	GC-B1-IA-04	4				
		5		GC-B1	GC-B1-IA-05	4				
		6		GC-B1	GC-B1-IA-06	4				
		7		GC-B1	GC-B1-IA-07	4				
		8		GC-B1	GC-B1-IA-08	4				
		9		GC-B2	GC-B2-IA-01	4				
		10		GC-B2	GC-B2-IA-02	4				
		11		GC-B2	GC-B2-IA-03	4				
		12		GC-B2	GC-B2-IA-04	4				
		13		GC-B2	GC-B2-IA-05	4				
		14		GC-B2	GC-B2-IA-06	4				
	Outdoor Air	1	Air (Canister)		GC-OA-01	4	VOCs[c]	Breathing zone	Assess background outdoor air concentrations in proximity to Greene County Highway Department	
		2			GC-OA-02	4				
		3			GC-OA-03	4				
		4			GC-OA-04	4				
	Meteorological	1	Weather Station		WS-H	4	d	N/A	Collect meteorological data to support vapor intrusion investigation.	
		2			WS-M	4	d	N/A		
		3			WS-A	4	d	N/A		

Notes:

[a] Phase 2, 3, and 4 sample locations and the number of samples are considered an initial proposal based on current understanding of conditions and are subject to change based on information gathered during a completed investigation phase.

[b] See Table 1, Data Quality Objectives.

[c] Petroleum-related VOCs and SVOCs including benzene, ethylbenzene, toluene, xylenes and naphthalene (BTEXN) and polyaromatic hydrocarbons (PAHs), gasoline-range total petroleum hydrocarbons (TPHg) and diesel-range total petroleum hydrocarbons (TPHd).

[d] Wind direction, wind speed, temperature, relative humidity and barometric pressure.

N/A = not applicable

Site Char. = site characterization

SVOCs = semi-volatile organic compounds

VOCs = volatile organic compounds

Table 3. Sample Matrix, Analytical Methods, and Sample Quantity Summary

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

				Phase 1						Phase 2						Phase 3						Phase 4						
Matrix	Sample Duration	Analyte	Analytical Method	Normal Samples	Field Duplicates	Trip Blanks	MS	MSD	Number of Samples	Normal Samples	Field Duplicates	Trip Blanks	MS	MSD	Number of Samples	Normal Samples	Field Duplicates	Trip Blanks	MS	MSD	Number of Samples	Normal Samples	Field Duplicates	Trip Blanks	MS	MSD	Number of Samples	Total Number of Samples
Groundwater - Monitoring Well	NA	VOCs, TPH	SW8260B, SW8015C	13	1	1	1	1	17	11	1	0	1	1	14	2	0	0	0	0	2	0	0	0	0	0	0	33
Groundwater - Monitoring Well	NA	SVOCs	SW8270D, SW8270D SIM	13	1	NA	1	1	16	11	1	NA	1	1	14	2	0	NA	0	0	2	0	0	0	0	0	0	32
Soil	NA	VOCs, TPH	SW8260B, SW8015C	34	3	3	1	1	42	7	1	3	1	1	13	2	0	1	1	1	5	0	0	0	0	0	0	60
Soil	NA	SVOCs	SW8270D; SW8270D SIM	34	3	NA	1	1	39	7	1	NA	1	1	10	2	0	NA	1	1	4	0	0	0	0	0	0	53
Soil Gas (exterior)	5-minute	VOCs	EPA Method TO-15	27	3	NA	NA	NA	30	18	2	NA	NA	NA	20	2	0	NA	NA	NA	2	0	0	NA	NA	NA	0	52
Sewer Line Cleanout Headspace Air	24-hour	VOCs	EPA Method TO-15 SIM[a,b]	17	2	0	0	0	19	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	20
Sewer Gas Headspace Air	24-hour	VOCs	EPA Method TO-15 SIM[a,b]	3	1	NA	NA	NA	4	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	4
Indoor/Crawlspace Air - Canister[c]	10-hour	VOCs	EPA Method TO-15 SIM	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	14	1	NA	NA	NA	15	15
Subslab Air[c]	5-minute	VOCs	EPA Method TO-15[a]	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	14	1	NA	NA	NA	15	15
Subslab Air[c]	25-minute	VOCs	EPA Method TO-15 SIM[a,b]	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	14	1	NA	NA	NA	15	15
Outdoor Air - Canister	12-hour	VOCs	EPA Method TO-15 SIM	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	0	0	NA	NA	NA	0	4	1	NA	NA	NA	5	5

Notes:

MS = matrix spike
MSD = matrix spike duplicate QC samples
QC = quality control
EPA = U.S. Environmental Protection Agency
NA = not applicable

[a] Includes ASTM D1946-Helium for leak check.

[b] Initial analysis using 1-liter canisters and EPA Method TO-15. Laboratory will analyze 6-liter canisters, if low levels using EPA Method TO-15 SIM seen in 1-liter canisters.

[c] Estimated, subject to change based on building survey.

Table 4. Phase 1 Investigation Plan—DNAPL Delineation and Soil Sampling

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Objectives:

(1) Delineate extents of DNAPL and impacted soil attributable to the Facility on western and northern part of GCHD property

(2) Assess potential risk exposure from impacted soil to construction workers in western part of GCHD property and south of GCHD on Facility property for future land use

(3) Assess vapor intrusion potential from impacted soil in western part of GCHD property

Field Method	Sampling Plan	Target Analytes	Method	Key Factors
Direct push Geoprobe (GC-01 through GC-07, and GC-12 on Figure 5)	1. Push eight borings to refusal 2. Log soil core, observe water saturation level and evidence of DNAPL or other indication of creosote impact	Lithology, moisture, stains, DNAPL, creosote staining, creosote odor, vapor readings	Visual, PID, UV light	• Push to and into weathered bedrock as able • Complete detailed log • Leave boring open with 1-in. PVC screen inserted up to 24 hours to check for water accumulation
Same borings as above (GC-01 through GC-07, and GC-12)	Collect soil samples at up to three depth intervals per boring for analysis. Target 0–2 ft, 5–6 ft, 9–10 ft	VOCs, SVOCs, TPH-GRO, TPH-DRO	8260B, 8270D, 8015C	• Shallow, mid-depth, deep samples needed for evaluating different exposure pathways • Use visual & PID results to target specific samples in depth ranges • Sample just above 10 ft needed for construction worker exposure evaluation
Direct push Geoprobe (GC-08 and GC-09 on Figure 5)	1. Push two borings to refusal 2. Log soil core, observe water saturation level and evidence of impact 3. Collect soil samples at up to three depth intervals per boring for analysis. Target 0–2 ft, 5–6 ft, 9–10 ft	Lithology, moisture, stains, odors, vapor readings, VOCs, SVOCs, TPH-GRO, TPH-DRO	Visual, PID, UV light, 8260B, 8270D, 8015C	• Shallow, mid-depth, deep samples needed for evaluating different exposure pathways • Use visual & PID results to target specific samples in depth ranges • Sample just above 10 ft needed for construction worker exposure evaluation

Table 5. Phase 1 Investigation Plan—Shallow Monitoring Wells

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Objectives:

(1) Delineate extents of DNAPL and impacted groundwater attributable to the Facility on western and northern part of GCHD property

(2) Assess potential risk exposure from impacted groundwater to construction workers in western part of GCHD property

(3) Assess vapor intrusion potential from shallow impacted groundwater in western part of GCHD property

Field Method	Sampling Plan	Target Analytes	Method	Key Factors
Install shallow monitoring wells at boring locations GC-01 and GC-12 that accumulate water	1. Measure water in Geoprobe borings for up to 24 hours (see Table 4) 2. Install permanent monitoring well in borings with water 3. Collect groundwater samples for analysis using low flow sampling technique	Accumulated water volume, VOCs, SVOCs, TPH-GRO, TPH-DRO	Water Level meter, Overdrill with augers 1–2 ft into top of bedrock, 8260B, 8270D, 8015C	• Drill into bedrock 1–2 ft • Only construct wells in borings with water • Screen from bottom up to 1 ft above highest water level data from nearby existing wells • Abandon dry borings or use as soil vapor points • Build wells & abandon borings per Missouri Well Construction Rules with subsurface vault completion • Install step-out shallow well near GC-13 if creosote impact or GWPS exceeded at GC-01 or GC-12. •Sample quarterly for one year. Use data obtained to determine an approrpiate sampling frequency for the long-term monitoring program. •All available data will be used with the trend analysis evaluation to recommend to MoDNR whether each well should be included in the long-term monitoring plan for the Facility or abandoned.
Install temporary shallow monitoring wells at boring locations GC-02 through GC-07 that accumulate water and had no observable DNAPL or creosote impacts in boring	1. Measure water in Geoprobe borings for up to 24 hours (see Table 4) 2. Install temporary monitoring wells in borings with both water and no creosote impacts. 3. Develop well. 4. Collect groundwater samples for "rush" turnaround using low-flow sampling technique. 5. Use results from groundwater samples to determine monitoring wells to designate as permanent (up to 3 locations) or abandon. 6. Complete temporary wells as permanent or abandon well within 30 days to comply with Missouri regulations.	Accumulated water volume, VOCs, SVOCs, TPH-GRO, TPH-DRO	Water Level meter, Overdrill with augers 1–2 ft into top of bedrock, 8260B, 8270D, 8015C	• Drill into bedrock 1–2 ft •Only install temporary wells at borings where no creosote impact was observed in soil samples. •Number and location of permanent wells subject to comprehensive review of soil and groundwater data from entire transect of locations GC-02 through GC-07 • Screen from bottom up to 1 ft above highest water level data from nearby existing wells • Abandon dry borings or use as soil vapor points • Well construction and abandonment implemented in accodance with Missouri Well Construction Rules • Complete permanent wells in traffic-rated vaults with flush-mount completion. •Sample permanent wells quarterly for one year. Use data obtained to determine if well should be abandoned or included (and at what frequency) in the long-term monitoring program." •All available data will be used with the trend analysis evaluation to recommend to MoDNR whether each well should be included in the long-term monitoring plan for the Facility or abandoned.

Table 6. Phase 1 Investigation Plan—Bedrock Monitoring Wells

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Objectives:

(1) Delineate edge of the UFZ groundwater plume across the northern GCHD property

(2) Confirm UFZ groundwater flow direction and water quality near southern GCHD property

Field Method	Sampling Plan	Target Analytes	Method	Key Factors
Install bedrock wells (air rotary drill rig) (GC-01, GC-04, GC-12 on Figure 5)	1. Log cuttings, void/fracture indications, note staining, creosote odor, vapor readings, water production 2. Develop well 3. Collect water samples using low flow sampling technique	Top of bedrock, voids, odor, DNAPL, creosote staining, creosote odor, vapor readings, moisture, water level, VOCs, SVOCs, TPH-GRO, TPH-DRO	Field screen, PID, binocular microscope, water level meter, 8260B, 8270D, 8015C	• Drill to target 30 ft. If no indication of voids or impact, wait 30 minutes to check for water production. If no water, drill additional 5 ft, check again, and repeat up to 40 ft depth • Screen well to include horizons of voids, fractures, PID readings, and/or water production. Include bedrock interface within screen if bedrock 10 ft or more deep • Install step-out bedrock well near GC-13 if creosote impact or GWPS exceeded in bedrock borings at GC-01 or GC-12. •Sample quarterly for one year. Use data obtained to determine an approrpiate sampling frequency for the long-term monitoring program. •All available data will be used with the trend analysis evaluation to recommend to MoDNR whether each well should be included in the long-term monitoring plan for the Facility or abandoned.
Install bedrock wells (air rotary drill rig) (GC-08 and GC-9 on Figure 5)	1. Log cuttings, void/fracture indications, note staining, creosote odor, vapor readings, water production 2. Develop well 3. Collect water samples using low flow sampling technique	Top bedrock, voids, odor, vapor readings, moisture, creosote, water level, VOCs, SVOCs, TPH-GRO, TPH-DRO	Field screen, PID, binocular microscope, water level meter, 8260B, 8270D, 8015C	• Drill to target 5 ft below top of bedrock. Wait 30 minutes to check for water production. If no water, drill additional 5 ft and check again, repeat to maximum depth of 20 ft below ground surface. • Screen well to be 1 ft above highest expected water level and include horizons of voids, fractures, PID readings, and/or water production

Table 7. Analytes, Laboratory Analytical Methods, Screening Levels, Detection Limits, and Reporting Limits

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

						Air Samples					Water Samples					Soil Samples				
Chemical	CAS No.	Notes	Analytical Method	Method Detection Limit [µg/m3]	Reporting Limit [µg/m3]	Analytical Method	Method Detection Limit [µg/m3]	Reporting Limit [µg/m3]	EPA RSL [a] - Industrial Air [µg/m3]	EPA VISL[b] - Industrial Sub-slab Vapor and Near-Source Soil Gas [µg/m3]	Analytical Method (Groundwater)	Method Detection Limit [µg/L]	Reporting Limit [µg/L]	Groundwater Protection Standard (GWPS) [c] [µg/L]	EPA VISL[b] - Groundwater [µg/L]	Analytical Method - Soil	Method Detection Limit [mg/kg]	Reporting Limit [mg/kg]	EPA RSL [a] - Industrial Soil [mg/kg]	EPA Protection of Groundwater SSL [c] - Risk-based (mg/kg)	EPA Protection of Groundwater SSL [c] - MCL - based (mg/kg)
Gasoline Range Organics (GRO) [d]	E1790672		TO-15	NA	NA	NA	NA	NA	130	4300	SW8015C	11	50	NA	570	SW8015C	0.18	1	420	0.017	--
Diesel Range Organics (DRO) [e]	E1790674		TO-15	NA	NA	NA	NA	NA	13	430	SW8015C	45	100	NA	660	SW8015C	4	12	600	0.023	--
Total Petroleum Hydrocarbons	TPH		TO-16				TO-15 SIM		--	--					--				--	--	--
1,1,1-Trichloroethane	71-55-6		TO-15	0.382	2.7	TO-15 SIM	0.207	0.11	22000	730000	SW8260B	1	0.2	--	31000	SW8260B	0.0004	0.005	36000	2.8	0.07
1,1,2,2-Tetrachloroethane	79-34-5		TO-15	1.236	3.4	TO-15 SIM	0.172	0.14	0.21	7	SW8260B	1	0.2	--	14	SW8260B	0.0003	0.005	2.7	0.00003	--
1,1,2-Trichloroethane	79-00-5		TO-15	0.273	2.7	TO-15 SIM	0.229	0.11	0.77	26	SW8260B	1	0.2	--	23	SW8260B	0.0003	0.005	5	0.000089	0.0016
1,1-Dichloroethane	75-34-3		TO-15	0.486	2	TO-15 SIM	0.158	0.081	7.7	260	SW8260B	1	0.2	--	34	SW8260B	0.0004	0.005	16	0.00078	--
1,1-Dichloroethene	75-35-4		TO-15	0.714	2	TO-15 SIM	0.21	0.04	880	29000	SW8260B	1	0.2	--	830	SW8260B	0.0004	0.005	1000	0.1	0.0025
1,2,4-Trichlorobenzene	120-82-1		TO-15	1.484	15	TO-15 SIM	NA	NA	8.8	290	SW8260B	5	0.4	--	150	SW8260B	0.0008	0.005	110	0.0034	0.2
1,2,4-Trimethylbenzene	95-63-6		TO-15	1.426	2.4	TO-15 SIM	NA	NA	260	8700	SW8260B	5	0.3	--	1000	SW8260B	0.0006	0.005	1800	0.081	--
1,2-Dibromo-3-chloropropane	96-12-8		TO-15	NA	NA	TO-15 SIM	NA	NA	0.002	0.067	SW8260B	5	1	--	0.33	SW8260B	0.0003	0.005	0.064	0.00000014	0.000086
1,2-Dibromoethane	106-93-4		TO-15	0.768	3.8	TO-15 SIM	0.284	0.15	0.02	0.67	SW8260B	1	0.3	--	0.75	SW8260B	0.0003	0.005	0.16	0.0000021	0.000014
1,2-Dichlorobenzene	95-50-1		TO-15	0.601	3	TO-15 SIM	NA	NA	880	29000	SW8260B	5	0.2	--	11000	SW8260B	0.0004	0.005	9300	0.3	0.58
1,2-Dichloroethane	107-06-2		TO-15	0.648	2	TO-15 SIM	0.194	0.081	0.47	16	SW8260B	5	2	--	9.7	SW8260B	0.0003	0.005	2	0.000048	0.0014
1,2-Dichloropropane	78-87-5		TO-15	1.017	2.3	TO-15 SIM	NA	NA	3.3	110	SW8260B	1	0.2	--	29	SW8260B	0.0004	0.005	11	0.00028	0.0017
1,3,5-Trimethylbenzene	108-67-8		TO-15	0.836	2.4	TO-15 SIM	NA	NA	260	8700	SW8260B	5	0.3	--	730	SW8260B	0.0005	0.005	1500	0.087	--
1,3-Dichlorobenzene	95-50-1		TO-15	0.601	1.1	TO-15 SIM	NA	NA	880	29000	SW8260B	5	0.2	--	11000	SW8260B	0.0004	0.005	9300	0.3	0.58
1,4-Dichlorobenzene	106-46-7		TO-15	0.541	3	TO-15 SIM	0.216	0.12	1.1	37	SW8260B	5	0.2	--	11	SW8260B	0.0004	0.005	11	0.00046	0.072
2-Butanone	78-93-3		TO-15	0.767	5.9	TO-15 SIM	NA	NA	22000	730000	SW8260B	10	1	--	9500000	SW8260B	0.001	0.01	190000	1.2	--
2-Hexanone	591-78-6		TO-15	0.574	8.2	TO-15 SIM	NA	NA	130	4300	SW8260B	10	3	--	34000	SW8260B	0.001	0.01	1300	0.0088	--
4-Methyl-2-pentanone	108-10-1		TO-15	0.901	2	TO-15 SIM	NA	NA	13000	430000	SW8260B	10	0.5	--	2300000	SW8260B	0.001	0.01	140000	1.4	--
Acetone	67-64-1		TO-15	1.853	12	TO-15 SIM	NA	NA	140000	4700000	SW8260B	20	0.8	--	98000000	SW8260B	0.006	0.02	670000	2.9	--
Benzene	71-43-2		TO-15	0.019	0.16	TO-15 SIM	0.019	0.16	1.6	53	SW8260B	0.2	1	5	7.1	SW8260B	0.0004	0.005	5.1	0.00023	0.0026
Bromodichloromethane	75-27-4		TO-15	0.335	3.40	TO-15 SIM	NA	NA	0.33	11	SW8260B	1	0.2	--	3.8	SW8260B	0.0003	0.005	1.3	0.000036	0.022
Bromoform	75-25-2		TO-15	1.654	5.20	TO-15 SIM	NA	NA	11	370	SW8260B	5	2	--	500	SW8260B	0.004	0.01	86	0.00087	0.021
Bromomethane	74-83-9		TO-15	0.583	19.00	TO-15 SIM	NA	NA	22	730	SW8260B	1	0.5	--	73	SW8260B	0.0008	0.005	30	0.0019	--
Carbon disulfide	75-15-0		TO-15	3.55	6.20	TO-15 SIM	NA	NA	3100	100000	SW8260B	5	0.3	--	5300	SW8260B	0.0004	0.005	3500	0.24	--
Carbon tetrachloride	56-23-5		TO-15	0.315	3.10	TO-15 SIM	0.403	0.12	2	67	SW8260B	1	0.2	--	1.8	SW8260B	0.0005	0.005	2.9	0.00018	0.0019
Chlorobenzene	108-90-7		TO-15	0.184	2.30	TO-15 SIM	NA	NA	220	7300	SW8260B	1	0.2	--	1700	SW8260B	0.0004	0.005	1300	0.053	0.068
Chloroethane	75-00-3		TO-15	0.449	5.30	TO-15 SIM	0.222	0.13	44000	1500000	SW8260B	1	0.3	--	97000	SW8260B	0.002	0.005	57000	5.9	--
Chloroform	67-66-3		TO-15	0.244	2.40	TO-15 SIM	0.391	0.10	0.53	18	SW8260B	1	0.2	--	3.5	SW8260B	0.0004	0.005	1.4	0.000061	0.022
Chloromethane	74-87-3		TO-15	0.991	10.00	TO-15 SIM	0.297	1.00	390	13000	SW8260B	1	0.3	--	1100	SW8260B	0.0005	0.005	460	0.049	--
cis-1,2-Dichloroethene	156-59-2		TO-15	0.436	2.00	TO-15 SIM	0.163	0.08	--	--	SW8260B	1	0.2	--	--	SW8260B	0.0005	0.005	2300	0.011	0.021
cis-1,3-Dichloropropene	10061-01-5		TO-15	0.635	2.30	TO-15 SIM	NA	NA	--	--	SW8260B	1	0.2	--	--	SW8260B	0.0004	0.005	--	--	--
Cyclohexane	110-82-7		TO-15	0.241	1.70	TO-15 SIM	NA	NA	26000	870000	SW8260B	5	2	--	4200	SW8260B	0.0005	0.005	27000	13	--
Dibromochloromethane	124-48-1		TO-15	0.682	4.20	TO-15 SIM	NA	NA	--	--	SW8260B	1	0.4	--	--	SW8260B	0.003	0.008	39	0.00023	0.021
Dichlorodifluoromethane	75-71-8		TO-15	NA	NA	TO-15 SIM	NA	NA	440	15000	SW8260B	1	0.3	--	31	SW8260B	0.0004	0.005	370	0.3	--
Ethylbenzene	100-41-4		TO-15	0.46	2.20	TO-15 SIM	0.009	0.09	4.9	160	SW8260B	0.2	1	700	15	SW8260B	0.0004	0.005	25	0.0017	0.78
Freon 113	76-13-1		TO-15	0.766	3.80	TO-15 SIM	NA	NA	22000	730000	SW8260B	10	2	--	1000	SW8260B	0.0004	0.01	28000	26	--
Isopropylbenzene	98-82-8		TO-15	NA	NA	TO-15 SIM	NA	NA	1800	60000	SW8260B	5	0.3	--	3800	SW8260B	0.0005	0.005	9900	0.74	--
Methyl acetate	79-20-9		TO-15	NA	NA	TO-15 SIM	NA	NA	--	--	SW8260B	5	0.6	--	--	SW8260B	0.001	0.005	1200000	4.1	--
Methyl tert-butyl ether	1634-04-4		TO-15	0.577	7.20	TO-15 SIM	0.105	0.36	47	1600	SW8260B	1	0.2	--	2000	SW8260B	0.0005	0.005	210	0.0032	--
Methylcyclohexane	108-87-2		TO-15	NA	NA	TO-15 SIM	NA	NA	--	--	SW8260B	5	0.2	--	--	SW8260B	0.0006	0.005	--	--	--
Methylene chloride	75-09-2		TO-15	0.625	17.00	TO-15 SIM	NA	NA	1200	40000	SW8260B	1	0.2	--	9000	SW8260B	0.001	0.005	1000	0.0029	0.0013
Naphthalene	91-20-3		TO-15	0.105	5.20	TO-15 SIM	0.031	0.26	0.36	12	SW8260B	--	--	20	20	SW8260B	--	--	17	0.00054	--
Styrene	100-42-5		TO-15	0.511	2.10	TO-15 SIM	NA	NA	4400	150000	SW8260B	5	0.2	--	39000	SW8260B	0.0004	0.005	35000	1.3	0.11
Tetrachloroethene	127-18-4		TO-15	0.678	3.40	TO-15 SIM	0.387	0.14	47	1600	SW8260B	1	0.2	--	65	SW8260B	0.0005	0.005	100	0.0051	0.0023
Toluene	108-88-3		TO-15	0.603	1.90	TO-15 SIM	0.038	0.08	22000	730000	SW8260B	0.2	1	1,000	81000	SW8260B	0.0003	0.005	47000	0.76	0.69
trans-1,2-Dichloroethene	156-60-5		TO-15	0.678	3.40	TO-15 SIM	0.254	0.40	--	--	SW8260B	1	0.2	--	--	SW8260B	0.0004	0.005	23000	0.11	0.031
trans-1,3-Dichloropropene	10061-02-6		TO-15	0.678	3.40	TO-15 SIM	NA	NA	--	--	SW8260B	1	0.2	--	--	SW8260B	0.0003	0.005	--	--	--
Trichloroethene	79-01-6		TO-15	0.43	2.70	TO-15 SIM	0.21	0.11	3	100	SW8260B	1	0.2	--	7.4	SW8260B	0.0004	0.005	6	0.00018	0.0018
Trichlorofluoromethane	75-69-4		TO-15	NA	NA	TO-15 SIM	NA	NA	--	--	SW8260B	1	0.4	--	--	SW8260B	0.0006	0.005	350000	3.3	--

Table 7. Analytes, Laboratory Analytical Methods, Screening Levels, Detection Limits, and Reporting Limits

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

						Air Samples					Water Samples					Soil Samples					
Chemical	CAS No.	Notes	Analytical Method	Method Detection Limit [µg/m3]	Reporting Limit [µg/m3]	Analytical Method	Method Detection Limit [µg/m3]	Reporting Limit [µg/m3]	EPA RSL ^{a} - Industrial Air [µg/m3]	EPA VISL^{b} - Industrial Sub-slab Vapor and Near-Source Soil Gas [µg/m3]	Analytical Method (Groundwater)	Method Detection Limit [µg/L]	Reporting Limit [µg/L]	Groundwater Protection Standard (GWPS) ^{c} [µg/L]	EPA VISL^{b} - Groundwater [µg/L]	Analytical Method - Soil	Method Detection Limit [mg/kg]	Reporting Limit [mg/kg]	EPA RSL ^{a} - Industrial Soil [mg/kg]	EPA Protection of Groundwater SSL ^{c} - Risk-based (mg/kg)	EPA Protection of Groundwater SSL ^{c} - MCL - based (mg/kg)
Vinyl chloride	75-01-4		TO-15	0.716	1.30	TO-15 SIM	0.148	0.03	2.8	93	SW8260B	1	0.4	--	2.5	SW8260B	0.0005	0.005	1.7	0.0000065	0.00069
Total Xylenes	1330-20-7		TO-15	NA	NA	TO-15 SIM	NA	0.17	440	15000	SW8260B	0.5	5	10,000	1600	SW8260B	0.0009	0.005	2500	0.19	9.9
o-Xylene	95-47-6		TO-15	0.651	2.20	TO-15 SIM	0.004	0.09	440	15000	SW8260B	--	--	10,000	2100	SW8260B	--	--	2800	0.19	--
m,p-Xylenef	108-38-3, 106-42-3		TO-15	0.347	2.20	TO-15 SIM	0.009	0.17	440	15000	SW8260B	--	--	10,000	1500	SW8260B	--	--	2400	0.19	--
1,1'-Biphenyl	92-52-4		--	--	--	--	--	--	1.8	60	SW8270D	3	10	NA	140	SW8270D	0.017	0.037	200	0.0087	--
2,2'-Oxybis(1-chloropropane)	629-36-7		--	--	--	--	--	--	--	--	SW8270D	0.5	2	NA	--	SW8270D	0.017	0.037	--	--	--
2,4,5-Trichlorophenol	95-95-4		--	--	--	--	--	--	--	--	SW8270D	0.5	2	NA	--	SW8270D	0.02	0.05	82000	4	--
2,4,6-Trichlorophenol	88-06-2		--	--	--	--	--	--	4	130	SW8270D	0.5	2	NA	38000	SW8270D	0.02	0.05	210	0.004	--
2,4-Dichlorophenol	120-83-2		--	--	--	--	--	--	--	--	SW8270D	0.5	2	NA	--	SW8270D	0.017	0.037	2500	0.023	--
2,4-Dimethylphenol	105-67-9		--	--	--	--	--	--	--	--	SW8270D	10	3	540	--	SW8270D	0.017	0.037	16000	0.42	--
2,4-Dinitrophenol	51-28-5		--	--	--	--	--	--	--	--	SW8270D	30	14	70	--	SW8270D	0.37	1	1600	0.044	--
2,4-Dinitrotoluene	121-14-2		--	--	--	--	--	--	0.14	5	SW8270D	5	1	NA	63000	SW8270D	0.067	0.17	7.4	0.00032	--
2,6-Dinitrotoluene	606-20-2		--	--	--	--	--	--	--	--	SW8270D	2	0.5	NA	--	SW8270D	0.02	0.05	1.5	0.000067	--
2-Chloronaphthalene	91-58-7		--	--	--	--	--	--	--	--	SW8270D	1	0.4	NA	--	SW8270D	0.007	0.033	60000	3.9	--
2-Chlorophenol	95-57-8		--	--	--	--	--	--	--	--	SW8270D	2	0.5	0.5	--	SW8270D	0.017	0.037	5800	0.089	--
2-Methylphenol	95-48-7		--	--	--	--	--	--	2600	87000	SW8270D	2	0.5	NA	53000000	SW8270D	0.027	0.067	41000	0.75	--
2-Nitroaniline	88-74-4		--	--	--	--	--	--	0.22	7.3	SW8270D	7	2	NA	91000	SW8270D	0.02	0.05	8000	0.08	--
2-Nitrophenol	88-75-5		--	--	--	--	--	--	--	--	SW8270D	10	3	NA	--	SW8270D	0.017	0.037	--	--	--
3,3'-Dichlorobenzidine	91-94-1		--	--	--	--	--	--	0.036	1.2	SW8270D	10	3	NA	31000000	SW8270D	0.1	0.33	5.1	0.00082	--
3-Nitroaniline	99-09-2		--	--	--	--	--	--	--	--	SW8270D	7	3	NA	--	SW8270D	0.067	0.17	--	--	--
4,6-Dinitro-2-methylphenol	534-52-1		--	--	--	--	--	--	--	--	SW8270D	21	8	NA	--	SW8270D	0.17	0.5	66	0.0026	--
4-Bromophenyl-phenylether	101-55-3		--	--	--	--	--	--	--	--	SW8270D	2	0.5	NA	--	SW8270D	0.02	0.05	--	--	--
4-Chloro-3-methylphenol	59-50-7		--	--	--	--	--	--	--	--	SW8270D	2	0.5	NA	--	SW8270D	0.017	0.037	82000	1.7	--
4-Chloroaniline	106-47-8		--	--	--	--	--	--	--	--	SW8270D	10	4	NA	--	SW8270D	0.033	0.17	11	0.00016	--
4-Chlorophenyl-phenylether	7005-72-3		--	--	--	--	--	--	--	--	SW8270D	2	0.5	NA	--	SW8270D	0.017	0.037	--	--	--
4-Methylphenol	106-44-5		--	--	--	--	--	--	2600	87000	SW8270D	2	0.5	NA	64000000	SW8270D	0.02	0.05	82000	1.5	--
4-Nitroaniline	100-01-6		--	--	--	--	--	--	26	870	SW8270D	3	0.9	NA	500000000	SW8270D	0.067	0.17	110	0.0016	--
4-Nitrophenol	100-02-7		--	--	--	--	--	--	--	--	SW8270D	30	10	NA	--	SW8270D	0.17	0.5	--	--	--
Acetophenone	98-86-2		--	--	--	--	--	--	--	--	SW8270D	10	4	NA	--	SW8270D	0.023	0.05	120000	0.58	--
Atrazine	1912-24-9		--	--	--	--	--	--	--	--	SW8270D	5	2	NA	--	SW8270D	0.033	0.17	10	0.0002	0.0019
Benzaldehyde	100-52-7		--	--	--	--	--	--	--	--	SW8270D	10	3	NA	--	SW8270D	0.067	0.17	820	0.0041	--
Bis(2-chloroethoxy)methane	111-91-1		--	--	--	--	--	--	--	--	SW8270D	2	0.5	NA	--	SW8270D	0.017	0.037	2500	0.013	--
Caprolactam	105-60-2		--	--	--	--	--	--	9.6	320	SW8270D	11	5	NA	9300000	SW8270D	0.033	0.17	400000	2.5	--
Carbazole	86-74-8		--	--	--	--	--	--	--	--	SW8270D	2	0.5	NA	--	SW8270D	0.017	0.037	--	--	--
Hexachlorobutadiene	87-68-3		--	--	--	--	--	--	0.56	19	SW8270D	2	0.5	NA	1.3	SW8270D	0.003	0.017	5.3	0.00027	--
Hexachlorocyclopentadiene	77-47-4		--	--	--	--	--	--	0.88	29	SW8270D	11	5	NA	0.80	SW8270D	0.17	0.5	7.5	0.0013	0.16
Hexachloroethane	67-72-1		--	--	--	--	--	--	1.1	37	SW8270D	5	1	NA	6.9	SW8270D	0.033	0.17	8	0.0002	--
Isophorone	78-59-1		--	--	--	--	--	--	8800	290000	SW8270D	2	0.5	NA	32000000	SW8270D	0.017	0.037	2400	0.026	--
N-Nitroso-di-n-propylamine	621-64-7		--	--	--	--	--	--	0.0061	0.20	SW8270D	3	0.7	NA	28	SW8270D	0.02	0.05	0.33	0.0000081	--
N-Nitrosodiphenylamine	86-30-6		--	--	--	--	--	--	4.7	160	SW8270D	3	0.7	NA	95000	SW8270D	0.017	0.037	470	0.067	--
Nitrobenzene	98-95-3		--	--	--	--	--	--	0.31	10	SW8270D	2	0.5	NA	320	SW8270D	0.027	0.067	22	0.000092	--
Pentachlorophenol	87-86-5		--	--	--	--	--	--	2.4	80	SW8270D	5	1	NA	2400000	SW8270D	0.037	0.17	4	0.000057	0.0014
Phenol	108-95-2		--	--	--	--	--	--	880	29000	SW8270D	2	0.5	300	65000000	SW8270D	0.023	0.05	250000	3.3	--
1,4-Dioxane	123-91-1		--	--	--	--	--	--	2.5	83	SW8270D SIM	0.3	0.1	NA	13000	SW8270D	0.0007	0.002	24	0.000094	--
1-Methylnaphthalene	90-12-0		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	NA	--	SW8270D	0.0007	0.002	73	0.006	--
2-Methylnaphthalene	91-57-6		--	--	--	--	--	--	--	--	SW8270D SIM	0.07	0.02	36	--	SW8270D	0.0007	0.002	3000	0.19	--
Acenaphthene	83-32-9		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	1200	--	SW8270D	0.0007	0.002	45000	5.5	--
Acenaphthylene	208-96-8		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	0.1	--	SW8270D	0.0003	0.002	--	--	--
Anthracene	120-12-7		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	9600	--	SW8270D	0.0007	0.002	230000	58	--
Benz[a]anthracene	56-55-3		--	--	--	--	--	--	0.2	6.7	SW8270D SIM	0.05	0.01	0.1	410	SW8270D	0.0007	0.002	21	0.011	--
Benzo[a]pyrene	50-32-8		--	--	--	--	--	--	0.0088	0.29	SW8270D SIM	0.05	0.01	0.2	470	SW8270D	0.0007	0.002	2.1	0.029	0.24

Table 7. Analytes, Laboratory Analytical Methods, Screening Levels, Detection Limits, and Reporting Limits

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

						Air Samples					Water Samples					Soil Samples					
Chemical	CAS No.	Notes	Analytical Method	Method Detection Limit [µg/m3]	Reporting Limit [µg/m3]	Analytical Method	Method Detection Limit [µg/m3]	Reporting Limit [µg/m3]	EPA RSL [a] - Industrial Air [µg/m3]	EPA VISL[b] - Industrial Sub-slab Vapor and Near-Source Soil Gas [µg/m3]	Analytical Method (Groundwater)	Method Detection Limit [µg/L]	Reporting Limit [µg/L]	Groundwater Protection Standard (GWPS) [c] [µg/L]	EPA VISL[b] - Groundwater [µg/L]	Analytical Method - Soil	Method Detection Limit [mg/kg]	Reporting Limit [mg/kg]	EPA RSL [a] - Industrial Soil [mg/kg]	EPA Protection of Groundwater SSL [c] - Risk-based (mg/kg)	EPA Protection of Groundwater SSL [c] - MCL - based (mg/kg)
Benzo[b]fluoranthene	205-99-2		--	--	--	--	--	--	0.2	6.7	SW8270D SIM	0.05	0.01	0.2	7400	SW8270D	0.0007	0.002	21	0.3	--
Benzo[ghi]perylene	191-24-2		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	NA	--	SW8270D	0.0007	0.002	--	--	--
Benzo[k]fluoranthene	207-08-9		--	--	--	--	--	--	2	67	SW8270D SIM	0.05	0.01	0.1	84000	SW8270D	0.0007	0.0002	210	2.9	--
Bis(2-chloroethyl)ether	111-44-4		--	--	--	--	--	--	0.037	1.2	SW8270D SIM	0.07	0.02	NA	53	SW8270D	0.00002	0.00007	1	0.0000036	--
Bis(2-ethylhexyl)phthalate	117-81-7		--	--	--	--	--	--	5.1	170	SW8270D SIM	1	0.08	NA	460000	SW8270D	0.01	0.023	160	1.3	1.4
Butylbenzylphthalate	85-68-7		--	--	--	--	--	--	--	--	SW8270D SIM	1	0.05	NA	--	SW8270D	0.007	0.02	--	--	--
Chrysene	218-01-9		--	--	--	--	--	--	20	670	SW8270D SIM	0.05	0.01	0.1	94000	SW8270D	0.0003	0.002	2100	9	--
Di-n-butylphthalate	84-74-2		--	--	--	--	--	--	--	--	SW8270D SIM	1	0.05	NA	--	SW8270D	0.007	0.02	82000	2.3	--
Di-n-octylphthalate	117-84-0		--	--	--	--	--	--	--	--	SW8270D SIM	1	0.09	NA	--	SW8270D	0.007	0.02	8200	57	--
Dibenz[a,h]anthracene	53-70-3		--	--	--	--	--	--	0.02	0.67	SW8270D SIM	0.07	0.02	NA	3500	SW8270D	0.0007	0.002	2.1	0.096	--
Dibenzofuran	132-64-9		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	7.9	--	SW8270D	0.0007	0.002	1000	0.15	--
Diethylphthalate	84-66-2		--	--	--	--	--	--	--	--	SW8270D SIM	1	0.05	NA	--	SW8270D	0.007	0.02	660000	6.1	--
Dimethylphthalate	131-11-3		--	--	--	--	--	--	--	--	SW8270D SIM	1	0.05	NA	--	SW8270D	0.007	0.02	--	--	--
Fluoranthene	206-44-0		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	300	--	SW8270D	0.0007	0.002	30000	89	--
Fluorene	86-73-7		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	1300	--	SW8270D	0.0007	0.002	30000	5.4	--
Hexachlorobenzene	118-74-1		--	--	--	--	--	--	0.027	0.90	SW8270D SIM	0.05	0.01	NA	0.39	SW8270D	0.00005	0.00001	0.96	0.00012	0.013
Indeno[1,2,3-cd]pyrene	193-39-5		--	--	--	--	--	--	0.2	6.7	SW8270D SIM	0.05	0.01	0.1	14000	SW8270D	0.0007	0.002	21	0.98	--
N-Nitrosodimethylamine	62-75-9		--	--	--	--	--	--	0.00088	0.03	SW8270D SIM	0.07	0.03	NA	12	SW8270D	0.0007	0.002	0.034	0.000000027	--
Naphthalene	91-20-3		--	--	--	--	--	--	0.36	12	SW8270D SIM	0.07	0.03	20	20	SW8270D	0.001	0.003	17	0.00054	--
Phenanthrene	85-01-8		--	--	--	--	--	--	--	--	SW8270D SIM	0.07	0.03	0.1	--	SW8270D	0.0007	0.002	--	--	--
Pyrene	129-00-0		--	--	--	--	--	--	--	--	SW8270D SIM	0.05	0.01	960	--	SW8270D	0.0007	0.002	23000	13	--

Notes:

µg = microgram
m3 = cubic meter
N/V = not volatile
ppbv = parts per billion by volume
-- = not applicable
NA = No indoor air RSL/VISL value available
EPA = U.S. Environmental Protection Agency
GWPS = groundwater protection standard (EWI, 2016)
RSL = regional screening level
SSL = soil screening level
tbd = to be determined
THQ = target hazard quotient (noncancer effects)
TRL = target risk level (cancer effects)
VISL = vapor intrusion screening level

a : USEPA (2019a) Indoor Air Regional Screening Levels (April 2019) (lower of the cancer [TRL=1E-06] and noncancer [THQ=1] RSLs). [https://semspub.epa.gov/src/document/HQ/199461] are applicable to indoor air sampling results and used for informational purposes only for outdoor air sampling results.

b : USEPA Vapor Intrusion Screening Levels. 2019. Attenuation factors (USEPA, 2015; USEPA, 2019b) of 0.03 and 0.001 at 25 degrees Celsius were applied to the indoor air screening level used for soil vapor-to-indoor air and groundwater-to-indoor air, respectively.

c: Groundwater Protection Standard (GWPS) per Environmental Works, Inc. (EWI), 2016. Remedial Action Optimization Work Plan, Former Tronox Facility 2800 West High Street, Springfield, Missouri RCRA Permit Number MOD007129406. August 16.

d: RSL based on total petroleum hydrocarbons (aromatic low)

e: RSL based on total petroleum hydrocarbons (aromatic medium)

f: m-Xylene used as chemical property/toxicity surrogate for m,p-Xylene.

Table 8. Sample Containers, Preservation, and Hold Times

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Matrix	EPA Analytical Method	Containers	Sample Volume	Preservation Requirements	Maximum Holding Time
Groundwater	SW846-8260B TCL Part 4.3 + Naphthalene	3 × 40 ml G VOA vials (Teflon®-line caps/lids)	40 mL × 3	HCl to pH<2, cool to 4ºC	14 days for analysis
Groundwater	SW846-8270D TCL Part 4.3	2 × 1L amber glass jar (Teflon®-line caps/lids)	1L × 2	Cool to 6ºC	40 days for analysis
Soil	SW846-8260B TCL Part 4.3 + Naphthalene	Method 5035 Kit	40 mL × 3 + 1 × 50 mL	NaHSO4, cool to 4	14 days for analysis
Soil	SW846-8270D TCL Part 4.3	2 × 250 mL Amber Glass	250 mL x 2	Cool to 6ºC	7 days for extraction/40 days for analysis
Soil Gas (exterior)	TO-15	1-L Passivated Stainless Steel Canister	1 L	NA	30 days for analysis
Soil Gas (exterior)	GEM5000 (CO2, CH4, O2)	Direct measurement	NA	none	NA
Sewer Line Cleanout Headspace Air	TO-15	1-L Passivated Stainless Steel Canister	1 L	NA	30 days for analysis
Outdoor Air	TO-15 SIM	6-L Passivated Stainless Steel Canister[a]	6 L	NA	30 days for analysis
Indoor Air/ Crawlspace Air	TO-15 SIM	6-L Passivated Stainless Steel Canister[a]	6 L	NA	30 days for analysis
Subslab Air	TO-15 (TO-15 SIM)[b]	1-L (and 6-L) Passivated Stainless Steel Canister[b]	1 L (6 L)[b]	NA	30 days for analysis
Subslab Air	ASTM D1946-Helium	1-L Passivated Stainless Steel Canister[c]	1 L	NA	30 days for analysis
Sewer Gas Headspace Air	TO-15 SIM	6-L Passivated Stainless Steel Canister[a]	6 L	NA	30 days for analysis
Outdoor Air	HAPSITE (SIM Scan)	Direct measurement	NA	none	NA

[a] Passivated stainless steel canisters supplied by analytical laboratory. Individually clean certified. Documentation must be provided by the laboratory with canister shipment.

[b] Passivated stainless steel canisters supplied by analytical laboratory. Initial analysis using 1-L canisters will be batch clean certified.

Laboratory will analyze individually-clean-certified 6-L canisters, if low levels seen in 1-L canisters.
Documentation must be provided by the laboratory with canister shipment.

[c] Passivated stainless steel canisters supplied by analytical laboratory. 1-L canisters will be batch clean certified.

[d] Low-volume PUF sampler

[e] Outdoor air samples are to be collected using the HAPSITE portable GC/MS.

TBD: to be determined when analytical laboratory is selected.

Notes:

G = glass
GC/MS = portable gas chromatograph/mass spectrometer
HCL = Hydrochloric acid
NA = Not Applicable
PUF = polyurethane foam
SIM = select ion monitoring
SOP = standard operating procedure

Table 9. Anticipated Work Plan Schedule

Greene County Highway Department Site Investigation Work Plan
Former Tronox/Kerr-McGee Facility, Springfield, Missouri

Activity	Activity Duration
Phase 1 Sampling Event	
Planning and Mobilization	8 weeks after work plan approved
Data Collection	3 weeks
Sampling Analysis and Data Validation	4 weeks
Data Evaluation and Reporting	4 weeks after data validation submission to the Multistate Trust
Phase 2 Sampling Event	
Planning and Mobilization	3 weeks after Phase 2 approval
Data Collection	1 weeks
Sampling Analysis and Data Validation	4 weeks
Data Evaluation and Reporting	4 weeks after data validation submission to the Multistate Trust
Phase 3 Sampling Event	
Planning and Mobilization	3 weeks after Phase 3 approval
Data Collection	1 week
Sampling Analysis and Data Validation	4 weeks
Data Evaluation and Reporting	4 weeks after data validation submission to the Multistate Trust
Phase 4 Sampling Event	
Planning and Mobilization	6 weeks after Phase 4 approval
Building Survey and HAPSITE Survey	1 week
Data Collection	1 week
Sampling Analysis and Data Validation	4 weeks
Data Evaluation	2 weeks
Final Summary Report	
Draft Submittal to the Multistate Trust	8 weeks after completion of Phase 4 sampling event
Final Submittal to the Multistate Trust	4 weeks after receipt of comments

Figures

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Legend

▭	FORMER TRONOX FACILITY BOUNDARY
🟨	GREENE COUNTY HIGHWAY DEPARTMENT PROPERTY LINE
●	FORMER TRONOX FACILITY LOCATION

Greenfield Environmental Multistate Trust, LLC, Trustee of the Multistate Environmental Response Trust

Date: 09/04/2018

CREATED BY: Jacobs

CHECKED BY: Mike Bedan

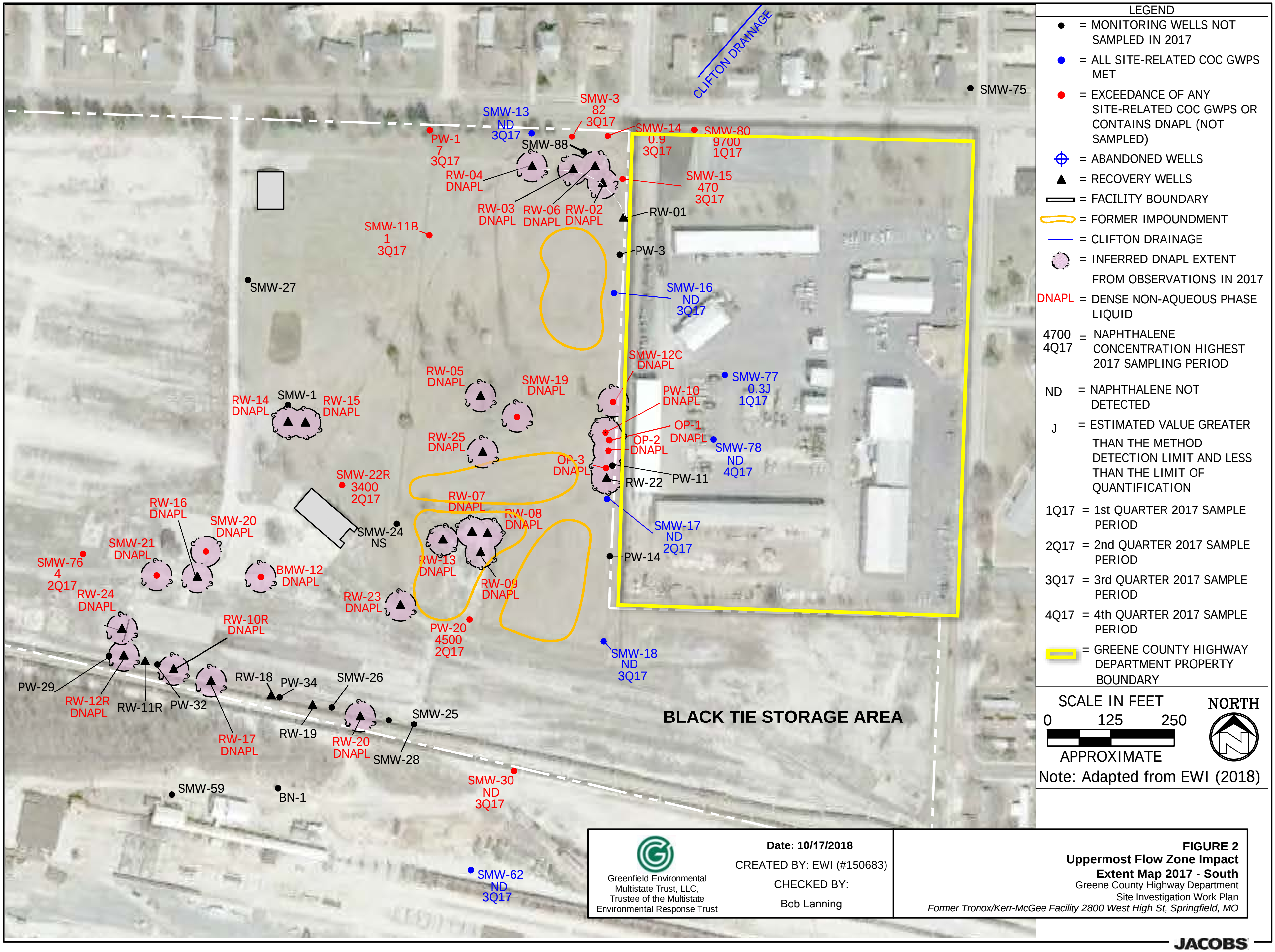
FIGURE 1

Former Tronox/Kerr-McGee Facility and Greene County Highway Department Location Map

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

JACOBS



Greenfield Environmental Multistate Trust, LLC, Trustee of the Multistate Environmental Response Trust

Date: 10/17/2018

CREATED BY: EWI (#150683)

CHECKED BY:

Bob Lanning

FIGURE 2

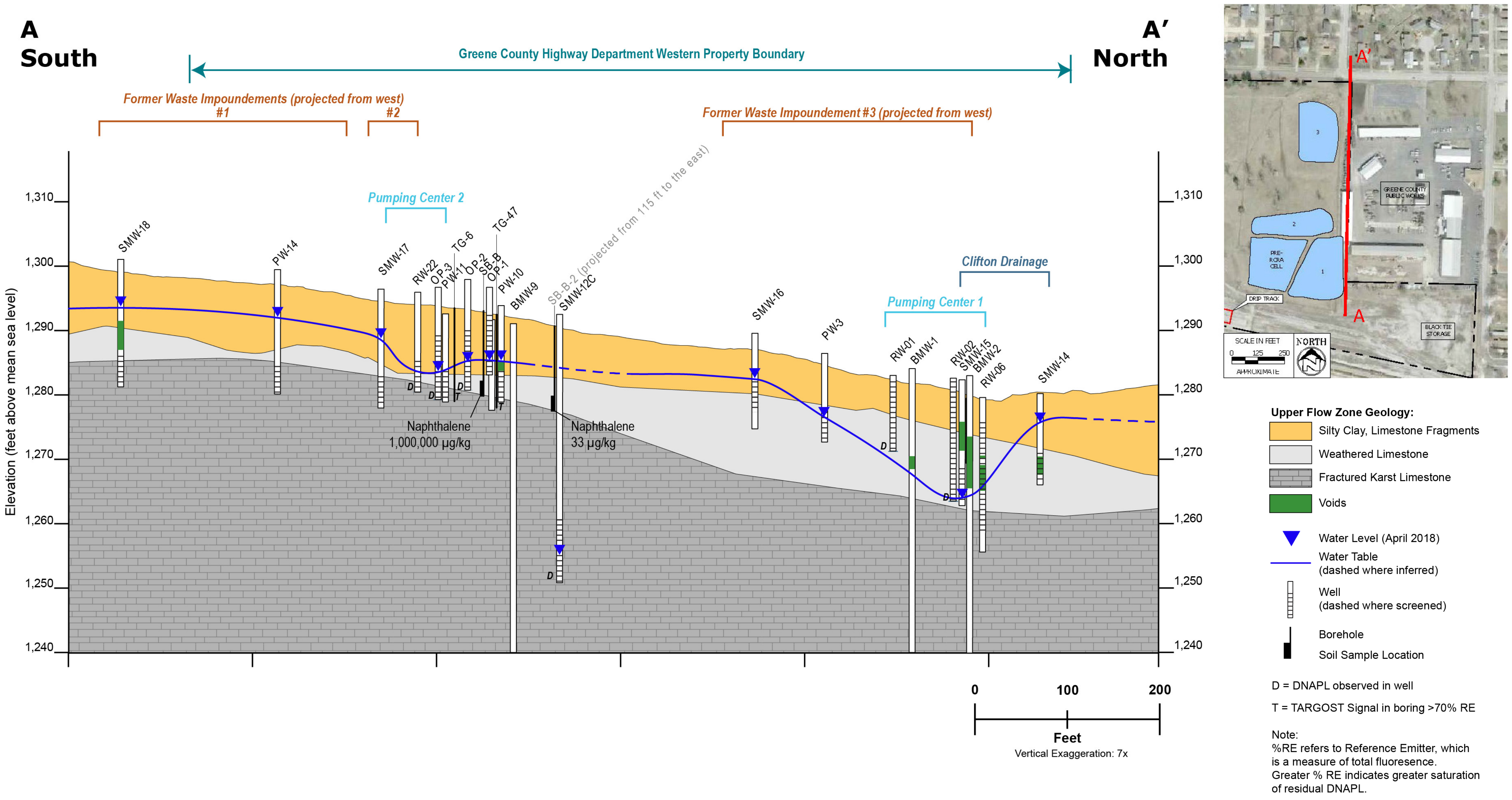
Uppermost Flow Zone Impact Extent Map 2017 - South

Greene County Highway Department

Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

JACOBS



D = DNAPL observed in well

T = TARGOST Signal in boring >70% RE

Note:
%RE refers to Reference Emitter, which is a measure of total fluoresence. Greater % RE indicates greater saturation of residual DNAPL.

