FINAL REPORT

New Application of Geotechnical Technology to Remediate Low-Permeability Contaminated Media

ESTCP Project ER-201627

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This project demonstrated and validated the effectiveness of the Grout Bomber geotechnical technology for the rapid installation of zero valent iron (ZVI) amendment-filled reaction columns within a high concentration trichloroethene source zone in low permeability (low-k) geologic material.

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ACRONYMS AND ABBREVIATIONS

bgs	Below ground surface
cis-1,2-DCE	*cis*-1,2-dichloroethene
CO_2	carbon dioxide
CMT	Continuous Multichannel Tubing
CSIA	Compound-Specific Isotope Analysis
CVOC	Chlorinated Volatile Organic Compound
DNAPL	Dense Non-Aqueous Phase Liquid
DoD	Department of Defense
DO	Dissolved Oxygen
DPT	Direct Push Technology
EISB	Enhanced *In Situ* Bioremediation
EK-BIO	Electrokinetic-Enhanced *In Situ* Bioremediation
ER	Electrical Resistivity
ERH	Electrical Resistance Heating
ESTCP	Environmental Security Technology Certification Program
ft	Foot, feet
ft^3	Cubic feet
GSI	GSI Environmental Inc.
HASP	Health and Safety Plan
ISCR	*in situ* chemical reduction
ITRC	Interstate Technology & Regulatory Council
in	inch
kg	kilogram
low-k	low permeability
L	Liter
m	meters
MCL	maximum contaminant level
mg	milligram
MS	Matrix spike
MSD	Matrix spike duplicate
µg	Microgram
MNA	Monitored Natural Attenuation
MST	Magnetic Separation Test
MW	Monitoring Well

NAVFAC	Naval Facilities Engineering Command
NSZD	Natural Source Zone Depletion
ND	Non-Detect
NRC	National Research Council
NSF	Naval Support Facility
O&M	Operation and maintenance
ORP	Oxidation Reduction Potential
pfc	Pound per cubic foot
PRB	Permeable Reactive Barriers
PVC	Polyvinyl Chloride
QA	Quality assurance
QC	Quality control
qPCR	Quantitative Polymerase Chain Reaction
RC-MW	Reaction Column Monitoring Well
RGM	Reaction Gas Monitoring
SERDP	Strategic Environmental Research and Development Program
SVC	Soil Vapor Column
TCE	Trichloroethene
VC	Vinyl Chloride
VOA	Volatile organic analysis
VOC	Volatile organic compound
yd^3	Cubic yard
ZVI	Zero Valent Iron

ABSTRACT

INTRODUCTION AND OBJECTIVES

A critical challenge preventing many chlorinated solvent (or chlorinated volatile organic compound [CVOC]) sites from reaching groundwater cleanup goals is the long-term and persistent release of residual contaminants from low-k media (e.g., clays, silts). Sites dominated by matrix diffusion processes are very difficult to remediate and have the effect of significantly prolonging restoration timeframes and increasing long-term site management costs. One of the common side effects of matrix diffusion is “rebound” of contaminant concentrations after an in situ treatment is applied. This ESTCP-funded project aimed to “repurpose” a commercially-available geotechnical technology, the Grout Bomber, for rapid and efficient delivery of remediation amendments (e.g., zero-valent iron [ZVI], vegetable oil) into a low-k shallow aquifer contaminated with CVOCs.

TECHNOLOGY DESCRIPTION

The Grout Bomber is a subsurface stabilization technology that uses an excavator equipped with a specialized “stitcher” mast to quickly push a mandrel (3.5 in. diameter hollow cylindrical rod) into the subsurface and subsequently fill the hole and subsurface voids with cement grout (from bottom to top) using an in-line grout delivery system. For our environmental application, a remedial amendment mixture of ZVI, vegetable oil, and sand was used (instead of cement grout) to create hundreds of biotic/abiotic reaction columns for degradation of chlorinated solvents. This application relies on diffusion to draw the contaminants from low-k silt and clay strata into the reaction column, where the contaminants are degraded by abiotic and biotic reductive dechlorination. The diffusion of CVOCs is driven by steep concentration gradients between the treated pore water within the reaction column and the surrounding media. The “long tail” of contaminant flux from low-k units can be significantly reduced if the diffusion lengths associated with matrix diffusion are reduced. Our hypothesis is that reaction columns spaced every 2-3 ft within the plume center of mass would greatly reduce the back diffusion time as the contaminant only has to travel 1-1.5 ft to the nearest treatment zone.

PERFORMANCE AND COST ASSESSMENT

Eight hundred reaction columns (ZVI, vegetable oil, and sand) were emplaced in less than 8 days (1-2 minutes per 30-ft column) over an approximately 4,700 ft^2 source zone at the Site 17 North Plume at Naval Support Facility (NSF) in Indian Head, Maryland. Groundwater data collected at seven post-installation monitoring events over a period of 26 months showed reductions in TCE in site monitoring wells and detections of key degradation indicators for both abiotic and biotic mechanisms (acetylene, ethene/ethane). Applied to a typical DoD middle-to-late-stage site, estimated treatment costs for the Bomber technology (including equipment, materials, mobilization, labor) are approximately $50-70 per cubic yard of source zone treated, which is less than the reported unit cost per cubic yard for comparable treatment technologies (i.e., excavation, thermal treatment, or soil mixing with ZVI). Results to-date are very promising and, although several operational improvements were identified, the Bomber technology appears to be a viable alternative for amendment delivery at low-permeability contaminated sites.

IMPLEMENTATION ISSUES

Re-purposing of the Grout Bomber technology for installation of ZVI reaction columns in low-k media presented a few implementation issues associated with i) preliminary pilot testing to determine appropriate remediation material mixture that satisfied both pumpability and treatability criteria, ii) site access and large area for equipment staging, iii) general mobility of large equipment in a tight work environment, and iv) need for detailed site characterization to minimize risk of vertical contaminant transport.

EXECUTIVE SUMMARY

INTRODUCTION

A critical challenge preventing many chlorinated solvent (or chlorinated volatile organic compound [CVOC]) sites from reaching groundwater cleanup goals is the long-term and persistent release of residual contaminants from low-permeability (low-k) media (e.g., clays, silts). Sites dominated by matrix diffusion processes are very difficult to remediate and have the effect of significantly prolonging restoration timeframes and increasing long-term site management costs for the Department of Defense (DoD) (SERDP/ESTCP, 2013; 2018). Currently, there are limited remediation options available to treat residual contamination trapped in low-k zones. For these long-lived, difficult-to-treat sites, inexpensive (in units of dollars per cubic yard, or dollars per acre) technologies are needed that will: i) reliably address mass flux limitations of contaminants leaving low-k source zones; and ii) increase the actual treatment of the contaminants leaving these low-k zones by enhancing natural attenuation processes.

The geotechnical industry offers a variety of well-established techniques for quickly and efficiently accessing the subsurface for the purposes of ground stabilization, foundation rehabilitation, porewater drainage, and structural support. The speed and efficiency of these techniques is advantageous to the field of environmental remediation, particularly for emplacement of remedial amendments (e.g., ZVI, vegetable oil, chemical oxidants) into the subsurface at contaminated sites. Two promising techniques with potential environmental applications were evaluated as part of this ESTCP project: i) prefabricated vertical drains (or "wick drains") and ii) cement grouting (the "Grout Bomber" or "Bomber"; **Figure ES-1**). Both technologies utilize specialized machinery to rapidly access the subsurface via a direct push technique, where hundreds of vertical drains or columns can be installed per day to depths greater than 80 ft below ground surface (bgs).

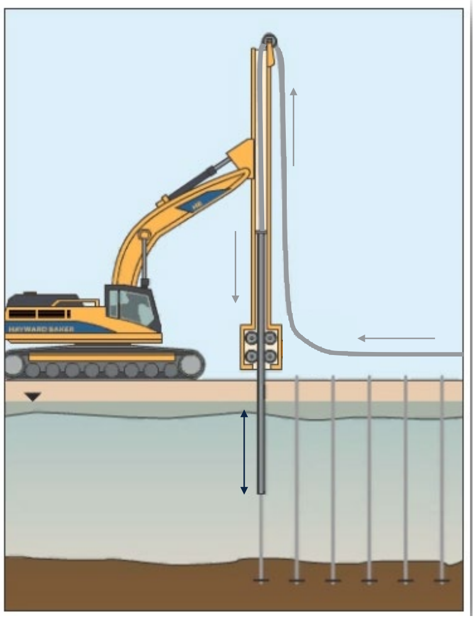


Figure ES-1. The "Grout Bomber"

This project initially focused on the application of wick drains as "reaction columns" for delivery of remediation amendments (e.g., ZVI, vegetable oil) to the subsurface, where the wick drains would be installed first followed by injection of the amendment into the wicks (in this scenario, the wicks serve as conduits for the emplaced remedial amendment). However, following discussions with our geotechnical contractor (Hayward Baker, now Keller), observations from site visits (to observe both wick drain installation and the Bomber technology), and preliminary laboratory testing, the project team concluded that the Grout Bomber was the most viable method to achieve rapid and reliable amendment delivery into the subsurface for the field demonstration.

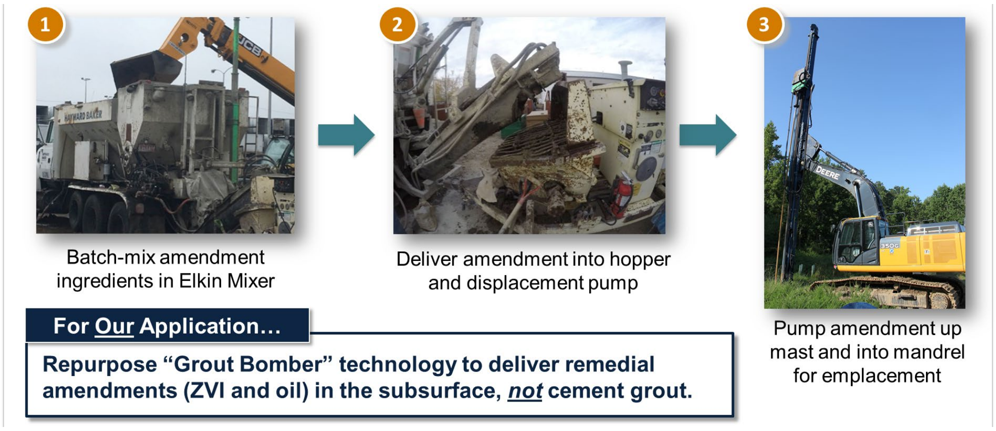
OBJECTIVES

The objective of the field demonstration was to test and validate an innovative application of a commercially-available geotechnical technology, the Grout Bomber, to improve delivery of remediation amendments at sites with contaminants trapped in low-k zones (clays, silts). We proposed to demonstrate that:

- conventional geotechnical techniques could be used to efficiently install hundreds of closely-spaced vertical reaction columns at contaminated sites;
- a remediation amendment (in this case, a "grout" mixture of ZVI, sand, and vegetable oil) could be delivered into the columns to serve as reactive zones for contaminated groundwater;
- the remediation amendment would stimulate abiotic and/or biotic degradation of CVOCs and generate concentration gradients to drive diffusion of contaminants into the reaction zones; and
- by having closely-spaced (every 2 to 3 ft) vertical reaction zones, CVOC concentrations in low-k zones would be reduced, thus, significantly shortening the "long tail" of contaminant flux commonly observed at these sites.

TECHNOLOGY DESCRIPTION

The Grout Bomber is a subsurface stabilization technology that uses an excavator equipped with a specialized "stitcher" mast to quickly push a mandrel (3.5 in. diameter hollow cylindrical rod) into the subsurface and subsequently fill the hole and subsurface voids with cement grout (from bottom to top) using an in-line grout delivery system. As shown in **Figure ES-2**, the typical arrangement of the Bomber includes the installation rig (excavator with the "stitcher" mast) and an on-site grout mixing and delivery unit (mixing hopper, pumps, hosing, power supply, etc.).



Batch-mix amendment ingredients in Elkin Mixer

Deliver amendment into hopper and displacement pump

Pump amendment up mast and into mandrel for emplacement

For Our Application…

Repurpose "Grout Bomber" technology to deliver remedial amendments (ZVI and oil) in the subsurface, *not* cement grout.

Figure ES-2. Grout Bomber Equipment Set Up

Raw material (e.g., sand, cement, aggregate) is loaded into a volumetric mixer (e.g., Elkin mixer), where it is mixed to the appropriate consistency, unloaded into the hopper, and pumped to the top of the "stitcher" mast via flexible, reinforced hose at a rate of approximately 0.25 cubic feet per pump stroke. At the exit end of the Bomber mandrel, the "grout mixture" flows in a continuous and uniform manner, filling the column and surrounding voids with grout as the mandrel is lifted from the desired depth to the surface. Hundreds of grout columns can be installed per day.

For this ESTCP project, the proposed application of the Grout Bomber technology was to replace the cement grout with a remedial amendment mixture (ZVI, sand, and vegetable oil) without any modifications to the existing equipment and assess the capabilities of the technology for rapid delivery of amendments into low-k zones (clays, silts). Key features of the proposed application of the Grout Bomber include:

Rapid installation of reaction columns within the source area. Utilize the Grout Bomber equipment to quickly install hundreds of reaction columns (3.5 in. diameter) per day, spaced 2-3 ft apart, to a depth of 30 ft bgs or greater.

Create amendment-filled reaction columns within the treatment zone. For our application, remediation amendment (mixture of ZVI/sand/water or oil/sand) was delivered into the subsurface (from bottom to top) to create vertical reaction columns. Minor amounts of neat soybean oil were used primarily to improve flow properties and pumpability of the ZVI amendment mixture and, secondarily, to serve as an electron donor to promote biotic reduction dechlorination of CVOCs.

Create hundreds of vertical reaction zones within the source area. Columns containing amendment serve as reactive interfaces (3.5 in. diameter) with the surrounding subsurface media. These vertical reaction zones stimulate biotic and/or abiotic degradation processes and drive steep concentration gradients which, in turn, promote diffusion of contaminants entrapped in surrounding low-k units. In the presence of ZVI, CVOC degradation proceeds abiotically via a combination of reductive β-elimination reactions (generating chloroacetylene and acetylene as intermediate products) and hydrogenolysis reactions (producing *cis*-1,2-DCE and vinyl chloride and ultimately ethene and other end products).

Not an injection technology, but treats low-k clays/silts by reducing contaminant diffusion lengths. This application of the Bomber technology relies on diffusion to draw the contaminants from low-k zones to the reaction column. The diffusion of CVOCs is driven by steep concentration gradients between the pore water within the reaction column and the surrounding media (see **Figure ES-3**). The "long tail" of contaminant flux from low-k units can be significantly reduced if the diffusion lengths associated with matrix diffusion are reduced. Our hypothesis is that reaction columns spaced every 2-3 ft within the plume center of mass would greatly reduce the back diffusion time as the contaminant only has to travel 1-1.5 ft to the nearest treatment zone.

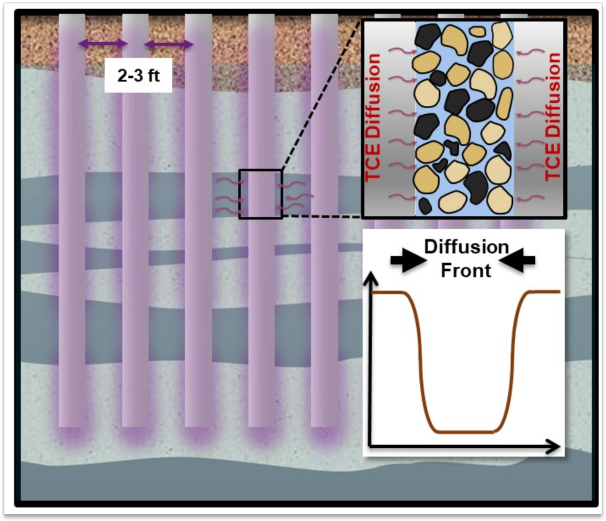


Figure ES-3. Illustration of TCE Diffusion Towards the Closely-spaced Reaction Columns

PERFORMANCE ASSESSMENT

The Bomber technology successfully met the established performance objectives as follows:

Installation Speed and Efficiency: Considering only fully-operational days (i.e. no weather or equipment related delays), an average of ~119 columns were installed per day, with a range of 82-180 columns per day. A total of 800 columns were installed over the course of 7.5 days (including half days due to weather or equipment related delays). This exceeded our goal of an average of 75 columns per day and confirms the technology's ability to install reaction columns quickly and efficiently. A total of 77,000 lbs (~39 tons) of ZVI was emplaced during the field demonstration into an approximately 5,200 yd^3 treatment zone.

Rate of Remediation Amendment Mixing: During the field demonstration, one operator was designated for replenishing the mixing truck bins with sand, ZVI, water, and oil as needed. This made material loading/mixing a continuous process and eliminated the need to prepare the amendment in batches. As result, material loading and amendment preparation did not halt operation and continuous operation of the installation rig was maintained.

Distribution of Amendment to Treatment Depth: Based on field observations, all columns received amendment that filled >90% of total column length (~30 ft) based on mass estimates and number of pump strokes per column. Most of the MST samples (7 of 10) resulted in ZVI content within ±30% of desired dosage (28%-52%). Three samples had ZVI content >52% (54%, 81%, and 88%).

Removal of Contaminant Mass: Groundwater data was collected at seven post-installation monitoring events over a period of 26 months and compared to baseline sampling results prior to column installation. For the wells with detectable CVOC concentrations during the baseline event (IS17MW04, MW12, MW14, and MW16) a greater than 70% reduction in TCE concentrations was observed relative to baseline concentrations after approximately two years. Degradation products (cis-1,2-DCE, vinyl chloride, ethene) were consistently detected in source area monitoring wells (due to several processes, including degradation via ZVI) and Continuous Multichannel Tubing (CMT) wells throughout the monitoring period, and acetylene (via degradation from ZVI) was detected in one monitoring well (IS17MW04) in four of eight post-installation groundwater sampling events and in two CMT intervals (CMT-1-Middle, CMT-1-Lower during 3 sampling events. Soil vapor results identified gaseous "higher coupling products" (>C3; e.g., propane, propene, butane, pentane, and hexanes) associated with the β-elimination pathway induced by the ZVI addition in the vadose zone directly above reaction columns.

Ability to Place Reaction Columns and Ease of Amendment Delivery: Site clearing activities were required (e.g. removal of trees and ground debris) to accommodate large installation rig/equipment. Additionally, the heavy rig required timber mats be laid in the demonstration area to retain mobility in muddy conditions. The Bomber rig has limited ability to install columns on steep slopes, to advance columns in areas with large tree roots, and has limited mobility in tight spaces (e.g. between wells, trees, etc.). The Grout Bomber rig itself has a footprint of 12-ft x 10.5-ft and requires support from an Elkin mixer (truck-powered mixer with a 8-ft x 10-ft feet footprint) and the hopper/amendment pump (4-ft x 3-ft trailer-mounted equipment). Additional footprint requirements include a bermed overspill/mixing area (~8-ft x 8-ft), storage area for amendment raw materials, and room for a reaching forklift to move sacks from the storage to the Elkin mixer. Loss of amendment was limited to clogging events when operators would detach hosing and clean out pump hopper and hoses. Some material loss at ground surface due to "over pumping" by pump operator. During normal operation, very minimal amendment loss was observed, and collection/ reuse of the over-pumped amendment can be managed using shovels.

COST ASSESSMENT

Costs associated with the field program have been used to develop costs for a typical full-scale implementation of the Grout Bomber technology at a chlorinated solvent source zone. Standard costs for implementation of the field demonstration include: i) baseline characterization activities (groundwater sample collection; analytical costs, labor); ii) remedial amendments (ZVI, oil) and other materials (sand, bentonite); iii) day rates for the Bomber equipment (excavator, Elkin mixer, fork-lift) and labor (4 personnel); iv) labor for site supervision; v) standard supplies, shipping, and equipment rental; and vi) sample analysis of groundwater after reaction column installation. Actual costs for the field demonstration at Site 17 were higher than for typical site conditions due to site clearance and preparation, weather delays and weather-related expenses, geophysical surveys, installation of CMTs and soil vapor probes for performance monitoring, and analytical costs for CMTs and soil vapor probes. These costs may not be incurred at all sites. Including only standard costs, the total cost for the field demonstration was \$399K, which translates to ~\$77/yd^3 of treatment volume. The cost for strictly installation of the reaction columns (excluding baseline and performance monitoring) was \$294K, or ~\$56/yd^3 of treatment volume.

IMPLEMENTATION ISSUES

This ESTCP project utilized the Grout Bomber compaction grouting technology to quickly install ~800 vertical reaction columns in a low-k site source zone. Re-purposing of the Grout Bomber technology for installation of ZVI reaction columns in low-k media presented a few implementation issues associated with i) preliminary pilot testing to determine appropriate remediation material mixture that satisfied both pumpability and treatability criteria, ii) site access and large area for equipment staging, and iii) general mobility of large equipment in a tight work environment.

1.0 INTRODUCTION

This Final Report summarizes the approach and results of a field demonstration project to assess and validate the application (or "repurposing") of a geotechnical technology to improve delivery of remediation amendments at sites with contaminants trapped in low-permeability (low-k) media (e.g., clays, silts). This project was performed in collaboration with Environmental Security Technology Certification Program (ESTCP) and the Naval Facilities Engineering Command (NAVFAC).

1.1 BACKGROUND

A critical challenge preventing many chlorinated solvent (or chlorinated volatile organic compound [CVOC]) sites from reaching groundwater cleanup goals is the long-term and persistent release of residual contaminants from low-k media (e.g., clays, silts). Sites dominated by matrix diffusion processes are very difficult to remediate and have the effect of significantly prolonging restoration timeframes and increasing long-term site management costs for the Department of Defense (DoD) (SERDP/ESTCP, 2013; 2018). These matrix diffusion-dominated sites are increasing as a percentage of total DoD chlorinated solvent sites as untreated sites continue to age and transform from early to middle-stage sites where dense non-aqueous phase liquid [DNAPL] sources are active to late-stage sites where matrix diffusion effects dominate (**Figure 1.1**; Sale et al., 2008). Further, as more chlorinated solvent sources are treated and the bulk of the DNAPL is removed, low-k source zones remain large contributors of CVOC mass to surrounding groundwater, resulting in persistent CVOC concentrations that are orders of magnitude above site-specific goals and too high to rely strictly on natural attenuation mechanisms for treatment within a reasonable timeframe.

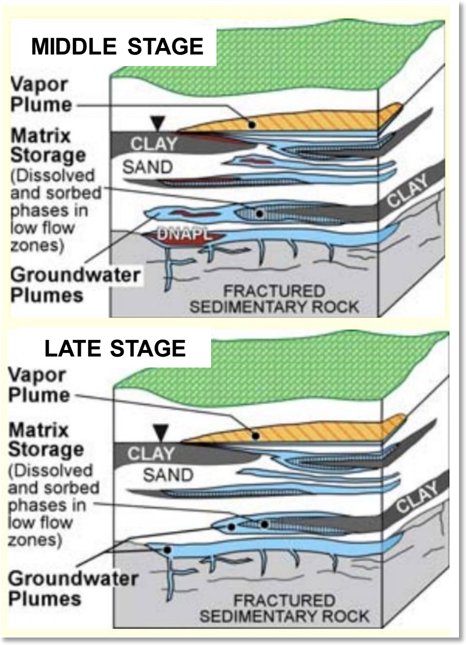


Figure 1.1. Middle and Late Stages of a Chlorinated Solvent Release

(adapted from Sale et al., 2008)

One of the common side effects of matrix diffusion is "rebound" of contaminant concentrations after an *in situ* treatment is applied. This has been observed at sites treated with chemical oxidation (e.g., McGuire et al., 2006; Krembs et al., 2010; McGuire et al., 2016) and has the potential to occur at *in situ* bioremediation sites after long-term depletion of electron donor (Adamson et al., 2011).

Currently, there are limited remediation options available to treat residual contamination trapped in low-k zones. Direct injection for enhanced *in situ* bioremediation (EISB) in low-k zones is limited by the capacity of the materials to receive the amendment and, as a result, may fail to achieve adequate amendment distribution and direct contact with entrapped contaminants. Hydraulic fracturing has shown demonstrative improvements to amendment delivery in low-k settings, though with some notable drawbacks including the potential for amendment surfacing and the unpredictable nature of induced fracture propagation. Excavation or large diameter auger soil mixing may require cost prohibitive and intensive measures to exhume contaminated soil or achieve contact area with amendments such as zero valent iron (ZVI), though with minimal to no operation and maintenance (O&M) requirements beyond long-term monitoring. Thermal treatments such as electrical resistivity heating have shown some promise in low-k contaminant zones, although costs can be relatively high, and require additional infrastructure (e.g., soil vapor extraction) to extract and treat gaseous products generated during treatment. Recent work from another ESTCP project (ESTCP ER-201325; Cox et al., 2018) has shown promise using electrokinetic-enhanced amendment delivery for *in situ* bioremediation (EK-BIO) in a clay soil-dominated shallow aquifer (Geosyntec 2018). EK-BIO practitioners demonstrated improved amendment (lactate) delivery in low-k zones and subsequent CVOC treatment after 14 months of pilot system testing. The EK-BIO technique, like most in situ techniques, requires periodic amendment addition to the supply wells to sustain favorable conditions for biodegradation and regular O&M of the above ground equipment.

For these long-lived, difficult-to-treat sites, inexpensive (in units of dollars per cubic yard, or dollars per acre) technologies are needed that will: i) reliably address mass flux limitations of contaminants leaving low-k source zones; and ii) increase the actual treatment of the contaminants leaving these low-k zones by enhancing natural attenuation processes. Further, such a technology should have "minimal ongoing operational and monitoring costs and be capable of providing long term protection over large areas if necessary" (SERDP/ESTCP, 2013). The geotechnical industry offers a variety of well-established techniques for quickly and efficiently accessing the subsurface for the purposes of ground stabilization, foundation rehabilitation, porewater drainage, and structural support. The speed and efficiency of these techniques is advantageous to the field of environmental remediation, particularly for emplacement of remedial amendments (e.g., ZVI, vegetable oil, chemical oxidants) into the subsurface at contaminated sites. Two promising techniques with potential environmental applications were evaluated as part of this ESTCP project:

- **Prefabricated vertical drains (or "wick drains"):** Wick drains are used to accelerate consolidation of silts and clays by creating closely-spaced artificial vertical pathways for drainage of porewater, prior to infrastructure development. Specialized machinery called a "stitcher" quickly installs the drains via a direct push technique into fill or natural soils in a production line technique, resulting in hundreds of wicks installed per day to depths greater than 80 ft below ground surface (bgs). A detailed description of the wick drain technology is presented in **Section 2.2** and additional documentation from geotechnical contractor, Hayward Baker is included in **Appendix B**.

- **Cement Grouting (the "Grout Bomber" or "Bomber"):** The Bomber technology is a soil stabilization technology that delivers cement grout into subsurface voids to displace, densify, and increase stability of surrounding soils. Specialized "stitcher" machinery, similar to the wick drain technology, pushes a mandrel (cylindrical rod) to depth and pumps high viscosity grout into surrounding voids as the mandrel is raised. Like wick drains, hundreds of grout "columns" can be installed per day to depths of 50 to 100 ft bgs. A detailed description of the Bomber technology is presented in **Section 2.1** and additional documentation from geotechnical contractor, Hayward Baker is included in **Appendix C**.

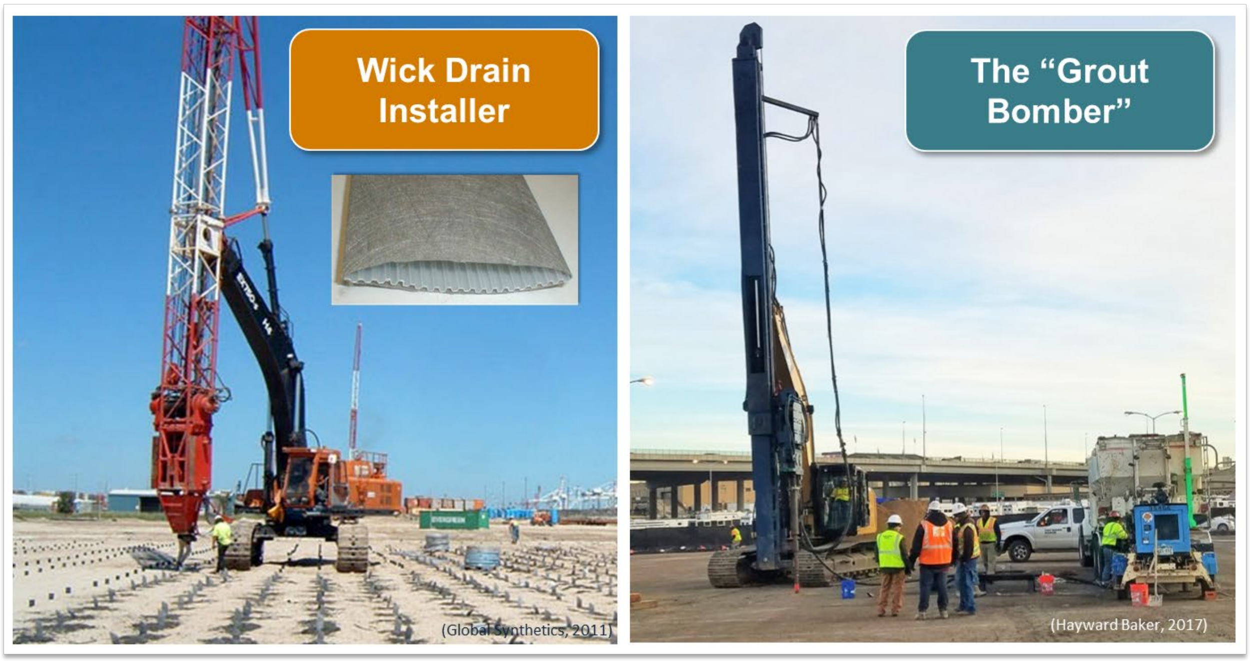


Figure 1.2. The Wick Drain and Grout Bomber Technologies

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of this project was to demonstrate an innovative application (or "repurposing") of a commercially-available geotechnical technology to improve delivery of remediation amendments (e.g., ZVI, vegetable oil, chemical oxidants) at sites with contaminants trapped in low-k zones. We proposed to demonstrate that:

- conventional geotechnical techniques could be used to efficiently install hundreds of closely-spaced vertical reaction columns at contaminated sites;
- a remediation amendment (in this case, a "grout" mixture of ZVI, sand, and vegetable oil) could be delivered into the columns to serve as reactive zones for contaminated groundwater;
- the remediation amendment would stimulate abiotic and/or biotic degradation of CVOCs and generate concentration gradients to drive diffusion of contaminants into the reaction zones; and

- by having closely-spaced (every 2 to 3 ft) vertical reaction zones, CVOC concentrations in low-k zones would be reduced, thus, significantly shortening the "long tail" of contaminant flux commonly observed at these sites.

This project initially focused on the application of wick drains as "reaction columns" for delivery of remediation amendments (e.g., ZVI, vegetable oil) to the subsurface, where the wick drains would be installed first followed by injection of the amendment into the wicks (in this scenario, the wicks serve as conduits for the emplaced remedial amendment). However, following discussions with our geotechnical contractor (Hayward Baker, now Keller), observations from site visits (to observe both wick drain installation and the Bomber technology), and preliminary laboratory testing, the project team concluded that the Grout Bomber was the most viable method to achieve rapid and reliable amendment delivery into the subsurface for the field demonstration.

The Bomber technology applies the same technique and works at a similar efficiency as the wick drain technology, without the need for actual wick drains for delivery of amendment after wick installation. Instead, using the Bomber technology, the remedial amendment can replace the grout and be directly placed into the subsurface from bottom to top (not injected into the surrounding formation), creating hundreds of vertical reaction columns. The "Bomber" technology has the potential to be an attractive remediation alternative for hard-to-treat CVOC source zones, particularly ones with strong matrix diffusion sources over large areas. It provides a method to circumvent the "delivery problem" associated with conventional injection-based remediation approaches, particularly in low-k zones.

1.3 REGULATORY DRIVERS

Overcoming the remediation challenges of difficult-to-treat sites (plagued by matrix diffusion effects) is a priority for the DoD and federal, state, and local regulatory agencies. Residual contaminants trapped in low-k zones serve as a long-term source to groundwater, extending remedial timeframes, increasing capital and O&M costs, and ultimately preventing closure of these sites. Two key directives that focus on remediation of low-k zones are discussed below.

DoD Directives. SERDP/ESTCP recently identified four "Critical" and one "High" research and development needs for sites dominated by matrix diffusion-type sources from low-k zones (SERDP/ESTCP 2013). These types of sites represent an increasing fraction of the DoD's chlorinated site portfolio, as the easier and smaller source zones are successfully treated. Key challenges associated with these difficult-to-treat sites are clearly understood:

- *"The literature demonstrates that zones of lower contaminant mobility can extend the remedial timeframe of a plume by providing a long term release of contaminants into transmissive zones. The contaminant storage and release processes are slow and can occur over the course of decades, perhaps centuries" (SERDP/ESTCP 2013).*
- *"Because these sites have estimated remedial timeframes on the order of decades to centuries, their potential life-cycle costs are high." (SERDP/ESTCP 2013).*

Sites dominated by matrix diffusion-type sources from low-k zones are increasing for two reasons: i) untreated sites continue to age and transform from Middle Stage sites (sites where DNAPL sources are active) to Late Stage Sites (sites where matrix diffusion sources dominate) (Sale et al., 2008); and ii) more chlorinated solvent source zones are treated and the bulk of the DNAPL is removed, but the low-k source zones are still too strong to close the site or rely on monitored natural attenuation (MNA) processes.

Remediation of Complex Sites. Complex sites require significant resources for environmental remediation and long timeframes to achieve remediation objectives due to the scale of contamination (plume size and depth) and complex geology and hydrogeology, which complicate remedial efforts. The National Research Council (NRC) advanced an important concept about managing complex sites called a “Transition Assessment”. The NRC discusses the need for developments that can aid in “transition from active remediation to more passive strategies and provide more cost-effective and protective long-term management of complex sites” (NRC, 2013). The Interstate Technology & Regulatory Council (ITRC) developed guidance to assist site stakeholders (regulators, site owners and managers) with the management of complex sites, including concepts such as adaptive site management and transition assessments (ITRC, 2017).

Successful demonstration of the Grout Bomber technology for efficient delivery of remediation amendments into the subsurface could provide an alternative approach to address residual contamination in low-k zones and large treatment areas at complex sites.

2.0 TECHNOLOGY

This project aimed to "repurpose" a commercially-available geotechnical technology, the Grout Bomber, for rapid and efficient delivery of remediation amendments (e.g., ZVI, vegetable oil) into low-k contaminated treatment zones. Overall, the geotechnical industry offers a variety of well-established techniques for quickly and efficiently accessing the subsurface for the purposes of ground stabilization, foundation rehabilitation, porewater drainage, and structural support. The speed and efficiency of these techniques is advantageous to the field of environmental remediation, particularly for injection and emplacement of remedial amendments at contaminated sites. This section provides an overview of the Grout Bomber technology, including advantages and potential limitations associated with its application at contaminated sites.

2.1 TECHNOLOGY DESCRIPTION

The Grout Bomber is a subsurface stabilization technology that uses an excavator equipped with a specialized "stitcher" mast to quickly push a mandrel (3.5 in. diameter hollow cylindrical rod) into the subsurface and subsequently fill the hole and subsurface voids with cement grout (from bottom to top) using an in-line grout delivery system. As shown in **Figure 2.1a**, the typical arrangement of the Bomber includes the installation rig (excavator with the "stitcher" mast) and an on-site grout mixing and delivery unit (mixing hopper, pumps, hosing, power supply, etc.). Raw material (e.g., sand, cement, aggregate) is loaded into a volumetric mixer (e.g. Elkin mixer), where it is mixed to the appropriate consistency, unloaded into the hopper (see **Figure 2.1b**), and pumped to the top of the "stitcher" mast via flexible, reinforced hose at a rate of approximately 0.25 cubic feet per pump stroke. At the exit end of the Bomber mandrel (see **Figure 2.1c**), the "grout mixture" flows in a continuous and uniform manner, filling the column and surrounding voids with grout as the mandrel is lifted from the desired depth to the surface. Hundreds of grout columns can be installed per day. Additional information on the Bomber technology is presented in **Appendix C**.

Figure 2.1. a) Grout Bomber Equipment Set Up; b) Hopper for Mixing and Delivery of Grout to the Stitcher; and c) Grout Exiting the Mandrel.

For this ESTCP project, the proposed application of the Grout Bomber technology was to replace the cement grout with a remedial amendment mixture (ZVI, sand, and vegetable oil) without any modifications to the existing equipment and assess the capabilities of the technology for rapid delivery of amendments into low-k zones (clays, silts). Specific aims for the field demonstration are described below.

Rapid installation of reaction columns within the source area. Utilize the Grout Bomber equipment to quickly install hundreds of reaction columns (3.5 in. diameter) per day, spaced 2-3 ft apart, to a depth of 30 ft bgs or greater. Column spacing of 2 ft is the closest spacing used for geotechnical applications of this technology and, as such, represents the shortest diffusion length for contaminant transport (discussed below). For geotechnical applications of the Bomber technology, installation rates of 15-25 columns per day are typical since the goal is to fill void spaces in the subsurface (beyond just the space created by the mandrel), as it is raised from the design depth to the surface. For our purposes, installation rates of greater than 75 columns per day were expected (and realized) since only the volume of the hole (created by the mandrel) was filled with remediation amendment (no amendment was injected into the surrounding formation).

In some ways, the Grout Bomber technology represents a simpler, less intensive, and easier to install version of complete soil mixing, although direct contact between the contaminant and amendment is only created along the interface of each column and not mechanically achieved by physical mixing. As a result, migration of CVOCs into the reaction columns is driven by diffusion and treatment times are expected to be longer (discussed below). In addition, the Bomber offers a speed advantage over traditional direct-push technique (DPT) injections by advancing to total depth in a single hydraulically-forced push (typically 1-2 minutes from top to bottom and then bottom to top) rather than requiring multiple sections of pipe and hydraulic hammering (ASTM, 2005). Additionally, the amendment is pumped into the column to fill only the void created by the 3.5-in Bomber mandrel rather than relying on acceptance capacity of geologic formation for the injectate. As result, spacing of reaction columns can be significantly reduced relative to typical well spacing for conventional injection techniques (see **Figure 2.2**).

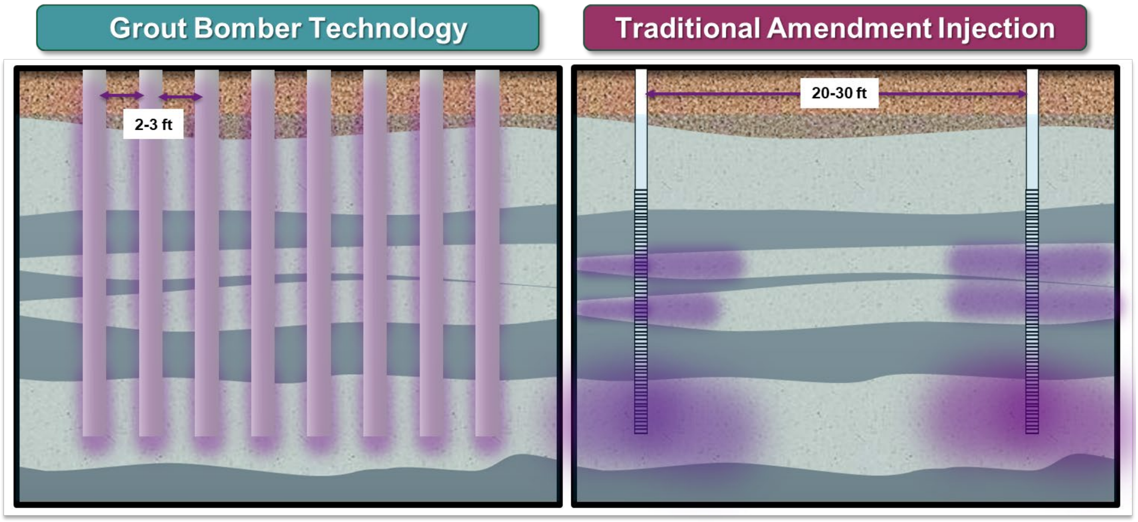


Figure 2.2. Illustration of Grout Bomber Reaction Column Spacing Compared to Traditional Amendment Techniques

Create amendment-filled reaction columns within the treatment zone. For our application, remediation amendment (mixture of ZVI/sand/water or oil/sand) was delivered into the subsurface (from bottom to top) to create vertical reaction columns. Minor amounts of neat soybean oil were used primarily as a lubricant to improve flow properties and pumpability of the ZVI amendment mixture and, secondarily, to serve as an electron donor to promote biotic reduction dechlorination of CVOCs.

Create hundreds of vertical reaction zones within the source area. Columns containing amendment serve as reactive interfaces (3.5 in. diameter) with the surrounding subsurface media. These vertical reaction zones stimulate biotic and/or abiotic degradation processes and drive steep concentration gradients which, in turn, promote diffusion of contaminants entrapped in surrounding low-k units. In the presence of ZVI, CVOC degradation proceeds abiotically via a combination of reductive β-elimination reactions (generating chloroacetylene and acetylene as intermediate products) and hydrogenolysis reactions (producing *cis*-1,2-DCE and vinyl chloride and ultimately ethene and other end products). The β-elimination reaction is generally the dominant pathway for ZVI-mediated TCE degradation. One benefit of the abiotic pathway for TCE degradation is potential for bypassing the generation of regulated intermediates (*cis*-1,2-DCE and vinyl chloride) in favor of the chloroacetylenes, which are unstable and rapidly reduce to ethene via β-elimination. Laboratory studies of TCE degradation by ZVI report that <10% by mole of initial TCE appears as daughter products *cis*-1,2-DCE and vinyl chloride via the slower hydrogenolysis pathway (Gillham et al., 2010; ITRC 2011; Wilkin et al, 2018).

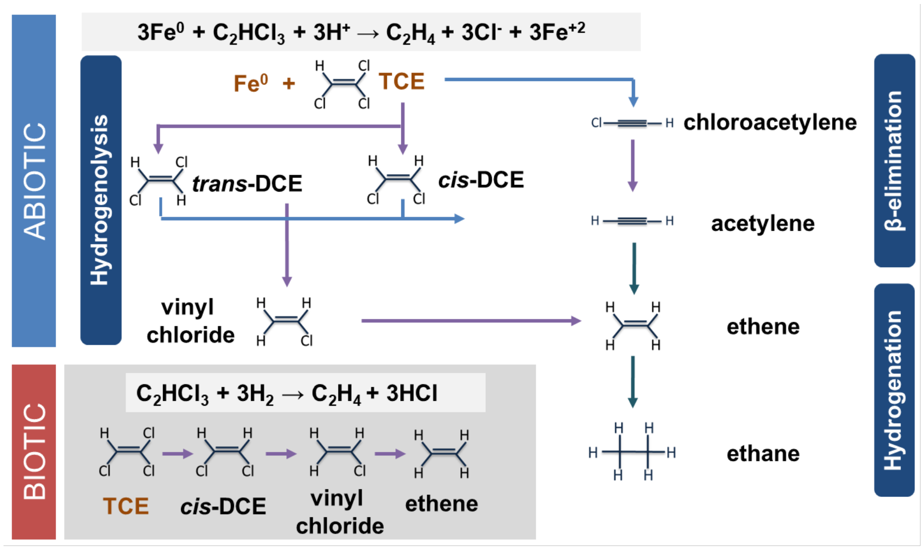


Figure 2.3. Abiotic and Biotic Reductive Dechlorination Pathways

Not an injection technology, but treats low-k clays/silts by reducing contaminant diffusion lengths. This application of the Bomber technology relies on diffusion to draw the contaminants from low-k zones to the reaction column. The diffusion of CVOCs is driven by steep concentration gradients between the pore water within the reaction column and the surrounding media (see **Figure 2.4**). The "long tail" of contaminant flux from low-k units can be significantly reduced if the diffusion lengths associated with matrix diffusion are reduced. Our hypothesis is that reaction columns spaced every 2-3 ft within the plume center of mass would greatly reduce the back diffusion time as the contaminant only has to travel 1-1.5 ft to the nearest treatment zone.

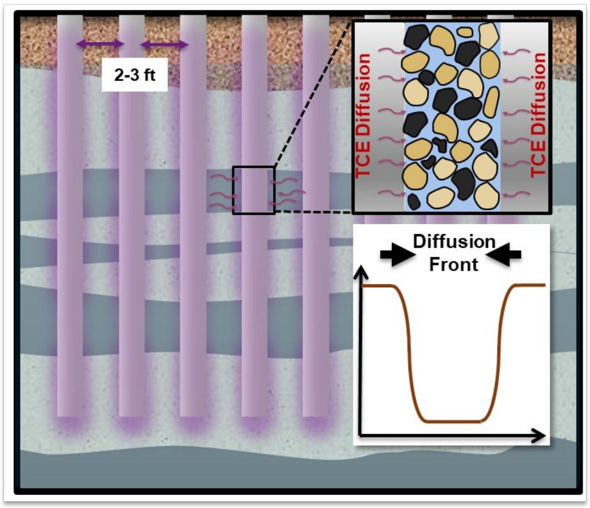
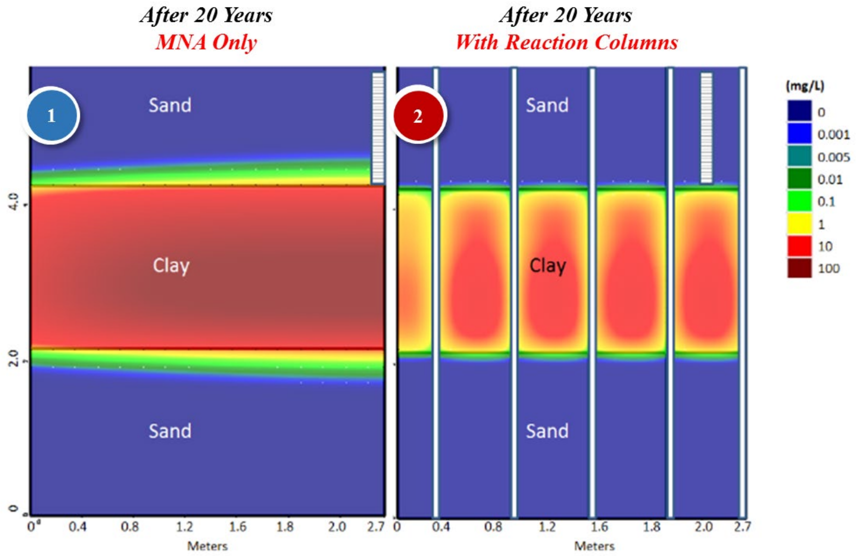


Figure 2.4. **Illustration of TCE Diffusion Towards the Closely-spaced Reaction Columns**

As proof-of-concept, a MODFLOW/MT3D model was developed to simulate a 2.7 m long, 6 m thick saturated zone with a 2 m thick clay layer in the middle containing TCE at ~20 mg/L. Under an MNA-only scenario, most of the contamination remained after 20 years (see **Figure 2.5a**). However, by installing reaction columns at 2 ft centers, significant reductions in TCE concentrations were achieved over the same time period (see **Figure 2.5b**).

The difference in TCE concentration at a hypothetical monitoring well screened in the upper sand is shown in **Figure 2.6**. Under MNA, it would take greater than 500 years to reach maximum contaminant levels (MCLs) in this well. With reaction columns, TCE concentrations fell below the MCL (5 µg/L) after ~26 years.


After 20 Years
MNA Only

After 20 Years
With Reaction Columns

Figure 2.5. **MODFLOW/MT3D Vertical Transect Simulation Showing Impact of Matrix Diffusion for a) MNA-only Case and b) Case with Reaction Columns Installed on 2-ft Spacing.**

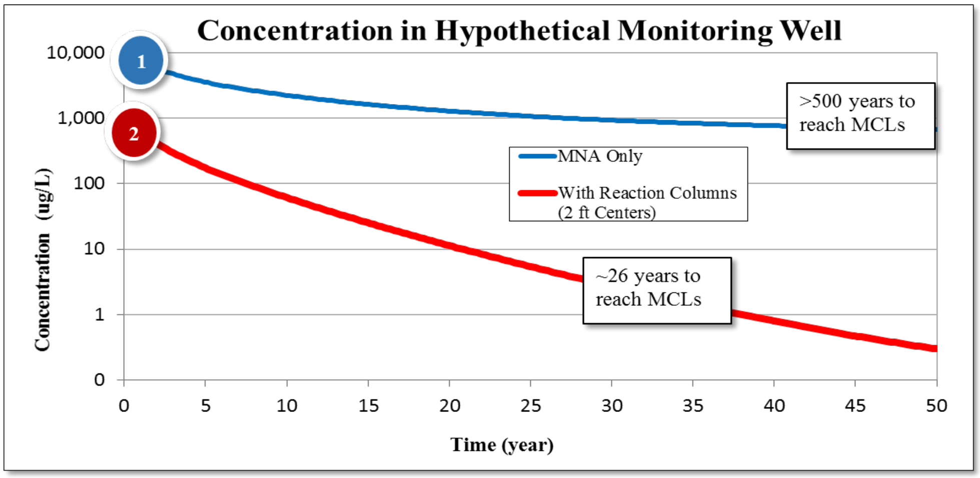


Figure 2.6. MODFLOW/MT3D Simulation Showing Concentration in Hypothetical Monitoring Well with 10-ft Screen for the MNA-only Case (blue line) and Concentrations When Reaction Columns Are Installed (red line).

Note log-scale for y-axis.

2.2 TECHNOLOGY DEVELOPMENT

This project initially focused on the application of prefabricated vertical drains (or wick drains) for delivery of remediation amendments to the subsurface. Wick drains are used in the geotechnical industry to accelerate consolidation of silts and clays by creating closely spaced artificial vertical pathways for drainage of porewater, prior to infrastructure development. Specialized machinery quickly “staples” the drains via a direct push technique into fill or natural soils in a production line technique, resulting in hundreds of wicks installed per day (see **Figure 2.7a**). The drains are 4 in. wide and ¼ in. thick, consisting of a geotextile filter-wrapped plastic strip with extruded channels that allow water to slowly flow into the drain, but keeps soil particles out (see **Figure 2.7b**). A detailed description of the wick drain technology is provided in **Appendix B**.

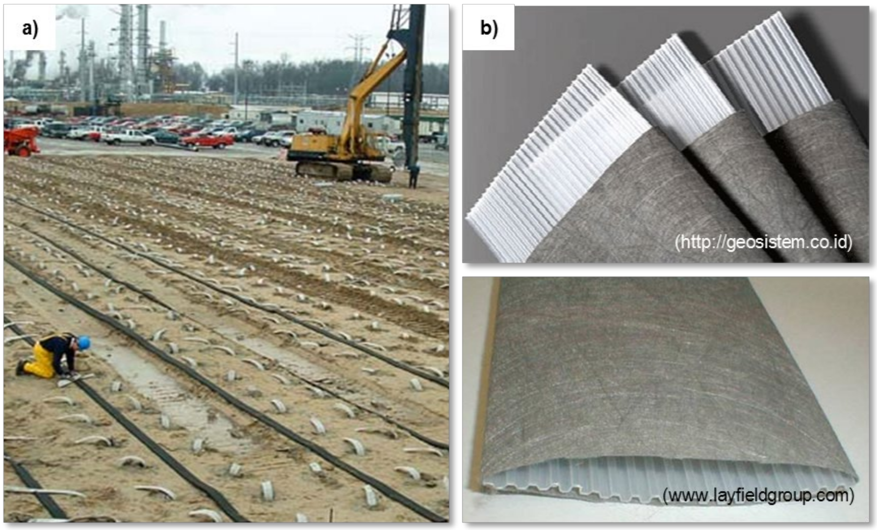


Figure 2.7. a) Wick Drain Installation and Spacing; b) the Center Core and Filter Sleeve

As an environmental application, wick drains would serve as closely-spaced vertical reaction zones (or reaction vessels), where remediation amendment is distributed into the wicks (along the channels of the plastic core) following installation. However, preliminary laboratory experiments identified some challenges with delivery of neat vegetable oil and, to a lesser extent ZVI slurry, along the length of the wick drains. Results from the small-scale demonstration (conducted at Rice University Design Kitchen) are provided in **Appendix D** and briefly described below.

- **Neat Vegetable Oil Distribution.** A 15-ft column test was conducted to determine the distribution of neat vegetable oil within a wick drain under saturated conditions (see **Figure 2.8a**). The test consisted of a 15-ft long, 6 in. diameter polyvinyl chloride (PVC pipe), filled with water, and a wick drain placed inside and along the centerline of the PVC pipe. Acrylic pieces were attached to the wick drain on either side to simulate low-k zones; gaps between pieces simulated high-k zones. Under a variety of head scenarios, distribution of oil in the wick drain was limited to the upper 3-4 ft of saturated length, due to the opposing buoyancy forces. This result was not completely unexpected and therefore an alternate amendment, ZVI, was investigated.

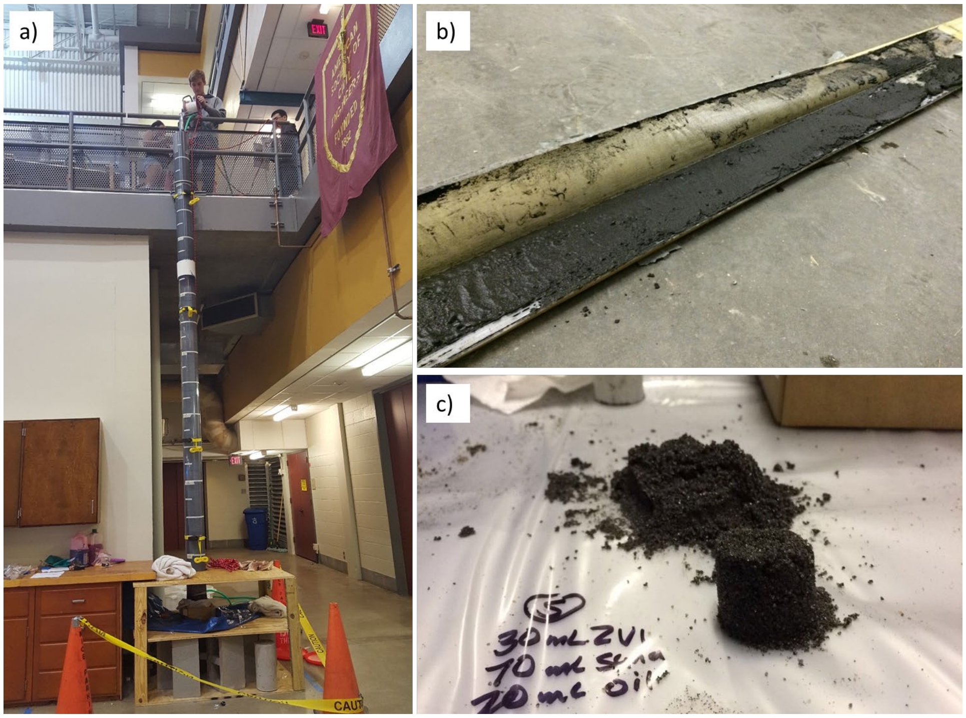


Figure 2.8. a) 15-ft Column Test Performed by Rice University; b) Distribution of ZVI Along Wick Drain Core; c) a Test Mixture of ZVI, Sand, and Vegetable Oil.

- **ZVI Distribution.** In a separate test, a ZVI slurry (1:20 ZVI:water) was successfully distributed along the length of a wick drain (see **Figures 2.8b and c**), with some minor clogging at the inlet and passing of finer particles through the filter sleeve. ZVI offers an advantage over neat oil, given that i) it is not subject to the same buoyancy limitations, and ii) it was successfully applied at Site 17 as part of a soil mixing remediation project for the South Plume area (see **Section 4.1**). Several particle sizes of ZVI were evaluated to reduce mass escaping the filter sleeve while allowing distribution along the wick drain.

Alternatively, the project team considered “pre-loading” of amendment into the wick drain during the wick drain manufacturing process (before the filter sleeve is wrapped around the plastic core). Under this scenario, the pre-loaded wick drains would be installed at a site in exactly the same manner as conventional wick drains; however, there would be no need for amendment addition after the pre-loaded wicks are emplaced into the subsurface. GSI’s geotechnical contractor (Hayward Baker) manufactures wick drains at an in-house manufacturing facility. GSI visited the manufacturing facility to evaluate minimally invasive approaches for filling the wicks with amendment during the manufacturing process. Observations suggested that pre-loading the wicks would be possible; however, major alterations to the manufacturing process would be required.

Ultimately, leveraging the expertise of Hayward Baker and the results from the small-scale demonstration, the Grout Bomber technology was identified and evaluated as a means to rapidly and efficiently deliver remediation amendments into the subsurface. Similar to the wick drain approach, the appeal of the Bomber method is its ability to install hundreds of grout columns over a large area in a relatively short timeframe (days to weeks). It uses a similar direct-push technique to the wick drain technology to push the mandrel into the subsurface; however, the Bomber technology eliminates the need to use wick drains, and offers a solution to the amendment delivery challenges observed during the small-scale demonstration. This method was consistent with the major project objective of repurposing a geotechnical technology to improve delivery of remediation amendments to low-k zones.

Prior to the field demonstration, a pilot test was conducted at the Hayward Baker yard in Denver, CO to field-test various ratios of amendment components including ZVI, sand, and water and soybean oil and an organic foam additive as potential lubricants or proppants to aid in pumping of the mixture. In total, four different ZVI/sand amendment mixtures of water, oil, and/or foam additive were mixed and tested for mix efficiency and pumpability, and an additional five mixtures were tested without ZVI for the oil/sand columns. Use of the foam additive added significantly to labor effort without noticeable benefit to pumpability or amendment consistency. Field observations indicated that only minimal oil was required in the early stages of pumping to “prime” (lubricate) the hose. As such, the oil fraction of the mixture was reduced in the ZVI amendment to 4-5% by volume (~0.67 gallons of vegetable oil per ZVI reaction column), generating an amendment slurry of approximately 35% solids (as calculated by mass of solids divided by mass of solids plus water). Photos of the various mixture testing are provided in **Appendix M**.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Advantages of the Technology

The Bomber technology has the potential to be an important remediation alternative for difficult-to-treat chlorinated source zones, particularly ones with large, persistent matrix diffusion sources over large areas. Large amounts of remedial amendment can be emplaced in the subsurface as a closely-spaced network of vertical reaction columns. These reaction columns can be composed of custom-designed remedial mixtures (ZVI, vegetable oil, chemical oxidants) that address the specific needs of a contaminated site based on contaminant type and distribution. The speed and efficiency of the Bomber (>100 columns per day) has the potential to lower treatment costs of extensive injection remedies. Applied to a typical DoD middle-to-late-stage site, estimated treatment costs for the Bomber technology (including equipment, materials, mobilization, labor) are approximately \$50 per cubic yard of source zone treated, which is in the lower range of the reported unit cost per cubic yard for enhanced *in situ* biodegradation (EISB; \$20-\$180/yd^3) and , chemical oxidation (\$40-200/yd^3), and less than thermal remediation (\$120-\$300/yd^3) (Federal Remediation Technology Roundtable; McDade et al. 2005; McGuire et al., 2016). As discussed in the **Section 8.1.2**, actual costs for this field demonstration were higher than expected for a typical site, including additional budget for treatability studies, weather delays, and site access issues.

The Bomber technology has the added benefit of being adaptable to a variety of site-specific conditions because of the following features:

- flexibility to various amendment types and mixtures such as ZVI, neat oil/sand, ZVI/oil, or potentially other mixes,
- minimal modifications to existing Bomber equipment are required to accommodate remedial amendment mixtures as a replacement for cement grout, and
- column depths of up to 100 ft bgs can be reached using this technology, creating 50-gallon capacity columns (empty volume). For the field demonstration, a column depth of 30 ft bgs was targeted (see **Section 5.3.3**), each of which was filled with approximately 15 gallons of ZVI/sand or oil/sand mixture. Columns are typically installed in a triangular or square grid pattern at 2 or 3 ft centers, although larger spacing can be employed.

The Bomber technology can also be used to install various sampling devices such as sample tubing, piezometers, transducers, and other data logging sensors into the subsurface, using a technique called “bottom feeding.” As explained in **Section 5.3.3** this method is achieved by feeding the device up through the bottom of the mandrel. The device is stabilized inside the mandrel using an anchor plate and pushed into the subsurface along with the mandrel. When the mandrel is retrieved, the device is left in-place and the annulus around the device is filled with the desired media (e.g., amendment, grout, sand, etc.). This capability offers a great deal of sampling and measurement alternatives to aid in site characterization and performance monitoring of remedies. For the field demonstration, four continuous multi-level tubing (CMT) wells were installed using this technique to monitor CVOC concentrations within the reaction columns.

2.3.2 Limitations of the Technology

General implementation issues to successful deployment of the Bomber technology are: i) site access due to the large footprint of the equipment and the need for closely spaced reaction columns; ii) subsurface lithology limitations (i.e., cannot penetrate bedrock or materials with blow counts greater than 35); and iii) since the application of the technology in low-k source zones relies on diffusion for contaminant migration, longer treatment times can be expected before beneficial results are observed, relative to conventional injection techniques that are typically applied to sandy water bearing units. An additional limitation of the technology is that the depth of remedial amendment installation is limited by the height of the Bomber rig’s mast. Although the rig utilized for this ESTCP project field demonstration extended to a height of 40 ft, rigs capable of reaching depths up to 100 feet have been developed by Hayward Baker.

One final technical issue that requires consideration on a site-by-site basis is the potential for DNAPL mobilization. If reaction columns are installed through DNAPL pools and through any underlying confining units, vertical downward migration is possible. In a small number of cases, this might be considered a benefit if mobilized DNAPL is captured by an existing pump and treat system or downgradient reactive barrier that is screened or positioned within the lower transmissive zone. In our experience, the presence of DNAPL in pools is relatively rare and has not prevented other injection-based projects that rely on chemical oxidation, chemical reduction, or biodegradation. Our conceptual model is that most DoD sites are likely in the Middle or Late Stage (Sale et al., 2008) where mobile DNAPL is not an important part of the conceptual model. However, for sites where the presence of mobile DNAPL has not been ruled out, DNAPL delineation tools and guidance should be considered, such as the ITRC Integrated DNAPL Site Characterization and Tools Selection Guidance (ITRC, 2015), the ESTCP Direct-Push Optical Screening Tool for High-Resolution, Real-Time Mapping of Chlorinated Solvent DNAPL Architecture (ESTCP Project ER-201121), the use of hydrophobic dyes to confirm presence of DNAPL, and other relevant resources.

3.0 PERFORMANCE OBJECTIVES

The goal of this project was to demonstrate the Grout Bomber technology's ability to quickly and efficiently deliver large amounts of remedial amendment to low-k source zones and to evaluate the extent to which diffusion-based reaction columns can treat low-k media. To evaluate the overall performance of the Bomber technology at the field site, several qualitative and quantitative performance objectives were established, as summarized in **Table 3.1**. As part of the field demonstration, a focused geophysical survey and detailed groundwater and soil vapor sampling were performed (see **Sections 5.5.1** and **5.5.3**) to evaluate distribution of amendment, changes in geochemistry and contaminant concentrations, and to determine efficacy and adaptability of the system for chlorinated solvent degradation.

Transition from the wick drain technology to the Bomber technology prompted some minor deviations from the original performance objectives outlined in the full proposal and Draft Site Selection Memo. Most notably, the Bomber technology did not require an additional crew to follow behind the installation rig to inject amendment, thus eliminating the concern for "lag time" between installation and amendment addition. The performance objective (Quantitative Objective 2) considered the time to "replenish" the on-site mixing and delivery unit as a criterion for success (see **Table 3.1**). Summaries of the five quantitative performance objectives and the results from the field demonstration are provided in the sections below.

3.1 PERFORMANCE OBJECTIVE: INSTALLATION SPEED AND EFFICIENCY

For our application of the Bomber method, installation rates of greater than 75 columns per day were expected since only the volume of the hole (created by the mandrel) was being filled with remediation amendment (no amendment was injected into the surrounding formation). The speed and efficiency of this technique, combined with the close spacing of the reaction columns, makes this a potential cost-effective treatment method, relative to conventional injection-based remedies (e.g., injection well installation; direct-push injections).

- **Data Requirements:** The number of reaction columns installed on a daily basis was recorded during the field demonstration.
- **Success Criteria:** The project team aimed to install at least 75 reaction columns (considered "highly efficient") each field day. The average number of reaction columns installed per day over the course of the column installation program should not be less than 50 columns.
- **Results:** Considering only fully-operational days (i.e. no weather or equipment related delays), an average of ~119 columns were installed per day, with a range of 82-180 columns per day. A total of 800 columns were installed over the course of 7.5 days (including half days due to weather or equipment related delays). This exceeded our goal of an average of 75 columns per day and confirms the technology's ability to install reaction columns quickly and efficiently. **Table 6.1** shows the number of reaction columns installed per day while in the field and demonstrates that this criterion has been met.

Table 3.1. Performance Objectives for the Field Demonstration

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
1. **Installation Speed and Efficiency:** Install reaction columns as fast as they are installed in geotechnical applications.	Number of reaction columns installed per day.	Average of at least 75 reaction columns per day for best day of production; average of at least 50 per day after full-scale start of installation sequence.	Averaged >100 reaction columns per day on full production days (i.e. days without weather related delays). Installed 180 columns on most productive day.
2. **Rate of Remediation Amendment Batch Mixing:** Confirm amendment batch replenishment to mixer is not a "rate limiting step" during construction.	Amount of time it takes the amendment mixing and delivery unit (e.g. mixer, pumps, etc.) and crew to prepare a new batch of amendment. Number of batches required each day.	Amendment batch mixing and loading should not exceed 1-hr; continuous operation of installation rig is maintained (>90% uptime)	Amendment batch mixing/loading was a continuous process during operation as one designated operator would replenish material as needed; material loading did not halt operation. Continuous operation of installation rig of >90% was maintained.
3. **Distribution of Amendment to Treatment Depth:** Prove we can deliver amendment to target treatment depth and proportionately throughout the reaction columns at desired dosage.	Magnetic separation tests (MSTs), mass and volume estimates (pump strokes), and geophysical survey (electrical resistivity) image comparisons to evaluate amendment distribution.	Based on mass estimates and number of pump strokes, 90% of total column length should contain ZVI/sand or oil/sand mixture. Based on magnetic separation tests, ZVI amendments should be within ±30% of desired dosage (e.g. 28%-52% ZVI). Oil columns should contain a minimum of 10% (of pore volume) oil by volume.	Based on field observations (mass estimates and pump strokes), all columns received amendment that filled >90% of total column length (~30 ft). Geophysical surveys showed only moderate changes in subsurface conditions following column installations (unclear if amendment distribution contributed to resistivity changes) MSTs were performed on 10 samples; 70% (7 of 10) of samples resulted in ZVI content within ±30% of desired dosage (28%-52%). Three samples had ZVI content >52% (54%, 81%, 88%). A design dosage of 40% of pore volume was achieved for oil columns (~12% by overall volume).

Performance Objective	Data Requirements	Success Criteria	Results
4. **Removal of Contaminant Mass:** Prove ability to remove mass from the system.	Baseline groundwater sampling. Semiannual groundwater monitoring. Two soil vapor sampling events.	Based on groundwater concentrations from within reaction columns after 1-2 years, a minimum 50% reduction (at 95% confidence) in parent compound concentrations is expected. Observed increase in biotic and abiotic daughter products (e.g., *cis*-1,2-DCE, vinyl chloride, acetylene) Increase degradation rate indicated by two modified Natural Source Zone Depletion (NSZD) measurement method(s) used at hydrocarbon sites (gradient method and/or carbon traps) after 1-2 years and/or observed increase in gaseous degradation byproducts in unsaturated zone immediately above the reaction column (ethane, ethene, and higher coupling products)	>50% reduction in concentrations shown in all source area monitoring wells. Maximum of 99.3% reduction in TCE concentration in source area well MW-16 from baseline to 26-month post-install event, coupled with 67% reduction in *cis*-1,2-DCE, increased vinyl chloride (57%) and increased ethene (>100% increase) concentrations. Acetylene was periodically detected in MW-04, including the most recent 26-month event. Propane, propene, butane, pentane, and hexanes were also detected from soil vapor sampling during the 26-mon event. Together these data suggest abiotic CVOC degradation is occurring.
Qualitative Performance Objectives			
1. Ability to place reaction columns at contaminated sites.	Observations of the effective footprint of reaction column installation rig; ability to approach structures and obstacles.	Ability to access most of intended design treatment area once equipment reaches the site (i.e. were unanticipated obstacles observed during install?).	Site clearing activities were required (e.g. removal of trees and ground debris) to accommodate large rig/equipment; heavy rig required timber mats in muddy conditions; limited ability to install columns on steep slopes; refusal in areas with large tree roots; limited mobility in tight spaces.
2. Ease of delivering remediation amendment to columns.	Observations of amendment addition.	Minimal loss of amendment during mixing and delivery process.	Loss of amendment was limited to clogging events when operators would detach hosing and clean out pump hopper and hoses. Some material loss at ground surface due to "over pumping" by pump operator. During normal operation, very minimal amendment loss was observed.

3.2 PERFORMANCE OBJECTIVE: RATE OF REMEDIATION AMENDMENT MIXING

Replenishment and mixing of amendment ingredients (e.g., ZVI, sand, water, and oil) was conducted on-site using a fork-lift (to unload ingredients) and volumetric mixing truck (Elkin mixer; capacity of 8 yd^3; see **Section 5.3.1**). The initial thought was that the amendment would need to be prepared in batches to ensure proper dosing and material ratios were achieved, therefore the project team established the performance objective of monitoring this process as a potential time sink during field implementation. Data requirements and success criteria originally stated for this objective included:

- **Data Requirements:** The amount of time it takes the amendment mixing and delivery unit (e.g., mixer, pumps, etc.) and crew to prepare a new batch of amendment will be recorded. The number of batches required each day will also be recorded.
- **Success Criteria:** Amendment batch mixing and loading should not exceed 1-hr or significantly interrupt continuous operation of installation rig (maintain >90% uptime).
- **Results:** As described in **Section 5.3.2**, one key characteristic of a volumetric mixing truck is that it can be calibrated to supply various materials at specified rates, therefore producing a consistent mixture of material at design ratios. Once the equipment is calibrated, it can be operated continuously if a steady supply of materials is provided. During the field demonstration, one operator was designated for replenishing the mixing truck bins with sand, ZVI, water, and oil as needed. This made material loading/mixing a continuous process and eliminated the need to prepare the amendment in batches. As result, material loading and amendment preparation did not halt operation and continuous operation of the installation rig was maintained. Thus this criterion has been met.

3.3 PERFORMANCE OBJECTIVE: DISTRIBUTION OF AMENDMENT TO TREATMENT DEPTH

The remediation amendment ingredients (ZVI/sand/water, and oil/sand) should be properly proportioned and uniformly mixed to maintain the design dosage (e.g., 40% ZVI/60% sand; ~10% oil/90% sand) throughout the length of the reaction column. The mixed amendment should reach target treatment depths, indicating that a continuous reactive interface with the surrounding media has been achieved.

- **Data Requirements:** Magnetic separation tests (MSTs) were performed on samples collected from installed reaction columns. A total of 10 samples (reaction columns) were analyzed for ZVI content. As a secondary line of evidence, electrical resistivity images from the dedicated geophysical electrode transects were used to identify contrasts between pre- and post-amendment addition.
- **Success Criteria:** Greater than 90% of total column length for the installed columns should contain ZVI or oil, based on resistivity survey results and injected volume estimates (or pump strokes). Using MSTs, the proportion of ZVI should remain within ±30% of desired dosage (i.e., 28%-52% ZVI). Oil columns should contain a minimum of 10% oil by volume.
- **Results:** Based on field observations, all columns received amendment that filled >90% of total column length (~30 ft) based on mass estimates and number of pump strokes per column. Most of the MST samples (7 of 10) resulted in ZVI content within ±30% of desired dosage (28%-52%). Three samples had ZVI content >52% (54%, 81%, and 88%).

Electrical resistivity imaging identified only moderate changes in subsurface conditions following column installations and were not a reliable means to evaluate amendment distribution in the columns due to the nature of the electrode configuration (as discussed in **Section 6.4**). Briefly, dedicated electrode lines were installed (trenched to a depth of 2 ft) prior to reaction column installation in order to capture electrical resistivity images before and after installation without any interferences from moving the electrodes. To avoid damage to the electrodes, the reaction columns were off-set from the electrode lines. Since the electrode lines did not sit directly above the reaction columns, electrical resistivity imaging of the columns was not possible.

Based on the field observations gleaned from MSTs, visual observation of "dog piling" amendment at the surface, and injection volumes estimated from pump strokes, greater than 90% of total column length contained an appropriate dose of ZVI material. Thus this criterion has been met.

For the oil columns, approximately 180 gallons of soybean oil was used to install 100 oil/sand columns. This is consistent with our design dosage of 40% of reaction column pore volume, supplying approximately 12% of total column volume with oil on average. Thus, the minimum 10% oil by volume criterion established for the oil columns has also been met.

3.4 PERFORMANCE OBJECTIVE: REMOVAL OF CONTAMINANT MASS

The overall objective of this project was to demonstrate that the Bomber technology can be used to effectively remove and treat residual contaminant mass retained in low-k materials (clays, silts). Since this technology relies on diffusion (and steep concentration gradients) to draw the contaminants from low-k zones, treatment times longer than a year (i.e., the length of the field demonstration) can be expected before dramatic reductions in parent compounds might be observed. As a result, demonstration of successful degradation of contaminant mass focused on production of reaction byproducts in groundwater and soil vapor within the reaction column, in addition to sampling of groundwater from surrounding monitoring wells.

- **Data Requirements:** Groundwater samples were collected from the existing monitoring wells prior to (baseline), after one month, and at approximate semiannual intervals after installation of the reaction columns. Groundwater sampling from within a subset of reaction columns (via CMT wells) was conducted immediately after column installation, and semiannually thereafter. A modified Natural Source Zone Depletion method (carbon traps) and traditional soil vapor sampling from within reaction column were conducted at approximately 9-months and 20-months after column installation, respectively.
- **Success Criteria:** Successful contaminant mass removal from the system will be indicated by the following: i) minimum of 50% reduction in groundwater concentrations from within the reaction columns after one to two years (at 95% confidence), ii) evidence of parent transformation to abiotic end products after one to two years (i.e. ethene, acetylene, CO_2), and iii) increased degradation rate after one to two years indicated by a modified Natural Source Zone Depletion measurement method(s) used at hydrocarbon sites (e.g. carbon traps) or presence of abiotic reaction products (e.g., propane, propene, hexanes) in soil vapor immediately above select reaction columns (see **Section 5.5.3**).

- **Results:** Groundwater data was collected at seven post-installation monitoring events over a period of 26 months and compared to baseline sampling results prior to column installation. For the wells with detectable CVOC concentrations during the baseline event (IS17MW04, MW12, MW14, and MW16) a greater than 70% reduction in TCE concentrations was observed relative to baseline concentrations after approximately two years.

  Degradation products (*cis*-1,2-DCE, vinyl chloride, ethene) were consistently detected in source area monitoring wells and CMTs throughout the monitoring period, and acetylene was detected in one monitoring well (IS17MW04) in four of eight post-installation groundwater sampling events and in two CMT intervals (CMT-1-Middle, CMT-1-Lower during 3 sampling events. Two monitoring wells (MW12, MW16) showed >50% increases in degradation daughter products (e.g., vinyl chloride) and three wells (MW12, MW14, MW16) showed >90% increases in ethene and/or ethane concentrations after two years. Additional evaluation of contaminant trends and groundwater sampling results is discussed in **Section 6.2**.

  Due to site groundwater levels rising to shallower than expected levels during the field demonstration (see **Figure 6.9**) it was not possible to conduct the modified gradient method, commonly used at NSZD hydrocarbon sites, which requires an adequate unsaturated zone for collection of soil gas at different depth intervals. Likewise, results from the deployed carbon traps were inconclusive due the unexpected saturated conditions at the site. As an alternative, soil vapor probes were installed at single depth intervals during a drier period of the field demonstration (20-months post-install). Soil vapor results identified gaseous “higher coupling products” (>C_3; e.g., propane, propene, butane, pentane, and hexanes) associated with the β-elimination pathway in the vadose zone directly above reaction columns. Based on the observed reduction in TCE, presence of abiotic and biotic daughter products, and presence of reaction gases in the vadose zone, this criterion has been met.

3.5 PERFORMANCE OBJECTIVE: ABILITY TO PLACE REACTION COLUMNS AND EASE OF AMENDMENT DELIVERY

Qualitative performance objectives included i) the overall ability to access contaminated sites with the Grout Bomber rig and ii) the ease with which remediation amendment could be delivered to the columns once onsite. In general, geotechnical equipment such as the Grout Bomber is designed to access field sites in urban areas for commercial development, soil stabilization, foundation redevelopment, and structural support. The application of this equipment to the environmental industry could potentially require more remote locations be accessed, and thus, one objective for this project was to demonstrate the ability of the Grout Bomber rig to access a contaminated field site and test the limits of its mobility and operation.

- **Data Requirements:** These include i) observations of the effective footprint of reaction column installation rig, ii) ability to approach structures and obstacles, and iii) observations of amendment addition.

- **Success Criteria:** These include: i) Ability to access most of intended design treatment area once equipment reaches the site (i.e., were unanticipated obstacles a problem during installation?) and ii) minimal loss of amendment during mixing and delivery process.
- **Results:** Site clearing activities were required (e.g., removal of trees and ground debris using a skid-steer mounted brush clearing machine) to accommodate large installation rig/equipment. Additionally, the heavy rig required timber mats be laid in the demonstration area to retain mobility in muddy conditions. The Bomber rig has limited ability to install columns on steep slopes, to advance columns in areas with large tree roots, and has limited mobility in tight spaces (e.g. between wells, trees, etc.). The Grout Bomber rig itself has a footprint of 12-ft x 10.5-ft and requires support from an Elkin mixer (truck-powered mixer with a 8-ft x 10-ft feet footprint) and the hopper/amendment pump (4-ft x 3-ft trailer-mounted equipment). Due to spatial constraints at Site 17, the Elkin mixer and hopper/amendment pump were stationed in a laydown area southwest of the demonstration site. Remediation amendment material was pumped to the Bomber rig via 50-ft sections of 2-inch diameter hose connected with cam-locks. Additional footprint requirements include a bermed overspill/mixing area (~8-ft x 8-ft), storage area for amendment raw materials, and room for a reaching forklift to move sacks from the storage to the Elkin mixer.

  Loss of amendment was limited to clogging events when operators would detach hosing and clean out pump hopper and hoses. Some material loss at ground surface due to "over pumping" by pump operator. During normal operation, very minimal amendment loss was observed, and collection/reuse of the overpumped amendment can be managed using shovels. Based on field observations and the overall success of column installation, these criteria have been met.

4.0 SITE DESCRIPTION

As outlined in the Site Selection Memorandum (dated 30 November 2016), Site 17 North Plume at the Naval Support Facility (NSF), Indian Head, Maryland was selected as the location for the field demonstration. This section provides a summary of relevant site information for the field demonstration.

4.1 SITE LOCATION AND HISTORY

Site 17 is a 1,000-ft stretch of shoreline located along the Mattawoman Creek in Indian Head, Maryland (see **Figure 4.1**). From the 1960s until the early 1980s, metals parts were discarded at the site, including shipping containers, empty drums, and motor casings (CH2MHill, 2008).

Figure 4.1. Location of Site 17 NSF, Indian Head, MD

(adapted from CH2MHill, 2016)

Site 17 consists of two shallow groundwater plumes (North and South Plumes; see **Figure 4.2**) with concentrations of TCE, *cis*-1,2-DCE, and vinyl chloride above respective MCLs. In 2012, *in situ* chemical reduction (ISCR) via soil mixing with ZVI was performed at the South Plume. Prior to the field demonstration, no remedial activities were performed at the North Plume. The design of the field demonstration at the Site 17 North Plume is presented in **Section 5.0**..

The current monitoring well network at Site 17 North Plume consists of ten monitoring wells (i.e., IS17MW04, IS17MW11 to 19), screened primarily in the sandy lean clay at 4-14, 8-18, 6-16, and 15-25 ft bgs. In addition, 23 DPT points were advanced for collection of depth-discrete groundwater and soil samples, as part of previous site investigations (see **Figure 4.3**; CH2MHill, 2016). Results from the site assessment and monitoring efforts are discussed in **Section 4.3**.

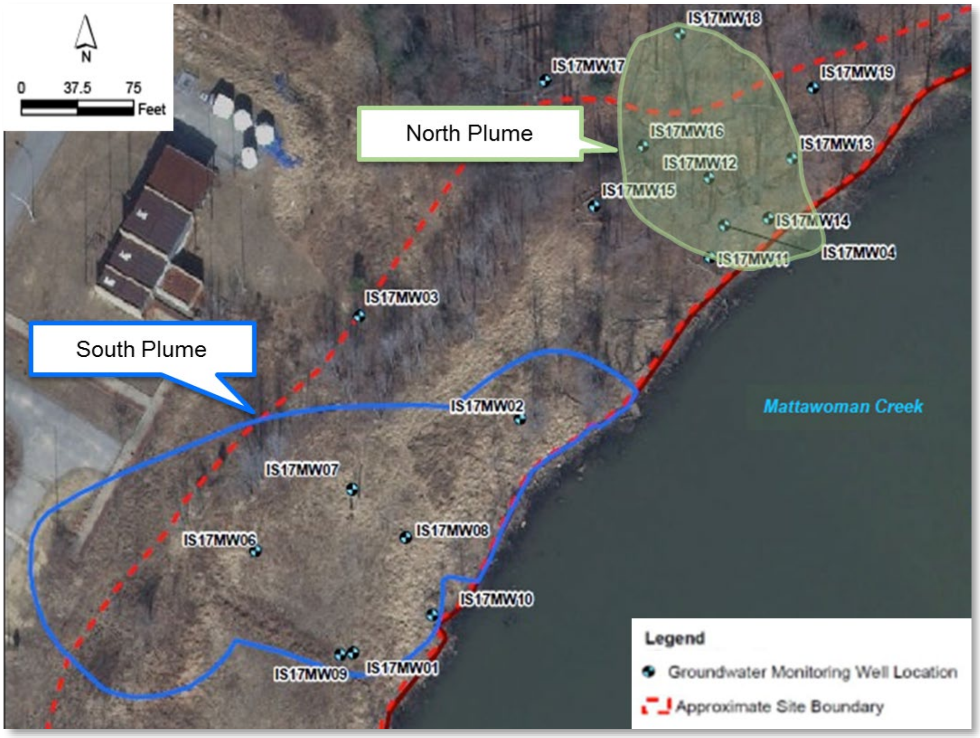


Figure 4.2. North and South Plumes at Site 17

(adapted from CH2MHill, 2016)

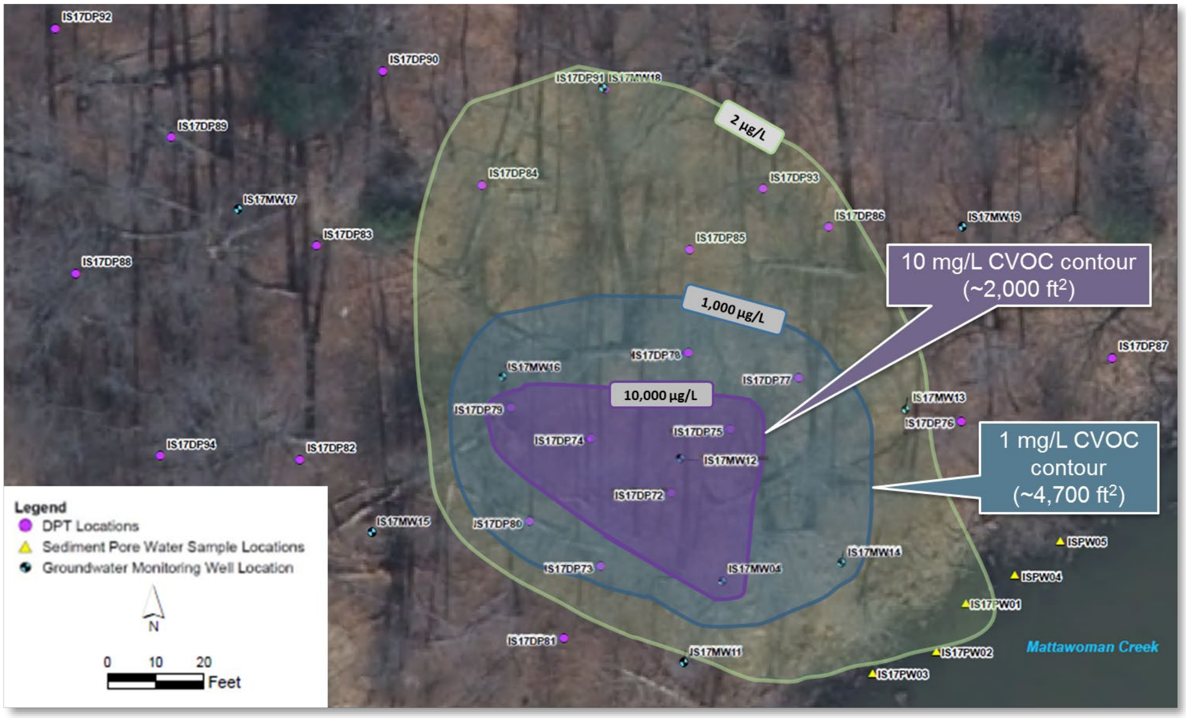
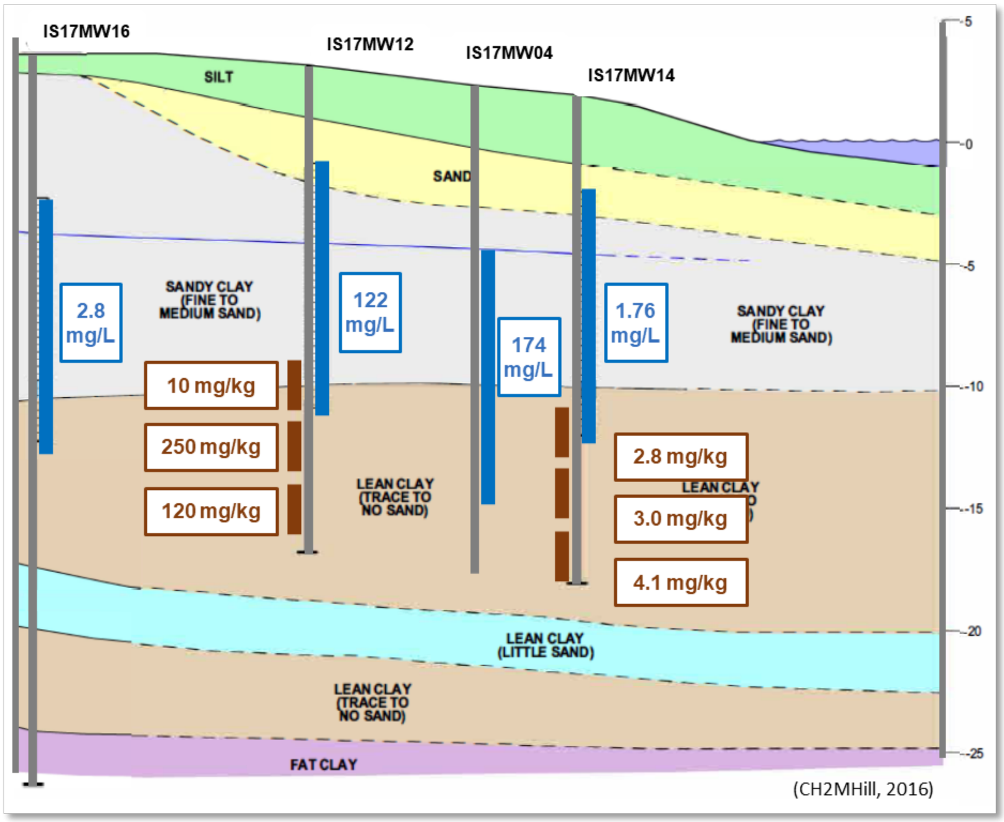


Figure 4.3. CVOC plume map at Site 17 North Plume

(adapted from CH2MHill, 2016)

4.2 GEOLOGY/HYDROGEOLOGY

The geology in the North Plume area consists primarily of silty sands, silts, sandy clays, and lean clays to a depth of 30 ft bgs (see **Figure 4.4**). Specifically, a sandy and/or silty clay layer typically occurs between 5 and 15 ft bgs and is underlain by a lean clay layer from approximately 10 to 25 ft bgs. Relevant figures and boring logs of DPT sampling locations are provided in **Appendix F**.



(CH2MHill, 2016)

Figure 4.4. Geologic cross-section at Site 17 North Plume

(adapted from CH2MHill, 2016)

Depth to groundwater is fairly shallow, ranging from 3 to 10 ft bgs. Direction of groundwater flow is primarily to the southeast towards the Mattawoman Creek, although tidal influences and flooding events can influence observed groundwater flow direction. The hydraulic gradient in the North Plume area is estimated to be 0.02 ft/ft, calculated based on a 2015 water level survey performed by CH2MHill (CH2MHill, 2016). The uppermost water bearing unit consists primarily of sandy lean clay beds interbedded with sandy silt and lean clay beds, underlain by a fat clay aquitard unit at approximately 25-40 ft bgs in the North Plume study area. A permeability test performed on a sample collected from the low-k material (lean clay) in the North Plume resulted in a hydraulic conductivity of 6.8×10^{-4} ft/day (CH2MHill, 2008). In addition, slug tests were performed at North Plume wells MW15, MW16, and MW17 (screened in sandy lean clay) resulting in hydraulic conductivity values from 2.4×10^{-2} to 1.4×10^{-1} ft/day (CH2MHill, 2016). Using the results above and assuming a porosity of 40% for clay and 25% for sandy clay, the groundwater seepage velocity is estimated to be 3.4×10^{-5} ft/day for clay and 1.9×10^{-3} to 1.1×10^{-2} ft/day for sandy clay.

4.3 CONTAMINANT DISTRIBUTION

Table 4.1 presents the concentration ranges of TCE, *cis*-1,2-DCE, and vinyl chloride at the ten monitoring wells in the North Plume area from 2014 to 2016 (prior to field demonstration). A contour plot for total CVOCs is presented in **Figure 4.3**.

Table 4.1. Historical Groundwater Concentrations of CVOCs at Site 17

Sample Location	Groundwater Concentration (µg/L)		
	Trichloroethene	cis-1,2-dichloroethene	Vinyl chloride
IS17MW04	**34,300 – 400,000**	**21,000 - 130,000**	**1,000 – 3,600**
IS17MW11	ND – 1.95 J	0.553 J – 2.7	ND – 2.5
IS17MW12	**8,750 - 122,000**	**1,900 – 15,600**	**90 – 4,540**
IS17MW13	ND – 38	3.2 - 10	1.4 J – 4.4
IS17MW14	**2.2 – 2,900**	**49 - 920**	**9.5 – 30.3**
IS17MW15	ND – 2.86	ND – 2.39	ND
IS17MW16	**1,040 – 2,800**	**138 - 527**	4.36 J – 15.5 J
IS17MW17	ND – 0.793 J	0.251 J – 1.07	ND
IS17MW18	1.02 – 7.0	ND	ND
IS17MW19	1.59 – 1.63	ND – 0.517 J	ND

Results from April 2014-2016 additional characterization sampling of North plume (CH2MHill, 2016)
ND = Non detect; J = Analyte estimated above detection limit but below reporting limit

In general, CVOC concentrations in soil correlated with the location where the highest groundwater concentrations were observed. The highest concentrations of TCE, *cis*-1,2-DCE, and VC in soil were 250,000 µg/kg (MW12 at 12-16 ft bgs); 14,000 µg/kg (DP74 at 9-10 ft bgs); and 11,000 µg/kg (DP80 at 9-10 ft bgs); respectively (sampling locations shown in **Figure 4.3**). Based on the soil and groundwater results collected prior to the field demonstration, the following conclusions were made:

- The North Plume areas contained sufficiently high concentrations of CVOCs for the purposes of the field demonstration.
- The presence of TCE daughter products (*cis*-1,2-DCE and VC) suggested that biotic transformation of TCE was already occurring at the site.
- Delivery of remedial amendments had the potential to complement and enhance existing CVOC degradation processes at the site.

5.0 TEST DESIGN

This section describes the design, installation, and implementation of the Bomber technology at Site 17 North Plume, NSF Indian Head.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

For the field demonstration, the Bomber technology was used to install 800 vertical reaction columns (each 3.5 in. in diameter; to a depth of 30 ft bgs) over an approximate 4,700 ft^2 source zone at Site 17 North Plume. A total of 390 ZVI/sand columns were spaced 2 ft apart in the area of highest CVOC mass (primarily within the 10 mg/L total CVOC contour; see **Figure 4.3**), located between monitoring wells IS17MW16 and IS17MW14 (~2,000 ft^2). An additional 410 columns were spaced ~3 ft apart in the remaining ~2,700 ft^2 1 mg/L treatment area. An area was also selected within the 1 mg/L treatment area for the installation of 100 columns (at 3 ft spacing) that were emplaced with an oil/sand mixture (no ZVI). **Figure 5.1** depicts the overall field demonstration area, the approximate reaction column grid, and the locations of the monitoring wells, CMT wells, soil vapor probes, and geophysical survey transects.

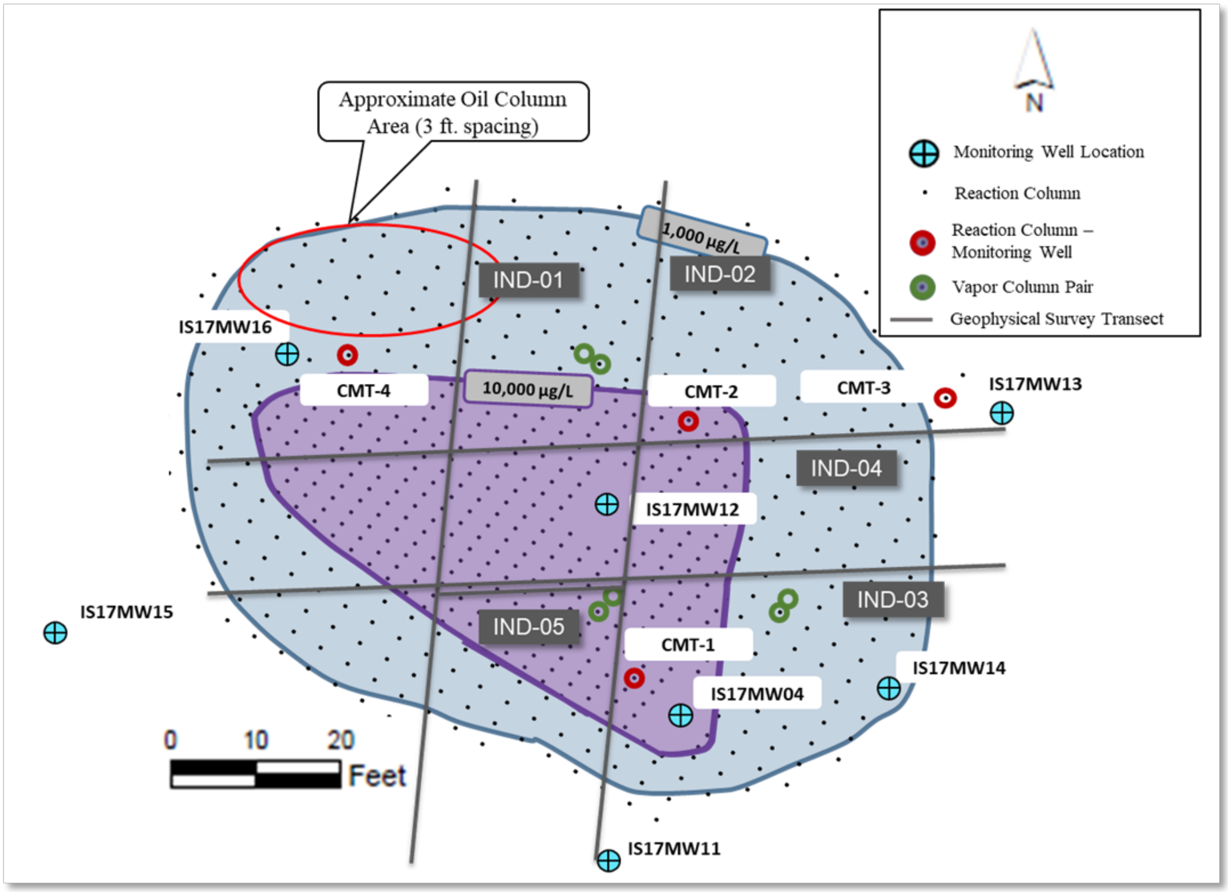


Figure 5.1. Field Demonstration Site Layout

(not to scale, CMT well locations approximate)

5.2 BASELINE CHARACTERIZATION

5.2.1 Baseline Assessment of Existing Site Data

Previous site assessments (e.g., CH2MHill, 2016) were conducted at Site 17 North Plume to delineate CVOC impacts to soil and groundwater. Ten permanent monitoring wells were installed and 23 DPT soil borings were advanced. Site assessment activities (from 2014 to 2016) resulted in >100 groundwater data points and 32 soil sample results from the North Plume area. Based on a detailed review of the Site 17 North Plume dataset, the extent of the CVOC plume was well-delineated and the dataset was sufficient to support the design of the field demonstration. As a result, no further site characterization activities (e.g., new monitoring wells, DPTs) were performed.

5.2.2 Baseline Groundwater Sampling

Prior to installation of the reaction columns, groundwater samples were collected from seven monitoring wells (IS17MW04, IS17MW11-16), located within and adjacent to the treatment area (see **Figure 5.1**). Samples were analyzed for field parameters (dissolved oxygen [DO], oxidation-reduction potential [ORP], specific conductivity, temperature, and turbidity), CVOCs (TCE, cis-1,2-DCE, and vinyl chloride), dissolved gases (methane, ethane, ethene, and acetylene), and total and dissolved iron, as listed in **Table 5.1**. Analysis of microbial biomarkers including *Dehalococcoides spp.* (DHC), *Dehalobacter spp.* (DHB), and associated functional genes (tceA, bvcA, and vinyl chloride reductases). The same sampling program was applied to the well network for the post-install sampling events. During the field demonstration, these data were supplemented by annual compliance groundwater results collected by the base site contractor. Field sampling and laboratory analyses were performed in accordance with procedures presented in **Section 5.5.**

Table 5.1. Baseline Groundwater Sampling Program

Well ID	Field Parameters	CVOCs	Dissolved Gases	Metals	Biomarkers
IS17MW04* IS17MW11 IS17MW12* IS17MW13 IS17MW14 IS17MW15 IS17MW16*	Dissolved oxygen pH ORP Spec. conductivity Temperature Turbidity	TCE *cis*-1,2-DCE Vinyl chloride	Methane Ethane Ethene Acetylene	Total Iron Dissolved Iron	Dehalococcoides spp. Dehalobacter spp. tceA, bvcA, vinyl chloride reductases

* Biomarker analysis was conducted at these locations.

Baseline groundwater sampling results of select key parameters are presented in **Tables 5.2** and **5.3**. Baseline results indicated that groundwater conditions at the site are generally acidic and moderately oxidizing with low DO concentrations (primarily < 1 mg/L). CVOC concentrations were consistent with historical values presented in **Table 4.1**. Briefly, TCE concentrations ranged from non-detect (IS17MW11, 13, and 15) to 257,000 µg/L. Daughter products (*cis*-1,2-DCE, vinyl chloride) and dissolved gases (methane, ethane, and ethene) were detected at all wells, suggesting natural attenuation mechanisms are active at the site. Acetylene was not detected at these wells. Comparison of post-installation performance monitoring relative to baseline groundwater results is included in **Section 6.2.**

Table 5.2. Baseline Groundwater Sampling: Geochemical Parameters

			Field Parameters						**Lab Parameters**	
Location ID	**Time Interval**	**Sample Date**	**pH, Field (SU)**	**Specific Conductance (mS/cm)**	**ORP (mV)**	**Dissolved Oxygen (mg/L)**	**Turbidity (NTU)**	**Temperature (deg C)**	**Iron, Total (µg/L)**	**Iron, Dissolved (µg/L)**
Monitoring Wells										
IS17MW04	Baseline	7/19/2017	5.3	1.317	113.3	2.12	10.3	24.22	-	19700
IS17MW11	Baseline	7/19/2017	5.5	0.982	6.4	0.48	9.7	22.62	-	76500
IS17MW12	Baseline	7/25/2017	5.2	0.56	89.9	0.69	9.6	19.58	10600	10500
IS17MW13	Baseline	7/20/2017	6.12	1.288	-54.2	0.37	9.7	20.94	48100	50800
IS17MW14	Baseline	7/20/2017	5.31	0.639	40	0.51	3.81	20.04	-	20200
IS17MW15	Baseline	7/20/2017	6.01	1.297	14.9	0.46	6.12	23.36	15400	14500
IS17MW16	Baseline	7/25/2017	5.79	0.935	46.3	0.41	9.8	20.35	16200	15000
Continuous Multi-Level Tubing (CMT) Wells										
CMT-01-UPPER	t>0	8/16/2017	6.3	0.834	-36	0	17.5	22.2	118000	90200
CMT-01-MIDDLE	t>0	8/16/2017	6.28	1.28	-10	1.81	220	21.92	62600	22600
CMT-01-LOWER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-
CMT-02-UPPER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	20700
CMT-02-MIDDLE	t>0	8/16/2017	6.95	0.44	-118	2.11	>4000	25.62	32500	25200
CMT-02-LOWER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-
CMT-03-UPPER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-
CMT-03-MIDDLE	t>0	8/16/2017	6.98	1.16	-147	3	787	28.36	43500	14000
CMT-03-LOWER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-
CMT-04-UPPER	t>0	8/16/2017	6.46	0.28	12	4.57	319	28.36	13400	2370
CMT-04-MIDDLE	t>0	8/16/2017	5.72	0.396	74	2.08	742	23.1	11900	3160
CMT-04-LOWER	t>0	8/16/2017	5.74	0.364	109	3.5	836	21.85	7060	2620

Notes:

1. "--" = not sampled / measured
2. "*vol*" = not sampled/measured due to insufficient well volume
3. The "t>0" time interval represents the earliest possible sampling event for CMT wells after installation of the reaction columns.

Table 5.3. Baseline Groundwater Sampling: CVOCs and Dissolved Gases

			CVOCs (ug/L)					Dissolved Gases (ug/L)			
Location ID	**Time Interval**	**Sample Date**	**Tetrachloroethene (PCE)**	**Trichloroethene (TCE)**	**cis-1,2-dichloroethene (cDCE)**	**trans-1,2-dichloroethene**	**Vinyl chloride**	**Methane**	**Ethane**	**Ethene**	**Acetylene**
Monitoring Wells											
IS17MW04	Baseline	7/19/2017	142	257000	67300	367	2790	1100	430	650	<0.048
IS17MW11	Baseline	7/19/2017	<0.33	<0.5	<0.48	<0.32	<0.21	6700	4200	<0.009	<0.048
IS17MW12	Baseline	7/25/2017	92.1	103000	6460	80.6	750	220	23	110	<0.048
IS17MW13	Baseline	7/20/2017	<0.39	<0.22	1	<0.11	<0.32	730	1.1	0.19	<0.048
IS17MW14	Baseline	7/20/2017	<0.39	84.4	291	1.2	32.5	2200	22	1.4	<0.048
IS17MW15	Baseline	7/20/2017	<0.33	<0.5	<0.48	<0.32	<0.21	4000	14	0.21	<0.048
IS17MW16	Baseline	7/25/2017	<0.39	1700	542	8.2	22.8	820	19	2.5	<0.048
Continuous Multi-Level Tubing (CMT) Wells											
CMT-01-UPPER	t>0	8/16/2017	<0.33	120	126	<0.32	25.7	7600	2400	89	<0.022
CMT-01-MIDDLE	t>0	8/16/2017	<0.33	7160	825	2.4	56.1	570	270	260	19
CMT-01-LOWER	t>0	8/16/2017	<0.33	191	116	<0.32	4.2	110	100	66	1
CMT-02-UPPER	t>0	8/16/2017	<0.33	19.6	3.8	<0.32	<0.21	160	16	13	<0.022
CMT-02-MIDDLE	t>0	8/16/2017	<0.33	259	26.2	<0.32	<0.21	38	41	15	<0.022
CMT-02-LOWER	t>0	8/16/2017	<0.33	6.3	1.6	<0.32	<0.21	14	4	6.7	<0.022
CMT-03-UPPER	t>0	8/16/2017	<0.33	<0.5	2.2	<0.32	<0.21	700	15	19	<0.022
CMT-03-MIDDLE	t>0	8/16/2017	<0.33	1.2	<0.48	<0.32	<0.21	43	16	11	<0.022
CMT-03-LOWER	t>0	8/16/2017	<0.33	<0.5	<0.48	<0.32	<0.21	22	4.9	8.5	<0.022
CMT-04-UPPER	t>0	8/16/2017	<0.33	<0.5	1.5	<0.32	<0.21	5.6	0.75	1	<0.022
CMT-04-MIDDLE	t>0	8/16/2017	<0.33	<0.5	1.5	<0.32	<0.21	2.7	0.17	0.34	<0.022
CMT-04-LOWER	t>0	8/16/2017	<0.33	<0.5	1.1	<0.32	<0.21	4.8	0.44	0.69	<0.022

Notes:

1. "--" = not sampled / measured
2. "*vol*" = not sampled/measured due to insufficient well volume
3. The "t>0" time interval represents the earliest possible sampling event for CMT wells after installation of the reaction columns.

5.2.3 Baseline Geophysical Survey

A baseline electrical resistivity survey was conducted to establish a baseline image of the treatment area and site geology prior to installation of the reaction columns. The geophysical survey uses proprietary electrical resistivity imaging and processing (Aestus, LLC; GeoTrax Survey LTM™) to identify subsurface anomalies and potentially verify emplacement of remedial amendments and track changes in contaminant distribution and strength. A total of five electrode transects (IND-01 to IND-05) were installed in shallow subgrade trenches across the perimeter of the proposed treatment area (see **Figure 5.2**) and left in place for conducting periodic time lapse ER imaging following installation of the reaction columns. The electrical resistivity imaging was intended as a secondary line of evidence to support baseline characterization activities (e.g., groundwater sampling; historical data) and potential changes in site conditions (e.g., geochemistry, CVOC distribution) after reaction column installation. Specific aims included:

i. Confirm the horizontal and vertical extent of CVOC-related impacts during the baseline event by tracking changes in saturating fluid electrical conductivity and, to the extent possible, correlate findings to geochemical changes observed by laboratory analytical results.

ii. Perform temporal electrical resistivity imaging to evaluate changes in the subsurface after reaction column installation relative to the baseline condition. Observed changes may be attributed to changes in CVOC distribution, ongoing chemical reactions, increased bioactivity, or some combination of these factors.

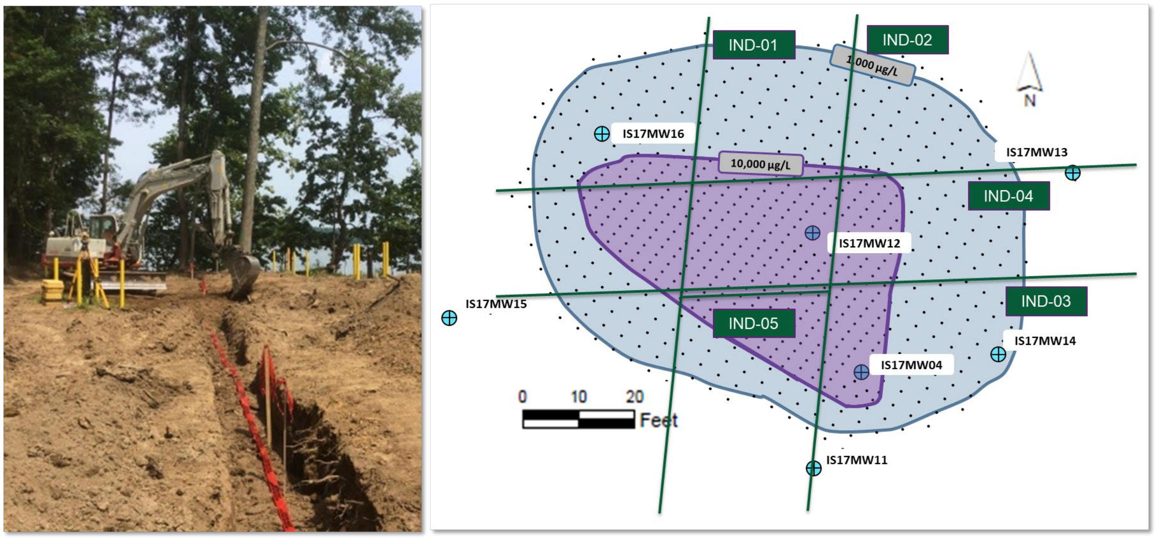


Figure 5.2. Installation and Layout of Electrical Resistivity Survey Transects

In general, the baseline electrical resistivity results were consistent with previous geological characterization of the site. For example, as shown in **Figure 5.3**, the baseline image for electrical resistivity transect IND-02 (located North-South across the eastern portion of treatment area) identified higher resistivity of materials at shallow depth (white to grey) and a transition to more conductive material (blue to purple) which appears to be well correlated with the top of a lean clay layer at approximately 15-25 ft bgs.

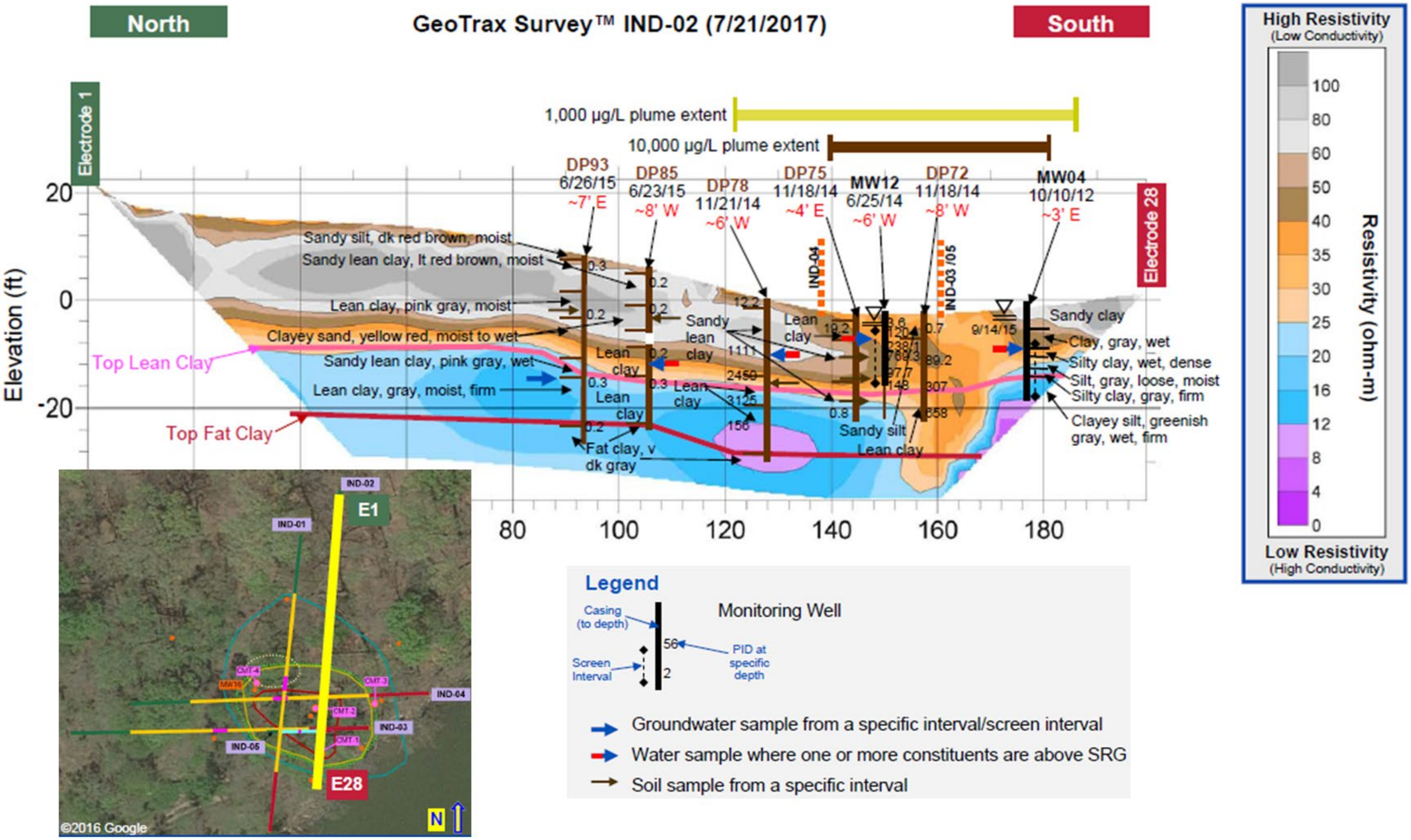


Figure 5.3. Baseline Image of Electrical Resistivity Survey Line IND-02

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 Bomber Equipment

As described in **Section 2.1** the Bomber technology uses the same general technique as the wick drain technology to push a large number of closely-spaced columns into the subsurface, with some equipment-related differences (e.g., the stitcher mast). The Bomber mast consists of a mandrel (a hollow pipe; 3.5 in. diameter) that is attached to a reinforced hose at the top for grout (or amendment) delivery. The grout mixture is generated on-site using a separate mixing and delivery system consisting of a volumetric mixing truck (Elkin mixer), mixing hopper, and positive displacement pump (see **Figure 5.4**). This system delivers the remediation amendment to the top of the mandrel once it has been pushed into the ground to the desired depth. The mandrel is carefully controlled and adjusted as needed by the rig operator(s) to ensure the mast remains vertical (on plum) during column installation. When the mandrel is retrieved, the delivered amendment is left in place, thus creating the vertical reaction column.