Greenfield Environmental
Multistate Trust, LLC,
Trustee of the Multistate
Environmental Response Trust

Date: 10/15/2018

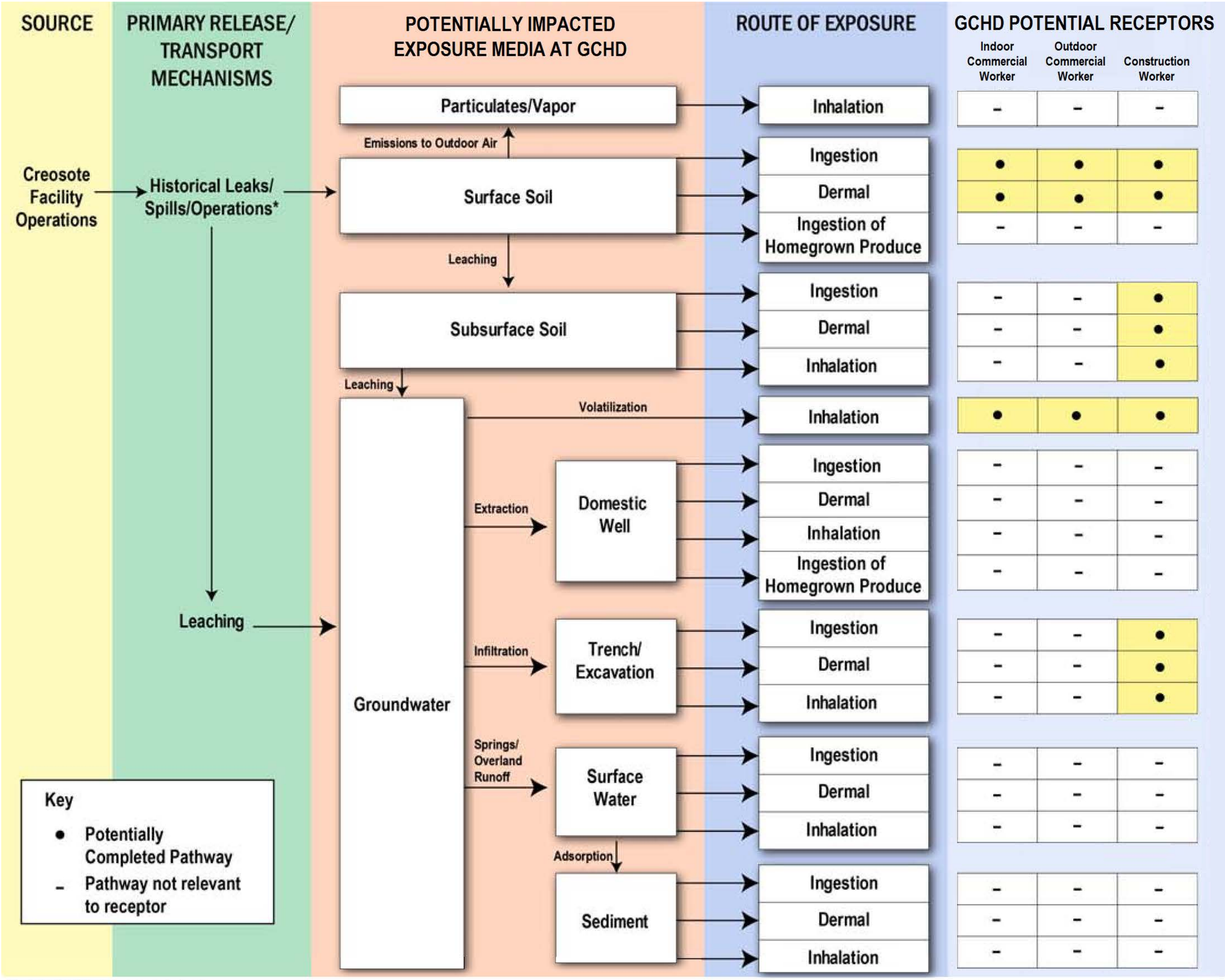
CREATED BY: Jacobs

CHECKED BY:
Julie Schucker

FIGURE 3
Site Layout - Cross Section

Greene County Highway Department Site Investigation Work Plan
Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

JACOBS



Potentially Impacted Exposure Media at GCHD	Route of Exposure	Indoor Commercial Worker	Outdoor Commercial Worker	Construction Worker
Particulates/Vapor	Inhalation	-	-	-
Surface Soil	Ingestion	●	●	●
	Dermal	●	●	●
	Ingestion of Homegrown Produce	-	-	-
Subsurface Soil	Ingestion	-	-	●
	Dermal	-	-	●
	Inhalation	-	-	●
Groundwater (Volatilization)	Inhalation	●	●	●
Domestic Well	Ingestion	-	-	-
	Dermal	-	-	-
	Inhalation	-	-	-
	Ingestion of Homegrown Produce	-	-	-
Trench/ Excavation	Ingestion	-	-	●
	Dermal	-	-	●
	Inhalation	-	-	●
Surface Water	Ingestion	-	-	-
	Dermal	-	-	-
	Inhalation	-	-	-
Sediment	Ingestion	-	-	-
	Dermal	-	-	-
	Inhalation	-	-	-

* Includes DNAPL and contaminated water.

* The potential Greene County Highway Department receptors and exposure routes that are addressed in this work plan are highlighted in yellow.

July 26, 2019

Greenfield Environmental Multistate Trust, LLC, Trustee of the Multistate Environmental Response Trust

Date: 7/26/2019

CREATED BY: Jacobs

CHECKED BY: Julie Schucker

FIGURE 4

Human Health Conceptual Site Exposure Model for GCHD Property

Greene County Highway Department Site Investigation Work Plan

Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

IGN, and the GIS User Community

JACOBS

Notes:
1. Labels are building descriptions and uses at Greene County Highway Department property based on available information.

Legend

- ▬ FORMER TRONOX FACILITY BOUNDARY
- ● EXISTING MONITORING WELL
- ▲ EXISTING SOIL BORING
- ☐ SAMPLE LOCATION
- ○ SOIL (UP TO 3 DEPTHS)
- ● SOIL GAS (UP TO 3 DEPTHS)
- ⊗ SHALLOW MONITORING WELL
- ⊕ BEDROCK MONITORING WELL
- ● MANHOLE HEADSPACE
- ● SEWER LINE CLEANOUT HEADSPACE
- — SEWER LINE
- - - APPROXIMATE LOCATION OF UNKNOWN SEWER LINE
- ▨ KNOWN EXTENT OF DNAPL
- ▭ APPROXIMATE AREA FOR TRENCHING

1 PHASE 1

Date: 7/15/2019

CREATED BY: JACOBS

CHECKED BY:
Keri Hallberg

Greenfield Environmental
Multistate Trust, LLC,
Trustee of the Multistate
Environmental Response Trust

FIGURE 5
Phase 1 Proposed Sampling Locations
Greene County Highway Department Site Investigation Work Plan
Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

JACOBS

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Notes:
1. Labels are building descriptions and uses at Greene County Highway Department property based on available information.
2. Phase 2 sample locations and the number of samples are subject to change based on information gathered during a completed investigation phase.

N

SCALE IN FEET
0 50 100
APPROXIMATE

Legend

▬ ▬	FORMER TRONOX FACILITY BOUNDARY
●	EXISTING MONITORING WELL
▲	EXISTING SOIL BORING
▢	SAMPLE LOCATION
○	SOIL (UP TO 3 DEPTHS)
●	SOIL GAS (UP TO 3 DEPTHS)
⊗	SHALLOW MONITORING WELL
⊕	BEDROCK MONITORING WELL
—	SEWER LINE
- - -	APPROXIMATE LOCATION OF UNKNOWN SEWER LINE
▨	KNOWN EXTENT OF DNAPL
2	PHASE 2

Date: 7/16/2019

CREATED BY: JACOBS

CHECKED BY:
Keri Hallberg

Greenfield Environmental
Multistate Trust, LLC,
Trustee of the Multistate
Environmental Response Trust

FIGURE 6
Phase 2 Proposed Sampling Locations
Greene County Highway Department Site Investigation Work Plan
Former Tronox/Kerr-McGee Facility 2800 West High St,
Springfield, MO

JACOBS

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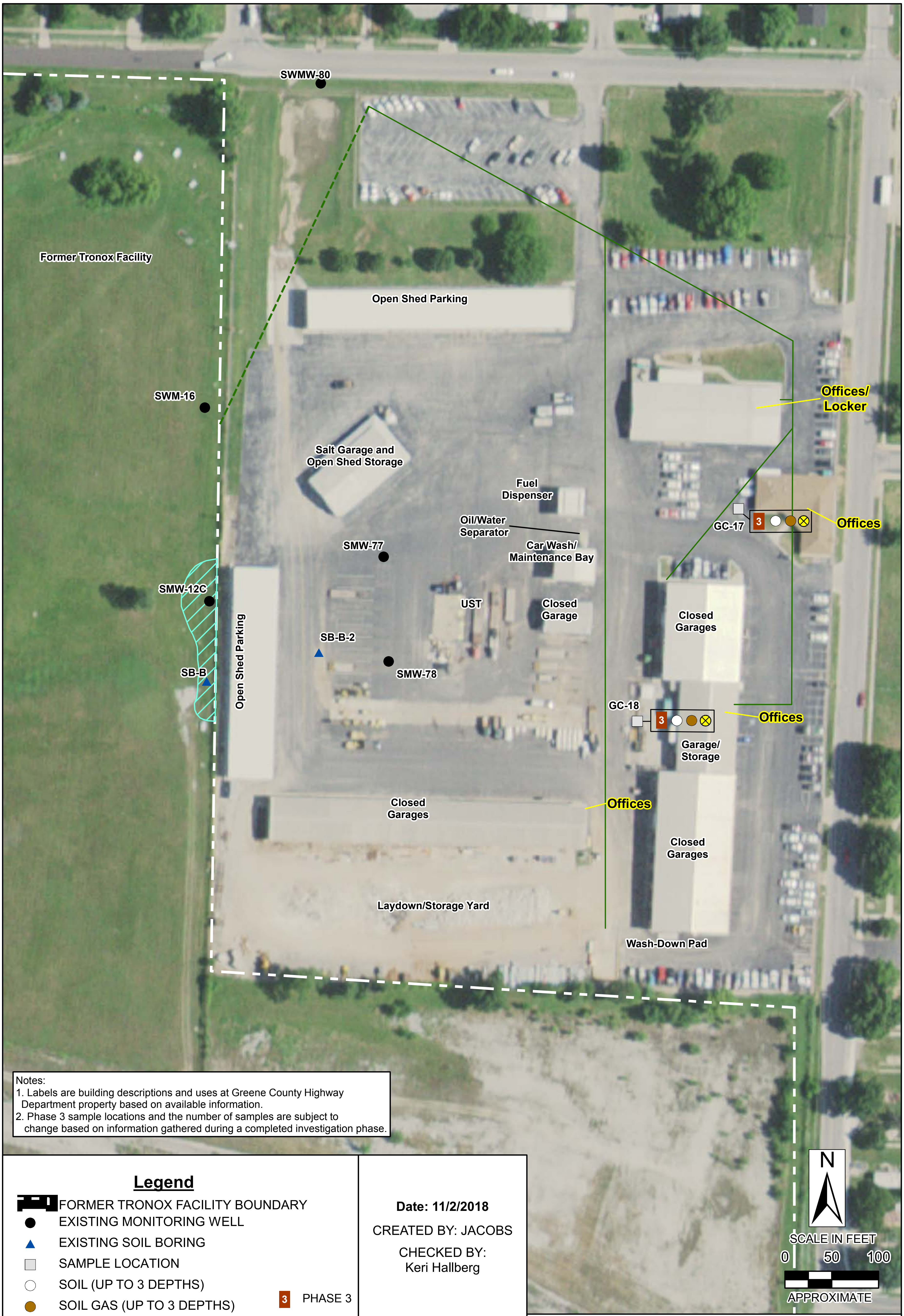

Notes:
1. Labels are building descriptions and uses at Greene County Highway Department property based on available information.
2. Phase 3 sample locations and the number of samples are subject to change based on information gathered during a completed investigation phase.

Legend

▬ ▬ FORMER TRONOX FACILITY BOUNDARY
● EXISTING MONITORING WELL
▲ EXISTING SOIL BORING
□ SAMPLE LOCATION
○ SOIL (UP TO 3 DEPTHS)
● SOIL GAS (UP TO 3 DEPTHS)
⊗ MONITORING WELL
― SEWER LINE
‐ ‐ ‐ APPROXIMATE LOCATION OF UNKNOWN SEWER LINE
▨ KNOWN EXTENT OF DNAPL
3 PHASE 3

Date: 11/2/2018

CREATED BY: JACOBS

CHECKED BY:
Keri Hallberg

Greenfield Environmental
Multistate Trust, LLC,
Trustee of the Multistate
Environmental Response Trust

FIGURE 7
Phase 3 Proposed Sampling Locations
Greene County Highway Department Site Investigation Work Plan
Former Tronox/Kerr-McGee Facility 2800 West High St,
Springfield, MO

JACOBS

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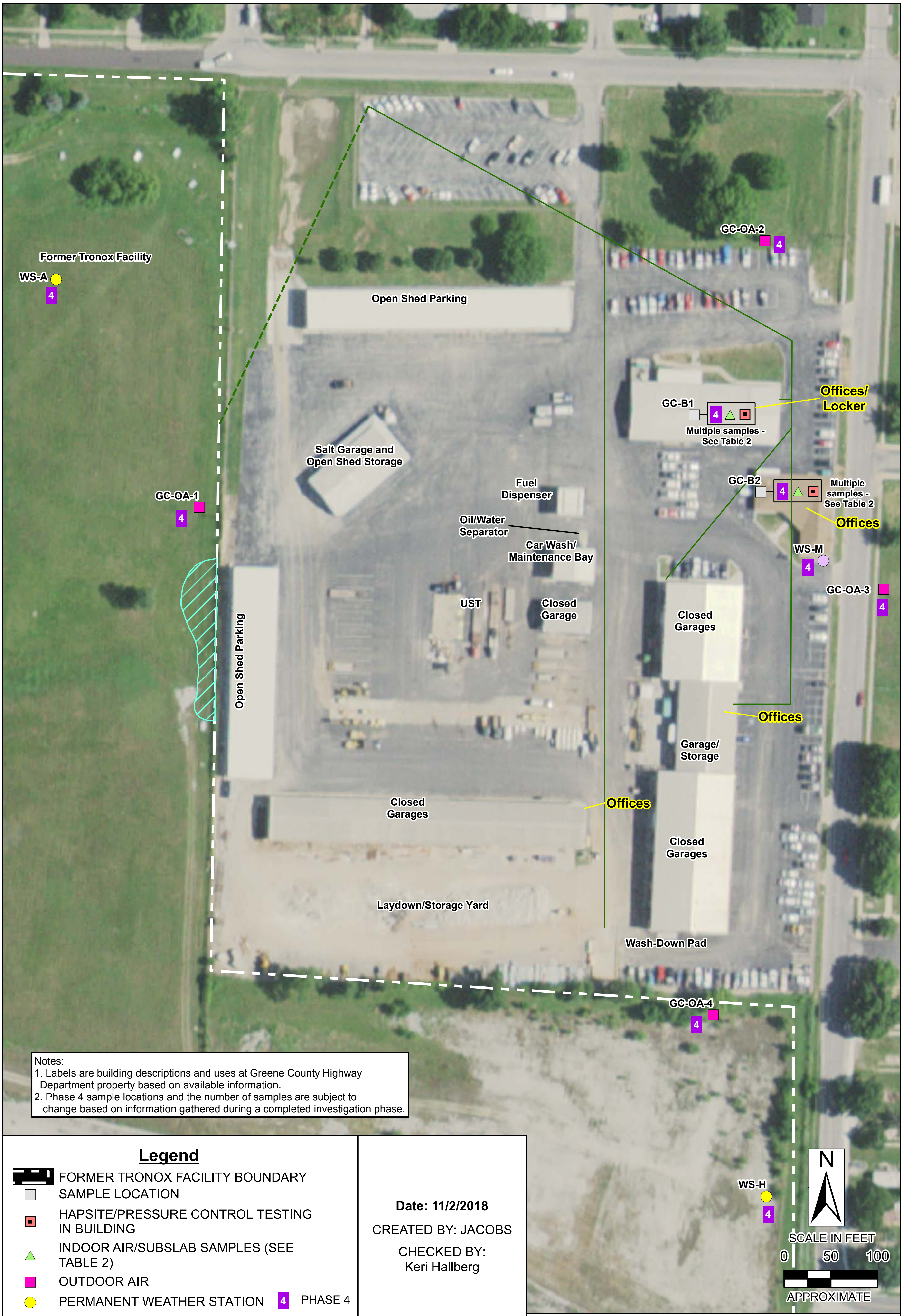


Notes:
1. Labels are building descriptions and uses at Greene County Highway Department property based on available information.
2. Phase 4 sample locations and the number of samples are subject to change based on information gathered during a completed investigation phase.

Legend

▬ ▬ FORMER TRONOX FACILITY BOUNDARY
☐ SAMPLE LOCATION
▣ HAPSITE/PRESSURE CONTROL TESTING IN BUILDING
△ INDOOR AIR/SUBSLAB SAMPLES (SEE TABLE 2)
■ OUTDOOR AIR
● PERMANENT WEATHER STATION
4 PHASE 4
○ TEMPORARY WEATHER STATION
— SEWER LINE
- - - APPROXIMATE LOCATION OF UNKNOWN SEWER LINE
▨ KNOWN EXTENT OF DNAPL

Date: 11/2/2018

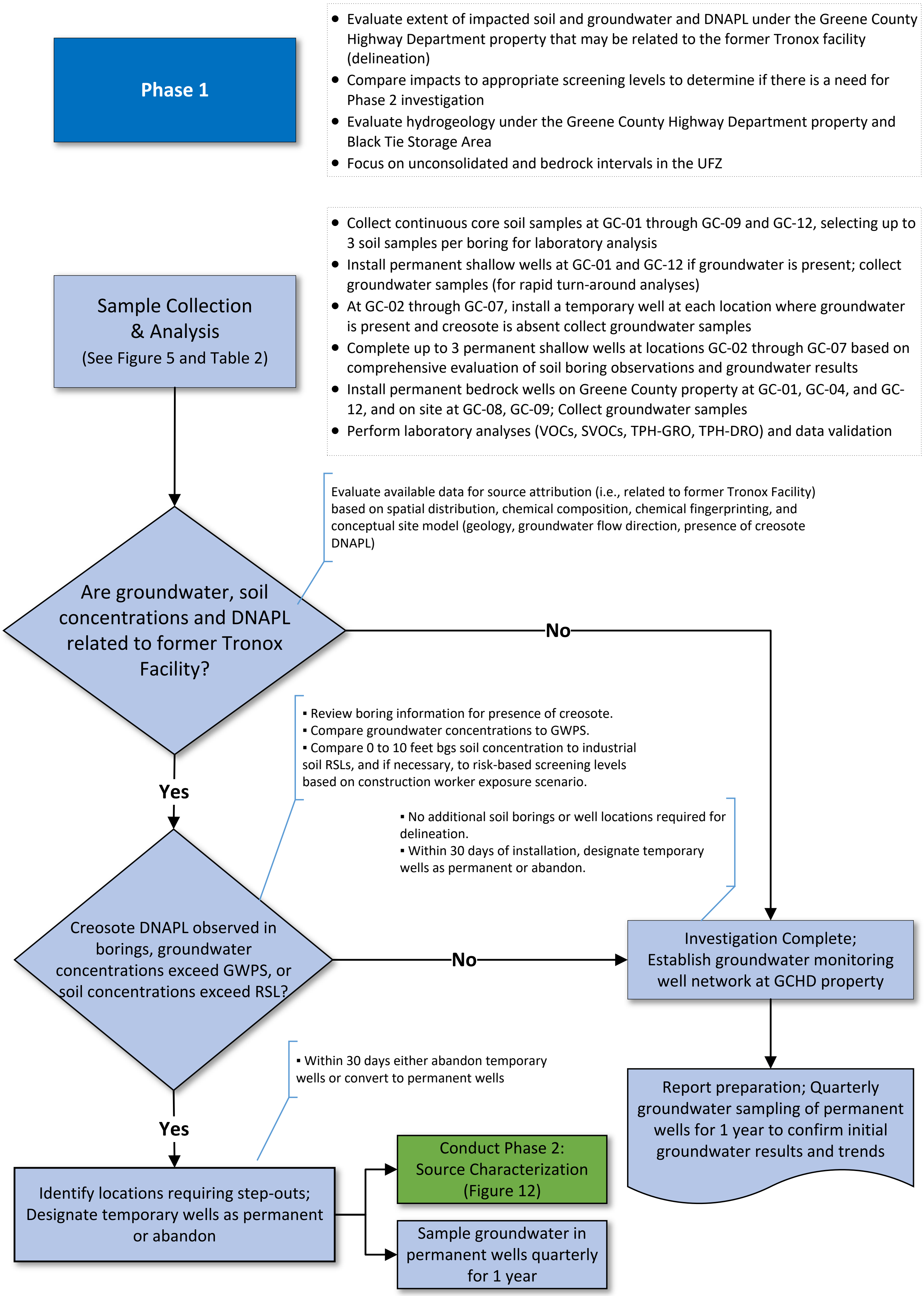
CREATED BY: JACOBS

CHECKED BY:
Keri Hallberg

Greenfield Environmental
Multistate Trust, LLC,
Trustee of the Multistate
Environmental Response Trust

FIGURE 8
Phase 4 Proposed Sampling Locations
Greene County Highway Department Site Investigation Work Plan
Former Tronox/Kerr-McGee Facility 2800 West High St,
Springfield, MO

JACOBS



- Evaluate extent of impacted soil and groundwater and DNAPL under the Greene County Highway Department property that may be related to the former Tronox facility (delineation)
- Compare impacts to appropriate screening levels to determine if there is a need for Phase 2 investigation
- Evaluate hydrogeology under the Greene County Highway Department property and Black Tie Storage Area
- Focus on unconsolidated and bedrock intervals in the UFZ

- Collect continuous core soil samples at GC-01 through GC-09 and GC-12, selecting up to 3 soil samples per boring for laboratory analysis
- Install permanent shallow wells at GC-01 and GC-12 if groundwater is present; collect groundwater samples (for rapid turn-around analyses)
- At GC-02 through GC-07, install a temporary well at each location where groundwater is present and creosote is absent collect groundwater samples
- Complete up to 3 permanent shallow wells at locations GC-02 through GC-07 based on comprehensive evaluation of soil boring observations and groundwater results
- Install permanent bedrock wells on Greene County property at GC-01, GC-04, and GC-12, and on site at GC-08, GC-09; Collect groundwater samples
- Perform laboratory analyses (VOCs, SVOCs, TPH-GRO, TPH-DRO) and data validation

Evaluate available data for source attribution (i.e., related to former Tronox Facility) based on spatial distribution, chemical composition, chemical fingerprinting, and conceptual site model (geology, groundwater flow direction, presence of creosote DNAPL)

- Review boring information for presence of creosote.
- Compare groundwater concentrations to GWPS.
- Compare 0 to 10 feet bgs soil concentration to industrial soil RSLs, and if necessary, to risk-based screening levels based on construction worker exposure scenario.

- No additional soil borings or well locations required for delineation.
- Within 30 days of installation, designate temporary wells as permanent or abandon.

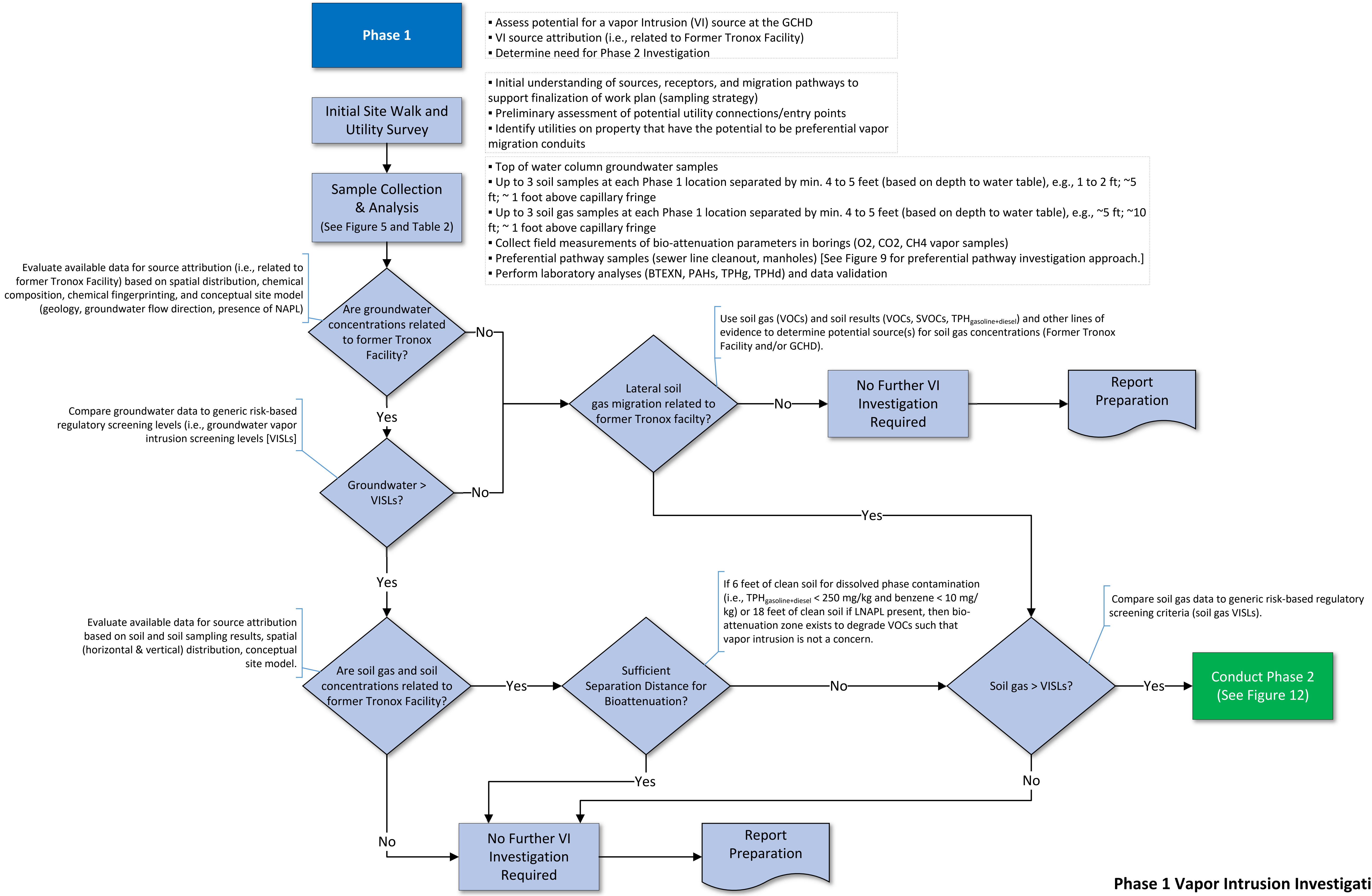
- Within 30 days either abandon temporary wells or convert to permanent wells

FIGURE 9

Phase 1 Site Characterization Approach

Greene County Highway Department Site Investigation

Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO



- Assess potential for a vapor Intrusion (VI) source at the GCHD
- VI source attribution (i.e., related to Former Tronox Facility)
- Determine need for Phase 2 Investigation

- Initial understanding of sources, receptors, and migration pathways to support finalization of work plan (sampling strategy)
- Preliminary assessment of potential utility connections/entry points
- Identify utilities on property that have the potential to be preferential vapor migration conduits

- Top of water column groundwater samples
- Up to 3 soil samples at each Phase 1 location separated by min. 4 to 5 feet (based on depth to water table), e.g., 1 to 2 ft; ~5 ft; ~ 1 foot above capillary fringe
- Up to 3 soil gas samples at each Phase 1 location separated by min. 4 to 5 feet (based on depth to water table), e.g., ~5 ft; ~10 ft; ~ 1 foot above capillary fringe
- Collect field measurements of bio-attenuation parameters in borings (O2, CO2, CH4 vapor samples)
- Preferential pathway samples (sewer line cleanout, manholes) [See Figure 9 for preferential pathway investigation approach.]
- Perform laboratory analyses (BTEXN, PAHs, TPHg, TPHd) and data validation

Evaluate available data for source attribution (i.e., related to former Tronox Facility) based on spatial distribution, chemical composition, chemical fingerprinting, and conceptual site model (geology, groundwater flow direction, presence of NAPL)

Use soil gas (VOCs) and soil results (VOCs, SVOCs, $\text{TPH}_{\text{gasoline+diesel}}$) and other lines of evidence to determine potential source(s) for soil gas concentrations (Former Tronox Facility and/or GCHD).

Compare groundwater data to generic risk-based regulatory screening levels (i.e., groundwater vapor intrusion screening levels [VISLs]

If 6 feet of clean soil for dissolved phase contamination (i.e., $\text{TPH}_{\text{gasoline+diesel}}$ < 250 mg/kg and benzene < 10 mg/kg) or 18 feet of clean soil if LNAPL present, then bio-attenuation zone exists to degrade VOCs such that vapor intrusion is not a concern.

Compare soil gas data to generic risk-based regulatory screening criteria (soil gas VISLs).

Evaluate available data for source attribution based on soil and soil sampling results, spatial (horizontal & vertical) distribution, conceptual site model.

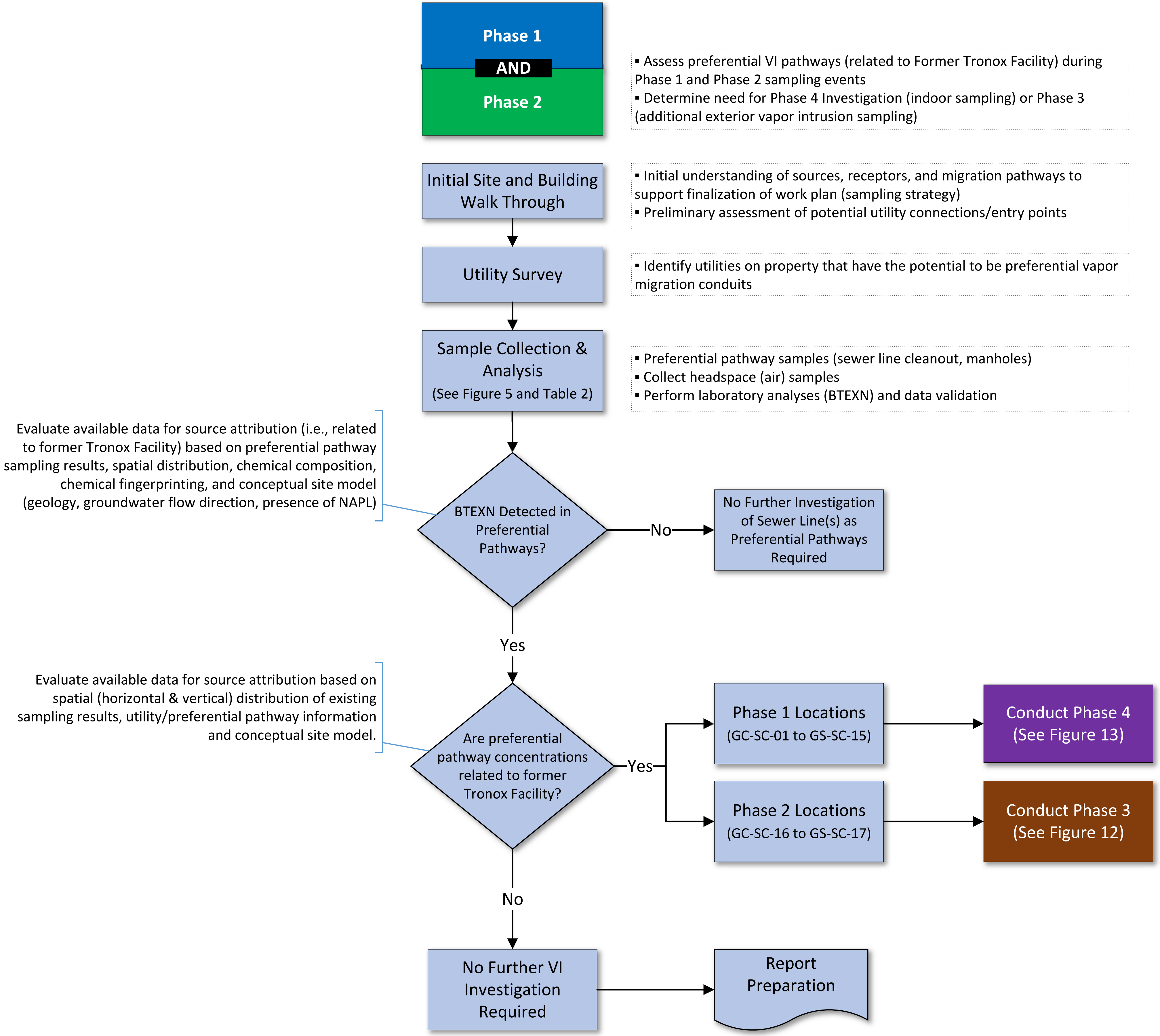
FIGURE 10

Phase 1 Vapor Intrusion Investigation Approach – Source Characterization

Greene County Highway Department Site Investigation

Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

July 15, 2019



- Assess preferential VI pathways (related to Former Tronox Facility) during Phase 1 and Phase 2 sampling events
- Determine need for Phase 4 Investigation (indoor sampling) or Phase 3 (additional exterior vapor intrusion sampling)

- Initial understanding of sources, receptors, and migration pathways to support finalization of work plan (sampling strategy)
- Preliminary assessment of potential utility connections/entry points

- Identify utilities on property that have the potential to be preferential vapor migration conduits

- Preferential pathway samples (sewer line cleanout, manholes)
- Collect headspace (air) samples
- Perform laboratory analyses (BTEXN) and data validation

Evaluate available data for source attribution (i.e., related to former Tronox Facility) based on preferential pathway sampling results, spatial distribution, chemical composition, chemical fingerprinting, and conceptual site model (geology, groundwater flow direction, presence of NAPL)

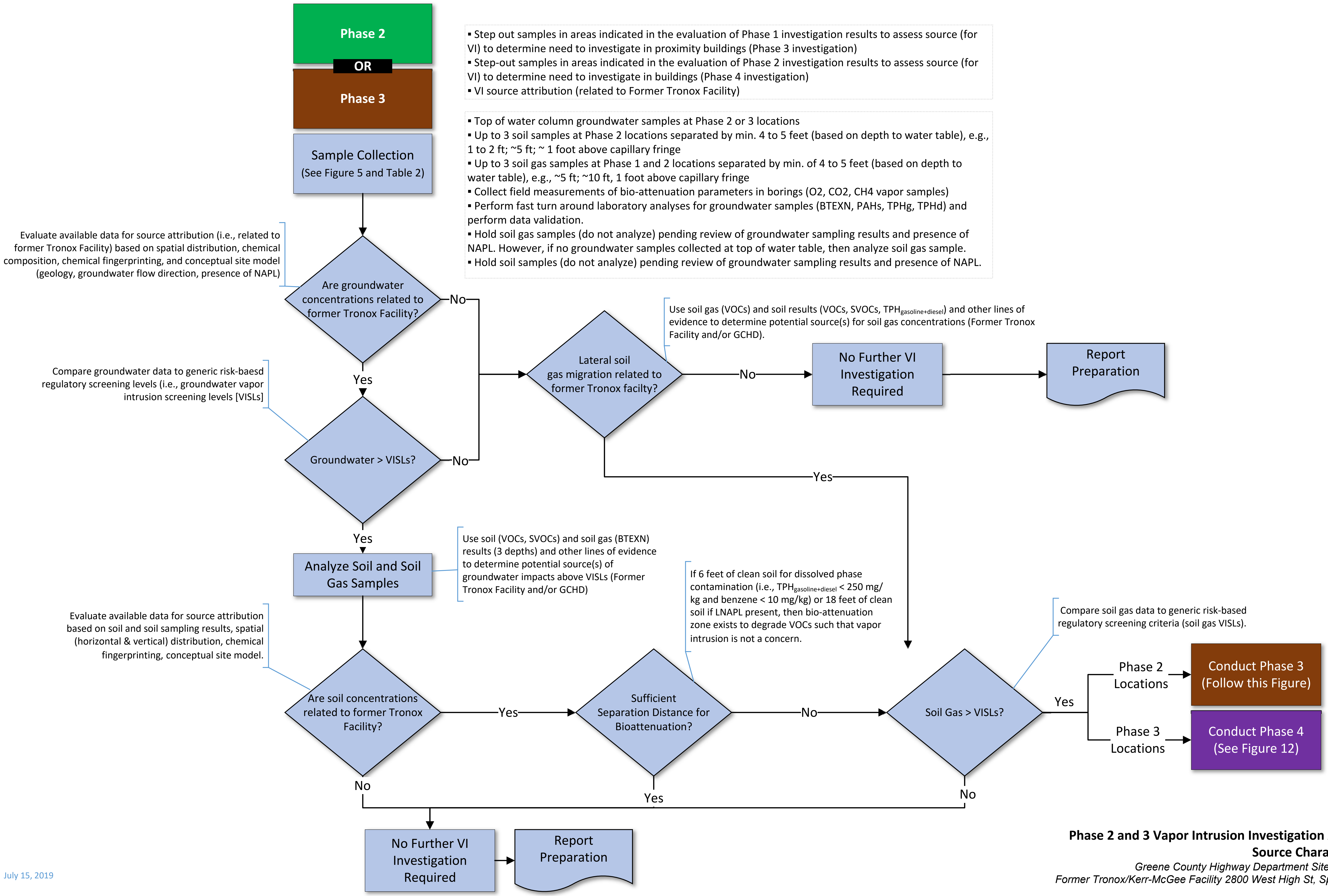
Evaluate available data for source attribution based on spatial (horizontal & vertical) distribution of existing sampling results, utility/preferential pathway information and conceptual site model.

FIGURE 11

Phase 1 and Phase 2 Vapor Intrusion Investigation Approach – Preferential Pathway Assessment

Greene County Highway Department Site Investigation
Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

July 15, 2019



- Step out samples in areas indicated in the evaluation of Phase 1 investigation results to assess source (for VI) to determine need to investigate in proximity buildings (Phase 3 investigation)
- Step-out samples in areas indicated in the evaluation of Phase 2 investigation results to assess source (for VI) to determine need to investigate in buildings (Phase 4 investigation)
- VI source attribution (related to Former Tronox Facility)

- Top of water column groundwater samples at Phase 2 or 3 locations
- Up to 3 soil samples at Phase 2 locations separated by min. 4 to 5 feet (based on depth to water table), e.g., 1 to 2 ft; ~5 ft; ~ 1 foot above capillary fringe
- Up to 3 soil gas samples at Phase 1 and 2 locations separated by min. of 4 to 5 feet (based on depth to water table), e.g., ~5 ft; ~10 ft, 1 foot above capillary fringe
- Collect field measurements of bio-attenuation parameters in borings (O2, CO2, CH4 vapor samples)
- Perform fast turn around laboratory analyses for groundwater samples (BTEXN, PAHs, TPHg, TPHd) and perform data validation.
- Hold soil gas samples (do not analyze) pending review of groundwater sampling results and presence of NAPL. However, if no groundwater samples collected at top of water table, then analyze soil gas sample.
- Hold soil samples (do not analyze) pending review of groundwater sampling results and presence of NAPL.

Evaluate available data for source attribution (i.e., related to former Tronox Facility) based on spatial distribution, chemical composition, chemical fingerprinting, and conceptual site model (geology, groundwater flow direction, presence of NAPL)

Compare groundwater data to generic risk-baesd regulatory screening levels (i.e., groundwater vapor intrusion screening levels [VISLs])

Use soil gas (VOCs) and soil results (VOCs, SVOCs, $TPH_{gasoline+diesel}$) and other lines of evidence to determine potential source(s) for soil gas concentrations (Former Tronox Facility and/or GCHD).

Use soil (VOCs, SVOCs) and soil gas (BTEXN) results (3 depths) and other lines of evidence to determine potential source(s) of groundwater impacts above VISLs (Former Tronox Facility and/or GCHD)

If 6 feet of clean soil for dissolved phase contamination (i.e., $TPH_{gasoline+diesel}$ < 250 mg/kg and benzene < 10 mg/kg) or 18 feet of clean soil if LNAPL present, then bio-attenuation zone exists to degrade VOCs such that vapor intrusion is not a concern.

Compare soil gas data to generic risk-based regulatory screening criteria (soil gas VISLs).

Evaluate available data for source attribution based on soil and soil sampling results, spatial (horizontal & vertical) distribution, chemical fingerprinting, conceptual site model.

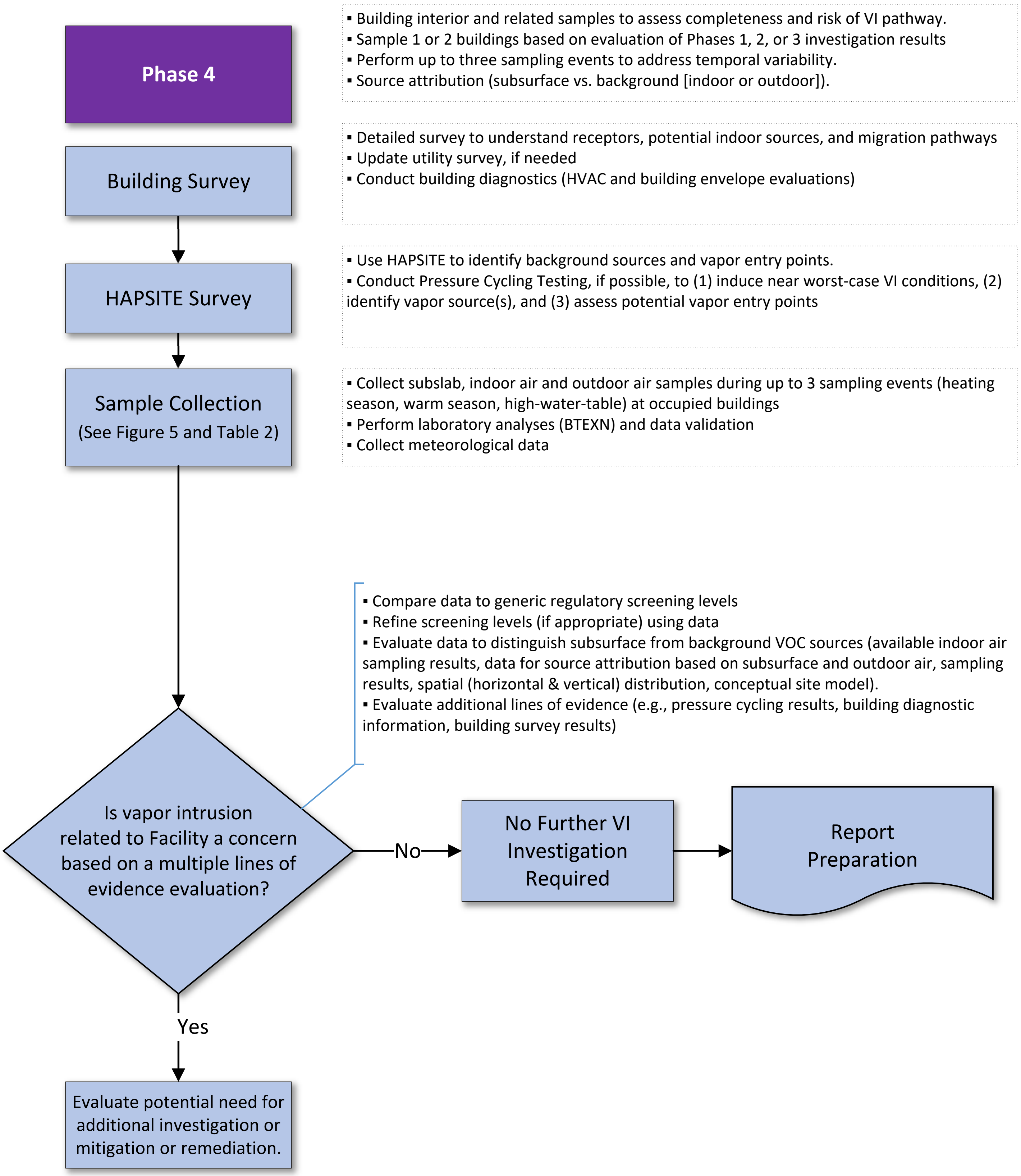
FIGURE 12

Phase 2 and 3 Vapor Intrusion Investigation Approach - Source Characterization

Greene County Highway Department Site Investigation

Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

July 15, 2019



- Building interior and related samples to assess completeness and risk of VI pathway.
- Sample 1 or 2 buildings based on evaluation of Phases 1, 2, or 3 investigation results
- Perform up to three sampling events to address temporal variability.
- Source attribution (subsurface vs. background [indoor or outdoor]).

- Detailed survey to understand receptors, potential indoor sources, and migration pathways
- Update utility survey, if needed
- Conduct building diagnostics (HVAC and building envelope evaluations)

- Use HAPSITE to identify background sources and vapor entry points.
- Conduct Pressure Cycling Testing, if possible, to (1) induce near worst-case VI conditions, (2) identify vapor source(s), and (3) assess potential vapor entry points

- Collect subslab, indoor air and outdoor air samples during up to 3 sampling events (heating season, warm season, high-water-table) at occupied buildings
- Perform laboratory analyses (BTEXN) and data validation
- Collect meteorological data

- Compare data to generic regulatory screening levels
- Refine screening levels (if appropriate) using data
- Evaluate data to distinguish subsurface from background VOC sources (available indoor air sampling results, data for source attribution based on subsurface and outdoor air, sampling results, spatial (horizontal & vertical) distribution, conceptual site model).
- Evaluate additional lines of evidence (e.g., pressure cycling results, building diagnostic information, building survey results)

FIGURE 13

Phase 4 Vapor Intrusion Investigation Approach - In-Building Investigation

Greene County Highway Department Site Investigation
Former Tronox/Kerr-McGee Facility 2800 West High St, Springfield, MO

Appendix A
Standard Operating Procedures

ENVIRONMENTAL WORKS INC.	**Standard Operating Procedure (SOP)**	Issue Date: 6-30-09 Updated:
Procedure No. 2: Direct Push and Augered Soil Borings		Technical Reference: Bob Lanning Page: 1 of 8

Skills Required:

1) 40-hour HAZWOPER training (if drilling on hazardous waste sites)
2) On-site training with experienced person desirable
3) Understanding of, and ability to, make decisions regarding site-specific objectives
4) Knowledge of corporate Safety requirements and health and safety plan
5) Training in soils characterization and sampling (if duties involve sampling)

1. OBJECTIVE / APPLICABILITY

The Objective of this Standard Operating Procedure (SOP) is to provide procedures for planning and observing direct push and hollow-stem auger drilling with considerations for sample collection.

This SOP serves as a reference tool to facilitate consistency among Environmental Works, Inc. (EWI) personnel. These operating procedures may be varied as required, depending upon site conditions, equipment limitations or limitations imposed by the project or client. In all instances, the ultimate procedures employed should be documented and associated with the final report.

2. SCOPE AND PERSONNEL APPLICATION

During any drilling operation, the purpose and ultimate reason for drilling need to be kept in mind. Oversight of drilling for sampling is normally performed by technical personnel (commonly EWI scientists and associate scientists). Any personnel performing these functions should be trained in proper planning and field techniques. The person performing the function is responsible for ensuring that all equipment and materials necessary for drilling are on-hand for the job. If there is any question regarding the purpose of the drilling, the person should confer with the project manager prior to mobilization to the work site.

3. EQUIPMENT

Equipment and materials needed for oversight of drilling operations to include sampling may include but is not limited to the following (this list excludes items specifically used for sample collection; see Sample Collection SOP for those items):

a. A work plan outlining project drilling objectives and locations
b. Field notebook or field documentation sheets
c. Small tape measure
d. Paper towels
e. Nitrile or appropriate disposable gloves
f. PID and calibration gas for VOC sites (including diesel and gasoline sites)
g. Camera (digital best)
h. Fine-tipped Sharpie
i. Trash bags
j. PPE appropriate for the site and COCs; must include hardhat, safety glasses with side shields, ear protection, and steel-toed boots (lace up for BNSF sites)

k. Soil boring logs, Air Monitoring Logs
l. Project Sampling Plan, Quality Assurance Project Plan
m. Site Safety and Health Plan, Tailgate Safety Form

4. PROCEDURES

4.1. General Planning and Procedures PRIOR to Mobilizing to the Field

1) Plan out number of bores, depths, samples needed and sample collection desired, well completion types (screened or open bore bedrock, above or below ground completion) and intervals, size and depths of borings and wells needed, materials needed for well construction, etc. prior to contacting drilling subcontractor for bids.
2) Research, or verify with drilling contractor, the State regulations and requirements for borehole abandonments, annular spaces for well casings and screens, filter pack requirements for monitoring wells, and registrations or reporting requirements
3) If collecting soil samples, plan the type of sample desired and specify to driller for bid: 2-foot split spoons of varying diameters (2”-3” depending on auger size), Shelby tubes, and 5-foot continuous samplers of varying diameter (1.25”-4”)
4) If installing wells, plan large enough casing diameters to accommodate purpose of the well or bore (i.e., is a pump going to be installed?)
5) If installing wells, in general use PVC for metals sampling or non-corrosive environments. In corrosive environments (includes high concentrations of chlorinated solvents), use stainless steel casing and screen.
6) If installing PVC wells, use Schedule 40 for depths shallower than 100 feet, and Schedule 80 for depths exceeding 100 feet.
7) Arrange for utility clearances both above and below ground well in advance of the drilling. Even if the client performs the utility clearance, EWI personnel must obtain written verification – and preferably on-site inspection – of utility clearance prior to commencing drilling. Remember that WE are responsible for OUR subcontractor!
8) Arrange for needed equipment, sampling containers, and special items well prior to job startup (i.e., PID monitoring, plastic for berms, drums for cuttings or waste water, or other special tanks or contingency items such as absorbents and floor-dry for spill cleanup).
9) Plan out decontamination procedures and decon areas with driller and client prior to job startup. Who is responsible for materials must be clearly understood.
10) Plan out waste handling, sampling, and disposal responsibilities prior to job startup.
11) Ensure a current Site Safety and Health Plan (SSHP) is available; some drillers require a copy for their records.
12) Prepare SSHP Tailgate Safety Meeting form with pertinent data before the field event.

4.2. General Procedures in the Field and during Drilling Operations.

1) Use Daily Field Logs, Boring Logs, and Air Monitoring Logs to record all pertinent information and activities as the job progresses (example logs are in the Attachments). Examples of what to record:
    - Documentation that Utility Clearance was performed.
    - Documentation that initial SSHP was reviewed and daily Tailgate Safety briefings were performed.
    - Names of drillers, type and condition of drill rig (no leaks!) and serial/State registration number.
    - Other personnel working on the task with you.
    - Key events, start and end times, footages reached, unusual PID readings or observations
    - Any problems arising – causes, details of discussions and decisions with client or regulatory agencies.
2) Measure lengths, and inside and outside diameters of drilling rods, hollow stem augers, bits, samplers, well casing and screens – anything that will go in the hole – and <u>record in field notes</u> using pictures as needed. Sometimes drillers need to change the size of bits or augers – <u>record changes in bit sizes and depths where changes occur on the boring log</u>.
3) Set up "hot zone" Exclusion Zone and Contaminant Reduction Zone perimeters appropriate for the project work and per the SSHP prior to starting drilling. This is advisable even if contaminants are not present to minimize pedestrian encounters. If contaminants are present, appropriate PPE and decon stations must be set up prior to drilling.
4) Set up a plastic-covered plywood stand (use sawhorses or back of pickup truck) if sampling will be conducted. Use a fresh or well-cleaned piece of plastic for each borehole.
5) Distances and directions from known locations (building corners, etc.) to the boring shall be measured and written on the field boring log for each boring or well installed, in addition to collecting GPS latitude/longitude/elevation data (pending equipment availability).
6) When sampling for VOCs or SVOCs, measure <u>and record</u> PID background readings immediately prior to start of drilling, and record breathing zone and background readings every 5 feet of depth or at points of any discoloration or odors.
7) Take photographs of the wellhead, drill rig, and samples for each borehole, and for any unusual circumstance and document in field notes.
8) All separate borings, including step-outs due to refusal or relocated borings for any reason, will be given a unique boring name. Each boring shall have its own field boring log prepared with appropriate notes as to the reason for stepping out, the geographical distances and directions between borings, and other information to provide complete documentation on the field log as well as in the field notes. Normally borings are named "SB-XX"; step-out borings can be numbered and lettered SB-XX**A**, SB-XX**B**, etc.