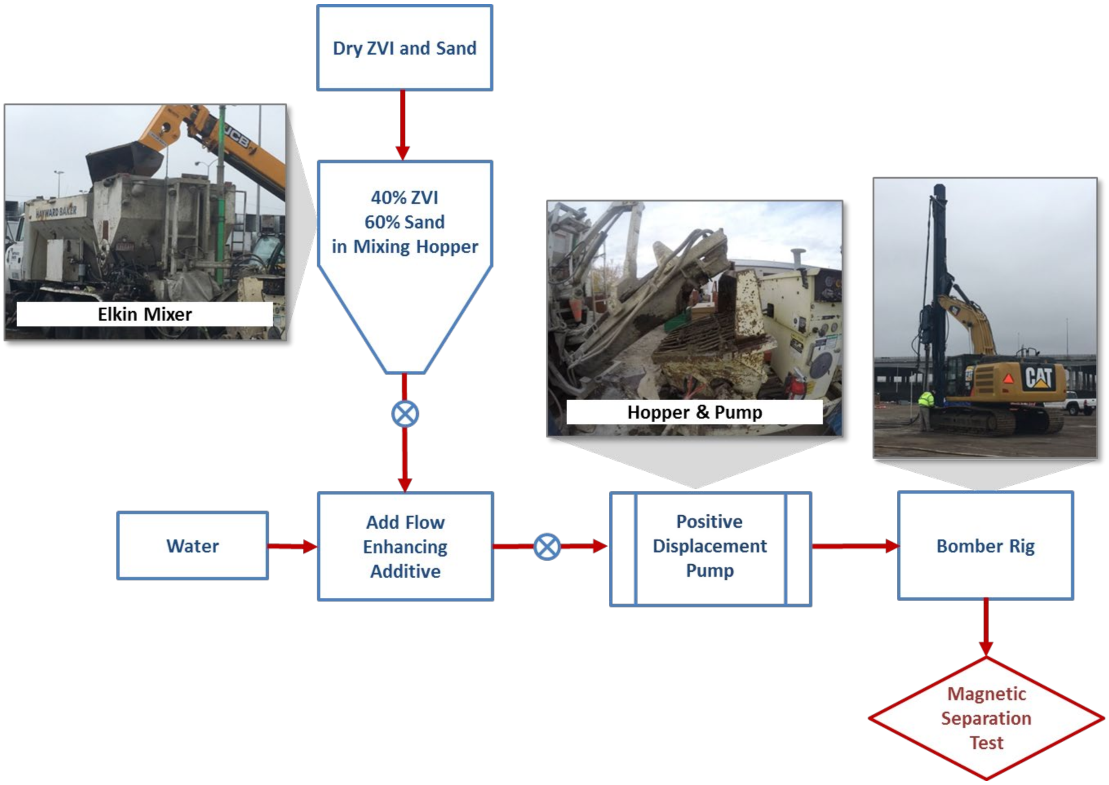


Figure 5.4. Process Schematic of On-site Mixing and Delivery Unit

An on-site volumetric mixing and delivery unit (Elkin mixer) was used to efficiently proportion, mix, and deliver the ZVI and/or oil amendment mixture to the Bomber rig (see **Figure 5.4**). As a first step, dry amendment materials (ZVI and sand) were loaded into 8 yd^3 bins (located on the truck) using a forklift and front-end loader. The mixer was then calibrated to supply ZVI and sand at specified rates into a mixing hopper where small amounts of water and vegetable oil (for flow/pumpability enhancement) were added to create a properly proportioned amendment mixture (i.e., 40% ZVI/60% sand). The hopper then fed the amendment directly to a positive displacement pump that delivered the ZVI mixture via hosing to the Bomber rig.

Magnetic separation tests (MSTs) were performed on samples collected from 10 installed reaction columns as a quality control measure to ensure the amendment was being properly mixed, and the appropriate ZVI dosage was being supplied to the reaction columns.

For geotechnical applications where the fluid being displaced is cement grout, the pump is capable of delivering 0.25 ft^3 of material per pump stroke, with a typical flow rate of 4 ft^3/min at the exit end of the mandrel. The pump stroke cycle can be adjusted by the operator to be delayed between 1 to 10 seconds apart, therefore a 2 ft^3 column (3.5 in diameter; 30 ft long) can be filled (from bottom to top) in anywhere from 30 to 110 seconds. For our application, the pump was able to deliver the ZVI amendment at a similar efficiency (~1-2 minutes).

5.3.2 Amendment Mixture

Small-scale demonstration testing conducted in collaboration with Rice University (see **Section 2.2**) indicated that a 40% ZVI content in each column can theoretically treat up to approximately 2,650 mg of TCE per kg of soil in each reaction column (includes safety factor of 2), which is well above the TCE concentrations observed at Site 17 North Plume. A fine-grained particle size range (>75% passing through 100 size sieve) was used for the ZVI powder (50-D ZVI), supplied by Compass Remediation Chemicals (see **Appendix H**). ZVI was delivered to the site in 3,000 lb "supersacks." Sand was delivered in trucks from a local source. A mixture of approximately 40% ZVI and 60% sand (by volume) was chosen as the remedial dosage for the field demonstration. The mixture also contained an appropriate percentage of water and vegetable oil, as needed. The project team also evaluated various flow enhancing options using organic additives (soybean oil and an organic foam additive) and found that a 4-5% by volume addition of oil met project objectives and logistical requirements for delivering the ZVI mixture into the subsurface (see **Section 2.2**).

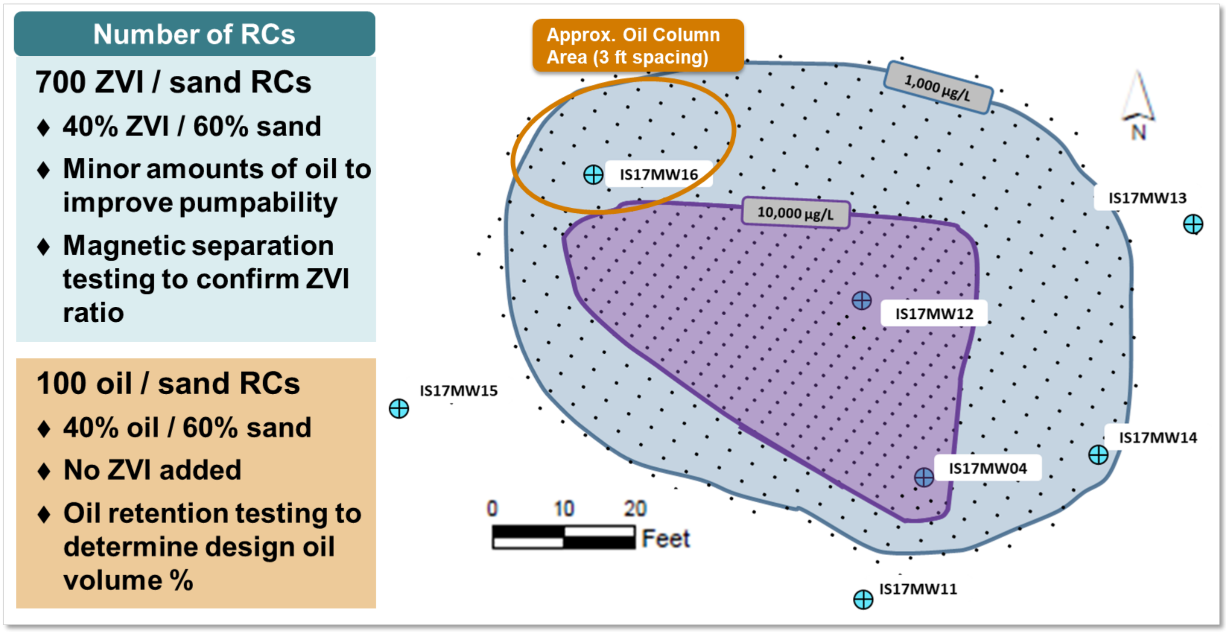
Approximately 77,000 lbs (~39 tons) of ZVI and approximately 70,000 lbs of sand was used to fill the reaction columns. This represents a mass ratio (ZVI:dry soil) of 0.55%. By comparison, for the South Plume soil mixing project, approximately 31 tons of ZVI was applied over a 3,500 ft^2 area (~1,300 yd^3), equating to a mass ratio of 1% (ZVI:dry soil). The South Plume project aimed to exceed a minimum iron-to-soil mass design ratio referenced as 0.4% (Gavaskar, 2005). Our design dosage (0.7%) meets the dosage criteria of ZVI used in the South Plume soil mixing project and the applied dosage (0.55%) falls within the range of the traditional 0.5% to 5% ratio used for soil mixing technology (Suthersan et al., 2017).

An approximate 900 ft^2 area was designated within the 1 mg/L contour area (see **Figure 5.1**) for the installation of 100 oil/sand reaction columns. Neat soybean oil was mixed with sand using a similar method as described for the ZVI amendment mixture. Efforts were made to achieve a minimum oil/sand ratio of 10% by volume in the reaction columns. The addition of vegetable oil serves as an electron donor for biotic reductive dechlorination of CVOCs.

5.3.3 Reaction Column Installation Design

Eight hundred reaction columns (700 with ZVI/sand and 100 with oil/sand mixtures) were installed over an approximate 4,700 ft^2 area where concentrations of TCE are primarily above 1 mg/L to a depth of about 30 feet to treat a volume of 141,000 ft^3 (~5200 yd^3) (see **Figure 5.5**). A total of 39 tons of ZVI were introduced into the treatment zone. Reaction columns were installed at least 4 ft away from existing site monitoring wells to avoid potential damage to the surface casing from the large equipment and direct influence from the injected amendment.

The reaction columns were spaced within the plume center of mass (CVOCs > 10 mg/L; ~2,000 ft^2) at a minimum 2 ft apart in a triangular grid pattern, which provides a maximum "diffusion distance" of 12-14 inches. Slightly more distant reaction column spacing (3 ft triangular centers) was implemented within the surrounding 1 mg/L treatment area (~2,700 ft^2). In addition, a section within the 1 mg/L treatment area was designated for the installation of 100 reaction columns emplaced with a strictly oil/sand amendment mixture (see **Figure 5.5**). This area was designated during site gridding activities. All reaction columns have a diameter of 3.5 in and were advanced to a depth of 30 ft bgs, resulting in a column volume of 2 ft^3 (15 gallons).


Number of RCs

700 ZVI / sand RCs
- ♦ 40% ZVI / 60% sand
- ♦ Minor amounts of oil to improve pumpability
- ♦ Magnetic separation testing to confirm ZVI ratio

100 oil / sand RCs
- ♦ 40% oil / 60% sand
- ♦ No ZVI added
- ♦ Oil retention testing to determine design oil volume %

Figure 5.5. Reaction Column Installation Design

5.3.3.1 *Reaction Column Monitoring Wells (CMT Wells)*

Reaction column monitoring wells (or "CMT wells") are an innovative means to collect groundwater samples directly from within a reaction column and compare results to adjacent monitoring wells (located no more than 4 ft away). These wells were constructed using the Solinst Continuous Multichannel Tubing (CMT) 7-channel system, which allowed for collection of groundwater samples from three depth discrete locations (upper, middle, and lower depth intervals) within the reaction columns. The CMT wells were positioned close to existing monitoring wells (creating CMT-monitoring well "pairs") for the purpose of comparing CVOC concentrations and confirming the presence/absence of a steep concentration gradient between locations as theorized. CMT well construction details and the location of the nearest monitoring wells are provided in **Table 5.4**. The CMT-monitoring well pairs are illustrated in **Figure 5.6.**

Table 5.4. Reaction Column Monitoring Well Construction

CMT Well ID	Depth Interval	"Screened" Interval (ft btoc)	Nearest Monitoring Well
CMT-1	Upper	7.96-8.46	IS17MW04
	Middle	18.15-18.65	
	Lower	28.2-28.7	
CMT-2	Upper	7.84-8.34	IS17MW12
	Middle	19.34-19.84	
	Lower	28.14-28.64	
CMT-3	Upper	6.97-7.47	IS17MW13
	Middle	17.6-18.1	
	Lower	27.45-27.95	
CMT-4	Upper	6.73-7.23	IS17MW16
	Middle	16.25-16.75	
	Lower	26.3-26.8	

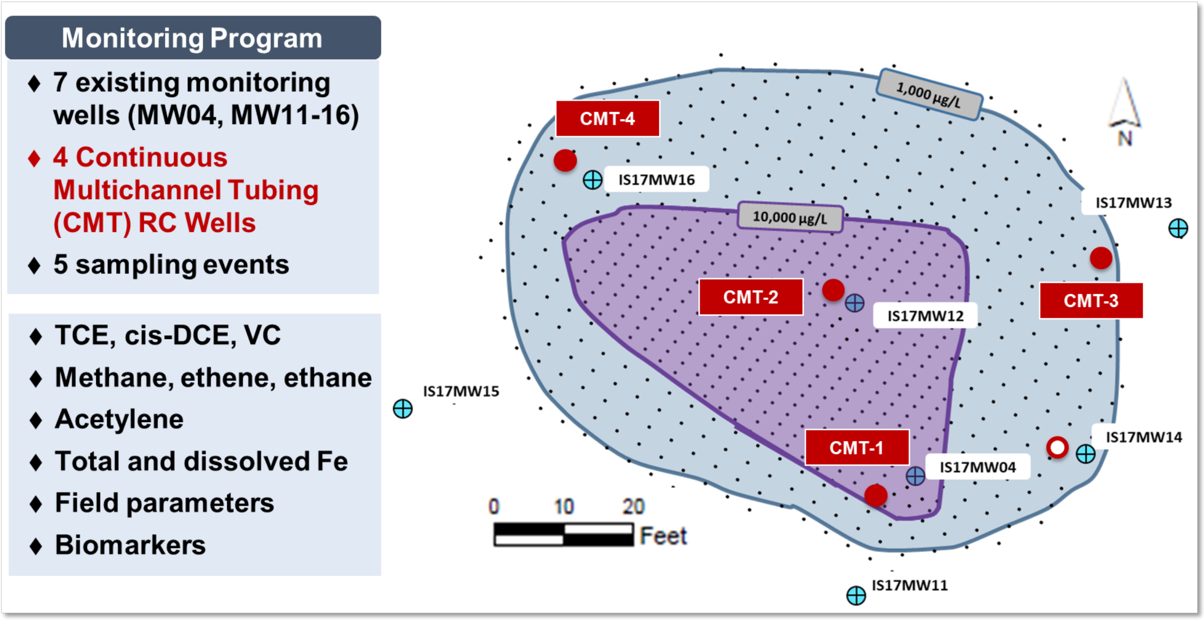


Figure 5.6. Locations of Reaction Column Monitoring Wells (CMT Wells)

The CMT wells were installed using an innovative approach with the Bomber equipment, called "bottom feeding", where the top of the CMT was fed through the bottom of the mandrel (see **Figure 5.7a**) prior to installation. The bottom of the CMT was then attached to an anchor plate that held the CMT in the reaction column when the mandrel was retrieved (see **Figure 5.7b**). Note that the CMT wells were installed concurrently with their associated reaction column, thus each CMT well annulus was filled with the ZVI or oil mixture (see **Figure 5.7c**).

Note, a fifth CMT well was installed adjacent to monitoring well IS17MW14; however, the well was damaged during installation and subsequently abandoned. As a result, the CMT well network consisted of four wells (CMT-1 to CMT4).

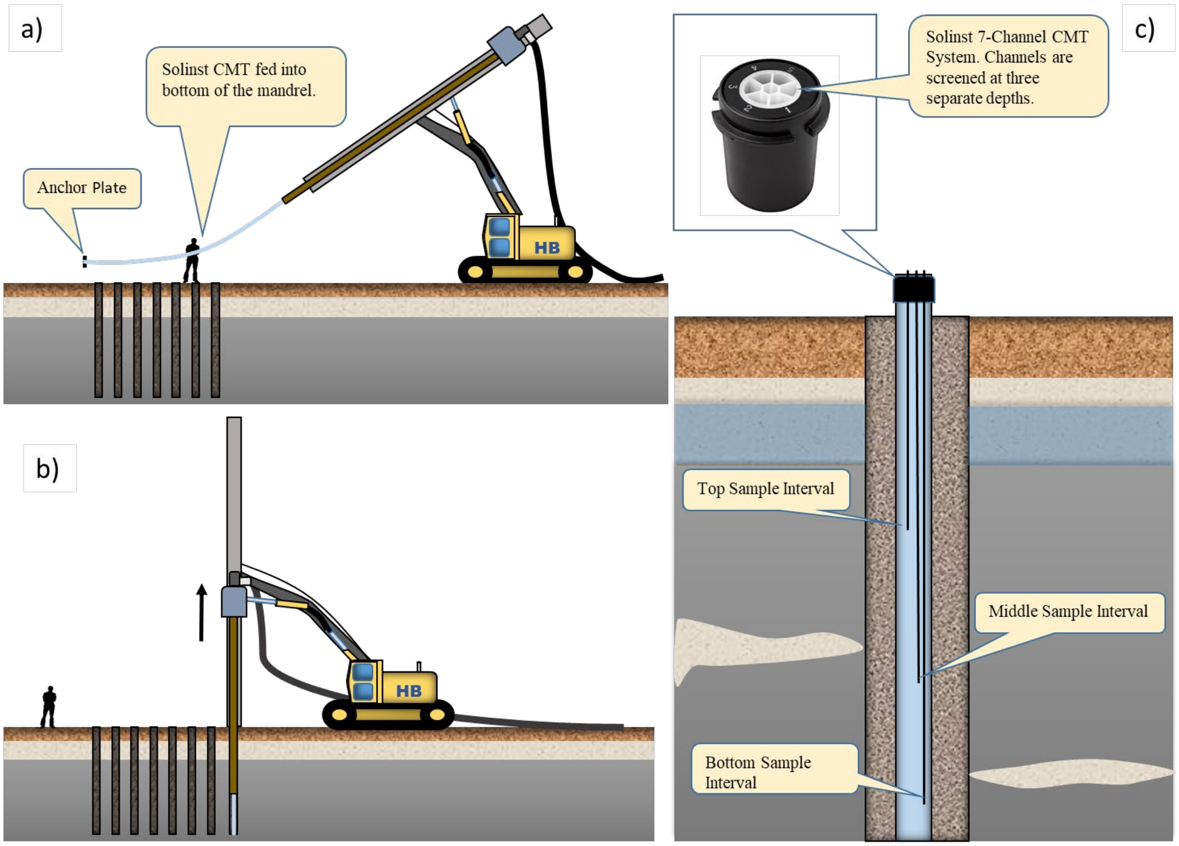


Figure 5.7. Reaction Column Monitoring Well Installation: a) Bottom Feeding the Pre-Assembled CMT System; b) Installation of CMT; c) Components of Reaction Column-Monitoring Well with Three Depth Discrete Sampling Zones

CMT wells were installed concurrently with the surrounding reaction columns and, as such, it was not possible to collect baseline (pre-install) results similar to the monitoring wells. Instead, the CMT wells were sampled within the first 1-2 days following installation to serve as a pseudo-baseline value (described as "t>0" hereafter). Like the monitoring wells, samples were analyzed for field parameters DO, ORP, specific conductivity, temperature, and turbidity), CVOCs (TCE, *cis*-1,2-DCE, and vinyl chloride), dissolved gases (methane, ethane, ethene, and acetylene), and select dissolved ions/metals (total and dissolved iron), as listed in **Table 5.1**. In some cases, insufficient volume was available for monitoring of field parameters. Likewise, microbial biomarkers were not analyzed at these wells due to limited well volume.

Baseline (t>0) groundwater results for the CMT wells are presented in **Table 5.2 and 5.3.** Like the monitoring wells, baseline results indicated that groundwater conditions are generally acidic, although ORP values suggested a mixture of moderately reducing and oxidizing conditions. DO concentrations were generally higher than the monitoring wells, likely due to oxygenated water in the amendment mixture. As expected, baseline CVOC concentrations (TCE, cis-1,2-DCE, and vinyl chloride) were lower in the CMT wells compared to the adjacent monitoring wells.

Concentrations of methane, ethane, and ethene were in the same ranges as reported for the monitoring wells. Acetylene was detected at two depth intervals (middle and lower) in well CMT-01, confirming the presence and rapid nature (within 1-2 days) of abiotic reactions within the newly-installed reaction columns. Additional discussion of baseline (t>0) groundwater results is included in **Section 6.2.**

5.3.3.2 Soil Vapor Columns

Soil vapor columns (SVCs) were constructed at three locations (see **Figure 5.8**) during the 20-month post-installation sampling event (April 2019) to measure gaseous products from abiotic and/or biotic reactions. These were installed as a replacement to two originally proposed techniques to monitor and estimate mass flux rates from the reaction columns: i) a modified version of the gradient method, a technique used to demonstrate Natural Source Zone Depletion (NSZD), and ii) passive CO_2 traps (Eflux, LLC), which are commonly used at hydrocarbon sites to estimate the mass degradation rates due to NSZD. However, due to groundwater levels rising to shallower than expected levels during the field demonstration (see **Figure 6.9**, it was not possible to install the nested soil vapor probes needed to conduct gradient method calculations (i.e., limited thickness of the vadose zone; only 2-3 ft deep; see **Appendix I**). Likewise, results from CO_2 traps installed at the site were inconclusive, likely due to the elevated groundwater levels during their installment (discussed below).

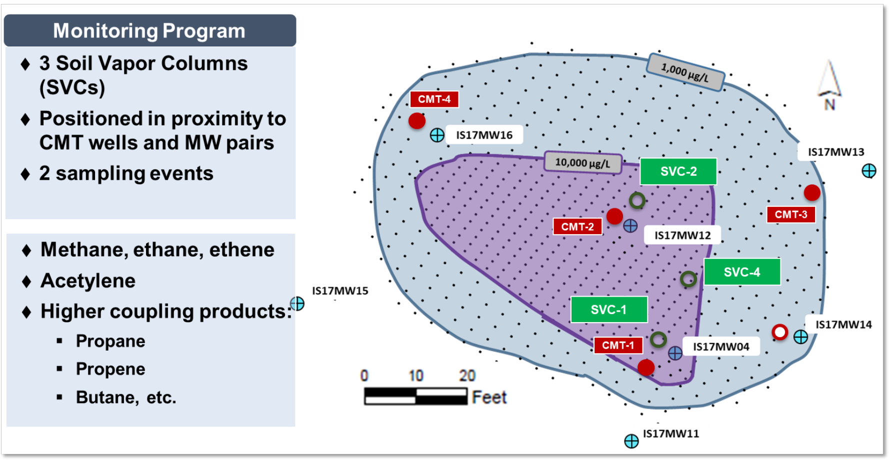


Figure 5.8. Locations of Soil Vapor Columns (SVCs) for Monitoring of Reaction Gases

SVCs were constructed at a single depth in each column and were installed, in pairs, at the three locations depicted in **Figure 5.8** (SVC-1, 2, and 4; adjacent to CMT-1, CMT-2, and IS17MW04, respectively). One SVC of each pair was placed directly over a reaction column, ~6 inches above the static water level. The second of each pair was installed adjacent to the first (1-2 ft separation), overlying the native low-k material. During the April 2019 sampling event, E-Flux carbon traps were deployed over the SVCs as shown in **Figure 5.9**. SVCs for carbon trap deployment were constructed using a 3-ft length of 3-in Schedule 40 PVC casing placed directly over excavated reaction columns or adjacent native soil. Photos of excavated reaction columns are provided in the photo log included in **Appendix M.** The excavations surrounding reaction columns were backfilled with native material surrounding the PVC casing, which isolated the SVC from surrounding vadose zone gases and facilitated the vertical flux of gas from the top of reaction column (or native soil) up through the casing. Later, the SVCs were converted to traditional soil vapor probes (SVPs), with the probe tip set ~6 inches above the static water level, surrounded with a 6-inch sand buffer, and sealed to the surface with a hydrated bentonite chip seal.

Figure 5.9. Installation of Passive CO_2 Traps (left) and Single-depth Soil Vapor Column (right) for Monitoring Gaseous Products from Reaction Columns

The SVCs were converted to traditional SVPs by inserting a screened probe tip at the interface between the unsaturated reaction column material (~6 inches above water table) and the atmosphere. The soil vapor probe tip was connected to ¼” Nylaflow tubing, encased in a 3-in PVC casing, and covered with a 3-inch buffer of sand. The annulus in and around the casing was sealed with hydrated bentonite to prevent vapor infiltration from the overlying vadose zone and/or atmospheric air, although leak testing was not conducted. The SVP tubing was terminated at an aboveground connection to a 3-way valve to allow shut-in testing, purging, and sampling. Sampling was conducted after an equilibration period of at least 48 hours. The SVPs were covered with a threaded PVC cap to prevent infiltration of rainwater. The design of the soil vapor column is illustrated in **Figure 5.10**.

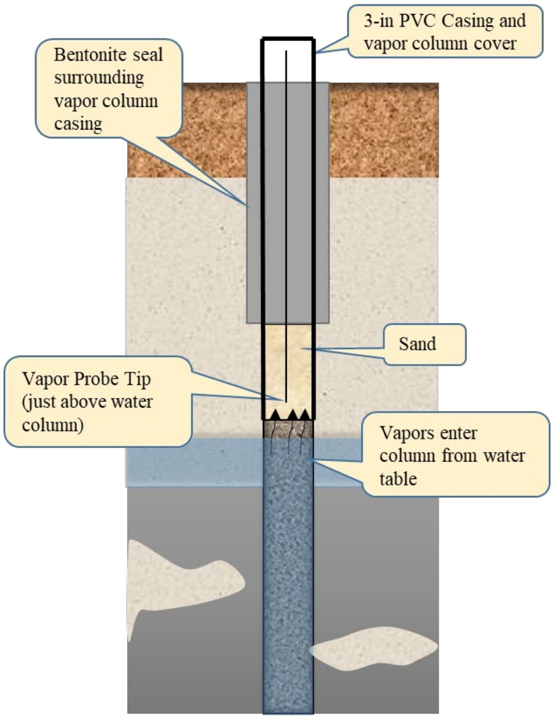


Figure 5.10. Illustration of Soil Vapor Column Design

5.4 FIELD TESTING

The field demonstration had four operational phases: i) prior to field implementation (baseline assessment), ii) reaction column installation, iii) immediately after reaction column installation and amendment addition (confirm amendment distribution and measure initial conditions), and iv) post-demonstration performance monitoring (to verify CVOC degradation). Major tasks associated with each phase are listed in **Table 5.5** and are discussed in following sections. Details of field sampling are discussed in **Section 5.5**.

Table 5.5. Demonstration Operational Phases

Operational Phase	Major Phase Components
Baseline Assessment	• Assessment and analysis of existing site data • Site preparation activities (tree and ground clearing, grid site) • Baseline geophysical survey (i.e. resistivity imaging) • Baseline groundwater sampling
Reaction Column Installation	• Site mobilization • Installation of approximately 800 reaction columns • Magnetic Separation Tests to verify amendment dosage • Installation of reaction column monitoring wells • Installation of vapor columns
Immediately after Reaction Column Installation	• Post installation geophysical survey • Groundwater sampling of newly installed reaction column wells • Groundwater sampling of existing site monitoring wells • Vapor sampling from newly installed vapor columns • Site demobilization
Post-Demonstration Performance Monitoring	• Groundwater sampling of reaction column wells • Groundwater sampling of existing site monitoring wells • "Proof of Reaction" vapor sampling from reaction column wells

Baseline Evaluation

Prior to reaction column installation, the demonstration area was cleared of trees and surface debris and the ground was scraped and minimally graded to provide a level installation area. All site clearing activities were performed by the Navy and did not take more than one week to complete. The reaction column locations were then marked/flagged in the triangular grid pattern previously discussed. Baseline groundwater sampling and geophysical surveys were then conducted as described in **Sections 5.2.2** and **5.2.3**, respectively.

Reaction Column Installation

Field implementation of the Bomber technology commenced in July 2017. Hayward Baker mobilized the Bomber rig, Elkin mixer, water trucks, and other necessary equipment and crew to the site from their regional office located in Baltimore, Maryland. Field engineers from GSI also mobilized to the site to perform field oversight and sampling activities. Approximately 800 reaction columns were installed. Four reaction columns were selected to be installed as CMT wells and were added to the post-demonstration performance monitoring plan. MSTs were conducted on 10 samples collected from installed reaction columns. The 800 reaction columns were installed in a total of 7.5 field days (see **Section 6.1)**.

Immediately after Reaction Column Installation

Upon completing installation of all reaction columns and CMT wells, Hayward Baker demobilized all equipment and crew from the site. A second geophysical survey was performed using the dedicated electrode transects to evaluate resistivity changes from the reaction column installation. The four newly installed CMT wells (CMT-1 through -4) were sampled (baseline time interval "t>0") for comparison to pre-existing monitoring well baseline data. Groundwater data from this time interval has been labeled "t>0" due to its being the first available data *within* the reaction columns, and thus does not represent pre-treatment conditions. CMT wells were not installed prior to installation of the reaction column, but rather concurrently during the installation phase.

Post-Demonstration Performance Monitoring

Post-demonstration performance monitoring was initially planned to include sampling events immediately following field implementation and one year afterward. Due to overlapping semiannual compliance monitoring events at Site 17 (conducted by the site contractor), additional groundwater monitoring data was available to supplement the field demonstration monitoring program. These activities aimed to validate the effectiveness of the technology and quantify the degradation rates of contaminant mass at the site. Throughout the post-demonstration performance monitoring period, eight sampling events were conducted at the following time intervals:

- Immediately after column installation, "t>0" (CMT wells only)
- 1-month (September 2017)
- 7-month (February 2018)
- 9-month (April 2018 – Existing monitoring wells only, courtesy of CH2M Hill)
- 12-month (August 2018)
- 16-month (December 2018)
- 20 month (April 2019)
- 26-month (October 2019)

Monitoring wells (IS17MW04; IS17MW11 through -16) were sampled at the seven events listed above (September 2017 – October 2019) and the four CMT wells were sampled during all eight events (August 2017 – October 2019). The resulting data were used to develop and analyze time-series trends for geochemical parameters, CVOCs, and dissolved gases. Particular attention was paid to differences in CVOC concentrations between CMT-monitoring wells pairs (CMT-1/IS17MW04; CMT-2/IS17MW12; CMT-4/IS17MW16) to confirm the presence/absence of a sustained concentration gradient between these locations. Results of the performance monitoring data are described in **Section 6.2.**

At the end of the project period, geophysical electrodes and newly installed reaction column monitoring wells were left in place for additional long-term performance monitoring. Decommissioning of CMT wells and dedicated geophysical electrodes will be arranged with base personnel following long-term performance monitoring of the system under a separate contract.

5.5 SAMPLING METHODS

Multiple media-specific sampling procedures were followed to assess the performance objectives outlined in **Section 3.0**. These include:

- groundwater sampling of existing monitoring well network;
- multi-level groundwater sampling in new-installed CMT wells;
- magnetic separation testing (MST) of emplaced ZVI/sand amendment; and
- reaction gas monitoring using traditional soil vapor probes.

A summary of the sampling plan for the field demonstration is provided in **Table 5.6,** and details of sampling during each stage of the demonstration are provided in following sections with supporting information referenced in the appendices. All analyses are based on methodologies that are used extensively in the industry. In general, sampling was aimed at verifying amendment distribution within the reaction columns and confirming CVOC degradation via abiotic and/or biotic reduction pathways within the demonstration area.

5.5.1 Groundwater Sampling

5.5.1.1 Existing On-Site Monitoring Wells

Groundwater samples were collected from existing on-site monitoring wells using constant volume purge low flow sampling protocols. A water quality indicator probe (e.g. Horiba U-52) with a flow through cell was used to measure water quality parameters. The field parameters listed in **Table 5.6** were recorded every 3-5 minutes, volume permitting, and documented using standard GSI Low Flow Sampling Forms (see **Appendix K**).

5.5.1.2 Newly Installed CMT Wells

CMT wells were sampled using an inertial pump or similar following a no-purge, "grab" sampling approach designed to collect water from within the reaction column, rather than from the surrounding formation. Where possible, water quality parameters were measured immediately after sample collection and after all sample bottles were filled. In many cases, some CMT well intervals did not produce enough groundwater volume for the collection of all sample bottles, thus field parameters may not have been recorded. CMT wells were installed in four reaction columns within the central CVOC mass of the demonstration area and were sampled for CVOCs, select cations/anions, and dissolved gases.

Several non-traditional "duplicates" (not for QA/QC purposes) were also collected from select CMT wells to evaluate changes in CVOC concentration immediately following recharge of CMT intervals. The CMT interval was purged dry following collection of the primary groundwater sample, and a "duplicate" was collected following recharge of at least 90% of the CMT interval tubing volume. In theory, TCE concentrations should be lower in the primary sample (due to contact with the reactive surface of the ZVI particles), while concentrations should be higher for the "duplicate" samples which represent pore water from the surrounding media that has not been in direct contact with the reaction column media. Results of CMT well "duplicate" sampling are discussed in **Section 6.2**.

5.5.2 ZVI Amendment Distribution

ZVI amendment distribution in the treatment area was verified using a combination of visual field observations and MSTs on samples of ZVI/sand mixture from completed reaction columns. During the field demonstration, each pump stroke was closely monitored and extraction of the mandrel timed such that amendment was uniformly delivered in the column from bottom to top.

The positive displacement pump is capable of delivering 0.25 ft^3 of material per pump stroke. The ZVI amendment was sampled from ten installed reaction columns over the course of the reaction column installation phase to evaluate the mixing and dosage delivered using MSTs in the field. Details of the MST method and completed field logs are provided in **Appendix H**. In general, the following parameters were measured:

- Wet density (lb/ft^3) of bulk amendment sample
- Wet weight (g) of bulk amendment sample
- ZVI weight (g)
- Moisture content (%)
- % ZVI total
- % ZVI dry

MSTs were performed on-site by a GSI field technician and results were used to verify the proper proportioning and mixing of the ZVI amendment in real time during the field demonstration. Mass fractions of ZVI measured in the field were converted to volumetric ratio and compared to the desired volumetric ZVI/sand ratio (40%/60%) ± 30%. Results of amendment distribution testing are described in **Section 2.2**.

Table 5.6. Sampling Plan for Field Demonstration

Sampling Component	Sampling Phases	Number of Samples	Sample Matrix	Collection Method	Analytes	Analytical Methods	Sample Locations
Existing On-Site Monitoring Wells	Baseline, 1-mon, 7-mon, 9-mon, 12-mon, 16-mon, 20 mon, and 26-mon	7 each sampling event (x 7 events)	Ground-water	Constant volume purge low flow sampling with flow through cell	**Field Parameters:** pH, Temperature, DO, ORP, Conductivity, Turbidity **CVOCs**: TCE, *cis*-1,2 DCE, VC **Dissolved Gases:** Methane, Ethane, Ethene **Metals:** Total Iron, Dissolved Iron **Biological:** Dechlorinating bacteria (i.e. Dehalococcoides spp., Dehalobacter spp.), Functional genes (i.e. tceA Reductase, bvcA Reductase, Vinyl Chloride Reductase) **Other**: Acetylene	**Field Parameters:** Water quality indicator probe (YSI or Horriba). **CVOCs**: Method 8260B **Dissolved Gases:** RSK-175 **Metals:** Method 3005A **Biological:** qPCR	MW-04, 11, 12, 13, 14, 15, and 16
Newly Installed RC-MWs	Immediately after reaction column installation (t>0), 1-mon, 7-mon, 9-mon, 12-mon, 16-mon, 20 mon, and 26-mon	12 each sampling event (4 x 3-interval CMTs) (x 8 events)	Ground-water	3-channel CMT wells; 3 depth intervals per RC-MW Inertial or other low flow method	**Field Parameters:** pH, Temperature, DO, ORP, Conductivity, Turbidity **CVOCs**: TCE, *cis*-1,2 DCE, VC **Dissolved Gases:** Methane, Ethane, Ethene **Metals:** Total Iron, Dissolved Iron **Biological:** Dechlorinating bacteria (i.e. Dehalococcoides spp., Dehalobacter spp.), Functional genes (i.e. tceA Reductase, bvcA Reductase, Vinyl Chloride Reductase) **Other**: Acetylene	**Field Parameters:** Water quality indicator probe (YSI or Horiba). **CVOCs**: Method 8260B **Dissolved Gases:** RSK-175 **Metals:** Method 3005A **Biological:** qPCR	Within central CVOC mass of demo area. One in oil column area.
Newly Installed SVCs	20-mon and 26-mon	6 CO_2 traps & 2 SVC grab samples	Vapor	Passive carbon traps; flow-controlled Summa canisters	**Vapor phase degradation indicators**: VOCs, methane, ethane, ethene, carbon dioxide, acetylene	Method AM20	Within central CVOC mass of demo area.
ZVI Amendment	During reaction column installation	10 reaction columns	Reaction Column Amend-ment	Grab sample	Magnetic separation tests to evaluate ZVI amendment mixing efficiency and distribution	Standard Magnetic separation tests methods (see **Appendix H**)	From Reaction Columns

5.5.3 Soil Vapor Sampling

Field screening of SVPs was conducted using a low detection ppbRAE 3000 photoionization detector (PID), calibrated in the field to a 100-ppb isobutylene standard. Prior to collection of field screening or laboratory samples, a shut-in test was conducted to verify the absence of leaks from the sampling manifold. A minimum of 3 tubing volumes were then purged from the soil vapor probe. For collection of samples for field screening, a clean 60-mL gas syringe was connected to the 3-way valve terminating the SVP tubing at the surface, and a 300 mL sample was slowly extracted (2-3 minutes) for temporary storage in 1-L dedicated Tedlar bags. The PID was then connected via MasterFlex tubing to the Tedlar bag, and the 300-mL sample was extracted by the internal pump of the PID. Field screening results indicated soil vapor concentrations ranging from 50 – 1,200 ppm during soil vapor sampling events.

As discussed in **Section 5.3.3**, soil vapor columns (SVCs) were constructed in pairs (one directly over reaction column and one adjacent over native material) at the locations shown in **Figure 5.8**. These were sampled using E-Flux carbon traps and flow-controlled Summa canisters during the April 2019 and October 2019 performance monitoring events, respectively. Carbon traps were deployed over the three SVC pairs (6 traps) for a period of two weeks, following the E-Flux sampling protocols provided in **Appendix J**. A sealed travel blank provided by E-Flux was also analyzed to perform ^{14}C correction for radiocarbon analysis and quantification of fossil fuel generated carbon flux.

Following the April 2019 carbon trap sampling event, SVCs were converted to traditional soil vapor probes (see **Section 5.3.3**), with soil gas samples collected using flow-controlled Summa canisters following standard soil-vapor sampling protocols, as detailed in the California Environmental Protection Agency's guidance on Active Soil Gas Investigations (CEPA, 2015; relevant sections provided in **Appendix I**). In general, soil vapor sampling included the following:

- shut-in tests of above-ground sampling system (to test for leaks in sampling system components);
- purging to remove stagnant air from sampling system components (e.g., sample tubing); and
- low-volume sampling techniques to avoid pulling additional sample volume from surrounding zones that may bias the results.

To prevent stripping of vapors from underlying saturated media, Summa canisters were equipped with 24-hr flow controllers and vacuum gauges to maintain minimal vacuum pressure (<30 in Hg) and <5 mL/min gas sampling rate. It should be noted that standard leak tests were not performed, as the SVCs were constructed to maintain equilibrium with ambient air. All SVCs were allowed to equilibrate to representative conditions for a minimum of 48 hours after installation and prior to vapor sampling. Details of the SVC sampling program are provided in **Table 5.6**; standard soil vapor sampling procedures are outlined in **Appendix I**.

Reaction gases (CO_2, methane, ethane, ethene, and acetylene) and VOCs were sampled from SVCs approximately two years after the field demonstration. The presence of reaction gases and higher coupling products (e.g., propane, propene, butane, pentane, and hexanes) were used to evaluate whether sustained biotic and abiotic reactions are maintained in the columns and provide information on the prevailing mechanisms of CVOC destruction in the columns. Soil vapor results are discussed in **Section 6.3**.

5.5.4 Calibration of Analytical Equipment

Analysis of groundwater and soil vapor samples was conducted at contracted analytical laboratories (i.e., Pace Analytical, Microbial Insights). Field measurements of organic vapaors and groundwater field parameters were performed using i) ppbRAE 3000 PID (or equivalent) for monitoring vapors in reaction column cores and in the workspace and ii) a Horiba U-52 series (or equivalent) for monitoring groundwater conditions, respectively. All instruments were calibrated at least once daily following manufacturer specifications, using appropriate calibration solutions and/or gases.

5.5.5 Quality Assurance Sampling

Laboratory analyses were completed using the methods and protocols outlined in **Table 5.6**. In all cases, method-specific containers were obtained from the respective laboratories prior to sampling. This includes containers requiring special preservatives (e.g., acids), all of which were added to containers by the commercial laboratories and not in the field. Laboratories were consulted on the necessary quality assurance/quality control (QA/QC) samples to ensure that appropriate sample containers were provided to field personnel. Key components of the QA/QC sampling program are listed in **Table 5.7**.

Table 5.7. QA/QC Sampling Program

QA/QC Sample Category	Sampling Frequency	Analytes
Equipment Rinsate	Not required	--
Trip Blanks	One per sample shipment	CVOCs
Field Duplicates	Approximately one for every ten samples	All requested analytes
Matrix Spike/Matrix Spike Duplicates	Approximately one for every twenty samples	Lab and method-specific
Laboratory Control Samples	One per method and batch	Lab and method-specific
Laboratory Method Blank	One per method and batch	Lab and method-specific

5.5.5.1 Field Quality Assurance Procedures

Field QA/QC samples were collected and analyzed to i) evaluate field precision and accuracy, and ii) facilitate validation of sample results. Field sampling precision and accuracy was assessed through the collection and laboratory analysis of field replicates and field blanks. Data from field QC samples were examined to determine if any problems were evident for specific media or with laboratory procedures. The GSI field and technical leads were responsible for reviewing the QA/QC data and developing appropriate corrective actions should any problems be encountered. Key components of the QA/QC sampling program are summarized below.

- **Equipment Rinsate Blanks:** Dedicated disposable sampling equipment was used in this field demonstration, therefore no equipment rinsate blanks were required.
- **Trip Blanks:** The effectiveness of sample handling techniques was evaluated by submitting preserved trip blank samples for laboratory analysis. Trip blanks consisted of a pair of 40-mL VOA vials with Teflon™ lined septa, filled in the laboratory (or organization*)* providing the sample containers) with laboratory-grade (organic-free/de-ionized or distilled) water.

The unopened trip blanks accompanied the VOC sample bottles to the sampling site and back to the laboratory in the same shipping cooler. Proper labeling and documentation were completed for trip blanks. Trip blanks were prepared and analyzed with other samples being analyzed for VOCs at a minimum frequency of one per day when sampling water only (i.e., no trip blanks were required if vapor was the only medium sampled on a particular day).

- **Field Duplicate Samples:** The precision of field sample collection techniques was evaluated by collecting and analyzing field duplicates. Duplicate samples are defined as those samples collected simultaneously from the same source under identical conditions into separate but identical containers, and preserved, stored, transported and analyzed in the same manner. Each duplicate was identically sampled, preserved, stored, transported and analyzed. Field duplicates were given a different identification number to disguise the source of the sample from the laboratory. Field replicates were analyzed by the same laboratory analyzing investigative samples. During the course of the demonstration, duplicates were collected at a minimum frequency of one duplicate for every 10 samples (10%).

  Note that non-traditional "duplicates" (not for QA/QC purposes) were also collected from CMT wells to evaluate changes in CVOC concentration immediately following recharge of CMT intervals. For these "duplicates", the CMT interval was purged dry following collection of the primary groundwater sample, and a "duplicate" was collected following recharge of at least 90% of the CMT interval tubing volume.

5.5.5.2 Laboratory Quality Assurance Procedures

The off-site laboratory at Pace Analytical implemented a QA/QC program to ensure the reliability and validity of analyses performed in the laboratory. Analytical procedures were documented in writing as standard operating procedures, each including a section addressing minimum QC requirements for the procedure. Internal quality control checks differ slightly for individual procedures, but in general QC requirements will include the following:

- Method blanks
- Instrument blanks
- Matrix spikes/matrix spike duplicates
- Surrogate spikes
- Laboratory duplicates
- Laboratory control standards
- Surrogate spikes
- Internal standard spikes
- Mass spectral tuning

Laboratories were provided with extra sample volume for preparation and analysis of matrix spike (MS) and matrix spike duplicates (MSD). Field personnel labeled all samples intended for MS/MSD analysis. All matrix spikes were completed by lab personnel.

QC sample results were properly recorded and included in the analytical data package. The data packages contained sufficient QC information to allow reconstruction and evaluation of the laboratory QC process by an independent data reviewer. Data generated in the laboratory was properly recorded and compiled into a deliverable package containing sufficient QC information for comparison to relevant criteria. Samples analyzed in non-conformance with the QC criteria were re-analyzed by the laboratory if sufficient volume was available.

5.5.6 Decontamination Procedures

Standard decontamination measures were employed during sampling activities and all other investigations associated with the project. This includes the one-time use of sample and method-appropriate containers, decontamination of all sampling equipment prior to sampling and between collecting each sample. Gloves were worn by all sampling personnel and changed out between each sample to minimize cross-contamination. All investigation-derived waste was collected and disposed of per site regulations.

5.5.7 Sample Documentation

Sample containers provided by the laboratory for this project were shipped by common carrier or other suitable method in sealed coolers to a location designated by the project team. The laboratory included a shipping form/laboratory chain-of-custody listing containers shipped and the purpose of each container. Containers were considered in the custody of the laboratory until received by GSI field personnel or a designated representative. Upon receipt, each shipment was checked to verify that all containers were intact. The containers were maintained in the custody of the receiver in a clean, secure area until used for sample collection. Copies of laboratory chains-of-custody (COCs) for all project sampling events are provided in **Appendix L**.

Procedures described below address custody during field sample collection, laboratory analysis, and file storage for the data collected as part of the project.

1) Field sampling personnel were personally responsible for the care and custody of the samples until transferred or properly dispatched.
2) Sample bottles and vessels were labeled with sample numbers and locations at the time of sample collection.
3) Sample labels were completed with permanent ink.
4) The sample labels affixed to containers were inspected to confirm that required information was provided.
5) If appropriate, the sample container was sealed in a zip-lock plastic bag, wrapped in bubble pack, and packed in a wet-ice or dry-ice cooler in a manner to minimize shifting or movement.
6) For each set of samples sent to the laboratory, a triplicate chain-of-custody form was completed. Information on the chain-of-custody form and the sample container labels was checked against the field logbook entries and the samples will be recounted.
7) If a commercial courier service (e.g., Federal Express) transported the samples to the laboratory, the chain-of-custody form was signed by a member of the field team, and a copy retained by the field team. The remaining two copies of the form were sealed in a zip-type plastic bag and placed in the cooler with the samples. The cooler was sealed with packaging tape and two custody seals signed and dated by a member of the field team. Custody seals were placed on the exterior of the cooler over the lid and sides. Package routing documentation maintained by the courier service served as chain-of custody documentation during shipment.

8) If samples were picked up by another third-party representative, a member of the field team signed the chain-of-custody record indicating that the samples have been transferred to the courier. The courier also signed the form, indicating that the samples were transferred to his or her custody. One copy of the chain-of-custody form was retained by the field team and the remaining two copies were sealed in a zip-type plastic bag and placed in the cooler chest with the samples.

9) All documentation was stored in duplicate at the GSI office. Access was limited to concerned project personnel. The Final Evidence File was maintained at this location until the conclusion of the project.

6.0 RESULTS

In this section, performance results from the field demonstration are presented, including efficiency of reaction column installation and post-installation performance monitoring (groundwater, soil vapor, and geophysics). Baseline groundwater sampling and geophysical results were discussed previously in **Sections 5.2** and **5.3** and are included in the discussion of the post-install monitoring results in the sections below.

6.1 EFFICIENCY OF REACTION COLUMN INSTALLATION

Table 6.1 summarizes the daily reaction column installation tally during the field demonstration. Overall, the Bomber technology installed 800 vertical reaction columns (700 ZVI/sand; 100 oil/sand) over approximately 7.5 operational day, resulting in an average installation rate of ~119 reaction columns per day.

Table 6.1. Daily Installation of Reaction Columns

Date	No. of RCs	Operating Days	Comment
July 24-26	--	--	Equipment arrival & setup; Grout Bomber assembly
July 27	1	0.5	Some mechanical issues with Bomber rig; replaced hydraulic motor;
July 28	82	1	Minor setbacks with pump/hose clogging; experimentation with amendment pumpability and practice priming hose with vegetable oil to prevent clogging
July 29	91	1	CMT-1 installed; stormwater controls installed
July 30 – Aug 7	--	--	Rain delay (9-day shutdown)
Aug 8	--	--	Timber mat delivery & installation; pump standing water out of demonstration area
Aug 9	180	1	
Aug 10	109	1	
Aug 11	122	1	Timber mat delivery & installation; CMT-2 installed
Aug 12	50	0.5	Rain delays; pump standing water; CMT-3 Installed
Aug 14	36	0.5	Rain delays; timber mat & aggregate placement; pump standing water
Aug 15	129	1	100 oil/sand columns; 29 ZVI/sand columns; CMT-4 installed
TOTAL	**800**	**7.5 days**	**Average of >100 columns installed daily during operation**
RCs = Reaction Columns			

As noted in **Table 6.1**, all 100 oil/sand columns were installed in a single day, as well as an additional 29 ZVI/sand columns following the batch mixing switch to the different amendment. The highest level of productivity was established during the middle stages of the demonstration while weather permitted a “sweet spot” of operational efficiency. During the field demonstration, the Grout Bomber was used to construct four CMT wells using the innovative bottom-feeding approach described in **Section 5.3.3** and illustrated in **Figure 5.7.** CMT wells were sampled at the earliest possible timeframe following column installation to establish the “t>0” monitoring event.

The baseline sample collected from the three depth intervals (upper, middle, lower) at CMT-1 (about 2 weeks after installation) exhibited an average TCE concentration of 2,490 ug/L between the dept intervals. For comparison, the adjacent source area monitoring well, IS17MW04, had a baseline TCE concentration of 257,000 µg/L. This 2-3 OoM difference between CMTs and their respective paired monitored wells was maintained with some consistency throughout the performance monitoring period and discussed further in **Section 6.2**.

6.2 GROUNDWATER SAMPLING RESULTS

As described in **Section 5.5.1,** a roughly semiannual sampling program (7-8 sampling events) was conducted at the monitoring wells and CMT wells during the approximately 2-year performance monitoring phase of the project. Performance results from the groundwater monitoring program are presented in **Tables 6.2 and 6.3**. Time series plots for TCE, cis-1,2-DCE, vinyl chloride, methane, ethene, and ethane at all CMT wells and monitoring wells, in addition to microbial biomarker time series plots for monitoring wells IS17MW04, IS17MW12, and IS17MW16 are presented in **Appendix E**.

Because this application of the Bomber technology relies on CVOC diffusion from low-k media into the reaction columns, significant reductions to CVOC mass were not expected within performance monitoring period. However, results from the four source area monitoring wells (IS17MW04, 12, 14, and 16) were very promising, showing greater than 70% reduction in TCE concentrations. At IS17MW16, TCE concentrations steadily decreased from 1700 ug/L (baseline) to 11.8 ug/L (26 months), a 99% reduction (see **Figure 6.1**). At IS17MW12, a 90% decrease in TCE concentrations was observed post-reaction column installation, coupled with increases in daughter products (*cis*-1,2-DCE and vinyl chloride) and ethene. Notably, ethane concentrations at IS17MW12 maintained an order of magnitude (OoM) increase following reaction column installation and throughout the monitoring period (see **Appendix E** Time-Series Plots). On a molar basis, total CVOC concentrations generally decreased over the monitoring period, with substantial variation in total concentrations and CVOC composition between sampling events (see **Figure 6.2**). This variability is likely due to tidal influences and changes in groundwater elevations at the site (see **Figure 6.3**).

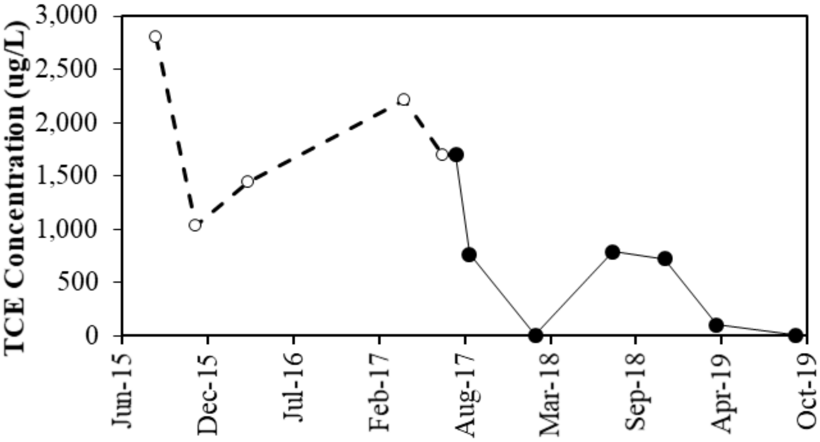


Figure 6.1. TCE Concentrations at Monitoring Well IS17MW16 (oil area)

Overall, geochemical parameters at the monitoring wells were consistent with baseline conditions, such that, groundwater remained acidic with a mixture of moderately oxidizing and reducing conditions and generally low DO concentrations. Specifically, oxidizing conditions were observed at wells IS17MW04, IS17MW12 and IS17MW14 and reducing conditions were observed at wells IS17MW11, IS17MW15 and IS17MW16. All CMT wells (with the exception of CMT-1-Middle) exhibited reducing conditions with ORP values generally ranging between approximately -50 and -200 mV (see **Table 6.2**). Gavaskar et al. (2005) reported that reducing aquifer conditions below -400 mV are required to generate conditions favorable for β-elimination, and that higher values of ORP coupled with increases in *cis*-1,2-DCE and vinyl chloride may indicate the predominance of the kinetically slower hydrogenolysis pathway (see **Figure 2.3**). While degradation rates were not estimated as part of this project, the slower reaction rates of the hydrogenolysis pathway of reductive dechlorination by ZVI may explain the slow response to treatment at Site 17. However, reaction gas monitoring results suggest that some β-elimination in the aquifer is probable, as discussed further in **Section 6.3**.

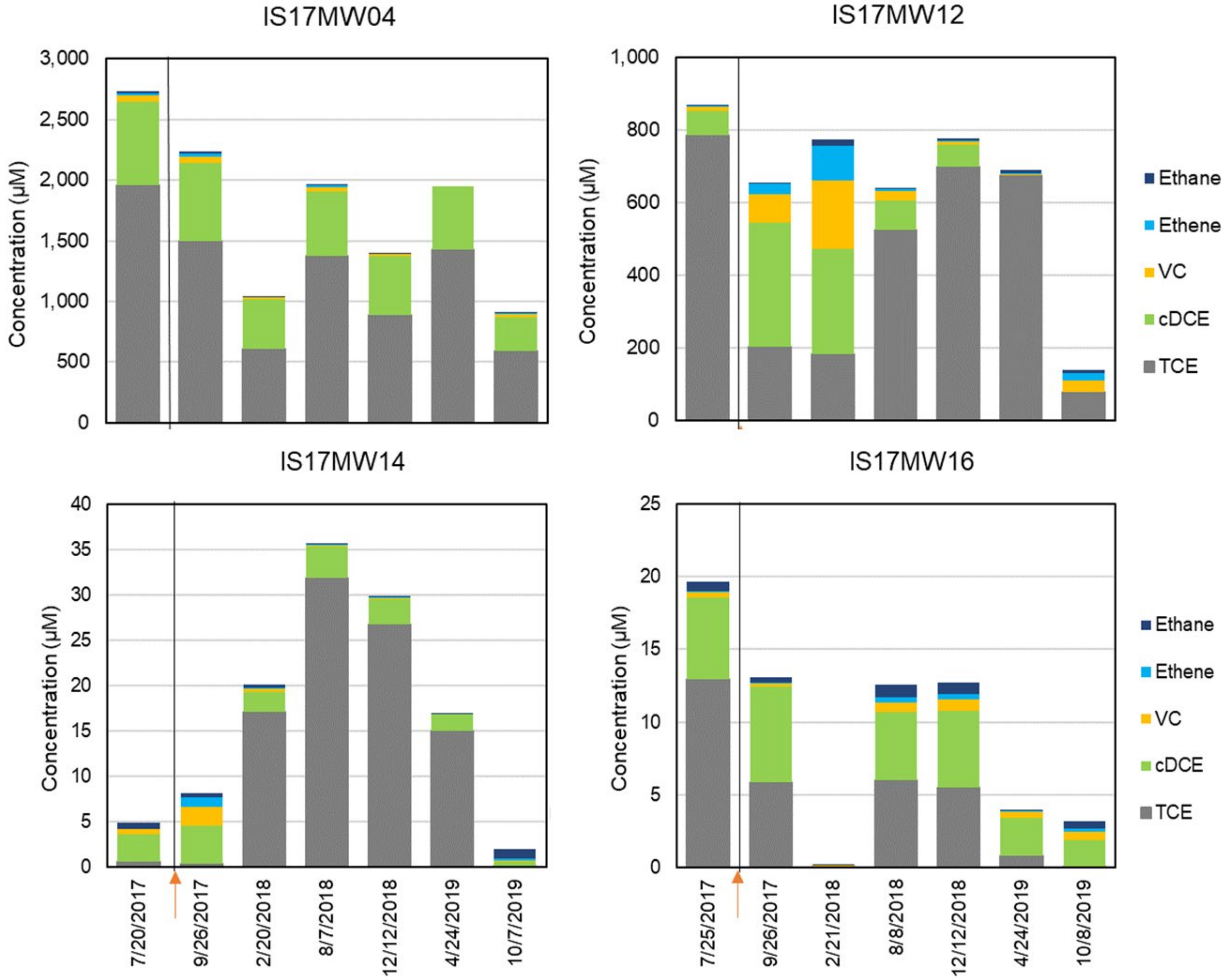


Figure 6.2. CVOC Concentrations at Monitoring Wells IS17MW04, -12, -14, and -16

(arrow denotes the start of post-install monitoring period)

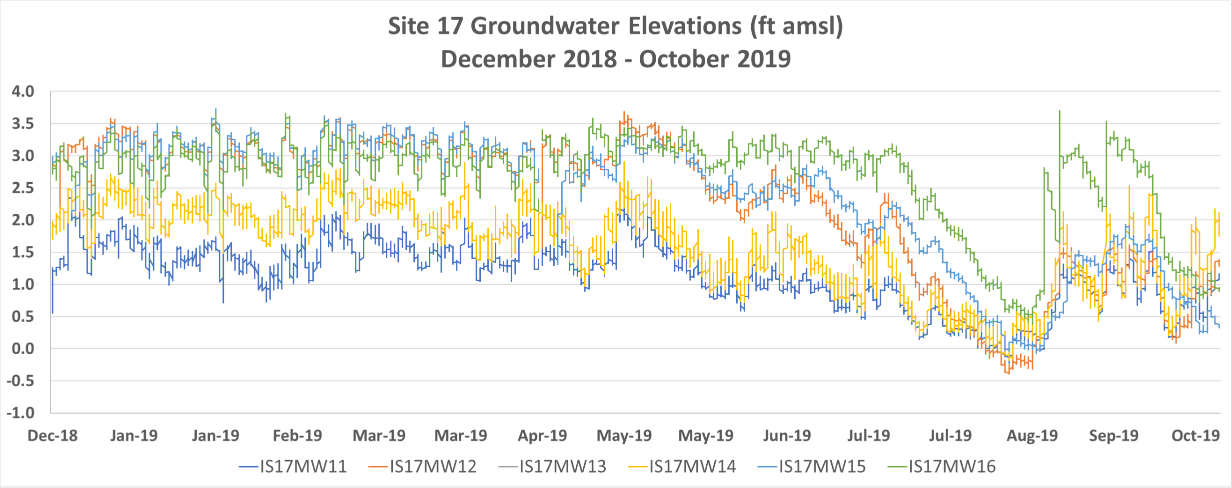


Figure 6.3. Groundwater Elevation Data from Select Monitoring Wells

(Dec 2018 – Oct 2019)

The current application of the Bomber technology relies on maintaining a steep concentration gradient between the reaction columns and surrounding contaminated low-k media to drive diffusion of CVOCs towards the hundreds of reaction columns. As discussed in **Section 5.3.3**, CMT wells were installed in reaction columns located in close proximity to three existing source area monitoring wells, creating CMT-monitoring well "pairs" for comparison over time (Pair 1: CMT-1/IS17MW04; Pair 2: CMT-2/IS17MW12; Pair 3: CMT-4/IS17MW16). As shown in **Figure 6.2**, TCE concentrations in the CMT wells are consistently lower than in the adjacent monitoring wells over the 26-month monitoring period. Specifically, differences in TCE concentrations range from approximately 1 OoM for well pair CMT-1/IS17MW04 to 4 OoM for well pair CMT-2/IS17MW12. These consistent, large differences in TCE concentration during the field demonstration provide indirect evidence of a concentration gradient established by the reaction columns. Given the long monitoring timeframe (~2 years), it is unlikely that the observed TCE reduction is strictly due to long-term dilution effects from the water added as part of the ZVI/sand mixture.

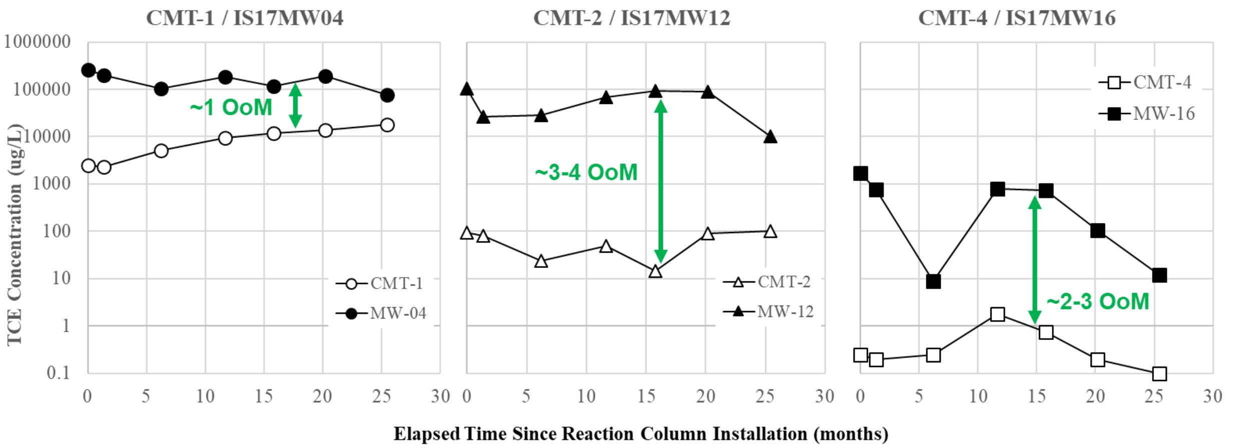


Figure 6.4. TCE Concentrations in CMT-monitoring Well Pairs

Table 6.2. Groundwater Monitoring: Geochemical Parameters

			Field Parameters						Cations/Anions					
Location ID	**Time Interval**	**Sample Date**	**pH, Field (SU)**	**Specific Conductance (mS/cm)**	**ORP (mV)**	**Dissolved Oxygen (mg/L)**	**Turbidity (NTU)**	**Temperature (deg C)**	**Chloride (µg/L)**	**Nitrate (µg/L)**	**Sulfate (µg/L)**	**Sulfide (µg/L)**	**Iron, Total (µg/L)**	**Iron, Dissolved (µg/L)**
Monitoring Wells														
IS17MW04	Baseline	7/19/2017	5.3	1.317	113.3	2.12	10.3	24.22	-	-	-	-	-	19700
	t>0	8/17/2017	5.3	1.317	113.3	2.12	10.3	24.27	-	-	-	-	-	-
	1-Month	9/27/2017	5.89	1.08	83	0.15	4.8	26.19	-	-	-	-	21400	-
	7-Month	2/22/2018	4.91	0.824	193	1.55	63.2	14.44	-	-	-	-	-	-
	12-Month	8/8/2018	6.06	1.4	35	0	14.4	21.17	343000	<102	-	-	-	-
	16-Month	12/13/2018	5.76	1.305	48.4	4.73	7.6	14.9	300000	-	-	-	7400	5640
	26-Month	10/10/2019	5.83	1.32	31	0.3	42.3	19.73	-	-	-	-	-	-
IS17MW11	Baseline	7/19/2017	5.5	0.982	6.4	0.48	9.7	22.62	-	-	-	-	-	76500
	1-Month	9/26/2017	5.95	1.06	-3	0	4.8	21.69	-	-	-	-	-	94500
	7-Month	2/20/2018	6.29	1.24	-78	0	18.6	12.97	-	-	-	-	118000	99700
	9-Month	4/16/2018	-	-	-	-	-	-	215000	<400	1670	<2000		-
	12-Month	8/8/2018	6.74	1.26	-100	0	21.4	20.26	247000	<102	-	-	88200	6470
	16-Month	12/11/2018	6.03	1.34	-79.3	0.05	14	14.1	260000	-	-	-	86800	5920
	20-Month	4/16/2019	6.47	1.29	-91	4.04	0	13.83	233000	137 J	193 J	<1080	-	-
	26-Month	10/7/2019	6.04	1.41	-88	0	78.8	22.41	280000	-	-	-	114000	6850
IS17MW12	Baseline	7/25/2017	5.2	0.56	89.9	0.69	9.6	19.58	-	-	-	-	10600	10500
	1-Month	9/27/2017	5.84	0.542	58	0	5.7	20.56	-	-	-	-	32500	-
	1-Month	9/27/2017	-	-	-	-	-	-	-	-	-	-	32000	-
	7-Month	2/21/2018	5.84	0.826	24	0	151	16.36	-	-	-	-	52400	42800
	9-Month	4/16/2018	-	-	-	-	-	-	118000	<400	41900	<2000	-	-
	12-Month	8/8/2018	6.59	0.505	43	0	67	23.9	75600	<102	-	-	6860	722
	16-Month	12/13/2018	5.37	0.416	78.9	0.02	30.4	14.5	70000	-	-	-	3220	1550
	16-Month	12/13/2018	-	-	-	-	-	-	71000	-	-	-	3060	1490
	20-Month	4/16/2019	5.71	0.42	106	1.01	2	15.52	73700	106 J	57900	<1080	-	-
	26-Month	10/9/2019	5.77	0.56	27	0.1	0	20.49	97000	-	-	-	20700	2400
IS17MW13	Baseline	7/20/2017	6.12	1.288	-54.2	0.37	9.7	20.94	-	-	-	-	48100	50800
	1-Month	9/26/2017	6.31	0.824	-45	0	7.2	20.87	-	-	-	-	38800	36400
	7-Month	2/20/2018	5.82	0.539	-43	0	47	14.53	-	-	-	-	50700	43300
	9-Month	4/18/2018	-	-	-	-	-	-	126000	<400	17200	<1080	-	-
	12-Month	8/8/2018	7.01	1.05	-81	0	40.8	29.72	189000	<102	-	-	31600	2960
	16-Month	12/12/2018	6.43	1.194	-58.8	1.9	10.5	13.4	150000	-	-	-	41900	2020
	20-Month	4/16/2019	6.45	0.944	-49	3.8	50.8	15.11	178000	102 J	71600	<1080	-	-
	26-Month	10/8/2019	6.31	1.04	-74	0.13	0	19.69	130000	-	-	-	29100	1240
IS17MW14	Baseline	7/20/2017	5.31	0.639	40	0.51	3.81	20.04	-	-	-	-	-	20200
	1-Month	9/26/2017	5.77	0.325	11	0	3.7	25.11	-	-	-	-	-	18900
	7-Month	2/20/2018	5.19	0.309	21	0	15.4	14.12	-	-	-	-	9440	8480
	9-Month	4/27/2018	-	-	-	-	-	-	49100	<200	39900	<2000	-	-
	12-Month	8/7/2018	6.62	0.416	36	1.55	31.3	24.99	74300	<102	-	-	4360	743
	16-Month	12/12/2018	5.92	0.452	32.1	2.34	10.1	14.8	58000	-	-	-	3970	878
	20-Month	4/17/2019	5.85	0.327	68	0	52.4	16.3	41300	106 J	51900	<1080	-	-
	26-Month	10/7/2019	5.76	0.577	-15	0	8.6	23.92	120000	-	-	-	31200	8470

Table 6.2. Groundwater Monitoring: Geochemical Parameters (cont.)

			Field Parameters						Cations/Anions					
Location ID	**Time Interval**	**Sample Date**	**pH, Field (SU)**	**Specific Conductance (mS/cm)**	**ORP (mV)**	**Dissolved Oxygen (mg/L)**	**Turbidity (NTU)**	**Temperature (deg C)**	**Chloride (µg/L)**	**Nitrate (µg/L)**	**Sulfate (µg/L)**	**Sulfide (µg/L)**	**Iron, Total (µg/L)**	**Iron, Dissolved (µg/L)**
IS17MW15	Baseline	7/20/2017	6.01	1.297	14.9	0.46	6.12	23.36	-	-	-	-	15400	14500
	1-Month	9/26/2017	6.4	0.945	11	1.88	5.1	23.5	-	-	-	-	-	13900
	7-Month	2/20/2018	6.58	1.29	-18	0	50.8	16.38	-	-	-	-	19600	16000
	9-Month	4/16/2018	-	-	-	-	-	-	282000	<400	54100	<2000	-	-
	12-Month	8/8/2018	-	-	-	-	-	-	265000	<102	-	-	25100	4260
	12-Month	8/8/2018	7.07	1.43	-67	0	9.5	19.36	290000	<102	-	-	23400	5430
	16-Month	12/13/2018	6.32	1.362	-35.8	0	92.1	13.4	270000	-	-	-	18100	2620
	20-Month	4/16/2019	6.84	1.38	-126	0.52	52.4	16.8	289000	106 J	41300	<1080	-	-
	26-Month	10/7/2019	6.51	1.36	-98	0.1	9.4	21.97	250000	-	-	-	28700	2120
IS17MW16	Baseline	7/25/2017	5.79	0.935	46.3	0.41	9.8	20.35	-	-	-	-	16200	15000
	1-Month	9/26/2017	6.14	0.779	19	0	9.7	22.1	-	-	-	-	16800	15000
	7-Month	2/21/2018	6.28	0.324	176	0	70.2	20.86	-	-	-	-	4470	1080
	9-Month	4/27/2018	-	-	-	-	-	-	25000	<400	13600	<2000	500	-
	12-Month	8/8/2018	5.86	0.975	-27	0	0	22.27	166000	<102	-	-	17000	2020
	12-Month	8/8/2018	-	-	-	-	-	-	-	-	-	-	16700	-
	16-Month	12/12/2018	6.14	0.971	-6	0	11.6	11.5	130000	-	-	-	38600	3980
	20-Month	4/16/2019	6.21	0.631	-36	0	181	15.23	69100	133 J	25900	<1080	-	-
	26-Month	10/8/2019	6.04	0.796	-8	0.2	0	19.72	100000	-	-	-	13700	1550
Continuous Multi-Level Tubing (CMT) Wells														
CMT-01-UPPER	t>0	8/16/2017	6.3	0.834	-36	0	17.5	22.2	-	-	-	-	118000	90200
	1-Month	9/27/2017	6.4	0.833	-28	0	70.2	23.99	-	-	-	-	109000	-
	7-Month	2/20/2018	6.19	0.544	-66	0.53	290	20.64	-	-	-	-	125000	88500
	12-Month	8/7/2018	6.92	1.1	-87	0.12	49.5	24.72	-	-	-	-	98300	-
	16-Month	12/11/2018	6.25	1.084	-59.8	3.28	10.8	12.9	240000	-	-	-	121000	15800
	20-Month	4/24/2019	6.1	1.26	-79	0.74	20.9	18.63	300000	-	-	-	102000	3510
	26-Month	10/9/2019	6.24	1.18	-86	3.44	19.7	23.05	300000	-	-	-	140000	26000
CMT-01-MIDDLE	t>0	8/16/2017	6.28	1.28	-10	1.81	220	21.92	-	-	-	-	62600	22600
	1-Month	9/27/2017	6.22	1.12	28	1.13	33.7	23.24	-	-	-	-	50000	-
	7-Month	2/21/2018	6.14	1.39	62	1.65	169	15.19	-	-	-	-	37200	21500
	12-Month	8/7/2018	6.65	1.35	21	1.15	27.5	25.29	-	-	-	-	39800	-
	16-Month	12/11/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	320000	-	-	-	25700	3420
	20-Month	4/25/2019	5.25	1.33	159	0.88	89.7	15.77	330000	-	-	-	13600	419
	26-Month	10/9/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	380000	-	-	-	16600	6310
CMT-01-LOWER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	-
	1-Month	9/27/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	1720	-
	7-Month	2/21/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	2270	589
	12-Month	8/7/2018	7.12	1.48	17	1.49	17.5	30.61	-	-	-	-	166	-
	16-Month	12/11/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	2340	805
	20-Month	4/25/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	350000	-	-	-	298	144
	26-Month	10/9/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	350000	-	-	-	473	112

Table 6.2. Groundwater Monitoring: Geochemical Parameters (cont.)

			Field Parameters						**Cations/Anions**					
Location ID	**Time Interval**	**Sample Date**	**pH, Field (SU)**	**Specific Conductance (mS/cm)**	**ORP (mV)**	**Dissolved Oxygen (mg/L)**	**Turbidity (NTU)**	**Temperature (deg C)**	**Chloride (µg/L)**	**Nitrate (µg/L)**	**Sulfate (µg/L)**	**Sulfide (µg/L)**	**Iron, Total (µg/L)**	**Iron, Dissolved (µg/L)**
CMT-02-UPPER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	20700
	1-Month	9/26/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*					-	
	7-Month	2/21/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	22100	-
	12-Month	8/7/2018	7.78	0.496	-168	0	187	25.28	-	-	-	-	12500	-
	16-Month	12/13/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	88000	-	-	-	32500	526
	20-Month	4/24/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	51000	-	-	-	2920	376
	26-Month	10/10/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	-
CMT-02-MIDDLE	t>0	8/16/2017	6.95	0.44	-118	2.11	>4000	25.62	-	-	-	-	32500	25200
	1-Month	9/27/2017	6.58	0.721	77	0.12	854	22.11	-	-	-	-	8200	-
	7-Month	2/21/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	26800	18800
	12-Month	8/7/2018	7.65	1.07	-21	1.48	27.5	23.77	-	-	-	-	18200	-
	16-Month	12/13/2018	6.69	1.087	-87.9	1.39	33.5	14.2	120000	-	-	-	26000	525
	20-Month	4/24/2019	6.72	1.09	-128	1.13	34	26.52	120000	-	-	-	26400	679
	26-Month	10/10/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	-
CMT-02-LOWER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	-
	1-Month	9/27/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	4100	-
	7-Month	2/21/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	4340	-
	12-Month	8/7/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	17500	-
	16-Month	12/13/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	96000	-	-	-	-	1350
	20-Month	4/24/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	1230
	26-Month	10/10/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	41000	528
CMT-03-UPPER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	-
	12-Month	8/7/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	173000	-
	16-Month	12/13/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	98000	-	-	-	-	432
	20-Month	4/24/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	94000	-	-	-	-	1780
CMT-03-MIDDLE	t>0	8/16/2017	6.98	1.16	-147	3	787	28.36	-	-	-	-	43500	14000
	1-Month	9/26/2017	6.82	1.03	-25	0.82	35	20.58	-	-	-	-	26000	19500
	7-Month	2/21/2018	7.24	1.15	-125	0	0	18.93	-	-	-	-	4700	4030
	12-Month	8/7/2018	7.66	1.2	-131	1.79	18.6	23.17	-	-	-	-	6590	-
	16-Month	12/13/2018	6.95	1.272	-88.2	1.11	32.2	12.7	200000	-	-	-	14000	699
	20-Month	4/24/2019	6.91	1.19	-124	0.83	37.5	23.21	200000	-	-	-	20600	560
	26-Month	10/10/2019	6.79	1.18	-94	0.84	23.8	18.58	180000	-	-	-	7540	1100
CMT-03-LOWER	t>0	8/16/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	-	-
	1-Month	9/26/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	23300	7530
	7-Month	2/21/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	15800	9240
	12-Month	8/7/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	2210	-
	16-Month	12/13/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	340000	-	-	-	13200	824
	20-Month	4/24/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	360000	-	-	-	3220	1110
	26-Month	10/10/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	8960	370

Table 6.2. Groundwater Monitoring: Geochemical Parameters (cont.)

			Field Parameters						Cations/Anions					
Location ID	**Time Interval**	**Sample Date**	**pH, Field (SU)**	**Specific Conductance (mS/cm)**	**ORP (mV)**	**Dissolved Oxygen (mg/L)**	**Turbidity (NTU)**	**Temperature (deg C)**	**Chloride (µg/L)**	**Nitrate (µg/L)**	**Sulfate (µg/L)**	**Sulfide (µg/L)**	**Iron, Total (µg/L)**	**Iron, Dissolved (µg/L)**
CMT-04-UPPER	t>0	8/16/2017	6.46	0.28	12	4.57	319	28.36	-	-	-	-	13400	2370
	1-Month	9/26/2017	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	15100	16500
	7-Month	2/21/2018	5.55	0.532	47	0.41	41	24.19	-	-	-	-	53400	37400
	12-Month	8/8/2018	5.89	0.619	-14	1.32	102	24.7	-	-	-	-	33400	-
	16-Month	12/13/2018	6.26	0.728	-46.2	1.91	93.2	10.4	82000	-	-	-	21300	4960
	20-Month	4/24/2019	6.13	0.697	-73	0.35	95.4	20.2	91000	-	-	-	24200	2580
CMT-04-MIDDLE	t>0	8/16/2017	5.72	0.396	74	2.08	742	23.1	-	-	-	-	11900	3160
	1-Month	9/26/2017	5.87	0.396	-1	0.34	82.9	22.63	-	-	-	-	-	22100
	7-Month	2/21/2018	6.33	0.858	-51	0	494	21.61	-	-	-	-	42400	33900
	12-Month	8/8/2018	6.05	0.912	-60	0	77.2	21.92	-	-	-	-	37500	-
	16-Month	12/13/2018	6.07	0.814	-36.5	0.58	*vol*	15.3	100000	-	-	-	26000	12300
	20-Month	4/24/2019	6.16	0.88	-54	0.18	79.4	19.32	110000	-	-	-	31000	4710
	26-Month	10/9/2019	6.36	0.808	-50	0.72	146	22.33	85000	-	-	-	29900	3530
CMT-04-LOWER	t>0	8/16/2017	5.74	0.364	109	3.5	836	21.85	-	-	-	-	7060	2620
	1-Month	9/26/2017	5.68	0.41	-10	0.2	266	22.15	-	-	-	-	-	35000
	7-Month	2/21/2018	5.34	0.385	5	0.19	535	26.63	-	-	-	-	53100	42800
	12-Month	8/8/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	40000	-
	16-Month	12/13/2018	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	87000	-	-	-	-	2510
	20-Month	4/24/2019	6.24	0.832	-57	0.73	276	22.53	120000	-	-	-	33800	3560
	26-Month	10/9/2019	*vol*	*vol*	*vol*	*vol*	*vol*	*vol*	-	-	-	-	45300	1460

Notes:

1. J= Estimated value detected between the Sample Detection Limit (SDL) and the Method Quantitation Limit (MQL; also referred to as PQL).
2. "--" = not sampled / measured
3. "*vol*" = not sampled/measured due to insufficient well volume
4. The "t>0" time interval represents the earliest possible sampling event for CMT wells after installation of the reaction columns.

Table 6.3. Groundwater Monitoring: CVOCs and Dissolved Gases

				CVOCs (ug/L)					Dissolved Gases (ug/L)			
Location ID	Sample Date	Time Interval	Sample Type	Tetrachloroethene (PCE)	Trichloroethene (TCE)	cis-1,2-dichloroethene (cDCE)	trans-1,2-dichloroethene	Vinyl chloride	Methane	Ethane	Ethene	Acetylene
Monitoring Wells												
IS17MW04	7/19/2017	Baseline	N	142	257000	67300	367	2790	1100	430	650	<0.048
	9/27/2017	1-Month	N	119	197000	62100	358	3240	1400	480	720	0.95
	2/21/2018	7-Month	N	-	80100	39500	-	1010	140	40	97	<0.055
	4/27/2018	9-Month	N	-	141000	32700	-	518 J	-	-	-	-
	8/8/2018	12-Month	N	110	181000	50900	348	2540	710	280	420	0.28 Jn
	12/12/2018	16-Month	N	69.9	116000	47500	239	1100	300	110	160	0.37 Jn
	4/16/2019	20-Month	N	-	188000	50500	-	<400	-	-	-	-
	10/10/2019	26-Month	N	85.7	77500	27500	348	1120	490	180	290	0.66
IS17MW11	7/19/2017	Baseline	N	<0.33	<0.5	<0.48	<0.32	<0.21	6700	4200	<0.009	<0.048
	9/26/2017	1-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	10000	8900	12	<0.022
	2/20/2018	7-Month	N	-	<0.5	<0.5	-	<0.5	15000	5700	<0.005	<0.055
	4/16/2018	9-Month	N	-	<0.5	<0.5	-	<0.5	3630	1620	0.269 J	-
	8/7/2018	12-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	12000	5400	0.06 Jn	<0.034
	12/11/2018	16-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	15000	6600	1.2	<0.034
	4/16/2019	20-Month	N	-	19	0.76 J	-	<0.2	7450	3210	<0.15	-
	10/7/2019	26-Month	N	<0.39	<0.29	<0.38	<0.28	<0.29	9800	6300	<0.004	<0.019
IS17MW12	7/25/2017	Baseline	N	92.1	103000	6460	80.6	750	220	23	110	<0.048
	9/27/2017	1-Month	N	29.7	26700	33000	421	4990	550	120	780	<0.022
	9/27/2017	1-Month	Dup	29.3	27100	34600	385	5520	510	130	770	<0.022
	2/21/2018	7-Month	N	-	24000	28100	-	11700	2400	500	2900	<0.055
	4/16/2018	9-Month	N	-	49200	21000	-	6200	1070	295	1340	-
	8/7/2018	12-Month	N	86.5	68900	7900	107	1580	200	91	210	<0.034
	12/13/2018	16-Month	N	87.8	91900	5800	30.4	458	330	210	100	<0.034
	12/13/2018	16-Month	Dup	91.4	92800	5410	32.5	483	330	210	100	<0.034
	4/16/2019	20-Month	N	-	88600	5120	-	<100	508	211	101	-
	10/9/2019	26-Month	N	24.9	10200	23000	<141	2070	1200	280	550	<0.019
IS17MW13	7/20/2017	Baseline	N	<0.39	<0.22	1	<0.11	<0.32	730	1.1	0.19	<0.048
	9/26/2017	1-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	11000	4.3	0.12	<0.022
	2/20/2018	7-Month	N	-	<0.5	<0.5	-	<0.5	17000	1.2	<0.005	<0.055
	4/27/2018	9-Month	N	-	<4.63	<0.636	-	<0.5	3460	1.18	<0.29	-
	4/27/2018	9-Month	Dup	-	<3.81	<0.514	-	<0.5	-	-	-	-
	8/7/2018	12-Month	N	<0.32	<0.39	1.3	<0.22	<0.31	1200	0.94	0.17	<0.034
	12/12/2018	16-Month	N	<0.32	<0.39	1.2	<0.22	<0.31	5900	1.1	0.46	<0.034
	4/16/2019	20-Month	N	-	<0.2	1.51	-	<0.2	3130	0.565 J	<0.15	-
	4/16/2019	20-Month	Dup	-	<0.2	1.51	-	<0.2	-	-	-	-
	10/8/2019	26-Month	N	<0.39	<0.29	<0.38	<0.28	<0.29	10000	0.79	0.027 J	<0.019
IS17MW14	7/20/2017	Baseline	N	<0.39	84.4	291	1.2	32.5	2200	22	1.4	<0.048
	9/26/2017	1-Month	N	<0.32	44.3	413	3.5	127	6300	14	29	<0.022
	2/20/2018	7-Month	N	-	2250	216	-	21.5 J	3100	12	0.88	<0.055
	4/27/2018	9-Month	N	-	4950	315	-	15.8 J	1.4 J	<0.22	<0.29	-
	8/7/2018	12-Month	N	2.5	4180	335	4.3	11.9	300	4.3	1.3	<0.034
	12/12/2018	16-Month	N	<1.6	3520	265	2.8 J	7.2	240	2.8	1.8	<0.034
	4/17/2019	20-Month	N	-	1970	181	-	<5	435	2.05	0.394 J	-
	10/7/2019	26-Month	N	<0.39	2	56.2	<0.28	10.6	8900	32	5.6	<0.019

Table 6.3. Groundwater Monitoring: CVOCs and Dissolved Gases (cont.)

				CVOCs (ug/L)					Dissolved Gases (ug/L)			
Location ID	Sample Date	Time Interval	Sample Type	Tetrachloroethene (PCE)	Trichloroethene (TCE)	cis-1,2-dichloroethene (cDCE)	trans-1,2-dichloroethene	Vinyl chloride	Methane	Ethane	Ethene	Acetylene
IS17MW15	7/20/2017	Baseline	N	<0.33	<0.5	<0.48	<0.32	<0.21	4000	14	0.21	<0.048
	9/26/2017	1-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	3600	33	0.56	<0.022
	2/20/2018	7-Month	N	-	<0.5	<0.5	-	<0.5	8200	18	<0.005	<0.055
	2/20/2018	7-Month	Dup	-	<0.5	<0.5	-	<0.5	-	-	-	-
	4/16/2018	9-Month	N	-	<0.5	<0.5	-	<0.5	9140	9.02	<0.29	-
	8/7/2018	12-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	8100	41	0.07 Jn	<0.034
	8/7/2018	12-Month	Dup	<0.32	<0.39	<0.18	<0.22	<0.31	9200	49	0.07 Jn	<0.034
	12/13/2018	16-Month	N	<0.32	1.2	<0.18	<0.22	<0.31	5300	17	0.11	<0.034
	4/16/2019	20-Month	N	-	<0.2	<0.2	-	<0.2	6280	6.29	<0.15	-
	10/7/2019	26-Month	N	<0.39	<0.29	<0.38	<0.28	<0.29	4200	41	<0.004	<0.019
IS17MW16	7/25/2017	Baseline	N	<0.39	1700	542	8.2	22.8	820	19	2.5	<0.048
	9/26/2017	1-Month	N	<0.32	769	635	28.8	15.2	470	11	1.2	<0.022
	2/21/2018	7-Month	N	-	7.4	6.44	-	0.586 J	77	0.62	0.29	<0.055
	2/21/2018	7-Month	Dup	-	8.51	8.67	-	0.879 J	-	-	-	-
	4/27/2018	9-Month	N	-	18.9	44.5	-	5.06	459	1.4	0.377 J	-
	8/8/2018	12-Month	N	<0.32	789	452	8	44.3	1200	26	9.3	<0.034
	8/8/2018	12-Month	Dup	<0.32	801	471	7.6	42.8	1400	31	9.8	<0.034
	12/12/2018	16-Month	N	<0.32	722	512	8.3	48.9	1600	23	11	<0.034
	4/16/2019	20-Month	N	-	106	254	-	26.1	975	2.04	2.15	-
	10/8/2019	26-Month	N	<0.39	11.8	177	1.9	35.8	1600	15	5.7	<0.019
Continuous Multi-Level Tubing (CMT) Wells												
CMT-01-UPPER	8/16/2017	t>0	N	<0.33	120	126	<0.32	25.7	7600	2400	89	<0.022
	9/27/2017	1-Month	N	<0.32	33.9	300	2.8	68	12000	1700	18	<0.022
	2/20/2018	7-Month	N	-	16.4	418	-	119	10000	2000	44	<0.022
	2/20/2018	7-Month	Dup*	-	2.46	67.9	-	19.6	12000	2800	55	<0.022
	8/7/2018	12-Month	N	<0.32	8.1	654	2.5	342	12000	1900	40	<0.034
	12/11/2018	16-Month	N	<0.32	7.4	162	<0.22	123	12000	1600	60	<0.034
	4/24/2019	20-Month	N	<0.32	94.9	806	4.2	288	19000	3400	14	<0.019
	4/24/2019	20-Month	Dup*	<0.32	3.8	19.6	<0.22	5.6	19000	3400	3.6	<0.019
	4/25/2019	20-Month	Dup*	<0.32	83.8	344	2.7	82.7	18000	3200	7.2	<0.019
	10/9/2019	26-Month	N	<0.39	22.2	82.3	<0.28	42.1	11000	1800	23	<0.019
	10/9/2019	26-Month	Dup*	<0.39	31	42.4	<0.28	7.8	13000	2200	5.3	<0.019
CMT-01-MIDDLE	8/16/2017	t>0	N	<0.33	7160	825	2.4	56.1	570	270	260	19
	9/27/2017	1-Month	N	1	6780	26300	87	211	630	420	480	1.9
	2/21/2018	7-Month	N	-	14500	32400	-	1220	1000	400	500	0.52
	8/7/2018	12-Month	N	3.5	23800	16500	173	906	1200	430	580	<0.034
	12/11/2018	16-Month	N	3.9 J	24100	18900	80.5	1250	1800	450	500	<0.034
	4/25/2019	20-Month	N	6.3	28500	11600	94.2	665	1800	500	530	<0.019
	4/25/2019	20-Month	Dup*	-	-	-	-	-	830	210	210	<0.019
	10/9/2019	26-Month	N	9.3	39300	13800	225	888	2100	440	310	<0.019
CMT-01-LOWER	8/16/2017	t>0	N	<0.33	191	116	<0.32	4.2	110	100	66	1
	9/27/2017	1-Month	N	<0.32	47.8	167	3.9	105	290	180	100	2.1
	9/27/2017	1-Month	Dup*	<0.32	4460	4300	29.6	140	2900	420	270	12
	2/21/2018	7-Month	N	-	727	5370	-	970	1600	250	190	<0.022
	2/21/2018	7-Month	Dup*	-	3470	15700	-	1500	-	-	-	-
	8/7/2018	12-Month	N	<0.32	4180	8960	78	778	1600	280	260	<0.034
	12/11/2018	16-Month	N	<1.6	12000	10700	30.7	742	1800	290	280	<0.034
	4/25/2019	20-Month	N	2.1	13600	8940	105	537	2400	310	230	<0.019
	10/9/2019	26-Month	N	2.5	14100	8770	95.3	444	2000	280	180	<0.019

Table 6.3. Groundwater Monitoring: CVOCs and Dissolved Gases (cont.)

				CVOCs (ug/L)					Dissolved Gases (ug/L)			
Location ID	Sample Date	Time Interval	Sample Type	Tetrachloroethene (PCE)	Trichloroethene (TCE)	cis-1,2-dichloroethene (cDCE)	trans-1,2-dichloroethene	Vinyl chloride	Methane	Ethane	Ethene	Acetylene
CMT-02-UPPER	8/16/2017	t>0	N	<0.33	19.6	3.8	<0.32	<0.21	160	16	13	<0.022
	9/27/2017	1-Month	N	<0.32	7.2	150	<0.22	5.4	6100	34	11	<0.022
	2/21/2018	7-Month	N	-	2	12.5	-	25.7	5100	21	6	<0.022
	8/7/2018	12-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	9300	31	0.11	<0.034
	12/13/2018	16-Month	N	<0.32	0.69 J	1.4	<0.22	20.4	10000	72	36	<0.034
	4/24/2019	20-Month	N	<0.32	2.6	491	4.6	229	1700	22	13	<0.019
	10/10/2019	26-Month	N	<0.39	<0.29	<0.38	<0.28	<0.29	9700	49	<0.004	<0.019
CMT-02-MIDDLE	8/16/2017	t>0	N	<0.33	259	26.2	<0.32	<0.21	38	41	15	<0.022
	9/27/2017	1-Month	N	<0.32	168	388	1.1	2.1	240	51	19	<0.022
	2/21/2018	7-Month	N	-	63.3	722	-	190	2700	46	65	<0.022
	8/7/2018	12-Month	N	<0.32	97.4	602	6.9	447	2000	65	150	<0.034
	12/13/2018	16-Month	N	<0.32	28	282	1.4	146	3400	89	140	<0.034
	4/24/2019	20-Month	N	<0.32	215	2270	18.3	367	3400	110	92	<0.019
	10/10/2019	26-Month	N	<0.39	102	368	2.6	121	4700	45	31	<0.019
CMT-02-LOWER	8/16/2017	t>0	N	<0.33	6.3	1.6	<0.32	<0.21	14	4	6.7	<0.022
	9/27/2017	1-Month	N	<0.32	64.4	40.6	<0.22	<0.31	130	38	16	<0.022
	2/21/2018	7-Month	N	-	<5	272	-	227	1600	28	24	<0.022
	8/7/2018	12-Month	N	<0.32	1.5	34.2	1.5	332	4200	67	180	<0.034
	12/13/2018	16-Month	N	<0.32	<0.39	65.9	1.9	284	6000	100	140	<0.034
	4/24/2019	20-Month	N	<0.32	56	555	8.3	321	5200	110	150	<0.019
	4/24/2019	20-Month	Dup*	<0.32	16.8	397	6	131	-	-	-	-
	10/10/2019	26-Month	N	<0.39	<0.29	17.7	<0.28	47.9	5500	92	140	<0.019
CMT-03-UPPER	8/16/2017	t>0	N	<0.33	<0.5	2.2	<0.32	<0.21	700	15	19	<0.022
	9/26/2017	1-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	4100	15	1.7	<0.022
	2/21/2018	7-Month	N	-	<0.5	<0.5	-	<0.5	6700	15	0.31	<0.022
	8/7/2018	12-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	7300	16	<0.005	<0.034
	12/13/2018	16-Month	N	<0.32	0.67 J	<0.18	<0.22	<0.31	11000	22	0.034 Jn	<0.034
	4/24/2019	20-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	7600	18	<0.004	<0.019
	10/10/2019	26-Month	N	<0.39	1.3	3.7	<0.28	<0.29	10000	12	<0.004	<0.019
CMT-03-MIDDLE	8/16/2017	t>0	N	<0.33	1.2	<0.48	<0.32	<0.21	43	16	11	<0.022
	9/26/2017	1-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	670	25	8.9	<0.022
	2/21/2018	7-Month	N	-	<0.5	0.666 J	-	<0.5	9700	27	5.3	<0.022
	8/7/2018	12-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	7600	30	0.23	<0.034
	12/13/2018	16-Month	N	<0.32	0.53 J	<0.18	<0.22	<0.31	7000	20	0.059 Jn	<0.034
	4/24/2019	20-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	7200	20	<0.004	<0.019
	10/10/2019	26-Month	N	<0.39	<0.29	<0.38	<0.28	<0.29	6300	16	<0.004	<0.019
	10/10/2019	26-Month	Dup*	<0.39	1.5	3.4	<0.28	<0.29	-	-	-	-
CMT-03-LOWER	8/16/2017	t>0	N	<0.33	<0.5	<0.48	<0.32	<0.21	22	4.9	8.5	<0.022
	9/26/2017	1-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	710	18	9	<0.022
	2/21/2018	7-Month	N	-	<0.5	<0.5	-	<0.5	9000	16	0.28	<0.022
	8/7/2018	12-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	5900	19	0.024 Jn	<0.034
	12/13/2018	16-Month	N	<0.32	0.64 J	<0.18	<0.22	<0.31	6100	15	0.15	<0.034
	4/24/2019	20-Month	N	<0.32	<0.39	<0.18	<0.22	<0.31	5400	15	<0.004	<0.019
	10/10/2019	26-Month	N	<0.39	<0.29	<0.38	<0.28	<0.29	5000	11	<0.004	<0.019

Table 6.3. Groundwater Monitoring: CVOCs and Dissolved Gases (cont.)

				CVOCs (ug/L)					Dissolved Gases (ug/L)			
Location ID	**Sample Date**	**Time Interval**	**Sample Type**	**Tetrachloroethene (PCE)**	**Trichloroethene (TCE)**	**cis-1,2-dichloroethene (cDCE)**	**trans-1,2-dichloroethene**	**Vinyl chloride**	**Methane**	**Ethane**	**Ethene**	**Acetylene**
CMT-04-UPPER	8/16/2017	t>0	N	<0.33	<0.5	1.5	<0.32	<0.21	5.6	0.75	1	<0.022
	9/26/2017	1-Month	N	<0.32	<0.39	1.3	<0.22	<0.31	1700	2.8	1.8	<0.022
	2/21/2018	7-Month	N	-	<0.5	1.45	-	<0.5	14000	2	0.66	<0.022
	8/8/2018	12-Month	N	<0.32	1.8	3	<0.22	<0.31	13000	0.083 Jn	0.042 Jn	<0.034
	12/13/2018	16-Month	N	<0.32	0.97 J	5.9	<0.22	<0.31	20000	0.15	0.18	<0.034
	4/24/2019	20-Month	N	<0.32	<0.39	3.8	<0.22	1.5	21000	<0.005	<0.004	<0.019
	10/9/2019	26-Month	N	<0.39	<0.29	1.1	<0.28	<0.29	13000	<0.005	<0.004	<0.019
CMT-04-MIDDLE	8/16/2017	t>0	N	<0.33	<0.5	1.5	<0.32	<0.21	2.7	0.17	0.34	<0.022
	9/26/2017	1-Month	N	<0.32	<0.39	1.7	<0.22	<0.31	160	1.4	1.1	<0.022
	2/21/2018	7-Month	N	-	<0.5	4.45	-	0.676 J	15000	0.9	0.24	<0.022
	8/8/2018	12-Month	N	<0.32	<0.39	7.3	<0.22	<0.31	14000	0.15	0.05 Jn	<0.034
	12/13/2018	16-Month	N	<0.32	0.98 J	6.4	<0.22	0.5 J	18000	0.064 Jn	0.029 Jn	<0.034
	4/24/2019	20-Month	N	<0.32	<0.39	4.8	<0.22	2.5	22000	<0.005	0.037 J	<0.019
	10/9/2019	26-Month	N	<0.39	<0.29	1.5	<0.28	3.7	15000	<0.005	0.04 J	<0.019
CMT-04-LOWER	8/16/2017	t>0	N	<0.33	<0.5	1.1	<0.32	<0.21	4.8	0.44	0.69	<0.022
	9/26/2017	1-Month	N	<0.32	<0.39	1.3	<0.22	<0.31	390	1.5	1.1	<0.022
	2/21/2018	7-Month	N	-	<0.5	2.81	-	<0.5	12000	0.5	0.16	<0.022
	8/8/2018	12-Month	N	<0.32	<0.39	3.9	<0.22	<0.31	11000	0.15	0.031 Jn	<0.034
	12/13/2018	16-Month	N	<0.32	0.74 J	2.9	<0.22	<0.31	16000	0.3	0.083 Jn	<0.034
	4/24/2019	20-Month	N	<0.32	<0.39	3.3	<0.22	1.1	20000	0.14	0.018 J	<0.019
	10/9/2019	26-Month	N	<0.39	<0.29	1.1	<0.28	1.8	16000	<0.005	<0.004	<0.019

Notes:

1. DUP* = CMT "duplicate" samples are representative of the formation groundwater immediately recharged into the column following the initial no-purge sample
2. J = Estimated value detected between the Sample Detection Limit (SDL) and the Method Quantitation Limit (MQL; also referred to as PQL).
3. "--" = not sampled
4. The "t>0" time interval represents the earliest possible sampling event for CMT wells after installation of the reaction columns.

Time-series plots of CVOC concentrations (in micromolar [µM] concentrations) at the four CMT wells are presented in **Figure 6.3**. Overall, total CVOC concentrations and the distribution of individual CVOCs are very different between CMT wells and depth intervals (upper, middle, lower) within a given CMT well. As expected, CVOC concentrations are highest at CMT-1, located closest to monitoring well IS17MW04 where the highest TCE concentrations were detected. At CMT-1 and CMT-2, the highest concentrations were observed in the middle depth interval, approximately 15 ft bgs, which corresponds with the highest soil concentrations (see **Figure 4.3**). Overall, concentration trends are generally increasing or stable at most CMT wells, suggesting that mass diffusion into the reaction column is either greater or equivalent to the rate of degradation within the reaction column. The CVOC composition strongly varies between the CMT wells, likely due to their proximity to the source area. For example, TCE makes up a larger proportion of the CVOC mass at CMT-1, while daughter products (cis-1,2-DCE and vinyl chloride) and ethene make up a larger portion of the mass at CMT-2 and CMT-4. At CMT-3, located on the outskirts of the 1 mg/L CVOC contour area, CVOC mass is dominated by ethane and ethene.

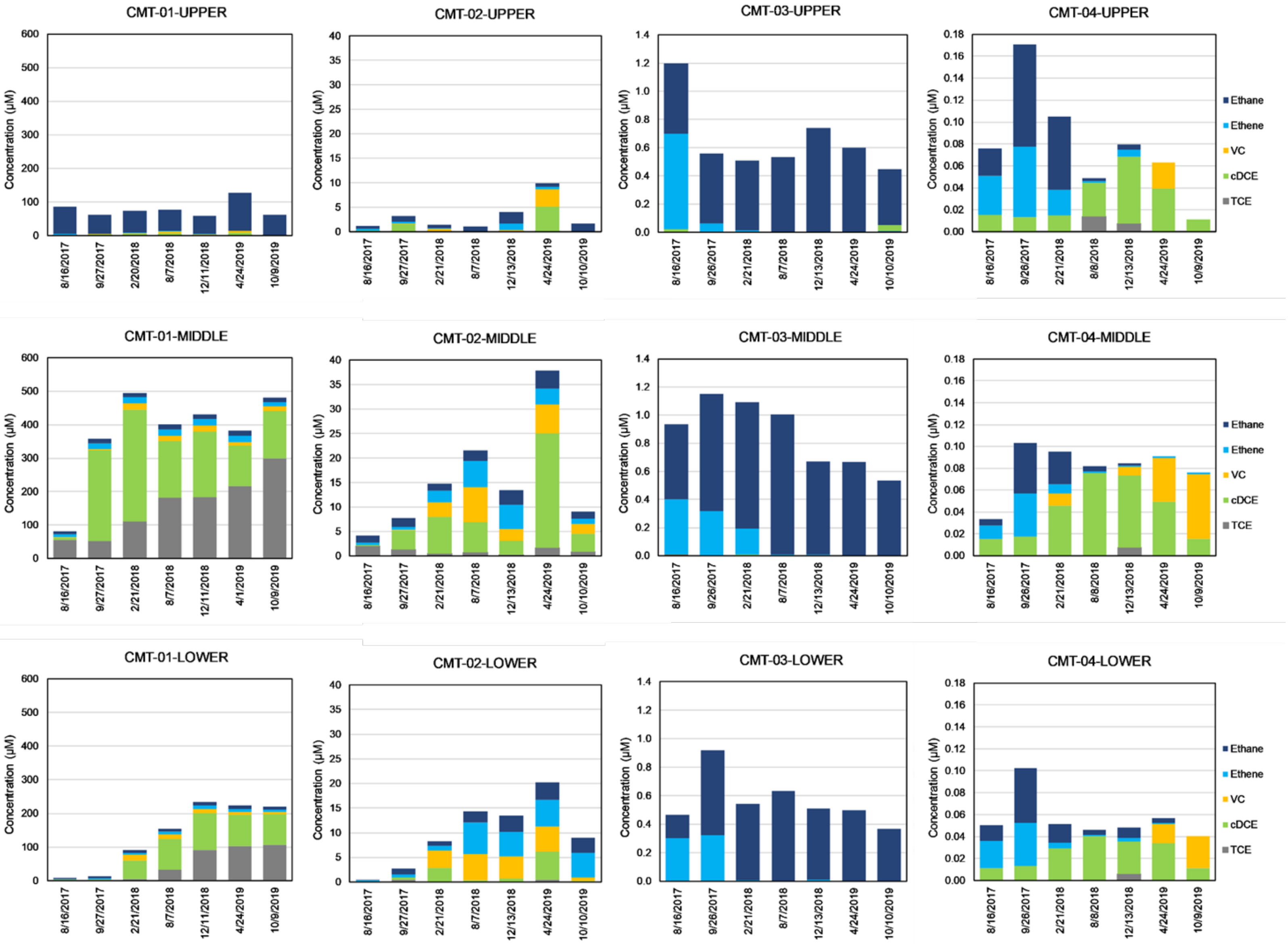


Figure 6.5. Time-series CVOC Concentrations in CMT Wells (CMT-1 through -4)

Contaminant reductions observed in IS17MW04 were coupled with periodic detections of acetylene (in months 1, 12, 16, and 26), indicating the ongoing occurrence of abiotic β-elimination reactions to degrade CVOCs. Acetylene was also detected during t>0, 1-month, and 7-month monitoring events in both the middle and lower intervals of CMT-1 (adjacent to MW-04), at 1-2 orders of magnitude higher concentrations (see **Table 6.3**). The absence of acetylene in the other CMT and monitoring wells does not necessarily suggest that abiotic degradation of TCE is not occurring. Due to its unstable nature, acetylene rapidly degrades to ethene and is difficult to detect in groundwater. During one event, a Microseeps "bubble strip" sampler (see photolog in **Appendix M**) was tested in an attempt to concentrate volatile gases from 1-2 liters of groundwater by flowing through the bubble strip cell, maintained with a 20-mL head of atmospheric air to equilibrate with groundwater. Results showed similar concentrations to aqueous samples for dissolved gas end products (methane, ethane, ethene) and acetylene was not detected. Improved methods are under consideration for future work at Site 17 to accurately quantify acetylene as a direct line of evidence for abiotic degradation of TCE.

6.3 REACTION GAS MONITORING

Since Site 17 North Plume is located along the northern shore of Mattowowan Creek, groundwater elevations were often within 1-3 ft of the creek elevation (see **Appendix N**), resulting in a thin vadose zone within the treatment area. As a result, conventional single-depth soil vapor probes and carbon traps (EFlux, LLC) were installed above reaction columns in lieu of the multi-level soil vapor probes needed to conduct gradient method calculations as originally proposed. Although the SVCs were installed in unsaturated soil at the time of carbon trap deployment, most columns were observed to be saturated upon trap retrieval two weeks later following heavy rains in the interim. In an ideal setting, reaction gas ebullition from the water table-vadose zone interface would freely diffuse vertically through the unsaturated zone to the atmosphere, allowing their capture on carbon trap sorbent material. However, as the water content of unsaturated systems increases, the effected vapor diffusion coefficient declines proportionally, dramatically slowing the flux of vapors upward (Scanlon et al., 2002). Thus only minimal mass of CO_2 was detected in the traps deployed at Site 17 (0.24 to 4.29 g) and the proportion of "fossil-fuel CO_2 associated with CVOC degradation was non-detectable above background concentrations. No NSZD rates (gallons of TCE degraded per acre of treatment area per year) were able to be calculated and results of carbon trap sampling were inconclusive.

Field screening of soil vapor probes was conducted using a low detection ppbRAE 3000 PID, calibrated in the field to a 100 ppb isobutylene standard. For collection of samples for field screening, a 60-mL gas syringe was connected to the 3-way valve terminating the SVP tubing at the surface, and a 300 mL sample was slowly extracted (2-3 minutes) for temporary collection in 1-L dedicated Tedlar bags following shut-in testing and purging (see **Section 5.5.3**). The PID was then connected via MasterFlex tubing to the Tedlar bag, and the 300-mL sample was extracted by the internal pump of the PID. Field screening results indicated soil vapor concentrations ranging from 50 – 1,200 ppm during soil vapor sampling events.

The SVCs used to conduct carbon trap sampling were converted to conventional soil vapor probe monitoring points during the October 2019 (26-month) sampling event. Although additional challenges with shallow water table prevented vapor sampling from all 6 installed SVPs, two samples were collected using 24-hr time-integrated, slow flow (<5 mL/min) Summa cannisters. The results were promising. Results of reaction gas monitoring indicate that gaseous "higher coupling" products (>C_3), associated with the abiotic β-elimination pathway such as propane, propene, butane, pentane, and hexanes are present above background concentrations in the unsaturated portion of the reaction columns (see **Table 6.4**). Increases in *cis*-1,2-DCE and VC concentrations support both a biotic degradation pathway (via reductive dechlorination) and abiotic degradation via hydrogenolysis reactions at the site. As part of this project, no effort was made to elucidate the primary degradation mechanism for DCE and VC formation, although compound specific isotope analysis (CSIA) has been recommended for future long-term monitoring activities at the site.

Table 6.4. Soil Vapor Monitoring: VOCs and Fixed Gases

	Reaction Column Soil Vapor Probe	*"Background" Soil Vapor Probe*
SAMPLE ID:	**SVP-RC-01**	**SVP-B-01**
SCREEN INTERVAL (ft, bgs):	3.25 ft bgs	2.15 ft bgs
SAMPLING DATE:	10/9/2019	10/9/2019
SAMPLE TYPE:	N	N
Volatile Organic Compounds - Method TO-15 (ppbv)		
1,1,1-Trichloroethane	<79.26	<1.52
1,1,2,2-Tetrachloroethane	<79.26	<1.52
1,1,2-Trichloroethane	<79.26	<1.52
1,1-Dichloroethane	<79.26	<1.52
1,1-Dichloroethene	<79.26	<1.52
1,2-Dichloroethane	<79.26	<1.52
Benzene	<79.26	<1.52
Ethylbenzene	<79.26	<1.52
Heptane	321	<1.52
Hexane	2510	<1.52
m & p-Xylenes	<158.52	<3.03
o-Xylene	<79.26	<1.52
Propene	7140	<3.03
Tetrachloroethene (PCE)	<79.26	<1.52
Toluene	<79.26	2.31
trans-1,2-Dichloroethene	<79.26	<1.52
Trichloroethene (TCE)	<79.26	<1.52
Vinyl Chloride	<79.26	<1.52
Fixed Gases - Method D-1945 (ppmv)		
Hydrogen, H_2	16,000	<15000
Nitrogen, N_2	750,000	790,000
Carbon monixide, CO	<2000	<2000
Carbon dioxide, CO_2	138,000	61,000
Argon / Oxygen, Ar/O_2	14,000	148,000
Methane, CH_4	97,000	64.9
C_2 (as Ethane)	1,279	< 0.8
C_3 (as Propane)	60.7	< 0.8
C_4 (as Butane)	36.1	< 0.8
C_5 (as Pentane)	18.5	< 0.8
C_6 (as Hexane)	9.7	< 0.8
C_6+ (as Hexane)	7.5	< 0.8
Fixed Gases - Method PAMS (ppbv)		
Acetylene	<793	<0.5
Propene	4270	<0.33

Notes:

1. All fixes gases have been normalized to 100% on a dry basis
2. "Background" refers to the treatment area soil vapor probe installed adjacent to, but not directly over, the reaction column soil vapor probe.

6.4 GEOPHYSICAL SURVEY RESULTS

In addition to the baseline imaging, three post-installation electrical resistivity imaging events were conducted using the GeoTrax Survey LTM™ methodology and AGI SuperSting R8IP resistivity meter. The layout and installation the five dedicated electrode transects are described in **Section 5.2.3** and depicted in **Figure 5.2**. Static image data from each surveying event was post-processed using several "differencing" analyses to determine electrical resistivity changes between monitoring events.