10) Divide your time between watching drilling activities, taking PID breathing space readings, collecting samples, logging soil, and recording everything. Avoid getting fixated on any one task at the expense of others. Remember that safety (i.e., breathing zone monitoring and drilling operations) is the top priority, followed by sample collection.

4.3. Procedures and Issues Specific to Direct Push Drilling

1) See EWI SOP ___ for details on how a direct push drilling machine is operated.
2) A DPT rig will push through cover materials, such as asphalt. Commonly, concrete is cored first, unless the rig has a concrete bit. Do not collect samples of these covering materials for analysis.
3) Drilling for samples may be performed using a macrocore (2-inch diameter) or using "dual tube" drilling with a smaller 1.25-inch diameter sampler. In both cases, the samplers will be 4 or 5 feet long and contain an acetate liner to collect the core. The smaller dual-tube system is used for non-cohesive geologic conditions where core may fall out through the larger sampler, or where the hole will not stay open to avoid sloughing. Note that less sample is collected using the dual tube system, so there could be insufficient sample volume if several analytes are required.
4) The sampler acetate tube should be measured to verify length, to provide an accurate reference for determining recovery.
5) Decontamination of drill samplers and rods (or augers, if used) should be conducted between samples and wells. The extent and techniques for decontamination can vary between simply brushing to remove gross surficial material, to standard soap and rinse scrubbing with or without a hotsy-type steam pressure sprayer. The appropriate methodology depends on project and regulatory requirements, and specified in the project sampling plan and/or quality assurance project plan.
6) If monitoring wells are to be installed using direct push technology, the maximum diameter will be 1-inch, pending State regulations for monitoring well construction (a variance may be required). The direct push rig (such as EWI's Geoprobe), may be equipped with augers, which enable a larger diameter (2-inch diameter) monitoring well.
7) Groundwater samples may be collected at selected footage intervals without installation of a monitoring well. DPT rigs may be equipped with a temporary well screen that can be inserted through the drill rods and "opened" at the desired depth. Tubing and a pumping or vacuum apparatus is used to extract groundwater so that a sample can be collected for analysis. Note that this technique yields a sample of undeveloped and unpurged groundwater.
8) DPT drilling may also be used for installing soil vapor points. This involves constructing "mini-monitoring wells" in the vadose (unsaturated) zone.

4.4. Procedures and Issues Specific to Auger Drilling

1) Auger rig rigs are larger and more powerful than DPT rigs, and capable of drilling larger diameter and deeper boreholes. Auger rigs can drill bores with an outside diameter from 4 to larger than 12 inches.
2) Augers can be solid stem or hollow stem. Hollow stem augers allow for soil sampling during drilling (split spoon, Shelby tube, or continuous sampler), and offer a "clean" way to construct a monitoring well. Inside diameter of hollow stem augers is about 2 to 4 inches smaller than the OD.
3) If monitoring wells are to be installed, be sure to plan large enough hollow stem augers to allow well construction inside the augers (per "Monitoring Well Construction" requirements for your State).
4) Auger drilling produces large quantities of soil cuttings, so containment, management, and disposal of soil cuttings must be planned prior to drilling. Saturated soil commonly produces a soupy cuttings mixture that can easily flow away from the wellhead area.
5) A good management technique is to set up plastic or plywood (with a hole cut in the center) around the wellhead for dry to moist cuttings placement if contaminants are known or could be anticipated, or to keep the work area clean if no contaminants are anticipated. Soil cuttings can be shoveled onto plastic and covered, or place in 55-gallon open-top drums.
6) If wet, soupy cuttings are anticipated, insure that a berm with plastic sufficient to contain liquid runoff around the wellhead is constructed.
7) Auger flights are decontaminated between wells, and samplers are decontaminated between samples, if sampling is conducted. If full scale decontamination is to be used, plan for a bermed area to contain spray water, and drums to contain decontamination fluids and mud that will be produced.
8) Auger drilling involves large equipment and heavy components, which are lifted manually and by drill hoist. Part of your job as a safety observer is to watch for dangerous situations, particularly when auger flights are being lifted and hoisted.

4.5. Completion Procedures and Hole Abandonment

1) At the completion of all drilling and sampling, the boring log must be checked to verify that it contains specific bore location, start and completion times, driller names (company and individual), type of drill equipment, sampling methodology (i.e. "2-in. diam., 4-ft. acetate liner), PID detections (including "0"), soil and groundwater sample IDs and intervals, and total depth (noting "refusal" if the case). Measure the location of the borehole with a direction and a distance from a known stationary object, such as to an existing well or corner of a building that has been surveyed in the past.
2) If not converted into monitoring well, boreholes need to be abandoned and plugged per State regulations. These steps explain the general procedure:

a. If possible, determine the actual depth of the borehole in case the hole collapsed, to calculate the volume of bentonite needed to plug the hole. Record the depth of the open borehole.

b. Pour bentonite pellets into the borehole up to the zone of saturation (note that some States require use of a tremie pipe in the saturated zone). If possible, tamp the pellets to insure compaction and no bridging in the bore.

c. Above the zone of saturation, add bentonite chips or pellets in one-foot lifts and hydrate with potable water.

d. Tamp the hydrated bentonite to compact the bentonite and to prevent bridging.

e. Repeat until the borehole is plugged to land surface. If within a building, the bentonite should extend to the base of concrete, and a concrete plug poured in the opening with the top smoothed.

f. Record the abandonment procedure on the boring's field lithologic log with types and quanitities of fill material used.

3) Mark each bore at ground surface with a labeled wooden stake driven into the ground, or by permanent marker/paint if indoors.

4) The back of the drilling rig and all equipment that went downhole needs to be decontaminated before the drill rig leaves the site. All equipment rinsate will be collected and subsequently disposed of at the site treatment facility.

5) Drill cuttings, decon water, and all trash (including acetate liners and cores) need to be properly stored and protected until disposed.

5. SAFETY

Acute or chronic exposure to chemically-contaminated soil could result in bodily injury. Routes of exposure include inhalation, ingestion, and dermal contact. Consult the appropriate chemical material safety data sheet (MSDS) before mobilization so that proper PPE and monitoring are planned and implemented.

Conduct an on-site safety meeting each day before the start of field work utilizing a Tailgate Safety Meeting form. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, alertness to heavy equipment, PPE, health monitoring, and emergency procedures). Take appropriate action if personnel are injured on-site per EWI policy guidance.

When working with potentially hazardous substances, follow the United States Environmental Protection Agency (US EPA), Occupational Safety and Health Administration (OSHA), EWI Corporate Health and Safety Plan, and site-specific health and safety plan.

6. REFERENCES

- "Corporate Health and Safety Plan" Environmental Works, Incorporated.
- "HAZWOPER Training Manual: 40-Hour Hazardous Waste & Emergency Response Training." Safety Source, Inc

Environmental Works, Inc. SOP No. 2

Soil Logging & Sampling for Direct Push and Hollow-Stem Auger Rotary Drilling

ATTACHMENTS

Soil Boring Log

Air Monitoring Log

DIRECT AIR MONITORING LOG

Page ____ of ____

LOCATION:____________ DATE:__________ DRILLER:__________ MONITOR:__________

WEATHER:____________________ TEMP:__________ WIND:________________

MONITORING INST:________________________________ READINGS: PPM___ PPB___

TIME	DEPTH	BREATH ZONE	HOLE/ CASING	PIT/ TANK	BACK GROUND	BORING-- COMMENTS

SOIL BORING LOG

Page ______ of ______

BORING NO. __________

Ground Elev __________

Sampler __________

Driller __________

Location __________

Date __________ Start Time __________ Finish Time __________

Drill Equipm't __________ Sample Method __________

BACKGROUND		PID HEADSPACE MONITORING - PID Instrument:									
Time	ppm	Time	ppm	Time	ppm	Time	ppm	Time	ppm	Time	ppm

Abandonment Method __________

Depth BLS	Recovery (ft/ft)		Sample Depth	Sample Ident	PID (ppm)	Description of Material Drilled	Unified Classif

ENVIRONMENTAL WORKS INC.	**Standard Operating Procedure (SOP)**	Issue Date: 6-30-09 Updated:	
Procedure No. 3: Soil Logging & Sampling for Direct Push and Hollow-Stem Auger Rotary Drilling		Technical Reference: Bob Lanning	
		Page:	1 of 7

Skills Required:

1) 40-hour HAZWOPER training (if sampling on hazardous waste sites)
2) Understanding of, and ability to make decisions regarding, site-specific objectives
3) Training in soils characterization and sampling
4) Training and ability to use PID
5) Knowledge of corporate Safety requirements and health and safety plan

1.0 OBJECTIVE / APPLICABILITY

The Objective of this Standard Operating Procedure (SOP) is to provide the proper procedure for characterizing and logging soil during direct push and hollow-stem auger drilling.

This SOP serves as a reference tool to facilitate consistency among Environmental Works, Inc. (EWI) personnel. These operating procedures may be varied as required, depending upon site conditions, equipment limitations or limitations imposed by the project or client. In all instances, the ultimate procedures employed should be documented and associated with the final report.

2.0 SCOPE AND PERSONNEL APPLICATION

Soil characterization and logging is performed to provide qualitative information for evaluating site conditions, extent of contamination, and potential for contaminant transport. Soil sampling is done to provide quantitative analytical data for total amounts of chemicals of concern (COCs) in the soil at specified locations and depths. These analytical data are compared to federal and State regulatory levels (e.g., Missouri Risk-Based Corrective Action (MRBCA) target levels), to provide information for remediation decision-making.

Soil logging and sampling is normally performed by technical personnel (commonly EWI scientists and associate scientists). Any personnel performing these functions should be trained in proper identification and techniques. The person performing the function is responsible for ensuring that all equipment and materials necessary for logging and sampling are on-hand for the job. If there is any question regarding materials, the logger/sampler should confer with the project manager prior to mobilization to the work site.

3.0 EQUIPMENT

Equipment needed for soil logging and sampling may include but is not limited to:

a. A work plan outlining project soil sampling requirements
b. Field notebook or field documentation sheets
c. Plastic for logging table
d. Table for logging (portable table or plywood and sawhorses, 3'x5'
e. Small tape measure
f. Soil sampling spatula (or stainless steel spoon or butter knife)
g. Small spray bottle
h. Small plastic bucket for rinse/used gloves, etc.

i. Paper towels
j. Munsell color charts (in plastic baggies)
k. Soil characterization guide sheets
l. Appropriate tool for cutting acetate liners (with extra blades)
m. Sandwich size baggies (zip-lock type)
n. Quart size baggies (zip-lock type)
o. Nitrile or appropriate disposable gloves
p. Terra Core Soil Kits (includes 1 methanol 40ml vial, 2 sodium phosphate tribasic 40ml vials, 2 unpreserved 40ml vials, 1 unpreserved amber jar, and 1 disposable Terracore^{RM} sampler) if required for sampling.
q. PID and calibration gas for VOC sites (including diesel and gasoline sites)
r. Camera (digital best)
s. Collection jars appropriate for analytes (provided by analytical laboratory)
t. Soil trip blank(s) (provided by analytical laboratory)
u. Temperature blank(s) (provided by analytical laboratory)
v. Sample labels
w. Chain of Custody (COC)
x. Cooler to store samples
y. Ice
z. Packing tape
aa. Duct tape
bb. Fine-tipped Sharpie
cc. UPS/Fed-Ex Shipping label(s)
dd. Custody Seal(s)
ee. Trash bags
ff. PPE appropriate for the site and COCs
gg. Soil boring logs, Air Monitoring Logs
hh. Site Safety and Health Plan, Tailgate Safety Form

4.0 PROCEDURES

4.1 General Procedures

1) Setup and organize logging area well before drilling starts. Have PID on and calibrated. Organize materials to be readily available within reach.
2) Know the type of soil sampling to be performed (Geoprobe 2” liners, 1” liners, 2-foot split spoons 2”-3” diameter, Shelby tube, 5-foot continuous samplers 3”-4” diameter, or grab samples from auger cuttings) and plan ahead how logging, sampling, PID readings will best be done. Procedures will vary whether operating alone or with another person.
3) The general procedure steps for logging and sampling are:
    - Note general geology, obvious areas of impact, recovery
    - Slit the core lengthwise, measure and record PID readings
    - Note water saturation level
    - Select horizons to sample and collect samples

- Collect small representative samples in baggies (labeled with depth)
- Perform detailed lithologic characterization of core
- Measure PID readings inside baggies, use for Munsell color determination
- Measure and record recovery (inches of core / inches sampler length)
- Take pictures of core

4) Stop driller if you get behind in logging and sampling a run. Don't just let sample tubes collect waiting for processing. Complete and accurate data are needed.
5) Divide your time between watching drilling activities, taking PID breathing space readings, collecting samples, logging soil, and recording everything. Avoid getting fixated on any one task at the expense of others.
6) Use Daily Field Logs, Boring Logs, and Air Monitoring Logs to record all pertinent information and activities as the job progresses. You do not have to record repetitive information. Example boring logs and air monitoring logs are attached.

4.2 Lithologic Characterization

Examine each different geologic material in the core, noting and recording the following properties for each type in the order presented. Different guide sheets in the attachments provide detailed explanations how to characterize each property, as well as an abbreviated list for use in the field.

- **MAIN TYPE OF MATERIAL** (fill, sand, clay, etc.)
  and **SUPPLEMENTAL** (sandy, silty, clayey, gravelly)

  (Usually written like Silty CLAY, or Clayey SAND, or Gravelly CLAY, or CLAY and GRAVEL (if 50/50). If mixture, note percentage of lesser (e.g., CLAY w/ 20% GRAVEL)

- **GRAIN SIZE** (if not clay) – fine, medium, coarse.

  For gravel also give size range in inches (e.g., 1/8" to pea size) and roundness (e.g., angular, subrounded, rounded)

- **SORTING AND GRADING** (if not clay):

  Poorly sorted (all different sizes) to well sorted (all same size)
  Poorly graded (different sizes all mixed up in position) to
  well graded (different sizes occur in sequential layers – coarse to fine)

- **COHESIVENESS**

  Very soft, soft, firm, stiff, v. stiff, hard *if cohesive*
  Very loose, loose, med dense, dense, extreme dense *if non-cohesive*
  Plasticity for clays (non-plastic, low, medium, or high plasticity)

- **COLOR**

  Note overall color. If two distinct colors, specify both. Note supplemental, like "mottled" or "brown laminations, etc". Specifically note areas of impact or discoloration. Use Munsell color charts, comparing soil to color spots and recording the Munsell color code. Add text color later from Munsell code sheet. OK to note "multicolored" without Munsell codes if many colors. Recommend keeping Munsell charts in large plastic baggies to protect color spots. See example Munsell color spots and code sheets in the attachments.

- **SATURATION**

  Note & record dry, damp, slightly moist, moist, very moist, saturated (or wet)

  Saturation can be difficult to determine in clay. Clay may be saturated and not appear "wet" – attempt to squeeze a small amount of sample to see if water is released.

- **ODOR**

  State either "no odor" or any noted odor, e.g., "petroleum-like". Limit use of specifics, e.g., diesel or gasoline, and always use "-like".

- **ANY INDICATORS OF CONTAMINATION**

  Discoloration, free product, odors

Abbreviations on field sheets are OK if logical. Include a key if not. The following are examples of log entries:

CLAY, 20% pea gravel, subround, stiff, low plastic, olive brn (2.5Y 4/3) w/ orange mottling, moist, no odor or visual impact

Clayey SAND, fin-gr, well sort, soft, pale brn (10YR 6/3) w/ dk gray irreg patches to ½", saturated, petroleum-like odor, impact in dk discolored areas

5.5′-6′: GRAVEL lens, poor sorted 1/8" – ½", well graded (coarse down), med dense, lt gray (5YR 7/1) and dk gray (5YR 4/1), v. moist, no odor or visual impact

While all of the above properties are needed to fully characterize geologic materials, the following are the key properties that must be recorded:

- Type of material including supplemental types
- Grain size if not clay
- Color by Munsell charts
- Saturation level
- Indications of impact

4.3 PID Measuring and Sampling Cores (liners, split spoons, Shelby tubes, continuous samplers)

1) Spoons/samplers/Shelby tubes should not be opened, or acetate liners cut open, until you are ready to begin logging.
2) As soon as the core is exposed, use a sampling spatula or other flat, dull-blade knife to slit the core lengthwise and measure PID readings. Carefully insert the

PID tip into the space made while "twisting" the spatula/knife - <u>care must be taken to avoid plugging the PID tip</u>. Measure every 6" and at areas of suspected impact. With a team of two persons, one person should measure starting depth and reading, while the 2nd person records the values – both the depth and reading should be noted on the boring log. If working alone, measure and record no more than 3 readings at a time to maintain accuracy.

3) Once core PID readings are recorded, and general lithology, saturation level, and potential areas of impact have been identified, samples must be collected.
4) Collect samples using a spatula/flat knife decontaminated between sampled horizons to fill sample jars. Collect samples as quickly as possible, remembering that samples for VOC analysis must be packed as tightly as possible in the sample container without over-pushing, squeezing samples. Label the sample container, insert in a baggie, and place in a cooler with ice. If time-constrained, write sample ID, depths, and time on lid and add labels later. If using a 5035 kit, see the 5035 SOP for proper procedures.
5) Samples should be given logical identifications to include the collection depth, e.g.: SB-4: 4.5-5 for a sample collected from SB-4 between 4.5'-5'.
6) Clearly depict sample horizons and ID on the boring log, noting depths.
7) After samples are collected, take depth baggies and measure headspace with PID after at least 5 minutes, and record. Beware of saturated samples, which can produce a temporary peak in PID readings. These baggies are also a good way to evaluate Munsell color of the interval when time allows

4.4 Logging and Sampling from Auger Cuttings

If hollow stem drilling is conducted without use of split spoons, Shelby tubes, or continuous samplers, grab soil samples for characterization and chemical analysis can still be collected from auger cuttings returned to the surface from the augers. The following are considerations and procedures related to soil sampling in these conditions.

1) There are limitations and potentially adverse effects from sampling auger cuttings that should be considered in collecting samples:
   - Collecting samples while actively augering involves your movement close to the drill rig and moving parts, so this action requires keen attention to detail and situational awareness.
   - The actual depth of the sample is uncertain, because there is a time delay in the sample reaching the surface while the augers continue downward.
   - Detailed PID depth profiles cannot be discerned due to mixing of thinner horizons of soil by the augers; however, auger movement can release more volatiles and yield more readily detected elevated PID readings.
   - If the chemicals of concern are highly volatile, it is likely that movement of the augers and the heat of friction will reduce the volatile content of samples, so results must be considered as minimal concentrations.

   - Finer details of lithology (thin horizons, sorting, grading, coloration, contamination details) are not possible when logging auger cuttings.
   - Moisture content can be difficult to accurately determine because of heat drying soils. However, saturated soil commonly produces a soupy return, making identification of true saturation easy to determine.

2) If samples are collected from auger cuttings, they must be collected using a sampling implement (not gloved hands) and placed rapidly into containers to minimize loss of volatiles. The freshest, most recently arrived sample should be selected. "Old" soil that has been stuck on augers should not be used.
3) Samples for lithologic description and color should be grabbed at regular intervals and set aside for logging and marked somehow with depth. Samples for PID headspace should be placed in baggies labeled with depth.
4) Actual depth of the augers immediately at the time of fresh sample collection should be recorded. Many variables (soil type, density, moisture content, power of the rig, etc.) result in unpredictable lag time of cutting reaching the surface.
5) Appropriate naming for grab samples from augers would be: SB-4: 6G for a grab sample collected at 6 ft depth. Depth cannot be determined accurately enough to provide a range over which a single grab sample was collected.
6) Use of auger cuttings for samples, technique of collection, and definition of depth assignment should be noted on the boring field log.

5.0 FIELD QA/QC SAMPLING PROCEDURES

Quality assurance/quality control sampling should be performed to assure quality of field analytical data. The following QA/QC sampling should be done as appropriate for regulatory or client requirements, or project constraints:

- Select 10% of total samples for duplicate sampling and analysis, with a minimum of one sample collected per event. Duplicate samples should be assigned a fictitious name, but one that can be recognized (e.g., add a "2" after the primary sample name: SB-32 as a duplicate of SB-3).
- Collect and analyze one field blank sample when collecting water samples.
- Utilize Trip Blanks sent from the laboratory when VOC sampling.
- Collect one equipment rinsate blank from geoprobe macrocores, split spoons, continuous samplers, or sampling utensils after being decontaminated.

Field duplicate samples are analyzed to check for sampling and analytical reproducibility.

Trip blanks will be used to assess the potential for contamination of samples due to contaminant migration during sample shipment and storage. One laboratory-supplied trip blank will be forwarded with each cooler containing samples and analyzed for VOCs.

Field blanks will be collected to assess possible impact from external contaminant sources in the area of sampling. Blanks will be collected by filling sample bottles with dionized/distilled water at the logging/sampling table and submitted for analysis of VOCs.

Equipment rinsate blanks will be taken to assess the effectiveness of decontamination and any potential impact on cross-contamination between samples. Blanks will be prepared by routing deionized/distilled water through decontaminated sampling equipment and before field sample collection. Rinsate blanks can be submitted for VOC and/or other analytes, depending on what the analytes of concern are at the job site.

6.0 SAFETY

Acute or chronic exposure to chemically-contaminated soil could result in bodily injury. Routes of exposure include inhalation, ingestion, and dermal contact. Consult the appropriate chemical material safety data sheet (MSDS) before mobilization so that proper PPE and monitoring are planned and implemented.

Conduct an on-site safety meeting each day before the start of field work utilizing a Tailgate Safety Meeting form. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, alertness to heavy equipment, PPE, health monitoring, and emergency procedures). Take appropriate action if personnel are injured on-site per EWI policy guidance.

When working with potentially hazardous substances, follow the United States Environmental Protection Agency (US EPA), Occupational Safety and Health Administration (OSHA), EWI Corporate Health and Safety Plan, and site-specific health and safety plan.

7.0 REFERENCES

- "Corporate Health and Safety Plan" Environmental Works, Incorporated.
- "HAZWOPER Training Manual: 40-Hour Hazardous Waste & Emergency Response Training." Safety Source, Inc

Environmental Works, Inc. SOP No. 3

Soil Logging & Sampling for Direct Push and Hollow-Stem Auger Rotary Drilling

ATTACHMENTS

- Soil Boring Log
- Air Monitoring Log
- GEOLOGIC LOGGING – INFO AND ORDER TO RECORD
- Visual Percent Estimation Charts (un-named)
- Field Guide for Soil and Stratigraphic Analysis v.2
- Unified Soil Classification System
- Soil Classification System (Modified U.S.C.)
  Conventional Soil Descriptions
- Instructional Diagram for Determining Soil Texture by Feel
- Munsell color chart (example pages)
- Munsell Soil Color Names (example pages)

Environmental Works, Inc.

Soil Boring Log

Date/Time: ____________________

Sampler: ____________________

Boring ID: ____________________

Driller: ____________________

Site Name: ____________________

Drill Equipm't and Method: ____________________

Location: ____________________

Depth	**Recovery**	**Sample Depth / ID**	**PID BZ**	**Sample PID**	**Description of Material**	**USCS**

Page ____ of ____

GEOLOGICAL LOGGING – INFO AND ORDER TO RECORD

MAIN TYPE OF MATERIAL (sand, clay, clay, etc.)
and **SUPPLEMENTAL** (sandy, silty, clayey with %)

GRAIN SIZE sand – fine, medium, coarse - and supplemental
gravel –size in inches, roundness, % if supplemental

SORTING AND GRADING (for sands and gravels)
Sorting (size): Poor to well
Grading (size mix): Poor to well

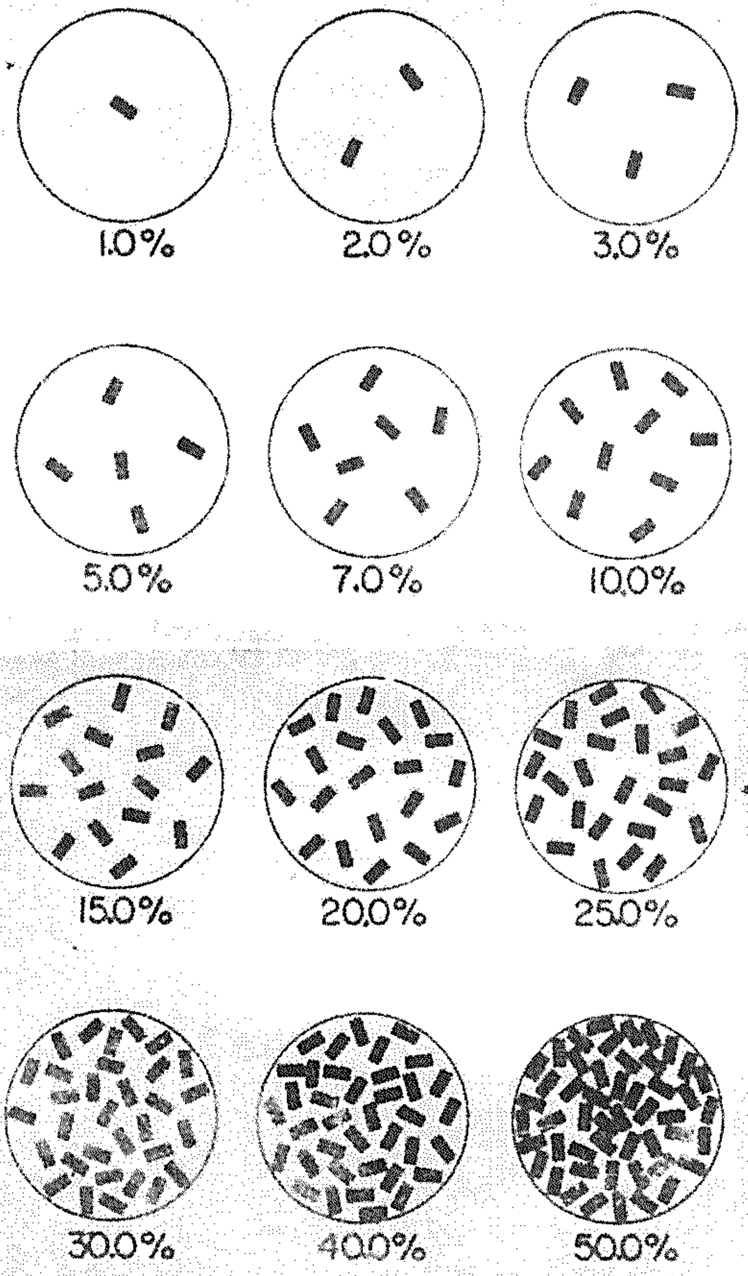
COHESIVENESS
Very soft….soft…firm…stiff… v. stiff… hard *(cohesive)*
Plasticity for clays
Very loose…loose…med dense…dense…extreme dense *(non-cohesive)*

COLOR Name (Munsell number)

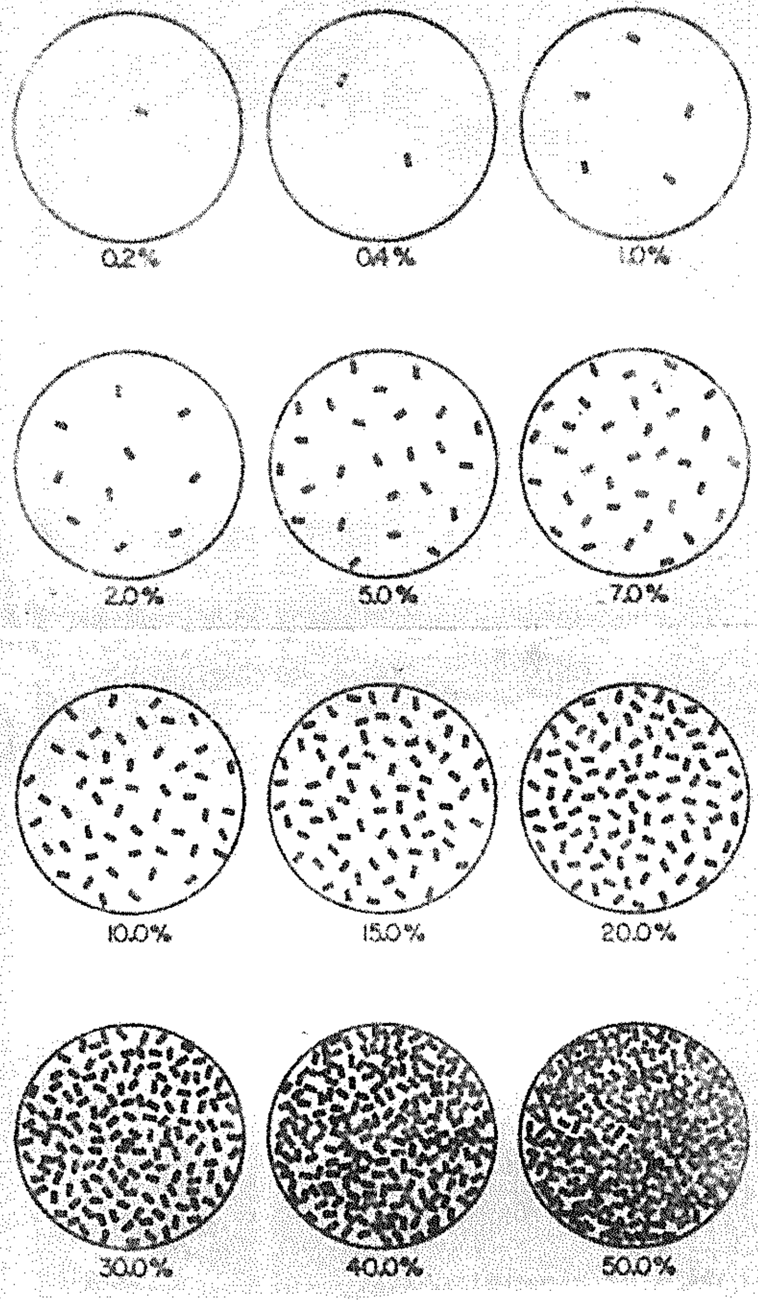
SATURATION
Dry…damp…slightly moist…moist…very moist…saturated

ODOR

ANY INDICATORS OF CONTAMINATION



particle size 3.2x14 mm



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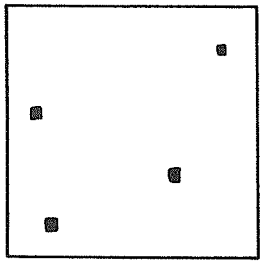
CHARTS FOR ESTIMATING PROPORTIONS OF MOTTLES AND COARSE FRAGMENTS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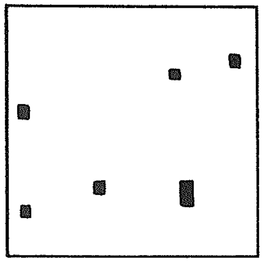
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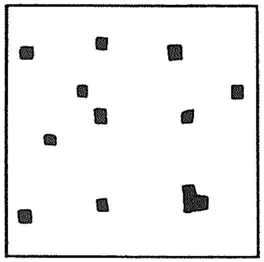
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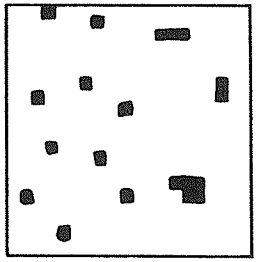
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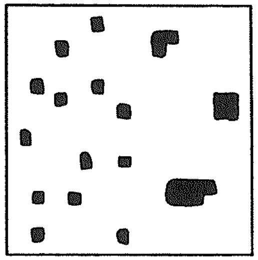
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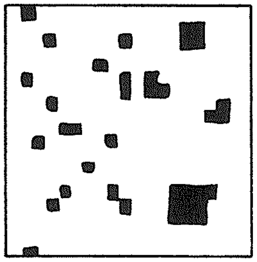
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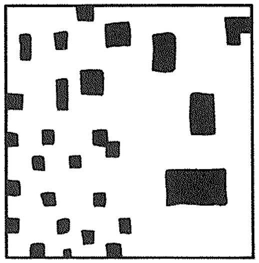
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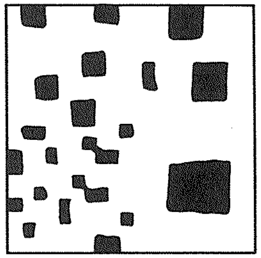
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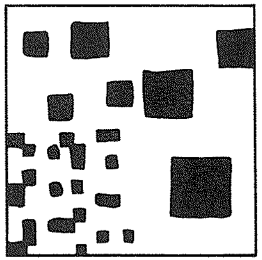
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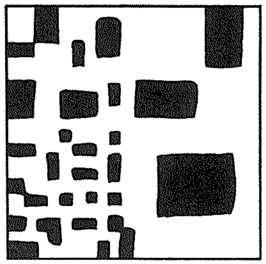
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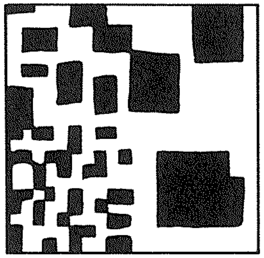
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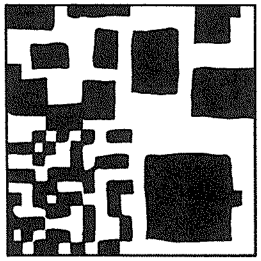
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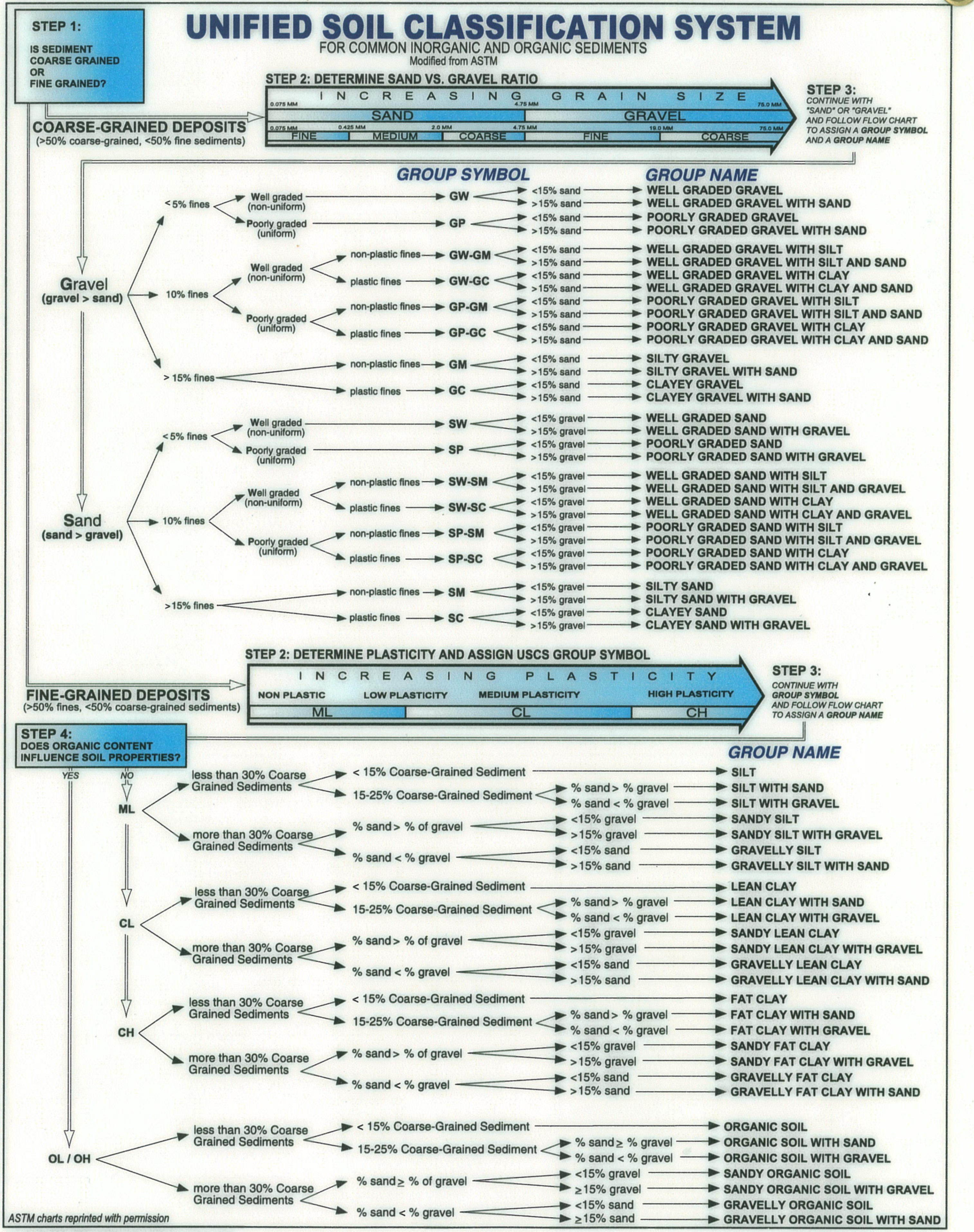
Each fourth of any one square has the same amount of black



UNIFIED SOIL CLASSIFICATION SYSTEM

FOR COMMON INORGANIC AND ORGANIC SEDIMENTS
Modified from ASTM

STEP 1:
IS SEDIMENT COARSE GRAINED OR FINE GRAINED?

STEP 2: DETERMINE SAND VS. GRAVEL RATIO

COARSE-GRAINED DEPOSITS
(>50% coarse-grained, <50% fine sediments)

STEP 3:
*CONTINUE WITH "SAND" OR "GRAVEL" AND FOLLOW FLOW CHART TO ASSIGN A **GROUP SYMBOL** AND A **GROUP NAME***

			GROUP SYMBOL		GROUP NAME
Gravel (gravel > sand)	< 5% fines	Well graded (non-uniform)	GW	<15% sand	WELL GRADED GRAVEL
				>15% sand	WELL GRADED GRAVEL WITH SAND
		Poorly graded (uniform)	GP	<15% sand	POORLY GRADED GRAVEL
				>15% sand	POORLY GRADED GRAVEL WITH SAND
	10% fines	Well graded (non-uniform), non-plastic fines	GW-GM	<15% sand	WELL GRADED GRAVEL WITH SILT
				>15% sand	WELL GRADED GRAVEL WITH SILT AND SAND
		Well graded (non-uniform), plastic fines	GW-GC	<15% sand	WELL GRADED GRAVEL WITH CLAY
				>15% sand	WELL GRADED GRAVEL WITH CLAY AND SAND
		Poorly graded (uniform), non-plastic fines	GP-GM	<15% sand	POORLY GRADED GRAVEL WITH SILT
				>15% sand	POORLY GRADED GRAVEL WITH SILT AND SAND
		Poorly graded (uniform), plastic fines	GP-GC	<15% sand	POORLY GRADED GRAVEL WITH CLAY
				>15% sand	POORLY GRADED GRAVEL WITH CLAY AND SAND
	> 15% fines	non-plastic fines	GM	<15% sand	SILTY GRAVEL
				>15% sand	SILTY GRAVEL WITH SAND
		plastic fines	GC	<15% sand	CLAYEY GRAVEL
				>15% sand	CLAYEY GRAVEL WITH SAND
Sand (sand > gravel)	< 5% fines	Well graded (non-uniform)	SW	<15% gravel	WELL GRADED SAND
				>15% gravel	WELL GRADED SAND WITH GRAVEL
		Poorly graded (uniform)	SP	<15% gravel	POORLY GRADED SAND
				>15% gravel	POORLY GRADED SAND WITH GRAVEL
	10% fines	Well graded (non-uniform), non-plastic fines	SW-SM	<15% gravel	WELL GRADED SAND WITH SILT
				>15% gravel	WELL GRADED SAND WITH SILT AND GRAVEL
		Well graded (non-uniform), plastic fines	SW-SC	<15% gravel	WELL GRADED SAND WITH CLAY
				>15% gravel	WELL GRADED SAND WITH CLAY AND GRAVEL
		Poorly graded (uniform), non-plastic fines	SP-SM	<15% gravel	POORLY GRADED SAND WITH SILT
				>15% gravel	POORLY GRADED SAND WITH SILT AND GRAVEL
		Poorly graded (uniform), plastic fines	SP-SC	<15% gravel	POORLY GRADED SAND WITH CLAY
				>15% gravel	POORLY GRADED SAND WITH CLAY AND GRAVEL
	>15% fines	non-plastic fines	SM	<15% gravel	SILTY SAND
				>15% gravel	SILTY SAND WITH GRAVEL
		plastic fines	SC	<15% gravel	CLAYEY SAND
				>15% gravel	CLAYEY SAND WITH GRAVEL

STEP 2: DETERMINE PLASTICITY AND ASSIGN USCS GROUP SYMBOL

FINE-GRAINED DEPOSITS
(>50% fines, <50% coarse-grained sediments)

STEP 3:
*CONTINUE WITH **GROUP SYMBOL** AND FOLLOW FLOW CHART TO ASSIGN A **GROUP NAME***

STEP 4:
DOES ORGANIC CONTENT INFLUENCE SOIL PROPERTIES?
YES — OL / OH
NO — ML, CL, CH

				GROUP NAME
ML	less than 30% Coarse Grained Sediments	< 15% Coarse-Grained Sediment		SILT
		15-25% Coarse-Grained Sediment	% sand > % gravel	SILT WITH SAND
			% sand < % gravel	SILT WITH GRAVEL
	more than 30% Coarse Grained Sediments	% sand > % of gravel	<15% gravel	SANDY SILT
			>15% gravel	SANDY SILT WITH GRAVEL
		% sand < % gravel	<15% sand	GRAVELLY SILT
			>15% sand	GRAVELLY SILT WITH SAND
CL	less than 30% Coarse Grained Sediments	< 15% Coarse-Grained Sediment		LEAN CLAY
		15-25% Coarse-Grained Sediment	% sand > % gravel	LEAN CLAY WITH SAND
			% sand < % gravel	LEAN CLAY WITH GRAVEL
	more than 30% Coarse Grained Sediments	% sand > % of gravel	<15% gravel	SANDY LEAN CLAY
			>15% gravel	SANDY LEAN CLAY WITH GRAVEL
		% sand < % gravel	<15% sand	GRAVELLY LEAN CLAY
			>15% sand	GRAVELLY LEAN CLAY WITH SAND
CH	less than 30% Coarse Grained Sediments	< 15% Coarse-Grained Sediment		FAT CLAY
		15-25% Coarse-Grained Sediment	% sand > % gravel	FAT CLAY WITH SAND
			% sand < % gravel	FAT CLAY WITH GRAVEL
	more than 30% Coarse Grained Sediments	% sand > % of gravel	<15% gravel	SANDY FAT CLAY
			>15% gravel	SANDY FAT CLAY WITH GRAVEL
		% sand < % gravel	<15% sand	GRAVELLY FAT CLAY
			>15% sand	GRAVELLY FAT CLAY WITH SAND
OL / OH	less than 30% Coarse Grained Sediments	< 15% Coarse-Grained Sediment		ORGANIC SOIL
		15-25% Coarse-Grained Sediment	% sand ≥ % gravel	ORGANIC SOIL WITH SAND
			% sand < % gravel	ORGANIC SOIL WITH GRAVEL
	more than 30% Coarse Grained Sediments	% sand ≥ % of gravel	<15% gravel	SANDY ORGANIC SOIL
			≥15% gravel	SANDY ORGANIC SOIL WITH GRAVEL
		% sand < % gravel	<15% sand	GRAVELLY ORGANIC SOIL
			≥15% sand	GRAVELLY ORGANIC SOIL WITH SAND

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FIELD GUIDE FOR SOIL AND STRATIGRAPHIC ANALYSIS v.2

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START HERE

DENSITY OR CONSISTENCY

COARSE GRAINED DEPOSITS N-VALUE	
0-4	► VERY LOOSE
5-10	► LOOSE
11-29	► MEDIUM DENSE
30-49	► DENSE
>50	► VERY DENSE

FINE GRAINED DEPOSITS N-VALUE	q_u (tsf)	
0-2	<0.25	► VERY SOFT
3-4	0.25-0.50	► SOFT
5-8	0.50-1.0	► MEDIUM
9-15	1.0-2.0	► STIFF
16-30	2.0-4.0	► VERY STIFF
>30	>4.0	► HARD

COLOR

Use Standard Munsell Color Notation

IS THE COLOR A MATRIX COLOR?

YES → **MATRIX COLOR** List in sequence, dominant first

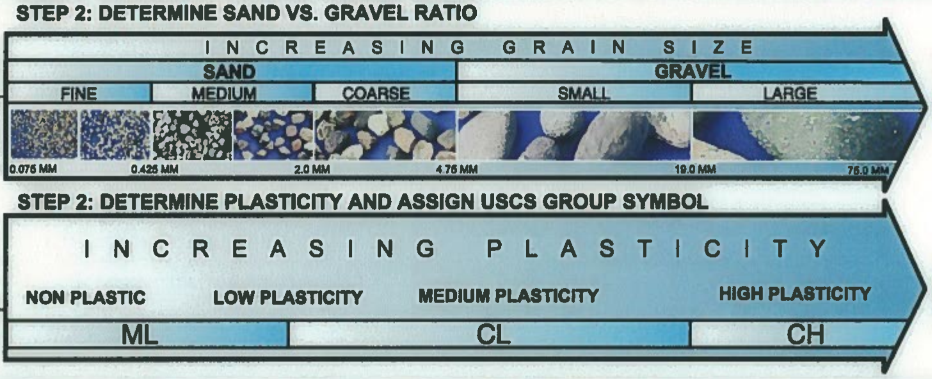
NO → IS THE COLOR FROM A COATING OR CONCENTRATION?

YES → **COATING or CONCENTRATION** Note frequency, color, and size

NO → **MOTTLE** Note contrast, color, and size

CLASSIFICATION

Unified Soil Classification System - adopted ASTM D2488



STEP 1: IS SEDIMENT COARSE GRAINED OR FINE GRAINED?

COARSE-GRAINED DEPOSITS
>50% coarse-grained sediments, <50%fines

STEP 2: DETERMINE SAND VS. GRAVEL RATIO

STEP 3: *CONTINUE WITH SAND OR GRAVEL ON FLOW CHART (REVERSE)*

FINE-GRAINED DEPOSITS
(organic and inorganic)
>50% fines, <50% coarse-grained sediments

STEP 2: DETERMINE PLASTICITY AND ASSIGN USCS GROUP SYMBOL

STEP 3: *CONTINUE WITH GROUP SYMBOL ON FLOW CHART (REVERSE)*

MOISTURE

MOISTURE ABSENT	► DRY
DAMP	► MOIST
VISIBLE WATER	► WET

FOR NON-PLASTIC FINES

WATER RISES TO SURFACE SLOWLY	► SLOW DILATENCY
WATER RISES TO SURFACE QUICKLY	► RAPID DILATENCY

PLASTICITY

(Use with CLASSIFICATION)

WILL NOT SUPPORT 6mm DIAMETER ROLL IF HELD ON END	► NON-PLASTIC
6mm DIA. ROLL CAN BE REPEATEDLY ROLLED AND SUPPORTS ITSELF, 4mm DIA. ROLL DOES NOT	► LOW PLASTICITY
4mm DIA. ROLL CAN BE REPEATEDLY ROLLED AND SUPPORTS ITSELF, 2mm DIA. ROLL DOES NOT	► MEDIUM PLASTICITY
2mm DIA. ROLL CAN BE REPEATEDLY ROLLED AND SUPPORTS ITSELF	► HIGH PLASTICITY

6mm
4
②

COHESIVENESS

6mm DIAMETER ROLL CANNOT BE FORMED	► NONCOHESIVE
6mm DIAMETER ROLL CAN BE FORMED	► COHESIVE

SEDIMENTARY STRUCTURE

UNIFORM		► MASSIVE
BEDS	>30cm	► THICKLY BEDDED
BEDS	3cm to 30cm	► BEDDED
BEDS	0.5cm to 3cm	► THINLY BEDDED
BEDS	<0.5cm	► LAMINATED

SECONDARY SOIL STRUCTURE (IN SOLUM ONLY)

Spheroidal peds or granules usually packed loosely	► GRANULAR
Irregular, roughly cubelike peds with planar faces (angular or subangular)	► BLOCKY
Flat and horizontal peds	► PLATY
Vertical, pillarlike peds with flat tops	► PRISMATIC
Vertical, pillarlike peds with curved tops (which are commonly "bleached")	► COLUMNAR

WEATHERING ZONE ABBREVIATION

MODIFIER SYMBOL (if present)		1st SYMBOL		2nd SYMBOL		LAST SYMBOL (if present)	
MOTTLED	► M	OXIDIZED	► O	LEACHED	► L	SECONDARY CARBONATE	► 2
JOINTED	► J	REDUCED	► R	UNLEACHED	► U		
		UNOXIDIZED	► U				

EXAMPLE

solum	
OJL	MRJU
MOJL	RJU
MOJL2	RU
MOJU	UU

SECONDARY GRAIN SIZE INFORMATION

< 5%	► TRACE
6% to 15%	► FEW
16% to 30%	► LITTLE
31% to 49%	► SOME


► UNIFORM (poorly graded)


► NON-UNIFORM (well graded)

► FINE SAND
► MEDIUM-GRAINED SAND
► COARSE-GRAINED SAND
► FINE GRAVEL
► COARSE GRAVEL

FOR GLACIAL DIAMICTONS
► CLAST FRACTION
► CLAST LITHOLOGY

DEPOSITIONAL ENVIRONMENT

VARIOUS DEPOSITIONAL ENVIRONMENTS (interpretation)
► EOLIAN (LOESS)
► FLUVIAL
► ALLUVIAL
► LACUSTRINE
► COASTAL
► RESEDIMENTED

GLACIAL DEPOSITIONAL PROCESSES
► SUBGLACIAL
► GLACIOFLUVIAL
► GLACIOLACUSTRINE
► RESEDIMENTED

GENERALIZED RESEDIMENTATION PROCESSES
► MASS SLUMP
► SEDIMENT FLOW
► COLLUVIUM

STRATIGRAPHIC NAME

USE FORMAL STATE GEOLOGICAL SURVEY NOMENCLATURE WHEN POSSIBLE;
IF NOT POSSIBLE, ASSIGN SITE-SPECIFIC UNIT NAME ACCORDING TO DEPOSITIONAL ENVIRONMENT / FACIES ASSEMBLAGE

STRATIGRAPHIC CONTACT

010106

< 10 cm	► **SHARP** (or **ABRUPT** for pedogenic alternation)
> 10 cm (Note transition interval)	► **GRADATIONAL** (or **TRANSITIONAL** for weathering zone change)

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1/9
LAB

(USDA Method)

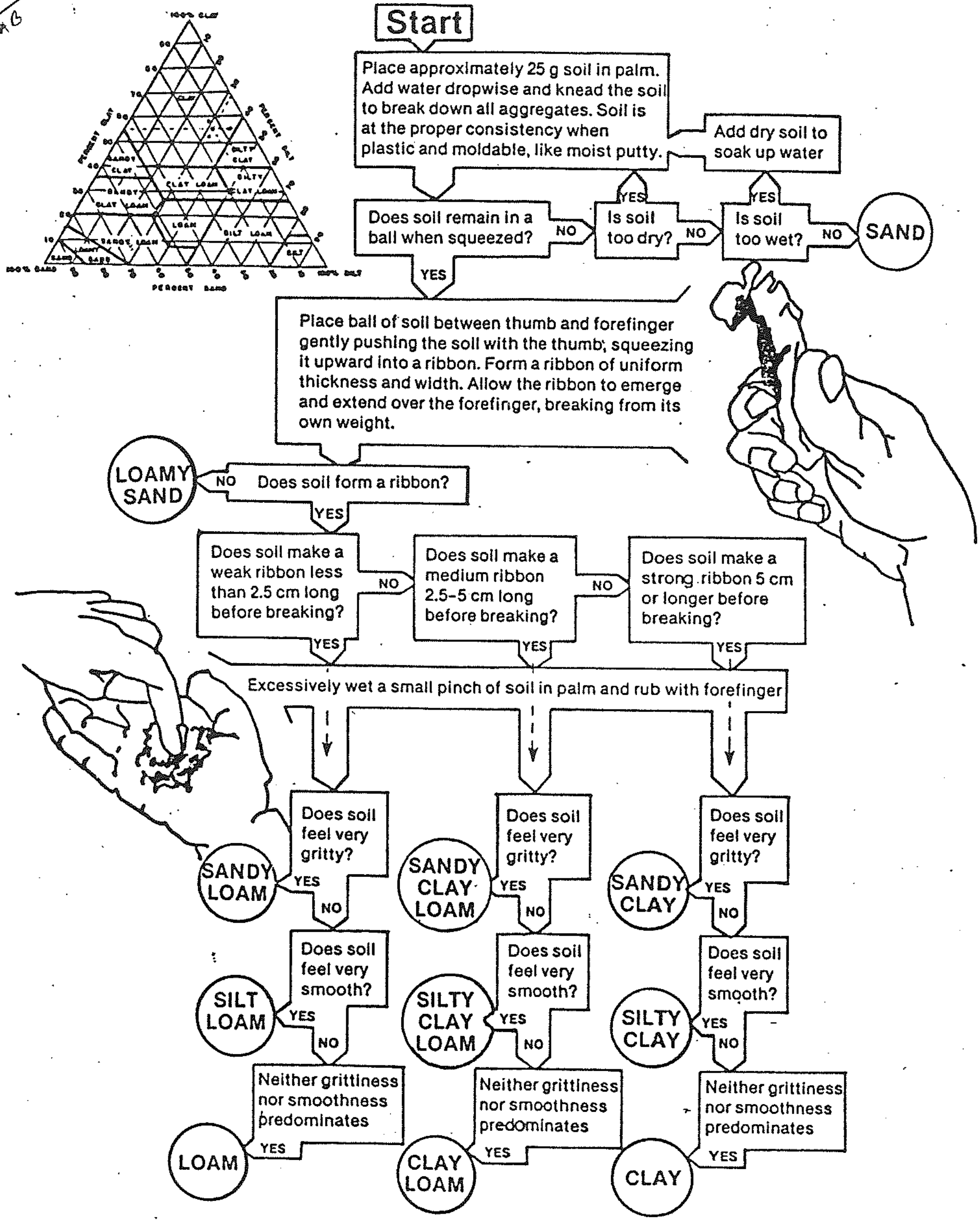

Fig. 1. Instructional diagram for determining soil texture by feel.