Overall, the time-lapse electrical resistivity surveys showed very little change between the baseline event and the three post-install events, resulting in an overall increase in conductivity (~30-70%) in the top 10 ft bgs and increase in resistivity (~20-70%) below the conductive layer. As shown in **Figure 6.7**, the vertical boundaries of notable resistivity changes in the upper 3-4 ft bgs between baseline and final imaging events from transect IND-04 (E-W across middle of treatment area) appear to align roughly with geological boundaries of upper silt later, and align very well with the observed changes potentiometric surface over the project period. As a result, Aestus concluded that the conductivity increase in the final imaging event was likely due to changes in the water table over time in the shallow subsurface. The water table as measured in nearby monitoring wells was highest during the final imaging event relative to two earlier post-install events and the baseline event.

Due to the nature of the electrode configuration, electrical resistivity imaging was not a reliable means to evaluate amendment distribution in the columns. Briefly, dedicated electrode lines were installed (trenched to a depth of 2 ft; see **Figure 5.2**) prior to reaction column installation in order to capture electrical resistivity images before and after installation without any interferences from moving the electrodes. To avoid damage to the electrodes, the reaction columns were off-set from the electrode lines. Since the electrode lines did not sit directly above the reaction columns, electrical resistivity imaging of the columns was not possible (see **Figure 6.6**).

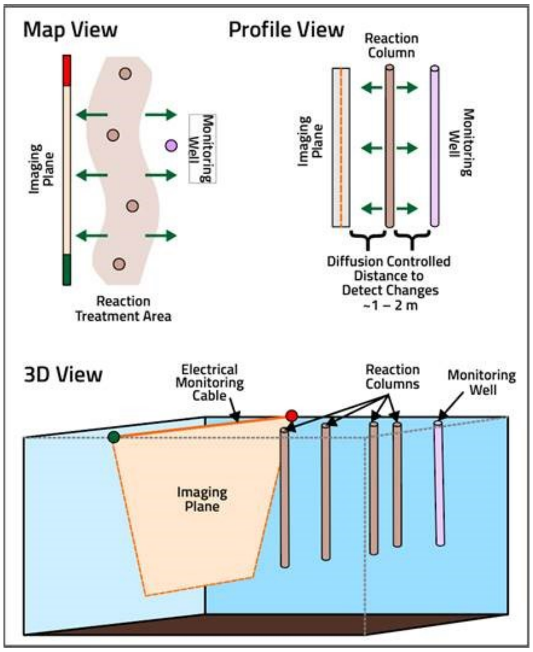


Figure 6.6. Configuration of Electrical Resistivity Electrodes at Site 17

Overall, very few changes were detected within the reaction column treatment zone through Phase IV temporal monitoring. Both imaging and monitoring well data indicate the most pronounced electrical imagery changes occurred outside of the remedy treatment area (see **Figure 6.7 and 6.8**; also **Appendix G**) for reasons that are unknown, and for which further investigation of this issue was outside the scope of this project. More time may be required with this remedial approach to induce changes outside the reaction columns themselves as could be expected given the typical timelines when using diffusion-controlled mechanisms. Additional findings and observations from the geophysical surveys include:

- Groundwater chemistry data mirror the temporal imaging results as they also do not indicate significant changes within the remedy area
- The resistive zone in the deeper portions (~-10 ft AMSL) of Survey Line IND-04 became more resistive over time potentially due to a loss of porosity or a small decrease in fluid EC. The deeper changes in resistivity across the remedy area may be caused by potential porosity changes due to potential soil compaction from treatment column installation
- The boundaries in resistivity changes seem to align with geological boundaries as larger electrical changes are seen above the bottom of the upper silt layer (e.g., see blue colored zones in IND-05 temporal image which indicate increased electrical conductivity from baseline to the final imaging event, which are likely based on fluid changes such as increased moisture content.
- The shallow changes in resistivity are likely the effect of tidal influences on site groundwater levels and resulting small changes in fluid electrical conductivity.

A complete description of the geophyical surveys conducted at Site 17 are provided in a separated report, authored by Aestus, LLC, located in **Appendix G**.

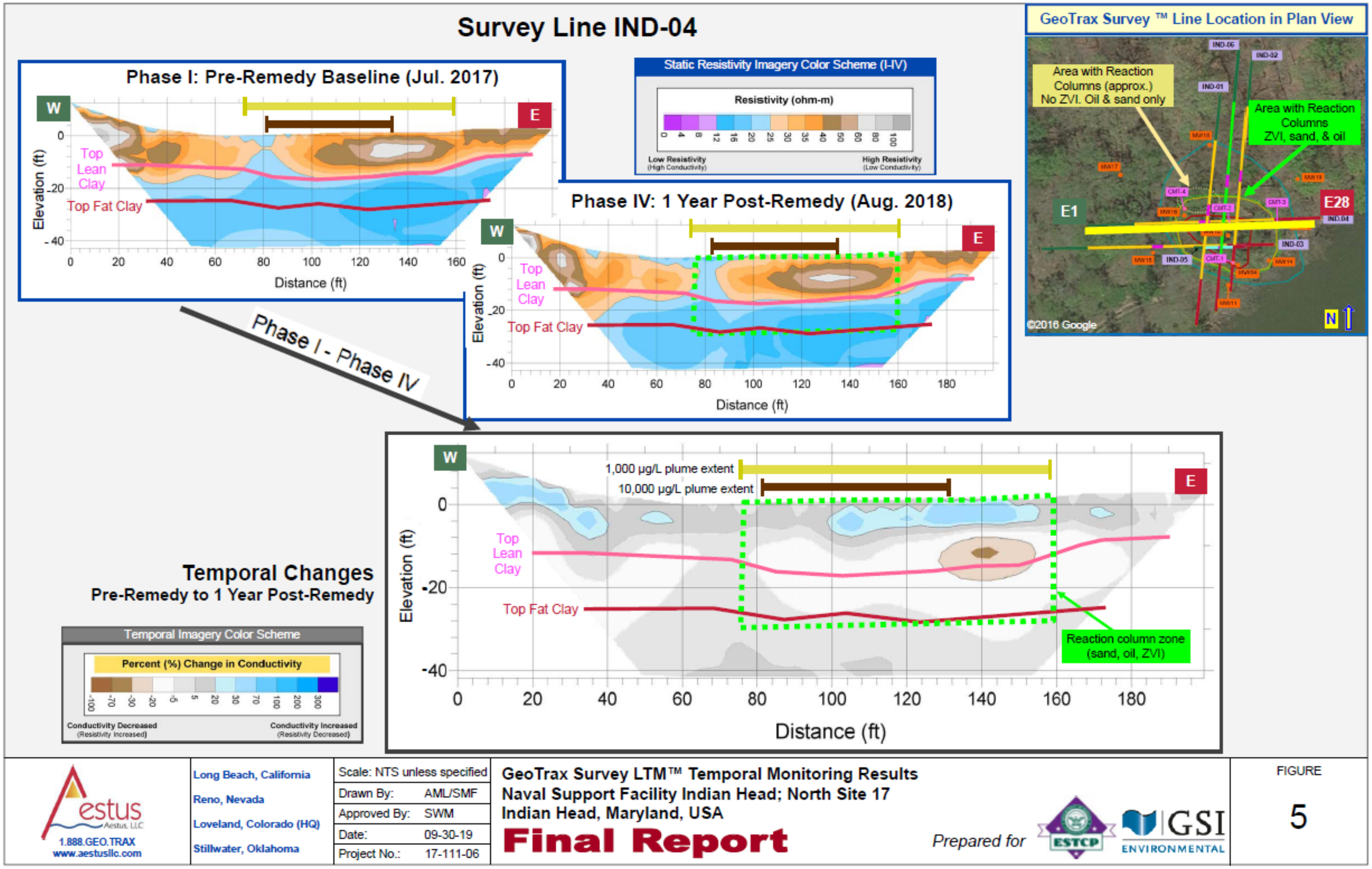
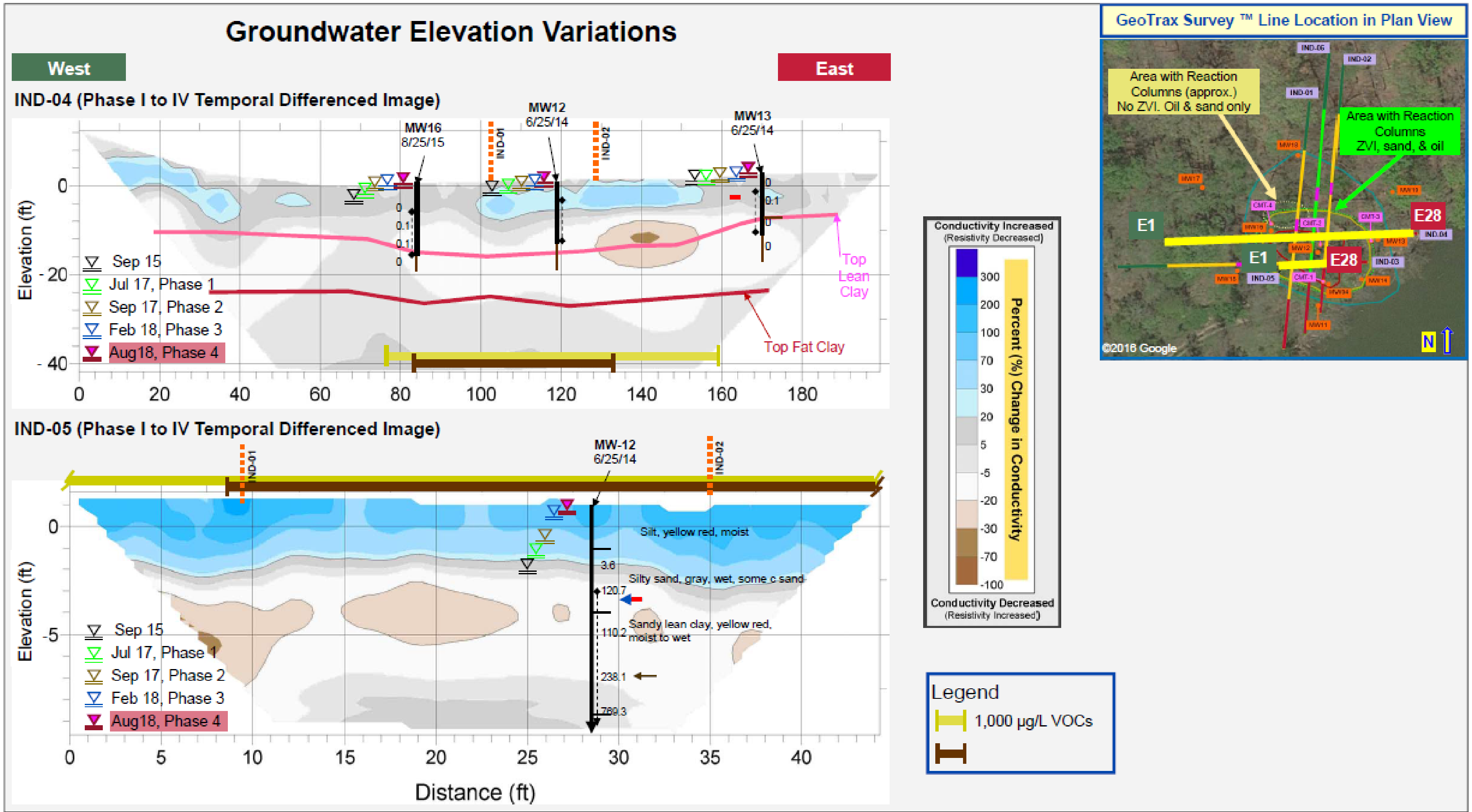


Figure 6.7. Static ER Survey Images of Transect IND-04 July 2017 (Aestus Phase I), August 2018 (Aestus Phase IV) and GeoTrax LTM Temporal Difference Image Showing Percent Differences (bottom)



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Date:	09-30-19
Project No.:	17-111-06

GeoTrax Survey LTM™ Temporal Monitoring Results
Naval Support Facility Indian Head; North Site 17
Indian Head, Maryland, USA

Final Report

Prepared for ESTCP GSI ENVIRONMENTAL

FIGURE
11

Figure 6.8. GeoTrax LTM Temporal Difference Images: July 2017 (Baseline) to August 2018 (Aestus "Phase IV") for ER Survey transects IND-04 and IND-05

7.0 PERFORMANCE ASSESSMENT

This section provides an assessment of the performance of the Bomber technology relative to the established performance objectives described in **Section 3.0**. Each subsection describes a specific success criterion and provides supporting information for the evaluation of the technology relative to the criterion.

7.1 INSTALLATION SPEED AND EFFICIENCY

Success Criterion: *The average number of reaction columns installed per day over the course of the column installation program should not be less than 50 columns after full-scale start of installation sequence. At least 75 reaction columns should be installed on the most productive operational day.*

Table 6.1 shows the number of reaction columns installed per day during the field demonstration. Initially, very few reaction columns were installed (1 column in first day of operation) due to equipment setup and configuration, minor equipment shutdowns and repair, parts replacement, and weather-related delays (muddy site conditions). On days that the installation rig was fully operational for the entire day (i.e. no weather or equipment related delays), an average of ~119 columns were installed per day, with a range of 82-180 columns per day. A total of 800 columns were installed over the course of 7.5 operational days (including half days due to weather or equipment related delays). This exceeded our goal of an average of 75 columns per day and confirms the Bomber technology's ability to install reaction columns quickly and efficiently. Thus, this criterion has been met.

7.2 RATE OF REMEDIATION AMENDMENT MIXING

Success Criterion: *Amendment batch mixing and loading should not exceed 1-hr or significantly interrupt continuous operation of installation rig (maintain >90% uptime).*

Replenishment and mixing of amendment ingredients (e.g., ZVI, sand, water, and oil) was conducted on-site using a fork-lift (to unload ingredients) and volumetric mixing truck (capacity of 8 yd^3; see **Section 5.3.1**). The initial thought was that the amendment would need to be prepared in batches to ensure proper dosing and material ratios were achieved, therefore the project team established the performance objective of monitoring this process as a potential time sink during field implementation. As described in **Section 5.3.2**, one key characteristic of a volumetric mixing truck is that it can be calibrated to supply various materials at specified rates, therefore producing a consistent mixture of material at design ratios. Once the equipment is calibrated, it can be operated continuously if a steady supply of materials is provided. During the field demonstration, one operator was designated for replenishing the mixing truck bins with sand, ZVI, water, and oil as needed. This made material loading/mixing a continuous process and eliminated the need to prepare the amendment in batches. As result, material loading and amendment preparation did not halt operation and continuous operation of the installation rig was maintained. Some downtime was experienced due to minor clogging of hoses which pumped remediation amendment from the Elkin mixer up to the Bomber mandrel (multiple 50-ft sections of hose connected with cam-locks); however, this did not significantly affect column installation operations and >90% uptime was maintained during operational days. Thus, this criterion has been met.

7.3 PERFORMANCE ASSESSMENT: DISTRIBUTION OF AMENDMENT TO TREATMENT DEPTH

Success Criterion: Greater than 90% of total column length for the installed columns should contain ZVI or oil, based on injected volume estimates (pump strokes) or resistivity survey results. Using MSTs, the proportion of ZVI should remain within ±30% of desired dosage (i.e., 28%-52% ZVI), although greater amounts of ZVI does not impact overall performance. Oil columns should contain a minimum of 10% oil by volume.

Manual field observations were recorded with the use of magnetic separation tests (MSTs), which were performed on samples collected from installed reaction columns. A total of 10 samples from reactions columns installed on different days were analyzed for ZVI content. Overall, 70% (7 of 10) of samples resulted in ZVI content within ±30% of desired dosage (28%-52%). Three samples had ZVI content >52% (54%, 81%, and 88%). Based on these field observations, all columns received amendment that filled >90% of total column length (~30 ft). Complete MST results are provided in **Appendix H**.

As shown in **Figure 5.2** geophysical survey transects were permanently installed (trenched into the treatment zone) and did not directly overlay the installed reaction columns. This configuration was selected to facilitate collection of both pre- and post-install images without the need to move the electrodes before reaction column installation and re-install them after installation. By doing so, this ensured high quality data could be collected from time-lapse resistivity surveys and avoided potentially detrimental damage to the permanently installed subgrade electrodes. However, this tactic also reduced the ability for survey images to "see" the reaction columns post-installation. Thus, geophysical surveys showed only moderate changes in subsurface conditions following column installations (see **Section 6.4**) and were not a reliable means to evaluate amendment distribution in the columns. Further explanation is provided in **Section 6.4**. Based on the field observations gleaned from MSTs, this criterion has been met.

7.4 REMOVAL OF CONTAMINANT MASS

Success Criterion: *Successful contaminant mass removal from the system will be supported by a minimum of 50% reduction in groundwater concentrations from within the reaction columns after one to two years (at 95% confidence),*

Groundwater data was collected at seven post-installation monitoring events over a period of 26 months and compared to baseline sampling results (and historical data) prior to column installation. All four monitoring wells with detectable COC concentrations during baseline sampling indicate >70% reduction in TCE concentrations relative to baseline concentrations after two years (26-months). For example, the TCE concentration in MW-12 decreased by ~75% after 1 month, and was further reduced to 90% of baseline concentration after 26 months. Similarly, TCE concentration in MW-12 was reduced by >99% after 7 months, rebounded slightly throughout year 2, and then fell to near minimum (>99% reduction) after 26-months. Similarly, in MW-04, TCE concentration decreased by 70% after 26 months. Therefore, this criterion has been met using the monitoring wells.

Success Criterion: *Successful contaminant mass removal from the system will be supported by evidence of parent transformation to abiotic (and biotic) end products after one to two years (i.e. acetylene, ethene, ethane).*

Contaminant reductions observed in MW-04 were coupled with periodic detections of acetylene (in months 1, 12, 16, and 26), indicating the ongoing occurrence of abiotic β-elimination reactions to degrade CVOCs. Acetylene was also detected during t>0, 1-month, and 7-month monitoring events in both the middle and lower intervals of CMT-1 (adjacent to MW-04), at 1-2 orders of magnitude higher concentrations (see **Table 6.3**). A 98% reduction of TCE concentration in MW-16 after 26 months was coupled with nearly 4x increase in ethene, relative to baseline. Degradation byproducts such as cis-1,2-DCE, VC, and ethene were consistently detected in source area monitoring wells (MW-04, MW-12, and MW-16) and all CMTs, except for CMT-3 (outside contaminated zone). Results of performance monitoring from MW-12 show >100% increase in all degradation daughter products (cis,1-2-DCE, VC, methane, ethane, and ethene) coupled with a 90% reduction in TCE. To date, results appear to be promising, though additional long-term monitoring is suggested to validate these preliminary trend observations which indicate this success criterion has been met. Time-series graphs for CVOCs and methane, ethane, and ethene at the monitoring wells and CMTs are presented in **Appendix E**, and an extended discussion of results is provided in **Section 6.2**. Therefore, this criterion has been met.

Success Criterion: *Successful contaminant mass removal from the system will be supported by increased degradation rate after one to two years indicated by a modified Natural Source Zone Depletion measurement method(s) used at hydrocarbon sites (e.g. carbon traps) or equivalent method.*

Due to site groundwater levels rising to shallower than expected levels during the field demonstration (see **Figure 6.9**), the modified gradient method, commonly used at NSZD hydrocarbon sites, was not able to be conducted, and carbon trap analysis proved inconclusive (see **Section 6.3**). However, reaction gas monitoring was conducted using conventional soil vapor probe sampling as described in **Section 5.5.3**. Results of reaction gas monitoring indicate that gaseous "higher coupling" products ($>C_3$), associated with the abioic β-elimination pathway such as propane, propene, butane, pentane, and hexanes are present above background concentrations in the unsaturated portion of the reaction columns (see **Table 6.3**. Increases in cis-1,2-DCE and VC concentrations support both a biotic degradation pathway (via reductive dechlorination) and abiotic degradation via hydrogenolysis reactions at the site. As part of this project, no effort was made to elucidate the primary degradation mechanism for DCE and VC formation, although compound specific isotope analysis (CSIA) has been recommended for future long-term monitoring activities at the site.

7.5 PERFORMANCE ASSESSMENT: ABILITY TO PLACE REACTION COLUMNS AND EASE OF AMENDMENT DELIVERY

Success Criterion: *Ability to access most of intended design treatment area once equipment reaches the site (i.e., were unanticipated obstacles a problem during installation?) and achieve minimal loss of amendment during mixing and delivery process.*

Similar to other large excavation or drilling equipment, the Grout Bomber rig has generally limited mobility for installing columns on steep slopes, advancing columns in areas with large tree roots, and accessing tight spaces (e.g., between wells, trees, etc.). Additionally, muddy site conditions due to heavy rain events prior to mobilization caused minor delays during demonstration startup, due to the weight of the Bomber rig and supporting equipment. However, most spatial constraints were addressed by distancing the raw amendment material storage, Elkin mixer, and hopper/amendment pumps from the demonstration area. Remediation amendment material was then pumped to the Bomber rig via 50-ft sections of 2-inch diameter hose connected with cam-locks. Supplying timber mats in the demonstration area and restoring the access road with aggregate allowed improved mobility during the main operational phase of the field demonstration. Because this application of the Bomber method does not rely on any acceptance capacity of geologic material to deliver amendment into the subsurface, reaction columns were easily filled with the ZVI/sand mixture at low injection pressures (mainly gravity fed) once the hole was pushed (~4.5 min/column). The flexibility provided by this setup facilitated the successful installation of approximately 800 reaction columns in the demonstration area and overall ability to meet this performance criterion.

Loss of amendment was limited to clogging events when operators would detach hosing and clean out pump hopper and hoses. Though clogging of amendment delivery equipment proved to be a persistent impediment to efficiency throughout the field demonstration, most clogging events were minor and were rectified in <30 min, though some caused delays of up to a few hours. Frequent cleaning of hoses and pump equipment proved to alleviate most issues, though in an ideal world, stationing of mixing equipment closer to the Bomber rig would eliminate the needed for additional pumps and the excess hose and connections, which contribute to clogging. Some material was lost at ground surface due to “over pumping” by pump operator. Though during normal operation, very minimal amendment loss was observed (<2%), and collection/reuse of the overpumped amendment can be managed using shovels. Based on field observations and the overall success of column installation, these criteria have been met.

8.0 COST ASSESSMENT

This section provides relevant cost information for the field demonstration to facilitate reasonable cost estimation of future applications of the Bomber technology at a given contaminated site. This cost analysis is based on i) actual costs incurred for specific tasks from the field demonstration and ii) where applicable, cost estimates for items/activities based on professional experience with similar projects. In addition, estimated costs to implement the Bomber technology were directly compared to related alternative remedies (where appropriate) to provide an "apples to apples" comparison.

8.1 COST MODEL

Table 8.1 presents a summary of cost elements and associated costs (e.g., labor, subcontractors, materials) incurred during the field demonstration.

Table 8.1. Cost Model for the Diffusion-Based Application of the Bomber Technology

Cost Element	Description	Cost ($K)
Project Planning & Design		
Feasibility Study	Assessment of wick drain/reaction column feasibility (Rice U)	$ 13 K
Engineering Design	Labor (site selection, demonstration plan preparation, field design)	***$ 23.5 K***
Field Demonstration Implementation		
Baseline Characterization	Contractor for geophysical survey (electrode install; imaging)	$ 101 K
	Laboratory analytical costs	***$ 8 K***
	Labor (sample collection; site supervision)	***$ 7 K***
Amendments/ Materials	Zero-valent iron (78,000 lbs)	***$ 50 K***
	Sand (92,000 lbs)	***$ 2 K***
	Soybean oil (550 gallons; 2 totes)	***$ 6 K***
Reaction Column Installation	Contractor for vegetation clearance & site preparation	***$ 25 K***
	Contractor for the Bomber technology (equipment mobilization; RC install)	***$ 130 K***
	Continuous multi-level tubing (CMT) wells; well stick up supplies	$ 4.5 K
	Bentonite (to seal reaction columns)	***$ 3 K***
	Travel, rental equipment, misc. supplies	***$ 22 K***
	Labor (site supervision)	***$ 32 K***
Performance Monitoring		
Performance Monitoring	Contractor for geophysics survey (3 post-install images & data analysis)	$ 63 K
	Laboratory analytical costs (4 events)	***$ 42 K***
	Travel, rental equipment, shipping, misc. supplies	***$ 19 K***
	Labor (sample collection; site supervision; 4 events)	***$ 30 K***
Weather-Related & Site Restoration (not typical)		
Weather-Related	Timber mats, equipment standby, stormwater controls, additional sand, etc.	$ 34 K
Site Restoration	Fill material	$ 1.5 K
	Contractor to lay fill and grade the site	$ 31.5 K
Total Field Demonstration Costs		**$ 648 K**
Total Field Demonstration Costs (including standard expenditures shown in bold and italics)		**$ 399 K**

Actual costs for the field demonstration at Site 17 were higher than for typical site conditions due to site clearance and preparation, weather delays and weather-related expenses, geophysical surveys, installation of CMTs and soil vapor probes for performance monitoring, and analytical costs for CMTs and soil vapor probes. These costs may not be incurred at all sites. Including only standard costs (bolded and italicized in **Table 8.1**), the total cost for the field demonstration was \$399K, which translates to $\sim\$77/\text{yd}^3$ of treatment volume. The cost for strictly installation of the reaction columns (excluding baseline and performance monitoring) was \$294K, or $\sim\$56/\text{yd}^3$ of treatment volume.

8.1.1 Cost Element: Project Planning and Design

Standard costs for the project planning and design phase include: i) review of historical site data and site selection; ii) site access and coordination with base personnel; and iii) engineering design and development of the demonstration plan. In addition, feasibility studies were performed by Rice University to determine the viability of amendment delivery.

8.1.2 Cost Element: Field Demonstration Implementation

Standard costs for implementation of the field demonstration include: i) baseline characterization activities (groundwater sample collection; analytical costs, labor); ii) remedial amendments (ZVI, oil) and other materials (sand, bentonite); iii) day rates for the Bomber equipment (excavator, Elkin mixer, fork-lift) and labor (4 personnel); iv) labor for site supervision; v) standard supplies, shipping, and equipment rental; and vi) sample analysis of groundwater after reaction column installation. Other costs that are site-specific include: i) site preparation (vegetation clearance and tree removal); ii) detailed site characterization (geophysical survey; electrode install; temporal electrical resistivity imaging), and iii) additional supplies to accommodate site conditions or weather-related events (e.g., timber mats to support the Bomber excavator, gravel aggregate to maintain site access to heavy equipment, stormwater controls to prevent runoff). With the exception of the Bomber equipment itself, no specialized equipment, supplies, or materials were required to execute the field demonstration at Site 17. Staying consistent with the goal of "repurposing" the Bomber technology for application in the environmental field, no modifications to the ancillary equipment (excavator, Elkin mixer, pumps, hoses) were made to accommodate the ZVI/oil/sand remedial mixture. In essence, the Bomber was used "off the shelf" as an amendment delivery system. Improvements to the design and operation of the Bomber for environmental applications are discussed in **Section 9.0**.

8.2 COST DRIVERS

The cost of implementing the Grout Bomber technology is driven by: i) treatment zone area, treatment depth, and site-specific geology, and ii) site access and clearance.

8.2.1 Cost Driver: Target Treatment Zone

As with most other technologies, the area and depth of the target treatment zone is a cost driver for technology implementation. Specifically, this influences the total volume of injection material required, as well as the drilling time for injection point installation. Note that the drilling rig has a limitation of 80-100 ft bgs for grout column installations, and the installation rate typically varies from 80 to 180 holes per day, depending on the desired depth and lithology (i.e., materials with greater blow counts will reduce the installation efficiency of reaction columns). Because this application of the Grout Bomber relies on diffusion to drive entrapped CVOCs towards nearby reaction columns, the column spacing is highly dependent on site-specific geology and remedial timeframe objectives. For the field demonstration, preliminary modeling results estimated that the contaminant plume could be reduced by 2-2.5 orders of magnitude and achieve MCLs in a 20- to 30-year timeframe with reaction columns spacing of 2 ft (see **Section 2.1**).

A potential drawback of the Grout Bomber technology in comparison to traditional direct push technology (DPT) methods of amendment application, is the inability of the technology to isolate target depth zones for remedial amendment. Whereas a DPT injection system may "screen" discrete intervals to inject amendment, the Bomber, at least in its current configuration, delivers remedial amendment bottom-to-top along the full length of the "push". However, minor adjustments to the process (i.e., dual source amendments) could be implemented to allow targeted intervals to be filled with remedial amendment while the remainder of the column is filled with another less expensive grout or other mixture (see **Section 9.1**).

8.2.2 Cost Driver: Site Access and Clearance

Due to the large footprint of the Bomber rig and supporting equipment, site access can be a cost driver for implementation, and some sites may require additional clearance (e.g., vegetation, etc.) before installation. The Bomber rig itself measures 12 x 10.5 ft and requires a laydown yard area for injection materials (sand and ZVI), support from a forklift and the Elkin mixer, which requires a bermed overspill/mixing area. The total required footprint of the Grout Bomber system is approximately 1,000 to 1,500 ft^2 of stable, nearly flat ground for storage and preparation area, and the installation site must be able to accommodate the rig, which has a 30-ft high mast or higher. Tree clearance and other site access accommodations (i.e., timber mats, road base aggregate application, etc.) can be a significant expense and should be considered on a site-specific basis. Additionally, any cleanup required after installation in order to restore the site to its initial conditions will impact the cost of a project.

8.2.3 Cost Driver: Amendment Selection and Mixing/Pumping Efficiency

Initial testing will be required for an application of the Bomber technology in order to achieve a custom amendment with similar flow properties to the typical grout mixtures that the equipment is designed for. As such, a cost driver for implementation will be testing the ability to pump various mixtures in order to avoid clogging and other equipment issues.

8.3 COST ANALYSIS

8.3.1 Estimated Costs of Bomber Technology at a Hypothetical Site

Costs associated with the field program have been used to develop costs for a typical full-scale implementation of the Grout Bomber technology at a chlorinated solvent source zone. Note that some tasks and costs incurred during the field demonstration would not be applicable for a full-scale implementation of the technology (i.e., site clearance, site access accommodations, etc.). As such, costs for these items have not been included in the full-scale technology application.

As described in Harkness and Konzuk's Chapter 16 in Kueper et al. (2014), the Case 2 Study Site (base case) was considered as a hypothetical site for the cost analysis. Key characteristics of this low-k case study site are:

- Area: 1,500 m^2
- Depth to Groundwater: 1.5 m
- Depth to Aquitard: 4.5 m
- Saturated Thickness: 3.0 m
- Porosity: 0.3
- Hydraulic Conductivity: 10^{-5} to 10^{-4} cm/s

Application of the Grout Bomber Technology at this site assumes:

- Well spacing of 2 ft

- Hole diameter of 3 inches each
- Injection material consists of 60% ZVI and 40% Sand
- Grout column installation rate of 150 holes per day
- No vegetation clearance included
- Total 5-year project, with quarterly groundwater monitoring in Year 1, and annual monitoring for Years 2-5 (7 events total)

Table 8.2 summarizes all unit costs, assumptions and cost breakdown. Here, the total project cost is estimated to be approximately $592K, including five years of performance monitoring.

Table 8.2. Project Costs for Application of Bomber Technology at a Hypothetical Site

Variable	Value	Units	Notes
Treatment Zone			
Length	178	ft	
Width	90.7	ft	
Total Depth	14.8	ft	
Depth to Water	4.9	ft	
Area	16,146	ft^2	
Area	0.37	acre	
Volume, Treatment Zone	5920	yd^3	
Total Porosity	0.30		
Injection Amendment Materials			
Hole Diameter	3	in	
Well Spacing	2	ft	
Influence Area of Injection Point	4.3	ft^2	14” radial diffusion distance
Number of Injection Points	3,776		
Total Volume of Injection Materials	24,625	gal	
Total Volume of Injection Materials	122	yd^3	
Cost of ZVI	$1,740	$\$/yd^3$	
Cost of Sand	$61	$\$/yd^3$	
Total Cost of Injection Materials	$733	$\$/yd^3$	Assuming 40% ZVI, 60% Sand
Total Cost of Injection Materials	***$89,320***		
Installation Using Grout Bomber			
Installation Rate	150	holes/day	
Total Installation Time	25	Workdays	
Mobilization of Rig	50,000	$	
Daily Rate	6,600	$/day	
Utility Clearance	5,000	$	
Car Rentals, Consumables, Field Supplies	300	$/day	
Labor and Related Expenses	3,160	$/day	Assume 2 staff on-site
Total Drilling Subcontractor and Clearance	***$221,144***		
Total Rentals, Consumables, Field Supplies	***$7,552***		
Total Labor and Related Expenses	***$82,425***		
Engineering Design and Reporting	***$23,500***		
Total Project Costs			
Total Design and Capital Cost	$423,950		
Total O&M Costs	$0		
Total GW Monitoring Costs for 5 Yrs	$168,000		Assume $24K/event; quarterly monitoring in Year 1; annual monitoring for Years 2-5
TOTAL PROJECT COST	**$591,940**		

8.3.2 Comparison of Bomber Technology with Other Remedial Options

Table 8.3 provides a cost comparison of the Grout Bomber technology with select conventional and innovative technologies aimed at improving amendment distribution in low-k settings. These include DPT injections of ZVI via hydraulic fracturing, *in situ* soil mixing (with ZVI), and electrical resistance heating (ERH) thermal treatment. As a point of comparison, estimated costs for excavation are include in the cost analysis.

As in **Section 8.3.1**, the Case 2 Study Site (base case) was applied as a hypothetical site for direct comparison of the Bomber technology and currently available remedial approaches. For this cost analysis, the objective of each technology was to reduce the source TCE mass by at least 90% and/or reduce the TCE flux coming from the source area by 90-95%, which is affected by the timing required for each technology to meet the objective. For example, while the comparable technologies considered in this analysis are assumed to meet the objective in 1-2 year timeframes, it is assumed that the Bomber technology has a treatment timeframe of approximately 20 years based on conceptual modeling described in Section 2.1. Specifically, the following technologies and key assumptions are as follows:

1. **Excavation**
    - Use sheet piling to isolate the source area and prevent infiltration
    - Approx. 900 ft of 16.3 ft of long sheet piling driven into the clay aquitard
    - A total of 8830 yd^3 of contaminated soil will be removed at an excavation rate of 500 yd^3/day
    - Landfill costs estimated to be $165 per metric tons and includes disposal, transportation, fuel surcharges, etc.
    - Groundwater will be pumped from the excavation pit and treated using a rented activated carbon treatment system.
2. **Thermal Treatment**
    - Thermal treatment consists of thermal conduction heating (TCH) combined with Soil Vapor Extraction (SVE)
    - Total 110 heater borings on 15-foot centers and 25 SVE wells on 25 ft centers
    - Treatment zone will be heated to near the boiling point of water (100C)
    - Captured volatilized gases will be captured by the SVE system and treated by an aboveground treatment system
3. ***In situ* Soil Mixing with ZVI**
    - Large diameter augers used to mix clay and microscale zero-valent iron (ZVI) into the source area.
    - A total of 250 overlapping columns needed to cover the source area
    - A total of 195 metric tons of iron and clay will be needed. Iron costs are estimated to be $860 per metric ton, and bentonite clay is estimated to be $275 per metric ton.
4. **Hydraulic Fracturing with *In situ* Chemical Oxidation (ISCO)**
    - Hydraulic fracturing consists of pressure injection of sand mixed with guar and will result in propagation of sand-filled fractures within the tighter silt and clay aquifer
    - Sixteen fracture locations used on 32 ft centers and fractures are vertically spaced (3.3 ft).

- Sodium permanganate will be used as the oxidant in ISCO to promote TCE degradation
- Sodium permanganate solution, mixed in above-ground tanks at concentration of 40 g/L, will be applied through network of 48 injection wells

Table 8.3 summarizes the design, capital, and O&M costs, as well as monitoring costs per sampling event. The total project costs with and without a monitoring program are presented. Here, the total 5-year project cost with monitoring for the other technologies range from $1,539K to $3,045K. As previously discussed, the implementation of the Grout Bomber technology at this site is $592K. While the Grout Bomber technology exhibits lower cost than those compared in this analysis, it is important to recognize that an extended treatment timeframe is required for Bomber approach to remediate low-k source zones.

Table 8.3. Cost Model for Full-Scale Implementation of Select Remediation Technologies

Cost Component	**Excavation ($K)**	**Thermal Treatment ($K)**	***In situ* Soil Mixing with ZVI ($K)**	**Hydraulic Fracturing with ISCO ($K)**	**Grout Bomber ($K)**
Design	70	255	111	134	23.5
Capital	2875	2260	1328	705	400
O&M	0	0	0	990	0
Monitoring/Event	16.6	16.6	16.6	24	24
Total Without Monitoring	**2945**	**2515**	**1439**	**1829**	**424**
Total with 5-Year Monitoring	**3045**	**2615**	**1539**	**1945**	**592**

9.0 IMPLEMENTATION ISSUES

Re-purposing of the Grout Bomber compaction grouting technology for installation of ZVI reaction columns in low-k media presented a number of implementation issues associated with i) preliminary pilot testing to determine appropriate remediation material mixture that satisfied both pumpability and treatability criteria, ii) site access and large area for equipment staging, and iii) general mobility of large equipment in a tight work environment. Specific components of the Bomber implementation which may require site-specific considerations include:

- **Site access** – The Grout Bomber rig and supporting equipment require a fairly large footprint to conduct amendment mixing, pumping to rig, and final column installation. Although the spacing and orientation of supporting equipment and mixing area can be made flexible to work in confined areas, some production efficiency may be lost by large separation distances between required work zones. Well maintained roads are required between all specified work zones, and a considerable footprint, in both the vertical (~30 ft mast height) and horizontal directions for Bomber rig maneuverability between column placements. Though columns can be installed at slight angles from vertical, sites with relatively flat topography will be best suited for implementation of this technology.
- **Material Pumping** – Additional expenses should be included in cost estimates for applying the Bomber technology at environmental sites to conduct thorough testing of amendment material pumpability through the specialized Elkin mixer and supporting reciprocating piston pumps which move fluid to the Bomber mandrel. Clogging of overly long sections of hosing between the Elkin mixer/hopper and the Bomber rig is to be expected for some amendments (such as ZVI/sand mixture used in this project), and efforts should be made to reduce the distance between supporting equipment and the treatment area. Though optimized efficiency may not be realized with longer separation distances, the Bomber technology may still outperform conventional DPT methods in terms of speed and efficiency as demonstrated at Site 17 North Plume. Additionally, communication with geotechnical contractors is a vital component to achieving successful and efficient operations. Thus efforts should be made to utilize well-trained and experienced operators of all geotechnical equipment.
- **Underground Clearance** – Strict underground clearance is required, due to amount and proximity of holes.
- **Equipment repair downtime** – Since the Bomber rig and supporting equipment are highly specialized, component breakdowns have the potential to significantly delay project (no easy repairs). However, during the field demonstration subject of this report, a hydraulic motor was able to be shipped overnight to Site 17 and was replaced in a single morning. Experienced geotechnical contracts with working knowledge of system components are a key resource when implementing the technology.

This ESTCP project utilized the Grout Bomber compaction grouting technology to quickly install ~800 vertical reaction columns in a low-k site source zone. One potential improvement to this application would be including dual-source amendment mixtures to target key treatment zones (i.e., in saturated zone), while filling remaining void with a cheap fill material (sand or permeable grout to surface). Additionally, many other applications of this or similar geotechnical equipment may be viable for the environmental industry and should be further evaluated for potential benefits to cost and remediation amendment delivery effectiveness at difficult-to-treat sites.

For example, depending on site-specific hydrogeology, the column installation procedure using low pressure injection at Site 17 could be easily modified to establish columns with much larger radii of influence for use in DPT injection or permeable reactive barriers (PRB) construction. However, the range of the potential radius of influence from Grout Bomber injection points will largely depend on site-specific characteristics and has not been studied as a focus of this project. Practitioners of the Bomber Method for any environmental remediation application should also consider the site-specific risks which may be posed by the presence of DNAPL at contaminated sites. Although not of concern at the field demonstration site for this project, reaction columns installed in DNAPL source zones could become a preferential pathway for vertical migration of vapors, and site conceptual models which previously did not consider vapor intrusion exposure pathways to be complete may need to be modified. However, the dual-source amendment improvement described above could theoretically be applied to install an impermeable capping grout with each reaction columns to mitigate risk. Further evaluation of dual-source amendment delivery using the Bomber rig as well as other applications described above are recommended to assess potential for added value to environmental practitioners.

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FINAL REPORT

New Application of a Geotechnical Technology to Remediate Low-Permeability Contaminated Media

ESTCP Project ER-201627

APPENDICES

APPENDICES

Appendix A. Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name, Address	Phone, Fax, E-mail	Role in Project
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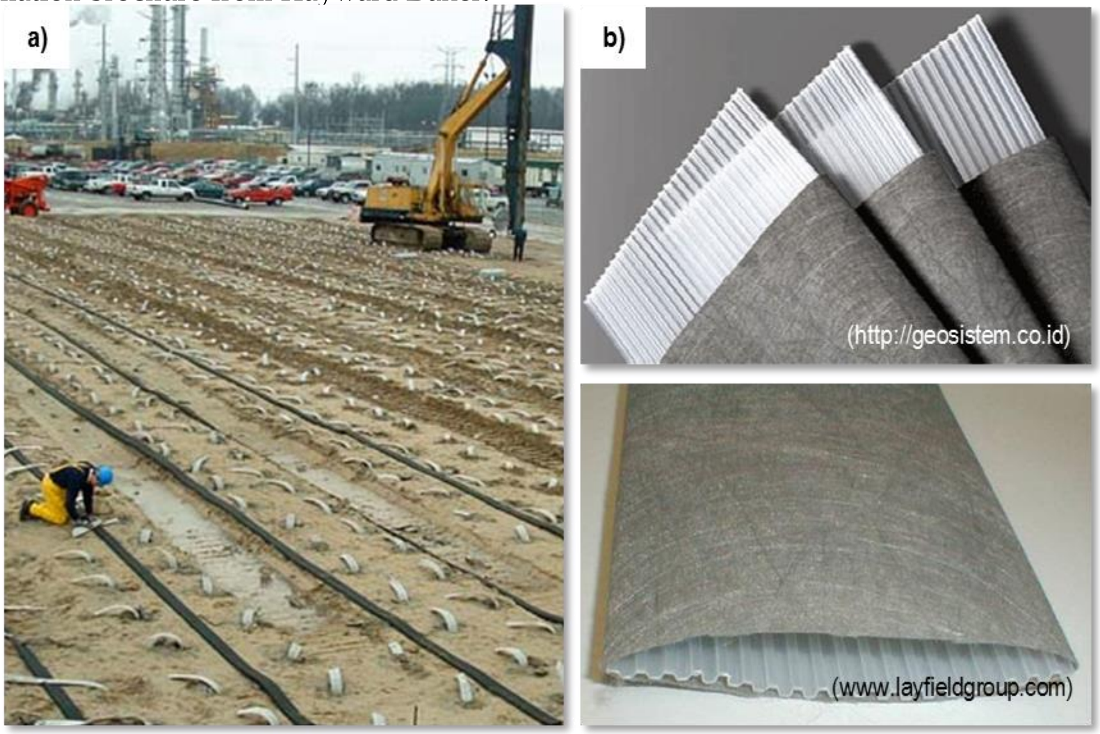
Charles Newell	GSI Environmental Inc. 2211 Norfolk Street, Suite 1000 Houston, Texas 77098	Ph: 713-522-6300 cjnewell@gsi-net.com	Co-Principal Investigator
Michael Schofield	GSI Environmental Inc. 9600 Great Hills Trail, Suite 350E Austin, Texas 78759	Ph: 512-346-4474 mlschofield@gsi-net.com	Health & Safety Officer
Justin Long	GSI Environmental Inc. 9600 Great Hills Trail, Suite 350E Austin, Texas 78759	Ph: 512-346-4474 jalong@gsi-net.com	Field Operations Lead
Dylan Hart	GSI Environmental Inc. 9600 Great Hills Trail, Suite 350E Austin, Texas 78759	Ph: 512-346-4474 dmhart@gsi-net.com	Field Operations Staff
Joshua Kolz	Hayward Baker Inc. 7989 Cherrywood Loop Kiowa, Colorado 80117	Ph: 303-627-1100 jkolz@haywardbaker.com	Installation Equipment Contractor
Stuart McDonald	Aestus, LLC Loveland, Colorado	Ph: 970-278-4090 swm@aestusllc.com	Geophysics Contractor

Appendix B. Prefabricated Vertical Drain (Wick Drain) Technology Fact Sheet

Wick drains are used in the geotechnical industry to accelerate consolidation of silts and clays by creating closely-spaced artificial vertical pathways for drainage of porewater, prior to infrastructure development. Specialized machinery quickly “staples” the drains via a direct push technique into fill or natural soils in a production line technique, resulting in hundreds of wicks installed per day (see **Figure B.1**). Wick drains are installed using a specialized piece of equipment, called a “stitcher”, which is typically mounted to an excavator (see **Figure B.1a**). The stitcher consists of a vertical mast and steel mandrel which houses the wick drain during operation. The wick drain is fed from a 1,000 ft roll at the base of the vertical mast to the top of the mast where it enters the steel mandrel and is fed through the mandrel back down to its base. The mandrel (with the wick drain inside) is controlled by the excavator’s hydraulic system, allowing the mandrel to be repeatedly pushed into and withdrawn from the subsurface. Prior to advancement of the mandrel into the subsurface, an anchor plate is placed on the wick drain to close off the opening and to secure placement of the wick drain at the desired depth. The mandrel is hydraulically pushed or vibrated into the ground and subsequently withdrawn leaving the inserted wick drain in place within the subsurface. After the mandrel is pulled to the surface, the wick drain is cut (typically 1-2 ft of wick drain protrudes at the surface) and a new anchor plate is installed in preparation for the next wick drain advancement. The drains are 4 in. wide and ¼ in. thick, consisting of a geotextile filter-wrapped plastic strip with extruded channels that allow water to slowly flow into the drain, but keeps soil particles out (see **Figure B.1b**). Detailed descriptions of the wick drain technology are provided in the attached information brochure from Hayward Baker.



(http://geosistem.co.id)

(www.layfieldgroup.com)

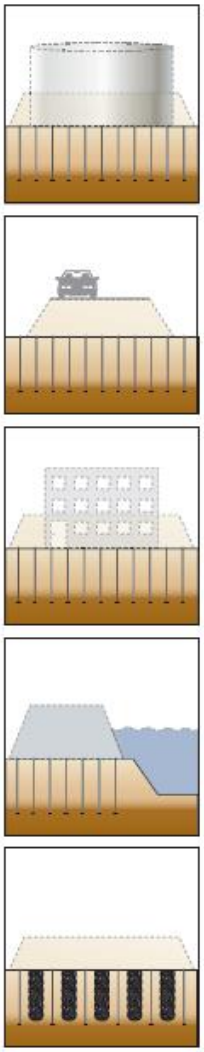
Figure B.1. a) Wick drain installation and spacing; b) the center core and filter sleeve of a wick drain

WICK DRAINS

Wick drains accelerate the consolidation of compressible soils, in turn accelerating your project schedule.

Above: Horizontal strip drains being placed after installation of wicks for a new maintenance facility on the Mississippi River floodplain in Memphis, TN.

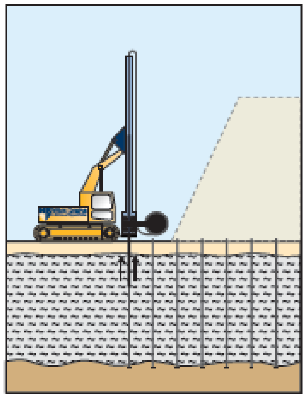
Right: Two of three rigs used to install 1,700,000 linear feet of wick drain to a maximum depth of 75 feet, and 55,000 feet of strip drain for a new housing development in Yorba Linda, CA.



Wick drains are prefabricated vertical drains installed to accelerate the consolidation of compressible soils. The drain consists of a geotextile filter-wrapped plastic strip with extruded channels that allow water to drain from soft soil as it consolidates under an applied surcharge load. The geotextile filter prevents soil particles from entering the channels and clogging the drain. The time required for the consolidation to occur depends on the permeability of the soft strata, the existence of sand layers in the strata, the weight of the surcharge, and the spacing of the wicks.

HB Wick Drains
A Division of Hayward Baker

Wick Drain Technology...



The prefabricated wick drain was invented in the mid-1930s by Walter Kjellman at the Swedish Geotechnical Institute. The first drain consisted of two cardboard sheets glued together, with internal channels. The modern wick drain consisting of geotextile filter-wrapped plastic with extruded channels was developed in 1971, also at the Swedish Geotechnical Institute. The plastic wick drain allowed for faster installation and increased flow rate volume over the early cardboard style. HB Wick Drains uses the Mebra™ brand of wick drains, the most effective and efficient design in the industry.

Applications

- Rapid consolidation of soft soils in conjunction with a preload fill (or applied negative pressure)
- Accelerated construction schedule for staged loading or staged construction on soft soils

Wick drains can be applied to any site that requires consolidation, including sites for:

- Roadway embankments
- Bridge approaches and overpasses
- Dams and levees
- Railway embankments
- Airports and seaports
- Storage tanks
- Commercial and residential buildings
- Mining wastes and tailings

Installation

Before installation can begin, the working surface must be prepared to ensure a stable working platform. Since wick drain sites are typically soft, a sand or gravel blanket may be needed to provide support for the equipment. The sand and gravel will also act as a drainage blanket to direct water away from the treatment area.

A specialized mast consisting of drain material and a mandrel is mounted on either a track-mounted excavator or crane, depending on the installation depth. Drains can be installed up to 140 feet deep from a track-mounted excavator. Drains deeper than 140 feet often require the mast to be mounted on a crane for stability.

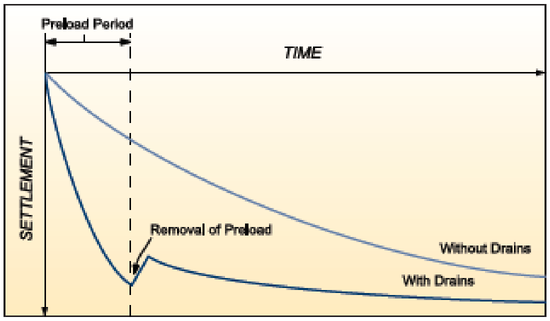
The wick drain is threaded through the mandrel, which protects it from damage as it is installed through the soil. The installation force is typically provided by vibratory hammers, static force methods, or a combination of these methods depending on the soil conditions. Water may be utilized to lubricate the mandrel during installation to reduce the friction on the mandrel. An anchor attached to the bottom of the drain keeps it in place during withdrawal of the mandrel. The drain is then cut several inches above ground, and a new anchor is fastened to the wick at the bottom of the mandrel in preparation for the next installation point.

Layout usually consists of triangular or square grid patterns. Typical spacing ranges from 2.5 to 8 feet on center.

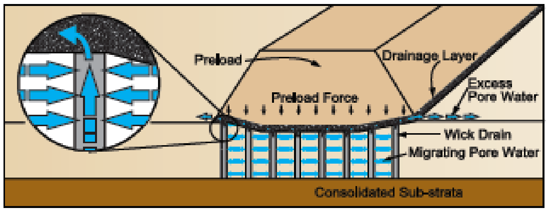
A total of 2,300,000 linear feet of wick drain was installed offshore (top photo) through as much as 40 feet of water, to depths up to 120 feet, and 8,800,000 linear feet of wick drain was installed on land (bottom photo), to depths of 98 feet, for the Port of Los Angeles Channel Deepening.

HB Wick Drains
A Division of Hayward Baker

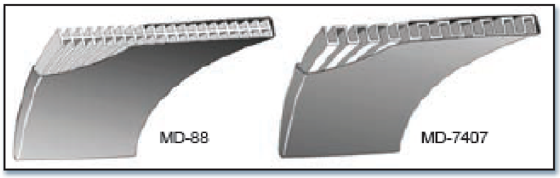
As a division of Hayward Baker, North America's leader in geotechnical construction, HB Wick Drains has direct contact with experts in other ground improvement methods that might be a suitable complement for your site.



Settlement/Time Curve



Pore Water Drainage Flow Path



Mebra™ wick drains, designed and fabricated by HB Wick Drains, are composed of a central core surrounded by a filter sleeve.

Design Considerations

Wick drains are typically used in soft saturated fine-grained soils, such as silts, clays, organic silts, organic clays, peat, sludges, mine tailings, and dredge fills.

The geotechnical investigation should include continuous sampling to identify any sand drainage layers that may contribute to faster consolidation. Appropriate consolidation tests should be performed on the soft material strata to estimate the magnitude and rate of the settlement.

Soft soils, when loaded by surcharge, will undergo:

- Initial elastic compression
- Consolidation
- Secondary compression

Geotechnical Considerations

Wick drains are effective in the following soil conditions:

- Moderate to highly compressible
- Low permeability
- Saturated soils
- Maximum past consolidation stress less than load induced stress

Some site and soil conditions that require evaluation prior to determining the economic and technical feasibility of wick drain systems include:

- Working surface stability
- Overhead and below grade obstructions
- Stiff to very stiff layers (may be addressed with pre-drilling)
- Softness of anchoring layer
- Site accessibility

Environmental Considerations

Water removed by wick drains will need to be collected and treated if the in situ soils are contaminated. For contaminated sites, the drain design length should not fully penetrate into an underlying aquifer.

Quality Assurance/Quality Control

Pore pressures may be monitored along with settlement and loading. Ground movement can be monitored by settlement plates, gauges, and inclinometers. Extensometers can be installed to evaluate settlement versus depth.

Advantages of HB Wick Drains

- *Fast mobilization and installation*
- *Reduced construction time*
- *Minimal post-construction settlement*
- *Increased strength gain rate due to consolidation of soft soils*
- *Several types of rigs with different capabilities that can be matched to the soil conditions to provide the best installation*

A total of 180,000 linear feet of wick drain was installed to 50 feet in sub-zero temperatures to accelerate drainage of soft compressible clay for the construction of an oil drilling platform in Prudhoe Bay, Alaska.

Why Should You Choose HB Wick Drains?

As a division of North America's leader in geotechnical construction, HB Wick Drains has the resources to build your project. Our network of offices and full-service equipment yards means fast mobilization and reduced start-up costs.

From job start-up to installation of the last drain, our attention to quality control helps to ensure that project specifications are achieved. We customize and design our equipment and tooling, helping to ensure that performance and reliability are the best in the industry.

HB Wick Drains has the experience and innovation to assist engineers, contractors, and owners with identifying, developing, and implementing the best wick drain solution.

HB Wick Drains
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Email wickdrains@HaywardBaker.com

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Appendix C. The “Grout Bomber” Technology Fact Sheet

The “Grout Bomber” is a subsurface stabilization technology that uses an excavator equipped with specialized equipment to quickly “push” vertical columns into the ground, subsequently filling them with cement grout (from bottom to top) via a separate grout delivery system. The purpose of this technology in the geotechnical field is to displace, densify, and increase stability of surrounding soils by delivering cement grout into subsurface voids.

As shown in **Figure C.1a**, the typical arrangement of the Bomber method includes the installation rig (excavator with specialized implements), and a separate on-site mixing and delivery unit (mixing hopper, pumps, hosing, power supply, etc.). Raw material (e.g. concrete aggregate) is unloaded into the mixing hopper (see **Figure C.1b**) where it is mixed to the appropriate consistency, then pumped to the bomber rig at a rate of approximately 0.25 cubic feet per pump stroke. At the exit end of the bomber mandrel (see **Figure C.1c**), the cement grout flows in a continuous and uniform manner, allowing the columns to be emplaced with grout while the mandrel (what pushes into the subsurface) is lifted to the surface. The “Grout Bomber” is a larger adaptation of conventional cement or compaction grouting techniques offered at Hayward Baker (see attached Information Brochure on Compaction Grouting).

Figure C.1. a) Grout Bomber arrangement, includes excavator with grout delivery implements and onsite cement mixer, pumps, and power supply; b) example of concrete mixing truck unloading into hopper for mixing and delivery to rig; and c) exit end of grout bomber, shows concrete grout used in geotechnical applications being pumped through mandrel.

HAYWARD BAKER INC.

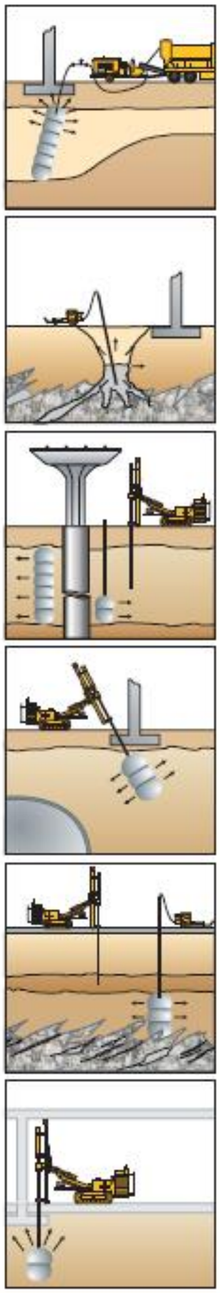
COMPACTION GROUTING

Compaction grouting improves a wide range of ground conditions by displacement, for a variety of site improvement and remedial applications.

Compaction grouting was used to seal this 160-foot diameter sinkhole that extended down to the Floridan aquifer.

When a properly designed compaction grout is injected into loose soils, homogeneous grout bulbs are formed that displace, densify and thus strengthen the surrounding soil. The technique was originally developed in the 1950's as a remedial measure for the correction of building settlement, and used almost exclusively for that purpose for many years. Over the past twenty years, however, compaction grouting technology has evolved to treat a wide range of subsurface conditions for new and remedial construction. These include rubble fills, poorly placed fills, loosened or collapsible soils, sinkhole sites, and liquefiable soils.

Hayward Baker's compaction grouting techniques, which include the internationally respected Denver System, offer an economic advantage over conventional approaches such as removal and replacement or piling. Compaction grouting can be accomplished where access is difficult and space is limited. Since compaction grouting's effectiveness is independent of structural connections, the technique is readily adaptable to existing foundations.



HAYWARD BAKER
Geotechnical Construction

KELLER

Compaction Grouting Technology…

Compaction grouting improves ground conditions by displacement. A very viscous (low-mobility), aggregate grout is pumped in stages to displace and densify the surrounding soils. By sequencing the grouting work from primary to secondary to tertiary locations, this densification process can be performed to achieve significant improvement. Hayward Baker's compaction grouting capability, spanning more than 25 years, is enhanced by the control features provided by the Denver System: batching-on-demand, and specialized, high pressure injection.

The grout mix must have specific characteristics: a very low mobility (low slump) mixture that is 'pumpable' but, upon installation, exhibits an internal friction enabling it to remain intact and displace the surrounding soil without fracturing it.

Site Investigation

For successful compaction grouting, comprehensive knowledge of subsurface conditions is important. In order to prepare a suitable program, a geotechnical engineering consultant will develop a site investigation report, which will generally contain site geology and history, soil gradation, and the in situ horizontal permeability of each treatment stratum. Type and condition of nearby structures and utilities, together with plan and elevation locations, will further assist program development.

Geotechnical Considerations

Conditions necessary for optimum compaction grouting results:

① The in situ vertical stress in the treatment stratum must be sufficient to enable the grout to displace the soil horizontally (if uncontrolled heave of the ground surface occurs, densification will be minimized).

② When compaction grout is injected into saturated soils, a pore pressure increase occurs as a result of ground displacement. This increased pressure must dissipate for effective densification to take place. Therefore, the grout injection rate should be slow enough to allow pore pressure dissipation. Sequencing of grout injection is also important.

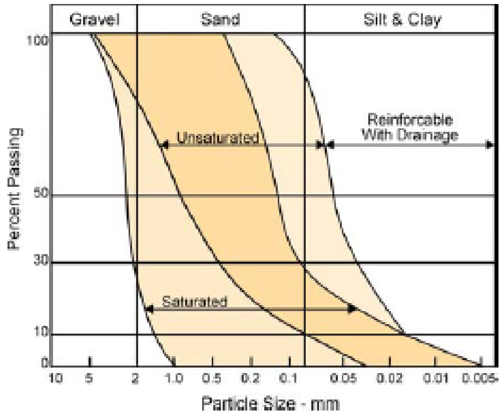
③ Compaction grouting can usually be effective in most silts and sands, provided that the soil is not near saturation.

④ Soils that lose strength during remolding (saturated, fine-grained soils; sensitive clays) should be avoided.

⑤ Greater displacement will occur in weaker soil strata. Excavated grout bulbs confirm that compaction grouting focuses improvement where it is most needed.

⑥ Collapsible soils can usually be treated effectively by adding water during drilling prior to compaction grout injection.

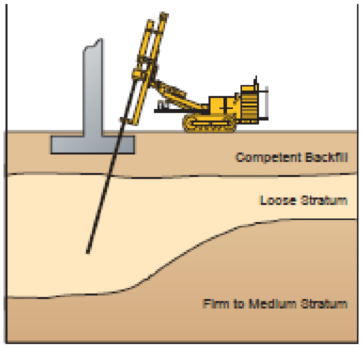
⑦ Stratified soils, particularly thinly stratified soils, can be cause for difficult or reduced improvement capability.



Range of soils that will show improvement by post-testing. Compaction grouting can also be used to reinforce soils beyond this guideline, provided that drainage is enhanced.

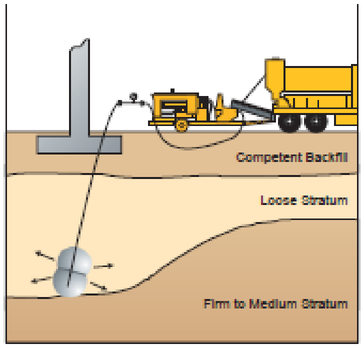
> *"The design and application of compaction grouting is always site-specific, considering the entire above- and below-ground conditions."*

Compaction Grouting Delivery Methods



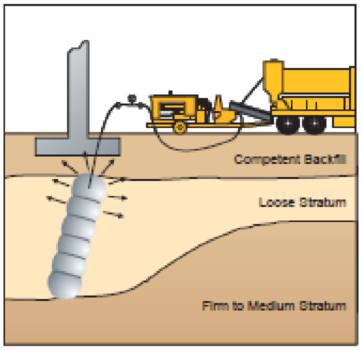
Installation of grout pipe:

- *Drill or drive casing*
- *Location very important*
- *Record ground information from casing installation*



Initiation of grouting:

- *Typically bottom up, but can be top down*
- *Grout quality important*
- *Pressure and/or volume of grout is usually limited*
- *Slow, uniform stage injection*



Continuation of grouting:

- *On-site batching can aid control*
- *Grout quality important*
- *Pressure, grout quantity and indication of heave are controlling factors*
- *Sequencing of plan injection points very important*

Improvement Conditions

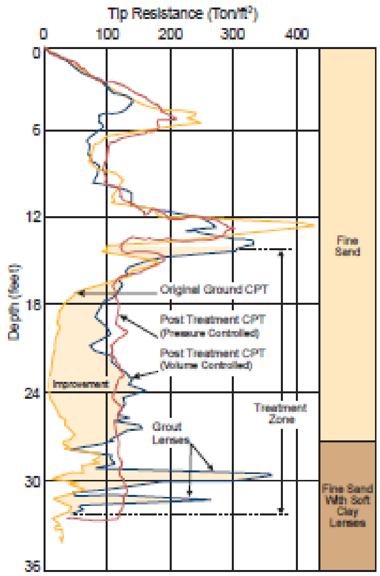
Typically greater than 1,500 psf overburden stress is required to maximize densification. Limited densification can be achieved with less overburden. This stress can come from overburden soils, surcharge loads and/or foundation loads. When densification is the primary intent, a replacement ratio and pressure criterion is applied to each stage of compaction grouting. This ratio is determined based on the existing density, the soil density range, and the amount of displacement necessary to affect the improvement.

$$\text{Replacement Ratio (RR)} = \frac{\text{CG Volume}}{\text{Treatment Volume}} \simeq 5 \text{ to } 15\% \text{ (typical)}$$

Experience has proven that treatment spacing should not exceed 6 to 10 ft. From this, a compaction grouting volume can be calculated. The maximum pressure criterion prevents fracture and ground heave and compensates for stiff zones in the treatment area. Vertical stages are usually set at 2- to 3-ft intervals; tighter grid spacing will generally lead to better results.

Quality Control/Quality Assurance

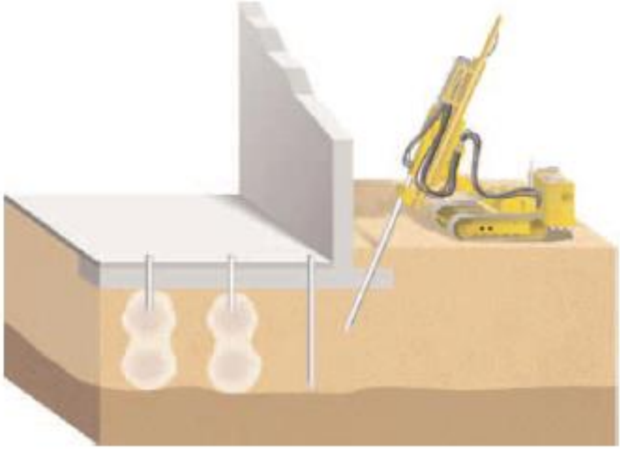
Quality control includes procedural inspection and documentation of the work activity, testing to ensure proper mix design and injection rates, and verification of ground improvement where applicable. Ground improvement can be assessed by Standard Peneteration Testing, Cone Penetrometer Testing, or other similar methods. Data recording of important grouting parameters has been utilised on sensitive projects.



Cone Penetrometer Test results, such as the ones illustrated above for volume cut-off and pressure cut off, show the degree of improvement achieved by compaction grouting.

Advantages of Compaction Grouting

- *Pinpoint treatment*
- *Speed of installation*
- *Wide applications range*
- *Effective in a variety of soil conditions*
- *Can be performed in very tight access and low headroom conditions*
- *Non-hazardous*
- *No waste spoil disposal*
- *No need to connect to footing or column*
- *Non-destructive and adaptable to existing foundations*
- *Economic alternative to removal and replacement or piling*
- *Able to reach depths unattainable by other methods*
- *Enhanced control and effectiveness of in situ treatment with Denver System*



Why Should You Choose A Hayward Baker Compaction Grouting Solution?

As North America's largest geotechnical contractor, Hayward Baker has the resources to build your project. We manufacture much of our own equipment, ensuring the best performance and reliability in the industry.

From job start-up to job end, our attention to quality control ensures project specifications are achieved. Our network of offices and full-service equipment yards means fast mobilization and reduced start-up costs.

Hayward Baker is committed to providing the most economical solution that satisfies the technical requirements of each project.

Whether a situation is typical or unique, we have the experience and innovation to assist engineers, contractors and owners with identifying and implementing the best solution. For a variety of subsurface conditions, compaction grouting may be the answer.

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Grouting
Cement Grouting (High Mobility Grouting)
Chemical Grouting
Compaction Grouting (Low Mobility Grouting)
Fracture Grouting
Jet Grouting
Polyurethane Grouting

Ground Improvement
Dry Soil Mixing
Dynamic Compaction
Injection Systems for Expansive Soils
Rapid Impact Compaction
Rigid Inclusions
Vibro Compaction
Vibro Concrete Columns
Vibro Piers™ (Aggregate Piers)
Vibro Replacement (Stone Columns)
Wet Soil Mixing

Structural Support
Augercast Piles
Drilled Shafts
Driven Piles
Franki Piles (PIFs)
Helical Piles
Jacked Piers
Macropiles™
Micropiles
Pit Underpinning

Earth Retention
Anchors
Anchor Block Slope Stabilization
Gabion Systems
Micropile Slide Stabilization System (MS³)
Sheet Piles
Soil Nailing
Soldier Piles & Lagging

Additional Services
Earthquake Drains
Slab Jacking
Slurry Walls
TRD – Soil Mix Walls
Wick Drains

Website	www.HaywardBaker.com
Email	info@HaywardBaker.com

Hayward Baker Inc.
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HI-MAR 30005-J May 2013

THINK SAFE

Appendix D. Small-Scale Demonstration

OBJECTIVES

For Task 2 (Small-Scale Demonstration), GSI collaborated with the Rice University Oshman Engineering Design Kitchen (http://oedk.rice.edu/). Led by GSI, a team of six mechanical engineering students developed and implemented the design for the small-scale demonstration as part of a capstone design project. The objective of the study was to design and execute several column tests to evaluate the distribution of ZVI and neat oil in prefabricated vertical drains (or wick drains).

METHODOLOGY

A 15-ft column test was conducted to determine the distribution of neat vegetable oil within a wick drain under saturated conditions (see **Figure D.1a**). The test consisted of a 15-ft long, 6 in. diameter PVC pipe, filled with water, and a wick drain placed inside and along the centerline of the PVC pipe. Acrylic pieces were attached to the wick drain on either side to simulate low-k zones; gaps between pieces simulated high-k zones. Approximately 3 gallon of vegetable oil was poured into the top of the wick drain using a funnel and tubing to direct the oil down the center core of the wick drain. A separate test was conducted using ZVI slurry (1:20 ZVI:water).

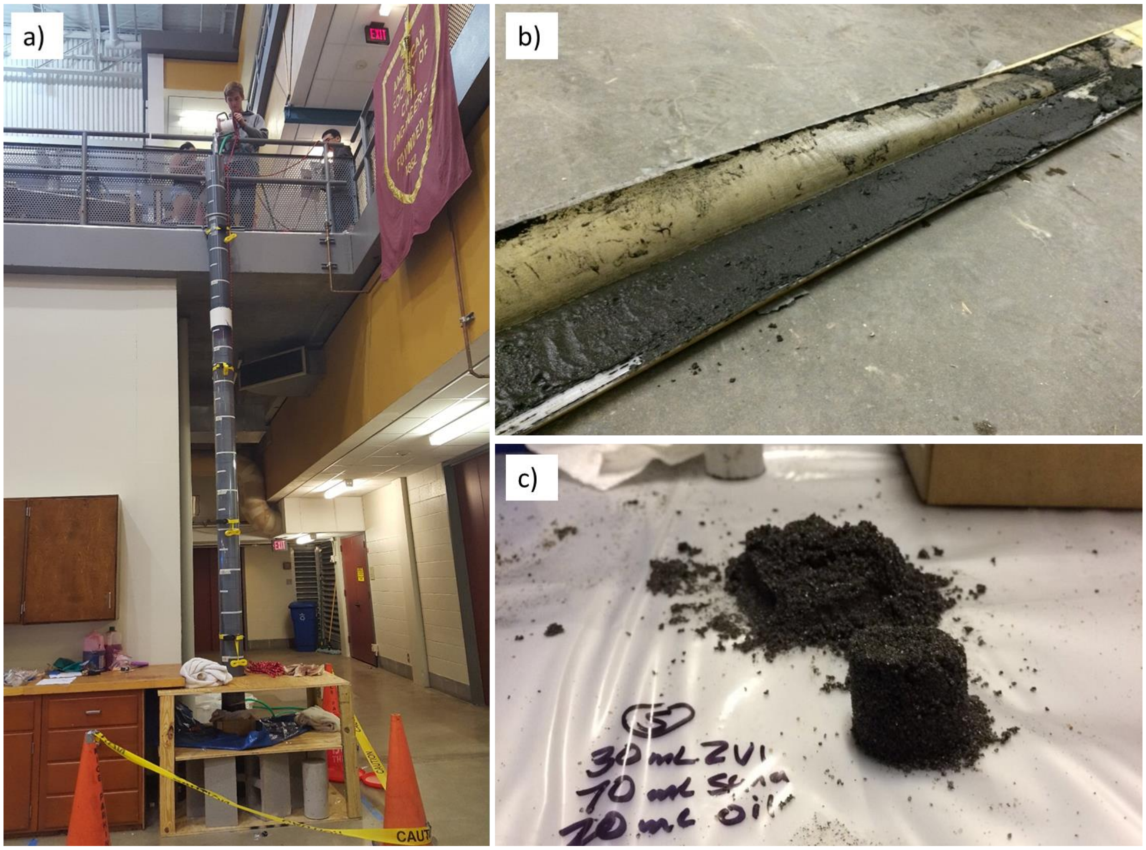


Figure D.1. a) 15-ft column test performed by Rice University engineering design students, b) wick drain following experiment to delivery ZVI solution throughout drain, c) a test mixture of 30 mg ZVI, 70 mL Sand, and 20 mL of oil.

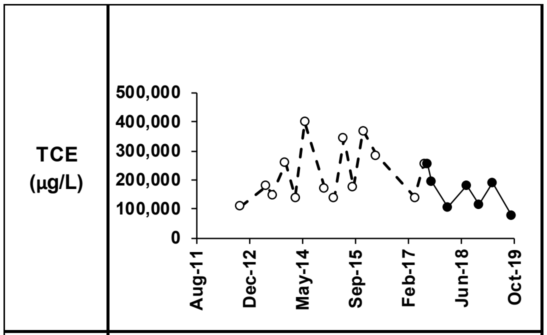
RESULTS & IMPLICATIONS

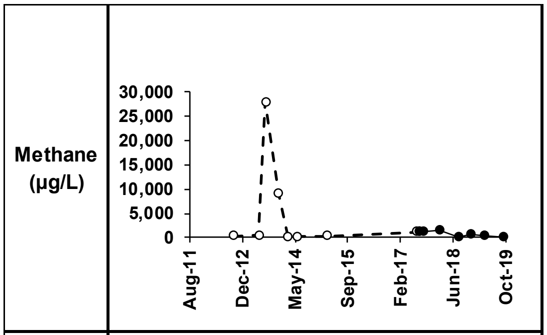
The students found that oil was easily distributed down the unsaturated section of the wick drain; however, at the water surface, the oil only penetrated the wick ~3 ft and spread at the surface due to opposing buoyancy forces. A second test was conducted with a greater pressure head; however, distribution of the oil was very similar to the first test. In a separate test, a ZVI slurry (1:20 ZVI:water) was successfully distributed along the length of a wick drain (see **Figure D.1b**), with some minor clogging at the inlet and passing of finer particles through the filter sleeve. ZVI offers an advantage over neat oil, given that it's not subject to the same buoyancy limitations. Several particle sizes of ZVI were evaluated to reduce the mass escaping the filter sleeve.

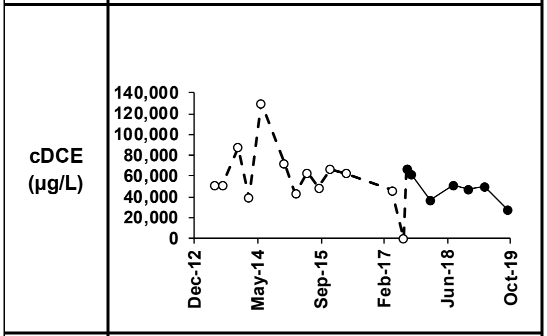
Results of the column tests led the GSI project team to evaluate other methods for filling the wick drains with amendments (i.e., pre-loaded wicks) and other geotechnical technologies that offer similar benefits and adaptability as the wick drain technology (i.e., "Grout Bomber). The Rice team then evaluated a variety of ZVI mixtures (ZVI, sand, organic substrates; see **Figure D.1c**) for usability in the Bomber system without the need for alterations to existing equipment. To test the viability of pumping ZVI amendment mixtures using Grout Bomber equipment (Elkin mixer, concrete mixing truck, grout pumps, etc.), the Rice team performed a series of "slump tests" and pipe flow tests to compare various ratios of sand, ZVI, and water mixtures to the grout mixtures typically handled by this equipment. These tests evaluated the "workability" of various sand, ZVI, and water slurry mixtures to determine the minimum amount of water needed to retain pumpability. It was concluded that the target design ratio of ZVI/sand (~40% ZVI) should be achievable with minimal water added, though additional field testing and periodic hose unclogging would likely be required. This finding was corroborated by field observations, and small amounts of vegetable oil were added to the mixture to improve amendment transfer efficiency from the mixing hopper through a positive displacement pump to the grout bomber rig.

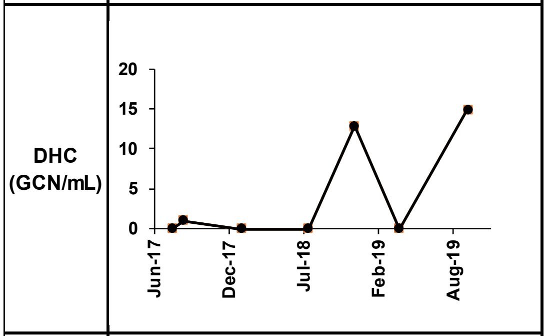
Figure D.2. Successful slump test, where material does not hold shape

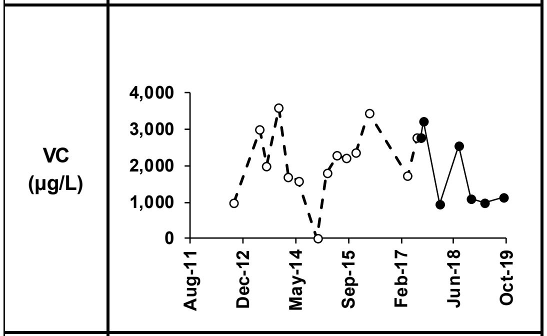
Appendix E. Time-Series Plots

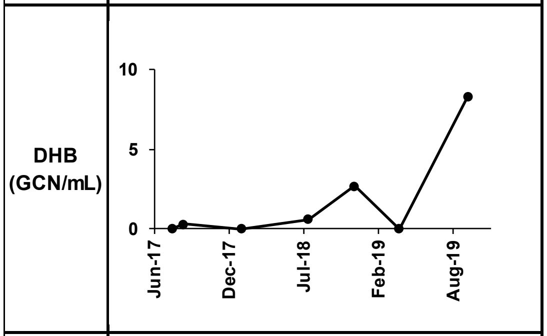


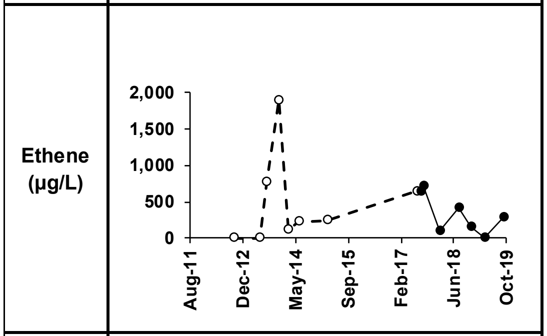


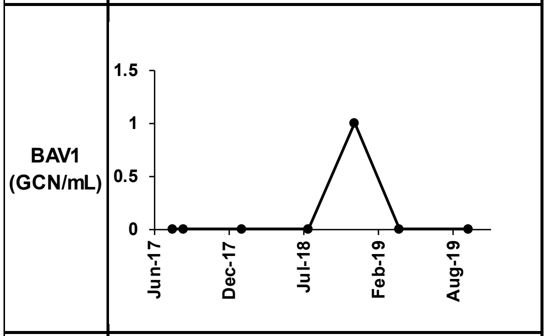


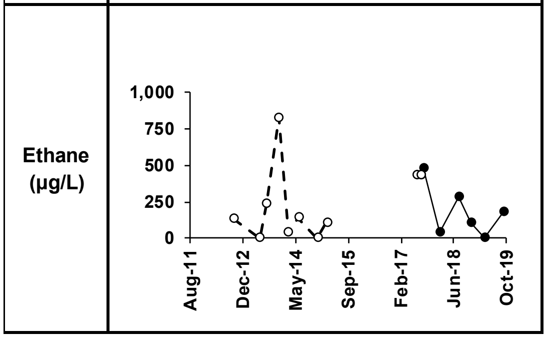


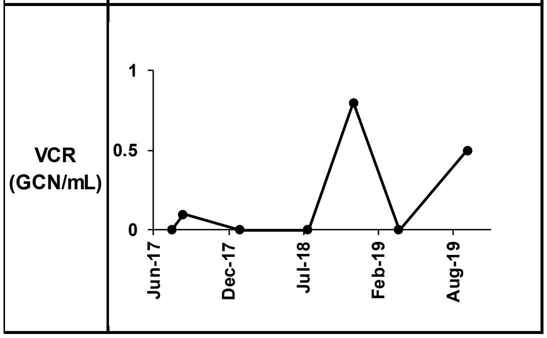












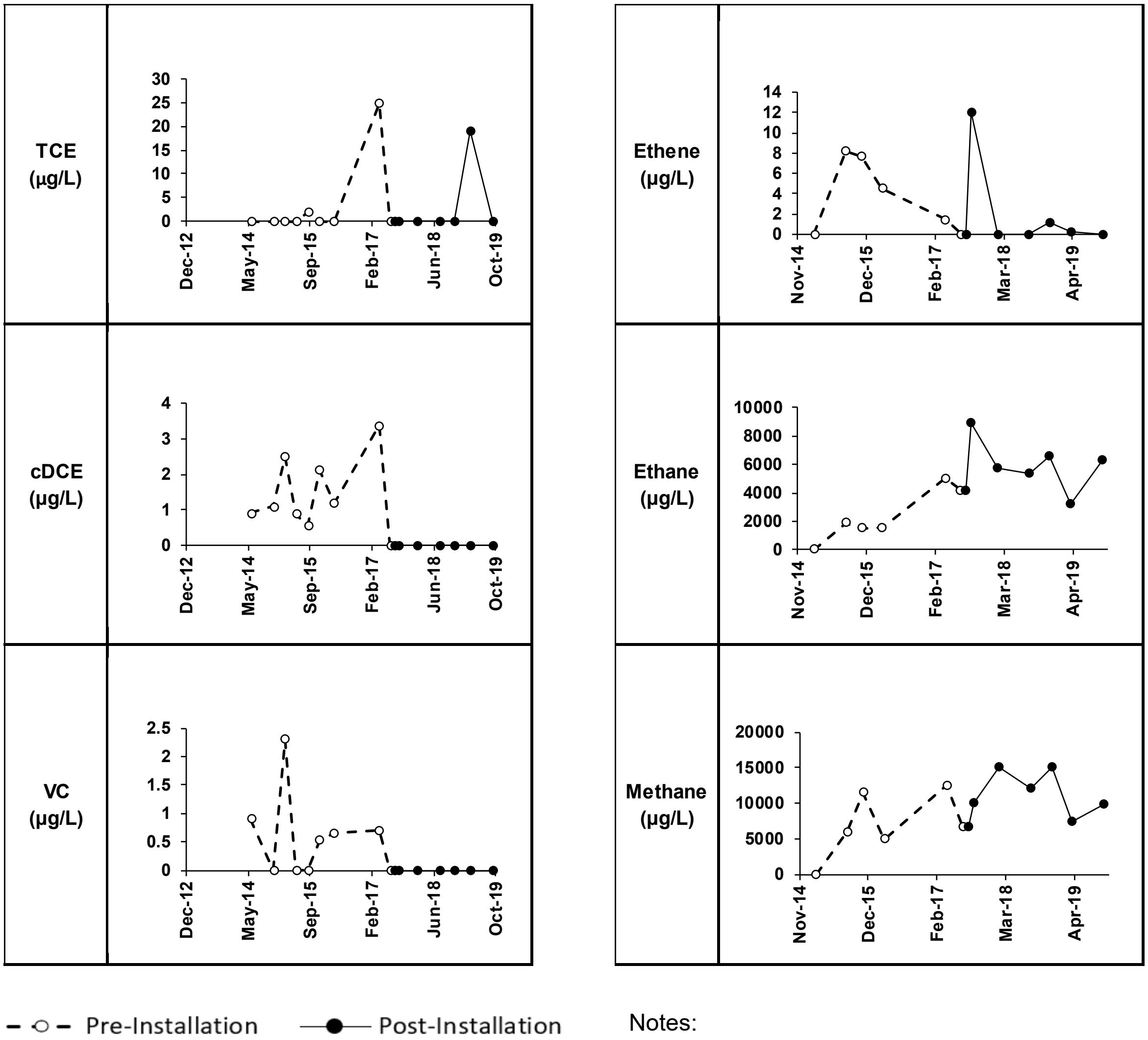
- ○ - Pre-Installation   —●— Post-Installation

Notes:
1. Non-detects (NDs) reported and plotted as zeros

GSI ENVIRONMENTAL

GSI Job No. 4460
Issued: 12 March 2020
Revised:
Scale:
Drawn By: DMH
Chk'd By: PCB
Aprv'd By: SDR

MW04

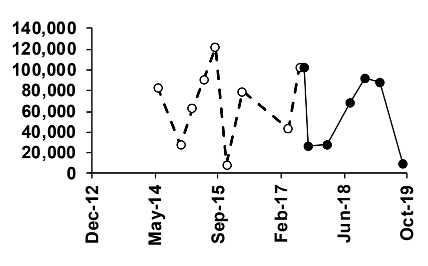


Notes:
1. Non-detects (NDs) reported and plotted as zeros

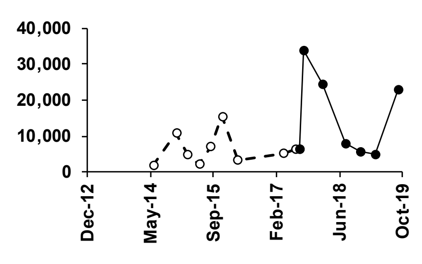
GSI ENVIRONMENTAL

GSI Job No. 4460	Drawn By: DMH	**MW11**
Issued: 12 March 2020	Chk'd By: PCB	
Revised:	Aprv'd By: SDR	
Scale:		

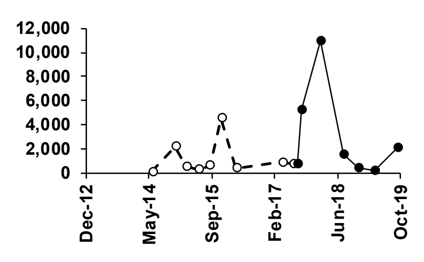
TCE (µg/L)



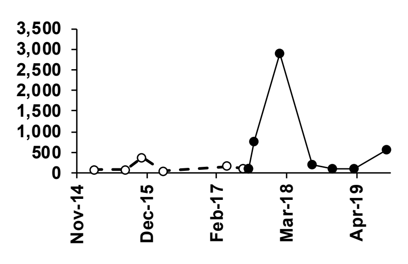
cDCE (µg/L)



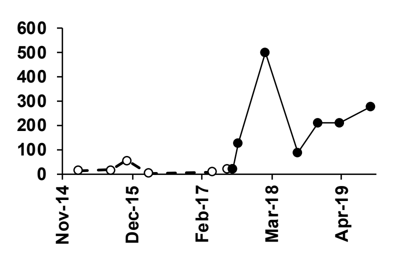
VC (µg/L)



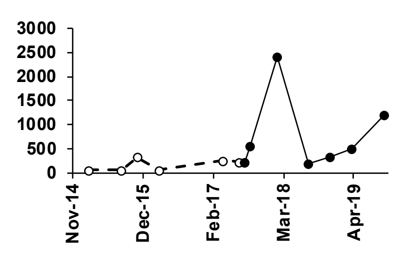
Ethene (µg/L)



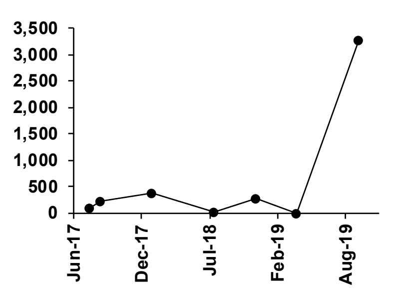
Ethane (µg/L)



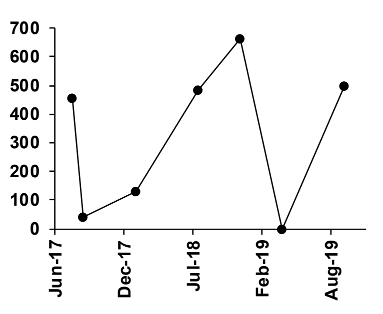
Methane (µg/L)



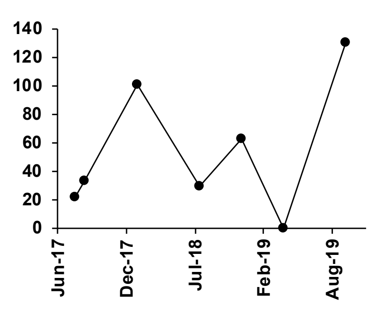
DHC (GCN/mL)



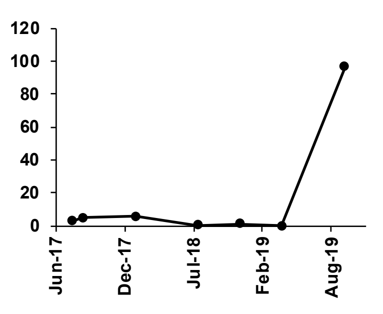
DHB (GCN/mL)



BAV1 (GCN/mL)



VCR (GCN/mL)



- ○ - Pre-Installation —●— Post-Installation

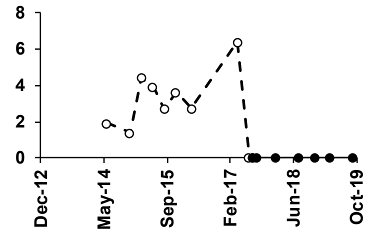
Notes:
1. Non-detects (NDs) reported and plotted as zeros

GSI ENVIRONMENTAL

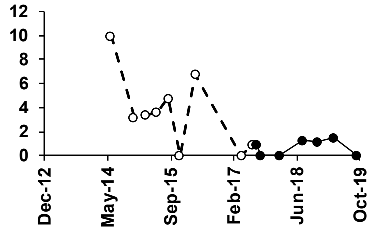
GSI Job No. 4460	Drawn By: DMH
Issued: 12 March 2020	Chk'd By: PCB
Revised:	Aprv'd By: SDR
Scale:	

MW12

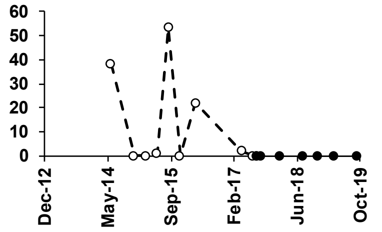
TCE (µg/L)



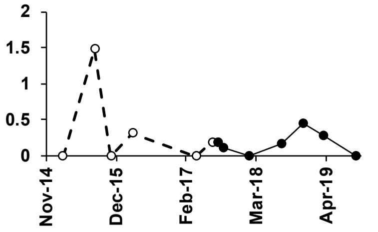
cDCE (µg/L)



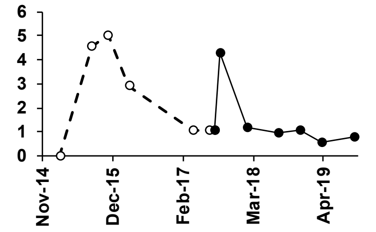
VC (µg/L)



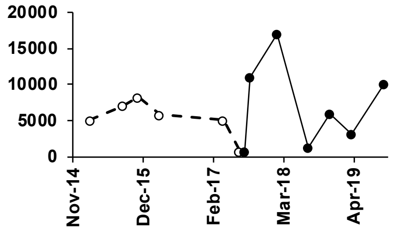
Ethene (µg/L)



Ethane (µg/L)



Methane (µg/L)



- ○ - Pre-Installation —●— Post-Installation

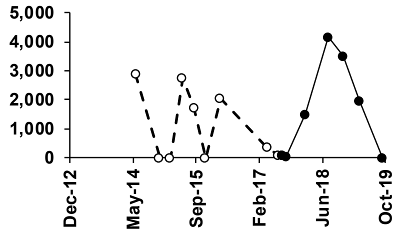
Notes:
1. Non-detects (NDs) reported and plotted as zeros

GSI ENVIRONMENTAL

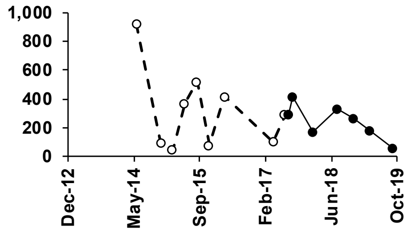
GSI Job No. 4460	Drawn By: DMH
Issued: 12 March 2020	Chk'd By: PCB
Revised:	Aprv'd By: SDR
Scale:	

MW13

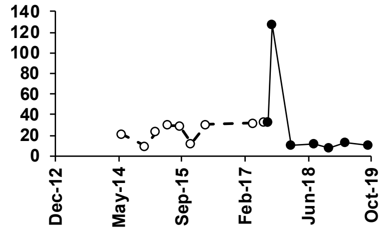
TCE (µg/L)



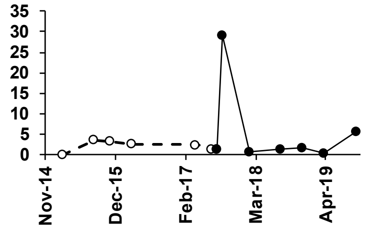
cDCE (µg/L)



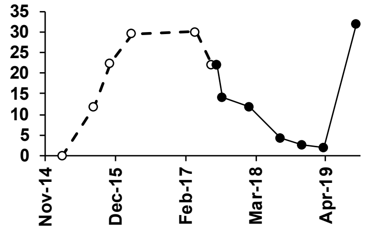
VC (µg/L)



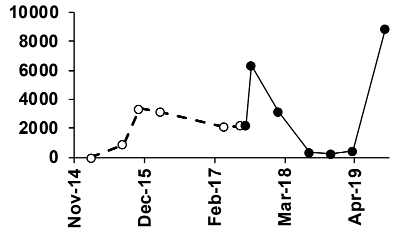
Ethene (µg/L)



Ethane (µg/L)



Methane (µg/L)



- ○ - Pre-Installation —●— Post-Installation

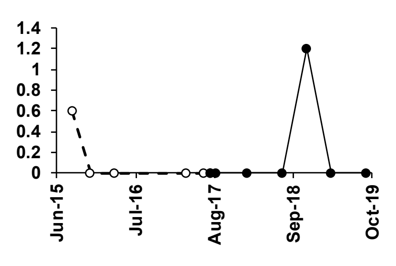
Notes:
1. Non-detects (NDs) reported and plotted as zeros

GSI ENVIRONMENTAL

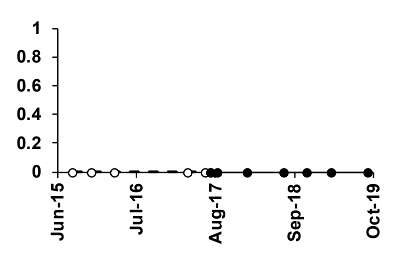
GSI Job No. 4460	Drawn By: DMH		
Issued: 12 March 2020	Chk'd By: PCB		
Revised:	Aprv'd By: SDR		
Scale:			

MW14

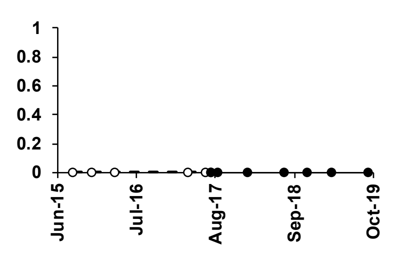
TCE (µg/L)



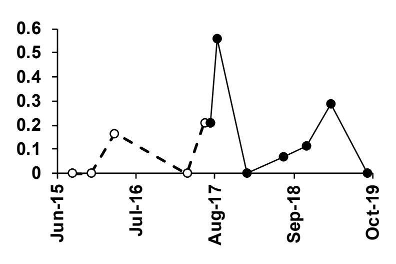
cDCE (µg/L)



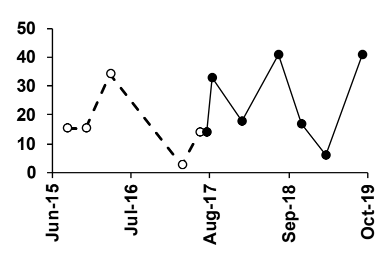
VC (µg/L)



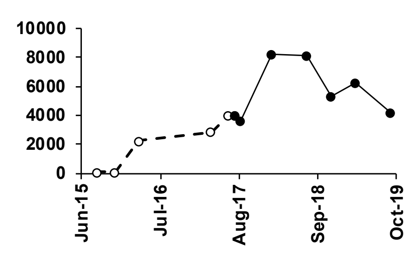
Ethene (µg/L)



Ethane (µg/L)



Methane (µg/L)



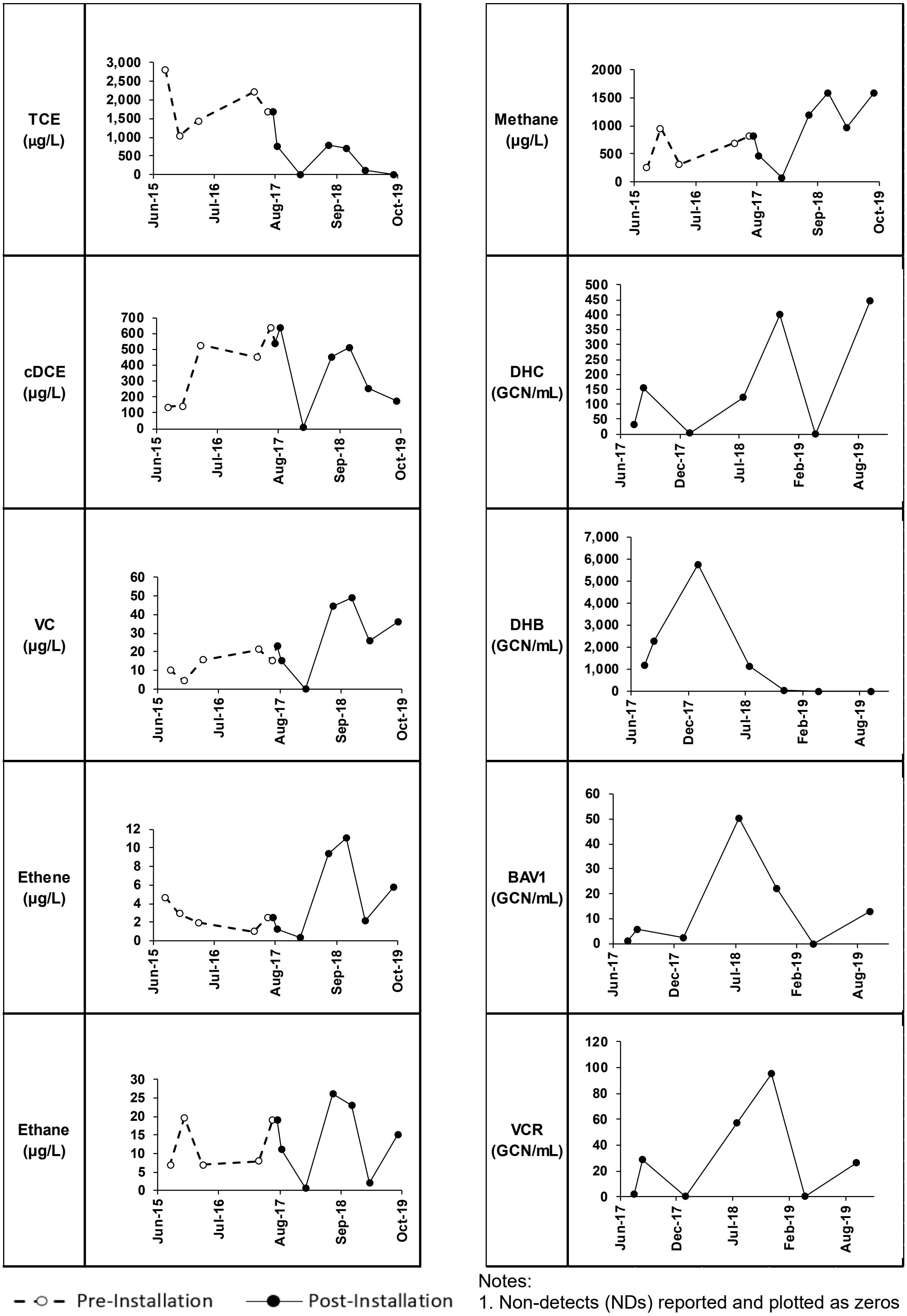
- ○ - Pre-Installation ——●—— Post-Installation

Notes:
1. Non-detects (NDs) reported and plotted as zeros

GSI ENVIRONMENTAL

GSI Job No. 4460	Drawn By: DMH		
Issued: 12 March 2020	Chk'd By: PCB		
Revised:	Aprv'd By: SDR		
Scale:			

MW15



Notes:
1. Non-detects (NDs) reported and plotted as zeros

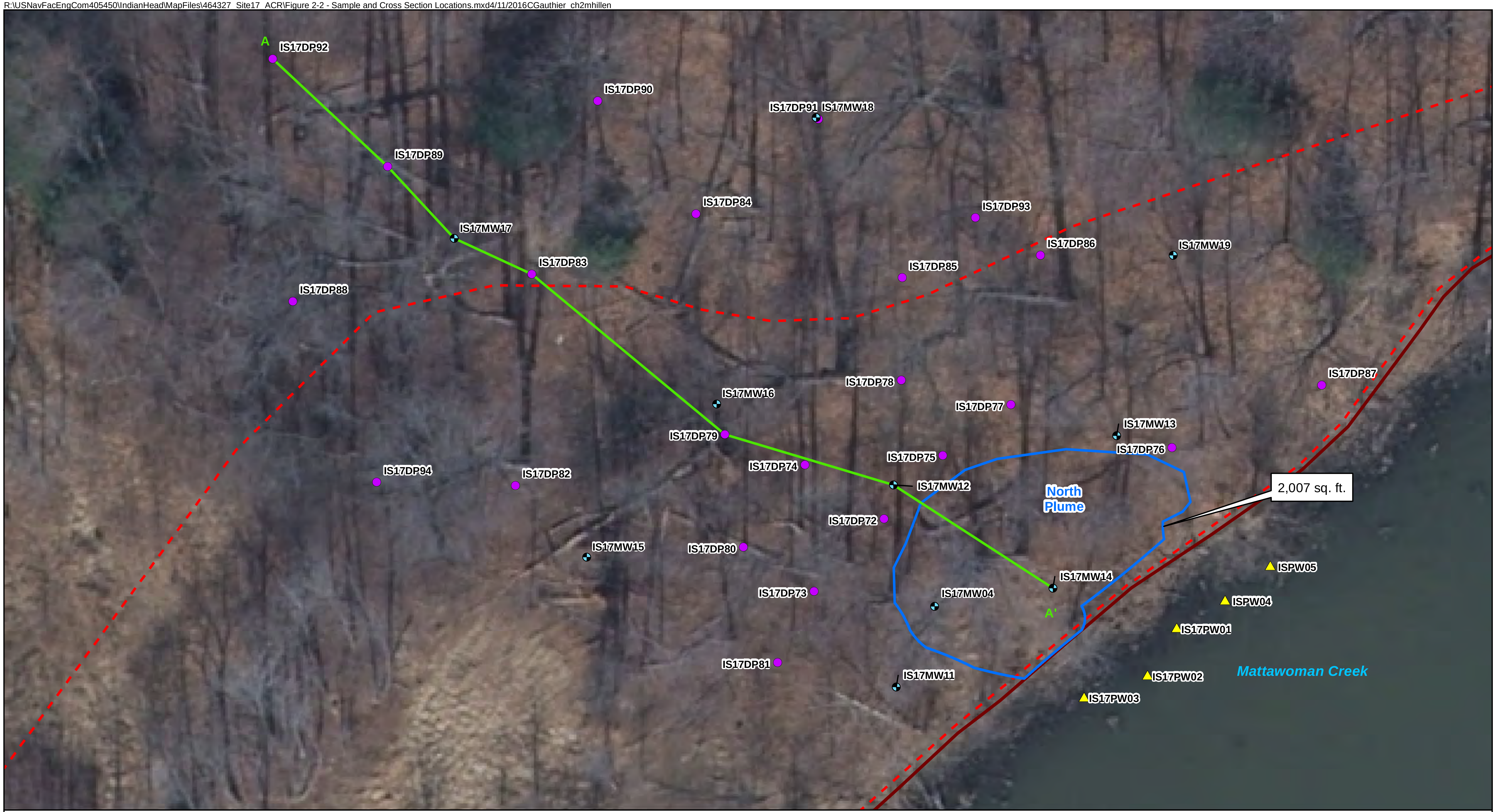
GSI ENVIRONMENTAL

GSI Job No. 4460	Drawn By: DMH		
Issued: 12 March 2020	Chk'd By: PCB		
Revised:	Aprv'd By: SDR		
Scale:			

MW16

Appendix F. Relevant Figures and Boring Logs from Previous Assessments

R:\USNavFacEngCom405450\IndianHead\MapFiles\464327_Site17_ACR\Figure 2-2 - Sample and Cross Section Locations.mxd4/11/2016CGauthier_ch2mhillen



Legend

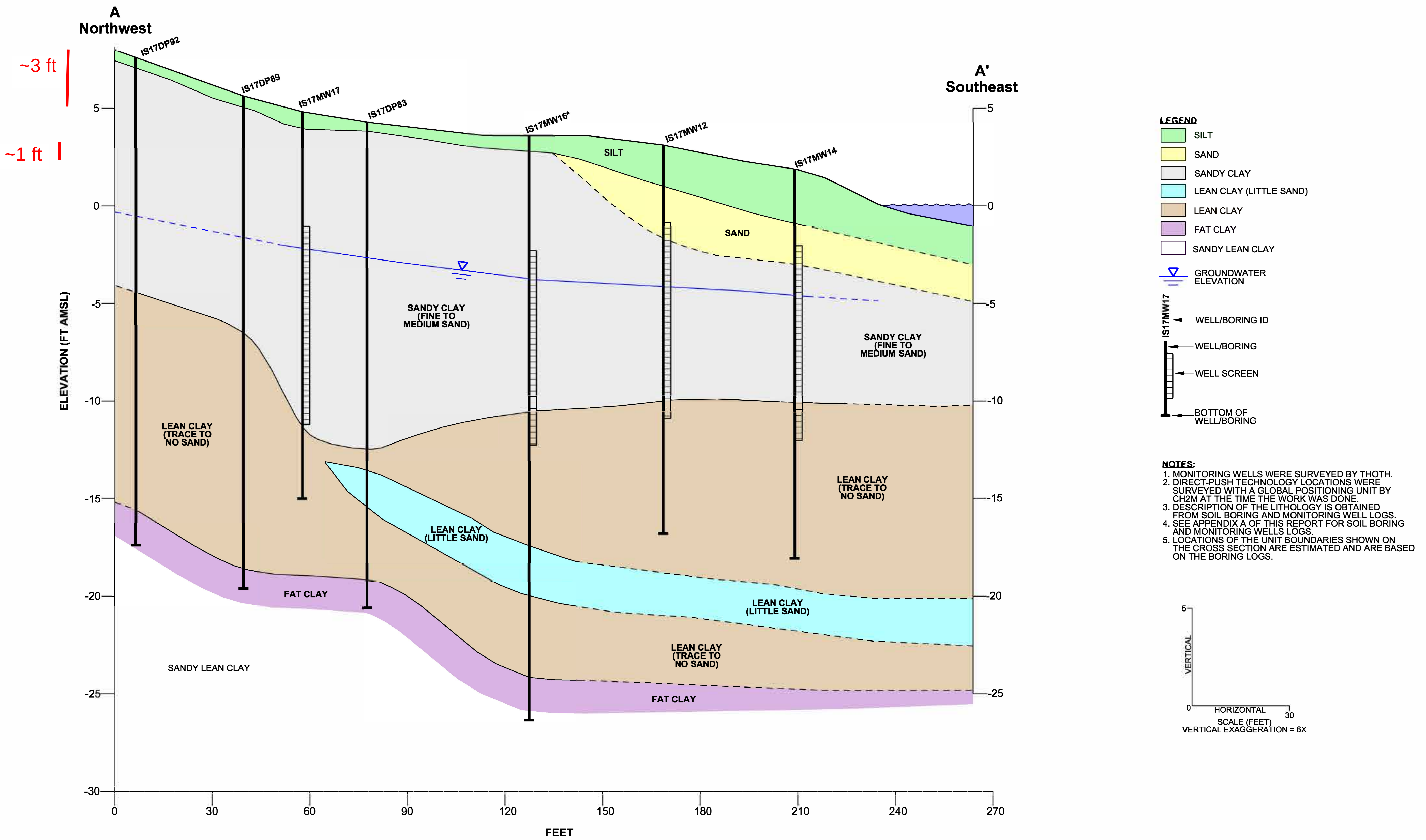
- ● DPT Locations
- △ Sediment Pore Water Sample Locations
- ● Groundwater Monitoring Well Location
- — Geologic Cross Section Line
- — Elevation Contour (feet)
- ▭ Area of Attainment, as defined in the Record of Decision (CH2M HILL, 2010), where groundwater concentrations exceed site remediation goals
- ▭ Approximate Site Boundary
- ▭ Base Boundary
- — Groundwater Contour
- → Groundwater Flow

N

0 10 20
Feet

Figure 2-2
Sample and Cross Section Line Locations
Site 17 North Plume Additional Characterization Report
NSFIH, Indian Head, Maryland

ch2m



NOTES:

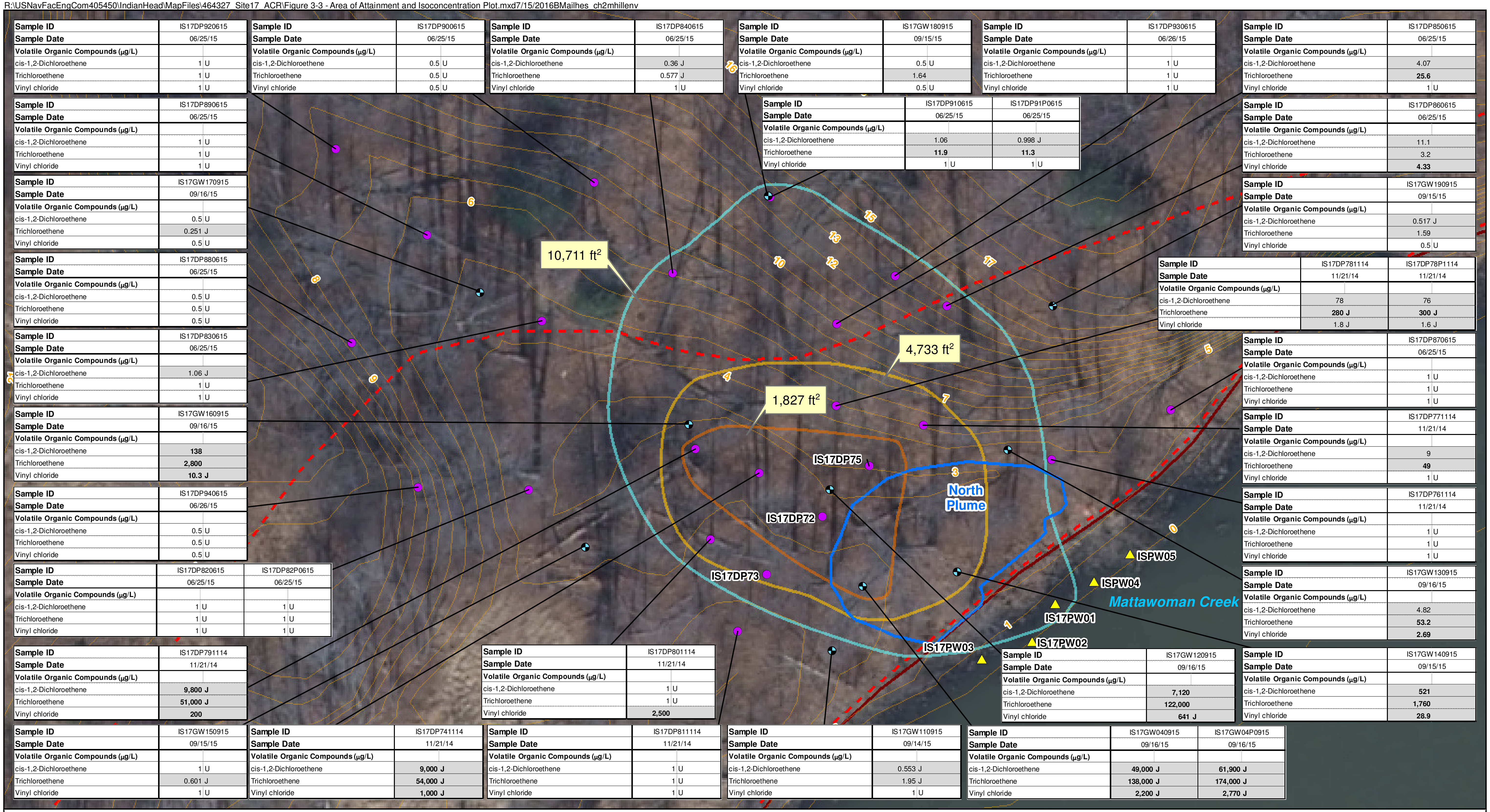
1. MONITORING WELLS WERE SURVEYED BY THOTH.
2. DIRECT-PUSH TECHNOLOGY LOCATIONS WERE SURVEYED WITH A GLOBAL POSITIONING UNIT BY CH2M AT THE TIME THE WORK WAS DONE.
3. DESCRIPTION OF THE LITHOLOGY IS OBTAINED FROM SOIL BORING AND MONITORING WELL LOGS.
4. SEE APPENDIX A OF THIS REPORT FOR SOIL BORING AND MONITORING WELLS LOGS.
5. LOCATIONS OF THE UNIT BOUNDARIES SHOWN ON THE CROSS SECTION ARE ESTIMATED AND ARE BASED ON THE BORING LOGS.