ENVIRONMENTAL WORKS INC.	**Standard Operating Procedure (SOP)**	Issue Date: 6-25-09 Updated: 6-25-09
Procedure No. 4: Terra Core® Method 5035 Soil Sampling		Technical Reference: Jason Smith
		Page: 1 of 3

Skills Required:

1) Site-specific health & safety training.
2) Corporate procedures on field documentation methods and soil boring logging
3) Drilling operations.
4) Site-specific data quality objectives and corporate quality assurance.

1.0 OBJECTIVE / APPLICABILITY

The Objective of this Standard Operating Procedure (SOP) is to provide procedures for EWI personnel to employ Terra Core® Method 5035 when collecting soil samples of soil for volatiles analysis.

In June 1997, the United States Environmental Protection Agency (EPA) adopted Method 5035 for the sampling and analysis of total amounts of volatile organic compounds (VOCs) in solids. This method does not apply to samples collected for leachate analysis such as those for the Toxicity Characteristic Leachate Procedure (TCLP).

Method 5035 was adopted because of studies showing that sampling according to the previous methods resulted in significant losses of selected VOCs. Method 5035 incorporates chemical preservatives and sample storage techniques to limit volatilization and biodegradation of VOCs.

This is a standard operating procedure, which may be varied as required dependent of site conditions, equipment limitations or limitations imposed by the procedure. In all instances, the ultimate procedure employed should be documented and associated with the final report.

2.0 SCOPE

This SOP describes the process of collecting soil samples using the 5035 method. The scope of this SOP is limited to retrieval of the soil to be sampled (using a push probe, excavator or hand auger) through packaging the sample for shipment to a laboratory.

3.0 EQUIPMENT

Equipment needed for Terra Core® Method 5035 Soil Sampling include:

a. A work plan outlining soil sampling requirements for the project
b. Terra Core Soil Kits (typical kit includes 1 methanol 40-ml vial, 2 sodium phosphate tribasic 40-ml vials, 2 unpreserved 40-ml vials, 1 unpreserved 2-oz or 4-oz jar, and 1 disposable Terra Core sampler).
c. Chain of Custody
d. Two gallon plastic bags
e. Cooler to store samples
f. Ice
g. Packing tape
h. Duct tape
i. Fine-tipped Sharpie

j. UPS/Fed-Ex Shipping label(s)
k. Custody Seal(s)
l. Disposable sampling gloves
m. Paper Towels
n. Trash bags

4.0 PROCEDURES

4.1 Pre-Operation

(1) Gather all equipment needed and review the work plan/work request.

(2) Review contents of the laboratory cooler. Ensure that all Terra Core® kits, trip blanks, temperature blanks, chain of custody, sample labels and shipping labels are present

(3) Conduct an on-site safety meeting each day before the start of the project. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, alertness to heavy equipment). Have all personnel sign the Tailgate Safety Meeting Form (see Appendix A) each day before the start of the project.

(4) Have the driller/excavator collect the soil to be sampled. Assess qualitative characteristics of soil (i.e. soil type, odor, presence of chert, color, etc) and record observations on soil boring log. Collect soil sample for PID reading according to SOP #4.

4.2 Operation

(5) Identify the zone in the soil core that is to be sampled. In a typical soil core, approximately six inches of soil will need to be present to collect a sample using this method. Avoid soil zones that contain excessive amounts of gravel or chert fragments.

(6) Insert the Terra Core sampler into the soil to the base of the plunger as shown in the first photo below. **Always wear disposable gloves when handling the vials, the Terra Core and the sample**.

(7) Wipe soil or debris from the outside of the Terra Core® sampler. The soil plug should be flush with the mouth of the sampler as shown in the second photo.

(8) Rotate the plunger that was seated in the handle top 90° until it is aligned with the slots in the body. Place the mouth of the sampler into the 40ml VOA vial containing the appropriate preservative and extrude the sample by pushing the plunger down (see third photo). Quickly place the lid back on the 40ml VOA vial.

(9) Repeat Steps #5 - #8 until all 40-mL vials are filled with approximately five grams of soil. For each sample, most laboratories provide five 40-mL vials: two preserved with sodium phosphate tribasic (TSP), two unpreserved and one preserved with methanol.

(10) Fill the 2 or 4 oz glass jar with soil from the same zone as where the sample was collected from. You do not need to use the Terra Core to fill this jar.

(11) Dispose of the Terra Core sampler.

(12) Write sample ID, date, time, and sampler name on each pre-labeled vial and glass jar. **Note: The sample kits are pre-labeled and pre-weighed. Do NOT attach a new label to any of the jars as this will alter the net weight of the jar or vial.**

(13) Place soil sample kit in a two gallon plastic bag, seal the bag, and then place the bag in the cooler on ice.

(14) Repeat steps 5-13 until all soil samples are collected.

(15) Make sure coolers are packed with plenty of ice to keep the samples at 4°C. Include one trip blank and one temperature blank per cooler or as required by the site-specific work plan.

(16) Keep the copy of chain of custody and place the completed original chain of custody in a plastic bag. Tape the plastic bag with the chain of custody securely to the inside of the cooler lid.

(17) Tape up cooler(s) with packing tape. Make sure to tape over drain valves on the coolers, if applicable.

(18) Sign and date the custody seal(s).

(19) Place the custody seal over the cooler opening and secure with a piece of packing tape.

(20) Complete the Shipping Label. Keep shipper's copy and attach original to the cooler(s).

(21) Ship coolers for next day delivery. NOTE: For the laboratory to analyze the samples using the unpreserved sample containers, the samples must be received by the laboratory no later than 48 hours after sample collection.

5.0 REFERENCES

(1) SW-846 EPA publication "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods." http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm

(2) En Novative Technologies, Inc. *Recommended Use Of The Terra Core®*

ENVIRONMENTAL WORKS INC.	**Standard Operating Procedure (SOP)**	Issue Date: 9-17-2010 Updated: *9-10-10 RML*
Procedure No 6: Monitoring Well Installation		Technical Reference: Bob Lanning Page: 1 of 10

Skills Required:

1) 40-hour HAZWOPER training (if working on hazardous waste sites)
2) Understanding of, and ability to make decisions regarding, site-specific objectives
3) Training in soils characterization and recognizing saturation (SOP #3)
4) Knowledge and training in types of wells and well materials
5) Knowledge of corporate Safety requirements and health and safety plan

1.0 OBJECTIVE / APPLICABILITY

The objective of this Standard Operating Procedure (SOP) is to provide general and specific procedures, methods and considerations to be used and observed when designing and installing permanent and temporary groundwater monitoring wells to be used for collection of groundwater samples and or measurement of water levels.

This SOP serves as a reference tool to facilitate consistency among Environmental Works, Inc. (EWI) personnel. These operating procedures may be varied as required, depending upon site conditions, equipment limitations or limitations imposed by the project or client. Exceptions are requirements by federal or state environmental regulatory agencies; monitoring well installation requirements specified by these agencies must be followed or an official variance obtained prior to field work. It is the responsibility of EWI personnel to research, understand, and follow such regulations. In all instances, the ultimate procedures employed should be documented and associated with the final report.

2.0 SCOPE AND PERSONNEL APPLICATION

Monitoring wells must be appropriately and correctly installed to enable collection of reliable and accurate data for evaluating site conditions, and extent and changes in contamination. Improperly constructed wells will yield non-representative data and lead to erroneous decisions leading to potentially adverse environmental and/or fiscal liabilities for the client and EWI.

Supervision of well installation should normally be performed by technical personnel (commonly EWI scientists and associate scientists). Personnel performing these functions should be trained in proper decision-making and techniques. If there is any question regarding specific circumstances of well installation, the project manager should be consulted.

Most states, including Missouri, require certification for drillers and supervisory personnel for installation of monitoring wells.

3.0 GENERAL PLANNING CONSIDERATIONS

The design and installation of monitoring wells requires an understanding of varying subsurface materials and conditions. There are several different drilling methods and installation procedures that can be deployed, depending on the geologic and hydrologic conditions, contaminants, and objective and desired length of time for monitoring. The selection of drilling method and installation procedures should be based on field data and/or search of existing data. Each monitoring well should be designed and installed to achieve the project objective and function properly throughout the duration of the monitoring program. When planning and designing monitoring wells, the following should be considered prior to starting field activities:

Skills Required:

1) 40-hour HAZWOPER training (if working on hazardous waste sites)
2) Understanding of, and ability to make decisions regarding, site-specific objectives
3) Training in soils characterization and recognizing saturation (SOP #3)
4) Knowledge and training in types of wells and well materials
5) Knowledge of corporate Safety requirements and health and safety plan

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This SOP serves as a reference tool to facilitate consistency among Environmental Works, Inc. (EWI) personnel. These operating procedures may be varied as required, depending upon site conditions, equipment limitations or limitations imposed by the project or client. Exceptions are requirements by federal or state environmental regulatory agencies; monitoring well installation requirements specified by these agencies must be followed or an official variance obtained prior to field work. It is the responsibility of EWI personnel to research, understand, and follow such regulations. In all instances, the ultimate procedures employed should be documented and associated with the final report.

2.0 SCOPE AND PERSONNEL APPLICATION

Monitoring wells must be appropriately and correctly installed to enable collection of reliable and accurate data for evaluating site conditions, and extent and changes in contamination. Improperly constructed wells will yield non-representative data and lead to erroneous decisions leading to potentially adverse environmental and/or fiscal liabilities for the client and EWI.

Supervision of well installation should normally be performed by technical personnel (commonly EWI scientists and associate scientists). Personnel performing these functions should be trained in proper decision-making and techniques. If there is any question regarding specific circumstances of well installation, the project manager should be consulted.

Most states, including Missouri, require certification for drillers and supervisory personnel for installation of monitoring wells.

3.0 GENERAL PLANNING CONSIDERATIONS

The design and installation of monitoring wells requires an understanding of varying subsurface materials and conditions. There are several different drilling methods and installation procedures that can be deployed, depending on the geologic and hydrologic conditions, contaminants, and objective and desired length of time for monitoring. The selection of drilling method and installation procedures should be based on field data and/or search of existing data. Each monitoring well should be designed and installed to achieve the project objective and function properly throughout the duration of the monitoring program. When planning and designing monitoring wells, the following should be considered prior to starting field activities:

(1) Short and long-term objectives – temporary or permanent well;
(2) Purpose of the well (hydraulic or chemical monitoring, or both);
(3) Probable duration of the monitoring program;
(4) Contaminants likely to be encountered;
(5) Surface and subsurface geologic conditions – unconsolidated or bedrock well?
(6) Properties of the aquifer(s) to be monitored;
(7) Type of drilling method most appropriate to use;
(8) Type of well materials to use;
(9) Length, slot size, and placement of well screen;
(10) Type of surface completion (above ground pedestal, or flush-mount);
(11) Control and management of solid and liquid drilling wastes;
(12) Regulatory requirements; and
(13) Potential site health and safety hazards.

The following sections discuss aspects of these considerations and provide procedural guidelines for installing a well.

4.0 WELL CONSTRUCTION MATERIALS

4.1 Well Screen and Casing (“Riser Pipe”) Materials:

- Must not contribute foreign constituents
- Must not remove contaminants of concern from the groundwater
- Durable for length of monitoring
- 2” minimum diameter for monitoring, less allowed for piezometers
    - Want large enough to accommodate well use (sampling? pump? data logger?)
- PVC Schedule 40 minimum (Sched 80 if over 100 ft deep)
- Mechanical, waterproof joints (threaded or welded, not glued if plastic)
- If metal, same type must be used
- Compatibility with contaminants - see Attachments for compatibility table (EPA document EPA/540/S-95/503, *Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation*)
- Types of casing and screen materials for checking compatibility:
    - Metal: stainless steel (304 and 316) (preferred on RCRA and Superfund sites) (carbon steel, low-carbon steel, galvanized steel not recommended)
    - Thermoplastics: polyvinyl chloride (PVC) and acrylonitrile-butadiene-styrene (ABS)
    - Fluoropolymers: polytetrafluoroethylene (PTFE), tetrafluoroethylene (TFE), fluorinated ethylenepropylene (FEP), perfluoroalkoxy (PFA) and polyvinylidene fluoride (PVDF)

4.2 Filter Pack Materials

- Clean, rounded, hard, insoluble siliceous particles (quartz sand)
- Base filter pack particle size on sieve analysis of aquifer material if possible.

- Filter pack size may be based on knowledge of expected geology.
- “Pre-pack” screens are available, which have an inner and outer screen with sandpack already placed inside. Good for small diameter well applications, wells that cannot be built within augers, or application in heaving sands.

4.3 Seal and Grout Materials

- Bentonite as chips or pellets is used for a seal above the filter pack (chips are cheaper and hydrate better than pellets)
- Grout above the seal may be pure (“neat”) cement (may shrink), a cement-bentonite mixture (5-20% bentonite, reduces shrinkage), or a bentonite slurry (check State regulations for requirements). Some states may not allow plain dry, powdered bentonite as a grout seal, so regulations must be checked. The Attachments contain a table showing amounts of cement, bentonite, and water for various percentage mixtures.
- Grout in deeper wells should be emplaced with a tremie tube, filling from the bottom up.

5.0 GENERAL MONITORING WELL INSTALLATION PROCEDURES

5.1 Unconsolidated Zone Wells

- Unconsolidated zone wells will always need a well screen and filter pack, and are normally constructed with the hollow stem augers in place to keep things centered in the hole and produce “cleaner” well conditions. Considerations:
  - Insure large enough hollow stem augers to allow proper well construction. Check State regulations for size requirements of the annular space between the boring walls and the casing diameter. 2” annular space is a common requirement.
  - If the bore is drilled with soil sampling and minimum or very little water is produced, the well can be constructed after removing the centerline drill rods and bit, pending size of the augers and casing/screen.
  - If very little water is produced, an option is to remove the augers and install the well materials using centralizers to insure the screen and casing are positioned mid-hole. Be careful of centralizer placement so as not to cause clumping of filter pack material with void space below (“bridging”) when it is added.
  - If water is produced during boring, remove the augers once total depth (TD) is reached and sampling is completed, install a wooden (or other inert material) plug in the lead auger, and drill down to TD. The well can then be constructed inside the augers by pushing out the plug by holding the casing in place as the augers are removed while the filter sand is introduced. This is a longer process, but is necessary to avoid infilling of soil into the augers and the sand pack getting impacted by muddy water (which makes the well very difficult to develop).
  - If the bore is to be drilled without sampling and material is fairly soft, it may be possible to install the plug in the lead auger bit before starting. The plug can then be pushed out once TD is reached, and the well constructed inside the augers.
- Once TD is reached, sketch out the well on paper (in your field notes) and check your depths before giving directions to the driller. For guidelines in planning wells:

  - Identification of the saturated or water-producing zone is critical to proper well construction. The saturated zone is normally determined by soil logging and/or information from the driller (depth where hole is "making water"). A drop in blow counts (if samplers advanced by pounding) may indicate saturated conditions. Selecting well screen depths for follow-up wells should utilize saturated zone and water level data from existing wells in the area.
  - Screen length must be long enough to effectively monitor the zone of interest, normally not less than 5 ft in length. Maximum length may be restricted by geology.
  - Normally a 0.01-inch slot size screen is used. A finer slot size may be needed if finer sand filter pack is required. This needs planned in advance and the driller alerted.
  - Screen placement should have top of screen above the water table sufficient to keep fluctuations in water table within the screen interval. Placing the bottom 2/3 of the screen below the water table is a good general guide.
  - If depth to saturation is questionable, it is better to use a longer well screen and install it deeper to insure the screen will encounter the water table.
  - If the boring TD is deeper than the desired monitoring interval, the excess depth can be filled in with sand prior to placement of the screen, or a blank casing can be installed on the bottom of the screen to create a "sump". A sump may be desirable if fine-grained aquifer material may cause sedimentation in the well.
  - Plan on installing filter pack (sand pack) to at least 2 feet above top of screen (check State regulations)
  - Sand pack size should be matched to lithology. Sand normally comes in the size grades 8-14 (very coarse), 10-20 (coarse), 20-40 (medium), and 40-60 (fine). For most mixtures of silt and sand matrices, Medium Sand is commonly used; this should be adjusted for known or measured sediment grain size.
  - Plan on installing a minimum 3-foot bentonite seal (check State regulations). Chips are commonly used versus pellets. They are just as effective and cheaper. Bentonite must be hydrated with water if installation of the seal is above the water table. Note that if bentonite slurry grout is planned, a thinner layer (or none) of bentonite chips may be used (check State regulations).
  - Use Well Construction Tables (if available) or calculations to estimate the volumes of filter pack, bentonite seal, and upper grout that will be needed to fill the annular space between the casing/screen and the boring wall.
- Measure all components of the well string – end cap, screen, and casing and record on the field well completion log (see Attachments).
- Drill crew actions when installing a well inside augers should be the following:
  - Emplace the casing and screen with end cap to TD. The top of casing should be capped or covered with tape to prevent materials from entering the casing during well construction activities.
  - Brace the casing appropriately while the augers are lifted slightly to "pop" out the wood plug (if used).
  - Begin slowly pouring in sand filter material as the depth is measured. For deep wells it may be necessary to use a tremie pipe to avoid "bridging" of the sand.

  - Slowly pull out augers as sand is added. The idea is to have enough sand inside the augers as they are pulled to avoid native soil and water from entering the augers, yet not so much sand as to “sand lock” the augers and prevent their removal.
  - Insure the driller progressively measures the depth of filter pack material and seal materials during installation using a weighted tape measure as the augers are removed; depth checks should be made circumferally around the casing.
- Note and record the number and weight of bags, manufacturer, and type of filter pack and bentonite seal material emplaced.
  - Compare actual volumes installed to the calculated quantities needed.
  - Note that bentonite seals must be hydrated in “lifts” if groundwater is lacking.
- If a cement seal is used above the bentonite seal, note and record the manufacturer and number and weight of neat cement bags. If powdered bentonite is added to the cement, note the quantity added. Record the quantity of water used in mixing the cement. Compare calculated volumes to those actually installed.
- Note the depth of the bentonite or cement grout from surface. Cement grout should be allowed sufficient time to set prior to the final surface completion.

5.2 Bedrock Wells

- Several bedrock drilling techniques are available, unlike unconsolidated wells:
  - Diamond core drilling: Desirable, since yields core samples for logging and testing, but requires constant water source, recirculation tank or pit, and is expensive.
  - Water (mud) rotary: Used for deeper wells, requires water source and water recirculation pit. Geology logged from cuttings.
  - Air rotary: Commonly used for unconsolidated and bedrock sockets and larger diameter bores. Produces lot of dust. Geology logged from cuttings.
  - Air hammer: Commonly used for bottom hole completions – fastest drilling, straightest holes. Also produces a lot of dust. Geology logged from cuttings.
- Wells in bedrock may complete as an open bore without screen and filter pack.
  - Need bedrock geology to support open bore without collapsing or caving in.
  - Will result in vertically extensive monitored interval, good if water entry horizons are not known.
  - Desirable if downhole geophysics or downhole videography is planned.
  - If extensive fractures or solution cavities are encountered, may need screen to keep out sediment (plan ahead).
  - May require a variance from state regulations (e.g., Missouri).
- Bedrock wells may have multiple casings (check State regulations for size requirements).
  - A surface casing will normally be needed regardless of type of bedrock completion.
  - The surface casing is grouted in a bedrock “socket” to insure the unconsolidated zone is sealed out.
  - If a casing and screen are used, the well will have dual casings.

  - Deep wells may have multiple casings-within-casings if needed to properly seal certain zones.
- For open bore bedrock wells, a surface casing must be securely in place and grouted prior to drilling the open borehole. Measure and record type of material, diameter, and length.
  - Depending on conditions, a "shale basket" (cone-shaped heavy rubber collar) can be placed at the bottom of the casing prior to installation to help hold annular seal and grouting materials in place.
- For wells using casing riser pipe and screen, planning and placement of screen, filter pack, seals, and grout is the same as for unconsolidated wells, but some procedures are different:
  - Centralizers will normally be required to insure central placement of the drill string
  - Filter pack and bentonite seal materials will commonly have to be emplaced using a tremie due to well depths (check State regulations)
- Drilling waste can be an issue with bedrock wells using air techniques, and management of wastes must be planned and coordinated with the driller prior to mobilization.
  - Wellhead diverters can be used to control wastes and channel wastes into tanks, bins, or other containers.
  - Water producing zones can produce a lot of water. Diverters and berms around the wellhead must be employed if water-producing zones could be present.

5.3 Surface Completions

- Two types: Flush (below ground) or Pedestal (above ground). Check State regulations for size, length, depth, placement hole, type of sealant, etc. requirements.
- Surface completion pads (whether above or below ground) should be installed using a 2-ft by 2-ft wood-framed square of concrete, or a circular pad using a mold. The surface should be elevated above the ground and should slope downward in all directions from the pedestal or vault lid.
  - Note the depth of the hole for the surface completion.
  - Note the type and quantity of seal (normally concrete or "quickrete") and water volume used to construct the pad area
  - Note the dimensions and type of pedestal or vault used for the installation.
- Proper procedures for cutting top of casing to final height:
  - Insure shavings from the casing cutting do not enter the well (bundled paper, etc. can be placed inside the casing with string to aid in its removal following cutting).
  - Top of casing should be a few inches minimum above the base of the vault or inside pedestal concrete to prevent build up of water that could seep inside the well.
  - A "J-Plug" expandable well cap should be placed on the casing and tightened to prevent easy removal of the well cap or seepage of water into the well.
  - Measure and record on the field log the final top of casing height above/below land surface
- Pedestal mount completions must be completed per State regulations.

  - Some states require drilling of a "weep hole" to drain water from inside the pedestal.
  - Pedestals should have 2 to 3 bumper guards ("bollards") installed to prevent damage to the pedestal and contained well riser.
- The well ID should be painted or stenciled on the inside and outside of vault or pedestal lids.

6.0 TEMPORARY MONITORING WELL INSTALLATION

- Normally used for short-term delineation of contaminants or for site screening purposes. May be installed, purged, sampled, removed, and backfilled in a matter of hours. Must not be used to replace permanent monitoring wells, and may be subject to State regulations for installation and the duration of time that temporary wells are allowed to remain in place; check State regulations.
- Construction and materials use are varied to meet objectives of the well. Sand pack materials may or may not be used, but typically there is no bentonite seal, grout, surface completion, or extensive development.
- Types of temporary wells:
  - **No Filter Pack** – Casing and screen are inserted in a bore without filter pack or development. Least expensive and fastest application, but is extremely sensitive to turbidity fluctuations.
  - **Traditional Filter Pack** – Casing and screen are inserted into the borehole, and sand is quickly poured into the annular space. Collapse of the bore may result in incomplete sand coverage, and the filter will be compromised by muddy water.
  - **Double Filter Pack** – The well screen is filled with filter pack material and the well screen and casing inserted until the top of the filter pack is at least 6 inches below the water table. Filter pack material is poured into the annular space around the well screen. May be effective in aquifers where fine silts or clays predominate.
  - **Well-in-a-Well** – A 1-inch well screen and riser are inserted into a 2-inch well screen with riser, and centered. Filter pack material is placed into the annular space surrounding the 1-inch well screen, to approximately 6 inches above the screen. The well is then inserted into the borehole. This is basically creating a "pre-pack" screen in the field.
- Temporary well boreholes must be decommissioned after sampling by removing the screen and riser, and backfilling the bore with bentonite chips to saturation.

7.0 VARIANCE, CERTIFICATION, AND REGISTRATION FOR MONITORING WELLS

State well regulations must be researched prior to planning and drilling monitoring wells. If site conditions and objections require installation of a well that will not comply with state regulations, a variance might be obtained by written request to that state's regulating entity; note that such requests need to be made and approved prior to initiating drilling. Most states require some form of formal certification or registration for installed monitoring wells, sometimes including temporary wells. Well logs are commonly required, and fees may be charged. Formal registration report forms may also be required for monitoring wells or soil borings that have been abandoned, with or without a fee. State regulations must be researched prior to installing or abandoning wells to insure compliance with requirements.

8.0 SAFETY

8.1 General Safety Precautions

Acute or chronic exposure to chemically-contaminated soil or water could result in bodily injury. Routes of exposure include inhalation, ingestion, and dermal contact. Consult the appropriate chemical material safety data sheet (MSDS) before mobilization so that proper PPE and monitoring are planned and implemented.

Conduct an on-site safety meeting each day before the start of field work utilizing a Tailgate Safety Meeting form. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, alertness to heavy equipment, PPE, health monitoring, and emergency procedures). Take appropriate action if personnel are injured on-site per EWI policy guidance.

When working with potentially hazardous substances, follow the United States Environmental Protection Agency (US EPA), Occupational Safety and Health Administration (OSHA), EWI Corporate Health and Safety Plan, and site-specific health and safety plan.

8.2 Safety Procedures Specific to Drilling Activities

- Utility clearances must be conducted and documented prior to start of drilling.
- Drill crews and others working near the rig should wear safety hats, safety glasses, and steel toed boots. Ear plugs are required and provided by the site safety officer or driller.
- Work gloves (cotton, leather, etc.) should be worn when handling drilling equipment.
- All personnel directly involved with the drilling rig should know where the “kill switch” is located in case of emergencies.
- All personnel should stay clear of the drill rods or augers while in motion. Rod wipers, rather than gloved or bare hands, should be used to remove mud or other material from the drill stem as it is withdrawn from the borehole.
- Do not hold drill rods or any part of the safety hammer assembly while taking standard penetration tests or while the hammer is being operated.
- Watch for slip/trip/fall hazards due to tools or drilling equipment on the ground.
- Only the driller and drill crew will conduct all drilling activities. The EWI supervisor will make decisions regarding bore locations, sampling, and well installations, and should act as a safety observer.
- Air monitoring of the breathing zone and wellhead must be conducted if volatile organic compounds are suspected to be present.
- A first-aid kit and fire extinguisher located in the drill rig trailer will be quickly accessible for emergencies. All personnel will be familiarized with their location.
- Be aware of loose clothing, jewelry, or long hair that could be caught up in moving parts.

- The drill rig should not be operated within a minimum distance of 10 feet of overhead electrical power lines and/or buried utilities. Drilling operations will cease if an electrical storm or lightening moves into the area, and the mast should be lowered.

9.0 REFERENCES

(1) U.S. EPA Region 4 Science and Ecosystem Support Division Guidance "*Design and Installation of Monitoring Wells*." February 2008.

(2) U.S. EPA Office of Research and Development and Office of Solid Waste and Emergency Response. "*Ground Water Issue: Nonaqueous Phase Liquids Compatibility with Materials used in Well Construction, Sampling, and Remediation*." July 1995.

(3) The American Society for Testing and Materials (ASTM). Standard D5092, *Design and Installation of Ground Water Monitoring Wells in Aquifers.*

(4) "*Corporate Health and Safety Plan*" Environmental Works, Incorporated.

(5) "*HAZWOPER Training Manual: 40-Hour Hazardous Waste & Emergency Response Training*." Safety Source, Inc.

(6) State regulations for well installations, e.g., Missouri Code of State Regulations 10 CSR 23-4.0 "*Rules of the Department of Natural Resources Division 23 – Division of Geology and Land Survey Chapter 4 – Monitoring Well Construction Code*." January 2019.

Environmental Works, Inc. SOP No. 6

Monitoring Well Installation

ATTACHMENTS

Chemical – Material Compatibility Chart

Table 1 – Cement, Bentonite, Water Mixtures

Well Construction Form

CHEMICAL COMPATIBILITY TABLE

For All Non- Metals

R = Resistant
A = Excellent - No effect
B = Good - Minor effect
C = Fair - Moderate effect
U = Unsatisfactory
X = Conflicting Data
- = No Data Available

For Metals

E < 2 mils Penetration/Year
G < 20 mils Penetration/Year
S < 50 mils Penetration/Year
U > 50 mils Penetration/Year
(1 mil = .001 inch)
A = Excellent - No effect*
B = Good - Minor effect*
C = Fair - Moderate effect*
* No corrision rate reported

	Plastics											**Elastopolymers**										**Metals**						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Acetaldehyde	U	A	U	R	U	U	A	A	U	U	X	A	A	C	U	U	A	U	U	-	R	E	E	G	E	G	U	U
Acetamide	-	A	-	R	R	R	A	A	U	-	C	A	A	B	A	U	B	U	B	-	-	G	G	-	-	G	-	-
Acetate Solvent	U	-	U	R	R	R	B	A	U	U	A	A	A	C	U	-	A	U	U	-	-	E	E	G	E	E	S	G
Acetic Acid 10%	X	X	C	R	U	R	B	A	U	-	C	A	A	C	C	-	C	U	R	A	R	E	E	U	E	G	U	G
Acetic Acid, Glacial	U	U	U	R	U	R	A	A	U	U	B	U	A	X	X	U	B	U	U	A	R	E	E	U	E	E	U	U
Acetone	U	A	U	R	R	R	A	A	U	U	U	A	A	U	U	U	B	U	U	A	R	E	E	G	E	E	G	E
Acetonitrile	U	-	-	R	R	-	R	R	-	-	R	R	-	-	-	-	-	-	-	-	-	G	G	G	-	E	G	G
Acetophenone	U	-	-	R	R	U	R	R	U	U	R	R	-	U	U	-	-	-	U	-	-	G	G	G	G	G	G	G
Acetyl Chloride	U	-	U	R	U	U	U	A	U	U	R	U	-	U	U	U	-	-	R	-	R	G	G	G	-	U	U	U
Acetylene	R	-	R	R	R	-	R	R	R	R	R	R	-	R	R	-	-	-	R	-	-	E	E	G	G	E	U	U
Acrylonitrile	U	-	X	R	R	R	A	A	X	U	A	X	-	C	U	-	U	-	U	-	-	G	G	G	G	E	G	G
Adipic Acid	R	-	A	R	-	R	B	A	R	R	A	A	A	B	X	-	U	-	X	-	-	G	G	G	E	G	-	G
Aldrin (1 oz/gal)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	E	E	G	-	E	-	-
Allyl Alcohol	U	-	R	R	R	R	R	R	R	R	R	R	-	R	R	-	-	-	R	-	-	E	E	G	G	G	G	E
Allyl Chloride	U	-	U	R	-	R	R	R	U	U	R	U	-	U	U	-	-	-	-	-	R	G	E	U	-	U	-	-
Ammonium Acetate	-	-	A	R	A	-	A	A	R	R	R	A	-	A	B	-	-	A	A	-	-	G	G	-	-	G	U	U
Ammonium Oxalate 10%	-	-	-	R	-	-	R	R	R	-	-	R	-	-	-	-	-	-	-	-	-	G	G	U	E	E	-	U
Amyl Acetate	U	B	U	R	R	R	X	A	U	U	A	A	A	U	U	U	U	U	U	A	R	E	E	G	E	E	E	G
Amyl Alcohol	R	A	A	R	A	R	B	A	R	U	A	A	A	A	B	U	U	A	B	A	R	G	G	G	G	G	G	G
Amyl Chloride	U	-	U	R	U	U	U	R	U	U	U	R	-	U	U	-	-	-	R	-	-	G	G	U	E	U	G	G
Aniline	U	A	X	R	X	R	X	A	U	U	A	X	A	U	U	U	U	C	B	A	R	E	E	G	G	G	U	U
Aniline Hydrochloride	U	-	U	R	U	U	X	A	X	U	A	B	-	U	U	-	U	U	A	-	R	U	U	U	U	U	U	G
Antifreeze	B	U	A	-	U	-	U	-	A	-	-	A	-	C	A	-	C	B	A	-	-	-	A	-	-	A	-	-
Aroclor 1248	-	-	-	R	A	U	U	A	-	-	-	B	A	U	X	-	B	-	A	-	-	G	G	G	E	E	E	E
Asphalt	-	B	X	R	A	R	B	A	A	-	A	U	A	U	X	-	U	-	A	-	-	G	G	G	-	E	E	E
Benzaldehyde	X	A	U	R	A	U	X	A	U	U	A	A	A	U	U	U	U	U	U	A	R	G	G	U	G	G	G	G
Benzene	U	A	U	R	A	U	X	A	U	U	A	U	B	U	U	U	U	C	A	A	R	G	G	G	G	E	G	G
Benzo Sulfonic Acid 10%	R	-	R	R	U	R	R	R	R	R	R	U	-	R	U	U	-	-	R	-	R	G	G	U	G	U	G	-
Benzyl Alcohol	U	A	X	R	B	U	A	A	U	U	A	B	A	X	X	U	-	U	A	A	R	E	E	G	G	G	G	E
Benzoic Acid	R	B	A	R	X	B	R	A	R	R	A	U	A	B	U	U	B	A	A	A	R	G	G	U	E	G	G	G
Benzol	U	A	U	R	X	U	U	A	U	U	A	U	A	U	U	U	U	C	A	A	R	G	G	G	G	E	G	G
Benzonitrile	-	-	-	R	R	A	-	A	-	-	-	-	A	-	-	-	A	-	-	-	-	U	U	-	C	-	-	-
Benzyl Chloride	U	A	U	R	R	-	C	R	R	-	R	U	-	U	U	-	U	-	A	-	-	G	G	U	-	U	U	U
Bromobenzene	-	-	-	R	-	-	U	R	-	-	R	U	-	U	U	-	-	-	R	-	-	-	-	-	-	-	-	-
Butadiene	U	A	A	R	R	U	U	A	R	U	A	X	A	B	X	U	U	-	B	-	-	G	G	G	G	G	G	G
Butane	B	A	C	R	R	U	U	A	R	R	A	U	A	A	A	R	U	C	A	-	-	G	G	E	G	G	G	G
Butyl Alcohol	U	A	A	R	B	B	R	A	R	U	A	A	A	A	X	-	B	B	A	-	R	E	E	G	G	E	G	G
n-Butyl Amine	-	X	U	R	R	U	U	A	U	U	X	-	U	U	R	-	B	U	U	-	-	-	G	G	G	G	-	-
Butyl Ether	-	U	U	R	A	-	-	A	R	-	A	U	A	U	B	-	U	A	U	-	-	-	E	E	-	E	-	-
Butyl Phenol	U	-	U	R	-	-	U	R	U	U	R	-	-	U	-	-	-	-	U	-	-	G	E	-	G	G	-	-
Butyl Phthalate	-	-	U	R	R	-	R	R	R	-	R	B	A	D	U	-	A	-	C	-	-	G	G	-	G	U	G	G

	Plastics											Elastopolymers										Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Butylacetate	U	A	X	R	A	R	X	A	U	U	B	B	A	X	U	-	U	U	U	-	R	G	G	G	G	E	G	G
Butyric Acid	U	A	U	R	U	U	R	R	U	U	A	B	A	U	U	-	U	U	B	-	R	G	G	U	E	G	G	G
Carbon Tetrachloride	U	B	U	R	X	U	U	R	U	U	R	U	A	U	U	U	U	B	A	A	R	E	E	G	E	U	G	E
Carbonic Acid	R	B	A	R	R	R	A	A	R	R	A	B	A	X	X	R	A	-	A	A	-	G	G	G	E	E	G	G
Chloroacetic Acid	U	U	U	R	U	U	C	A	R	R	A	B	A	U	U	U	U	A	U	-	-	U	U	U	E	U	U	U
Chlorobenzene	U	X	U	R	R	U	U	B	U	U	A	U	A	U	U	-	U	A	A	A	R	G	G	G	E	G	G	G
Chlorobromomethane	-	-	-	-	C	-	A	A	U	-	-	B	-	U	U	-	U	-	A	A	-	-	-	-	-	-	B	-
Chlordane (1/4 lb/gal)	U	-	-	-	-	-	-	R	-	-	-	U	-	C	B	-	U	-	A	-	-	G	G	G	-	-	-	-
Chloroethane	U	A	U	R	R	R	X	A	U	U	A	X	A	U	U	-	U	-	B	-	-	G	G	G	-	-	-	G
Chloroform	U	A	U	R	R	U	X	A	U	U	A	U	B	U	U	U	U	B	A	A	R	E	E	U	G	G	G	G
Chloronaphthalene	U	-	-	-	-	-	-	-	R	-	-	-	-	U	U	-	-	-	-	-	-	-	G	-	E	U	-	-
Chlorophenol 5% (aq.)	-	R	U	R	U	-	-	R	U	U	R	-	-	-	-	-	-	-	-	-	-	G	G	S	E	-	-	-
Citric Acid	U	B	B	R	R	A	A	A	R	-	A	A	A	A	A	-	A	-	A	A	R	E	E	U	E	E	-	E
Cresol	U	U	U	R	U	U	U	R	X	U	R	U	A	U	U	U	U	U	X	-	R	E	G	G	G	G	-	-
Cresylic Acid 50%	U	U	U	R	U	R	X	R	R	R	R	X	-	U	U	U	U	-	A	-	-	G	G	G	G	G	-	-
Crude Oil	R	R	R	R	R	U	R	U	U	U	U	U	-	U	R	R	-	-	R	-	-	E	E	G	E	E	G	G
Cyclohexane	R	A	U	R	R	R	U	A	X	-	R	U	A	U	B	R	U	U	A	-	-	G	G	G	G	G	G	G
Cyclohexanone	U	A	U	R	R	U	U	A	U	U	R	B	U	U	U	-	U	U	U	A	-	G	G	U	G	G	G	G
DDT 5%	-	-	U	-	-	-	-	-	U	U	-	-	-	-	-	-	-	-	-	-	-	E	E	G	-	E	-	-
Detergents (general)	B	A	A	R	R	R	A	A	R	R	A	A	A	B	A	-	A	A	A	A	-	E	G	G	E	G	G	E
Diacetone Alcohol	-	A	U	R	R	R	R	A	R	-	A	A	B	U	U	-	U	B	U	-	-	G	G	G	E	E	E	E
Dibutyl Phthalate	U	-	U	R	R	U	R	R	U	U	U	R	-	U	U	U	-	-	U	-	-	G	G	G	G	G	G	G
Dichlorobenzene	U	-	U	R	X	U	C	A	U	U	A	U	-	U	U	-	U	-	C	-	-	-	G	-	E	G	-	-
Dichloroethane	U	A	U	R	R	R	X	A	U	U	A	U	A	U	U	-	-	U	C	A	R	G	G	G	G	G	G	-
Dichloroethylene	U	-	-	R	R	-	R	R	U	U	R	U	-	U	U	-	-	-	R	-	-	G	G	-	G	G	-	-
Dichlorofluoromethane	-	-	-	R	-	-	-	R	U	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diesel Fuel	-	A	A	R	R	R	A	A	R	-	A	U	A	B	A	-	U	-	A	-	-	E	E	G	G	E	E	-
Diethanolamine	-	-	-	R	R	-	R	R	U	U	U	-	-	R	-	-	-	-	-	-	-	E	E	E	E	E	-	G
Diethyl Amine	U	B	U	R	R	U	A	X	U	-	X	B	A	A	C	-	B	C	A	-	-	G	G	U	-	G	-	-
Diethyl Ether	U	R	U	R	R	U	R	A	U	U	R	U	C	U	U	-	U	-	U	-	-	G	G	G	G	G	G	G
Diethyl Phthalate	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diethylene Glycol	B	A	A	R	R	R	A	A	X	-	A	A	-	A	A	-	B	C	A	-	-	E	E	E	G	G	-	G
Dimethyl Aniline	U	U	U	R	R	-	X	A	U	U	A	B	A	U	U	-	U	U	U	-	-	B	B	-	B	A	-	-
Dimethyl Ether	-	-	-	R	-	-	-	R	-	-	-	-	-	U	R	-	-	-	-	-	-	G	G	-	G	-	G	G
Dimethyl Formamide	U	X	U	R	R	R	A	X	U	U	U	X	A	X	U	-	C	U	X	-	-	-	G	U	-	E	-	-
Dimethyl Phthalate	U	-	-	R	R	-	R	R	U	U	R	-	-	U	U	-	-	-	R	-	-	E	E	E	-	E	-	-
Dimethyl Sulfoxide	-	R	U	R	R	R	R	R	U	-	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinitrotoluene	-	-	-	-	-	-	-	R	-	-	-	U	-	U	U	-	U	-	X	-	-	G	G	-	-	-	-	-
Dioctyl Phthalate	U	-	U	R	R	U	U	R	U	U	R	R	-	U	U	U	-	-	R	-	-	G	G	G	-	E	-	-
Dioxane	U	R	-	R	R	U	R	R	U	-	U	U	-	U	U	-	-	-	U	-	-	G	G	G	G	G	G	G
Diphenyl	-	-	-	R	R	-	U	A	U	-	-	U	-	B	U	R	U	-	A	-	-	G	G	G	G	G	G	G
Diphenyl Oxide	-	U	-	-	-	-	U	A	U	-	B	U	-	U	A	-	C	U	A	-	-	B	A	-	B	B	-	A
Esters (general)	-	-	U	R	R	-	-	R	U	U	R	-	-	-	-	-	-	-	-	-	-	-	G	-	-	-	-	-
Ethane	-	A	A	-	U	-	U	A	A	-	A	U	-	B	A	-	U	A	A	-	-	A	A	-	-	-	-	A
Ethanolamine	-	U	U	R	R	-	X	A	U	-	X	B	U	B	B	-	B	-	U	A	-	E	E	G	G	G	-	-
Ethers (general)	U	A	U	-	R	U	U	A	U	U	R	C	B	U	X	-	U	C	X	-	R	E	E	G	G	G	G	G
Ethyl Acetate	U	A	U	R	R	R	A	A	U	U	X	B	A	U	U	U	B	U	U	A	R	G	G	G	G	-	G	G
Ethyl Alcohol	B	A	B	R	R	R	A	A	R	R	R	A	B	A	C	U	B	C	A	A	R	G	G	G	E	E	G	G
Ethyl Benzene	-	R	-	R	-	U	U	R	U	U	R	U	-	U	U	-	-	-	R	-	-	S	G	U	E	G	-	-
Ethyl Benzoate	U	-	U	-	-	U	B	A	U	-	U	-	-	U	U	-	U	U	A	-	-	-	-	-	-	-	-	-
Ethyl Chloride	U	R	U	R	R	U	U	R	U	U	R	R	-	U	R	U	-	-	B	-	R	E	E	G	G	-	-	G
Ethyl Ether	U	A	U	R	R	U	U	A	U	U	R	U	A	U	X	U	U	-	U	-	R	G	G	G	G	G	G	G

	Plastics											Elastopolymers										Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Ethyl Sulfate	-	-	-	-	-	-	-	A	-	-	-	-	A	-	A	-	-	-	A	-	-	U	U	-	-	-	-	B
Ethylene Bromide	U	-	U	R	R	U	U	A	U	U	A	X	B	X	U	-	U	U	A	-	-	E	E	-	E	-	-	-
Ethylene Chloride	U	A	U	R	R	R	X	A	U	U	A	X	A	U	U	-	U	-	B	-	-	G	G	G	-	-	-	G
Ethylene Chlorohydrin	U	U	U	R	U	U	X	A	U	U	A	B	-	X	U	U	C	U	A	-	-	G	G	G	G	G	G	G
Ethylene Diamine	U	X	U	R	U	-	R	A	U	U	B	A	U	X	A	-	A	-	B	-	-	G	G	G	U	G	U	U
Ethylene Dibromide	-	-	-	R	-	-	R	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	G	-	G	-	G	-
Ethylene Glycol	A	B	A	R	R	R	A	A	R	R	A	A	A	A	A	R	A	B	R	A	-	G	G	G	E	E	G	G
Ethylene Oxide	U	U	X	R	R	R	U	A	U	U	A	X	C	U	U	U	U	-	U	-	R	G	G	G	E	E	U	-
Formaldehyde 100%	B	A	A	-	U	-	C	A	A	-	A	A	A	C	C	-	B	B	U	-	-	C	A	-	A	A	-	A
Formaldehyde 37%	A	A	A	R	R	R	A	A	R	R	A	A	A	B	X	U	-	-	R	-	R	E	E	U	G	G	E	G
Formic Acid 5%	-	U	R	R	U	R	R	R	R	-	R	R	-	R	U	-	-	-	R	-	-	G	E	-	E	U	S	E
Fuel oils	U	A	-	R	R	R	A	B	R	R	B	U	A	B	X	R	U	A	A	-	-	G	G	G	G	G	G	G
Gasoline (high-aromatic)	U	B	A	-	-	-	A	B	A	-	A	U	A	A	A	-	U	A	A	A	-	A	A	-	A	U	-	-
Gasoline (leaded)	U	A	U	R	R	U	X	A	R	-	A	U	A	B	A	R	U	C	A	A	-	G	G	G	E	G	G	G
Gasoline (unleaded)	U	A	X	R	R	U	X	A	R	-	A	U	A	B	A	R	U	C	A	-	-	G	G	G	E	G	G	G
Glycolic Acid	B	A	A	R	-	R	A	A	R	R	B	A	B	A	A	-	A	A	A	-	-	G	G	U	G	G	-	-
Heptane	X	A	A	R	R	R	C	A	R	R	A	U	A	B	A	U	U	B	A	-	-	G	G	G	E	G	G	G
Hexachloroethane	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	G	G	S	G
Hexamine	-	-	-	R	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	E	E	-	E	E	G	-
Hexane	U	A	B	R	R	U	B	A	R	R	A	U	A	B	A	R	U	U	A	-	-	E	E	G	E	G	G	-
Hexyl Alcohol	-	A	-	-	A	-	-	A	A	-	-	C	-	A	A	-	B	A	C	-	-	A	A	-	A	A	-	-
Hydraulic Oil (petro.)	-	B	-	-	A	-	U	A	A	-	A	U	-	A	A	-	B	A	A	-	-	A	A	-	A	A	A	A
Hydraulic Oil (synthetic)	-	-	-	-	A	-	U	A	A	-	A	A	-	A	U	-	B	A	A	-	-	A	A	-	A	A	A	A
Hydrazine	-	B	U	-	-	U	C	C	-	-	A	A	-	B	B	-	B	-	A	-	-	A	A	-	-	-	-	A
Hydrogen Peroxide (dilute)	R	R	U	R	R	R	R	R	R	-	R	R	-	U	R	-	-	-	R	-	-	G	G	U	E	E	U	U
Hydroquinone	X	A	A	R	U	-	A	A	R	R	R	U	-	A	X	-	-	-	B	-	-	G	G	G	G	G	G	-
Hydroxyacetic Acid 70%	-	A	A	-	-	-	-	A	U	-	A	A	-	A	A	-	-	-	A	-	-	-	-	-	-	-	-	-
Iodoform	-	-	-	R	-	-	R	C	-	-	C	A	-	A	U	-	-	C	R	-	R	E	E	U	U	G	-	G
Isobutyl Alcohol	B	A	-	-	A	-	A	A	A	-	-	A	-	A	B	-	A	A	A	-	-	-	-	-	-	-	-	-
Isooctane	-	-	-	-	A	B	A	A	A	-	A	U	A	B	A	-	U	A	A	-	-	A	A	-	-	A	A	-
Isopropyl Acetate	U	U	U	R	R	R	B	A	U	U	X	B	-	U	U	-	U	-	U	-	-	E	G	E	G	G	-	-
Isopropyl Alcohol	R	A	C	R	U	R	A	A	R	R	R	A	-	B	B	U	A	A	A	A	-	G	G	G	G	G	G	G
Isopropyl Ether	-	U	R	R	R	-	X	A	R	R	X	U	A	U	B	R	U	A	U	-	-	E	G	-	-	-	G	G
Isotane	-	-	-	-	U	-	U	-	A	-	A	-	-	U	A	-	-	-	-	A	-	-	-	-	-	U	-	-
Jet Fuel JP-4, JP-5	-	A	R	R	R	-	A	A	R	R	A	U	A	U	A	U	U	A	A	-	-	G	G	G	E	G	E	-
Kerosene	X	A	R	R	R	R	R	A	R	R	A	U	A	A	A	U	U	U	A	A	-	G	G	G	G	G	G	G
Lacquer thinners	A	U	-	-	A	-	U	A	U	-	-	U	-	U	U	-	U	U	U	-	-	-	G	-	-	G	-	-
Lacquers	A	U	-	-	A	-	U	A	U	-	U	U	-	U	U	-	U	A	U	-	-	E	E	-	-	-	-	-
Lactic Acid	U	B	A	R	R	-	B	A	R	R	B	A	A	A	X	-	A	A	A	A	-	G	G	U	G	G	G	G
Lead Acetate	B	B	A	R	R	R	A	A	R	R	A	A	A	A	B	-	A	B	U	A	-	G	G	U	G	U	U	G
Linoleic Acid	A	B	A	R	U	U	B	A	R	R	A	U	-	U	B	-	B	A	B	-	-	G	G	U	G	G	U	U
Maleic Acid	R	A	A	R	X	R	R	A	R	R	A	X	-	U	U	-	-	C	A	-	R	G	G	U	G	-	G	-
Malic Acid	R	A	R	R	X	R	A	A	R	R	A	U	-	X	A	-	B	A	A	-	-	E	E	U	G	G	-	U
Melamine	-	A	A	-	A	-	A	A	U	-	-	A	-	U	C	-	C	U	A	-	-	-	U	-	-	-	-	-
Methane	-	A	-	R	R	-	A	A	R	R	A	X	-	B	A	-	U	-	A	-	-	E	E	G	E	E	E	G
Methyl Acetate	U	X	U	R	R	R	X	A	U	U	B	X	A	X	U	-	U	A	U	-	-	G	G	S	E	G	-	-
Methyl Acetone	-	U	-	-	A	-	-	A	U	-	U	A	-	U	U	-	-	A	U	-	-	A	A	-	-	A	A	-
Methyl Acylate	-	B	-	-	-	-	U	-	-	-	B	B	-	B	U	-	U	-	U	-	-	A	-	-	-	-	-	-
Methyl Alcohol	U	A	A	R	R	R	A	A	R	R	A	A	A	A	A	U	A	A	U	A	R	G	G	G	E	G	G	G
Methyl Alcohol 10%	U	A	A	-	B	B	A	A	-	-	A	A	A	A	A	-	A	A	A	A	-	-	-	-	-	-	-	-
Methyl Amide	U	U	-	-	-	-	A	A	U	-	C	A	A	-	B	-	-	U	U	-	-	A	A	-	-	A	U*	-
Methyl Bromide	U	U	U	R	U	R	X	A	U	U	A	U	-	U	B	-	-	-	A	-	-	G	G	G	-	U	-	-
Methyl Butyl Ketone	-	U	-	-	U	U	U	-	-	-	U	A	-	U	U	-	U	-	U	-	-	A	A	-	-	-	-	-

	Plastics											Elastopolymers										Metals						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Methyl Chloride	U	B	U	R	R	U	U	A	U	U	A	U	A	U	U	U	U	U	A	-	-	E	E	U	G	U	E	G
Methyl Chloroform	U	-	U	R	-	-	U	R	U	U	R	U	-	U	U	-	-	-	R	-	-	-	-	-	-	-	-	-
Methyl Dichloride	-	U	-	-	C	-	U	-	-	-	U	U	-	-	U	-	-	-	A	-	-	-	-	-	-	-	-	-
Methyl Ethyl Ketone	U	U	U	R	R	U	B	A	U	U	U	A	A	U	U	U	U	U	U	A	-	G	G	G	G	G	G	G
Methyl Isopropyl Ketone	-	-	-	-	A	-	-	A	U	-	-	C	-	U	U	-	C	-	U	-	-	A	A	-	-	A	-	A
Methyl Methacrylate	-	U	R	R	-	-	X	R	R	U	B	U	-	U	U	-	C	-	U	-	-	G	G	U	-	G	-	-
Methyl Pentanone	U	-	U	R	R	R	R	A	U	U	X	B	A	U	U	-	U	-	U	-	-	G	G	G	G	G	G	G
Methylene Chloride	U	B	U	R	U	U	B	A	U	U	B	X	A	U	U	U	-	U	B	-	R	G	G	G	E	E	G	G
Monochloroacetic acid	-	U	-	-	U	U	-	A	-	-	B	C	B	A	U	-	-	-	C	-	-	A	A	-	A	U*	B	
U*																												
Monoethanolamine	-	U	-	R	R	-	B	A	U	U	U	B	-	X	B	-	B	-	X	-	-	E	E	G	G	G	G	G
Motor Oil	C	B	A	R	R	U	U	A	R	R	B	U	A	B	A	-	-	A	R	A	-	G	G	G	-	-	G	G
Napthalene	U	X	U	R	R	U	R	A	U	U	A	U	A	U	U	R	U	C	A	A	-	E	E	G	G	G	G	G
Nitrobenzene	U	X	U	R	R	U	B	A	U	U	A	U	A	U	U	U	U	U	B	-	R	G	G	G	G	E	G	G
Nitromethane	U	A	U	R	U	-	R	A	R	R	A	B	A	U	U	-	U	B	U	-	-	G	G	G	-	G	-	-
Nitrophenol	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	-	G	-	G
Octane	-	-	-	R	-	R	R	R	U	U	R	U	-	R	R	-	-	-	R	-	-	-	G	G	-	G	G	G
Octyl Alcohol	A	A	B	-	A	-	-	-	-	-	-	B	-	B	B	-	B	-	B	-	-	A	A	-	C	A	-	A
Oleic Acid	X	A	A	R	R	U	B	A	R	R	A	B	B	X	B	R	U	C	B	A	-	E	E	G	G	G	S	G
Oxalic Acid 5%	R	U	R	R	U	R	R	R	R	R	R	R	-	R	U	-	-	-	R	-	-	U	G	U	G	G	S	G
Palmitic Acid 10%	A	A	A	R	R	R	B	A	R	R	A	B	-	U	A	R	U	B	A	-	-	-	G	-	-	G	G	G
Pentachlorophenol	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	E	-	-	-	-
Pentane	-	B	-	-	A	-	U	A	A	-	A	U	-	B	A	-	U	A	A	-	-	C	C	-	A	B	-	-
Petroleum	B	B	A	R	-	U	B	A	R	-	A	U	-	B	A	-	U	-	A	-	-	G	G	-	-	G	G	G
Phenol 10%	U	X	A	R	U	R	B	A	U	U	A	B	B	U	U	U	U	C	A	A	-	G	G	G	G	E	G	G
Phthalic Acid	B	C	X	R	R	-	A	A	U	U	A	A	-	A	U	-	B	-	A	-	-	G	E	S	G	G	G	G
Phthalic Anhydride	B	C	U	R	-	-	U	A	U	-	A	A	-	A	U	-	-	B	A	-	-	E	E	G	E	E	G	-
Picric Acid	X	A	U	R	U	U	A	A	U	U	A	A	-	A	X	-	B	-	A	-	R	G	G	U	G	E	U	U
Propyl Alcohol	X	A	A	R	U	R	A	A	R	R	A	A	A	A	A	-	A	A	A	A	-	E	E	G	E	G	G	G
Propylene	B	-	-	-	-	-	-	A	B	-	-	U	-	U	U	-	U	B	A	-	-	B	A	-	-	A	-	A
Propylene Glycol	B	B	X	R	R	R	A	A	U	U	A	A	-	C	A	-	A	-	A	A	-	G	G	G	G	G	G	G
Propylene Oxide	-	-	-	R	-	R	R	R	U	U	U	R	-	U	U	-	-	-	U	-	-	E	E	-	-	-	-	-
Pyridine	-	B	U	R	R	R	A	A	U	U	U	X	A	U	U	-	U	U	U	A	-	G	G	G	E	G	G	G
Sodium Acetate	B	B	A	R	R	R	A	A	R	R	A	A	A	B	B	-	U	-	U	A	-	G	G	U	G	E	G	G
Sodium Benzoate	A	-	A	R	R	R	A	A	R	R	A	A	-	A	B	-	-	B	A	-	-	-	-	-	G	G	-	E
Sodium Hypochlorite 20%	R	U	R	R	U	R	R	R	R	R	R	R	A	U	U	-	B	C	A	-	U	U	U	U	U	G	G	S
Stearic Acid	U	A	B	R	R	R	A	A	R	R	A	X	-	B	B	R	B	B	A	-	R	G	E	S	E	G	S	G
Styrene	-	A	U	-	A	U	-	A	U	-	-	U	-	U	U	-	U	-	B	-	-	A	A	-	U*	A	A	B
Tartaric Acid	-	B	A	-	B	-	A	A	A	-	B	B	A	A	A	-	A	B	A	A	-	C	C	-	B	B	U*	A
Tetrachloroacetic Acid	R	-	R	R	R	R	R	R	R	R	R	U	-	R	R	R	-	-	R	-	-	E	E	-	G	G	S	U
Tetrachloroethane	-	A	X	R	R	-	C	A	U	U	A	U	A	U	U	-	U	-	A	-	R	E	E	E	E	G	-	S
Tetrachloroethylene	U	A	U	R	R	U	U	A	U	U	R	U	A	U	U	U	U	-	A	-	-	E	E	G	G	G	G	G
Tetrachlorophenol	-	-	-	-	-	-	R	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraethyl Lead	U	-	R	R	-	U	R	R	R	R	R	U	-	-	U	-	-	-	R	-	-	G	G	G	-	G	G	-
Tetrahydrofuran	U	A	U	R	R	U	C	A	U	U	B	U	A	U	U	-	U	-	X	A	-	E	G	E	E	U	-	-
Toluene	U	X	U	R	R	U	C	A	U	U	A	U	B	U	X	U	U	U	C	A	-	E	E	E	E	E	E	E
Toxaphene-Xylene 10-90%	-	-	U	R	-	-	R	R	U	-	-	-	-	-	-	-	-	-	-	-	-	G	G	S	-	S	-	-
Trichloroacetic Acid	-	-	R	R	U	R	A	A	R	-	B	B	A	U	R	-	U	C	C	A	-	U	U	U	G	U	G	G
Trichlorobenzene	-	-	-	-	-	-	-	R	U	-	-	-	-	U	U	U	-	-	R	-	-	-	-	E	-	-	-	-
Trichloroethane	-	A	-	-	-	-	C	A	C	-	A	U	A	U	U	-	U	-	A	-	-	-	-	-	-	-	-	-
Trichloroethylene	U	U	U	R	R	U	C	A	U	U	B	U	A	U	U	U	U	-	X	A	-	G	G	G	E	E	G	G
Trichlorofluoromethane	-	-	-	-	-	-	-	-	U	-	-	-	-	U	U	-	-	-	-	-	-	-	G	-	-	G	-	-
Trichloropropane	U	A	-	-	-	-	-	A	-	-	-	-	A	A	U	-	-	U	A	-	-	A	A	-	A	U*	-	A

	Plastics											**Elastopolymers**										**Metals**						
	ABS	Acetal (Delrin)	CPVC	FEP	Nylon 6, 66	HDPE	Polypropylene	PTFE (Teflon)	PVC Type I	PVC Type II	PVDF (Kynar)	EPDM	Kel-F	Neoprene	Nitrile Buna-N	Polyurethane	Silicone	Tygon	Viton-A	Ceramic	Silica	304 Stainless	316 Stainless	Carbon Steel	Hastelloy-C	Aluminum	Brass	Copper
Triethanolamine	R	U	R	R	R	U	R	R	U	U	R	R	-	R	U	U	-	-	R	-	-	G	G	G	G	G	U	E
Triethylamine	U	U	A	R	R	-	U	A	R	R	A	A	A	A	C	-	-	A	X	B	-	G	G	-	-	-	-	-
Trimethylpropane	U	-	R	R	-	-	U	R	R	R	R	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-
Turpentine	U	A	A	R	R	U	X	A	X	U	A	U	A	U	R	U	U	B	A	A	-	E	E	G	G	G	S	G
Vinyl Acetate	U	-	U	R	-	U	B	A	U	U	A	B	-	X	X	-	U	U	A	B	-	E	E	G	E	E	G	-
Vinyl Chloride	U	-	U	-	A	-	-	A	U	-	B	C	-	U	U	-	-	U	A	A	-	B	A	-	A	B	-	B
White liquor (Pulp mill)	X	U	R	R	R	-	R	R	R	R	R	R	-	R	R	-	-	-	R	-	-	G	G	S	G	G	-	-
White Water (Paper mill)	R	B	-	-	R	-	R	-	R	-	-	-	-	A	-	-	-	-	A	-	-	A	A	-	-	-	-	-
Xylene	U	A	U	R	R	U	B	A	U	U	A	U	A	U	U	U	U	U	X	A	-	G	G	G	E	G	G	G

This table should only be used as a guide since it is difficult to duplicate operating conditions. To fully guarantee the suitability of a particular material, chemical resistance tests should be conducted under actual operating conditions.

No data was found on the following environmentally important chemicals:

Acenaphthene (1)
Acenapthalene (1)
Acrolein
Anthracene (1)
Benzidine
Benzo(a)athracene (1)
Benzo(b)fluoranthene (1)
Benzo(g,h,i)perylene (1)
Benzo(a)pyrene (1)
Bromophenylphenylether
Butylbenzylphthalate
Chlorodibromomethane
Chloroethoxymethane
Chloroethylether
Chloroethylvinylether
Chloroisopropylether
Chloromethylether
Chlorophenylphenylether
Chrysene (1)
DDD (2)
DDE (2)
Dichlorobenzidine
Dichlorobromomethane
Dichlorophenol
Dichlorophenoxyacetic acid
Dichloropropane
Dichloropropylene
Dieldrin (2)
Dinitrophenol
Diphenylhydrazine
Endosulfan
Endrin (2)
Fluoranthene (1)
Fluorene (1)
Heptachlor (2)
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclohexane
Indeno(1,2,3-c,d)pyrene (1)
Isophorone
2-Methylnapthalene
Parachlorometa cresol
Phenanthrene (1)
Phenylenepyrene
Pyrene (1)
Trichlorophenol
Trichlorophenoxyacetic acid

(1) *Component of cresotoe and coal tar. At room temperature and below, these compounds are solid in pure form.*
(2) *Pesticides*

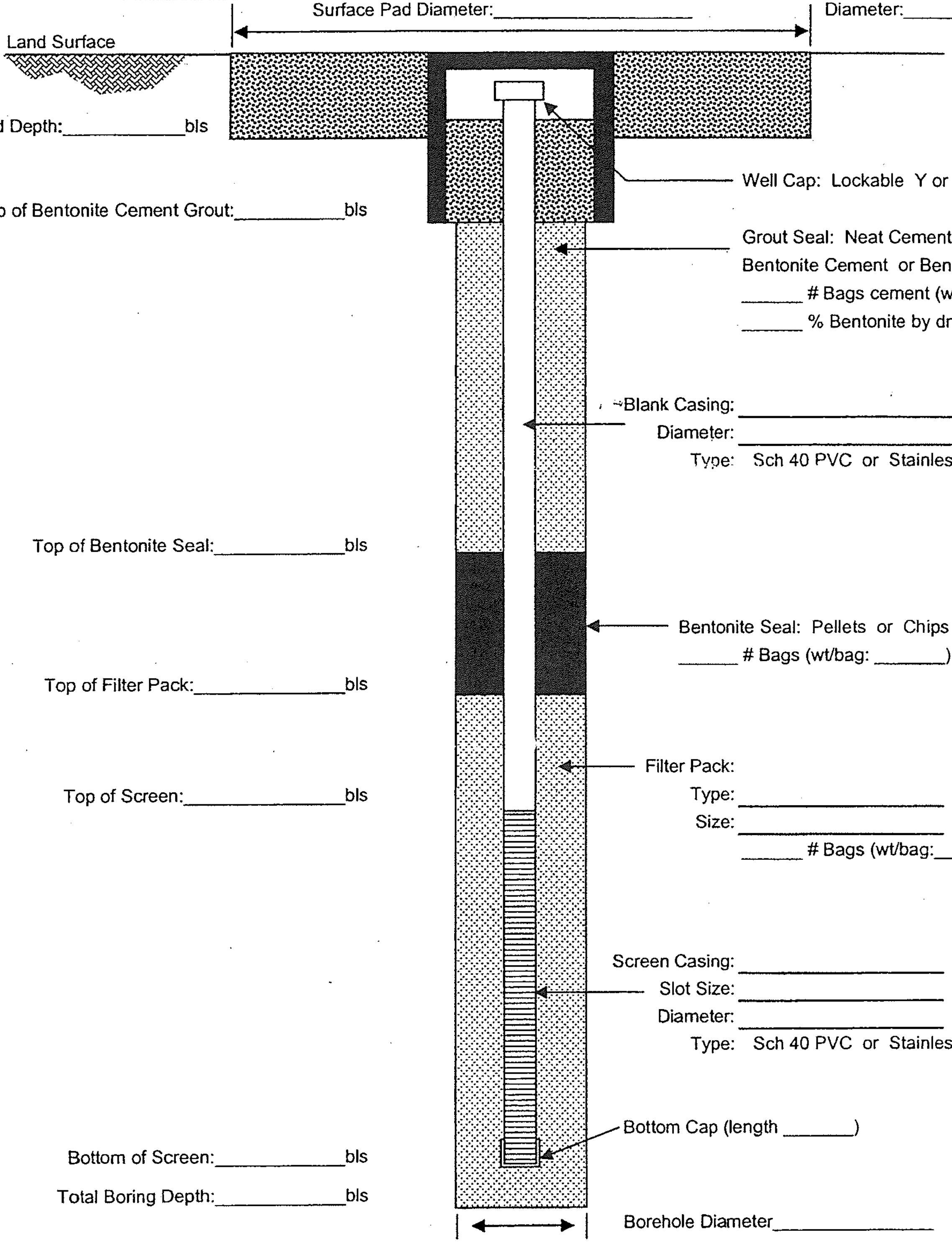
TABLE 1.0
CEMENT/BENTONITE SLURRY CALCULATIONS

Product	% Bentonite added/sk cement	Total water requirements (gallons)
Type I Portland (1 sack = 94 lbs)	0	5.2 to 6
	1% bentonite - 0.94 lbs bentonite/sk of cement	5.8 to 6.6
	2% bentonite = 1.9 lbs bentonite/sk of cement	6.4 to 7.2
	3% bentonite = 2.8 lbs bentonite/sk of cement	7 to 7.8
	4% bentonite = 3.8 lbs bentonite/sk of cement	7.6 to 8.4
	5% bentonite = 4.7 lbs bentonite/sk of cement	8.2 to 9
	6% bentonite = 5.7 lbs bentonite/sk of cement	8.8 to 9.6

Boring ID: ______________

Logged By: ______________

Drilled By: ______________



Aboveground:
Casing height agl ________

Protective Casing: Aboveground or Flush Mount (circle one)

Flush Mount: Traffic Rated Y or N
Diameter:__________

Surface Pad Diameter:______________

Land Surface

Cement Pad Depth:__________bls

Well Cap: Lockable Y or N

Top of Bentonite Cement Grout:__________bls

Grout Seal: Neat Cement or
Bentonite Cement or Bentonite Slurry (circle one)
______ # Bags cement (wt/bag ______)
______ % Bentonite by dry weight

Blank Casing: ______________
Diameter: ______________
Type: Sch 40 PVC or Stainless Steel (circle one)

Top of Bentonite Seal:__________bls

Bentonite Seal: Pellets or Chips or Slurry (circle one)
______ # Bags (wt/bag: ______)

Top of Filter Pack:__________bls

Filter Pack:
Type: ______________
Size: ______________
______ # Bags (wt/bag:______)

Top of Screen:__________bls

Screen Casing: ______________
Slot Size: ______________
Diameter: ______________
Type: Sch 40 PVC or Stainless Steel (circle one)

Bottom Cap (length ______)

Bottom of Screen:__________bls

Total Boring Depth:__________bls

Borehole Diameter______________

NOT TO SCALE

ENVIRONMENTAL WORKS

Well Construction Details Form

DRAWN	CHECKED	APPROVED	DATE
FILENAME			

Skills Required:

1) 40-hour HAZWOPER training (if working on hazardous waste sites)
2) Understanding of, and ability to make decisions regarding, site-specific objectives
3) Training in pump and water quality instrument calibration and use
4) Knowledge and understanding of monitoring well construction
5) Knowledge of EWI quality standards
6) Knowledge of corporate Safety requirements and health and safety plan

1.0 OBJECTIVE / SCOPE / APPLICABILITY

This Standard Operating Procedure (SOP) is intended to provide an overview of monitoring well development and establish recommended procedures and documentation for EWI personnel to properly develop a monitoring well.

The purpose of monitoring well development is threefold:

1) To remove fine sediment from the well and screen/filter pack (if installed) that may have been generated during drilling activities;
2) To diminish any smear zone that may be in the well bore as a result of drilling activities; and,
3) To re-establish the normal flow of groundwater through the formation, well screen (if installed), and well bore.

Monitoring wells should be developed within the first 48 hours following well construction. Development is commonly done through the use of a bailer (shallow wells or slow recharge) and/or pump (deeper wells or rapid recharge) to rapidly remove water from the well and allow recharge to occur. Whatever method is employed, it should be repeated until sediment free water is produced. A surge block or jetting may also be used to help loosen and mobilize sediment in a well or filter pack. In the case of open borehole bedrock wells, potable water may be flushed, pumped, or blown into and out of the well to clean out sediment.

Surging involves use of a piston-like device either manually or affixed to the end of a rod. The up-and-down plunging action alternately forces water to flow into and out of the well, similar to a piston in a cylinder. Periods of surging should be alternated with periods of water extraction from the well so that sediment, brought into the well, is removed. Surging should initially be gentle to assure that water can come into the well and that the surge block is not so tight as to damage the well casing or screen.

Development of a monitoring well is considered done when any of the following criteria are met:

1) The water being removed from the well has cleared of suspended sediment;
2) A minimum of 10 well volumes of water have been removed from the well; or,
3) The well is dry and potable water is added, surged, and removed with no inflow of groundwater.

Note: The number of volumes removed during development is **less important** than sediment removal and aquifer restoration.

2.0 EQUIPMENT

Specific equipment needed for monitoring well development/purging include:

a. A work plan outlining development/purging specifications for the project
b. Bailer(s) if using bailing method
c. Water pump if using pumping method
d. Power source (generator or 12 volt battery)
e. Fishing line
f. 5-gallon bucket(s)
g. Polytank or 55-gallon drum(s)
h. Calculator
i. Interface Probe w/ extra batteries
j. Monitoring Well Development Form (see Attachments)
k. Disposable gloves
l. Plastic to place around wellhead if contaminated water is present
m. Decontamination buckets, water, soap, etc.
n. Source of potable water
o. Trash bags
p. Fish hooks and other supplies as contingency for equipment lost in well.

3.0 PROCEDURES

The following should be done in preparation for well development

- Determine appropriate type of purge: (1) bailer for shallow, smaller diameter wells with slow recharge; (2) bailer or pump for shallow, smaller diameter wells with good recharge; (3) pump for deeper wells.
- Plan logistics for setup at wellhead, and for pumping option estimate tubing lengths and order as needed.
- Estimate volumes to be purged for each well and arrange appropriate purge water management (drums, tanks, disposal, etc.). Consider non-hazardous vs. hazardous status and any storage and sampling of purge water that might be required.
- Gather all equipment, materials, and forms needed and verify operational status.

Field Procedures for Bailer-Type Monitoring Well Development

- Conduct on-site safety meeting and organize equipment and materials. Place plastic on ground around wellhead to catch spills and keep in-well equipment clean. Measure initial water level in well and record all information on development form (see attachment).
- Calculate well volume of water based on well diameter and depth, water level, and conversion factors on the well development form.
- Measure appropriate length of fishing line (if used) and securely attach bailer. If using wire reel, attach bailer.
- Drop bailer to the water surface and allow to sink a few feet. Rapidly raise and lower the bailer to create a surge wave that loosens trapped sediment, and raise bailer. Empty in 5-gallon bucket. Repeat action.

- Note time bailing begins, and record the time every gallon of water is removed. The color, visual turbidity, and other physical features should be recorded as well.
- Continue development and data recording until a minimum of 10 well volumes have been removedl, the well goes dry, or water removed from the well has cleared of sediment.

Procedures for use of a surge block to aid in development:

- Surge blocks are sometimes used to supplement well development, and may be a closed, weighted cylinder, or disk or plunger device on a rod. The surge block is built so that it has an outside diameter that is only slightly less than the inside diameter of the well.
- Lower the surge block on cable, rope, or rods to below the level of the screen.
- Gently plunge up and down to mobilize particulates around the well screen.
- Surging should be alternated with bailing or pumping to remove groundwater and sediment brought into the well.
- Repeat several iterations of surging and water removal that cover the entire length of the screen.

Procedures for use of a pump vs bailer for development

For larger diameter or deeper wells, a development pump is normally used to remove water. Specific procedures may vary depending on the type of pump used, but the following procedures will generally apply.

- Plan the pump depth to be able to lower it to the bottom of the screen interval. Measure out a sufficient length of clean discharge tubing and attach to the pump.
- Tubing should be long enough to come out of the well and discharge into a bucket with gallon marks to accurately track volume pumped. Multiple buckets are useful to prevent delays in pumping operation. Drums or a poly tank should be in place to transfer pumped water from buckets.
- Lower pump to near bottom of well, and attach electrical leads from the pump to an appropriate electrical source, or attach to an air compressor if using an air-operated pump. Be sure discharge line is in the first bucket and begin pumping. Note time.
- If pumping rate is adjustable, set to allow constant pumping without running the well dry. Water level should be visually checked or gauged during pumping, and periodically recorded. Record the time each gallon (or more if rapidly pumping) is removed. Note color and turbidity of effluent after each gallon(s) are removed. Record all information.
- If little change in water level occurs, the pump string should be raised and lowered incrementally to cover the length of the wells screen. Depending on the size of the pump and well, the pump can be used as a surging device while pumping.
- Continue development and data recording until a minimum of 10 well volumes have been removed from the well, or water removed from the well has cleared of sediment. If the well is being pumped dry and pumping rates cannot be adjusted, turn off pump and allow the well to recharge between pumping intervals. In this case the well should be surged between pumping intervals. Consider adding potable water to the well to aid in development with surging (will normally require regulatory approval). If potable water is used, the well should be allowed to recharge following the last pumping cycle, and the recharged water pumped out. If time permits, to this at least twice.

Procedures for developing open bore bedrock wells generally involve the following:

- Open bore bedrock wells require very little development; this normally only involves removal of drilling cuttings and dust from the well.
- If the well recharges rapidly, the groundwater can be blown out by using compressed air applied through the drill rods. Alternatively, most drill rigs are equipped with a pump that can remove the water. Two to three well recharge volumes removed normally result in fairly clear return. If not clear, repeat recharge and removal.
- More commonly, bedrock wells recharge very slowly. In this case, potable water can be added to the well bore and blown or pumped out by the drill rig (may require regulatory approval).
- In either case, coordination with the driller is needed prior to mobilization to insure appropriate control, collection, and management of development water. If potable water may be needed, this also needs planned with the driller and a source of potable water identified prior to start of work.

Regardless of the method used for well development, all data should be accurately recorded on an appropriate form. This includes times for known volumes of water removed by bailing, start and stop times for pumping and surging, water levels, water quality changes as development continues, and times and volumes of potable water used, plus final recharged volumes removed. The ending water quality condition and total volumes removed must be recorded.

4.0 SAFETY

Acute or chronic exposure to chemically-contaminated soil or water could result in bodily injury. Routes of exposure include inhalation, ingestion, and dermal contact. Consult the appropriate chemical material safety data sheet (MSDS) before mobilization so that proper PPE and monitoring are planned and implemented.

Conduct an on-site safety meeting each day before the start of field work utilizing a Tailgate Safety Meeting form. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, alertness to heavy equipment, PPE, health monitoring, and emergency procedures). Take appropriate action if personnel are injured on-site per EWI policy guidance.

When working with potentially hazardous substances, follow the United States Environmental Protection Agency (US EPA), Occupational Safety and Health Administration (OSHA), EWI Corporate Health and Safety Plan, and site-specific health and safety plan.

5.0 REFERENCES

(1) U.S. EPA Environmental Response Team Standard Operating Procedures "*Monitoring Well Development*", October 2001.

(2) "*Corporate Health and Safety Plan*" Environmental Works, Incorporated and Site-specific HASP.

(3) "*HAZWOPER Training Manual: 40-Hour Hazardous Waste & Emergency Response Training.*" Safety Source, Inc.

Environmental Works, Inc. SOP No. 7

Monitoring Well Development and Purging

ATTACHMENTS

Well Development Form

ENVIRONMENTAL WORKS

WELL DEVELOPMENT FORM

Well No: ______________________________

Project Name: ______________________________

Date: ______________ Time: ______________

Project No: ______________________________

Well Type: Monitor Extraction Other: ____________

Recorded By: ______________________________

Sampled By: ______________________________

WELL PURGING

PURGE VOLUME:

Casing Diameter (inches): ______________

2-inch 4-inch 6-inch Other: ______________

Total Depth of Well (TD in feet BTOC): __________

Water Level Depth (WL in feet BTOC): __________

Number of Well Volumes to be Purged (# Vols)

3 4 5 10 Other: ____________________

PURGE METHOD:

Bailer -Type: ______________________________

Submersible Centrifugal Bladder; Pump No: ____________

Other - Type: ______________________________

PUMP INTAKE SETTING:

Near Bottom Near Top Other: ____________________

Depth in feet (BTOC): ______________________________

Screen Interval in Feet (BTOC) from ________ to ________

PURGE VOLUME CALCULATION:

(____________ - ____________) X ____________ ^{2} X ____________ X 0.0408 = ____________ gallons

TD (feet) WL (feet) D (inches) # Vols Cal. Purge Volume

PURGE TIME:

_____ Start _____ Stop _____ Elapsed

PURGE RATE:

Initial _____ gpm Final _____ gpm

ACTUAL PURGE VOL:

________ gallons

FIELD PARAMETER MEASUREMENTS

Minutes Since Purging Began	pH	Cond. (µmhos/cm)	Temp. C F	Description: well condition, turbidity, color, odor, etc.

Discharge Water Disposal: Sanitary Sewer Storm Sewer Drummed/Retained Onsite

Other (describe): ______________________________

United States Environmental Protection Agency
Office of Solid Waste and Emergency Response
April 1992

René

EPA Ground Water Forum

MONITORING WELL DEVELOPMENT GUIDELINES FOR SUPERFUND PROJECT MANAGERS

Ruth Izraeli* Doug Yeskis, Mark Collins, Kathy Davies, Bernard Zavala

The Ground Water and Engineering Forums were established by EPA professionals in the ten EPA Regional Offices. The Forums are committed to the identification and resolution of scientific, technical and engineering issues impacting the remediation of Superfund and RCRA sites. The Forums are supported by and advise OSWER's Technical Support Project, which has established Technical Support Centers in laboratories operated by the Office of Research and Development, Office of Radiation Programs, and the Environmental Response Team. The Centers work closely with the Forums in providing state-of-the-science technical assistance to EPA project managers.

This document provides well development guidelines and recommended additional sources of information. It was developed by the Superfund Ground Water Forum and draws upon U.S. Army Corps of Engineers and draft RCRA SW-846 field protocols. Comments from ORD and Regional Superfund hydrogeologists have been incorporated. These guidelines are applicable to the great majority of sites. However, unusual, site-specific circumstances may require alternative approaches. In these instances, the appropriate Regional hydrogeologist should be contacted to establish alternative development protocols.

Introduction

The goal of ground-water sampling is to obtain water samples that best represent natural undisturbed hydrogeological conditions. Adequate well development is critical to minimize the introduction of biases into the sampling effort. Well development is necessary because every drilling method disturbs the geologic materials around the well bore to some extent. Development processes are used to try to ensure proper hydraulic connection between the well and the geologic materials in the vicinity of the well. This is done by stressing the formation around the screen so that mobile, artifact particulates are removed. This process is necessary to obtain a ground water sample which is as similar as possible to *in situ* conditions.

One of the major goals of well development is to produce a well capable of yielding ground-water samples of acceptably low turbidity. Excess turbidity may alter water quality and result in erroneous chemical analysis (particularly for unfiltered metals samples which require acid preservation).

Turbidity in ground-water samples is minimized by well development. Proper well development creates a graded filter pack around the well screen. When pumping is first initiated, natural materials in a wide range of grain sizes are drawn into the well, producing very turbid water. However, as pumping continues, the natural materials are drawn into the filter, producing an effective filter pack through a sorting process. This sorting process begins when the largest particles of natural materials are retained by the filter pack, resulting in a layer of coarse particles against the well screen. With continued development, this process produces progressively finer layers until an effective graded filter is produced, which then minimizes turbidity. Development is also necessary to remove any foreign materials introduced during drilling, such as drilling water and mud.

These guidelines are directed toward the development of relatively permeable (i.e., $K>10^{-6}$ cm/sec) aquifers. However, it is sometimes necessary to screen wells in water-bearing zones containing significant quantities of silt and clay, which would not normally be considered producing aquifers. Low-yielding wells located in marginal aquifers often cannot be developed using standard methods. For a discussion of the construction and development of wells in low-yielding forma-

Communication • Training
Technical Support Project
Technical Support

Technology Innovation Office
Office of Solid Waste and Emergency Response
U.S. EPA, Washington, DC

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tions, see Aller et al. (1989), Gass (1989), and Paul et al. (1988).

Wells constructed in bedrock may require special protocols. For example, wells constructed as open boreholes (cased to monitored zone) generally should not be developed using a surge block due to the potential for damaging the borehole walls. Bedrock wells constructed with screens may be developed in two stages, before and after the screen is installed. Since bedrock wells may require special development protocols other than those described here for wells in unconsolidated aquifers, Regional hydrogeologists should be consulted when designing bedrock well development procedures.

Finally, it is important to note that there are some hydrogeologic environments, such as fine-grained "marginal" aquifers and karst terraines, where excess turbidity may still exist even after optimizing well construction (e.g., filter pack size and thickness, screen size, drilling technique) and development.

Development Methods

The common methods for developing wells are described by Aller et al. (1989) and Driscoll (1986) and include:

- Overpumping
- Backwashing
- Surging
- Bailing
- Jetting
- Airlift pumping
- Air surging

Well development procedures that have the potential to alter ground-water quality should not be used. Therefore, methods which involve adding water or other fluids to the well, or use air to accomplish development, are not recommended. Generally unsuitable methods for monitoring well development include jetting, airlift pumping, and air surging. However, air development techniques may be used if they offer site-specific advantages over other methods, and extreme care is taken to prevent air from contacting the screened interval. Air development techniques must only be implemented by an experienced operator.

Recommended monitoring well development methods include pumping, overpumping, bailing and backwashing, in combination with some form of surging. The most effective combination and timing of these methods must be determined through field testing, or from experience developing wells in similar hydrogeologic regimes.

Movement of ground water into the well in one direction generally results in bridging of the particles, and a means of inducing flow reversal is necessary to break down the bridging and produce a stable filter. Aller et al. (1989) state that one of the most effective and efficient methods to induce flow reversal is through careful use of a properly-constructed surge block. For a more detailed description of proper usage of a surge block and other methods of achieving flow reversal, see Aller et al.

One example of a well development field protocol is described below:

1. Record static water level and total well depth.

2. Set the pump and record pumping rate and turbidity. Pump until turbidity (as measured by a nephelometer) reaches desired level or stabilizes.

3. Discontinue pumping and surge the well.

4. Measure depth to the bottom of the well. If more than 10% of the screen is occluded by sediments, remove excess sediment by bailing.

5. Reset the pump, recording pumping rate and turbidity. Pump until turbidity reaches desired level or stabilizes. If the well has been properly designed, the amount of pumping required to achieve the desired turbidity level will be substantially less than required in the first pumping cycle.

6. Repeat surging and pumping until the well yields water of acceptable turbidity at the beginning of a pumping cycle. A good way to ensure that development is complete is to shut the pump off during the last anticipated pumping cycle, leaving the pump in place, and restart it some time later. The turbidity of the discharge water should remain low.

The pumping rate used during development must be greater than the highest rate expected to be used during subsequent purging and sampling. In fact, recent field experience suggests that extremely low (i.e., 100 to 500 ml/min) purging and sampling pumping rates may significantly reduce the turbidity of ground-water samples (Puls et al., 1990). The pump intake should be placed close to, or within, the well screen interval.

The development techniques listed above are most efficient in wells with screens having the greatest area open to the aquifer. Therefore, continuous slot, or wire wrapped screens are recommended for use in formations where adequate development is expected to be difficult. The additional cost of continuous slot screen is typically more than compensated for by significantly less cost in development time and subsequent well purging times.

Development Criteria

Development should continue until clear, artifact-free, formation water is produced. Water quality parameters such as specific conductance, pH, temperature, and turbidity should be measured during development, and should stabilize before development is stopped. Turbidity measurements are the most critical development criteria. Other parameters should be used to provide supplemental information regarding aquifer conditions, and stabilization of these parameters is indicative of the presence of formation water. If water was added during well construction or development, two to three times the volume of water added must be removed. Finally, the well should be producing visually clear water before development is stopped.

Experience has shown that development may take from less than an hour to several days, depending on the formation, development procedures, and well characteristics or construction. In some marginal aquifers such as glacial tills and interbedded sands and clays, it may not be possible to attain the 5 NTUs turbidity target level used as guidance in RCRA. However, poor well construction practices, failure to emplace an adequate filter pack, poor selection of screen slot size and sand pack materials, as well as inadequate development may result in high turbidity levels. In these situations, the PRP or contractor must demonstrate that the well has been constructed properly and all reasonable efforts have been expended to develop the well. The determination of whether to abandon the well or address the turbidity problem during sampling and analysis should be made by the project manager in consultation with a Regional hydrogeologist.

After development is completed, wells should be allowed to stabilize and re-equilibrate before sampling. The time necessary for stabilization depends on the characteristics of the aquifer and the geochemistry of the parameters to be monitored. Generally, high permeability formations require less time (i.e., several days) than low permeability formations (i.e., several weeks).

Development Documentation

Monitoring well development must be thoroughly documented to verify that foreign materials have been removed, formation water is being sampled, and turbidity has reached acceptable levels or stabilized.

The following data should be recorded before and during well development:

1. Date and duration of development

2. Water level from the marked measuring point on the top of casing before and 24 hours after well development.

3. Depth from top of well casing to the top of any sediment present in the well, before, during, and after development.

4. Types and quantity of drilling fluids introduced during drilling and development.

5. Field measurements (e.g., turbidity, specific conductance, pH, dissolved oxygen, temperature) taken before, during, and after well development.

6. Volume and physical characteristics of developed water (e.g., odor, color, clarity, particulate matter).

7. Type and capacity of pump and/or bailer used and pumping rates.

8. Detailed description of all development methods used.

Glossary

Backwashing	The surging effect or reversal of water flow in a well that removes fine-grained material from the formation surrounding the borehole. Only formation water is used during this process.
Jetting	Bursts of high-velocity water injected into the well.
Overpumping	Pumping at rates generally greater than those used during sampling or well purging. Commonly combined with surging of the well.
Surge Block	A plunger-like tool, consisting of leather or rubber discs sandwiched between steel or wooden disks that may be soild or valved, that is used in well development.
Surging	A well development technique where the surge block is alternately lifted and dropped within the borehole above or adjacent to the screen to create a strong inward and outward movement of the water through the well intake.
Turbidity	Solids and organic matter suspended in water.

References

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Nielsen, and J.E. Denne, 1989. Handbook of Suggested Practices for the Design and Installation of Ground-water Monitoring Wells: Technology Support Center, Environmental Monitoring Systems Laboratory, EPA600/4-89/034, United States Environmental Protection Agency, 398pp.

Driscoll, Fletcher G., 1986. Ground Water and Wells; Johnson Division, St. Paul, Minnesota, 1089pp.

Gass, T.E., 1989. Monitoring Wells in Non-aquifer Formations, Water Well Journal, v. XXXXII, no. 2, pp. 27-28.

Paul, D., C. Palmer, and D. Cherkauer, 1988. The Effect of Construction, Installation and Development on the Turbidity of Monitoring Wells in Fine-grained Glacial Till. Ground Water Monitoring Review, v. 8, no. 1, pp. 73-82.

Puls, R.W., J.H. Eychaner and R.M. Powell, Colloidal-Facilitated Transport of Inorganic Contaminants in Ground Water: Part I. Sampling Considerations, Environmental Research Brief, USEPA, EPA/600/M-90/023, December 1990.

U.S. Army Corps of Engineers, Missouri River Division, 1990. Installation of Ground-water monitoring wells and exploratory borings at hazardous waste sites, Chapter 6: Well development, pp. 38-44.

ENVIRONMENTAL WORKS INC.	**Standard Operating Procedure (SOP)**	**Issue Date:** **Updated:** *Draft 3-4-10*
Procedure No 8: Groundwater Sampling-Pump or Bailer Purge		**Technical Reference: Bob Lanning**
		Page: 1 of 6

Skills Required:

1) 40-hour HAZWOPER training (if working on hazardous waste sites)
2) Understanding of, and ability to make decisions regarding, site-specific objectives
3) Training in operation of pumps, use of bailers, and collecting water samples
4) Knowledge of EWI quality control standards
5) Knowledge of corporate Safety requirements and health and safety plan

1.0 OBJECTIVE / APPLICABILITY

The objective of this Standard Operating Procedure (SOP) is to provide the proper procedure for purging and sampling monitoring wells. Groundwater samples are often tainted with trace quantities of contaminants. When dealing with trace quantities, it is relatively easy to bias a sample through cross contamination, absorption, agitation, etc. The goal of this procedure is to reduce or eliminate sampling bias and collect a representative groundwater sample.

This SOP should serve as a reference tool and facilitate consistency among Environmental Works, Inc. (EWI) personnel. These are standard operating procedures which may be varied as required, dependent upon site conditions, equipment limitations or limitations imposed by the procedure. This SOP should generally be used only for the sampling of shallow wells installed within the unconsolidated zone. Certain site-specific sampling may require additional data collection or alternate purging/sampling techniques. This procedure does not apply to low flow sampling (see SOP #9). In all instances, the ultimate procedures employed should be documented in field notes and included in the final report.

2.0 SCOPE

Many site inspections and remedial investigations require groundwater sampling within a defined criterion of data confidence or data quality. This necessitates that the personnel collecting the samples are trained and aware of proper sample collection procedures.

Purging, which must be conducted prior to initiating groundwater sampling, is the process of removing standing water in the well, which may not be representative of formation groundwater, and bringing fresh water from the aquifer into the well casing. This is due to standing water being in contact with the atmosphere, which allows the influx of atmospheric oxygen, changing the reduction/oxidation (redox) potential of groundwater, and hence, the solubility of certain dissolved species.

3.0 EQUIPMENT

Some or all of the following equipment is needed for purging and sampling based on project conditions:

a. Submersible pump
b. Tubing
c. Bailers
d. Photo-ionization device (PID)
e. YSI or Hydac meter (if necessary)
f. Power source for pump
g. Fishing line, Teflon coated wire (reel), or appropriate weight cotton string

h. 5-gallon buckets
i. 55-gallon drums or poly tanks
j. Interface probe or water level meter
k. Filtration equipment (if needed)
l. Sample containers and labels
m. Disposable gloves
n. Decontamination supplies
o. Trip blanks & Temperature blanks
p. Chain of custody
q. Cooler and ice
r. Shipping labels
s. Trash bags and Tape
t. Field notes and forms

4.0 PROCEDURE

4.1 Pre-Purge Operation

- Gather all equipment needed, ensure it is working properly, and review well and sampling requirements (well diameter, well depth, screened interval, anticipated contaminants, required analyte parameters, sample container requirements).
- Review and verify correct sample containers and preservatives are available. Check minimum holding times for set of parameter.
- Conduct an on-site safety meeting, documenting on Tailgate Safety Meeting form.
- For below ground vaults, remove any standing water with sponge or bailer prior to removing the casing plug. Containerize the water in a 5-gallon bucket.
- Open all wells and take PID readings, if required, when VOCs with low permissible exposure levels (PELs) are expected. Note if the well was pressurized, and let it stabilize for 15-30 minutes prior to gauging.
- Gauge total depth and depth to water/free product and record on a Water Level Record form. Contact the Project Manager for further instruction if free product is present and contingency procedures have not been established.

4.2 Purging Operations

- Calculate the amount of water to purge from each well. A single well volume equals the water level subtracted from the total depth, multiplied by a casing volume per foot factor for the appropriate diameter well (see Attachment). Normally, a minimum of 3 well volumes should be purged.
- If purging with a submersible pump, decontaminate the pump and tubing per EWI standard procedures.
- Slowly lower the pump and attached tubing into the top of the standing water column and not deep into the column. This is done so that the purging will pull water from the formation into the screened area of the well and up through the casing so that the entire static volume can be removed.

- Attach the pump to a power source and allow purge water to drain into a bucket or 55-gallon drum. Measure the water level (and record with time noted) while pumping, and lower the pump as the water level decreases.
- If purging with a bailer, securely fasten the bailer to the line/wire/string. When removing the bailer, keep the line/wire/string over plastic (if used) and prevent it from touching the ground. Using coated wire on a reel simplifies this procedure.
- Whether using a pump or bailer, remove three well volumes before sampling – there are two exceptions that may apply to certain project-specific requirements:
  - If specified by the workplan, an adequate purge may be achieved when the pH, specific conductance or ORP, temperature, and turbidity of the groundwater have stabilized. This can be determined by using a YSI or Hydac meter when using a pumping method of purging. Connect the pump input to the YSI unit. Once a steady flow is achieved, begin writing down the readings for the parameters above. Continue to write down readings once every 2-3 minutes noting the time, until the values are within 10% of the previous values. When this occurs, an adequate purge has been achieved even if three well volumes have not been removed.
  - Wells with slow recovery might be purged to dryness. If this occurs, all water should be removed from the well. Once done, sample as soon as there is sufficient volume in the well for the parameters to be analyzed. If the well does not sufficiently recover within the same day as purged, it should be checked and sampled the following day. Record all times and water levels measured during this procedure.
- In all cases regardless of technique, incremental volumes purged and times should be accurately recorded. The final, total purge volume removed should be noted. See example forms in the Attachments.
- Following purging activities at each well, decontaminate all reusable equipment and discard disposable equipment.
- Procedures used to sample temporary wells will differ from permanent wells if temporary wells are installed for immediate sample acquisition. As such, water is not stagnant, but will normally have a high level of turbidity. Temporary wells should be developed sufficiently to remove sediment-laden water and water disturbed by drilling. As such, this development can serve as a purge for sampling. However, the longer a temporary well is in place and not sampled, the more stagnant the water column becomes and the more appropriate it is to apply standard well purging criteria to achieve representative aquifer conditions.
- Purging generates quantities of purge water classified as investigation derived waste (IDW), the disposition of which must be considered. Disposal of this waste must be in accordance with EWI standard procedures.

4.2 Sampling Operations

- Groundwater sampling should be conducted immediately following the purging activities described above. Clean disposable gloves should be utilized for each well.

- Measure and record the water level and time just prior to sampling. Use a new bailer to collect samples, and sample wells from least to most contaminated. Decontaminate all equipment after each well sampled. New gloves, a new bailer, and fresh string or line should be used for each well.
- When sampling with a disposable bailer, slowly immerse the bailer into the top of the water column. This is particularly important in order to minimize turbidity and disturbance of volatile organic constituents. Improper use may result in an unrepresentative sample
- When sampling volatile constituents, do not open the sample container until immediately prior to sampling. Do not touch the inside of the sample container. Slowly fill sample containers, using slow, laminar flow (not turbulent) from the bailer to avoid aeration. Fill sample containers with just enough water to form a meniscus. Do not overfill to spillage, as this depletes preservative in the container.
- If sampling for dissolved metals analysis, filter the water before sampling using a 0.45 μm filter and pump mechanism. Filtering is performed by collecting approximately 500 mL in a clean, unpreserved plastic bottle and using a hand pump to pump the sample from this container through the in-line filter into a new 500-mL sample container. Approximately 1/10 Liter (100 mL, or slightly less than 3 VOA containers) of water should be pumped through the filter and disposed of before sample collection.
- If specified, collect a "duplicate sample": an extra sample collected from a well. The duplicate and original should be virtually the same water, collected at the same time and location, using the same sampling techniques. Duplicate samples are used to evaluate the precision of the overall sample collection and analysis process. The location and sample ID of the duplicate should be noted in the field notes and sample log, and it should be labeled with a coded sample identity on the chain of custody.
- Cap the container and fill out a label for the sample, using waterproof ink, including the name of sampler, date, time, unique sample ID, and analysis desired. Place the label around the sample container, partially over the cap, creating a custody seal.
- Place all samples, including trip blanks and temperature blanks, in zip lock plastic bags and put them in a cooler with ice. Use cushioned packs/sleeves for glass sample bottles (supplied by the lab if requested).
- Fill out sampling information on an appropriate sample form (see Attachments), to include: Sample ID, time collected, color, odor, method of collection, water level, PID reading (if applicable), and any measured parameters (pH, temperature, conductivity).

4.3 Post-Operation

- Close all wells, replace locks, and secure lids.
- Fill out chain of custody per EWI SOP and place in a Ziploc bag (taped to the inside lid of the cooler). Ensure that each cooler contains sufficient ice for proper temperature and enough packing material to prohibit breakage of containers.
- Tape the cooler and place signed custody seals and shipping labels on the outside of the cooler. If present, tape the drain valve shut.

- Record all pertinent information in the Sampling Form (see Appendix A) and Field Notes. This should include purge volumes, observations made during sampling, water quality parameters, any needed well repairs, and the fate of purge water. Complete all other paperwork as required for the project.

5.0 SAFETY

Acute or chronic exposure to hazardous substances could result in health issues. Routes of exposure include inhalation, ingestion, and dermal contact. Consult the appropriate chemical material safety data sheet (MSDS) for anticipated hazardous substances before the initiation of well purging and sampling.

Conduct an on-site safety meeting each day before the start of the project. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, PPE required, health monitoring and action levels, emergency procedures, other physical or chemical hazards) using a Tailgate Safety Meeting form and have all personnel sign it each day before the start of the project. Take appropriate action if personnel are injured on-site in accordance with EWI directives.
When working with potentially hazardous substances, follow the U.S. Environmental Protection Agency, Occupational Safety and Health Administration, the Environmental Works, Inc. "Corporate Health and Safety Plan" guidelines, and the Site-Specific Health and Safety Plan.

6.0 REFERENCES

To properly implement this procedure, please look to the following documents for further information related to this SOP.

- "*Corporate Health and Safety Plan*" Environmental Works, Incorporated.
- U.S. Environmental Protection Agency Science and Ecosystem Support Division, "*Groundwater Sampling*", November 2007.

Environmental Works, Inc. SOP No. 8

Groundwater Sampling – Pump or Bailer Purge

ATTACHMENTS

Calculating Well Volumes

Calculating Well Volume

Prior to the development or purging of a groundwater monitoring well, the volume of water in either the well casing or well annulus (if it is an uncased or partially cased well) must be determined. A construction diagram of a typical monitoring well illustrating the well casing and other components is shown on the following page.

To calculate the volume of water in a well, the following information is required:

(1) Total Depth of the well (to the nearest 0.10 foot)
(2) Depth to the water (to the nearest 0.10 foot)
(3) Inside diameter of well casing or annulus (in inches)

Once the above information has been obtained, calculate the volume of water by subtracting the depth to water (DW) from the total depth (TD), then multiply the number with the appropriate casing/annulus conversion number (see below). The formula is:

(TD – DW) X Conversion Number = Volume of water in a well

Conversion numbers express the gallons of water that can occupy one foot of schedule40 PVC pipe (gallons per linear foot).

Common Well Conversion Numbers

Well Diameter (inches)	Gallons per Foot
1.25 inches	0.08
2 inches	0.17
3 inches	0.38
4 inches	0.66
6 inches	1.5
8 inches	2.6
12 inches	5.81

Once you have calculated the volume of water in each well, multiply the volume of water by however many well volumes you need to purge from the well (10 for development and 3 for purging).

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GROUNDWATER SAMPLING LOG

PROJECT NAME: ____________________________

PROJECT NO: ____________________ **EVENT:** ______________________________

DATE: ____________________ **TIME:** _________ **PERSONNEL:** ___________________________________

WELL ID: ____________________ **WELL DIAMETER:** ________ **SAMPLE ID:** ______________________________

PURGING DATA

WATER LEVEL: __________ **WELL TD:** _________ **FT WATER IN WELL:** __________ X FACTOR* = __________ **GALLONS**

EVACUATION METHOD: _____________________________________ **TOTAL GAL PURGED:** __________

***FACTOR:** **2" diam well = 0.2** **3.5" diam well = 0.5** **4" diam well = 0.7** **6" diam well = 1.5** **8" diam well = 2.6**

PURGING PARAMETER MEASUREMENTS

TIME	VOLUME	COLOR	ODOR	TEMP	pH	DO%	COND	

SAMPLING DATA

(fill in blanks or circle as appropriate)

SAMPLING METHOD: ______________________________ **DATE:** ______________ **TIME:** __________

ANALYTES: VOC TPH-DRO TPH-GRO TPH-ORO Oxygenates METALS Other __________________

CONTAINER: 40 ml VOA (#____) 1 L Amber Glass (#____) 250 ml Poly (#____) 500 ml Poly (#____)

PRESERV. None Hydrocloric Acid Sulfuric Acid Nitric Acid Na Thiosulfate

APPEARANCE: ______________________ **COLOR:** _______________________ **ODOR:** __________________________

DUPLICATE COLLECTED? ____ **ID:** _____________ **SPLIT SAMPLE?** ____ **FOR WHO?** _____________________

SAMPLING NOTES:

Skills Required:

1) 40-hour HAZWOPER training (if working on hazardous waste sites)
2) Understanding of, and ability to make decisions regarding, site-specific objectives
3) Training in operation of pumps and collecting water samples (see SOP #8)
4) Knowledge of EWI quality control standards
5) Knowledge of corporate Safety requirements and health and safety plan

1.0 OBJECTIVE / APPLICABILITY

The objective of this Standard Operating Procedure (SOP) is to provide a framework for collecting groundwater samples using a low flow purging and sampling procedure in order to collect samples representative of the formation water from the aquifer's identified zone of interest with minimum stress on the aquifer. The technique minimizes chemical changes that can occur as a result of traditional "purge and sample" techniques, and greatly reduces the amount of purge water to be managed. See the attached article by Kaminski for further information.

This SOP should serve as a reference tool and facilitate consistency among Environmental Works, Inc. (EWI) personnel. Low flow sampling procedures allow little departure from procedural standards. If site conditions or equipment issues limit adherence to the procedures, any variance needs to be discussed with the project manager and recorded in field notes. The ultimate procedures employed should be documented in field notes and in related reports.

2.0 SCOPE

This SOP outlines the procedure needed to provide samples indicative of mobile organic and inorganic loads at ambient flow conditions (both the dissolved fraction and the fraction associated with mobile particulates). The low flow method minimizes aquifer stress by using reduced pumping rates at or below groundwater recharge rates to minimize alteration of water chemistry. This SOP is aimed primarily at 2" or larger diameter monitoring wells that have either a short (less than 10 feet) screen length or monitoring interval (if open bore), or have identified target horizons to be monitored. This procedure can be used in a variety of well construction situations. As with all groundwater sampling, this procedure does not address the collection of samples from wells containing light or dense non-aqueous phase liquids (LNAPLs and DNAPLs).

3.0 EQUIPMENT

All equipment will be calibrated per manufacturer specifications. Specialized equipment is needed for the Low Flow procedures (see below and attached Low Flow Equipment sheet). The following specifies the QED "Sample Pro" pump and MP-10 controller currently used by EWI:

a. QED Sample Pro Low Flow Sampling pump kit including wellhead support plate
b. QED MP-10 Controller kit (3 AA batteries), blue & red air lines with fittings
c. Disposable bladders (one per sample) and push grab plate (one per sample)
d. Double ¼" air/discharge tubing (enough length for wells)
e. Single ¼" or ½" tubing for discharge from YSI
f. Cable or 50-lb test fishing line backup to hang pump (sufficient length for wells)
g. 5-gallon buckets (one graduated in gallons)
h. 55-gallon drum(s) (enough to hold expected purge water) and large funnel

i. Interface probe (capable of measuring to 0.01 foot accuracy)
j. YSI meter (or equivalent) for measuring pH, Eh, dissolved oxygen, specific conductance, ORP, and temperature, calibration fluids (4 C-cell batteries if YSI)
k. Turbidity meter (4 AA batteries), bottles in kit, & calibration fluid
l. Photoionization detector (PID), calibrated and charged battery
m. Wheelbarrow compressor or bottled nitrogen tank & regulator, and hose
n. Decontamination supplies (non-phosphate detergent, distilled water)
o. Tool kit (basic tools, incl knife to cut tubing) & tools to open well covers
p. Plastic sheeting and knife
q. Folding plastic table
r. Key for well locks
s. Nitrile gloves
t. Sample bottles, labels, baggies, tape
u. Cooler, Chain of Custody (COC) forms, Shipping labels
v. Low Flow sampling field forms and field notes

5.0 PROCEDURE

5.1 Pre-Operation

1. Review project objectives and desired analytes, and order appropriate bottles, coolers, COCs, and shipping materials from the laboratory at least one week prior to the field event.
2. Utilized the attached "LoFlowPlanCalc" Excel sheet to plan out tubing lengths needed for each well and total purge volumes to expect. Tubing for each well = pump depth plus 4-5 ft.
3. QED bladders, push fitting grab plate, and tubing need to be ordered a minimum of one week prior to the field event. Gather and check all equipment needed. Insure you have spare batteries for the QED controller, YSI, and flowmeter.