* Geology from adjacent boring IS17DP79

Figure 3-1
North Plume Geologic Cross Section A-A'
Site 17 North Plume Additional Characterization Report
NSFIH, Indian Head, Maryland

ch2m:

R:\USNavFacEngCom405450\IndianHead\MapFiles\464327_Site17_ACR\Figure 3-3 - Area of Attainment and Isoconcentration Plot.mxd7/15/2016BMailhes_ch2mhillenv



Sample ID	IS17DP920615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17DP900615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.5 U
Trichloroethene	0.5 U
Vinyl chloride	0.5 U

Sample ID	IS17DP840615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.36 J
Trichloroethene	0.577 J
Vinyl chloride	1 U

Sample ID	IS17GW180915
Sample Date	09/15/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.5 U
Trichloroethene	1.64
Vinyl chloride	0.5 U

Sample ID	IS17DP930615
Sample Date	06/26/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17DP850615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	4.07
Trichloroethene	**25.6**
Vinyl chloride	1 U

Sample ID	IS17DP890615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17DP910615	IS17DP91P0615
Sample Date	06/25/15	06/25/15
Volatile Organic Compounds (µg/L)		
cis-1,2-Dichloroethene	1.06	0.998 J
Trichloroethene	**11.9**	**11.3**
Vinyl chloride	1 U	1 U

Sample ID	IS17DP860615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	11.1
Trichloroethene	3.2
Vinyl chloride	**4.33**

Sample ID	IS17GW170915
Sample Date	09/16/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.5 U
Trichloroethene	0.251 J
Vinyl chloride	0.5 U

Sample ID	IS17GW190915
Sample Date	09/15/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.517 J
Trichloroethene	1.59
Vinyl chloride	0.5 U

Sample ID	IS17DP880615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.5 U
Trichloroethene	0.5 U
Vinyl chloride	0.5 U

Sample ID	IS17DP781114	IS17DP78P1114
Sample Date	11/21/14	11/21/14
Volatile Organic Compounds (µg/L)		
cis-1,2-Dichloroethene	78	76
Trichloroethene	**280 J**	**300 J**
Vinyl chloride	1.8 J	1.6 J

Sample ID	IS17DP830615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1.06 J
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17DP870615
Sample Date	06/25/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17GW160915
Sample Date	09/16/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	**138**
Trichloroethene	**2,800**
Vinyl chloride	**10.3 J**

Sample ID	IS17DP771114
Sample Date	11/21/14
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	9
Trichloroethene	**49**
Vinyl chloride	1 U

Sample ID	IS17DP940615
Sample Date	06/26/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.5 U
Trichloroethene	0.5 U
Vinyl chloride	0.5 U

Sample ID	IS17DP761114
Sample Date	11/21/14
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17DP820615	IS17DP82P0615
Sample Date	06/25/15	06/25/15
Volatile Organic Compounds (µg/L)		
cis-1,2-Dichloroethene	1 U	1 U
Trichloroethene	1 U	1 U
Vinyl chloride	1 U	1 U

Sample ID	IS17GW130915
Sample Date	09/16/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	4.82
Trichloroethene	**53.2**
Vinyl chloride	**2.69**

Sample ID	IS17DP791114
Sample Date	11/21/14
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	**9,800 J**
Trichloroethene	**51,000 J**
Vinyl chloride	**200**

Sample ID	IS17DP801114
Sample Date	11/21/14
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	**2,500**

Sample ID	IS17GW120915
Sample Date	09/16/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	**7,120**
Trichloroethene	**122,000**
Vinyl chloride	**641 J**

Sample ID	IS17GW140915
Sample Date	09/15/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	**521**
Trichloroethene	**1,760**
Vinyl chloride	**28.9**

Sample ID	IS17GW150915
Sample Date	09/15/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	0.601 J
Vinyl chloride	1 U

Sample ID	IS17DP741114
Sample Date	11/21/14
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	**9,000 J**
Trichloroethene	**54,000 J**
Vinyl chloride	**1,000 J**

Sample ID	IS17DP811114
Sample Date	11/21/14
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	1 U
Trichloroethene	1 U
Vinyl chloride	1 U

Sample ID	IS17GW110915
Sample Date	09/14/15
Volatile Organic Compounds (µg/L)	
cis-1,2-Dichloroethene	0.553 J
Trichloroethene	1.95 J
Vinyl chloride	1 U

Sample ID	IS17GW040915	IS17GW04P0915
Sample Date	09/16/15	09/16/15
Volatile Organic Compounds (µg/L)		
cis-1,2-Dichloroethene	**49,000 J**	**61,900 J**
Trichloroethene	**138,000 J**	**174,000 J**
Vinyl chloride	**2,200 J**	**2,770 J**

Legend

- ● DPT Locations
- ▲ Sediment Pore Water Sample Locations
- ◐ Groundwater Monitoring Well Location
- — Elevation Contour (feet)
- ▭ Area of Attainment, as defined in the Record of Decision (CH2M HILL, 2010), where groundwater concentrations exceed site remediation goals
- ▭ Approximate Site Boundary
- ▭ Base Boundary

Isoconcentration Lines

- ▭ 2 µg/L
- ▭ 1,000 µg/L
- ▭ 10,000 µg/L

Notes:
1. Site VOCs are Trichloroethene, cis-1,2-dichloroethene, and vinyl chloride
2. µg/L – microgram per liter
3. Site Remediation Goals (SRGs): Trichloroethene – 5 µg/L; cis-1,2-dichloroethene – 150 µg/L, and vinyl chloride – 2 µg/L.
4. Duplicate samples are denoted with a P in the sample ID.
5. J – Analyte present, value may or may not be accurate or precise.
6. U – The material was analyzed for, but not detected.

N

0 12.5 25 Feet

Figure 3-3
Area of Attainment and Isoconcentration Plot
Site 17 North Plume Additional Characterization Report
NSFIH, Indian Head, Maryland

ch2m:

Appendix G. Geophysics Final Report (Aestus, LLC)

FINAL REPORT

GEOTRAX SURVEY LTM™
ULTRA-HIGH RESOLUTION TEMPORAL MONITORING OF INSTALLED REMEDY

ESTCP RESEARCH PROJECT
EVALUATION OF REACTION COLUMN REMEDY
NAVAL SUPPORT FACILITY INDIAN HEAD
NORTH SITE 17
INDIAN HEAD, MARYLAND, USA

September 30, 2019

Aestus Project No. 17-111-06

Prepared for:

and

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AGI	Advanced Geosciences, Inc. (2121 Geoscience Dr., Austin, TX 78726, USA)
AMSL	Above Mean Sea Level
AST	Aboveground Storage Tank
BGS	Below Ground Surface
COC	Contaminant of Concern
CSM	Conceptual Site Model
CVOC	Chlorinated Volatile Organic Compounds
DCE	Dichloroethene
DNAPL	Dense Non-aqueous Phase Liquid
EC	Electrical conductivity, mS/cm (millisiemens per centimeter)
ERD	Enhanced Reductive Dechlorination
ERI	Electrical Resistivity Imaging
EVO	Emulsified Vegetable Oil
ISCO	In-situ Chemical Oxidation
MW	Monitoring Well
ORP	Oxidation-reduction potential, mV (millivolts)
PCE	Tetrachloroethene
PIDs	Reading from a Photoionization Detector, ppm (parts per million)
SB	Soil boring
TCE	Trichloroethene
UST	Underground storage tank
VC	Vinyl Chloride
VOC	Volatile Organic Compound
ZVI	Zero-valent Iron
3D	Three-dimensional

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1.0 PROJECT OVERVIEW

Aestus, LLC (Aestus) performed its GeoTrax Survey LTM™ temporal subsurface imaging process at the North Site 17 of the Naval Support Facility located in Indian Head, Maryland. This high-resolution subsurface geophysical mapping technology was used in a phased approach to help assess the distribution of CVOC related impacts and the effects of vertical reaction columns filled with remediation amendments (sand, oil, and zero valent iron [ZVI]).

Standard (non-temporal) GeoTrax Survey™ data can also be used during site characterization to help identify subsurface locations where dense non-aqueous phase liquids (DNAPL) are present in the subsurface and to optimize injection well locations. However, the primary focus of this project was to evaluate changes to the subsurface on a temporal basis after the installation of ZVI reaction columns.

Aestus' imaging technology provides tremendous data density (thousands of proprietary electrical resistivity imaging samples at a resolution of approximately 0.25-1.125 meters (horizontally and vertically; resolution is half the electrode spacing) in a 2-D plane for site characterization, which overcomes the inherent limitation of standard approaches using only one-dimensional data points (via borings/monitoring wells) installed without the benefit of imaging targets. These image data were integrated with historical data to develop a better understanding of the subsurface at North Site 17.

This report outlines the activities and results of all work performed at North Site 17 of the Indian Head Naval Support Facility with detailed discussion on the long-term trends of subsurface changes.

1.1 Project Objectives

The project objectives of the investigation program were to use Aestus' imaging technology to assist GSI with the following project goals:

1. Confirm the horizontal and vertical extent of CVOC related impacts during initial pre-remedy imaging event.
    a. Utilize ERI to track changes in saturating fluid electrical conductivity
    b. Correlate to geochemical changes observed by laboratory analytical results, to the extent possible
2. Perform Long Term Monitoring (LTM) temporal imaging to evaluate changes to the subsurface post-remedy by:
    a. Assessing the effects of remedy work with vertical reaction columns filled with remediation amendments
    b. Tracking changes in CVOC distribution, ongoing chemical reactions, increased bioactivity, and/or other changes that may occur to the subsurface due to this experimental remediation technology implementation

1.2 Site Location and Description

North Site 17 of the Naval Support Facility is located southwest of the intersection of Olsen and Caffee Roads, and just north of the Mattawoman Creek in Indian Head, Maryland. It is a vegetated/wooded area with limited activity and traffic at/near the site.

1.2.1 Site Background and Hydrogeology

The following site information is summarized from documents provided to Aestus by GSI:

- North Site 17 has a groundwater contaminant plume dominated by chlorinated volatile organic compounds (CVOCs) with an unknown source location
- The site is a vegetated/wooded area near the northern edge of Mattawoman Creek which is connected to the Potomac River
- The ground surface of the site is primarily sandy with wetland vegetation and some areas of the site flood and retain surface water during/following heavy rains
- North Site 17 hydrogeology involves three principal formations (listed from shallowest to deepest) and groundwater levels as follows:
    - Silty sand, alluvial clay and silt
    - Lean clay, interbedded sandy lean clay (~12-16 ft BGS, ~10-15 ft thick)
    - Fat Clay (~24-28 ft BGS)
    - Groundwater surface is variable, ranging from 0 ft BGS to 5 ft+ BGS
    - Groundwater flow direction is thought to be predominately southwest and toward the Potomac River.

1.2.2 Remedial Technology Implemented for ESTCP Evaluation

After baseline data collection by Aestus (i.e. between Phases I and II), GSI and its subcontractor installed 800 reaction columns ~2 feet apart in a triangular pattern to depths of ~30 feet BGS. Seven hundred (700) of the columns were filled with sand, oil, and ZVI and another 100 were filled with sand and oil only.

1.3 Aestus' Scope of Work

Aestus' scope of work for this project was to use subsurface imaging technology to scan the earth's subsurface (i.e., to depths of ~40 feet) at five transect locations selected jointly by GSI and Aestus. These transects were centered above the known contamination plume (see Figure PV-1) such that Aestus could perform Phase I Pre-Remedy and Phase II-IV Post-Remedy imaging of CVOC related impacts and effects of the remedy on the subsurface.

Phases I, II, and IV were originally planned for when Aestus and GSI developed the scope of work for this project. Aestus (in consultation with GSI) added/inserted Phase III (at Aestus' expense) with the intention of better documenting the effects of the reaction columns and enhance site characterization knowledge. The phases of work are described in more detail below:

- Phase 1 was designed to obtain baseline electrical images of the site prior to the implementation of the remedy
- Phases II-IV were subsequently compared to the baseline images and temporal images were developed to display the electrical changes between Phases I, II, III, and IV to enable interpreting and visualizing the remedy effect

The electrode spacing, end electrode survey coordinates, and resulting survey line length and imaging depth at North Site 17 are shown in the legend on Figure PV-1 and are also listed in Table 1. The distance along each survey line from Electrode 1 to 28 (or 56) is provided in Tables 2 through 4.

Figure PV-1 also shows the location and orientation (i.e., the green ends of the survey lines represent Electrode 1 and the red ends represent Electrode 28) of the temporal surveys performed at North Site 17. As shown in Figure PV-1, Lines IND-01 and IND-02 extend north-northeast from the Mattawoman Creek and the Lines IND-03 and IND-04 extend west from the Mattawoman Creek with intersections centered above the plume. IND-05 is approximately co-located along IND-03, centered above the plume with a smaller electrode spacing to provide a shallower, higher resolution image of the plume/remedy area.

Although not part of the original work scope for this ESTCP project, Aestus added a static (non-temporal) 56 electrode survey line (IND-06) during Phase III that was located parallel to and in between survey lines IND-01 and IND-02. This static image was performed in an attempt to image the presence of the in-situ reaction columns since the other temporal transect lines were specifically placed such that they would not be spatially coincident with the vertical remediation columns (i.e., to avoid damage to Aestus' dedicated electrode cables during column installation). Figure 16 shows the layout of the electrode cables used for temporal imaging relative to the location of the vertical reaction columns which were installed after cable burial and away from the cables to avoid damaging them.

Aestus used a robotic total station and/or RTK GPS land survey equipment to establish North Site 17 control points with known coordinate system and datum, and subsequently land survey the as-built locations of the GeoTrax Survey LTM™ lines (i.e., buried electrode cables). The imaging data were integrated with historical drilling and other site data in 2D (report figures) and 3D (visualization model) to inform data interpretation of the electrical imagery.

1.4 Project Schedule

The nature of temporal monitoring work required multiple mobilizations by Aestus to perform the following field data acquisition events along the same exact transect line locations:

1. **Phase I:** Pre-Remedy; underground cable installation; acquire baseline images (July 2017)
2. **Phase II:** 1 Month Post-Remedy**;** track subsurface changes as a result of reaction column installation (September 2017)
3. **Phase III:** 6 Months Post-Remedy; track subsurface changes as a result of reaction column installation (February 2018; Phase added by Aestus, courtesy of Aestus)
4. **Phase IV:** 1 Year Post-Remedy; track subsurface changes as a result of reaction column installation (August 2018)

A detailed timeline for project work completed to date is shown below:

- **April 4, 2017**: Discuss and agree upon project objectives and goals (Project Team)
- **May 24, 2017**: Aestus submits final proposal to GSI
- **July 18-21, 2017**: Phase I data acquisition field work (Aestus)
- **July 27-Aug. 15, 2017**: Installation of reaction columns (GSI)
- **Sept. 5, 2017**: Phase I Interim Report submitted (Aestus, presented to Project Team)
- **Sept. 18-19, 2017**: Phase II data acquisition (Aestus)
- **Oct. 17, 2017**: Phase II Interim Report submitted (Aestus, presented to Project Team)
- **Feb. 14-15, 2018**: Phase III data acquisition (Aestus)
- **Aug. 3, 2018**: Discussion on upcoming sampling and field work (Project Team)
- **Aug. 7, 2018**: Phase IV data acquisition (Aestus)
- **Feb. 6, 2019**: Discussion on GeoTrax Survey and sampling results (Project Team)
- **September 30, 2019:** Final Report submitted to GSI by Aestus

2.0 METHODOLOGY

This section provides an overview of the technology used and a general description of the data acquisition, data processing and interpretation processes, with special reference to features and activities specific to the North Site 17 project.

2.1 GeoTrax Survey™ Technology Overview

Aestus uses a non-intrusive proprietary form of electrical resistivity imaging (ERI) technology to scan the subsurface of environmentally impacted sites for a variety of anomalies, including those associated with dense and light non-aqueous phase liquids (DNAPLs/LNAPLs) and related dissolved phase contamination. This technology has been successfully used for a number of other applications including mapping geology, locating other subsurface environmental impacts, leaking pipelines, buried tanks, landfill and burial pit boundaries, and the presence or absence of contaminant transport channels/preferential migration pathways. The use of this technology for temporal monitoring is discussed in more detail below in Section 2.2.

Electrical resistivity measurements have been used since the 1830's to interpret the earth. Electrical resistivity imaging (ERI) works by imparting an electrical current into the ground, and then measuring voltage at one or more other locations along a straight survey line/transect. Based on these data, the apparent resistivity of subsurface materials is calculated using Ohm's Law. These measurements are then inverted to provide measurements of model resistivity or true resistivity at regular points. For this report, these data will be referred to as resistivity data or electrical resistivity data.

Similar to a single pixel in a digital photo, a single resistivity measurement does not yield significant information. However, modern ERI acquisition instruments combined with modern computer processing speeds facilitate hundreds or thousands of resistivity measurements in a short timeframe. These measurements are performed along a survey alignment and are subsequently used to produce a two-dimensional (2-D) electrical image (analogous to a CAT-scan in the medical industry) of the subsurface that graphically illustrates the presence or absence of subsurface anomalies and provides quantitative measurements of the subsurface resistivity. The 2-D continuous images help minimize interpolation between 1-D data points such as soil borings or wells, and assist in confirming or redefining conceptual site models.

Aestus' technology is based on conventional electrical resistivity imaging (ERI) techniques developed decades ago in its original form. However, Aestus worked with Oklahoma State University (OSU) to vastly improve the core technology specifically for use in the environmental industry. Aestus is currently the sole worldwide licensee of trade secret intellectual property from OSU which provides proprietary data collection algorithms and processing software to achieve higher data quality and ultimately increased image quality, relative to standard ERI approaches. The higher sensitivity provided by GeoTrax Survey™ is required to adequately image complex environmental sites and perform temporal imaging (GeoTrax Survey LTM™) to detect subsurface changes via temporal long-term monitoring. Aestus collects its data using established quality assurance and quality control (QA/QC) protocols as discussed in Section 4.0 of this report.

2.2 GeoTrax Survey LTM™ Used for Electrical Temporal Monitoring

Aestus' imaging technology has been used successfully on other sites to perform monitoring of results from in-situ chemical oxidation methods. Temporal monitoring allows Aestus to perform a "differencing" analysis on pre- and post-remediation subsurface image data to effectively visualize effects of remediation efforts intended to cause chemical and/or biochemical reactions in the subsurface (i.e., highlight zones of the subsurface that have changed electrical signatures due to remediation efforts).

In Aestus' experience, increased biological activity is usually seen as an electrically conductive change in the subsurface, whereas injectates can produce either electrically conductive or resistive changes depending upon the interaction with groundwater and amount of precipitation. Aestus has observed the presence of ZVI in the subsurface causing electrically conductive changes in the short term on another project. The magnitude and direction (i.e. more electrically conductive or more resistive) of electrical resistivity changes in Aestus' image data varies depending on the time elapsed between images, interactions with groundwater, and additional environmental factors.

This temporal monitoring process is more robust than standard site characterization work using this technology and is more schedule, labor, and equipment-intensive as electrode cables must remain in place (undisturbed) for the duration of the monitoring project, and additional data acquisition, processing, and interpretation time is required. Multiple mobilizations are also required for certain projects.

2.3 Technology Limitations

As with any technology, GeoTrax Survey LTM™ has some limitations which are detailed below. This discussion is included for completeness relative to educating the reader on this technology. For North Site 17, the only limitation encountered of those mentioned below was that interpretation certainty could be strengthened by performing additional confirmation drilling. However, confirmation drilling was not scoped or originally deemed necessary for this project (see further discussion in Section 2.3.4). Additionally, two of the buried electrode cables sustained some damage presumably during installation of vertical treatment columns during very muddy and soft soil conditions (see Section 6.1 for additional discussion), but data integrity was not significantly compromised.

2.3.1 Metallic Interference

If imaging is performed overtop of an extensive grounding grid (such as is sometimes found at electrical substations for instance), this metallic grid can effectively blank out survey images. In addition, when surveying immediately adjacent and parallel to buried metallic pipelines; some degree of interference may be experienced to metallic interference. Aestus attempts to maintain a 15-foot (4.6 m) buffer zone rule when surveying parallel to metallic pipelines. Under certain conditions (e.g., geology dependent, etc.), Aestus can successfully image within the 15-foot (4.6 m) buffer zone.

Historically, Aestus has been able to achieve project objectives by selectively working around known buried pipeline locations to achieve high quality survey images and avoid interference from buried metallic pipelines. Should a survey be performed perpendicular to a buried metallic pipeline, the pipe sometimes shows up in the image as a conductive anomaly and can cause a narrow conductive shadow to the bottom of the survey image. In this situation, the survey image on either side of the pipeline location is intact with good data quality.

2.3.2 Comparison of Electrical Imagery to Analytical Data Is Required

Most environmental sites on which Aestus acquires data have regulatory drivers which are chemical concentration based (i.e., not based on electrical resistivity levels) and upon which project decisions are made. Because Aestus' imaging technology is not a quantitative analytical chemical sampling tool, it does not immediately identify or quantify the chemical, geological, and biological (i.e., level of ongoing bioactivity) composition of anomalies detected. Therefore, comparison of electrical resistivity signatures to soil boring and monitoring well data is a required part of Aestus' process to allow the electrical imagery to accurately reflect and predictive regarding relevant subsurface conditions.

Therefore, Aestus employs its GeoTrax Viz™ data integration process to integrate historical and follow-up confirmation drilling data with its 2-D images and 3D visualization model. This process allows Aestus to use these other lines of evidence to effectively compare and "calibrate" the electrical resistivity signatures back to the subsurface features of interest to its clients, such as physical (geology signatures), chemical (contamination presence/absence and relative concentration), and biological signatures (indicating potential presence/absence of bioactivity). The data integrated for comparison and interpretation purposes typically includes but is not limited to boring logs, analytical sample data, and fluid level measurements and are presented in conjunction with Aestus' GeoTrax Survey™ images.

Aestus is often successful at developing a semi-quantitative relationship between subsurface resistivity values and concentrations of contaminants. The relative conductivity of common signals, in order from least electrically conductive (most resistive) to most electrically conductive (least resistive) is as follows: non-aqueous phase liquids, aqueous phase contaminants, soil/rock, salt water, and bioactivity. As the site complexity increases with multiple signals present from bioactivity, remediation attempts, and the other potential signals listed below, developing these semi-quantitative relationships become more challenging.

1. Soil and rocks (geology/lithology)
2. Groundwater (quality/chemistry)
3. Presence of contamination (e.g., NAPLs, aqueous phase impacts, etc.)
4. Remedial action fluids and/or their effects (e.g., injectates or chemistry/biochemistry shifts which occur as a result of remediation)
5. Biological activity (biomass and related groundwater chemistry shifts)
6. Effects of metallic utility lines

The above item Nos. 3, 4, 5, and 6 can often partially or fully "overprint" signatures of underlying geology. Typically, contaminants are directly detected when present in the range of 1-10 ppm. At concentrations lower than that, the hydrogeologic structures and/or bioactivity are the dominant signals. This "overprinting" that can occur is normally acceptable because identifying contamination and issues related to remedial attempts and presence/absence of bioactivity are typically project objectives. The drilling data helps constrain the geological contacts and variability. Aestus' robust data integration process helps parse out issues of interest relative to project objectives.

2.3.3 Special Considerations for Temporal Monitoring

When performing GeoTrax Survey LTM™ of remediation effects, Aestus' experience is that it is important to use dedicated electrode stakes and/or cables that do not move between pre- and post-remediation imaging. Additionally it is important to minimize the duration of time between imaging to avoid other subsurface changes over time showing up in the differenced images designed to show chemical reactions as the only subsurface change over time between the imaging events.

2.3.4 Confirmation Drilling Typically Required

Once "calibrated" to the subject site, the GeoTrax Survey™ images are normally a very powerful tool to accurately predict locations and oftentimes relative concentrations (and/or NAPL saturation) of contamination in subsurface soils. In cases when Aestus' images show subsurface features/anomalies which are not part of the existing site conceptual model, additional confirmation boring data may be required to correctly redefine the site conceptual model. Additional confirmation borings, should they be required, are limited in number because the imagery provides specific drilling targets and therefore facilitate a very focused confirmation drilling program.

2.4 Geophysical Survey Data Acquisition Activities at North Site 17

Five temporal survey transects were installed at North Site 17 during Phase I (July 2017) for Phase I-IV data acquisition. Dedicated (i.e. left in place between imaging events) electrode cables with stainless steel "takeouts" were utilized so that these exact electrode positions were retained for subsequent Phase II (September 2017), Phase III (February 2018), and Phase IV (August 2018) data acquisition. Aestus has empirically determined that not moving the electrodes between imaging events facilitates higher-precision "difference" numerical processing that is used to develop the temporal imagery which shows percent change in resistivity between imaging events.

Aestus also conducted a sixth static (i.e., non-temporal) 56 electrode survey (IND-06) during Phase III to address GSI's inquiry concerning Aestus' potential ability to directly image the installed reaction columns, because the other temporal transect lines were specifically placed such that they would not be spatially coincident with the vertical remediation columns (i.e., to avoid damage to Aestus' dedicated electrode cables during column installation).

Surveys IND-01 through IND-04 were performed with 28 equally-spaced electrodes placed at 2.25 meter electrode spacing (see line layout on Figure PV-1). This yielded a total line length of ~200 feet (~61 meters), a total survey depth of ~40 feet (~12 m), and a vertical and horizontal resolution of ~1.125 m. The fifth temporal line, IND-05, was co-located with IND-03 and centered between lines IND-01 and IND-02 with 28 equally-spaced electrodes placed 0.5 meters apart for a total line length of ~44 feet (~13.5 meters),a total survey depth of ~9 feet (~2.7 meters), and a vertical and horizontal resolution of ~0.25 m.

The sixth survey, IND-06, was performed during Phase III using 56 equally-spaced electrodes placed 1.25 meters apart to yield a total survey length of ~226 feet (~68.75 meters),a total survey depth of ~45 feet (~13.75 meters), and a vertical and horizontal resolution of ~0.625 m.

Aestus personnel collected field notes (see Appendix F) of site features (e.g. Mattawoman Creek and monitoring well locations) proximate to electrode locations. Additionally, site features and electrode geospatial locations (including elevation data) were land surveyed by Aestus personnel to properly position site data into Aestus' GeoTrax Viz™ three-dimensional (3D) visualization model. The electrode elevation data were also utilized as topographic correction for the geophysical data processing for each survey image.

2.5 Standard Aestus Data Processing

Once data collection is completed, raw data files collected by the SuperSting R8 earth resistivity meter were transferred to the Aestus field laptop for an initial QC review to verify proper data collection. The raw data files were then transferred to Aestus' home office staff for topographic correction and full data processing. Topographic correction for each data file was achieved by creating a terrain file with the distance in meters to each land surveyed electrode along with the elevation of each land surveyed electrode in meters (land survey data collected by Aestus field crew using a Topcon total station). The topographically-corrected data files are then processed using numerical modelling inversion software and other Aestus developed post-processing software to convert raw apparent resistivity data into an inverted subsurface electrical resistivity image of the subsurface). The data are trimmed to remove faulty data points and inversions are run until the difference in RMS error between inversions is <1%.

2.6 Temporal Differencing Aestus Data Processing

In-situ monitoring of remedy effects is accomplished by performing several temporal "differencing" analyses on GeoTrax Survey™ data sets to determine subsurface electrical resistivity changes (in percent difference in conductivity) between different time periods and can be divided into three categories of differencing images:

1. **QA/QC Differencing:** Differences between subsurface image data over a short time period on surveys performed during the same phase on the same line to ensure high quality data collection.
2. **Single-Period Differencing:** Differencing of subsurface image data over sequential phases (i.e. Phase I to II, Phase II to III, and Phase III to IV).
3. **Long-Term Differencing:** Differencing between Phase IV (1 year post-remedy) and Phase I (pre-remedy/background) subsurface image data to see long-term remedy effects/data trends.

These analyses allow Aestus to effectively visualize distribution of contaminants and the effects of the reaction wells (i.e., highlight zones of the subsurface that have changed electrical signatures due to the installation of the reaction wells).

2.6.1 Historical Data Integration onto 2-D Subsurface Images

Aestus reviewed available Site 17 data provided by GSI, and used its GeoTrax Viz™ process to incorporate the following historical site characterization data onto 2-D survey images as shown in the Figures section of this report:

- Site features from field notes generated by Aestus' field crew
- Monitoring well construction
- Boring log data
- PID data from soil borings
- Groundwater analytical data
- Groundwater quality parameter data
- Groundwater level data
- Reaction column locations and composition

It is important to understand that not all of these data sets integrated into 2-D are exactly aligned temporally and/or spatially and interpretations of integrated data should account for this issue.

2.6.2 Historical & Subsurface Image Data Integration into 3D

To assist ourselves and Aestus' clients' with visualizing the subsurface images as they relate to one another, Aestus used data collected from its 2-D imaging process to generate a 3D representation of these data in the subsurface of North Site 17. Aestus and its clients typically find that the results of the 3D visualization work are very helpful in providing a more complete and somewhat simplified understanding of the survey data/images, ultimately yielding a better understanding of subsurface issues at a given site. The 3D visualizations are also very useful in explaining site conceptual models and features to both technical and non-technical stakeholders.

To allow viewing of Aestus' survey images to scale in 3D space, Aestus developed a technique to import and properly position and scale the survey images in 3D drawing space and relative to the site base map using Rockworks™ 3D visualization software. Although the perspective 3D views resulting from these efforts are based on 2-D data sets (i.e., the individual electrical resistivity image data was not collected in 3D during the survey work), Aestus has a higher confidence in its approach relative to the conventional approach of using only 1-D monitoring well data points and the resulting interpolations between these discrete points.

For Aestus' 3D visualization work, thousands of field data points (collected in 2-D) were used as input to develop the 3D perspective views. Other data imported into Aestus' 3D model for North Site 17 include but are not limited to the following:

- Transect locations and identification labels
- Vertical GeoTrax Survey™ 2-D subsurface images
- Vertical GeoTrax Survey LTM™ temporal images

- Horizontal elevation slices (interpolated GeoTrax Survey™ data at specific depths)
- Site monitoring wells
- Site reaction column locations
- Aerial photo(s)
- Various site maps (provided by Aestus' client)
- Utility information
- Groundwater level data
- Analytical data and field parameter data from groundwater samples

It is important to understand that not all of these data sets integrated into 3D are exactly aligned temporally and/or spatially and interpretations of integrated data should be account for this issue.

Because the 3D visualization work performed by Aestus was extensive and many different views of these data can be generated using this tool, it is not practical to provide all of these views as part of the hardcopy report. However, Aestus is providing a copy of its 3D model files for viewing by Aestus' client personnel using Rockworks™ software. These data and instructions on downloading and using the free viewer software are contained in Electronic Appendix H to this report.

To further aid in client and Aestus understanding of subsurface conditions, Aestus uses a color scheme for the resistivity data that is customized to the site.

2.6.3 Development of Site-Specific Custom Color Contouring Scheme

Upon completion of the data processing work discussed in Section 2.5 of this report, the resistivity data set is fixed and is not modified from that point forward. However, Aestus does modify the color contouring scheme(s) used to effectively contour these data (i.e., show various ranges of resistivity detected at the site using different colors) to allow Aestus and its clients to understand what the data means relative to properties of the subsurface that are of foremost interest to Aestus' clients (i.e., contaminant distribution, geology, presence of biological activity, etc.). The color modification process is similar to re-contouring a topographic map (i.e., the elevation points never change, but the contour interval is altered to produce different maps highlighting various features or ranges of resistivity). The regular electrical GeoTrax Survey™ images and the temporal GeoTrax Survey LTM™ images are displayed with specific custom color schemes.

For the North Site 17 project, the custom color contouring schemes used for static imagery is shown on the figures contained in Appendix B and is consistent through all of the static images contained in this report. The color contouring scheme developed for temporal differenced imagery is shown on Figure 2 (and also on the figures contained in Appendix C) and is consistent through all of the temporal images contained in this report.

2.6.4 Discussion of Multiple Color Schemes in 3D

On some sites, Aestus finds that it is helpful to isolate certain resistivity ranges to more easily explain certain interpretations of subsurface features. As discussed in Section 2.5, the data is never modified once it is processed; only color contours representing electrical resistivity ranges are changed. Typical color contouring schemes shown in the 3D visualization model are described below:

1. **Custom Site-Specific Color Scheme:** This color scheme highlights both the low end (i.e., highly conductive end) of the resistivity scale to highlight resistive anomalous zones detected.
2. **Statistical Color Scheme:** This color scheme assigns each of 20 ranges of resistivity (i.e., "bins") a unique color; the resistivity ranges are determined statistically and includes 5% of the data points in each "bin". A spectrum of cool (purple) to warm (red) colors is used.
3. **High Resistivity Only Range**: Color contouring scheme highlighting relatively higher resistivity anomalous zones. This color scheme focuses on the high end of the resistivity scale to highlight resistivity anomalies.
4. **Low Resistivity (High Conductivity) Only Range:** Color contouring scheme highlighting low resistivity anomalous zones. This color scheme focuses on the low end of the resistivity scale (i.e., conductive end) to highlight conductive anomalies.
5. **Custom Temporal Imagery Color Scheme:** The 3D visualization model may also contain one or more custom site specific color scheme developed to highlight specific electrical ranges (static imagery) and/or specific electrical changes between temporal data sets.

3.0 EQUIPMENT USED

Aestus LLC used the following geophysical and project support equipment imaging field work at North Site 17:

Type	Manufacturer	Use
Supersting R8IP	Advanced Geosciences, Inc.; 2121 Geoscience Dr., Austin, TX 78726, USA	Earth Resistivity Meter; ERI data acquisition
Supersting R8IP	Same as above	Backup instrument
AGI Switchbox 56	Same as above	Resistivity data acquisition
AGI Switchbox 56	Same as above	Backup instrument
Topcon Robotic Total Station and Hiper SR RTK GPS Units	Topcon Positioning Systems, Inc., 400 National Drive, Livermore, CA 94550, USA	Geospatial data acquisition
Electrode Cables	Advanced Geosciences, Inc.; 2121 Geoscience Dr., Austin, TX 78726, USA and/or Proseismic; 5291 Langfield Rd, Houston, TX 77040	Resistivity data acquisition
Traffic Cones	Various	Traffic control
Traffic Ramps	Yellow Jacket Cable Protectors; 2350 East Central Ave. Durante, CA 91010	Protect cables in road crossings
Rotary Hammer	Bosch	Drill holes for electrode stakes in concrete/asphalt
Equipment Trailer	Wells Cargo	Equipment mobilization/storage

4.0 QUALITY CONTROL

Aestus is focused on delivering a work product based on high quality data. For this North Site 17 project, understanding contaminant distribution and any reactions as a result of the vertical column remedy in the subsurface as it relates to updating the overall conceptual site model (CSM), is dependent upon accurate geophysical data. This section discusses the various QA/QC protocols, tests, and data files collected to verify that data of acceptable quality was collected from the site. Three sets of QA/QC protocols pertaining to different steps in the data collection were applied:

1. Instrument QC tests
2. Dedicated Electrode Cable Installation QC Tests
3. Imaging QC Check

The results of the below mentioned QC tests indicated that instruments were functioning properly during data collection for this project. The only exception was lost connection to a few electrodes as discussed in subsequent sections of this report. However, this issue did not render the overall data as poor quality or unusable.

4.1 Instrument Quality Control (QC) Tests

To verify GeoTrax Survey LTM™ data is accurate and collected in accordance with industry standard levels of care, Aestus utilizes four QC tests recommended by the manufacturer of the geophysical survey instrumentation (i.e., Advanced Geosciences, Inc.), prior to data collection in the field. The below QC tests are run at the beginning of each work day. If any issues with the equipment are discovered during any one of the tests, Aestus' backup equipment is used and compromised instruments are sent to the manufacture for diagnostics and repair. Each of the QC tests is discussed in detail below.

4.1.1 Receiver Test

The Receiver Test verifies that the geophysical equipment is functioning properly by utilizing a test box with a known resistance to verify all of the SuperSting R8 receivers are working correctly. A Receiver Test is completed at the start of each day and as needed should troubleshooting become necessary during the work day.

4.1.2 Switchbox Relay Test

The switchbox contains two relays per electrode. The Switchbox Relay Test ensures both relays for each electrode are functioning properly. A Switchbox Relay Test is completed at the start of each day and as needed should troubleshooting become necessary during the work day.

4.1.3 Cable Test

The switchbox also has two multiplexers per electrode to set that electrode as P1-P9. The cable test goes through and sets each P line and verifies each mux connection is solid for every electrode. A Cable Test is completed at the start of each day and as needed should troubleshooting become necessary during the work day.

4.2 Dedicated Electrode Cable Installation Quality Control (QC) Tests

To allow the cables to remain in-situ throughout the entire duration of the project (i.e. not be removed in between phases), the cables were buried in shallow trenches with PVC “stick-ups” located at one end of the electrode cable to serve as connection points to the buried cables and to provide a visual cue for the cable location.

The Contact Resistance Test was run following cable installation in each trench and prior to backfill activities to verify each electrode had good electrical contact with the earth. Bentonite and water were mixed to form a roughly 12-inch diameter and 2 inch thick electrically conductive zones in which each respective electrode was placed to promote improved electrical contact with surrounding soils and native backfill materials.

The Contact Resistance Test was then run to verify each electrode along the trenched-in cable had good electrical contact with the earth. This test measures the resistance between each electrode, starting with Electrodes 1 and 2, then 2 and 3, and so on until the last pair of Electrodes 27 and 28 are tested. Poor connections between the ground and electrode cable can be identified in this manner.

This procedure was performed following backfill of the trench and also before each data set was collected at the various field data acquisition dates discussed above. Aestus’ standard goal is to achieve contact resistance values at each electrode at an acceptable level (typically < 2,000 Ohms as Aestus’ goal, although this can be site dependent based on soil type, moisture content, etc.).

4.3 Imaging Precision Quality Control (QC) Check

To confidently compare a Phase IV to a Phase I image, Aestus verified that the collected data and resulting image from each phase was an accurate representation of that time period by performing an image quality control check. Specifically, Aestus collected two data files along each line during both Phases I and IV then produced a differenced image of the two surveys and analyzed the results. To be considered representative of the phase, Aestus’ criteria was that there ideally should be no more than a 10% change in subsurface resistivity over the short (i.e., ~same day) time frame. Results of these analyses are discussed in Section 6.2 and on Figure 9.

5.0 RESULTING DATA SETS

Aestus' geophysical survey work yielded high quality/high resolution two-dimensional (2-D) static (i.e., one point in time) electrical resistivity images of the subsurface at North Site 17 from locations shown on Figure PV-1. This static image data was post-processed to create differenced temporal imagery in the following three categories:

1. QA/QC Temporal Images (each survey line during Phases I and IV)
2. Single-Period Temporal Images (differencing for each survey line from Phases I to II, II to III, and III to IV)
3. Long-Term Temporal Images (differencing for each survey line from Phase I to IV)

Additionally, during Aestus' data interpretation process, historical site data were integrated with the various image data sets. Finally, temporal data sets were graphically compared and contrasted.

The abovementioned work resulted in numerous graphical data sets for this project. Therefore, Aestus has placed some of this supporting data in Appendices for reference by the reader if needed. Specifically, the graphical data results are found at these locations within this report and are explained further below:

- Figures 1 through 16: Survey Locations, Interpretive Data, Select Site Photos
- Appendix A GeoTrax Survey LTM™ Data Quality Assessment
- Appendix B Static GeoTrax Survey™ Imagery (All Surveys from Phases I to IV)
- Appendix C Temporal GeoTrax Survey LTM™ Imagery
- Appendix D GeoTrax Viz™ Data Integration - Geology Data
- Appendix E GeoTrax Viz™ Data Integration - Chemistry Data
- Appendix F Aestus Field Notes
- Appendix G 3D Model and Free Viewer (Electronic Data Transfer)
- Appendix H: Site Photos (Electronic Data Transfer)
- Appendix I-1 Phase I - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)
- Appendix I-2 Phase II - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)
- Appendix I-3 Phase III - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)
- Appendix I-4 Phase IV - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)

Temporal QA/QC images for each line performed during Phases I and IV are contained in Appendix A and both the single-period and long-term temporal images are provided in Appendix C. All temporal differenced imagery is plotted in percent change in conductivity (i.e., inverse of resistivity) and a single color contouring scheme was used to show percent change in the various temporal imagery.

The final 2-D static imagery for Phases I, II, III, and IV are contained in Appendix B and in one custom (site specific) color contouring scheme as discussed above in Section 2.6.3 (Development of Site Specific Color Contouring Scheme) of this report.

Site geology and groundwater chemistry data were integrated during Aestus' interpretation process and are contained in Appendices D and E, respectively. Historical site data (provided by GSI) and Aestus' field note data (see Appendix F) were also integrated into Aestus' 3D visualization model which is provided electronically for reference as Appendix G.

Select site photos taken during Aestus' field work are shown in Figure 17 and the entire set of photos is provided as Electronic Appendix H.

The "XYZR" data output files containing geo-referenced (i.e., X, Y, and Z coordinate data) resistivity (R) data sets were used to color contour the abovementioned survey images and are provided as Appendices I-1 through I-4 of this report (i.e., for Phases I through IV respectively as listed above)

Aestus' interpretations and conclusions from interpretation of the abovementioned data sets are discussed in the following section of this report.

6.0 CONCLUSIONS

All of the imaging data collected during this project was useful data met Aestus' quality standards for temporal monitoring with exceptions discussed below. Aestus' GeoTrax Survey LTM™ technology achieved the project objectives of mapping the lateral and vertical distribution of contamination in the subsurface and tracking the effects of the reaction columns during the time span of this project. Aestus understands from GSI that actual reaction column maximum effectiveness is predicted to take longer than the originally scoped schedule for geophysical temporal monitoring of remedial effectiveness. Discussions of specific conclusions in these three categories follow:

1. Data Quality Using Buried Electrode Cables
2. Pre-Remedy Site Characterization
3. Post Remedy Imaging

6.1 Data Quality Using Buried Electrode Cables

Part of the evaluation of Aestus' data for this ESTCP research project relates to how well data could be collected over time using a dedicated buried electrode cable system versus standard temporary electrode stakes that are more prone to noise between temporal measurements. As discussed in Section 4.0 above, Aestus performed numerous quality control (QC) checks to promote high quality data acquisition. Conclusions from this research project are as follows:

- Overall, good results were achieved with the dedicated electrode cable installation and temporal monitoring. While some survey lines had noise or issues with electrode connectivity, there were still a sufficient number of dependable data points available to conduct a reliable interpretation of North Site 17.
- The stainless steel electrodes seemed to provide good quality data at a lower price point than graphite electrodes (which do not corrode in any environment over time) for this project duration and environment.
- There was no visual degradation of the buried electrode cable electrical end connectors (i.e., to which instrumentation is connected for temporal data collection) over the course of this roughly one year long project (relative to data acquisition events).
- Survey Lines IND-04 and IND-05 have the best data quality throughout all phases with minimal noisy data points and less than 3% difference on Cable QC images in Phases I and IV. These two lines can therefore be considered the most representative of the electrical changes on the site independent of instrumentation or cable installation. Despite some noisier data on the other lines, the results of IND-01, IND-02, and IND-03 still corroborate the changes seen on IND-04 and IND-05 and are considered usable data sets relative to achieving project objectives.
- Survey Lines IND-02 and IND-03 experienced data loss due to poor electrode connection during Phases II and III, but none during Phase I and IV when cable QC data recorded differences of less than 10 percent; differences between phases may be result of variability in soil moisture content over the course of the project. Overall, more than sufficient data were collected to allow reliable interpretation of IND-02 and IND-03.

- Limited failed electrodes (i.e. electrodes with no/poor connection with the surrounding soil) occurred during Phases II-IV on survey lines IND-01, IND-02, and IND-03, with IND-01 experiencing the greatest connectivity loss. Notably, only IND-01 had failed electrodes during Phase IV, indicating the connectivity with the ground improved for IND-02 and IND-03 after Phase III (likely due to increased moisture contents of soils zones surrounding the buried electrodes).
- Some noise is to be expected and overall the amount of noise observed did not inhibit successful generation of survey images. The noisiest data occurred along survey line IND-01; specifically, IND-01 had greater than 30% difference between the two repeat files during Phase IV data acquisition. While this is higher than the desired 10% maximum difference between same day/repeat data collections, the inconsistencies between repeat image events in Phase IV were greatest in the vicinity of the failed electrodes (see Figure A-1 in Appendix A) and the rest of the survey data were of satisfactory quality.
- The higher noise levels on IND-01 increased over time indicating that the primary cause was likely due to damage to the cable during vertical reaction columns (e.g. the construction equipment used to install reaction columns after the initial imaging event may have damaged the cable, particularly given the muddy and soft conditions encountered during remedial construction). The problematic electrodes were sequential, indicating it was not a random degradation issue.
- IND-01 is the least reliable data set for the reasons discussed above and in Table 5 and Figure 9, although it did not undergo sufficient data loss to warrant it being discounted entirely.
- Additional trouble-shooting and/or repair attempts for failed/noisy electrodes were not possible due to the buried nature of the cables. Specifically, a visual inspection or adding water/bentonite (i.e., as is typically done with temporary surface electrodes for static imaging) to increase contact could not occur because digging the cable up would disturb the ground (i.e., goal of temporal monitoring is not to disturb electrodes between imaging events) and possibly damage the cable further.

Table 5 provides a full summary of cable QC results and Figure 9 shows graphical comparison of results from Survey Lines IND-01 (unfavorable precision results) and IND-04's (favorable levels of precision). Cable QC images for all data sets collected during Phases I and IV are contained in Appendix A.

6.2 Pre-Remedy Site Characterization

Aestus' pre-remedy installation imaging event indicated the overall resistivity structure of the site (as correlated to geology and chemistry data provided by GSI) from historical drilling data was as follows:

- The site had resistivity values ranging from 4 to 1190 Ωm with the majority of the values <100 Ωm
- Resulting images are generally more conductive (~0-25 Ωm on this site) where the materials are finer grained; conversely, resistive signatures (>~25 Ωm) primarily represent sandier/drier subsurface conditions

- There are highly resistive (>100 Ωm) areas under the hills to the west as shown on west edges of Survey Lines IND-03 and IND-04, see Figures 1 and 3.
- Resistivity changes correlate well with geology; horizontal trends are seen at clay boundaries and along the dip in beds (that corresponds with topography); these changes are viewable in the imagery and were confirmed with drilling data; see IND-04 on Figure 10 and all lines in Appendix D.
- The contamination appears to correlate spatially with mid-range resistive zones (see Figure 3); the contamination plume has similar resistivity vertically and the survey images confirm the historical lateral plume extent.
- The resistive anomaly is visible on Survey Line IND-04 in the treatment zone, see Figure 5, and resistive zones are generally spatially coincident with the historical contamination plume (see Figure 3); as expected based on Aestus' experience at CVOC sites; extremely high resistivity values are not present in the images for this dominantly TCE plume, as are typically observed for less soluble impacts such as PCE.

6.3 Post Remedy Imaging

As discussed in Section 4.0 above, the imaging data collected during this project generally met Aestus' quality standards for temporal monitoring (note: with the exception of data from survey line IND-01 that was likely compromised by cable damage inadvertently caused during remedial construction). This section discusses the results of temporal post remedy imaging as well as the single static image that was performed to test whether GeoTrax Survey™ would discern the installed reaction columns.

6.3.1 Temporal Post Remedy Imaging Results

Overall, very few changes were detected within the reaction column zone through Phase IV temporal monitoring. Both imaging and monitoring well data indicate the most pronounced electrical imagery changes occurred outside of the remedy treatment area (see Figures 2 and 4) for reasons that are unknown, and for which further investigation of this issue was outside the scope of this project. More time may be required with this remedial approach to induce changes outside the reaction columns themselves as could be expected given the typical timelines when using diffusion controlled mechanisms (see Figure 16). Discussions of specific conclusions follow:

- Groundwater chemistry data mirror the temporal imaging results as they also do not indicate significant changes within the remedy area; see Figures 12-15 for ORP and EC data in the shallow and deeper subsurface.
- There was a general increase in fluid electrical conductivity (EC) in the shallow subsurface and a general decrease in conductivity in the deeper subsurface (~ -2 to -5 feet AMSL); see Figures 14 and 15, respectively, for groundwater EC (as provided by GSI).
- In the remedy area, very little changed from Phase I to II, there was a large change from Phase II to III where the shallow subsurface became much more resistive (~20-100% more resistive in the top ~15 feet BGS), but between Phases III and IV the same area became more conductive (up to ~70%); see Figures 6 and 8.

- Overall, there was very little change between Phases I and IV with an overall increase in conductivity (~30-70%) in the top 10 ft BGS and increase in resistivity (~20-70%) below the conductive layer; see Figures 5 and 7.
- The resistive zone in the deeper portions (~-10 ft AMSL) of Survey Line IND-04 became more resistive over time (i.e., Phase I through Phase IV); see Figure 5, potentially due to a loss of porosity or a small decrease in fluid EC.
- The boundaries in resistivity changes seem to align with geological boundaries as larger electrical changes are seen above the bottom of the upper silt layer (e.g., see blue colored zones in IND-05 temporal image which indicate increased electrical conductivity from Phase I to Phase IV), which are likely based on fluid changes such as increased moisture content (see next conclusion).
- The conductivity increase in Phase IV is likely due to changes in the water table over time in the shallow subsurface; it should be noted that the groundwater elevation was higher during Phase IV as compared to prior phases; see Figure 11.
- The shallow changes in resistivity are likely the effect of tidal influences on site groundwater levels and resulting small changes in fluid electrical conductivity (see left panel on Figure 4).
- The deeper changes in resistivity across the remedy area may be caused by potential porosity changes due to potential soil compaction from treatment column installation (see right panel on Figure 4)

6.3.2 Static Post Remedy Imaging Results

Although not an original objective of this ESTCP project, Aestus performed a static (i.e., single snapshot in time versus temporal imaging) GeoTrax Survey™ over the reaction treatment area to evaluate if any changes to resistivity were present and discernable, due to the installation of the reaction columns. The reaction columns were not aligned in a perfect grid and their exact locations (post-installation) were not known. Therefore Aestus suspected that the static image transect would likely cross some unknown subset of columns as it crossed the treatment area.

The resulting electrical resistivity data from survey line IND-06 (post-installation of treatment columns) were compared against resistivity data from survey line IND-04 (pre-installation of treatment columns). These two datasets were statistically evaluated using a "t-test" which is commonly used to compare the mean of two groups of samples and evaluate whether the means of the two sets of data are statistically significantly different from each other. The results of this statistical t-test were found to be statistically different. Specifically, the results of this comparison indicate that the installation of the treatment columns resulted in a statistically significant increase in resistivity from mean values of 31 ohm-m (pre-treatment) to 43 ohm-m (post-treatment).

This post-treatment electrical resistivity increase is interpreted as resulting primarily from significant amount of sand that was added to the domain during installation. Because changes in resistivity towards the more electrically conductive end of the spectrum were not observed, it appears that significant bioactivity likely did not occur prior to post-treatment imaging, and that the ZVI did not created a conductive electrical pathway through the imaging domain. The following support this conclusion:

- Per GSI: ~77,000 pounds (~39 tons) of ZVI were emplaced and the design mass ratio (ZVI: dry sandy soil) was 0.7% and a 0.7% change to the geologic material in the imaging domain may not have had an appreciable effect on overall electrical resistivity
- Sand and oil are typically electrically resistive signatures in Aestus' imagery and the addition of a significant amount of sand (and some oil) during installation of the vertical reaction columns may have overprinted any electrically conductive signature which may have otherwise been present from the ZVI
- Changes as a result of the redox reactions intended to be caused by the ZVI were probably most likely to be detected in this case, but might not have been given sufficient time to occur to produce an appreciable effect on the bulk resistivity of the subsurface
- GeoTrax Survey™ IND-06 appears to show more some unique results within the treatment zone (i.e., presence of vertically parsed mid-range resistive halos (~25-50 Ohm*m) in upper ~10 feet between monitoring wells MW12 and MW11; see Figure B6-III in Appendix B). Aestus experience is these type of signatures indicate that a lot of changes are occurring in a relatively small zone of the subsurface which mirrors the scenario of closely spaced reaction columns. However, it should be noted that these signatures do not extend to the full treatment column depth so this interpretation is not fully clear.

In summary, Aestus is uncertain as to whether GeoTrax Survey™ imaging technology can discern the presence of the remediation columns, particularly because 5 of 6 of the transect lines were intentionally not geospatially coincident with the column locations (see Figure 16 which shows the spatial disparity of the reaction columns and GeoTrax Survey™ line locations). Additionally, the 6th static only image that Aestus collected (i.e., transect line IND-06) was performed not knowing exactly where the columns were actually located.

To fully test the capability of imaging the installed reaction columns, Aestus would need to run a transect line directly over top of a line of the columns for which the exact geospatial locations were known. This test was not planned as part of this ESTCP project, but this capability could be properly evaluated at a later date if additional reaction columns were installed in a straight line which was marked in the field or land surveyed such that Aestus' imaging work could be performed directly over top of the installed line of reaction columns.

7.0 RECOMMENDATIONS

This section provides Aestus' recommendations moving forward, based on the results and conclusions developed from its work on the North Site 17 project.

7.1 3D Visualization Model Review

To be able to fully understand the static GeoTrax Survey™ imagery and temporal GeoTrax Survey LTM™ imagery and visualize it in a robust manner in 3D, the reader can use the provided free 3D visualization model viewer (see Appendix G) to view data more closely on-screen and from different perspectives. Screen captures from the 3D visualization model which are included in this report as figures, do not typically provide as complete of an understanding of the available site data. Additionally, the resolution of these hardcopy figures is lower than reviewing the model on a computer monitor screen.

7.2 Web Conference Review

Because this report discusses a complex site and multiple data sets encompassing thousands of field data points, Aestus believes that GSI (and potentially ESTCP) personnel may benefit from a web conference and/or in person meeting to further review this report together, field questions, and assist in conveying understanding of conclusions based on this work. Aestus would be pleased to organize and attend and contribute to such a meeting if deemed helpful by GSI.

7.3 Potential Follow-up Confirmation Drilling

While not originally anticipated as part of this injection monitoring project scope of work, should GSI desire to more fully understand the cause of potentially anomalous zones detected by Aestus that exist in areas without proximate monitoring well data, targeted confirmation drilling and sampling would provide more certainty relative to data interpretations provided in this report.

7.4 Further Evaluation of Groundwater Chemistry Changes

Fluid electrical conductivity changes, as discussed in Section 6.3 above, could be a result of groundwater/surface water mixing in alluvial systems causing shifts in groundwater EC. This could be tested by installing an EC transducer in a shallow monitoring well after a rain event.

7.5 Additional Temporal Imaging

As discussed in Section 6.0 above, the temporal imaging and chemistry data indicate that one year might not have been sufficient time for significant chemical reactions to occur as a result of the reaction column installation. Additional/continued periodic temporal monitoring may provide additional insights to the effectiveness of this experimental remedial approach, if the reaction rate of the remedy with the contamination is longer than the roughly one-year study period for this ESTCP research project.

8.0 STATEMENT OF REPORT LIMITATIONS AND ASSUMPTIONS

8.1 Purpose of Report

Aestus understands this Report is to be used for the purpose described in the project objectives section of the Report. This stated purpose has been a significant factor in determining the work scope and level of services provided for in the Agreement. Should the purpose for which the Report is to be used, or the proposed use of the site(s) change, this Report may no longer be valid, and use of this Report by GSI or others without Aestus' review and written authorization shall be at the user's sole risk. Should Aestus be required to review the Report more than three (3) months after its date of submission, Aestus shall be entitled to additional compensation at then existing rates or such other terms as agreed between Aestus and GSI.

8.2 Use of Report

The work is prepared for the sole and exclusive benefit of GSI and Aestus accepts no liability for decisions made based on the information presented herein. The contents of this report may not be modified, in whole or in part, without the prior written approval of Aestus. The report may not be distributed, disclosed in any form to, used by, or relied upon by any third party without the prior written consent of Aestus.