5.2 Field Procedures

1. Mobilize to site, and conduct and record an on-site safety meeting (do each morning). Review planned sampling well order for the day.

2. Visit all wells, remove well J-plug and immediately take PID readings, and record on field sampling sheet (see attachment).

3. Measure water level after stabilization (minimum of 15 minutes) and record on field sample sheet. Check water level against sample plan (LoFlowPlanCalc sheet) to verify appropriate pump placement.

4. Note: If NAPL present, contact the project manager for direction on handling that well.

5. Utilize the attached "LowFlowSampling-OnePage" sheet to aid in setting up for sampling. Cut appropriate size plastic and position around wellhead. Set up folding table and organize equipment; set up YSI in shade area (block with cardboard, etc.) to avoid solar heating.

6. Calibrate YSI and flowmeter. Install bladder and grab plate inside pump. Cut dual ¼" tubing to length for that well and affix to pump by pushing into grab plate (note "A" for air and "D" for discharge tubing).
7. Tie off 50-lb fishing line to pump and lower pump to pre-determined depth. Lower gently to minimize disturbances in the well.
8. Thread tubing through wellhead support plate and tie off fishing line as backup for pump loss.
9. Connect ¼" air tube from pump to blue airline fitting. Hook up blue airline to controller and red airline to air source (compressor or nitrogen tank).
10. Connect ¼" discharge tube from pump to bottom YSI fitting, using ½" tubing as adapter if necessary. Connect single discharge line from upper YSI fitting to flow into graduated 5-gallon bucket.
11. Thread interface probe through wellhead support plate and verify water level. Raise to just above water level and turn off to conserve battery.
12. Calculate submergence (pump depth minus water level) and set MP-10 controller to no more than 10-15 psi above the submergence amount (If submergence <5 ft, do not exceed 18-20 psi on MP-10 controller).
13. Set MP-10 controller to 4 cpm (cylces per minute) and record ID (103). Start air compressor or open regulator on nitrogen tank.
14. Start the pump by selecting CYCLE on the MP-10. Watch for water to enter discharge tubing and fill YSI.
15. Check water level once discharge begins. If water level drop approaches 0.33 ft, use DOWN arrow to lower flow rate or change the CPM to 3 or 2 CPM. Note: anytime you change the flow rate, record the ID on the sample field form. Note flow rate by recording volume in calibrated 5-gallon bucket and times one gallon, etc. are reached.
16. If drawdown exceed 0.33 ft, stop pump and allow time for well to recover. Then restart pump at lower rate. If adjustments result in a minimal discharge that still results in drawdown exceeding 0.33 feet, but remains stable, continue purging but record detailed information in field notes. Measure and record water levels between YSI readings to verify minimal drawdown.
17. Once YSI cell fills with water, start monitoring indicator field parameters: temperature, specific conductivity, ORP, pH, and dissolved oxygen. Record every 5 minutes until parameters begin to stabilize, then record every 3 minutes.
18. Use cuvette vial for flowmeter to collect water from YSI discharge, clean outside of vial with alcohol solution (in flowmeter kit), place in flowmeter, and measure and record reading with every YSI reading set.
19. Purging is considered complete and sampling may begin when indicator field parameters have stabilized. Stabilization is achieved when three consecutive readings, taken at three to five minute intervals, are with the following limits:

- Turbidity = 10% for values greater than 1 NTU
- Dissolved oxygen = 10%
- Specific conductivity or ORP = 3%
- Temperature = 3%
- pH = ± 0.1 unit

20. Collect water samples after stabilization is verified. Collect samples at the same low flow rate. On the MP-10 controller, use the PAUSE function, and collect samples from the discharge tubing PRIOR to entry into the YSI cell. Fill appropriate bottles, beginning with VOCs. Measure and record water level during sampling to verify drawdown criterion is maintained.
21. Label all samples, using waterproof ink, including the sample ID, date, time, sampler name, and analysis desired. Place inside plastic baggie and put in cooler with ice. Record all information on sample field form.
22. Stop compressor/turn off air and allow air lines to purge (check pressure gauge). Decontaminate equipment between wells. Disassemble pump and dispose of bladder, tubing, and grab plate. Wash pump decontaminating solutions from buckets.
23. Collect rinsate blank, if part of sampling QA/QC, near end of sampling event. Collect field blanks, if part of sampling QA/QC, during sampling event.

5.3 Post-Operation

1. After each well is sampled record total purge volume and place purge water into a 55-gallon drum for disposal per project planning.
2. When ready to ship samples, fill out the COC, place it in a zip lock plastic bag, and tape it to the lid of the cooler (see EWI SOP#5). Tape the cooler and place signed custody seal and shipping labels on the outside of the cooler.
3. Return equipment to the Equipment Room, noting any malfunctions or issues.
4. Verify all field sample sheets and progress notes are complete, fill out a Daily Equipment Log, and return all paperwork to the Project Manager.

6.0 SAFETY

Acute or chronic exposure to chemically-contaminated soil or water could result in bodily injury. Routes of exposure include inhalation, ingestion, and dermal contact. Consult the appropriate chemical material safety data sheet (MSDS) before mobilization so that proper PPE and monitoring are planned and implemented.

Conduct an on-site safety meeting each day before the start of field work utilizing a Tailgate Safety Meeting form. Review safety hazards (e.g. high-traffic areas, exposure to chemicals, alertness to heavy equipment, PPE, health monitoring, and emergency procedures). Take appropriate action if personnel are injured on-site per EWI policy guidance.

When working with potentially hazardous substances, follow the United States Environmental Protection Agency (US EPA), Occupational Safety and Health Administration (OSHA), EWI Corporate Health and Safety Plan, and site-specific health and safety plan.

7.0 REFERENCES

The following documents may be reviewed for further information appropriate to this SOP.

- U.S. Environmental Protection Agency Region I, "*Low Stress (low flow) Purging and Sampling Procedure for the Collection of Ground Water Samples from Monitoring Wells*", SOP # GW 0001, DATE: 7/30/1996, REV. #2.
- U.S. Environmental Protection Agency, Ground Water Issue, "*LOW-FLOW (MINIMAL DRAWDOWN) GROUND-WATER SAMPLING PROCEDURES*," EPA/540/S-95/504, April 1996.
- ASTM Standard D6771
- Kaminski, David, "*Low Flow Ground Water Sampling: What does the sample represent?*"
- Richey, Joe, 2002, "*Low Flow Purging and Sampling Groundwater*", ASTM Standard News
- Technology Overview of Passive Sampler Technologies (Section 2), ITRC, March 2006. With pp. 35-36 from 2007 ITRC document on *Protocol for Use of Five Passive Samplers*
- "Corporate Health and Safety Plan" Environmental Works, Incorporated.
- Site Specific Health and Safety Plan

Environmental Works, Inc. SOP No. 9

Groundwater Sampling – Low Flow Methodology

ATTACHMENTS

Low Flow Planning Spreadsheet

Low Flow Equipment List – Single Page

Low Flow Procedure – Single Page

Low Flow Groundwater Sampling Form

Article: "Low Flow Groundwater Sampling:
What Does the Sample Represent?"

LOW FLOW SAMPLING SETUPS
MONITORING WELLS
____________________ Site

Monitor Well ID	TD (Ft BTOC)	Water Level (Ft BTOC)	2" Casing Volume (gal)	Top Screen (FtBTOC)	Pump Depth BTOC	Tubing Length (ft)
Example	11.98	3.1	1.5	4.0	7.0	11
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
			0.0			
	Total Volume		1.5	**Total tubing needed**		11

Pump depth is 1/3 submergence

Tubing Length includes 4 ft TOC to YSI

Low Flow Sampling Volume Calculation

Time to Purge (min)	Volume @0.2 l/min	Volume @0.4 l/min
15	0.7 gal	1.3 gal
25	1.1 gal	2.2 gal
35	1.5 gal	3.1 gal
45	2.0 gal	4.0 gal
55	2.4 gal	4.8 gal

Low Flow Sampling Equipment List

Equipment	Quantity	Comment
Low Flow Sampling pump kit (extra bladders and parts)	1 kit	
MP-10 Controller kit (3 AA batteries)	1 kit	
Double ¼" air/discharge tubing (enough length for wells)	roll	Need new tubing for each well
Single ¼" or ½" tubing for discharge from YSI (sm spool)	3-5 ft	Can re-use between wells
Pump wellhead support bracket	Set	Modified as needed for size of casing
Tool kit (basic tools, incl knife to cut tubing)	1 kit	
Blue air line with fittings	set	
Red air line with fittings	set	
50-lb test fishing line (sufficient length for wells)		Backup to hang pump
YSI meter/case/calibration fluids (4 C-cell batteries)	set	
YSI pH 4, 7, 10 and conductivity calibration fluids; Confidence Solution if available	set	
Turbidity meter & calibration fluid (4 AA batteries)	set	
"Y" connection for ¼" discharge line (split YSI / turbidity)	1	Optional – can just use flow cell discharge
Interface probe	1	
Wheelbarrow compressor	1	
5-gallon buckets, one marked in gallons	2	
Plastic sheeting / knife	roll	
55-gallon drums / funnel	1-2	
Decon buckets & soap	set	
Nitrile gloves	3	
Sample bottles, Coolers, ice	As req'd	
Logging – sampling forms	set	
Folding table (optional)	1	

Low Flow Sampling Procedure

1. Divide preparation and setup tasks. For first well of the day:
   - Person #1measure and record water levels; prepare pump, tubing, etc. and organize equipment around wellhead (see picture for set-up). <u>Set up with YSI flow through cell location in shade.</u> Set compressor close to well in downwind location and start up to build air pressure in tank. Set up MP-10 controller with red air line from compressor to AIR IN port on MP-10 controller. Install blue air line in AIR OUT port on MP-10.
   - Person #2 calibrate YSI (daily) and Turbidty Meter (monthly). Install pH probe from separate vial. Save YSI probe storage fluid and pH probe vial fluid (use poly bottles in case). If available, use YSI confidence solution to check previous day's YSI calibration and calibrate only needed parameters. <u>Calibrate % DO first, then Conductivity, then pH</u>.
2. Assemble Lo-Flow pump with new bladder and tubing grab plate, verify O-ring placements. Verify tubing length for well (pump depth + 4 to 5 ft), and measure and cut if not previously prepared. Insert tubing into pump, noting which tube is in "A" (airline) and "D" (discharge) openings on pump, and verify secure. Tie off pump with 50-lb test fishing line and lower into well to desired depth. Cut fishing line and tie off on wellhead support plate. Separate dual air/discharge tubing and thread through wellhead support plate. Place wellhead plate on casing. Connect ¼" air line from pump into blue air line fitting. Connect ¼" pump discharge line to bottom port on YSI flow-through cell using clear plastic adapter tubing. Connect YSI discharge tubing from top port on YSI to discharge to 5-gallon bucket.
3. Thread interface probe through plate opening verify water level; record on log. Raise probe to just above water level and turn off to conserve battery.
4. Check pump submergence (pump depth minus water level) and set MP-10 controller no more than 10-15 psi above the pump's submergence on MP-10 gauge. Note: If submergence < 5 ft, do not exceed 18-20 psi on MP-10 gauge.
5. Set MP-10 controller to 4 CPM (ID 103) and record ID setting (e.g., "103") under FLOW RATE on log. Record the ID number anytime you change the CFM or UP/DOWN arrows.
6. Hit CYCLE on MP-10 controller to begin pumping. Watch for water movement in tubing, and for YSI to fill. Do not begin recording YSI parameters until cell has been full for 3 min.

   <u>Note</u>: for Amory, MS, initially set the controller on CPM 6 & max flow. It's OK to get a drop in water level for the first 5-10 minutes since at least one well casing volume must be removed. Carefully monitor water level but YSI parameters need not be monitored. After 5-10 min, reduce CPM to 3 or 4, and record low flow parameters with stable water level
7. Check water level once pumping begins to insure drop is < 0.33 ft. If approaches 0.33 ft drop, use DOWN arrow to lower flow rate, or use CPM ◄► to change MP-10 CPM to 3 or 2.
8. Record YSI readings every 5 minutes initially, checking water level. Note if any bubbles occur in YSI flow through cell. After first 15-20 minutes, or when values appear to be stabilizing, record every 3 minutes. Record TEMP, pH, DO%, COND.
9. Use cuvette vial from Turbidity Meter and collect sample from YSI discharge at each recording. Wipe outside of cuvette, check in Turbidity Meter, and record with YSI readings.
10. Measure water levels between reading events to insure stable (less than 0.33 ft drop).
11. Carefully check stabilization criteria on Log. When ALL parameters are within criteria for three consecutive readings, sampling can be done.
12. Sample at the same low flow pump rate - use PAUSE function on MP-10. Sample from discharge tubing <u>before</u> YSI flow thorough cell. Verify stable water levels during sampling activities.
13. Disassemble pump, decon wash/rinse, and install new bladder between wells.

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LOW FLOW WELL SAMPLING LOG

WELL: ____________________________

PROJ. NAME/NO.: ____________________________

DATE: ____________________ **TIME:** ________ **PERSONNEL:** ______________________________________

WATER LEVEL: _________ **WELL TD:** ________ **PUMP DEPTH:** ________ **MODEL:** _________________

LOW FLOW PURGING DATA

TIME	FLOW RATE	COLOR	ODOR	W. LEVEL	TEMP	pH	DO%	ORP	COND	TURBID
TARGET CRITERIA FOR STABLIZATION				**0.33' diff**	**10%**	**0.1**	**10%**	**10%**	**3%**	**10%**

SAMPLING DATA

(fill in blanks or circle as appropriate)

VOLUME PURGED: ______________ **DATE/TIME COLLECTED:** ___________/________ **SAMPLE ID**: ________________

ANALYTES: VOC TPH-DRO TPH-GRO TPH-ORO Oxygenates PAH METALS Other _____________

CONTAINER: 40 ml VOA (#____) 1 L Amber Glass (#____) 250 ml Poly (#____) 500 ml Poly (#____)

PRESERV. None Hydrocloric Acid Sulfuric Acid Nitric Acid TSP

APPEARANCE: ____________________ **COLOR:** _______________________ **ODOR:** ____________________

DUPLICATE COLLECTED? ____ **ID:** _____________ **SPLIT SAMPLE?** ____ **FOR WHO?** _________________

SAMPLING NOTES:

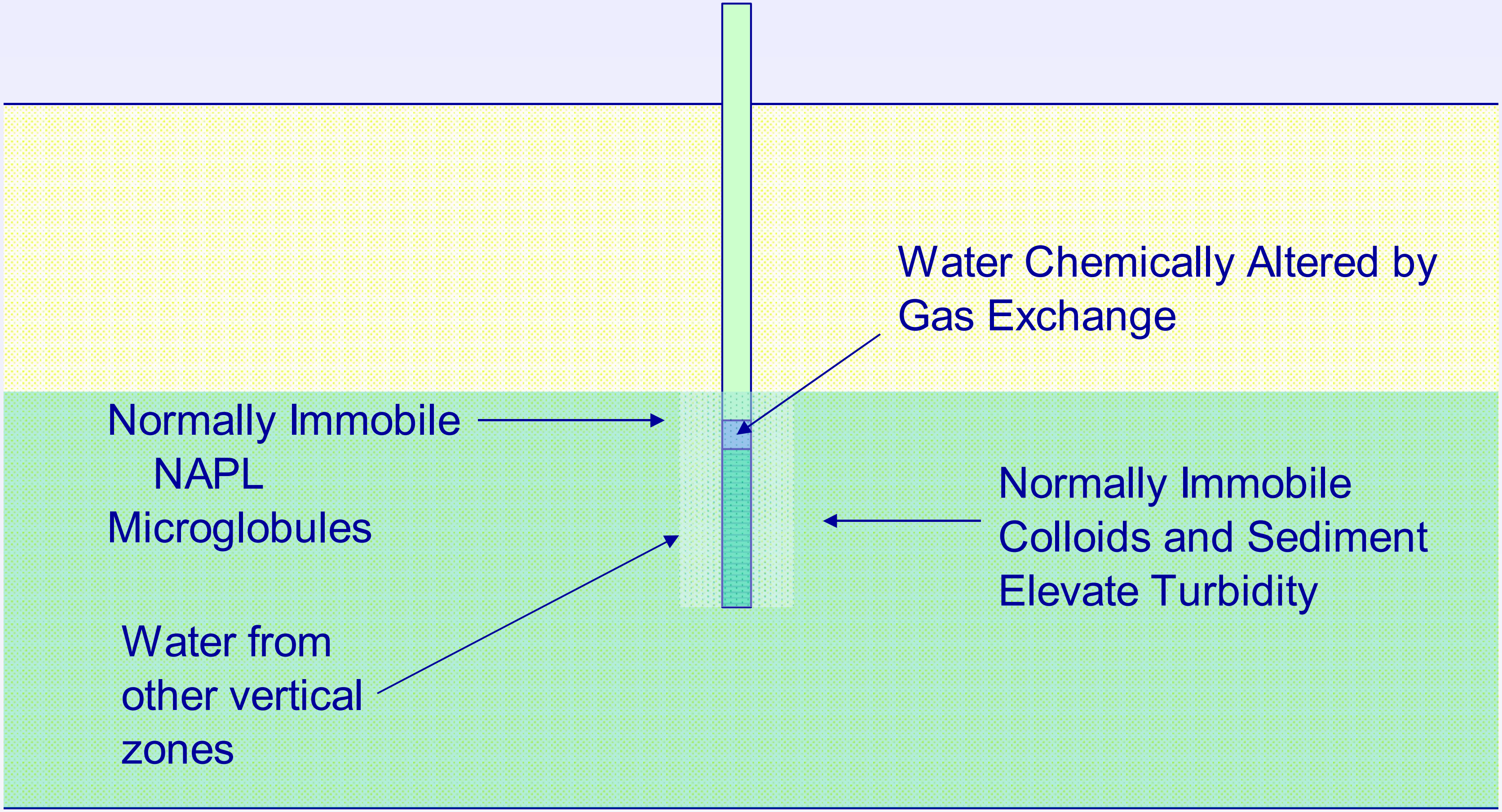
Low-Flow Ground Water Sampling:
What does the sample represent?

David Kaminski
QED Environmental Systems Inc.
Ann Arbor, MI / Oakland, CA

Early research into purging resulted in guidelines to purge wells to remove “stagnant” water

- Where wells would produce sufficient water, the “rule of thumb became “3 to 5 well volumes” prior to sampling.
- Where wells would not yield sufficient water, they were evacuated and sampled upon recovery, typically within 24 hours.
- In practice, little concern was given to how purging methods and devices (e.g., bailers) affected the chemistry of subsequent ground water samples.

What does the sample represent with traditional purging methods?



Water Chemically Altered by Gas Exchange

Normally Immobile NAPL Microglobules

Normally Immobile Colloids and Sediment Elevate Turbidity

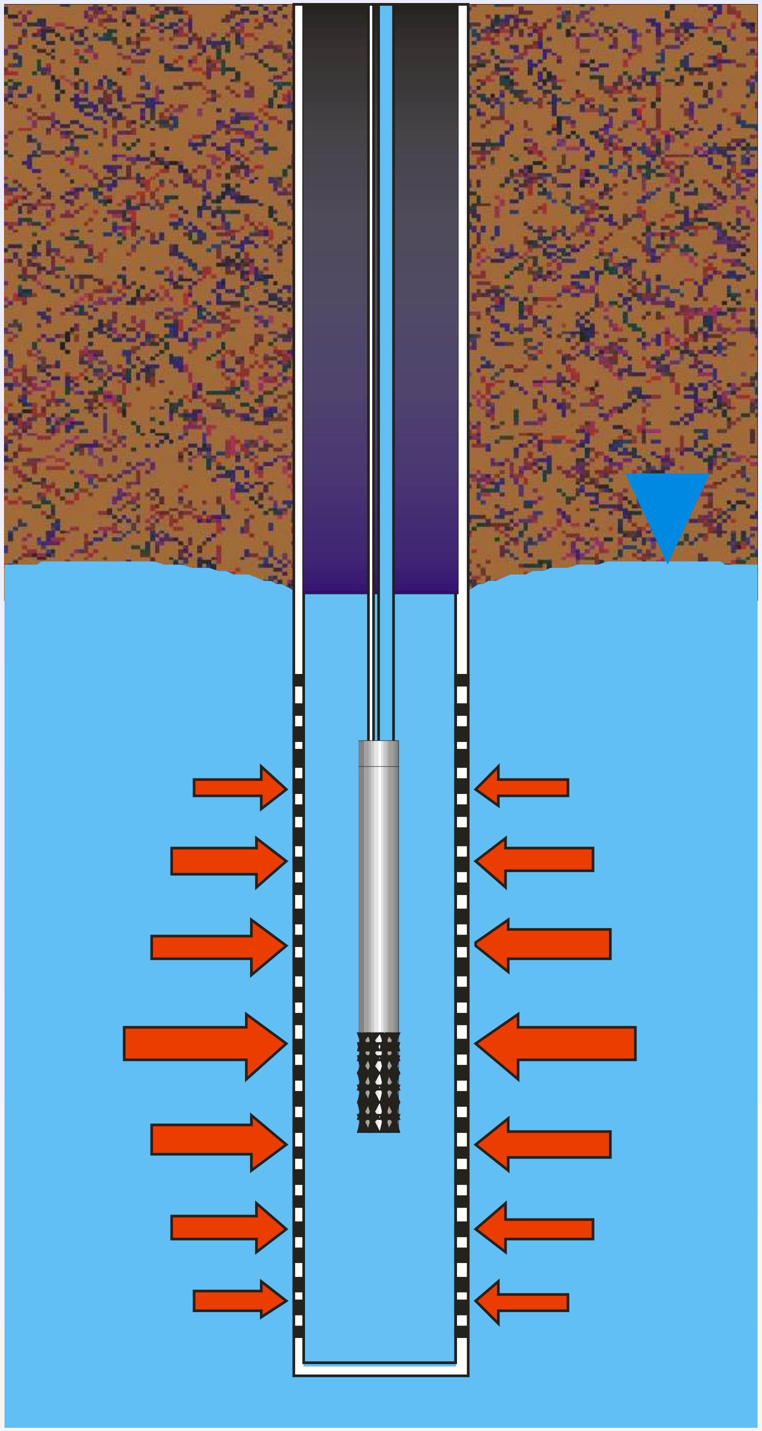
Water from other vertical zones

Limitations in traditional purging methods led to the evolution of low-flow purging

- Low-flow purging and sampling is a methodology that reduces disturbance to the well and aquifer typically caused by bailing or over-pumping.
- Contrary to popular belief, the development of the low-flow purging approach was based on a need to control artifactual turbidity, not to reduce purge water volumes.
- Low-flow pumping from the well screen controls turbidity that could affect analytical results.
- Because turbidity is low, unfiltered samples can be used to get a better estimation of the true mobile contaminant load.
- Purge volume is based on indicator parameter stabilization or evacuation of the sampling system.

Low-Flow Sampling

- Low pumping rate minimizes drawdown, mixing and formation stress, isolates stagnant water.
- Low stress = low turbidity, improved sample accuracy, reduced purge volumes.
- Samples represent formation water and naturally mobile contaminants, not stagnant water in the well or mobilized contaminants.



What Does a Low-Flow Sample Represent?

- While low-flow sampling is recognized as a solution for improving sample quality and reducing purge water volume, defining what the sample represents, in terms of the zone within the well screen that is sampled, is still often questioned.
- Pump placement can be an issue when changing to LFS from traditional purging; the concern is that samples will come from a narrow zone within the well screen, possibly "missing" contamination above or below the pump intake.
- Field experiments, laboratory simulations and numerical modeling support the position that samples are derived from the entire screen zone under low-flow pumping conditions.

Vertical Concentration Profiles from Puls and Paul, 1998

- In a field study, Puls and Paul found that well bore concentrations were averaged throughout the well screen zone under very low flow pumping conditions (0.25 lpm) where analyte concentrations were known to be measurably stratified within the surrounding formation.
- The concentrations from low-flow samples were virtually identical to the mean concentration of the multi-level and direct-push samples taken.
- Bailed sample concentrations were biased lower than the low-flow pumped sample results.

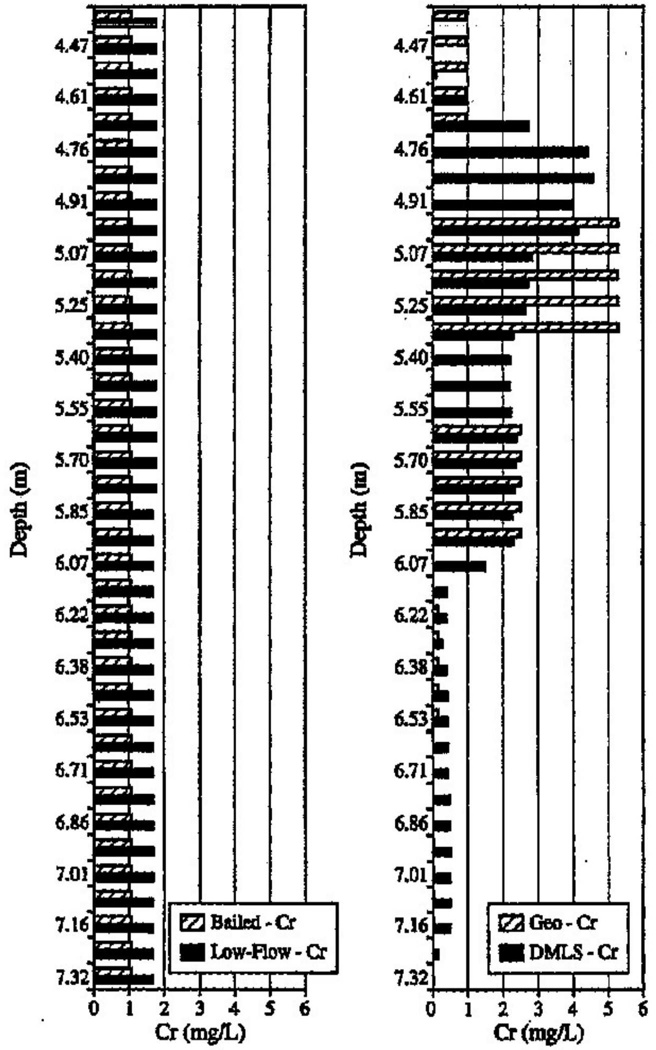


FIG. 6. Chromium Data for Samples Collected Using DMLS, Low-Flo, and Bailed Sampling Approaches for Well 45 in September 1995

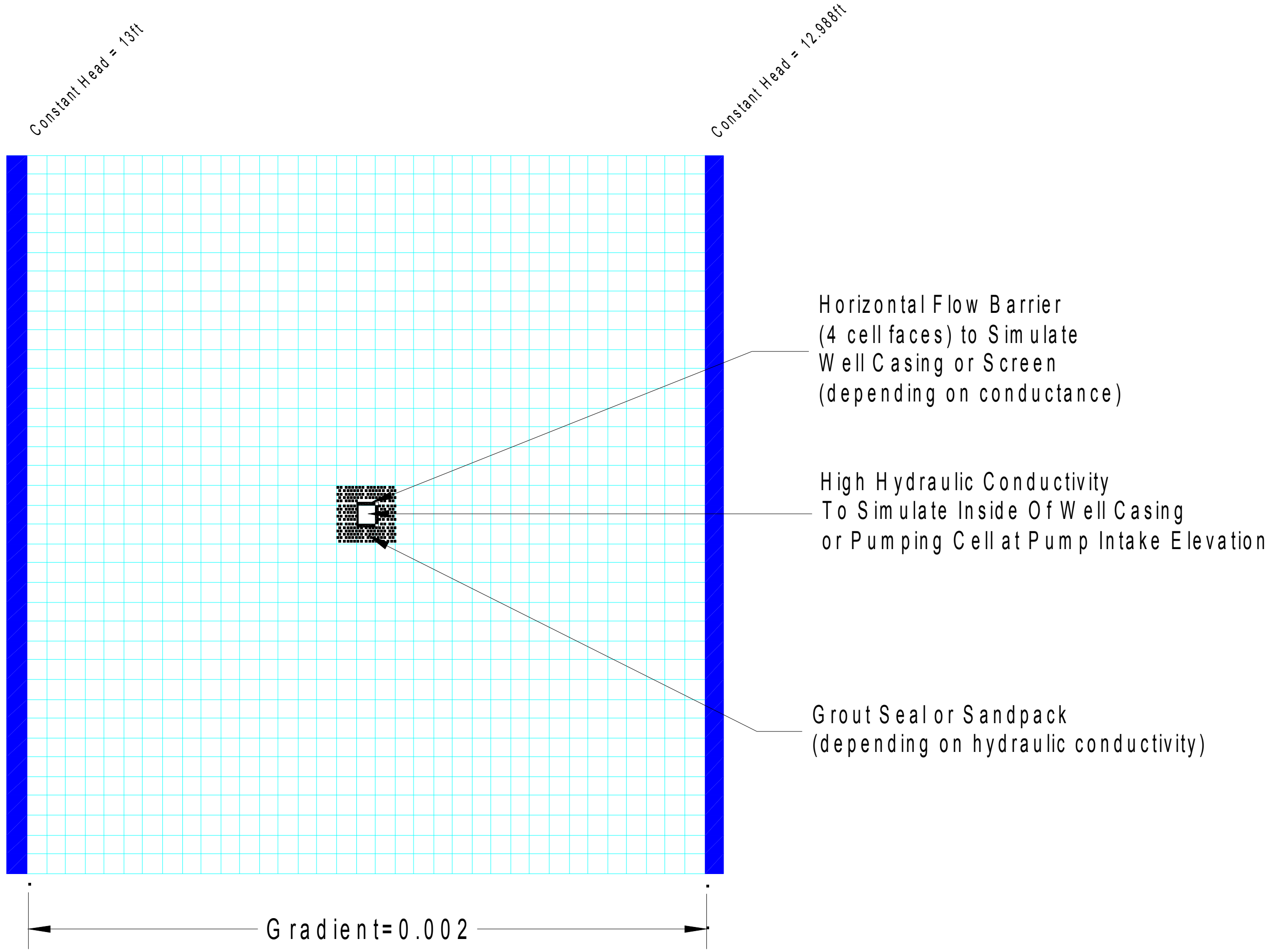
MODFLOW Simulations

- MODFLOW computer simulations with high vertical definition by Varljen, et al. (GWMR, Winter 2006) show that flow across a well screen, regardless of pump placement, captured water from the entire well screen zone.
- The objectives of the modeling experiment were to demonstrate the actual monitoring zone achieved during low flow purging and sampling and assess the effects of:
  - screen length
  - pumping rate
  - pump position in screen
  - sand pack configuration
  - formation heterogeneity and anisotropy
  - full vs. partial screen penetration

Varljen et al. Model Configuration

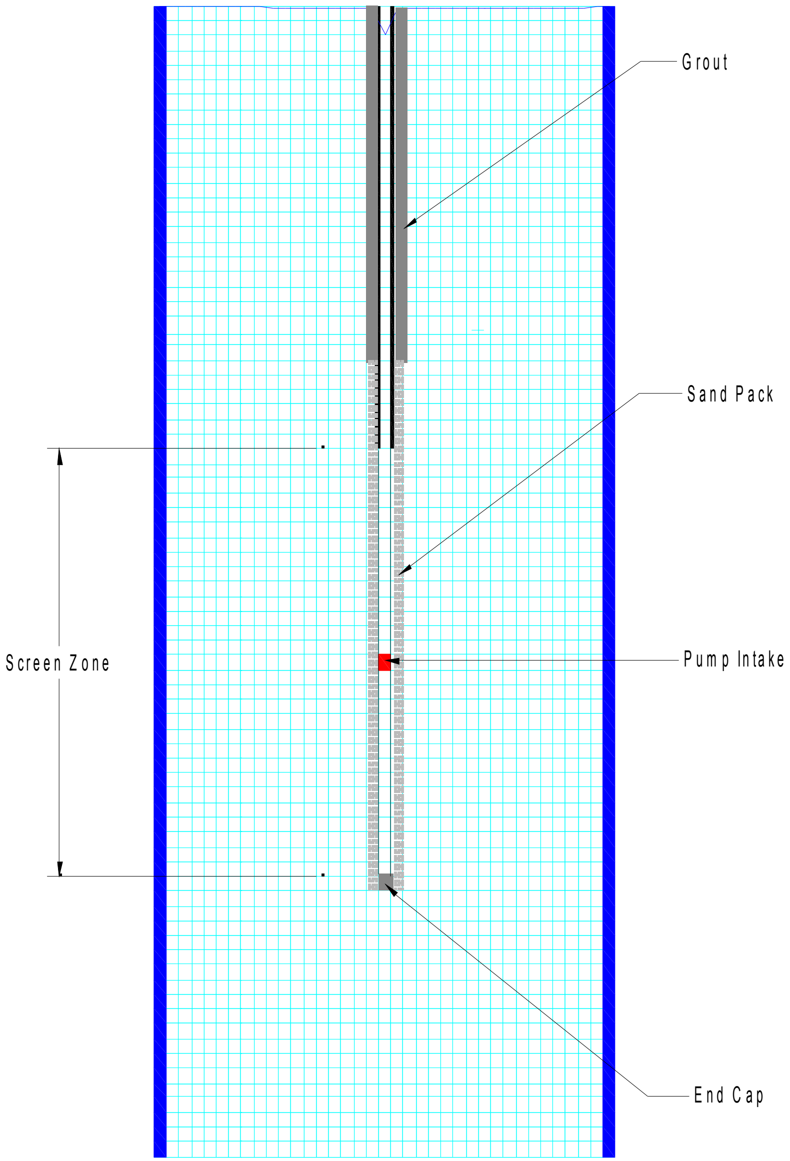
- 106,782 node finite-difference simulation using MODFLOW
- 78 layers (2-, 4-, or 8-inch thickness depending on screen length)
- 2-inch horizontal grid spacing
- Pumping rates of 250 and 500 ml/min @ steady state

Plan View of MODFLOW Simulation



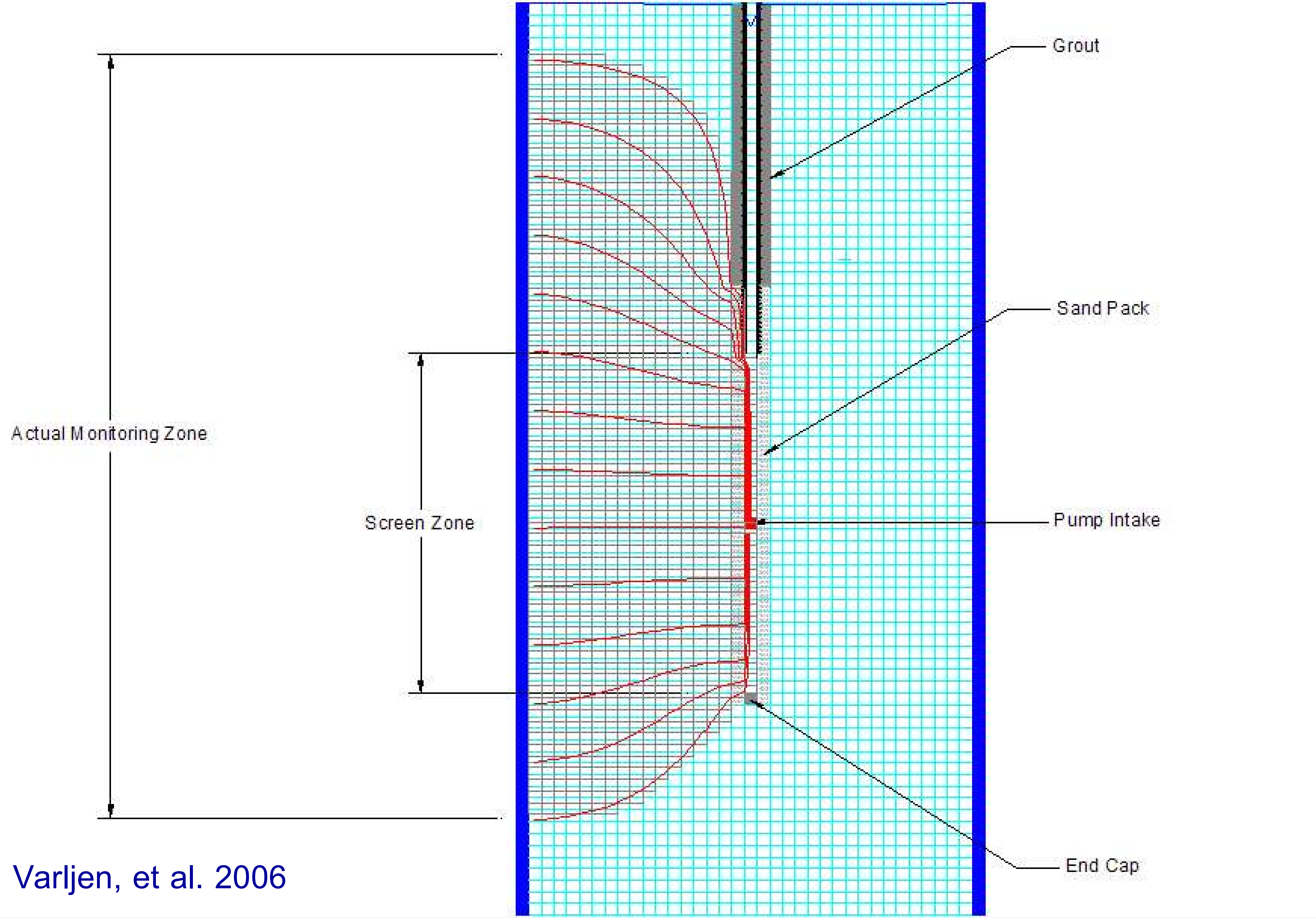
Varljen, et al. 2006

Horizontal View of MODFLOW Simulation



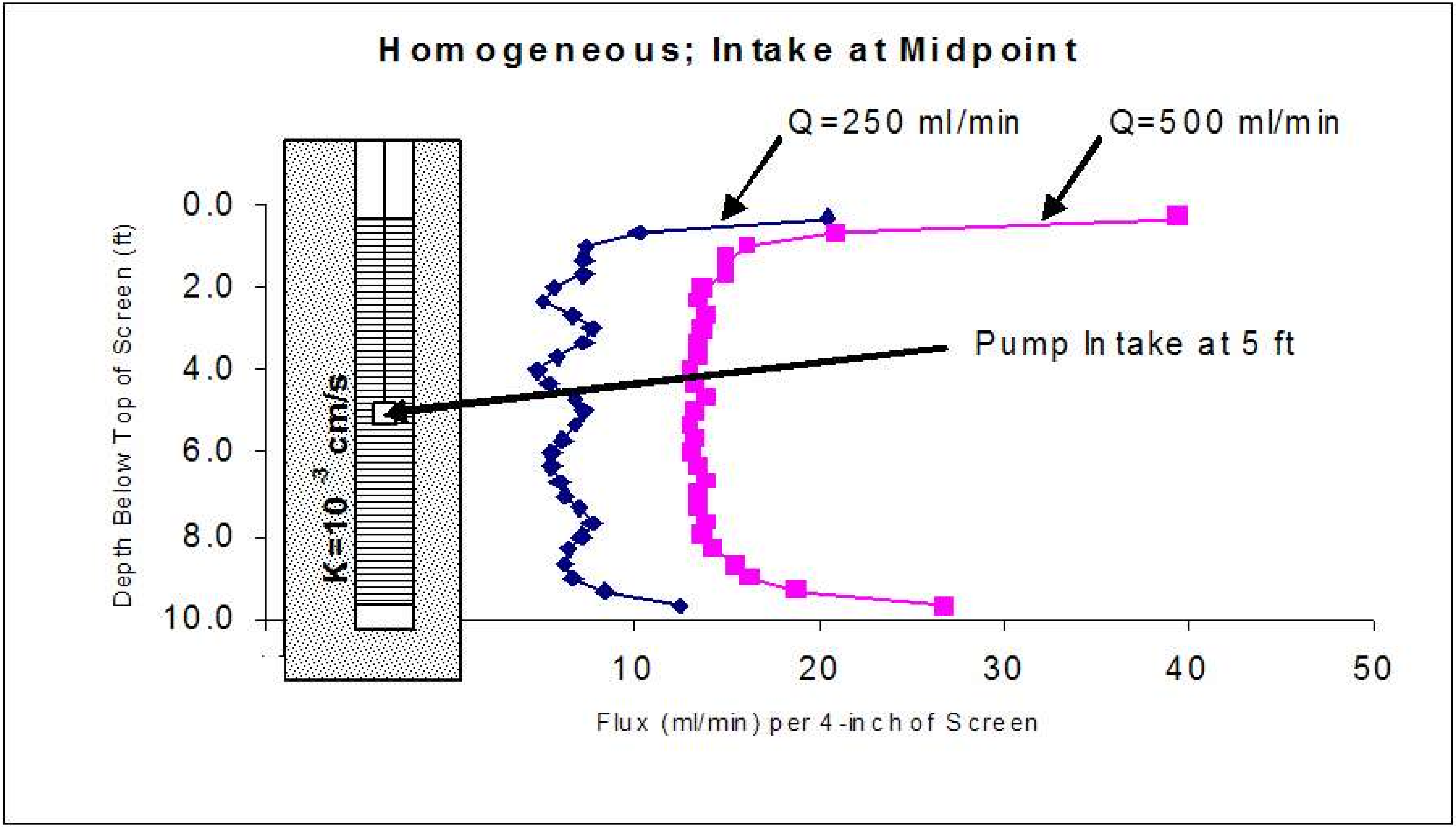
Varljen, et al. 2006

Model Output at 0.25 L/min Steady State Flow



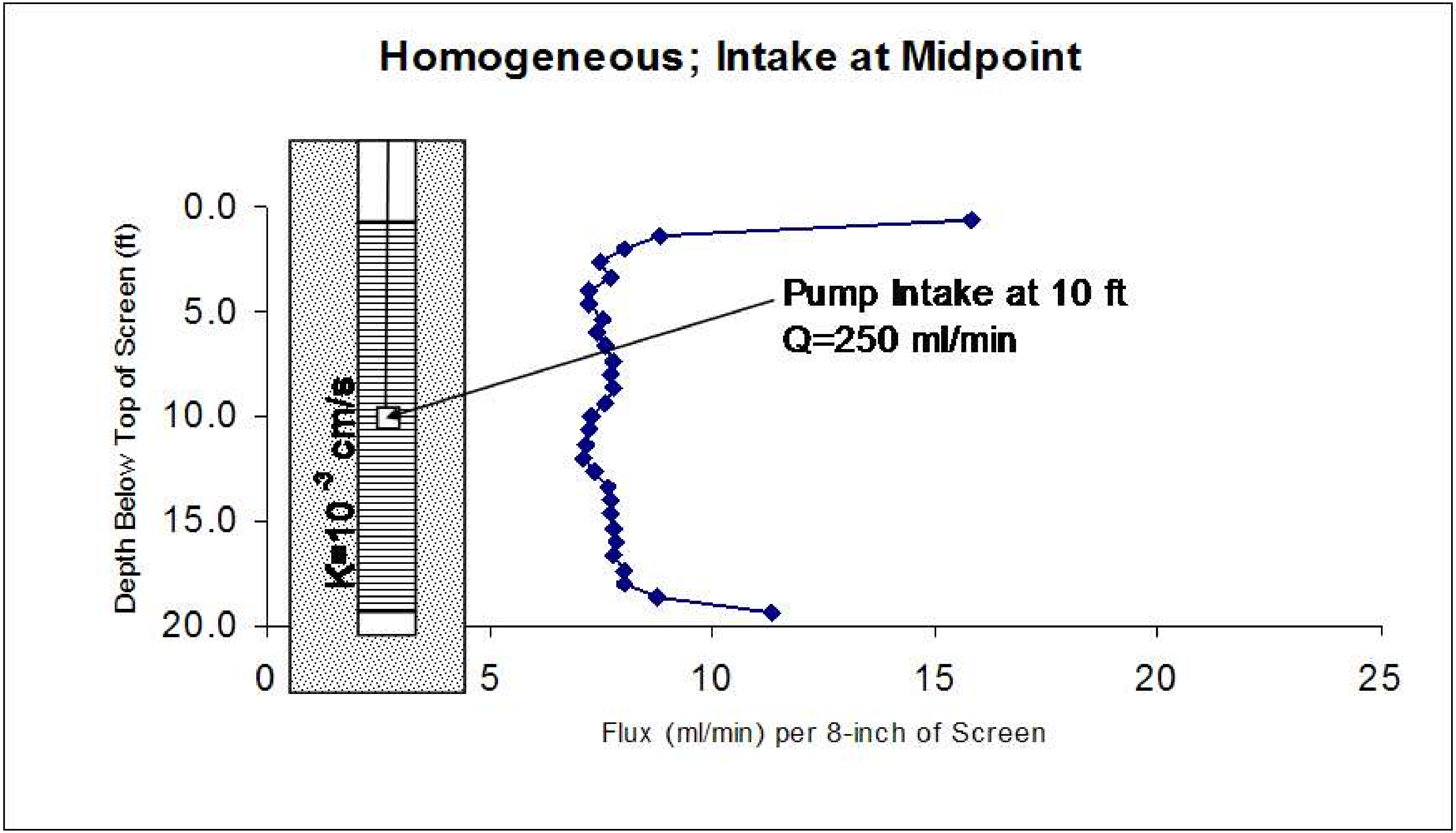
Varljen, et al. 2006

Vertical Distribution of Flux into a 10-foot Well Screen and Effect of Changes in Pumping Rate



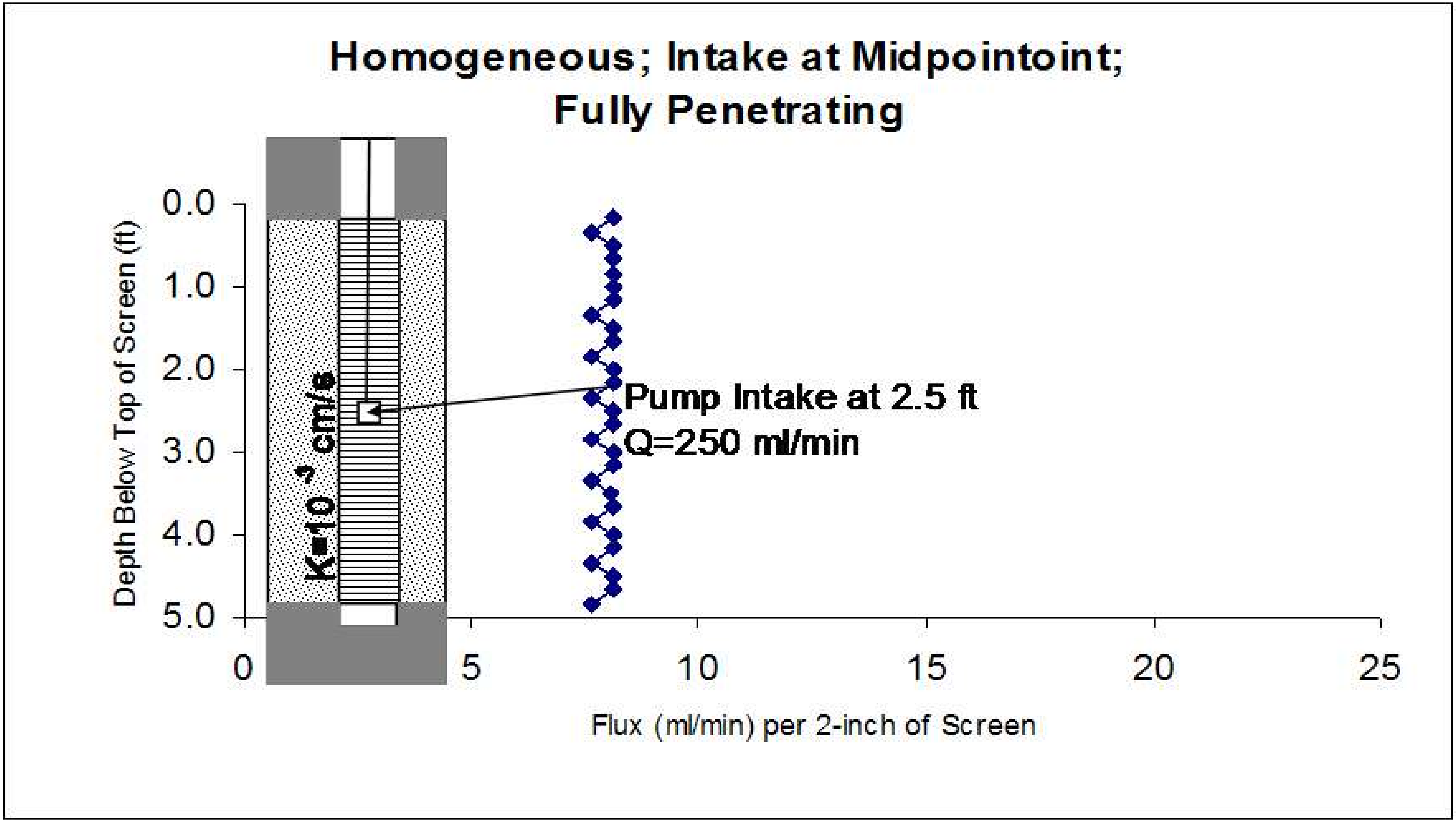
Varljen, et al. 2006

Vertical Distribution of Flux into 20-foot Well Screen



Varljen, et al. 2006

Effect of Removing Sand Pack Extensions on Flux Distribution Pattern

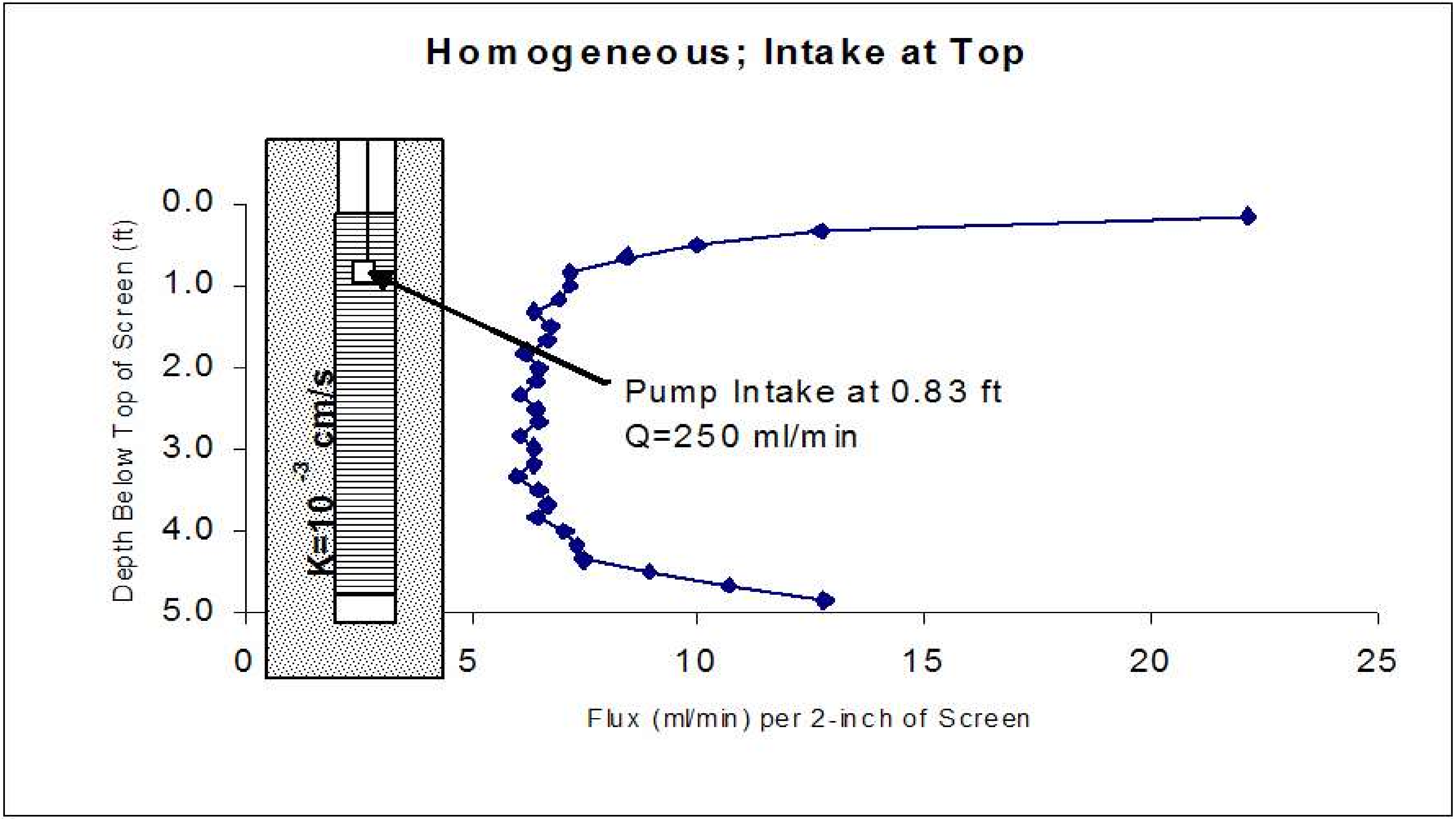


Varljen, et al. 2006

CONCLUSIONS:

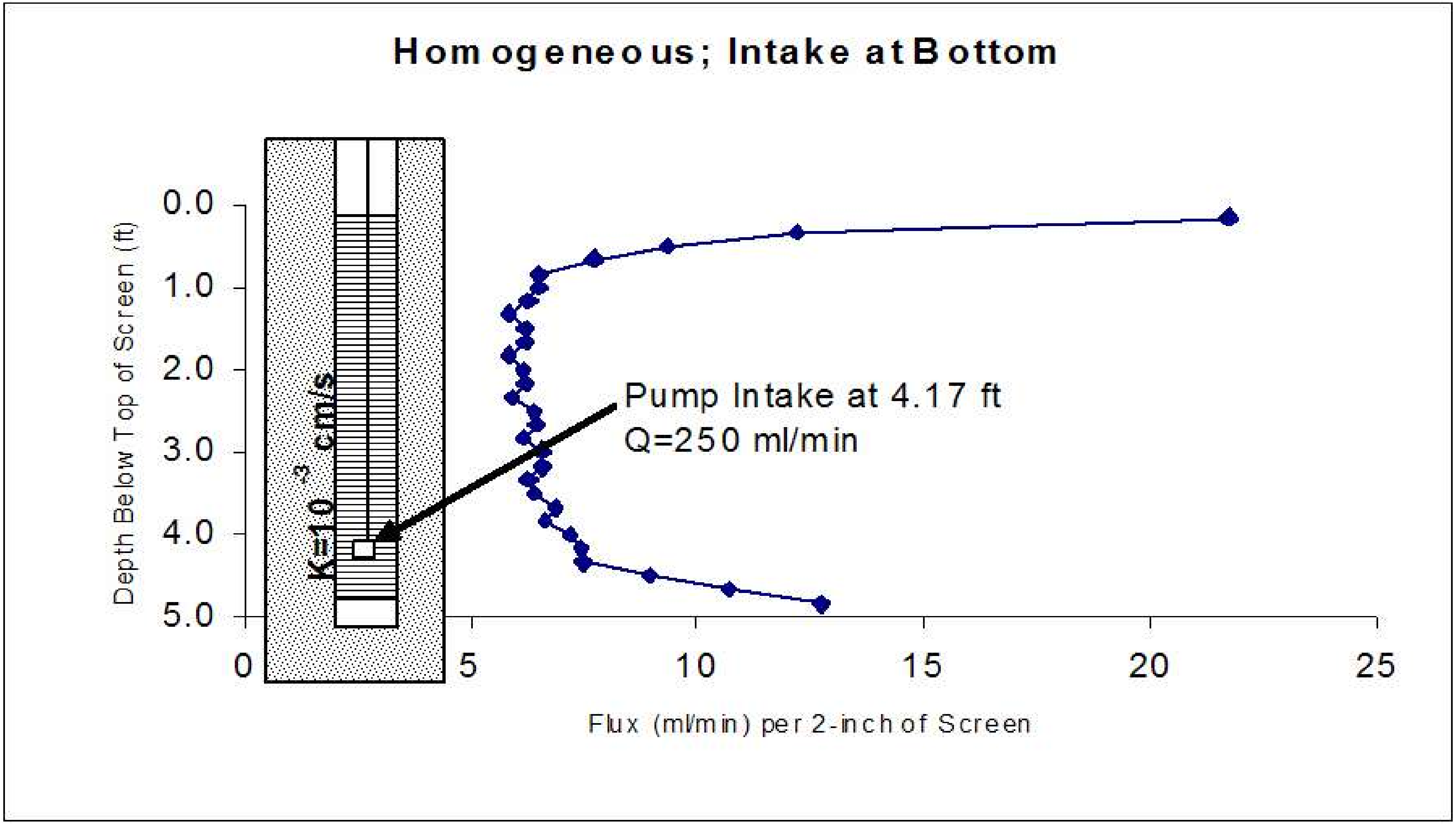
- Water is drawn from the entire length of the well screen during low-flow purging and sampling.
- More water comes from the top and bottom of the screen in partially penetrating wells due to capture from above and below the screen.
- The flow pattern remains the same with changes in flow rate and in screens from five feet to 20 feet long.

Effect of Pump Placement on Vertical Flux Distribution



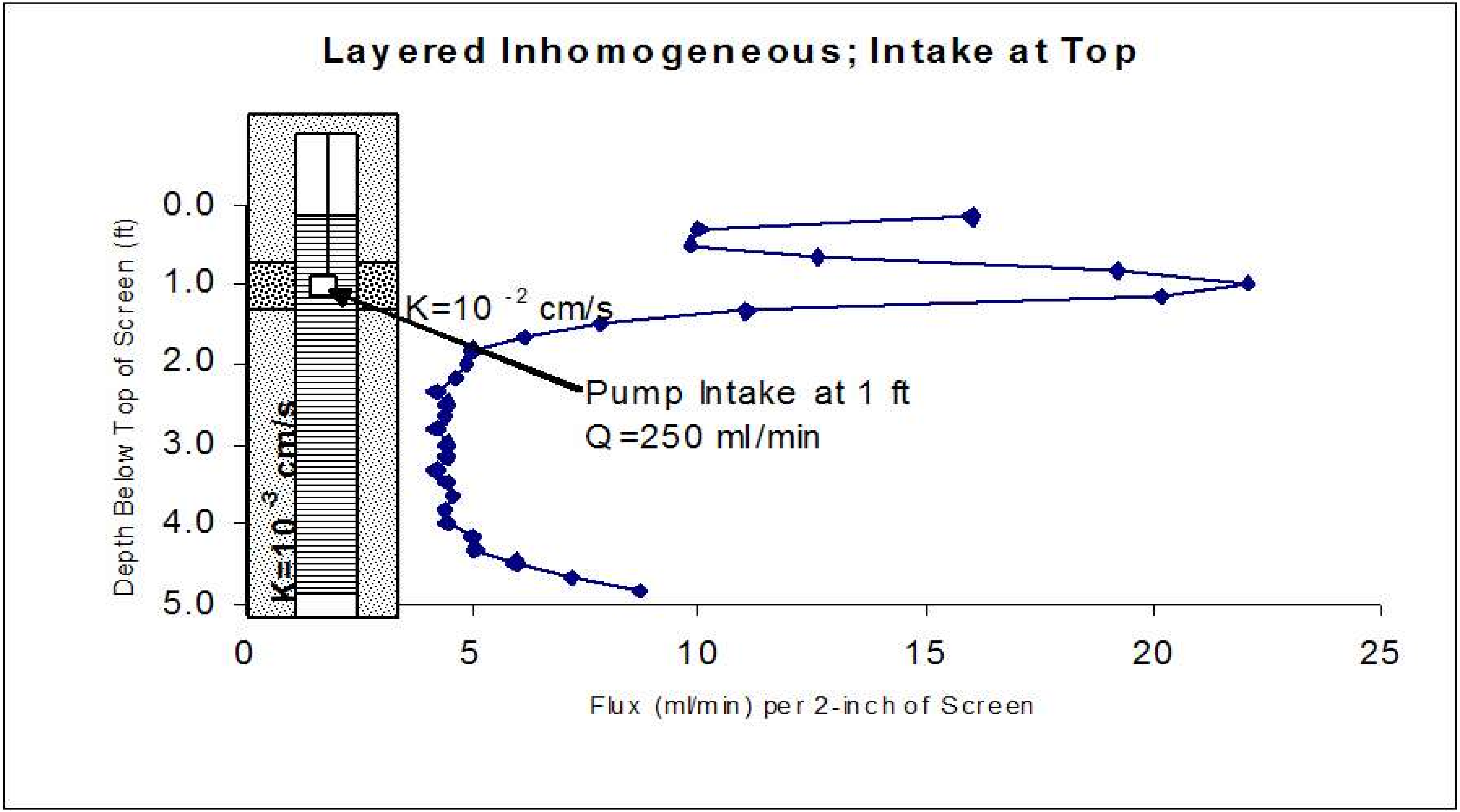
Varljen, et al. 2006

Effect of Pump Placement on Vertical Flux Distribution



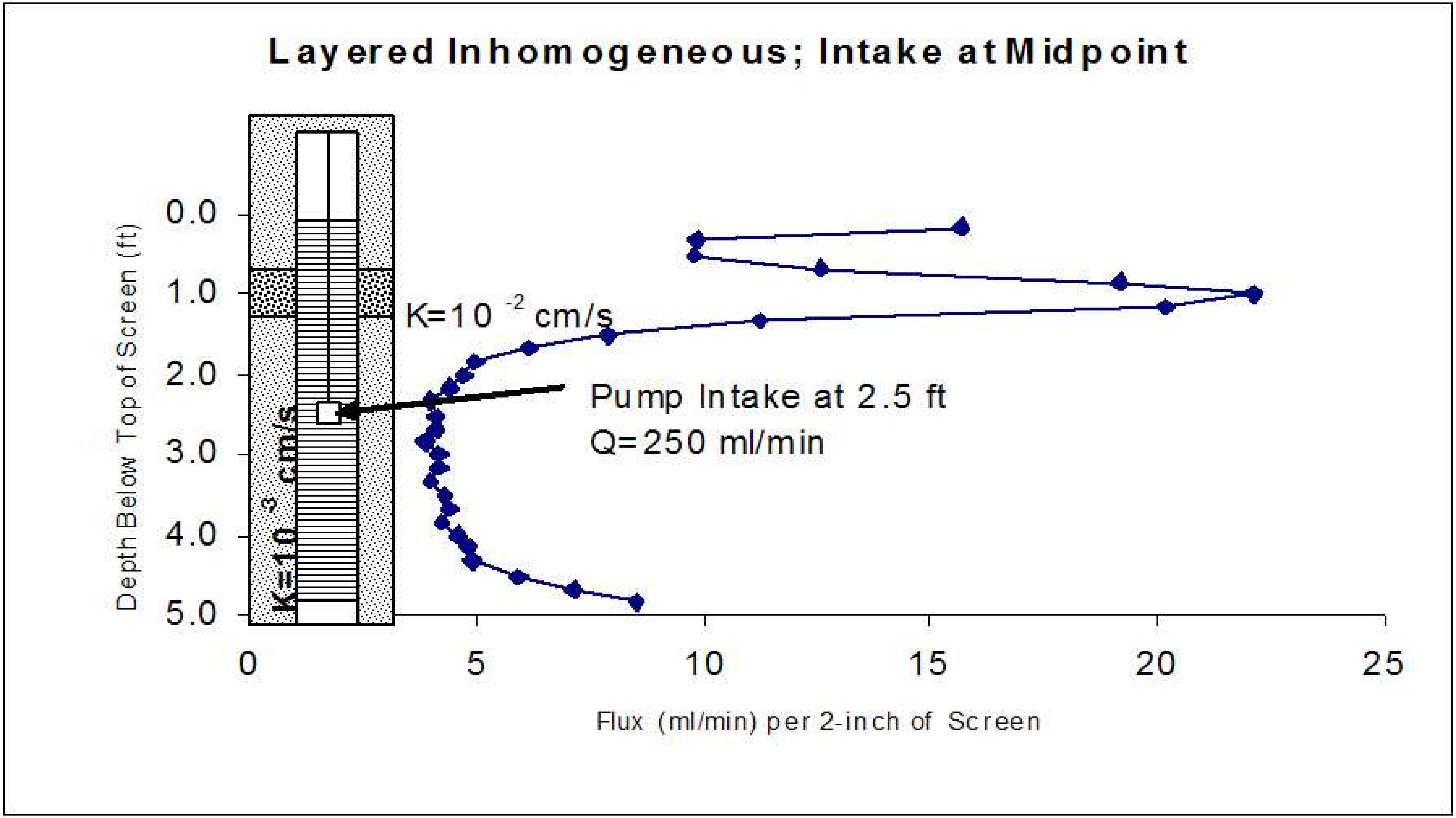
Varljen, et al. 2006

Effect of Heterogeneities on Flux Distribution Pattern



Varljen, et al. 2006

Effect of Heterogeneities on Flux Distribution Pattern



Varljen, et al. 2006

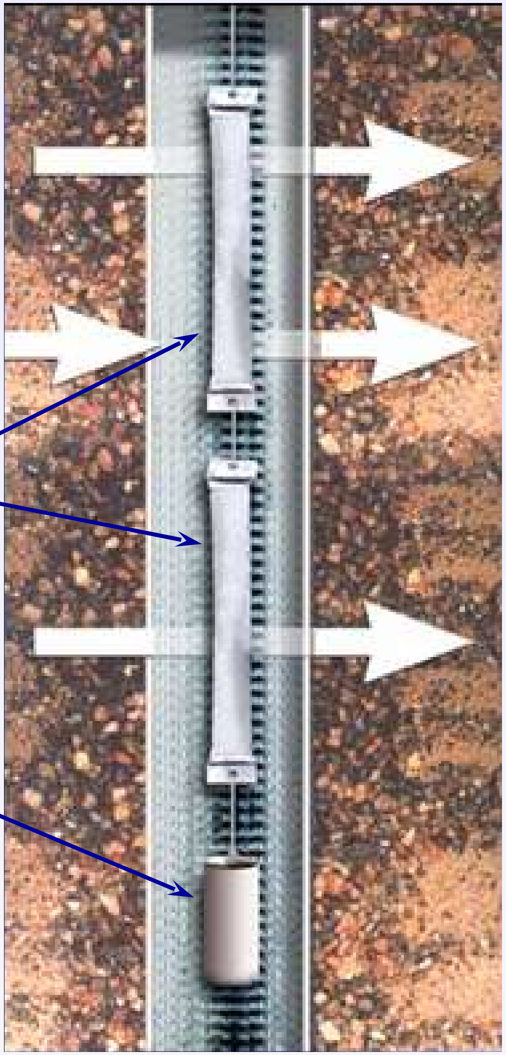
CONCLUSIONS:

- Pump placement has no significant effect on where the water comes from.
- While more water comes from the most permeable zones near the well screen, the flow pattern remains the same regardless of pump position.

Passive and No-Purge Sampling: The next evolutionary step?

- Over the past 10-12 years, research and developers have studied the potential to sample wells without purging.
- The methodology is based on the concept of ambient horizontal flow through the well screen that would maintain an approximation of the formation water chemistry within the well screen zone.
- Samples taken represent the discrete interval within the screen where the samplers are placed or activated, rather than a flow-weighted average of the screen zone.
- Several passive or no-purge samplers can be deployed in a single well in order to identify any contaminant stratification within the water column.

Polyethylene Diffusion Samplers



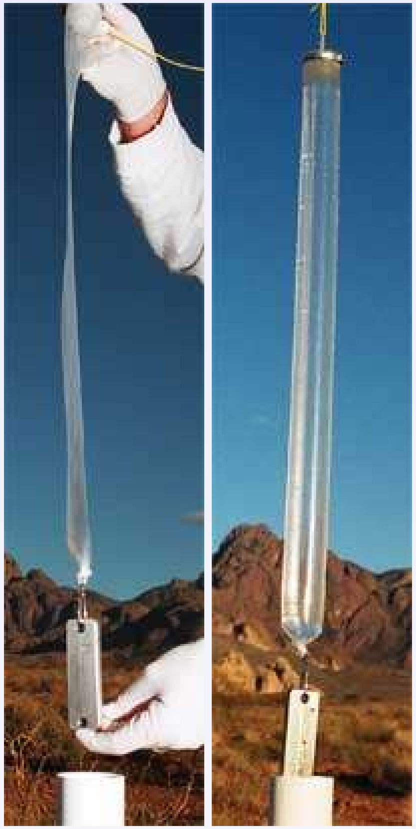
Cross Sectional View

Diffusion Samplers

Weight

Typical PDB sampler is 1-2 feet in length

No-Purge Sampling can be performed with grab samplers



HydraSleeve

Snap Sampler™

Kemmerer Sampler

No-Purge/Passive Sampling Advantages

- Eliminate or greatly reduce purge water volume.
- Samplers are inexpensive to make or buy – low capital cost.
- Easy to deploy and recover samplers, except in very deep wells.
- Some samplers are disposable, so no decontamination is needed between wells.
- Minimal amount of field equipment is required.
- Can provide information on contaminant stratification within the well.
- Samplers are not subject to interference from turbidity.

No-Purge/Passive Sampling Limitations

- Must identify sufficient ambient flow in the screen zone through use of borehole flow meters or other methods. As an alternative, developers suggest trying passive/no-purge methods and comparing results to historical methods, or to traditional purge-and-sample methods if no historical data.
- Target monitoring zone is determined through analysis of multiple samplers or flow meter studies; improper placement can result in significant concentration differences. The cost of these initial studies can often be as much as the cost of traditional dedicated sampling pumps.
- Collecting background water chemistry parameters (pH, DO, etc.) requires a separate sampling step.
- Resampling to verify questionable data requires redeployment and waiting a minimum of days or weeks.

How do low-flow sampling and no-purge/passive sampling compare?

- Studies comparing LFS and no-purge/passive sampling show good correlation in some wells but often result in significant differences for some analytes in others. This may be the effect of ambient vertical flow and mixing or the limitations of some passive sampling devices.
- Cost comparisons showing no-purge/passive savings are typically based on a single sampling point. If significant contaminant stratification exists within a well that would warrant multiple samplers, sampling cost savings are quickly offset by increased analytical costs.
- The biggest difference is the sample itself. LFS represents a flow-weighted average of the well screen, while a no-purge/passive sample may represent either a depth-discrete sample, or may be influenced by ambient vertical flow.

The bigger question is…

What is the well really telling us?

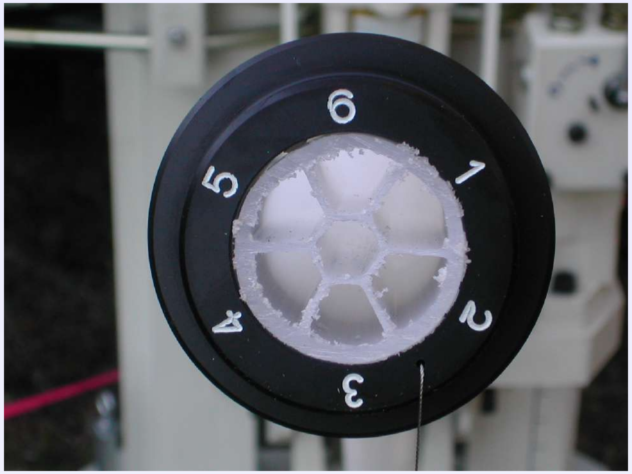

CAUTION
THIS SIGN HAS
SHARP EDGES
DO NOT TOUCH THE EDGES OF THIS SIGN
ALSO, THE BRIDGE IS OUT AHEAD

Monitoring Well Biases

- Results depend on screen position and length relative to contaminant pathways. *What you screen is what you get!*
- Pumped samples are averaged values of the screen zone and beyond, depending on pumping rate. This averaging effect may underestimate maximum concentrations by an order of magnitude.
- Wells often redistribute contaminant mass in the aquifer when vertical gradients are present, making correlation with contaminant distribution within the aquifer a guessing game.
- In effect, there is little point in trying to determine anything from depth-discrete samples taken within the screen. The only solutions for obtaining spatial resolution are discrete, short wells screens or multi-level sampling systems.

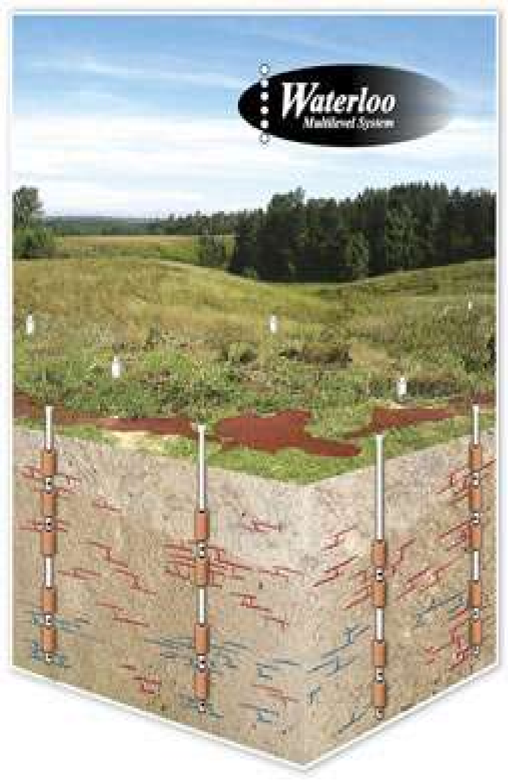
Multi-Level Samplers

FLUTe™ Liner/Sampler



Solinst CMT System

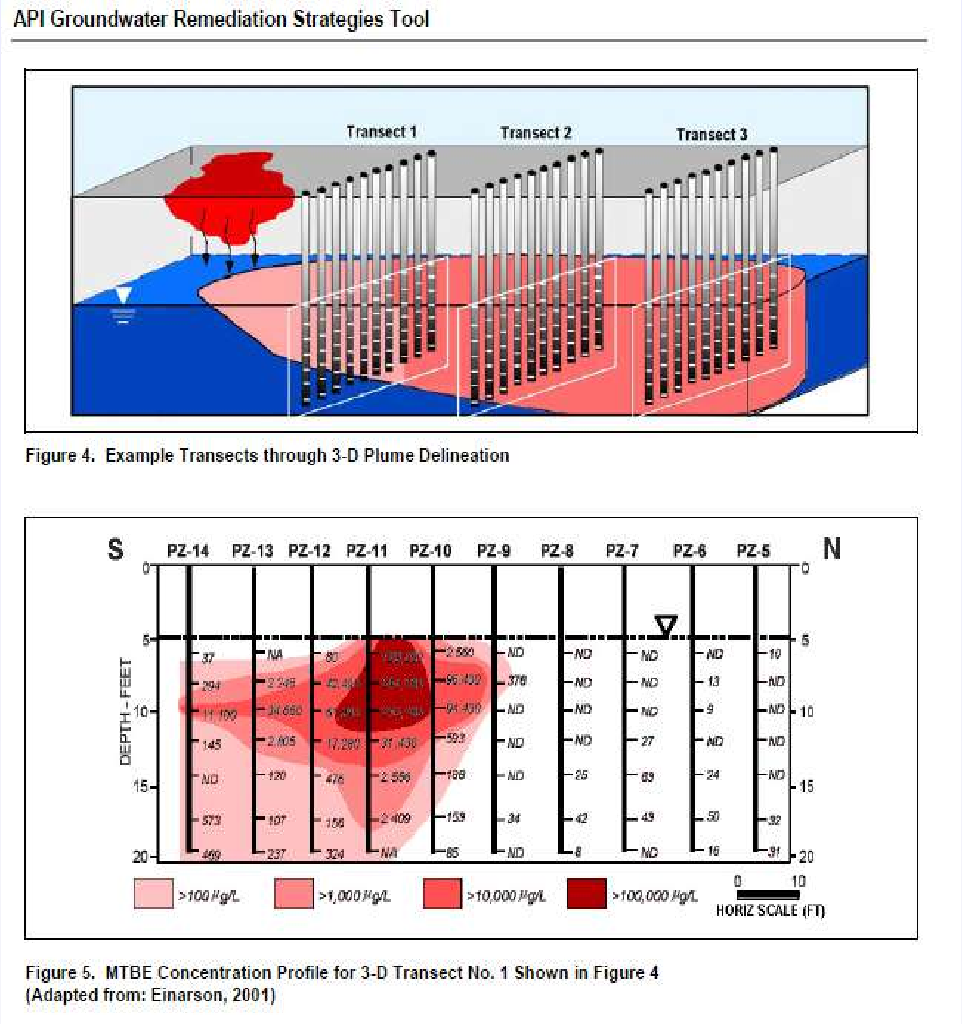
WestBay® System



Waterloo Multi-Level System

Advantages of Multilevel Sampling Systems

- Samples represent a very small slice of the formation relative to the total saturated thickness
- Opportunity for much better spatial resolution than wells, even those with very short screens
- Accurately identify high-concentration zones
- Insensitive to shifts in the plume position
- Provides date to calculate the *rate* at which contaminants are moving in the aquifer (mass discharge)



API Groundwater Remediation Strategies Tool

Figure 4. Example Transects through 3-D Plume Delineation

Figure 5. MTBE Concentration Profile for 3-D Transect No. 1 Shown in Figure 4
(Adapted from: Einarson, 2001)

Summary

- Low-flow sampling provides flow-weighted average concentrations from the entire screen zone, while multi-level sampling systems can provide depth-discrete samples with much greater spatial resolution.
- The issue of well screen length is one of monitoring program objectives and is not a sampling method issue.
- The screen length should relate to the saturated thickness of interest and identifiable flow paths and should not be based on an arbitrary design or guideline.
- The sampling system design and sampling method used should be based on the type of monitoring program (e.g., compliance or detection monitoring, site characterization, remedial performance).
- Sampling methods are like tools in a toolbox – each has an appropriate use based on the task at hand. In many cases, averaged samples from wells are more appropriate and economical than high spatial resolution sampling with multi-level systems.

Thank you!

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STANDARD OPERATING PROCEDURE

Soil Vapor Sampling from Exterior Soil Vapor Probes

Purpose

This standard operating procedure (SOP) presents general guidelines for collecting soil vapor samples from temporarily-, semipermanently-, or permanently-installed exterior soil vapor probes. The number, location, analytical method (including sampling container), and sampling duration of soil vapor samples should be determined on a project-specific basis.

Scope

This is a general description of how to purge and leak test exterior soil vapor probes and then collect soil vapor samples. This SOP describes sampling with evacuated canisters and additional optional sampling methods including Bottle-Vacs, gas sampling bags, and sorbent tubes.

Equipment and Materials

Purge and Helium Leak Test:

- Three-way sampling manifold consisting of Swagelok gas-tight fittings with three valves and one vacuum gauge to attach the probe to the vacuum pump and the sample canister.
- Vacuum pump (battery-powered) with rotometer to control flow to 200 milliliters per minute (mL/min).
- Teflon tubing, 0.25-inch outer diameter.
- Swagelok nut and ferrule set (part #SS-400-NFSET) for purge and sampling train connections.
- Gas sampling bag (such as Tedlar brand) (1-liter or 3-liter) to collect the purged soil vapor so the approximate volume of purged soil vapor can be measured and field screening can be performed on the purged vapor.
- Wrenches and screwdriver, various sizes as needed for connecting fittings. A 9/16-inch wrench fits the 0.25-inch Swagelok fittings.
- Helium enclosure to fit around the flush-mount probe cover for permanent soil vapor probes or over the drill rod for temporary probes.
- Helium - canister of high-purity helium with 0.5-liter per minute flow regulator.
- MGD Dielectric Helium Detector.
- Photoionization detector (PID; MiniRae or MultiRae) to monitor breathing zone volatile organic compound (VOC) concentrations. It is also optional to collect field measurements of total VOCs from the purged soil vapor; may warn the laboratory if high concentrations are detected so they can dilute the sample before analysis.
- LandTec GEM Landfill Gas Meter (optional) to collect field measurements of oxygen, carbon dioxide, and methane.

Soil vapor sampling with evacuated canisters:

- Stainless-steel sample canister(s) certified clean and evacuated (canisters are cleaned, evacuated, and provided by the laboratory.)
- Flow controller(s) set at desired sampling rate. (Flow controllers are cleaned, set, and provided by the laboratory.)
- Analog pressure gauge dedicated to the canister may be permanently attached to either the canister or flow controller. This pressure gauge will be used to monitor the canister pressure during sampling.
- Digital pressure gauge with a -30 to 0 inch mercury (Hg) range, and 0.50 inches Hg accuracy that should be verified annually. This pressure gauge should have a Swagelok 1/4-inch female connection because it will be used to measure the initial and final canister pressure. Digital gauges should not be shared between soil vapor samples and air samples (indoor, outdoor, or crawlspace) to prevent cross-contamination.
- Wrenches and screwdriver, various sizes as needed for connecting fittings. A 9/16-inch wrench fits the 0.25-inch Swagelok fittings, which most canisters and flow controllers have.
- Swagelok nut and ferrule set (part #SS-400-NFSET) to connect tubing to the sampling manifold.
- T-connector (provided by the laboratory) to collect simultaneous duplicate samples.
- Shipping container, suitable for protection of canister(s) during shipping. Typically, strong cardboard boxes are used for canister shipment. The canisters should be shipped to the laboratory in the same shipping container(s) in which they were received.

Alternative soil vapor sampling methods:

- Bottle-Vacs:
  - Bottle-Vac(s) (evacuated, and provided by the laboratory).
  - Flow controller set at desired sampling rate. (Flow controllers are cleaned, set, and provided by the laboratory.)
  - Digital pressure gauge with a -30 to 0 inch Hg range, and 0.50 inches Hg accuracy which should be verified annually. This pressure gauge should have a quick-connect connection because it will be used to measure the initial and final Bottle-Vac pressure. Digital gauges should not be shared between soil vapor samples and air samples (indoor, outdoor, or crawlspace) to prevent cross-contamination.
  - T-connector (provided by the laboratory) for collecting simultaneous duplicate samples.
  - Shipping container, suitable for protection of Bottle-Vac(s) during shipping. The Bottle-Vac(s) should be shipped to the laboratory in the same shipping container(s) in which they were received.
- Gas sampling bag (such as Tedlar brand):
  - Gas sampling bag
  - Lung box
- Sorbent Tubes:
  - Sorbent tube(s) (provided by the laboratory. Include one extra to use for flow calibration purposes.

- SKC flow calibrator 5 to 500 mL/min to measure the exact flow rate while sampling.

Procedures and Guidelines

This SOP describes the general guidelines for purging and leak testing exterior soil vapor probes, then collecting soil vapor samples. Purging, leak testing, and sampling information should be recorded in the field logbook and on the attached "Soil Vapor Sampling Log" form.

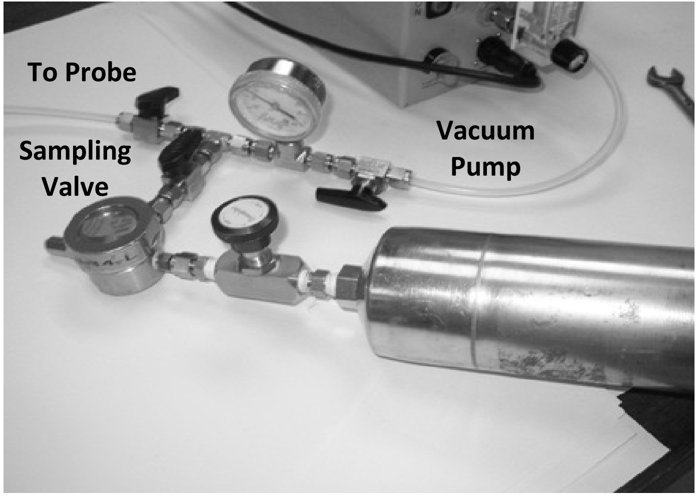
General Guidelines

- Wait at least 48 hours after installation of permanent or semi-permanent soil vapor probes and at least 30 minutes after installation of temporary soil vapor probes with the Geoprobe post-run tubing system before purging, leak testing, and sampling the probes to allow the subsurface to equilibrate. Check local guidance and regulations to confirm these are appropriate equilibration times for the soil vapor probes.
- Soil vapor sampling should not be performed until 48 hours after a significant rain event (defined as greater than 1 inch of rainfall). Check local guidance and regulations to confirm these are appropriate waiting periods for sampling after precipitation.

System Setup:

1. Remove the protective cover (such as a flush-mount cover, or semi-permanent polyvinyl chloride [PVC] cover) on the soil vapor probe (if present).
2. Place the helium enclosure over the soil vapor probe and adjust it so that it will allow a buildup of helium in the enclosure. The enclosure should not be sealed tightly, and there should be an exhaust for the helium so pressure does not build up in the enclosure. Where the ground surface is soft, the helium leak-check enclosure can be pressed down slightly into the ground surface. Where the ground surface is hard (for example, asphalt), use a sealing material (foam tape or modeling clay) and apply a slight downward pressure to achieve a buildup of helium in the leak-check enclosure.
3. Remove the cap from the probe tubing and connect the probe tubing to the sampling manifold.
4. Attach the vacuum pump to the sampling manifold using Teflon tubing and Swagelok nut and ferrule sets.
5. System set up for canister sampling:
    - 5.1. Measure the initial canister pressure with the digital pressure gauge. The initial pressure should be between -28 to -30 inches Hg. If it is less than -26 inches Hg, do not use the canister for sampling. If it is between -28 to -26 inches Hg only use the canister if there are no other spare canisters available. In the field log, record the canister identification (ID), flow controller ID, initial vacuum, desired flow rate, sample location information, and all other information pertinent to the sampling effort.
    - 5.2. Connect the flow controller and analog pressure gauge to the canister. When the flow controller and pressure gauge are attached correctly they will not move separately from the canister (they will not spin around).
    - 5.3. Connect the canister via the flow controller to the sampling manifold.

Figure 1. Sampling Manifold Setup for Canister Sampling



Manifold Vacuum Leak-Check:

The purpose of the manifold leak test is to make sure the connections in the sampling train are air tight. For canister sampling, the connections on the sampling manifold through the flow controller to the valve on the canister will be leak tested (Figure 1). For duplicate samples, the whole assembly with the T-connector should be vacuum leak tested. For alternative sampling methods, the connections on the sampling manifold will be leak tested.

1. Close the valve to the probe, open the valve to the pump. For canister sampling, open the sampling valve to the canister on the manifold; the valve on the canister is closed.
2. Turn the pump on and wait for the gauge on the manifold to reach approximately -10 inches Hg. Close the valve to the pump and turn the pump off. The sampling train is now a closed system.
3. Wait approximately 30 seconds to ensure that the vacuum is maintained and there are no leaks (as shown by the stability of the pressure gauge).
4. If there is a visible loss of vacuum, tighten the connections and redo the leak test until it passes.

System Purge and Helium Leak Check:

A purge of the soil vapor probe and sampling manifold system is required before taking each sample. The helium leak-check procedure is also performed during this step. This helium leak check will verify the integrity of the probe seal, sampling adapter (or post-run tubing [PRT] adapter if using the Geoprobe PRT system) seal, as well as the probe and ground interface; this is accomplished by completing the following steps:

1. Start the flow of helium under the leak-check enclosure. Let the helium fill the enclosure for a couple of minutes.
2. Turn the helium leak detector on while in outdoor air and ensure that the detector exposed to helium because it does a zero calibration every time it is turned on.
3. Verify that the helium concentration inside the leak-check enclosure is more than 10 percent by placing the probe of the helium detector into the enclosure.
4. Purging is carried out by pulling soil vapor through the system at a rate of 200 mL/min for a period sufficient to achieve a purge volume that equals 3 to 5 dead volumes (internal volume) of the in-ground annular space, sample line, and sampling manifold system.

    4.1. When calculating the dead volume, be sure to consider the inside diameter and length of the Teflon sample tubing, as well as the probe outside diameter and retraction distance for the annular space of temporary probes.

    4.2. For permanent probes, calculate the volume of the annular space using a nominal 30 percent porosity for the sand pack.

    4.3. The gas sampling bag should be attached to the vacuum pump exhaust to collect the purged soil vapor so the approximate volume of purged soil vapor can be measured and field screening can be performed on the purged vapor.

5. Open the sample valve and the purge valve and start the vacuum pump. Verify that the flow rate is still 200 mL/min.

6. If there is shallow groundwater in the area, carefully watch the tubing as the pump is turned on. If water is observed in the sample tubing, shut the pump off immediately. Soil vapor collection will not be feasible if the probe is in contact with water.

7. Monitor the purging vacuum on the sampling manifold pressure gauge. The purging vacuum should not exceed -7 inches Hg; if it does, turn the pump off, close the valve to the pump, and wait to see if there is recovery. If there is no noticeable change in vacuum after several minutes, then there is an insufficient amount of soil vapor to collect a sample and the vacuum is too great to collect a soil vapor sample. Several factors can cause this situation, including the following (consult with the project manager and take corrective action):

    7.1. The soil formation is too “tight” (that is, high clay or moisture content). Try using a lower flow rate (temporary or permanent probe). Try a different depth or location (temporary probe).

    7.2. The probe screen, or annular space for temporary probes, may be in water even if the water has not yet come up in the tubing. Soil vapor sampling is not feasible if the probe is in contact with water. Try a different depth or location (temporary probe). Try sampling the probe again in dryer conditions (permanent probe).

    7.3. With a temporary probe system (such as the Geoprobe PRT system), the expendable tip may not have released when the drive rod was retracted. Try retracting the probe a little further, or use the point run popper to poke the tip loose.

    7.4. If purging cannot be completed without creating a vacuum exceeding -7 inches Hg, then the probe cannot be sampled.

8. Measure the helium concentration in the enclosure several times during purging to calculate an average concentration in the enclosure during the purge duration.

9. At the end of the calculated purge time and after the system is verified to be leak free, turn off the pump, close the valve to the pump, and close the valve to the probe. Close the valve on the gas sampling bag and remove the bag from the pump.

10. Measure the helium concentration in the purged soil vapor in the gas sampling bag. The helium concentration in the purged soil vapor must be less than 5 percent of what it was in the helium enclosure during purging to pass the leak test.

    10.1. For example, if the helium concentration in the purged soil vapor is 2,300 parts per million (ppm), that is 0.23 percent, and the average helium concentration in the enclosure was 35 percent, then the percentage leak is 0.66 percent [0.23/35*100 = 0.66 percent]).

    10.2. If the probe fails the leak check, then corrective action is required; this includes first checking the fittings and connections and trying another purge and leak check. It may also be necessary to remove the soil vapor probe, if it is temporary, and re-install it in a nearby location.

10.3. Helium leak detectors may be sensitive to high concentrations of methane or other atmospheric gasses. If high methane concentrations are expected to be present in the soil vapor, then caution should be used with this technique, as false positive readings may be encountered during leak testing. Use a Landtec GEM Landfill Gas Meter to determine if methane is present in the soil vapor.

11. Optional - Field readings of total VOCs with a PID, and/or oxygen, carbon dioxide, and methane with a LandTec GEM Landfill Gas meter may be performed on the purged soil vapor.
12. Record the purge and leak-check information on the Soil Vapor Sampling Log (attached).

Canister Sampling:

1. For extended duration samples (for example, 8- or 24-hour)
    1.1. Remove the sampling manifold by detaching the canister from the manifold, then detaching the probe tubing from the manifold and quickly attaching it to the canister via the flow controller.
    1.2. Attach the sign (identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information) to the canister.
    1.3. Make sure the canister will be secure at the sampling location; place traffic cones around the probe and canister if necessary.
2. To begin sampling, open the canister valve one full turn and record the sample start time. (For grab samples, the canister will still be attached to the sampling manifold.)
3. Monitor the canister pressure on the analog gauge (if present) several times during the sample period, to ensure the canister is filling at the desired rate and the final canister pressure does not fall to 0 inch Hg.
4. At the end of the sample period, close the canister valve and record the sample end time. Detach the canister from the manifold or probe tubing.
5. Measure the final canister pressure with the digital pressure gauge. The final pressure should be between -10 to -2 inches Hg. If it is 0 inch Hg, do not submit the sample for analysis. If it is between -2 and 0 inch Hg re-deploy the sample if possible; if not submit it to the laboratory for analysis but make sure it is received with some residual negative pressure.
6. Replace the protective cap on the canister.
7. Duplicate samples should be collected simultaneously with a dedicated T-connector.
    7.1. Grab sample duplicates should be collected by attaching the T-connector to each canister and then connecting one flow controller to the top of the T-connector. (If there was a flow controller on each canister, then the sampling flow rate would exceed the maximum allowable flow rate of 200 mL/min.) The duplicate sample will take twice as long to collect.
    7.2. Extended duration samples should be collected by attaching a flow controller to each canister and then connecting the T-connector to each flow controller. (If only one flow controller was used, then the sampling duration would be twice as long.)

Bottle-Vac Sampling:

1. Measure the initial pressure with the digital pressure gauge. The initial pressure should be between -28 to -30 inches Hg. If it is less than -26 inches Hg, do not use the Bottle-Vac for sampling. If it is between -28 to -26 inches Hg, only use the Bottle-Vac if there are no other spares available. In the

field log record the Bottle-Vac ID, flow controller ID, initial vacuum, desired flow rate, sample location information, and all other information pertinent to the sampling effort.

2. For extended duration samples (for example, 8- or 24-hours):
    2.1. Remove the sampling manifold and attach the probe tubing to the flow controller.
    2.2. Attach the sign (identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information) to the canister.
    2.3. Make sure the canister will be secure at the sampling location; place traffic cones around the probe and canister if necessary.
3. For grab samples – Attach the flow controller to the sampling valve on the sampling manifold.
4. To begin sampling, attach the Bottle-Vac to the to the flow controller via the quick-connect and record the sample start time.
5. At the end of the sample period, detach the Bottle-Vac from the flow controller and record the sample end time. Detach the flow controller from the probe tubing or sampling manifold.
6. Measure the final Bottle-Vac pressure with the digital pressure gauge. The final pressure should be between -10 to -2 inches Hg. If it is 0 inch Hg, do not submit the sample for analysis. If it is between -2 and 0 inch Hg, re-deploy the sample if possible; if not submit it to the laboratory for analysis but make sure it is received with some residual negative pressure.
7. Duplicate samples should be collected simultaneously with a dedicated T-connector as described in the Canister Sampling section of this SOP.

Tedlar Bag Sampling:

1. Detach the vacuum pump from the sampling manifold and attach it to the lung box, then attach the probe tubing via the sampling manifold to the lung box influent.
2. Place a Tedlar bag in the lung box using dedicated Teflon and flexible silicon tubing.
3. To begin sampling, turn the pump on and record the sample start time.
4. Turn the pump off when the Tedlar bag is full and record the sample end time. The Tedlar bag should only be filled 50 percent if it will be shipped via plane.
5. Detach the probe tubing and vacuum pump from the lung box.

Sorbent Tube Sampling:

1. Disconnect the pump tubing from the manifold.
2. Attach a spare sorbent tube provided by the lab to the vacuum pump tubing using a 1/4-inch Swagelok union or flex tubing. Do not use a tube that is intended for sampling. Be sure to attach the sorbent tube so that the flow direction is correct.
3. Attach the SKC flow calibrator to the vacuum pump exhaust.
4. Turn on the vacuum pump and adjust the flow to achieve the desired flow rate of 200 mL/min using the flow calibrator.
5. Remove the spare sorbent tube from the pump tubing.
6. Remove the end caps from the sorbent tube to be used for sampling and attach it to the vacuum pump tubing using a 1/4-inch Swagelok union or flex tubing. Be sure to attach the sorbent tube so that the flow direction is correct. Record the sample tube ID on the field form.

7. Attach the other end of the sorbent tube to the sample manifold where the pump tubing used to be attached using either Swagelok fittings or flex tubing.
8. Make sure both the probe valve and the vacuum pump valve are open and the sampling valve is closed.
9. Start the pump and record the start time. Using flow calibrator, record initial flow rate.
10. If the flow rate starts to drop, it may indicate that the sorbent tube is becoming plugged with water. Stop the vacuum pump and record the end time.
11. After the required amount of time, record the final flow rate from the flow calibrator. Turn off the pump and remove the sorbent tube. Record the end time.
12. Replace the end caps on the sorbent tube. Replace the sorbent tube into the container it was received in.

After Sample Collection is Completed:

1. Disassemble the sampling system and replace the cap on the probe tubing.
2. For permanent probes - replace the protective cover (such as a flush-mount cover, or semi-permanent PVC cover) on the soil vapor probe (if present).
3. Fill out all appropriate documentation (chain of custody, sample tags) and return samples and equipment to the laboratory in the same shipping container in which they were received. Do not place sticky labels or tape on surface of the canister.
4. Canisters, Bottle-Vacs, and Tedlar bags should not be cooled during shipment. DO NOT put ice in the shipping container. Sorbent tubes may require ice for shipping.

Quality Control and Quality Assurance

- Canisters supplied by the laboratory must follow the performance criteria and quality assurance prescribed in U.S. Environmental Protection Agency (EPA) Method TO-14/15 for canister cleaning, certification of cleanliness, and leak checking.
- Flow controllers supplied by the laboratory must follow the performance criteria and quality assurance prescribed in EPA Method TO-14/15 for flow controller cleaning and adjustment.
- Field duplicates and trip blanks (sorbent tube methods only) may be required. Check the work plan for frequency.

Attachments

- Soil Vapor Sampling Log
- Sign identifying the canisters or Bottle-Vacs as an air sample, saying “Do Not Disturb” and providing contact information.

References

U.S. Environmental Protection Agency (EPA). Office of Solid Waste and Emergency Response. 2015. *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. June.

Soil Vapor Sampling Log

Project: Sampler:

Sample Location Information

Property ID/Address:

Condition of ground in the surrounding area:

Location ID: Sample ID:

Sample Location Description:

Soil Vapor Probe Leak Checking and Sampling Log

Manifold Leak Check

Manifold leak check (procedure: ensure manifold holds pressure at -10 "Hg for 30 seconds). If using a pelican-case pump, open the lid during leak check to ensure all interior pieces are in-tact. *Pass* *Fail*

Describe corrective measures taken to pass the manifold leak test:

Soil Vapor Probe Helium Leak Check and Purge Results

Purge rate (mL/Min): Helium Conc. in the Purged Vapor:

Start and End Times: Calculated leak percentage:

Purge Vacuum ("Hg): Probe Leak Check Result*: *Pass* *Fail*

Avg. Helium Conc. in the Enclosure:

Total Volume Purged (L):

*The soil vapor probe passes the leak test if the helium concentration in the purged soil vapor is less than 5% of what it was in the helium enclosure during purging. For example, if the helium concentration in the purged soil vapor is 2,300 ppm that is 0.23%, and the average helium concentration in the enclosure was 35%, then the percentage leak is 0.66% [0.23/35*100 = 0.66%]). Do NOT collect a soil vapor sample if the leak check fails.

Field Analysis (required readings are determined on a project-specific basis. Fill in all that are necessary):

MiniRAE or MultiRAE Photoionization Detector					LandTec GEM Landfill Gas Meter	
Total VOCs (ppm):		O_2 (%):			O2 (%):	
H_2S (ppm):		LEL (%):			CO2 (%):	
CO (ppm):					CH4 (%):	

Sampling Information

Evacuated Canister or Bottle-Vac

Canister Size (L): Initial Pressure (" Hg):

Canister ID: Start Date and Time:

Flow Controller ID: End Date and Time:

Sampling Rate (mL/min, hours): Final Pressure (" Hg):

Sampling Vacuum ("Hg):

Tedlar Bag

Tedlar Bag size (L): Sampling Rate (mL/min):

Sampling Date: Sampling Start and End Times:

Sorbent Tube

Sorbent Tube type and size: Sampling Date:

Sorbent Tube ID: Sampling Start and End Times:

Initial Flow Rate (mL/min): Final Flow Rate (mL/min):

Calculated Sampling Volume:

Weather Conditions and Additional Notes

Weather Conditions During Sampling:

Additional Notes:

Air Testing in Progress

Please Do Not Disturb

Contact for Further Information:

Name: ______________________________

Organization:______________________

Phone:______________________________

STANDARD OPERATING PROCEDURE

Indoor, Outdoor, and Crawlspace Air Sampling Using Canisters

Purpose

This standard operating procedure (SOP) presents general guidelines for collecting indoor, outdoor, and crawlspace air samples using evacuated canisters. The type, number, location, and sample duration of indoor, outdoor, and/or crawlspace air samples should be determined on a project-specific basis.

A building survey should be performed before air sampling to obtain building characteristic information and identify potential confounding indoor sources of volatile organic compounds.

Scope

This is a general description of how to collect indoor air, outdoor air, and crawlspace air samples using evacuated canisters.

Equipment and Materials

- Stainless-steel sampling canister(s), certified clean and evacuated (canisters are cleaned, evacuated, and provided by the laboratory). Note that separate canisters of the same size may be designated by the laboratory for use in collecting subslab soil vapor samples versus indoor air, outdoor air, and crawlspace air samples and may been certified in different manners. It is important to make sure that canisters are used for their designated sample type.
- Flow controller(s), certified clean, and set at desired sampling rate (flow controllers are cleaned, set, and provided by the laboratory).
- Analog pressure gauge dedicated to the canister may be permanently attached to either the canister or flow controller. This pressure gauge will be used to monitor the canister pressure during sampling.
- Digital pressure gauge with a -30 to 0 inch mercury (Hg) range, and 0.50 inch Hg accuracy, which should be verified annually. This pressure gauge should have a Swagelok 1/4-inch female connection because it will be used to measure the initial and final canister pressure. Digital gauges should not be shared between air samples (indoor, outdoor, or crawlspace) and soil vapor samples to prevent cross-contamination.
- Wrenches and screwdriver, various sizes as needed for connecting fittings. A 9/16-inch wrench fits the 0.25-inch Swagelok fittings, which most canisters and flow controllers have.
- For crawlspace air sampling:
  - Sampling probe, new Teflon tubing, fitted with compression fittings (for crawlspace air samples).
  - Swagelok nut and ferrule set (part #SS-400-NFSET) to connect tubing to the canister.
  - Rod for placing the crawlspace air sampling tubing or the canister at the desired location in the crawlspace. These can be metal, plastic, or wooden rods.

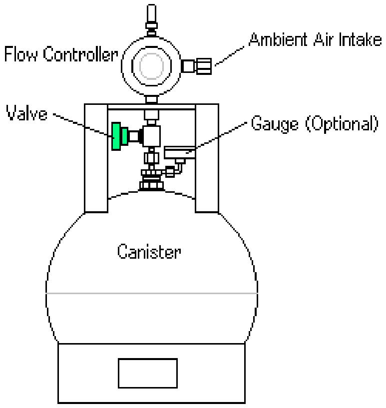
- T-connector (provided by the laboratory) for collecting simultaneous duplicate samples. This is optional for indoor and outdoor air samples, but may be necessary for crawlspace air samples if the canisters are not being placed into the crawlspace.
- For outdoor air samples:
  - Sampling cane or aluminum foil tent to prevent water from entering canister during sampling.
  - Bike lock or chain and lock to secure the canister and prevent theft.
- Shipping container, suitable for protection of canister(s) during shipping. Typically, strong cardboard boxes are used for canister shipment. The canisters should be shipped to the laboratory in the same shipping container(s) in which they were received.
- Recommended – field instrument such as a MultiRAE photoionization detector (PID) to measure total volatile organic compound (VOC) and carbon monoxide concentrations in the breathing zone for health and safety monitoring
- Optional – signs identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information. The sign should be laminated and attached to the canister with a zip tie. (These signs are for extended duration samples only because grab samples will not be left unattended.)

Procedures and Guidelines

This SOP describes the general guidelines for collecting indoor, outdoor, and crawl space air samples using evacuated canisters. Sampling information should be recorded in the field logbook and on the attached form “Indoor, Outdoor, and Crawlspace Air Sampling Log—Canister Method”.

- Measure the initial canister pressure with the digital pressure gauge. The initial pressure should be between -28 to -30 inches Hg. If it is less than -26 inches Hg, do not use the canister for sampling. If it is between -28 to -26 inches Hg, then only use the canister if there are no other spare canisters available. In the field log, record the canister identification (ID), flow controller ID, initial vacuum, desired flow rate, sample location information, and all other information pertinent to the sampling effort.
- Connect the flow controller and analog pressure gauge to the canister (**Figure 1**). When the flow controller and pressure gauge are attached correctly, they will not move separately from the canister (they will not spin around).

Figure 1. Assembled Canister Sampler for Integrated Sample Collection



- For outdoor samples, be sure that the inlet to the flow controller is protected from precipitation. Either place the canister and flow controller under a shelter/enclosure, use a sampling cane provided by the laboratory, or use a clean piece of aluminum foil to build a tent over the flow controller inlet. Secure the canister to an immovable structure with the bike lock or chain and lock to prevent theft.
- For sampling crawlspace air through Teflon tubing, adjust the length of the sample tubing to be able to reach the desired sampling location, attach it to the rod with tape or zip ties, and place the sampling probe into the crawlspace using the rod. Make sure the sample tubing influent is several inches above the ground level. Now connect the sample tubing to the inlet of the flow controller.
- For sampling crawlspace air by placing the canister in the crawlspace, use a rod to position the canister in the correct location.
- For indoor air samples, place the canister in the desired sampling location. Indoor air samples are typically collected at breathing zone height (3 to 5 feet above the floor).
- Attach the sign (identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information) to the canister.
- To begin sampling, open the canister valve one full turn and record the sample start time.
- Monitor the canister pressure several times during the sample period to ensure the canister is filling at the desired rate and the final canister pressure does not fall to 0 inch Hg.
- At the end of the sample period, close the canister valve and record the sample end time.
- Measure the final canister pressure with the digital pressure gauge. The final pressure should be between -10 to -2 inches Hg. If it is 0 inch Hg, do not submit the sample for analysis. If it is between -2 and 0 inch Hg, redeploy the sample if possible; if not, submit it to the laboratory for analysis but make sure it is received with some residual negative pressure.
- Replace the protective cap on the canister.
- Fill out the appropriate documentation (chain of custody, sample tags) and return canisters and equipment to the laboratory in the same shipping container in which they were received.
- The samples should not be cooled during shipment. DO NOT put ice in the shipping container.

- Do not place sticky labels or tape on any surface of the canister.

Quality Control and Quality Assurance

- Canisters supplied by the laboratory must follow the performance criteria and quality assurance prescribed in U.S. Environmental Protection Agency (EPA) Method TO-14/15 for canister cleaning, certification of cleanliness, and leak checking.
- Flow controllers supplied by the laboratory must follow the performance criteria and quality assurance prescribed in EPA Method TO-14/15 for flow controller cleaning and adjustment.

Attachments

- Indoor, Outdoor, and Crawlspace Air Sampling Log—Canister Method
- Sign identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information.

References

U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response. 2015. *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air.* June.

Indoor, Outdoor, Crawlspace Air Sampling Log - Canister Method

Project: Multistate Trust: Springfield Former Tronox Facility--Greene County Highway Dept

Building(s): ______

is now **JACOBS**

Field Sample ID	Location Description	Canister ID	Flow Controller ID	Pressure Gauge ID	Start Date	Start Time	Initial Pressure ("Hg)	Check (6/20 hr)		End Date	End Time	Final Pressure ("Hg)
								Time	Pressure ("Hg)			

Weather Conditions and Notes

General weather conditions: ______

Temperature Range (indoor and outdoor): ______

Was there significant precipitation within 12 hours prior to (or during) the sampling event? ______

Other Notes: ______

Air Testing in Progress

Please Do Not Disturb

Contact for Further Information:

Name: ______________________________

Organization:______________________

Phone:______________________________

STANDARD OPERATING PROCEDURE

Subslab Soil Vapor Sampling from Vapor Pins

Purpose

This standard operating procedure (SOP) presents general guidelines for collecting subslab soil vapor samples from Cox-Colvin & Associates, Inc. (Cox-Colvin), Vapor Pins; methods for purging and leak-checking the Vapor Pins are also included in this SOP. The number, location, analytical method (including sampling container), and sampling duration of subslab soil vapor samples should be determined on a project-specific basis. A building survey is typically performed before sampling to obtain building characteristic information.

Scope

This is a general description of how to purge and leak test Vapor Pins and then collect subslab soil vapor samples. This SOP describes sampling with evacuated canisters and additional optional sampling methods including Bottle-Vacs, Tedlar bags, and sorbent tubes.

Equipment and Materials

Purge and water dam leak-check:

- Vacuum pump with rotometer to control flow to 200 milliliters per minute (mL/min)
- Water
- Vapor Pin water dam
- Volatile organic compound (VOC)-free modeling clay (like Play-Doh)
- Paper towels
- Turkey baster or large plastic syringe (for removing water from the water dam)
- Three-way sampling manifold consisting of Swagelok gas-tight fittings with three valves and one vacuum gauge to attach the probe to the vacuum pump and the sample canister
- Teflon tubing, 0.25-inch outer diameter
- Flexible silicon tubing (3/16-inch inner diameter to connect Teflon tubing from Vapor Pin)
- 1-liter Tedlar bag to collect the purged soil vapor so: (1) it is not discharged into the building; (2) the approximate volume of purged soil vapor can be measured; and (3) field screening can be performed on the purged soil vapor
- Recommended – field instrument such as a MultiRAE photoionization detector (PID) to measure total volatile organic compound (VOC) and carbon monoxide concentrations in the breathing zone for health and safety monitoring. It is also optional to collect field measurements of total VOCs from the purged soil vapor; may warn the laboratory if high concentrations are detected so they can dilute the sample before analysis.
- Optional – LandTec GEM Landfill Gas Meter to collect field measurements from the purged soil vapor of oxygen, carbon dioxide, and methane

Subslab soil vapor sampling with evacuated canisters:

- Stainless-steel sample canister(s) certified clean and evacuated (canisters are cleaned, evacuated, and provided by the laboratory.) Note that separate canisters of the same size may be designated by the laboratory for use in collecting subslab soil vapor samples versus indoor air, outdoor air, and crawlspace air samples and may been certified in different manners. It is important to make sure that canisters are used for their designated sample type.
- Flow controller(s) set at desired sampling rate. (Flow controllers are cleaned, set, and provided by the laboratory.)
- Analog pressure gauge dedicated to the canister may be permanently attached to either the canister or flow controller. This pressure gauge will be used to monitor the canister pressure during sampling.
- Digital pressure gauge with a -30 to 0 inch mercury (Hg) range, and 0.50 inch Hg accuracy, which should be verified annually. This pressure gauge should have a Swagelok 1/4-inch female connection because it will be used to measure the initial and final canister pressure. Digital gauges should not be shared between soil vapor samples and air samples (indoor, outdoor, or crawlspace) to prevent cross-contamination.
- Wrenches and screwdriver, various sizes as needed for connecting fittings. A 9/16-inch wrench fits the 0.25-inch Swagelok fittings, which most canisters and flow controllers have.
- Swagelok nut and ferrule set (part #SS-400-NFSET) to connect tubing to the sampling manifold
- T-connector (provided by the laboratory) for collecting simultaneous duplicate samples.
- Shipping container, suitable for protection of canister(s) during shipping. Typically, strong cardboard boxes are used for canister shipment. The canisters should be shipped to the laboratory in the same shipping container(s) in which they were received.
- Optional – signs identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information. The sign can be laminated and attached to the canister with a zip tie. (These signs are for extended duration samples only because grab samples will not be left unattended.)

Alternative subslab soil vapor sampling methods:

- Bottle-Vacs:
  - Bottle-Vac(s) (evacuated, and provided by the laboratory.)
  - Flow controller set at desired sampling rate. (Flow controllers are cleaned, set, and provided by the laboratory.)
  - Digital pressure gauge with a -30 to 0 inch Hg range, and 0.50 inch Hg accuracy, which should be verified annually. This pressure gauge should have a quick-connect connection because it will be used to measure the initial and final Bottle-Vac pressure. Digital gauges should not be shared between soil vapor samples and air samples (indoor, outdoor, or crawlspace) to prevent cross-contamination.
  - T-connector (provided by the laboratory) for collecting simultaneous duplicate samples.
  - Shipping container, suitable for protection of Bottle-Vac(s) during shipping. The Bottle-Vac(s) should be shipped to the laboratory in the same shipping container(s) in which they were received.
  - Optional – signs identifying the Bottle-Vac(s) as an air sample, saying “Do Not Disturb” and providing contact information. The sign can be laminated and attached to the Bottle-Vac(s)

with a zip tie. (These signs are for extended duration samples only because grab samples will not be left unattended.)

- Tedlar Bags:
  - Tedlar Bags
  - Lung box
- Sorbent Tubes:
  - Sorbent tube(s) (provided by the laboratory. Include one extra to use for flow calibration purposes.
  - SKC flow calibrator 5 to 500 mL/min to measure the exact flow rate while sampling

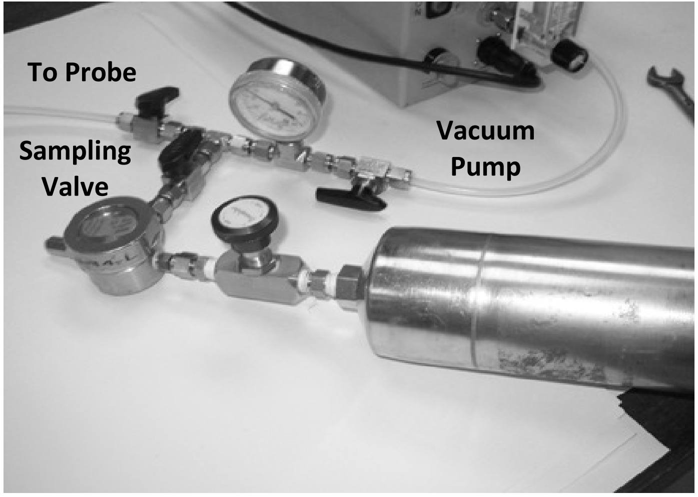
Procedures and Guidelines

This SOP describes the general guidelines for purging and water dam leak testing Vapor Pins, then collecting subslab soil vapor samples using evacuated canisters. Purging, leak testing, and sampling information should be recorded in the field logbook and on the attached form “Subslab Soil Vapor Sampling Log”.

System Setup:

1. Wait at least 2 hours after probe installation is complete before collecting subslab soil vapor samples to allow the subsurface to equilibrate.
2. Remove the secure cover and the white cap on the Vapor Pin.
3. Attach a new piece of flex tubing, approximately 1 inch long, to the barbed fitting at the top of the Vapor Pin. Then attach 0.25-inch Teflon tubing to the flex tubing.
4. Place the water dam over the subslab probe by threading the Teflon tubing through the hole of the water dam. Press the water dam down so it seals on the concrete slab using VOC-free modeling clay. Fill with water. The water level should be above the connection between the flex tubing and the Teflon tubing.
5. Attach the other end of the Teflon tubing to the sampling manifold using a Swagelok nut and ferrule set.
6. Attach the vacuum pump to the sampling manifold using Teflon tubing and Swagelok nut and ferrule sets.
7. System set up for canister sampling:
   - 7.1. Measure the initial canister pressure with the digital pressure gauge. The initial pressure should be between -28 to -30 inches Hg. If it is less than -26 inches Hg do not use the canister for sampling. If it is between -28 to -26 inches Hg only use the canister if there are no other spare canisters available. In the field log record the canister identification (ID), flow controller ID, initial vacuum, desired flow rate, sample location information, and all other information pertinent to the sampling effort.
   - 7.2. Connect the flow controller and analog pressure gauge to the canister. When the flow controller and pressure gauge are attached correctly they will not move separately from the canister (they will not spin around).
   - 7.3. Connect the canister via the flow controller to the sampling manifold.

Figure 1. Sampling Manifold Setup for Canister Sampling



Manifold Vacuum Leak Check:

1. The purpose of the manifold leak test is to make sure the connections in the sampling train are air tight.
2. For canister sampling, the connections on the sampling manifold through the flow controller to the valve on the canister will be leak tested (Figure 1); for duplicate samples the whole assembly with the T-connector should be vacuum leak tested. For alternative sampling methods, the connections on the sampling manifold will be leak tested.
3. Close the valve to the probe, open the valve to the pump. For canister sampling open the sampling valve to the canister on the manifold; the valve on the canister is closed.
4. Turn the pump on and wait for the gauge on the manifold to approximately -10 inches Hg. Close the valve to the pump and turn the pump off. The sampling train is now a closed system.
5. Wait approximately 30 seconds to ensure that the vacuum is maintained and there are no leaks (as shown by the stability of the pressure gauge).
6. If there is a visible loss of vacuum, tighten the connections and redo the leak test until it passes.

Purge and Water Dam Leak-Check

8. Purging and leak testing the soil vapor probe is required before sampling every time. Purging removes ambient air from the sampling train and stagnant soil vapor around the probe.
9. Open the valves to the pump and probe, and attach the Tedlar bag to the pump effluent. The sampling valve should be closed.
10. Turn the pump on with the flowrate at 200 mL/min and purge for approximately 5 minutes to fill the 1-liter Tedlar bag.
11. Monitor the purging vacuum on the sampling manifold pressure gauge. The purging vacuum should not exceed -7 inches Hg; if it does, turn the pump off, close the valve to the pump, and wait to see if there is recovery.
    - 11.1. The probe may be clogged or there may be water or tight soils present beneath the slab that do not allow for soil vapor sampling.
    - 11.2. Try unclogging the probe with a thin metal rod, or remove the probe and check for blockages.

    11.3. If purging cannot be completed without creating a vacuum exceeding -7 inches Hg, then the probe cannot be sampled.

12. Observe the water level in the water dam for indications that water is entering the subslab (drop in water level or bubbles). If there is, the Vapor Pin failed the leak check and corrective action is required. The leak test must be performed again after corrective actions are taken until the Vapor Pin passes the leak test. Note: Water level might drop slightly because of absorption into the concrete.
13. There are five corrective action options (first remove the water from the water dam with a turkey baster):
    - 13.1. Remove the Vapor Pin, clean out the drilled hole thoroughly, replace the silicone sleeve with a new one, and reinstall.
    - 13.2. Fill in visible concrete cracks inside the drilled hole with quick-setting cement and, after allowing the cement to cure, retest.
    - 13.3. Try fortifying the Vapor Pin seal by adding modeling clay to the base of the Vapor Pin. This temporary repair is only acceptable if grab samples will be collected; permanent repairs must be made for extended duration samples (for example, 8- or 24-hour) because the clay may dry and crack.
    - 13.4. Add Teflon tape to the barbed connector and the Teflon tubing, reattach the flex tubing and the Teflon tubing, make sure that all the fittings are tight and repeat the purge and leak-check procedure.
    - 13.5. If the previous options fail, then the Vapor Pin should be abandoned.
14. Optional - Field readings of total VOCs with a PID, and/or oxygen, carbon dioxide, and methane with a LandTec GEM Landfill Gas meter may be performed on the purged soil vapor. Perform readings outside of the building so that soil vapor is not released into indoor air.
15. Record the purge and leak-check information on the Subslab Soil Vapor Sampling Log.

Canister Sampling:

1. For extended duration samples (for example, 8- or 24-hour)
    - 1.1. Remove the sampling manifold by detaching the canister from the manifold, then detaching the probe tubing from the manifold and quickly attaching it to the canister via the flow controller.
    - 1.2. Attach the sign (identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information) to the canister.
    - 1.3. Make sure the canister will be secure at the sampling location; place traffic cones around the probe and canister if necessary.
2. To begin sampling, open the canister valve one full turn and record the sample start time. (For grab samples the canister will still be attached to the sampling manifold.)
3. Monitor the canister pressure on the analog gauge (if present) several times during the course of the sample period to ensure the canister is filling at the desired rate and the final canister pressure does not fall to 0 inch Hg.
4. At the end of the sample period, close the canister valve and record the sample end time. Detach the canister from the manifold or probe tubing.

5. Measure the final canister pressure with the digital pressure gauge. The final pressure should be between -10 to -2 inches Hg. If it is 0 inch Hg, do not submit the sample for analysis. If it is between -2 and 0 inches Hg, re-deploy the sample if possible; if not, submit it to the laboratory for analysis but make sure it is received with some residual negative pressure.
6. Replace the protective cap on the canister.
7. Duplicate samples should be collected simultaneously with a dedicated T-connector.
    7.1. Grab sample duplicates should be collected by attaching the T-connector to each canister and then connecting one flow controller to the top of the T-connector. (If there was a flow controller on each canister, then the sampling flow rate would exceed the maximum allowable flow rate of 200 mL/min.) The duplicate sample will take twice as long to collect.
    7.2. Extended duration samples should be collected by attaching a flow controller to each canister and then connecting the T-connector to each flow controller. (If only one flow controller was used, then the sampling duration would be twice as long.)

Bottle-Vac Sampling:

1. Measure the initial pressure with the digital pressure gauge. The initial pressure should be between -28 to -30 inches Hg. If it is less than -26 inches Hg, do not use the Bottle-Vac for sampling. If it is between -28 to -26 inches Hg, only use the Bottle-Vac if there are no other spares available. In the field log, record the Bottle-Vac ID, flow controller ID, initial vacuum, desired flow rate, sample location information, and all other information pertinent to the sampling effort.
2. For extended duration samples (for example, 8- or 24-hour)
    2.1. Remove the sampling manifold and attach the probe tubing to the flow controller.
    2.2. Attach the sign (identifying the canisters as an air sample, saying “Do Not Disturb” and providing contact information) to the canister.
    2.3. Make sure the canister will be secure at the sampling location; place traffic cones around the probe and canister if necessary.
3. For grab samples – Attach the flow controller to the sampling valve on the sampling manifold.
4. To begin sampling, attach the Bottle-Vac to the to the flow controller via the quick-connect and record the sample start time.
5. At the end of the sample period, detach the Bottle-Vac from the flow controller and record the sample end time. Detach the flow controller from the probe tubing or sampling manifold.
6. Measure the final Bottle-Vac pressure with the digital pressure gauge. The final pressure should be between -10 to -2 inches Hg. If it is 0 inch Hg, do not submit the sample for analysis. If it is between -2 and 0 inch Hg, redeploy the sample if possible; if not submit it to the laboratory for analysis but make sure it is received with some residual negative pressure.
7. Duplicate samples should be collected simultaneously with a dedicated T-connector as described in the Canister Sampling section.

Tedlar Bag Sampling:

1. Detach the vacuum pump from the sampling manifold and attach it to the lung box, then attach the probe tubing via the sampling manifold to the lung box influent.
2. Place a Tedlar bag in the lung box using dedicated Teflon and flexible silicon tubing.

3. To begin sampling, turn the pump on and record the sample start time.
4. Turn the pump off when the Tedlar bag is full and record the sample end time. The Tedlar bag should only be filled 50 percent if it will be shipped via plane.
5. Detach the probe tubing and vacuum pump from the lung box.

Sorbent Tube Sampling:

1. Disconnect the pump tubing from the manifold.
2. Attach a spare sorbent tube provided by the laboratory to the vacuum pump tubing using a 1/4-inch Swagelok union or flex tubing. Do not use a tube that is intended for sampling. Be sure to attach the sorbent tube so that the flow direction is correct.
3. Attach the SKC flow calibrator to the vacuum pump exhaust.
4. Turn on the vacuum pump and adjust the flow to achieve the desired flow rate of 200 mL/min using the flow calibrator.
5. Remove the spare sorbent tube from the pump tubing.
6. Remove the end caps from the sorbent tube to be used for sampling and attach it to the vacuum pump tubing using a 1/4-inch Swagelok union or flex tubing. Be sure to attach the sorbent tube so that the flow direction is correct. Record the sample tube ID on the field form.
7. Attach the other end of the sorbent tube to the sample manifold where the pump tubing used to be attached using either Swagelok fittings or flex tubing.
8. Make sure both the probe valve and the vacuum pump valve are open and the sampling valve is closed.
9. Start the pump and record the start time. Using flow calibrator, record initial flow rate.
10. If the flow rate starts to drop, it may indicate that the sorbent tube is becoming plugged with water. Stop the vacuum pump and record the end time.
11. After the required amount of time, record the final flow rate from the flow calibrator. Turn off the pump and remove the sorbent tube. Record the end time.
12. Replace the end caps on the sorbent tube. Replace the sorbent tube into the container it was received in.

After Sample Collection is Completed:

1. Disassemble the sampling system and replace the white silicone cap on the Vapor Pin.
2. For permanent probes - replace the black plastic or stainless steel secure cover and make sure it is securely in place.
3. Fill out all appropriate documentation (chain-of-custody and sample tags) and return samples and equipment to the laboratory in the same shipping container in which they were received. Do not place sticky labels or tape on surface of the canister.
4. Canisters, Bottle-Vacs, and Tedlar bags should not be cooled during shipment. DO NOT put ice in the shipping container. Sorbent tubes may require ice for shipping.

Quality Control and Quality Assurance

- Verify no less than 2 hours between probe installation and collecting subslab soil vapor samples.

- Canisters supplied by the laboratory must follow the performance criteria and quality assurance prescribed in U.S. Environmental Protection Agency (EPA) Method TO-14/15 for canister cleaning, certification of cleanliness, and leak checking.
- Flow controllers supplied by the laboratory must follow the performance criteria and quality assurance prescribed in EPA Method TO-14/15 for flow controller cleaning and adjustment.
- Field duplicates and trip blanks (sorbent tube methods only) may be required. Check the work plan for frequency.

Attachments

- Subslab Soil Vapor Sampling Log
- Sign identifying the canisters or Bottle-Vacs as an air sample, saying "Do Not Disturb" and providing contact information.

References

U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response. 2015. *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. June.

Cox-Colvin & Associates, Inc. (Cox-Colvin). 2016. *Standard Operating Procedure – Installation and Extraction of the Vapor Pin*. September.

Subslab Soil Vapor Sampling Log

Project:

Sampler(s):

Sample Location Information

Property ID/Address:

Condition of slab in the surrounding area:

Slab thickness (in):

Location ID:

Sample ID:

Sample Location Description (Room Name/Number and surrounding, identifying features):

Subslab Soil Vapor Probe Leak Checking and Sampling Log

Manifold Leak Check

	Pass	*Fail*
Manifold leak check (procedure: ensure manifold holds pressure at -10 "Hg for 30 seconds). If using a pelican-case pump, open the lid during leak check to ensure all interior pieces are in-tact.		

Describe corrective measures taken to pass the manifold leak test:

Subslab Soil Vapor Probe Water Dam Leak Check and Purge Results

Purge rate (mL/Min):

Start Time:

Purge Vacuum ("Hg):

End Time:

	Pass	*Fail*
Probe Leak Check Result*:		

*The subslab soil vapor probe passes the water dam leak check if there are no bubbles observed and the water level does not draw down during purge. Do NOT collect a subslab soil vapor sample if the leak check fails.

Helium Leak Check Results

Helium in shroud (%)

Helium in purge gas (%):

Field Analysis (required readings are determined on a project-specific basis. Fill in all that are necessary):

MiniRAE or MultiRAE Photoionization Detector			LandTec GEM Landfill Gas Meter
Total VOCs (ppm):	O_2 (%):		O2 (%):
H_2S (ppm):	LEL (%):		CO2 (%):
CO (ppm):			CH4 (%):

Sampling Information

Evacuated Canister or Bottle-Vac

Container Size (L):

Initial Pressure (" Hg):

Container ID:

Start Date and Time:

Flow Controller ID:

End Date and Time:

Sampling Rate (mL/min, hours):

Final Pressure (" Hg):

Sampling Vacuum ("Hg):

Tedlar Bag

Tedlar Bag size (L):

Start Date and Time:

Sampling Rate (mL/min):

End Date and Time:

Weather Conditions and Additional Notes

Weather Conditions During Sampling:

Additional Notes:

Air Testing in Progress

Please Do Not Disturb

Contact for Further Information:

Name: ______________________________

Organization:______________________

Phone:______________________________

STANDARD OPERATING PROCEDURE

Conducting Building Surveys for Vapor Intrusion Investigations

Purpose

This standard operating procedure (SOP) presents general guidelines for conducting building surveys for vapor intrusion (VI) investigations. A building survey is performed as part of a VI investigation to obtain information for development of the building-specific aspects of a conceptual site model (CSM) and to prepare for VI sampling (for example, select optimal sampling locations and determine if there are potential confounding indoor sources of volatile organic compounds [VOCs]).

A CSM for VI pathway investigation describes potential VOC subsurface sources, migration pathways, and potential human receptors under current and/or future land uses at the site. The important building characteristics for VI pathway investigation include the following:

- Building use and occupancy
- Condition of the building envelope
- Presence of a basement or crawl space
- Presence of preferential pathways for vapor intrusion
- Dimensions of the building and interior compartments
- Condition of the slab and basement walls and presence of potential VI pathways
- Type, zoning, and typical operational settings of the heating, ventilation, and air conditioning (HVAC) system
- Presence of potential indoor sources of VOCs
- Evidence of groundwater infiltration into the structure

This SOP can be used to perform building surveys in residential, commercial, or industrial buildings.

Scope

This SOP provides a general description of the information that should be observed and documented during building surveys. Sources of information about the building can include conversations with the occupants, landlords, visual observations, and possibly building plans or building inspection reports the occupant may be willing to share. The level of detail to which each building characteristic is evaluated will depend on the data quality objectives for each project.

Equipment and Materials

- CH2M HILL, Inc. (CH2M) Building Survey Form – to record survey information. Either electronic or paper.
- Figure showing the footprint of the building (if available) – to mark up during the building survey
- Flashlight

- Laser measuring tool, walking wheel, or measuring tape – to measure building and room dimensions
- Camera – to photograph the building (interior and exterior)
- Recommended – field instrument such as a MultiRAE photoionization detector (PID) to measure total volatile organic compound (VOC) and carbon monoxide concentrations in the breathing zone for health and safety monitoring

Procedures and Guidelines

Procedures for Performing a Building Survey

- **Gain access to the building**. Field staff should be trained for their role in courteous public interaction, aware of common safety hazards that may exist in buildings, and work closely with risk communication specialists.
- **Obtain occupant information**. The building occupants are the potential receptors in the VI CSM. Is the building use residential, commercial, or industrial? How many people typically occupy the building? Are there sensitive receptors (children, elderly, pregnant women, or immune-impaired) in the building? How much time do occupants spend in the building? What areas of the building do the occupants typically use (that is, where do they spend the most time)? If there is a basement, it is helpful to understand the amount of time people spend in the basement – for example, is there a family room in it or is it just storage or laundry?
- **Obtain building information.** How old is the building? What was its original use? Have there been additions or other significant modifications? Additions will likely have slabs that are separate from the original building. Differing shingles or roof pitches can sometimes indicate additions as well. How many floors does the building have? Does the building have a basement? If so, how far does it extend below grade? Is the slab on grade? Is the slab elevated above the ground surface? Is there a crawlspace? If so, where is the crawlspace access?
- **Survey the building envelope**. Walk around the inside and outside of the building and record information on the building construction and condition. How many doors/windows/loading docks are there, what condition are they in, and are they typically left open or closed? Are there obvious cracks in the walls or at the eaves that provide ventilation? What are the building construction materials? Look up at the roof for signs of a whole-house fan or other exhaust ventilation. Observe any exhaust fans that may be present in the walls or ceilings.
- **Determine the indoor air volume and the location and volume of separate indoor air compartments within the building**. Measure the building dimensions (length, width, and height). Measure the dimensions of compartments or rooms within the building. How are rooms connected? Are interior doors typically kept open or shut? Are there separate compartments within the building (that is, areas that are not connected to other areas such that the indoor air does not mix)?
- **Observe the slab condition**. How thick is the slab? What is the general condition of the slab? What is the floor covering in each room of the lowest floor (carpet, tile, or wood)?
- **Identify potential vapor intrusion pathways**. Any openings, cracks, or penetrations in the slab or basement walls may be entryways for subslab soil vapor.

  Are there utilities that penetrate the slab or basement walls? Are they sealed properly? It may be helpful to inventory utilities systematically by asking where the water line comes in, and where the sewage line goes out. Ask if the building has central utility services for water and sewer or uses septic and/or well. Similarly, telecommunications, cable TV, and power lines can come into the building overhead or underground. Overhead services can frequently be identified on the exterior of the structure and are unimportant for vapor intrusion. Underground services can either be directly buried wire/cable or installed in a conduit.

Are there cracks in the slab or basement walls? If so, note where these cracks are and their approximate size. Are there sumps? If so, note the dimensions of each and their typical operating conditions (is pump present? Is the top of the sump sealed? Where does the sump discharge?). Is the wall/floor juncture sealed well? Is there a french drain? Is there an open drain provided in the laundry room or for draining water from the furnace or gas fired hot water heater? Has the basement been waterproofed? Are there expansion joints in the slab? If so, note their condition.

- **Evaluate the HVAC system**. Record the type and model of the systems and the typical operating conditions. Is there one air conditioning zone or multiple zones (look for multiple thermostats)? Does the HVAC system use radiant heat or forced air? If the HVAC system is forced air, where are the heating and cooling and return air vents? Where is the HVAC system's fresh air intake? What is the heating fuel source (that is, natural gas, oil, or propane)? Are there ventilation fans (such as bathroom exhaust, kitchen exhaust and/or whole house fans)? If so, note where and their typical operating conditions. Are there window air conditioning units? Is a heat recovery ventilator in use? Is there a fireplace or woodstove, and if so how frequently is it used?
- **Identify any existing vapor mitigation systems.** Is there a radon mitigation system or other subslab depressurization system? Is there sealant on any cracks or crevices? Is there a sealant coat on the floor or basement walls for vapor or water mitigation?
- **Identify if the building experiences seasonal flooding**. Ask the building owner and/or occupants if seasonal flooding in the building is experienced. If so under what conditions/how frequently/how bad? If the building experiences flooding, document the condition of gutters/downspouts and whether the lot is graded away from the foundation. This will help assess the source of the water.
- **Sketch the building floor plan**. Include building dimensions, locations of windows/doors/loading docks, outdoor surface cover (such as, grass and asphalt), and locations of potential indoor or outdoor VOC sources. Attached garages or attached storage sheds can be important sources of VOCs. Fully detached garages or storage buildings do not normally need to be surveyed unless they are routinely occupied.
- **Identify potential indoor VOC sources within the building**. Record the location of the potential sources and determine if they can be removed before indoor air sampling is performed. Potential indoor sources of VOCs may include cleaning products, paint, dry-cleaned clothes, craft glues, air fresheners, gasoline, cosmetics, or cigarette smoke. Recent remodeling activities, including painting, installing new carpeting or flooring, and moving in new furniture should be identified, because they could be potential sources of VOCs. A field instrument can also be used to pinpoint potential indoor VOC sources. In situations with numerous products such as numerous cleaning supplies, it can be efficient to photograph both the front and back of the containers lined up.
- **Identify potential outdoor contaminant sources**. These may include gas stations, major roadways, dry cleaners, repair shops, industries, outdoor cooking areas, or landfills.
- **Identify possible indoor air, outdoor air, crawl space air, and subslab soil vapor sample locations** that meet the project-specific data quality objectives and are acceptable to building occupants.

Quality Control and Quality Assurance

Adequate time should be reserved for performing building surveys and detailed notes should be recorded at the time of the building survey. Verify that indoor air samples are collected no less than

24-hours after chemical products that may contain VOCs are temporarily removed from the building. The field notes should be reviewed by the Field Quality Manager at the end of each work day performed.

Attachments

- CH2M Building Survey Form

References

Interstate Technology and Regulatory Council. 2007. V*apor Intrusion Pathway: A Practical Guideline. Prepared by The Interstate Technology & Regulatory Council Vapor Intrusion Team*. Available at http://www.itrcweb.org/documents/VI-1.pdf.

U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response. 2015. *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. June.

Building Survey Form for Vapor Intrusion Investigations

Property ID: ________________________

Site/Project Name: ________________________

____

Date of Survey: ________________________

Preparer(s): ____

Building Occupancy and Use

1. What is the estimated number of building occupants?

____

____

(Make general observations about age range and percentage of male to female ratio)

2. Are there any sensitive receptors in the building? (elderly, children, immuno-compromised, women of child bearing age,

____

3. How long have the current occupants occupied the building? ________________________

4. What is the building type/use? Circle all that apply and describe.

Residential (single family, duplex, apartments) / Office / Strip Mall / Commercial / Industrial / Other:

____

Describe building use (circle all that apply):

Residential / Manufacturing / Storage / Chemical Storage / Administrative / Instrumentation / Othe

____

____

5. What are the historical activities within the building (if different than above)?

____

____

Building Occupancy and Use - continued

Questions 6 - 8 are applicable to non-residential buildings only.

6. What type of work is performed within the building?

7. How many hours per day or week do workers spend in the building?

8. Is the building accessed by the public? (Describe approximate number of persons, frequency of visits, and duration of vis

Building Construction

1. What year was the building constructed?

2. Have there been additions to the building? If so, when? (Identify on building sketch)

3. What are the approximate dimensions of the building?

4. What are the construction materials of the exterior of the building?

5. How many floors does the building have?

Does the main floor sit on, below, or above grade?

(How many feet above or below grade?)

Number of floors at or above grade?

Number of floors below grade?

(How many feet below grade?)

Building Construction - continued

6. Describe the basement (if present):

Does the building have a basement and/or crawl space ____________________

____

How many feet below grade? ____________________

Approximate square footage: ____________________

Approximate ceiling height (give range if varying height): ____________________

Is the basement separated into multiple rooms? Describe (note use, if space is finished/unfinished):

____

____

Construction materials of walls (i.e. poured concrete, cinderblock, brick, etc.; are the walls covered with epoxy?)

____

Are significant cracks present in the walls? ____________________

7. Describe the main floor:

Approximate square footage: ____________________

Approximate ceiling height (give range if varying height): ____________________

Is the main floor separated into multiple rooms? ____________________

____

____

Construction materials of walls (i.e. framing, siding, cinderblock, etc.):

____

____

Building Construction - continued

8. Describe the building slab:

Construction materials of floor/slab: ________________________________

____

Describe the floor coverings (epoxy paint, carpet, tile, etc.) ________________________________

____

If concrete slab, are expansion joints present? ________________________________

Are they sealed/showing deterioration? ________________________________

Are significant cracks present in the slab? ________________________________

Are there any penetrations in the slab? (utility conduits, etc.) ________________________________

____

Is there a subslab vapor/moisture barrier in place? ________________________________

Are any floor drains or sumps present? Is there standing water in them? ________________________________

____

Are there any subsurface vaults present? (if so describe and add locations to building sketch)

____

9. Does the building have a moisture/dampness problem?

No / Rarely (less than 1 time per year) / Occasionally (1-2 times per year) / Frequently

10. Does the building ever flood?

No / Rarely (less than 1 time per year) / Occasionally (1-2 times per year) / Frequently

11. Is there a septic system? ☐ Yes ☐ Yes, but not in use ☐ No

12. Is there irrigation or a private well? ☐ Yes ☐ Yes, but not in use ☐ No

13. Type of ground cover outside: Grass / Concrete / Gravel / Asphalt / Other ______________________________

14. Additional notes on building construction:

____

____

____

Existing Vapor Mitigation Systems

1. Has a radon or vapor mitigation system been installed in this building? (Show location on building sketch)

____

If yes: Installation Date: ______________

Type of System: Passive Venting / Active Subslab Depressurization
Crack and Crevice Sealing / Dilution Ventilation Control / Other

Notes: ______________________________

Air Flow Within the Building and Outdoor Air Exchange

1. Are there any areas of the building that are positively or negatively pressurized (look for doors not opening and/or closing properly, perceptible air flow, audible fan noises)?

____

____

____

2. Is there one HVAC zone or multiple zones? How many zones? Add thermostat locations to building floorplan, if available.

____

____

____

3. Type of ventilation system (circle all that apply):

Central Air Condition / Mechanical Fans / Bathroom Ventilation Fans / Individual Air Condition Units
Kitchen Range Hood Fan / Outside Air Intake / Industrial Floor Fans
Whole-Building Attic Exhaust Fan / Other: ___________________________________

4. Type of heating system (circle all that apply):

Forced Hot Air / Hot Air Radiation / Wood / Steam Radiation / Heat Pump / Individual Heater / Hot Water Radiation
Kerosene Heater / Fireplace / Electric Baseboard / Other: ____

5. Type of fuel utilized (circle all that apply):
Natural Gas / Electric / Fuel Oil / Wood / Coal / Solar / Kerosene / Other:

6. Are there any sources of outdoor air?

☐ Mechanical (AHU) ☐ Doors

☐ Windows ☐ Other

Are windows/doors left open routinely (seasonal differences)? ______________________

____

Evaluation of Potential Indoor VOC Sources

1. Are SDSs available for chemicals used with in the building? If possible, obtain a copy of the Table of Contents. List items in additional notes section (include approximate quantities and frequency).

☐ Yes ☐ No

2. Do any of the products stored in the building contain VOCs?

☐ Yes ☐ No

3. Are any of the target analytes used in the building?

☐ Yes ☐ No

If yes, is the usage confined to a specific room/area?

☐ Yes ☐ No

4. Are pesticides used for indoor pest control?

☐ Yes ☐ No

If yes: Name of product:

Frequency of use:

Has there been an application within the last 6 months?

5. Is smoking permitted inside the building?

☐ Yes ☐ No

If yes, does smoking typically occur within a specific room/area?

☐ Yes ☐ No Notes:

How often?

Last time someone smoked in the building?

6. Has there been any remodeling or construction within the past 6 months (i.e. new carpeting/tiling, painting, additions, new furniture, etc.)

☐ Yes ☐ No

Is there any planned for the near future?

☐ Yes ☐ No

Evaluation of Potential Indoor VOC Sources - continued

7. Does the building have an attached garage or do vehicles regularly enter the space (example: a vehicle repair shop)?

☐ Yes ☐ No

8. Are gas-powered equipment or cans of gasoline/fuels stored in the building or attached garage?

☐ Yes ☐ No

9. Do building occupants dry clean their clothes? ☐ Yes ☐ No

If yes, how often? Weekly / Monthly / Infrequently (3-4 times a year)

10. Has there ever been a fire in the building? ☐ Yes ☐ No

11. Has there ever been a known chemical spill immediately outside or inside the building?

☐ Yes ☐ No

12. Was the building screened with a ppbRAE to identify indoor VOC sources? If yes, describe the results:

☐ Yes ☐ No

Evaluation of Potential Outside VOC Sources

1. Are there stationary sources nearby (i.e. gas stations, emission stacks, hazardous waste storage, etc.):

☐ Yes ☐ No

2. Is there heavy vehicular traffic nearby (or other mobile sources)?

☐ Yes ☐ No

FIELD OPERATING PROCEDURE

Analytical Method for the Determination of Volatile Organics in Soil Vapor or Air Using the HAPSITE Field GC/MS

Purpose

This field operating procedure (FOP) presents general guidelines for using a HAPSITE gas chromatograph (GC)/mass spectrometer (MS) to analyze soil vapor or air samples in the field using U.S. Environmental Protection Agency (EPA) Method TO-15 as guidance.

Scope

This is a general description of how to analyze soil vapor or air samples in the field with a HAPSITE GC/MS. This FOP is intended to be used by GC/MS chemists with proper training and experience. These procedures are based upon EPA Method TO-15, *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, *Second Edition*(1999), and the HAPSITE user manual. This method is applicable to specific volatile organic compounds (VOCs) in soil vapor or air. Table 1 presents a list of VOCs with reporting limits (RLs) that can be analyzed with this procedure.

Equipment and Materials

HAPSITE GC/MS sampling materials:

- Inficon HAPSITE Smart, Smart Plus, or ER GC/MS
- GC Column – VOC (Standard)
- Gas sampling bags (such as Tedlar brand) in varying sizes as needed (including canister-to-bag adapter for calibration standards).
- Gastite syringes in various sizes from 25 microliters (µl) to 100 milliliters (mL) with Teflon plunger and rounded needle tip.
- Portable Windows-based laptop computer, equipped with HAPSITE Smart IQ software for acquisition, integration, quantitation, and storage of mass spectral data (including communication cable between HAPSITE and laptop). The HAPSITE can operate without connection to a computer, but a computer is necessary for higher-quality data reprocessing.
- Power source – either line power or an automobile power inverter. The HAPSITE has an onboard battery, but it needs to be re-charged periodically.
- Internal/Surrogate/Tuning Standard mix, provided with the HAPSITE in a disposable gas cylinder.
- Nitrogen Carrier Gas, provided with the HAPSITE in a disposable gas cylinder.
- Two-stage regulator for nitrogen cylinder (optional). CGA 580 fitting.
- Calibration standards – 6 liter (L) evacuated canisters prefilled with 5 parts per billion by volume (ppbV) and 0.5 ppbV of mixed gas standard for calibrating the HAPSITE and verifying calibration daily.

- Method blank standard – 6 L evacuated canister prefilled with high-purity nitrogen, to verify the HAPSITE is free of contamination daily.

Procedures and Guidelines

This FOP describes the general procedures and guidelines for using a HAPSITE GC/MS, to analyze soil vapor or air samples in the field.

Overview of the Analytical Process

- Soil vapor and air samples are collected through the sampling probe at ambient pressure.
- The HAPSITE can be operated in two different modes. Analytical mode for quantitative (quant) and qualitative results, or survey (sniff) mode for qualitative screening.
- Quant mode: Samples are introduced into the GC/MS system by way of a sample probe and concentrator. The concentrator traps the sample onto an adsorbent trap, which allows atmospheric gases to pass through (such as, carbon dioxide, oxygen, and nitrogen [N_2]). The trap is then heated, and the analytes are transferred to the GC column, then to the MS detector.
- Survey mode: Samples are introduced through the sample probe directly into the MS detector.
- Data are collected and stored into the HAPSITE system memory. The data can then be used by an external computer for calibration, data processing, reporting of samples, and data archiving.
- SIM and SCAN: The MS system can operate in SCAN or SIM mode, depending on analytical or specific project requirements. SCAN mode is used for more conventional TO-15 analysis or if tentatively identified compounds (TIC) are required. In this mode, the MS scans a range of ions (typically 35 to 250 atomic mass units). This range contains all ions necessary to identify and quantitate all compounds in the TO-15 list. If lower detection levels are required, SIM mode may be used. In SIM mode, the analyzer only looks at ions specific to the target compounds. Up to three ions are used per compound, 1 for quantitation and 1 or 2 for qualification. This increases the dwell time that the analyzer spends scanning for each specified ion, which increases sensitivity at the cost of selectivity. Because of this, it is not possible to produce TIC reports in SIM mode.
- After samples are analyzed, processed, and meet all acceptance criteria herein, a client report is generated and typically reviewed by a peer.

Target Analytes, Reporting Limits, and Detection Limits

Standard target analytes and RLs for the base analyte list for analysis in SIM mode are listed in Table 1. To keep the analysis time as short as possible, the analyte list should be kept to the minimum number of compounds of interest. To produce the analyte list and RLs in Table 1, it takes approximately 10 to 15 minutes from injection to injection (including sampling time, analytical run time, and post-run instrument cool down).

The RLs shall be at or above the lowest calibrated point on the initial calibration curve. RLs may increase or decrease based on the amount of time the sample is loaded onto the concentrator. Typical achievable limits for a 1-minute fill time are listed in Table 1 for SIM mode.

Interferences

Contamination may occur in the sampling system if it is not properly cleaned before use. Therefore, the probe should be heated and an ambient system flush performed at the start of each day, and between samples with elevated (greater than double the highest point on the calibration curve) concentrations of VOCs.

Contamination may occur from impurities in the carrier gases and from background sources. These sources of contamination are monitored through analysis of method blanks.

Cross-contamination can occur whenever samples containing high VOC concentrations are analyzed. Therefore, whenever an unusually concentrated sample is encountered (greater than double the highest point on the calibration curve), the analyst uses professional judgment when reviewing the samples to determine whether reanalysis is necessary.

Sample Collection, Storage, Holding Times, and Preservation

Samples are collected in gas sampling bags. Analysis of gas sampling bags should be performed immediately after sample collection. Samples should be field screened with a photoionization detector before analysis to obtain an approximate dilution factor.

Standards, Gases, and Reagents

All standards are logged into the chemical inventory database upon receipt. Any standard that is prepared in the laboratory will be verified against current standards before use.

- Calibration standard—Purchase a premade standard or have a vendor prepare a calibration standard in a 6-L Summa canister. Actual concentration and composition varies by project, but typically 5 ppbV and 0.5 ppbV are good targets.
    - Stock standards—Standards are purchased as custom made mixtures in gas cylinders. Cylinders purchased from vendors are traceable to a National Institute of Standards and Technology. 62-component mixture from Scott Gases (catalog number 41973-U). Stock standard is 1,000 ppbV.
    - Primary Field Standard (5 ppbV)—Dilute the 1,000-ppbV primary standard(s) 1:200. Evacuate a clean 6-L canister. Add 50 µl of DI water. Add 90 mL of 1,000-ppbV standard. Fill canister to final pressure of 2,280 torr using Ultra High Purity (UHP) N_2. This provides 12 L of usable 5-ppbV standard (16 L total).
    - Primary Field Standard (0.5 ppbV)—Dilute the 1,000-ppbV primary standard(s) 1:2000. Evacuate a clean 6-L canister. Add 50 µl of DI water. Add 9 mL of 1,000-ppbV standard. Fill canister to final pressure of 2,280 torr using UHP N_2. This provides 12 L of usable 0.5-ppbV standard (16 L total).
    - Daily Field Calibration standards—Primary Field Daily Calibration Standard—Fill a 1-L gas sampling bag with 5-ppbV primary field standard.
- Internal/Surrogate/Tuning standard—The internal/surrogate/tuning standard mix is provided with the HAPSITE in a disposable gas cylinder. Each cylinder is prepared with bromopentafluorobenzene (BPFB) and 1,3,5-tris (trifluoromethyl) benzene (TRIS) at approximately 5 ppbV, with nitrogen as the balance gas.
- Nitrogen Carrier Gas—UHP 99.999 percent or better. Either in disposable Inficon canisters or commercially provided cylinder (if HAPSITE will be used in a fixed location and large quantities are required).

Analytical Procedure

- Startup when the HAPSITE is received:
    - Unpack the HAPSITE. It is usually shipped with the power off and the MS pumped down. Be sure that it has a significant amount of time (at least an hour or overnight if possible) to warm up and equilibrate before use.

  - Insert the carrier gas (or attach external supply) and internal standard gas cylinders. Visually verify that the sample trap has not broken during shipment.
  - Plug the HAPSITE into an external power source.
  - Attach the computer (turn on and start software). Then push the power button on the HAPSITE. The HAPSITE will go through a warm up routine, then a tune. When prompted for a trap clean out, press 'yes' on the HAPSITE screen.
  - Load the desired method on the HAPSITE screen and then denote this method as the default method. This is important because otherwise it will default to a different method at the end of each run and change zone temperature settings. Note: All files (method, tune, data) reside on the HAPSITE, not the laptop computer.
- Create a new subdirectory each day. This can be done in the method editor (Data page).
  - Startup from extended standby:
    - Press power button
    - Insert internal standard and carrier gas.
    - Wait for instrument to warm up and run tune.
  - Analytical standards and/or diluted samples in gas sampling bags are attached to the sample probe manifold with a compression fitting. Ambient air samples are simply drawn directly into the probe. Pressurized or evacuated sample or standard sources cannot be used as they will significantly change instrument response.
- Quantitation Mode
  - Using the method editor on the PC, verify that the desired sample time is set correctly in the method to be used for analysis. Typically, this will be 1 minute, but may differ depending on project requirements or dilutions. Save the method.
  - Load the appropriate quantitation method onto the HAPSITE. This can either be done from the touch screen or the PC. Be sure that the method is appropriate for the target compounds. If necessary, sensitivity can be increased by using SIM to target the most important ions of interest.
  - Run the quality control (QC) (either an initial calibration [ICAL] or calibration verification [CV] and blank). Attach a gas sampling bag containing the standard or UHP blank gas to the sample probe. Open the bag and press run on the HAPSITE. Once QC has passed criteria, then sample analysis can begin.
  - Attach a gas sampling bag containing the sample to the sample probe and press the run button on the HAPSITE. Once the desired sample time has been completed, the gas sampling bag can be removed.
  - Once the analysis is complete, allow the GC oven to cool, then inject the next sample.
  - All the sample and QC information for an analytical run, such as laboratory and client sample identifications (IDs), injection volumes, standard IDs, and run methods, are added to the field log.
- Sample Dilution
  - Any sample that has target analytes over the calibrated range of the instrument should be diluted if possible. The subsequent dilution should be run such that the final value of the maximum concentration analyte recovers within the calibrated range on the instrument (before dilution factors are applied).

  - Required dilutions for HAPSITE analysis can be achieved in two different ways:
    - Concentrator fill time: Inject a smaller sample volume. Record all dilutions in the field form. For example, normalized to a 1 minute fill time (100 mL), a dilution of 5 times can be performed by only sampling for 0.2 minute (20 mL). Using the method editor on the PC, set the desired sample time in the method to be used for analysis. Save the method. Then load the appropriate quantitation method onto the HAPSITE. This can either be done from the touch screen or the PC
    - Gas sampling bag dilution: Take a sample with a syringe and inject it into a gas sampling bag with a known volume of clean air. Attach the bag to the instrument sampling port and withdraw an aliquot. The aliquot can be less than the normalized value (as in the section before). Both the gas sampling bag dilution factor and concentrator fill injection factors are applied to the final instrument result.
- At the end of the day, put the HAPSITE into external standby and remove carrier gas and internal standard (ISTD) if the instrument is going to be used again next day. Otherwise, the HAPSITE can be powered off.

Quality Control and Quality Assurance

All RLs, QC frequency, and QC acceptance criteria are subject to change on a project specific basis.

- The instrument is tuned using BPFB and TRIS. This is performed before analysis each day. The HAPSITE software runs a tuning program set to optimize its instrument parameters for analysis. This program optimizes sensitivity and enables library matching of the spectra.
  - There are short- and long-tune algorithms. Typically, the short tune is performed. A long tune is performed only after major instrument maintenance.
  - After running a successful tune (tune passes internal instrument criteria), it is saved to the default tune file.
  - The HAPSITE is not designed to pass the TO-15 bromofluorobenzene (BFB) tune criteria to operate at its highest potential. Therefore, BFB tune criteria are not relevant for this FOP.
- Initial Calibration—An initial calibration curve is required to demonstrate adequate instrument performance for sensitivity, linearity, resolution, and absence of active sites.
  - A valid initial calibration curve must be established before samples can be analyzed. The GC/MS is calibrated following the outline herein. Variations from this standard calibration scheme are sometimes necessary because of project RL requirements.
  - As the RL is driven by the lowest calibration point, any lowering of the RL will require either (A) calibrating to a lower level or (B) injection of more sample volume.
  - Calibration schemes.
  - The following calibration schemes have been successfully used, the actual scheme used should be tailored to the instrument and project requirements. It is based on a 1-minute sampling period (1 minutes at 100 mL/min = 100 mL)

    Cal Levels (1-minute sampling time normalization)

Cal level	Std Concentration, ppbV	Sampling time, min.	Concentration, ppbV
Level 1	0.5	0.2	0.1
Level 2	0.5	1.0	0.5

Level 3	0.5	2.0	1.0
Level 4	5.0	1.0	5.0
Level 5	5.0	5.0	25.0

  - The curve can be shifted to be more or less sensitive by increasing or decreasing the sampling time. Longer sampling time increases sensitivity, and vice versa.
  - For the initial calibration, a response factor and a percent relative standard deviation (%RSD) are calculated for each analyte.
  - After a new calibration is performed, the method needs to be saved with the correct filename. The method name should be the date followed by an identifier. For example, an ICAL performed on October 29, 2014, for client X shall be named 102914X.
  - There must be at least three points to have a valid calibration curve. The lowest point will be below the quantitation limit required in the Quality Assurance Project Plan.
  - The %RSD for all compounds must be less than 30 percent.
  - If the %RSD greater than 30 percent, then a linear curve fit may be used if the curve fit greater than 0.995.
    - If the requirements are not met, then a new initial calibration must be performed. If this does not result in an acceptable initial calibration, then system maintenance may be necessary.
    - Calibrations are valid for 1 year (or until the end of the project, whichever occurs first) if QC continues to meet acceptance criteria.
    - In the following instances, a new calibration shall be required:

      Major instrument maintenance such as cleaning the MS.

      Repeated failure (more than 3 attempts) to pass continued calibration criteria.

- Method Blanks—Method blanks are required at a rate of one per day. Method blanks are analyzed to monitor possible instrument contamination. Laboratory method blanks are prepared with UHP nitrogen in a gas sampling bag every day samples are to be analyzed. The method blank is carried through the same analytical procedure as a field sample.
  - Method blanks are analyzed by injecting the full normalized volume of nitrogen (varies by system) into the HAPSITE and following procedures outlined in Section 9.
  - The blank must not contain any target analyte at a concentration greater than the RL and must not contain additional compounds with elution characteristics or mass spectral features that would interfere with identification and measurement of a method analyte. If target analytes are found in the method blank above the RL, the source of the contamination must be considered. Usually, rerunning the blank will resolve most problems (especially if the sample run prior to the blank was high in target analyte concentration). If blank contamination is still present, the analyst must perform system maintenance. Some common problems that cause a blank to show contamination are:
    - Cold spots—check heated zones for failure
    - Contaminated sample probe—flush the probe
    - Dirty gas sampling bag—flush and refill the bag or use new bag

- Continuing Calibration Verifications—a primary source standard analyzed at the beginning of an analytical batch to ensure that the instrument continues to meet the instrument sensitivity and linearity requirements originally established by the initial calibration.
  - The opening CV for each compound of interest shall be verified prior to sample analysis using the same introduction technique and conditions as used for samples. This is accomplished by analyzing one of the calibration standards used for initial calibration.
  - Concentrations for CV must be at or below the midpoint of the instrument calibration curve.
  - No closing calibration check is required for TO-15 analysis. However, a closing calibration check will be analyzed to increase confidence in data quality.
  - The percent difference (%D) for each compound may not exceed 30 percent.
  - Failure to pass continuing calibration criteria requires corrective action are performed. Repeated failure (more than 3 consecutive attempts) to pass response factor criteria requires the performance of a new initial calibration.

Attachments

- HAPSITE Log Sheet – Quant Mode
- HAPSITE Log Sheet – Sniff Mode

References

U.S. Environmental Protection Agency (EPA). 1999. *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition*. January.

Infilcon. 2017. Operating Manual: HAPSITE ER Chemical Identification System. IPN 074-471-P1D.

Infilcon. 2008. Operating Manual: HAPSITE Smart Plus Chemical Identification System. IPN 074-472-P1D. November.

Table 1: Method Analytes (1-minute fill time)	
Standard Analytes	**Reporting limit µg/m3**
Benzene	0.32
Toluene	038
Ethylbenzene	0.44
m,p-Xylene	0.88
o-Xylene	0.44
Naphthalene	0.53

*All RLs are subject to change on a client specified basis as requested by that client.

Hapsite Log Sheet
Quant Mode

Site ______________________

Date ______________________

Operator ______________________

SubDirectory ______________________

Location	Time	File ID	Fill Time	DF	Notes

Comments: ____

____

Hapsite Log Sheet
Sniff Mode

Site ____________________

Date ____________________

Operator ____________________

General Location ____________________

SubDirectory ____________________

File ID ____________________

Start time ____________________

Location	Time	Notes

Comments: ____________________