8.3 Scope of Services

The conclusions described in this Report are based solely on the Scope of Services provided pursuant to the Agreement between Client and Aestus and summarized in the introduction of this Report. Aestus has not performed any additional observations, investigations, studies, or testing not specifically stated therein. Aestus shall not be liable for the existence of any condition, the discovery of which required the performance of services not authorized under the Agreement.

8.4 Time

The passage of time may result in changes in technology, economic conditions, site variations, or regulatory provisions which would render the Report inaccurate. Accordingly, neither the Client, nor any other party, shall rely on the information or conclusions contained in this Report after three (3) months from its date of submission without the express written consent of Aestus. Reliance on the Report after such period of time shall be at the user's sole risk. Should Aestus be required to review the Report after three (3) months from its date of submission, Aestus shall be entitled to additional compensation at then existing rates or such other rates as may be agreed upon between Aestus and the Client.

8.5 Preliminary or Interim Stage Findings and Submittals

The following limitation is applicable if this report is stamped “DRAFT”, “INTERIM”, and/or otherwise identified as preliminary:

Aestus has prepared this preliminary information at the specific request of the client. Due to Client or circumstance imposed time, information, and/or financial restrictions, Aestus have not performed the full scope of services necessary for it to render any final opinions or conclusions. Accordingly, the studies, data, information, and findings contained in this Preliminary Report are not the final conclusions of Aestus, but merely basic information requested by the client upon which the Client may draw its own conclusions. Client agrees that Aestus shall not be liable for *any claims, loss, damage, or expenses incurred by the Client or others arising out of the use of, or reliance on, any information contained in this Preliminary Report.*

8.6 Disclaimer

Aestus has performed work on this project in accordance with its understanding of industry-accepted practices. The conclusions offered in this report are based on Aestus' professional judgment when interpreting integrated geophysical, drilling, and other available data sets provided by its client or others, as of the date of this report. These data typically include analyses provided by independent testing and information services or laboratories upon which Aestus is entitled to reasonably rely. Aestus was not authorized and did not attempt to independently verify the accuracy or completeness of information or materials received from third parties during the performance of its services.

Aestus shall not be liable for any conditions, information, or conclusion, the discovery of which required information not available or independent investigation of information provided to Aestus unless otherwise indicated. Any site drawing(s) provided within this Report is not meant to be an accurate base plan, but is used to present the general, relative locations of features on, and surrounding, the site.

As with all environmental and geophysical assessments, these conclusions are reached with a certain inherent degree of uncertainty, due to the non-uniqueness of geophysical signatures and the possibility that relevant subsurface conditions may exist beyond the scope of this geophysical investigation. Aestus can be retained to reevaluate these conclusions, if warranted, based on additional site data that may be obtained in the future.

TABLES

Table 1

GeoTrax Survey LTM™ Temporal Imaging Line Properties and Endpoint Electrode Land Survey Coordinates
Naval Support Facility Indian Head, North Site 17
Indian Head, Maryland

Survey ID	Electrode Spacing	Line Length (ft)	Image Depth (ft)	Survey Date	Coordinate System and Datum	Electrode 1				Electrode 28			
						Easting (ft)	Northing (ft)	Elevation (ft)	Endpoint Marker Type	Easting (ft)	Northing (ft)	Elevation (ft)	Endpoint Marker Type
IND-01	2.25	199	40	7/18/2017	Maryland STPCS, NAD83, ft	1,257,296.74	328,111.59	15.75	lathe	1,257,277.36	327,915.56	5.10	lathe
IND-02	2.25	199	40	7/18/2017		1,257,323.44	328,143.13	22.50	lathe	1,257,307.22	327,946.89	1.30	lathe
IND-03	2.25	199	40	7/20/2017		1,257,143.75	327,981.81	13.66	lathe	1,257,341.77	327,984.06	2.21	lathe
IND-04	2.25	199	40	7/20/2017		1,257,184.07	328,000.57	12.49	lathe	1,257,381.34	328,008.62	2.62	lathe
IND-05	0.50	44	9	7/20/2017		1,257,274.85	327,982.90	1.39	lathe	1,257,319.23	327,983.55	1.27	lathe
						Electrode 1				Electrode 56			
IND-06	1.25	226	45	2/15/2018		1,257,312.67	328,151.55	23.27	lathe & plastic[1]	1,257,291.91	327,928.48	5.88	lathe & plastic[1]

Notes:

1. Sample image of plastic GeoTrax Survey™ Endpoint Marker (for Electrodes 1 and 56) for IND-06

Plastic Marker

Table 2
Distance Along Survey Line from Electrode No. 1 (0.5 m spacing)
28 Electrode Array - GeoTrax Survey LTM™ Temporal Imaging
Naval Support Facility Indian Head, North Site 17
Indian Head, Maryland

Electrode	Meters	Feet
1	0.00	0
2	0.50	2
3	1.00	3
4	1.50	5
5	2.00	7
6	2.50	8
7	3.00	10
8	3.50	11
9	4.00	13
10	4.50	15
11	5.00	16
12	5.50	18
13	6.00	20
14	6.50	21
15	7.00	23
16	7.50	25
17	8.00	26
18	8.50	28
19	9.00	30
20	9.50	31
21	10.00	33
22	10.50	34
23	11.00	36
24	11.50	38
25	12.00	39
26	12.50	41
27	13.00	43
28	13.50	44

* NOTE: Survey IND-05 has 28 electrodes at a 0.5 meter spacing.

Table 3
Distance Along Survey Line from Electrode No. 1 (1.25 m spacing)
56 Electrode Array - GeoTrax Survey™ Static Imaging
Naval Support Facility Indian Head, North Site 17
Indian Head, Maryland

Electrode	***Meters***	***Feet***	***Electrode***	***Meters***	***Feet***
1	0.00	0	**29**	35.00	115
2	1.25	4	**30**	36.25	119
3	2.50	8	**31**	37.50	123
4	3.75	12	**32**	38.75	127
5	5.00	16	**33**	40.00	131
6	6.25	21	**34**	41.25	135
7	7.50	25	**35**	42.50	139
8	8.75	29	**36**	43.75	144
9	10.00	33	**37**	45.00	148
10	11.25	37	**38**	46.25	152
11	12.50	41	**39**	47.50	156
12	13.75	45	**40**	48.75	160
13	15.00	49	**41**	50.00	164
14	16.25	53	**42**	51.25	168
15	17.50	57	**43**	52.50	172
16	18.75	62	**44**	53.75	176
17	20.00	66	**45**	55.00	180
18	21.25	70	**46**	56.25	185
19	22.50	74	**47**	57.50	189
20	23.75	78	**48**	58.75	193
21	25.00	82	**49**	60.00	197
22	26.25	86	**50**	61.25	201
23	27.50	90	**51**	62.50	205
24	28.75	94	**52**	63.75	209
25	30.00	98	**53**	65.00	213
26	31.25	103	**54**	66.25	217
27	32.50	107	**55**	67.50	221
28	33.75	111	**56**	68.75	226

* NOTE: Survey IND-06 has 56 electrodes at a 1.25 meter spacing.

Table 4
Distance Along Survey Line from Electrode No. 1 (2.25 m Spacing)
28 Electrode Array - GeoTrax Survey LTM™ Temporal Imaging
Naval Support Facility Indian Head, North Site 17
Indian Head, Maryland

		2.25
Electrode	**Meters**	**Feet**
1	0.00	0
2	2.25	7
3	4.50	15
4	6.75	22
5	9.00	30
6	11.25	37
7	13.50	44
8	15.75	52
9	18.00	59
10	20.25	66
11	22.50	74
12	24.75	81
13	27.00	89
14	29.25	96
15	31.50	103
16	33.75	111
17	36.00	118
18	38.25	125
19	40.50	133
20	42.75	140
21	45.00	148
22	47.25	155
23	49.50	162
24	51.75	170
25	54.00	177
26	56.25	185
27	58.50	192
28	60.75	199

* NOTE: Surveys IND-01, IND-02, IND-03, and IND-04 each have 28 electrodes at a 2.25 meter spacing.

Table 5
Electrode Performance Assessment
28 Electrode Array - GeoTrax Survey LTM™ Temporal Imaging
Naval Support Facility Indian Head, North Site 17
Indian Head, Maryland

Phase 1 (Pre-Remediation)	**IND-01**	**IND-02**	**IND-03**	**IND-04**	**IND-05**	
Electrode HVOVL(1)	-	-	-	-	-	
Number of noisy electrodes (2)	-	-	-	-	-	
Total noisy data points per survey line	14%	11%	10%	9%	0%	
Phase 2 (Post Remediation)	**IND-01**	**IND-02**	**IND-03**	**IND-04**	**IND-05**	
Electrode HVOVL(1)	E17 thru E20	E25 & E26	E20 & E21	-	-	
Number of noisy electrodes (2)	5	1	1	-	-	
Total noisy data points per survey line	33%	16%	21%	8%	0%	
Phase 3 (Post Remediation)	**IND-01**	**IND-02**	**IND-03**	**IND-04**	**IND-05**	**IND-06 (3)**
Electrode HVOVL(1)	E17 thru E20	E25 thru E27	E19 thru E21	-	-	-
Number of noisy electrodes (2)	7	3	2	-	-	-
Total noisy data points per survey line	38%	20%	22%	10%	0%	0%
Phase 4 (Post Remediation)	**IND-01**	**IND-02**	**IND-03**	**IND-04**	**IND-05**	
Electrode HVOVL(1)	E17 thru E20	-	-	-	-	
Number of noisy electrodes (2)	5	-	-	-	-	
Total noisy data points per survey line	33%	12%	13%	9%	0%	

NOTES:

1. HVOVL = poor/no connection on buried electrode cables presumably due to inadvertent damage during remedial construction
presumably due to inadvertent damage during remedial construction and/or moisture content variation at buried electrode

2. Noisy electrodes are different from those with poor connections (HVOVL reading); no data is collected from HVOVL electrodes;
Data is considered excellent quality when there are no noisy or HVOVL electrodes;
However, some noisy data points are to be expected typically and in this case all data was considered usable.

3. Survey line IND-06 was not originally scoped; was performed as a static 56 electrode static survey line

FIGURES

GeoTrax Survey LTM ™
Remedial Long Term Monitoring
Naval Support Facility Indian Head;
North Site 17
Indian Head, Maryland, USA

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FIGURE
TITLE PAGE

Legend and Symbols

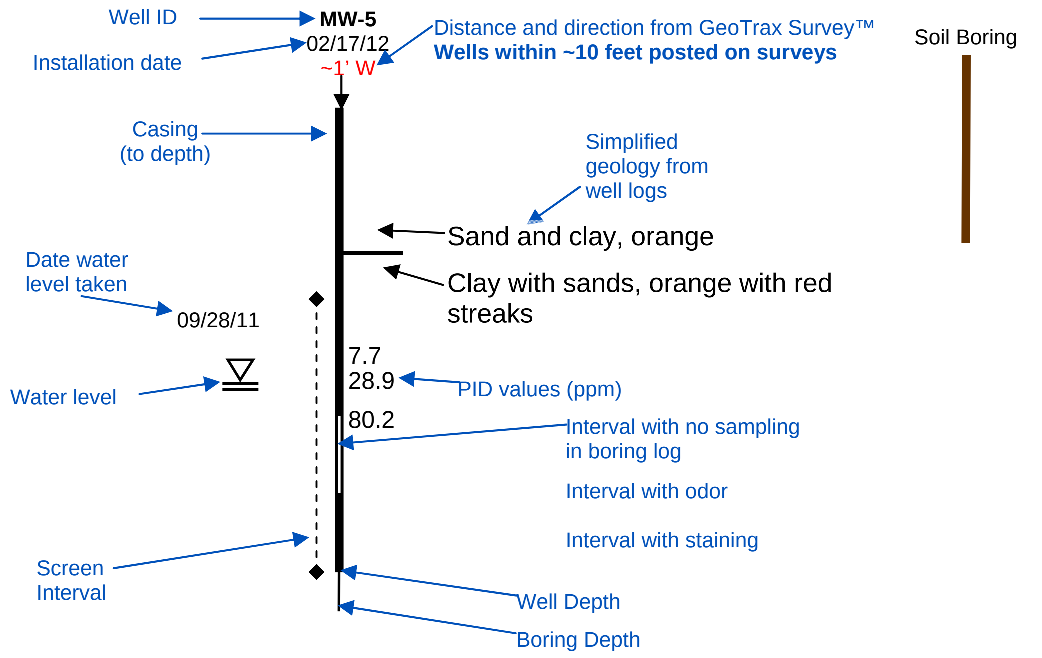
(for reference when reviewing all Figures)

Site Features

▭	Indicates various site features which are labeled accordingly on the figures
┆ IND-02	Indicates areas where GeoTrax Surveys™ intersect
➡	Groundwater sample from a specific interval/screen interval
➡	Water sample where one or more constituents are above SRG
→	Soil sample from a specific interval
⬚	Reaction column installation zone

See Appendix E for groundwater and soil chemistry data

Monitoring Well Explanation



Analytical Data

Analytical Soil and Water Data and Groundwater Quality Parameters for Wells Near GeoTrax Surveys ™.
Data provided by GSI.

Site Remediation Goal (SRG) provided by GSI

Bold: Constituent concentration exceeds SRG
B - Analyte note detected above the level reported in blanks
J - Analyte present, value may or may not be accurate/precise
K - Analyte present, value may be biased high
L - Analyte present, value may be biased low
D - Compound identified in an analysis at a secondary dilution factor

NS - Not Sampled

cis-1,2-DCE: cis-1,2-Dichloroethene
TCE: Trichloroethene

Groundwater Sample Results

Well		**MW-15**	**DP80**	**MW-12**
Sample Date		**09/15/15**	**11/21/14**	**9/16/2015**
Parameters (µg/L)	**SRG (µg/L)**		7-12	
cis-1,2-DCE	150	ND	ND	**7,120**
TCE	5	0.601 J	ND	**122,000**
VC	2	ND	**2,500**	**641 J**

Note: Groundwater sampling for soil borings DP74 and DP76-DP81 occurred 2 ft north of soil boring locations

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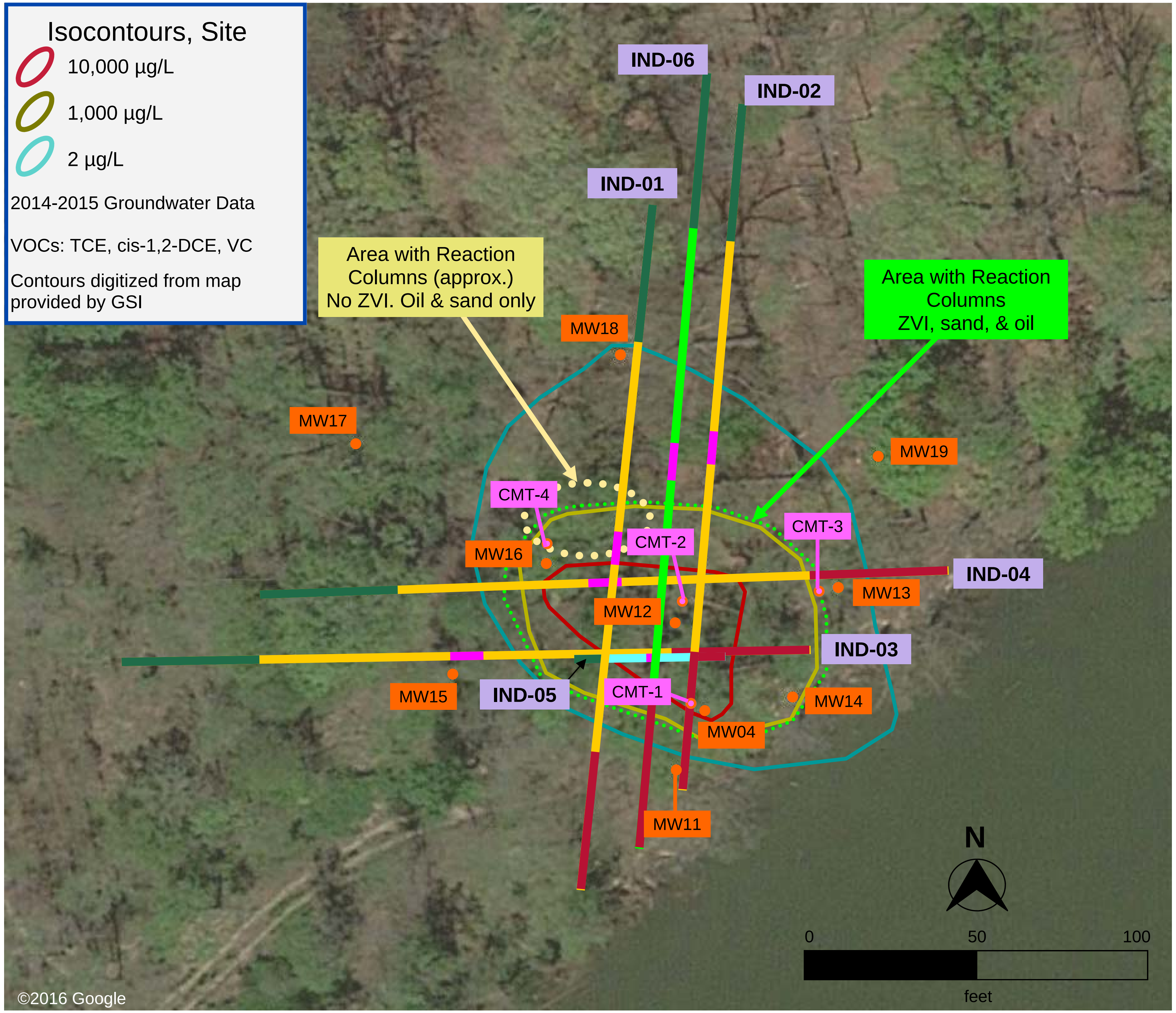
FIGURE
LS-1

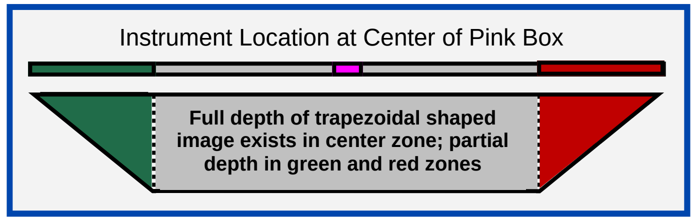


LEGEND:

Electrode 1 Electrode 28

GeoTrax Survey™ Orientation and Designation

IND-01	**2.25 Meter Electrode Spacing** **28 Electrode Array** Line Length ~200 feet (~61 m)
IND-05	**0.5 Meter Electrode Spacing** **28 Electrode Array** Line Length ~44 feet (~13.5 m)
IND-06	**1.25 Meter Electrode Spacing** **56 Electrode Array** Line Length ~226feet (~68.75 m)



● MW01	Monitoring Well Locations
● CMT-1	CMT Well Locations, approximate

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GeoTrax Surveys™ and Historical Monitoring Well Locations
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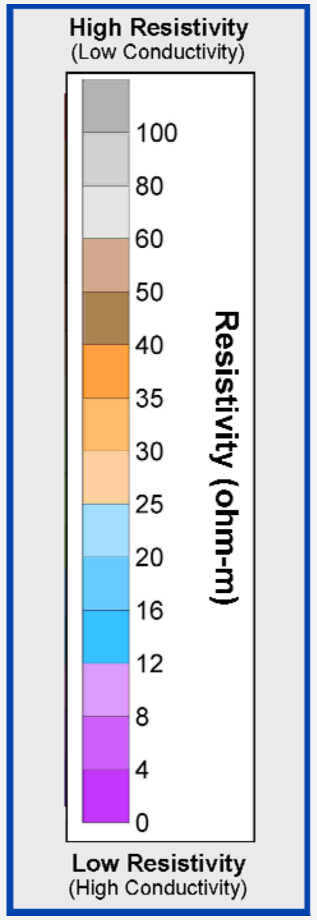
FIGURE

PV-1

Static Imagery (Phase I)
Pre-Remedy Baseline (July 2017)
Resistivity Structure of Subsurface
3D Perspective View



Legend

⬭ 10,000 µg/L VOCs

⬭ 1,000 µg/L VOCs

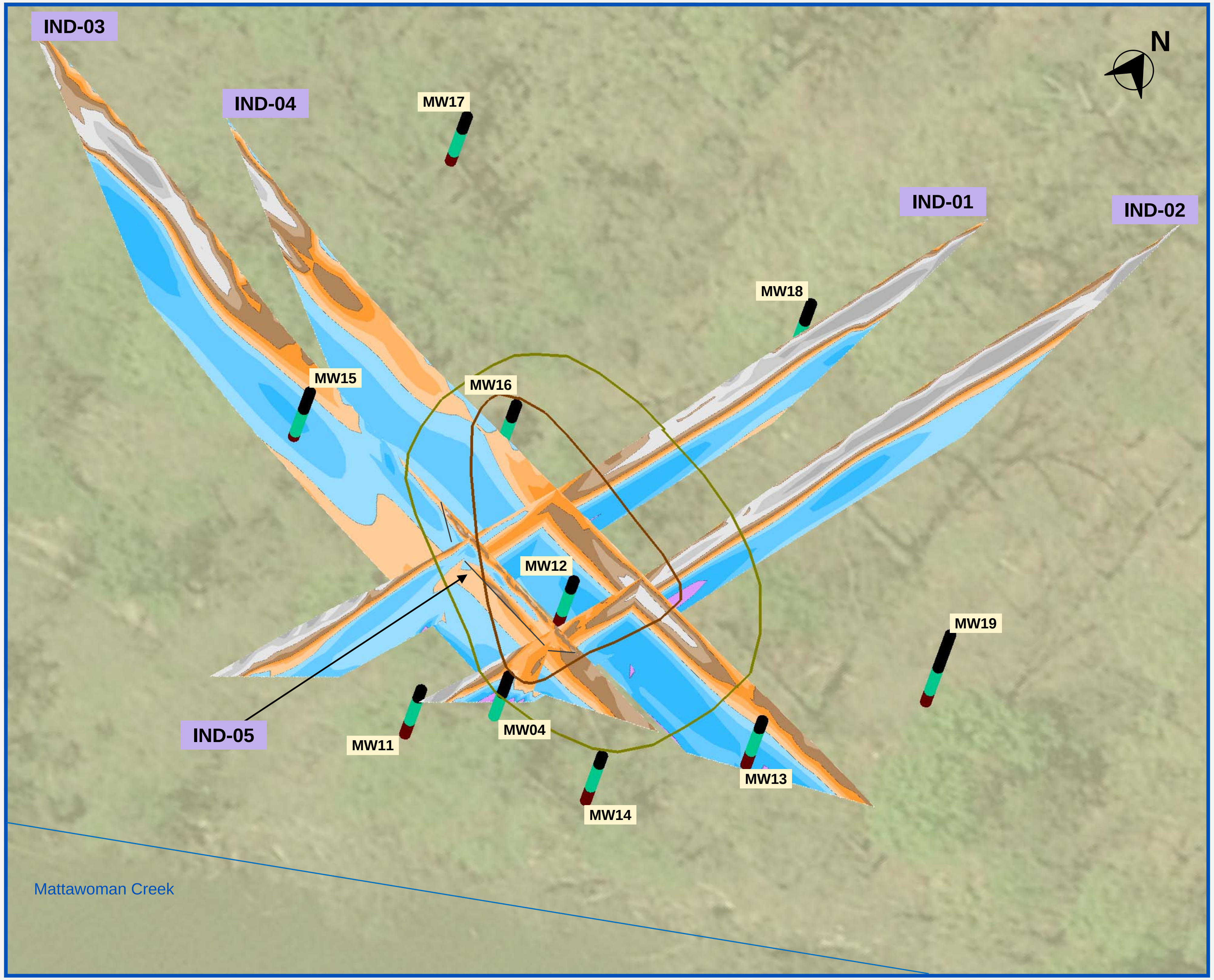


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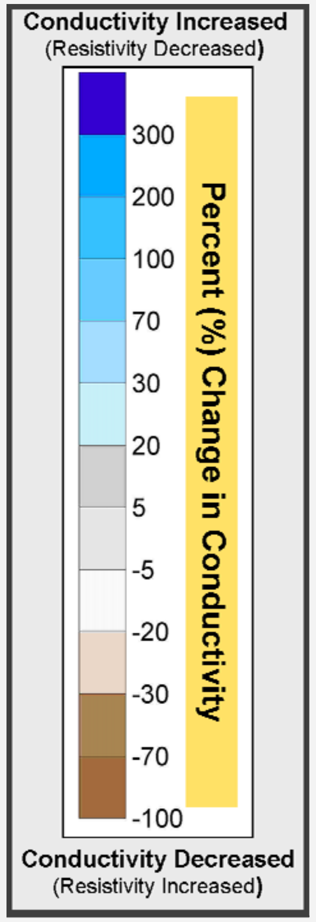
FIGURE

1

Temporal Differenced Image (Phase I to IV)
Pre-Remedy to 1 Year Post-Remedy
(July 2017 to August 2018)
3D Perspective View



Legend

- ○ 10,000 µg/L VOCs
- ○ 1,000 µg/L VOCs / Remedy Zone
- ○ Oil Only

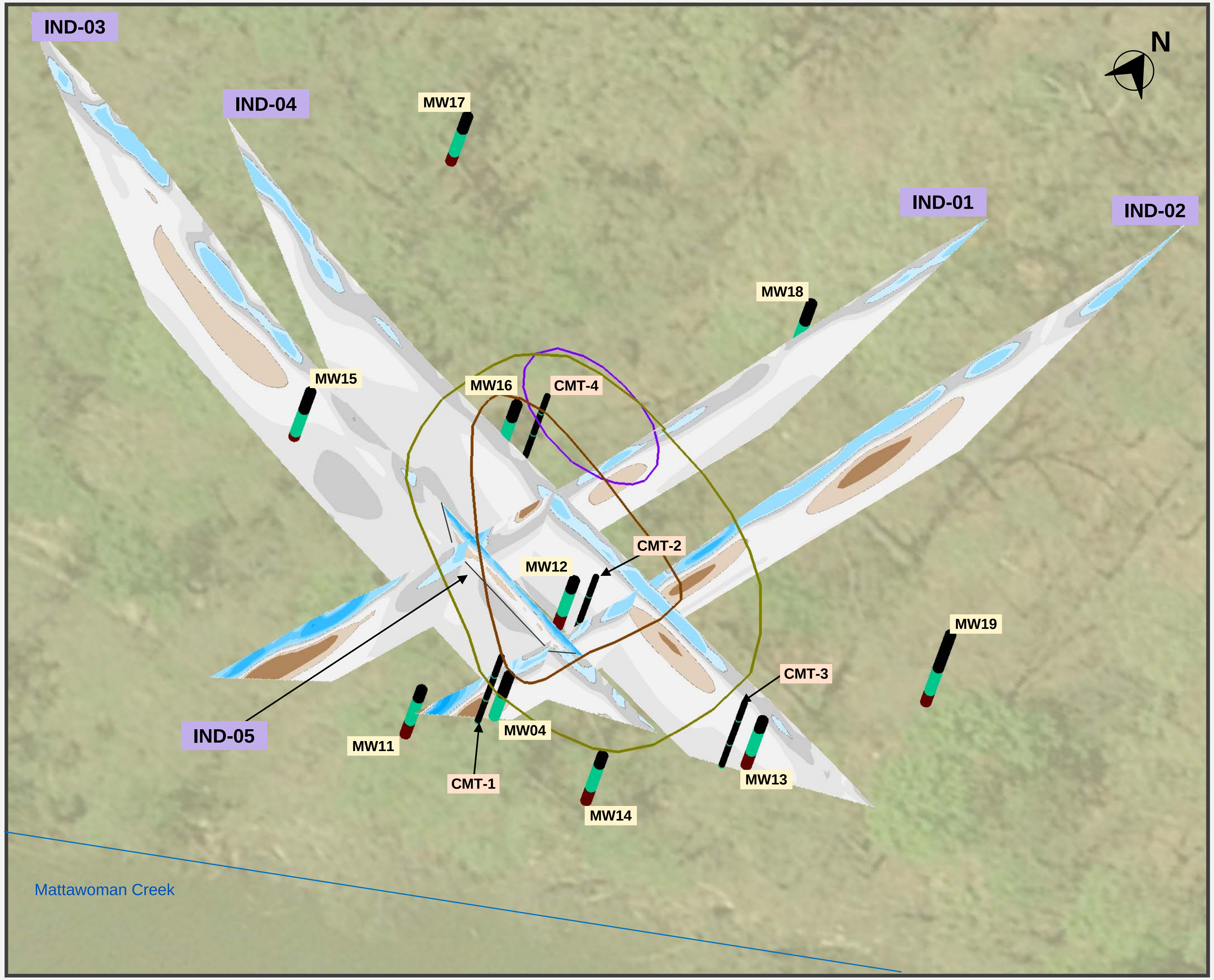


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FIGURE

2

Horizontal Elevation Slices (Static Imagery showing Resistivity Structure)
Phase I (Pre-Remedy Baseline, July 2017)
Interpolated GeoTrax Survey™ Data

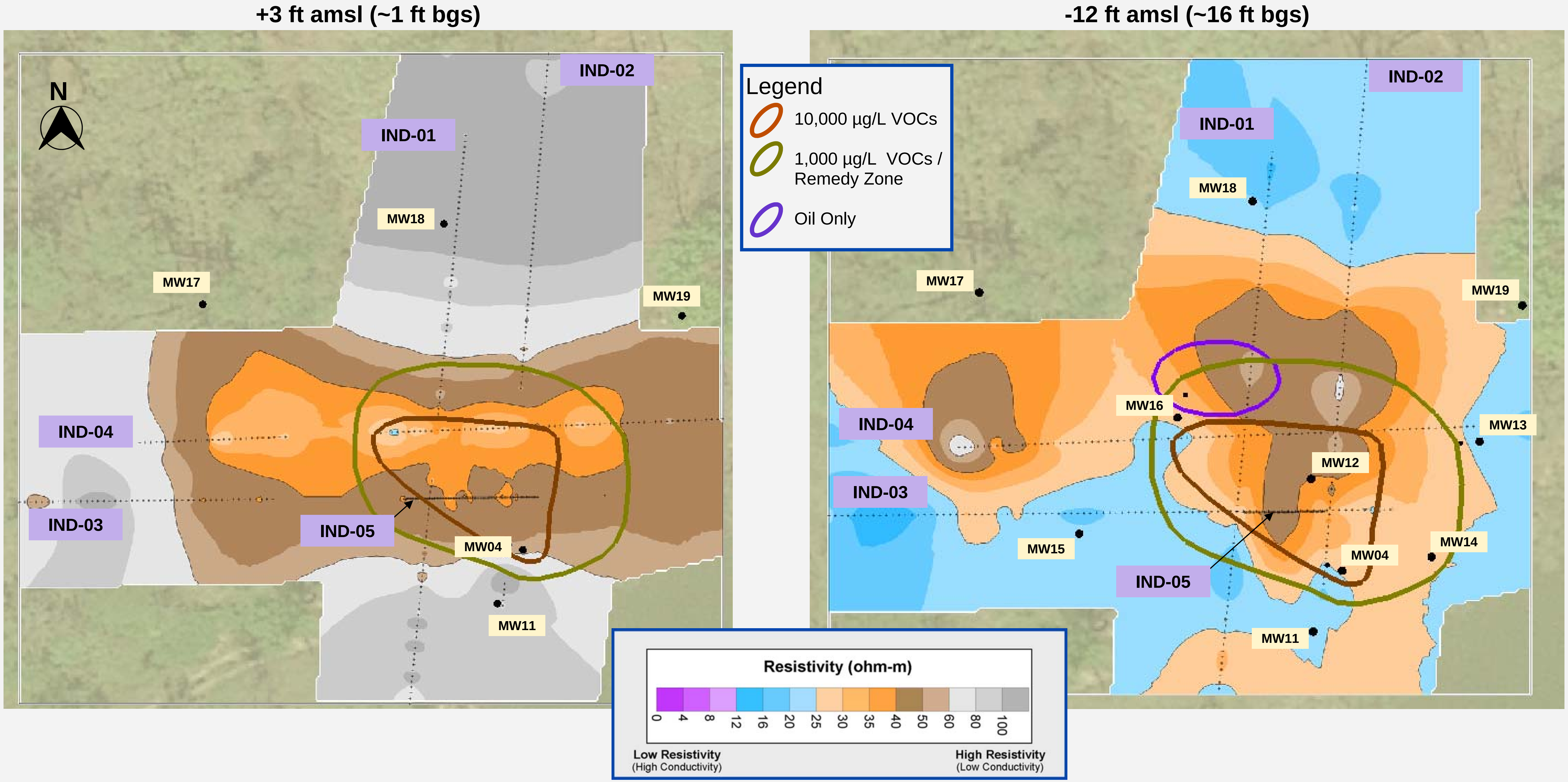

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FIGURE
3

Horizontal Elevation Slices (Temporal Imagery)
Phase I to IV (Pre-Remedy to 1 Year Post-Remedy)
Interpolated GeoTrax Survey™ Data

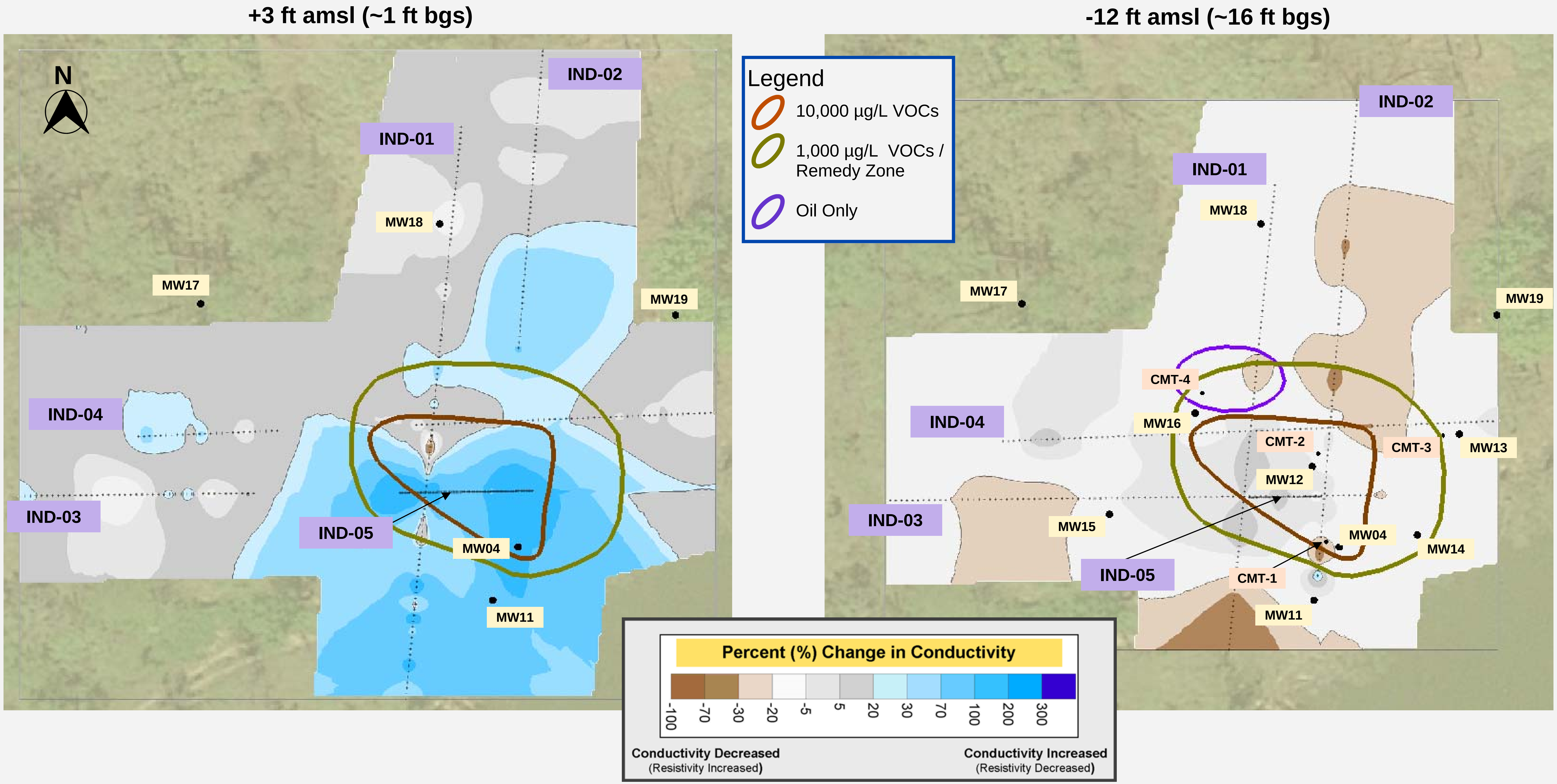

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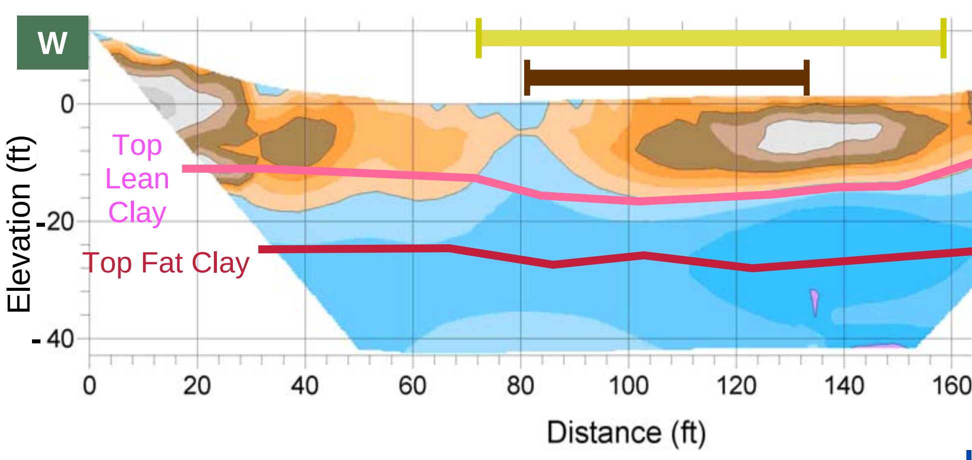
FIGURE
4

Survey Line IND-04

Phase I: Pre-Remedy Baseline (Jul. 2017)



Static Resistivity Imagery Color Scheme (I-IV)

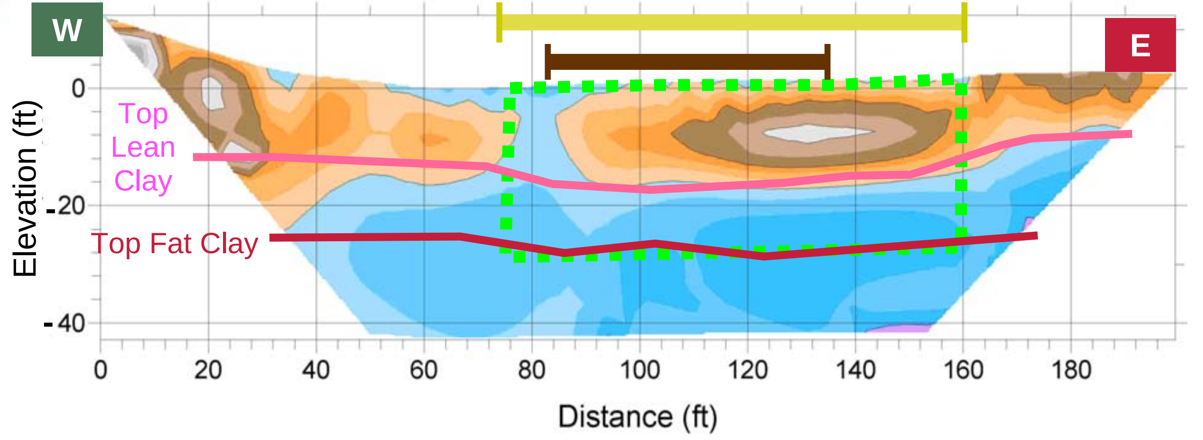
Resistivity (ohm-m)

0 4 8 12 16 20 25 30 35 40 50 60 80 100

Low Resistivity
(High Conductivity)

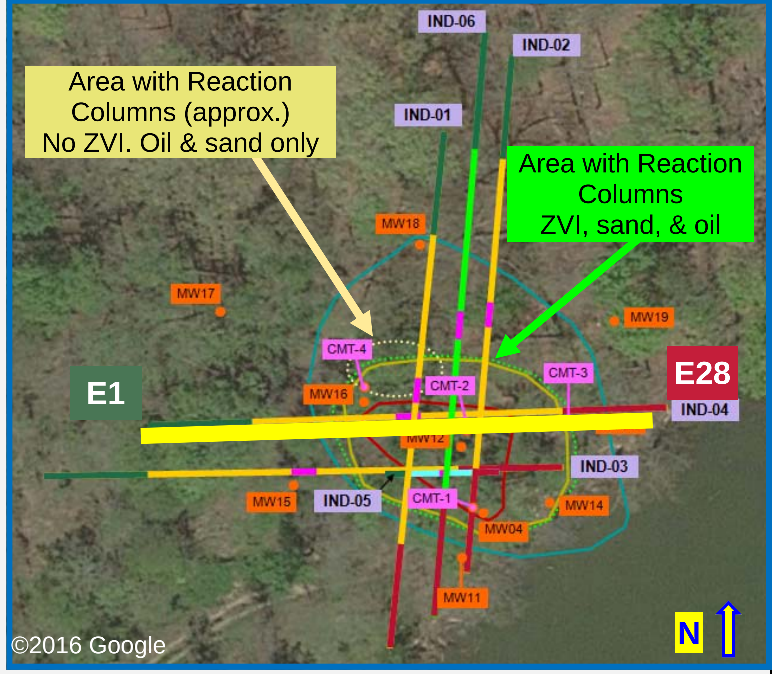
High Resistivity
(Low Conductivity)

Phase IV: 1 Year Post-Remedy (Aug. 2018)



Phase I - Phase IV

GeoTrax Survey ™ Line Location in Plan View



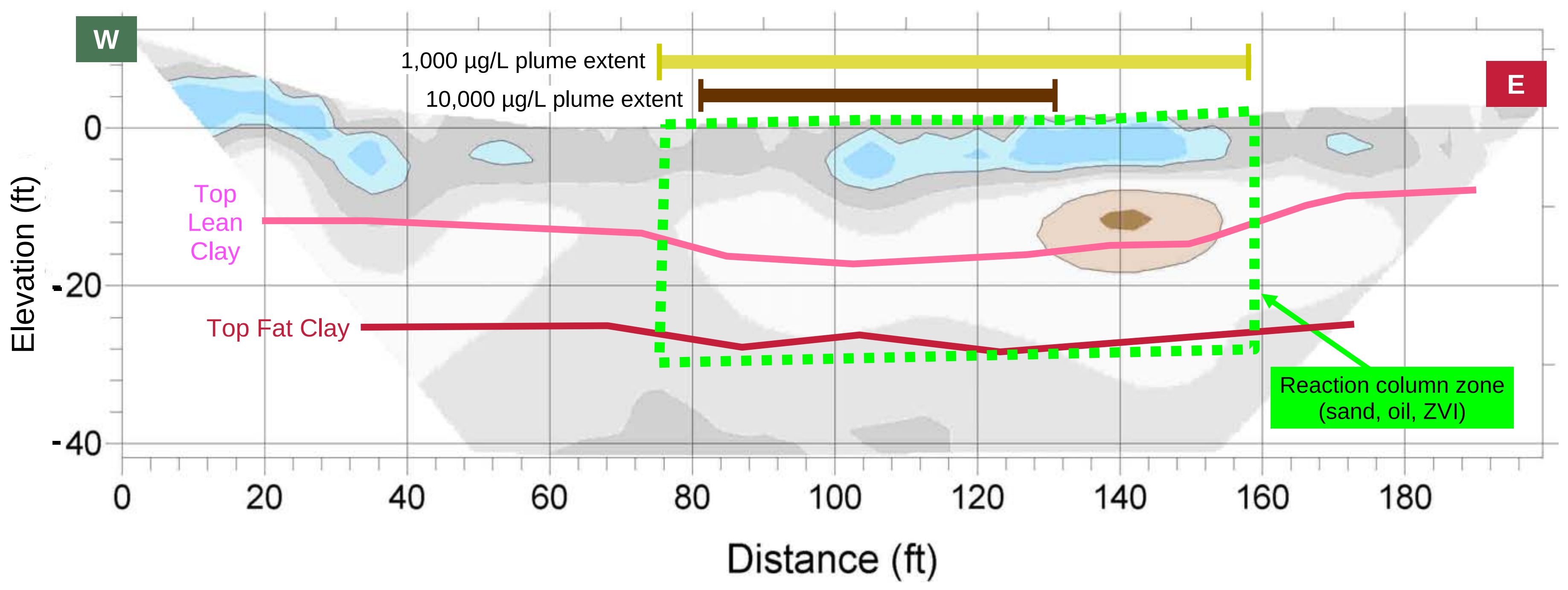
Area with Reaction Columns (approx.)
No ZVI. Oil & sand only

Area with Reaction Columns
ZVI, sand, & oil

©2016 Google

Temporal Changes

Pre-Remedy to 1 Year Post-Remedy



1,000 µg/L plume extent

10,000 µg/L plume extent

Reaction column zone
(sand, oil, ZVI)

Temporal Imagery Color Scheme

Percent (%) Change in Conductivity

-100 -70 -30 -20 -5 5 20 30 70 100 200 300

Conductivity Decreased
(Resistivity Increased)

Conductivity Increased
(Resistivity Decreased)

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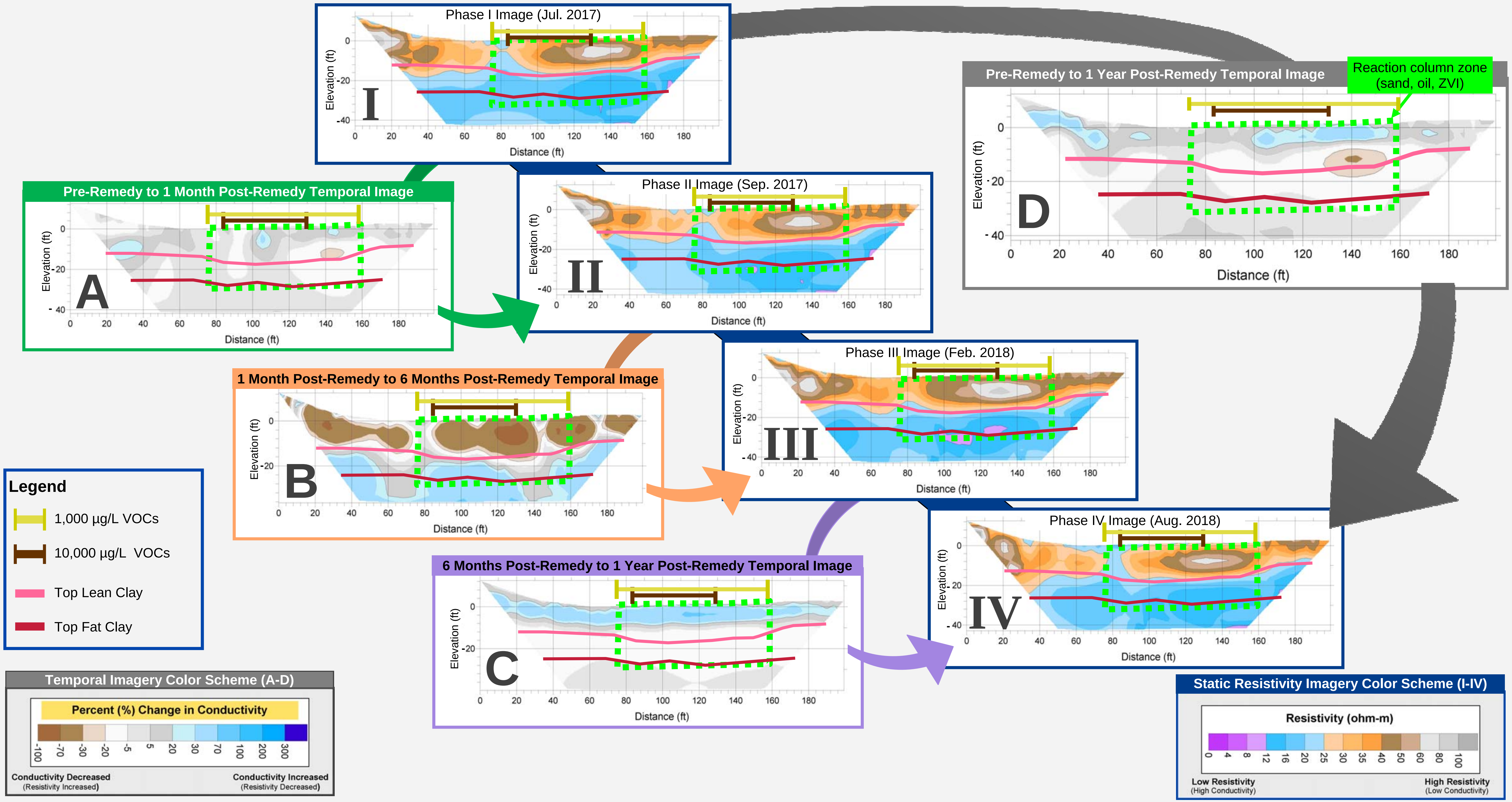
FIGURE

5

Survey Line IND-04 — Phases I, II, III, and IV Resistivity and Temporal Changes



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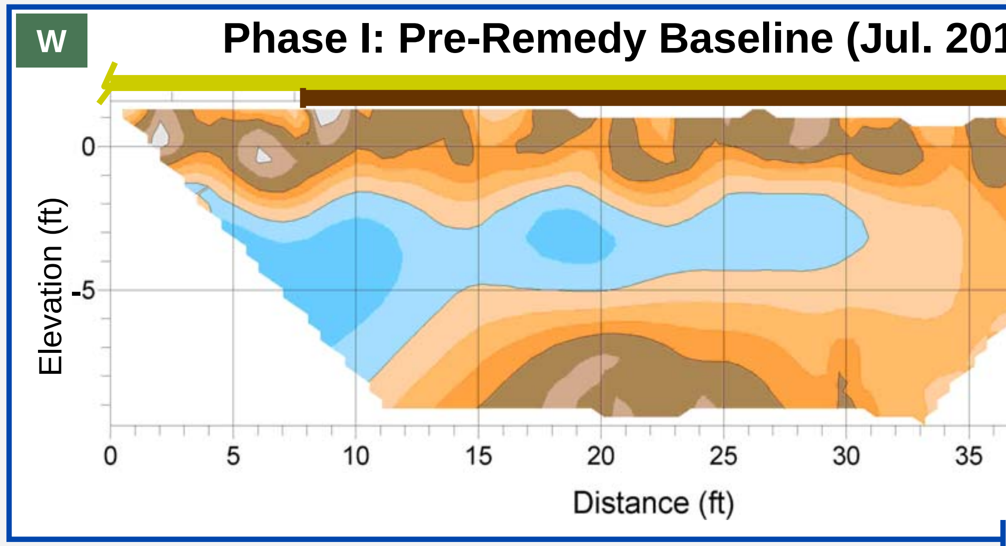
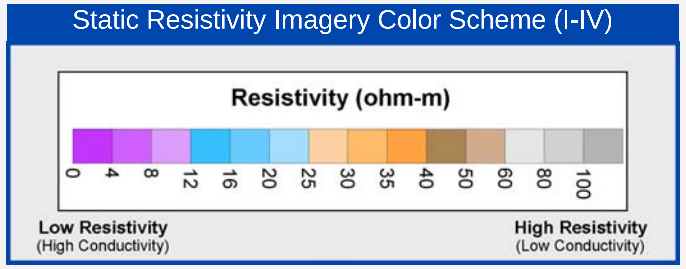
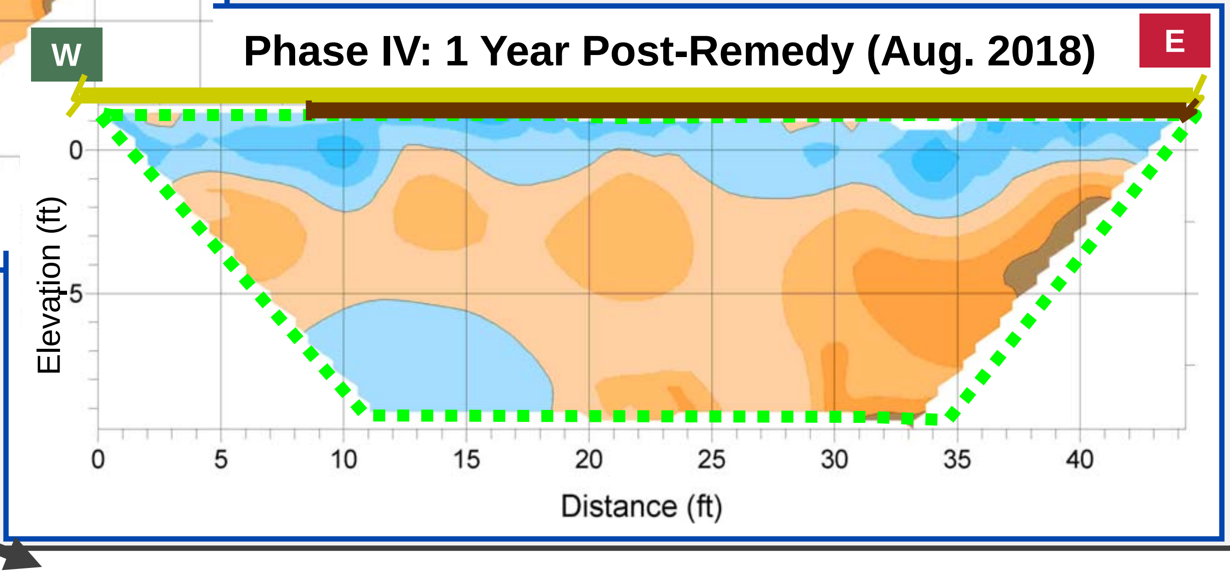
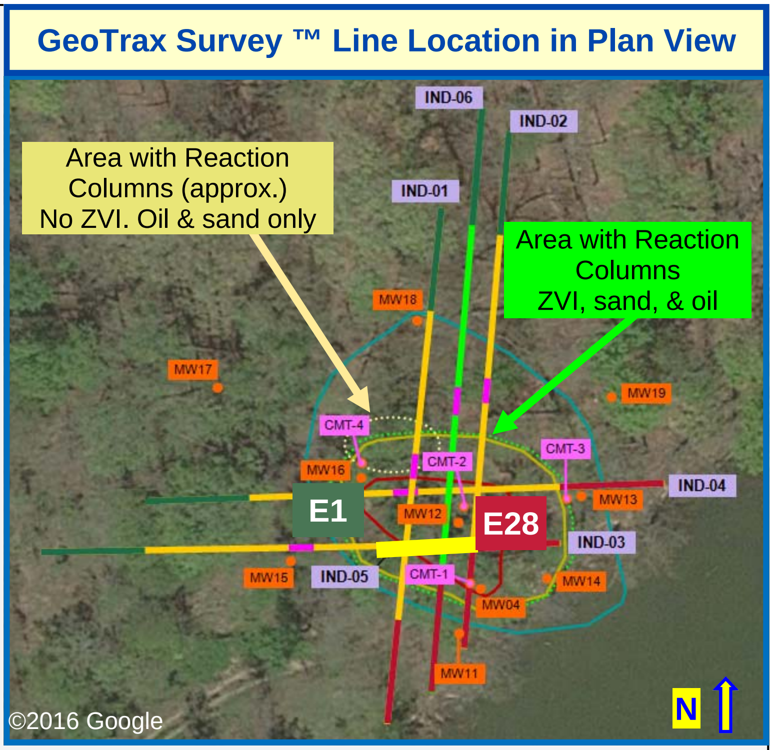
Survey Line IND-05









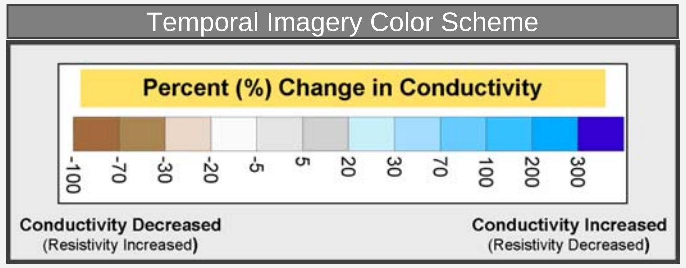
Phase I - Phase IV

Legend

▬ 1,000 µg/L VOCs

▬

Temporal Changes
Pre-Remedy to 1 Year Post-Remedy



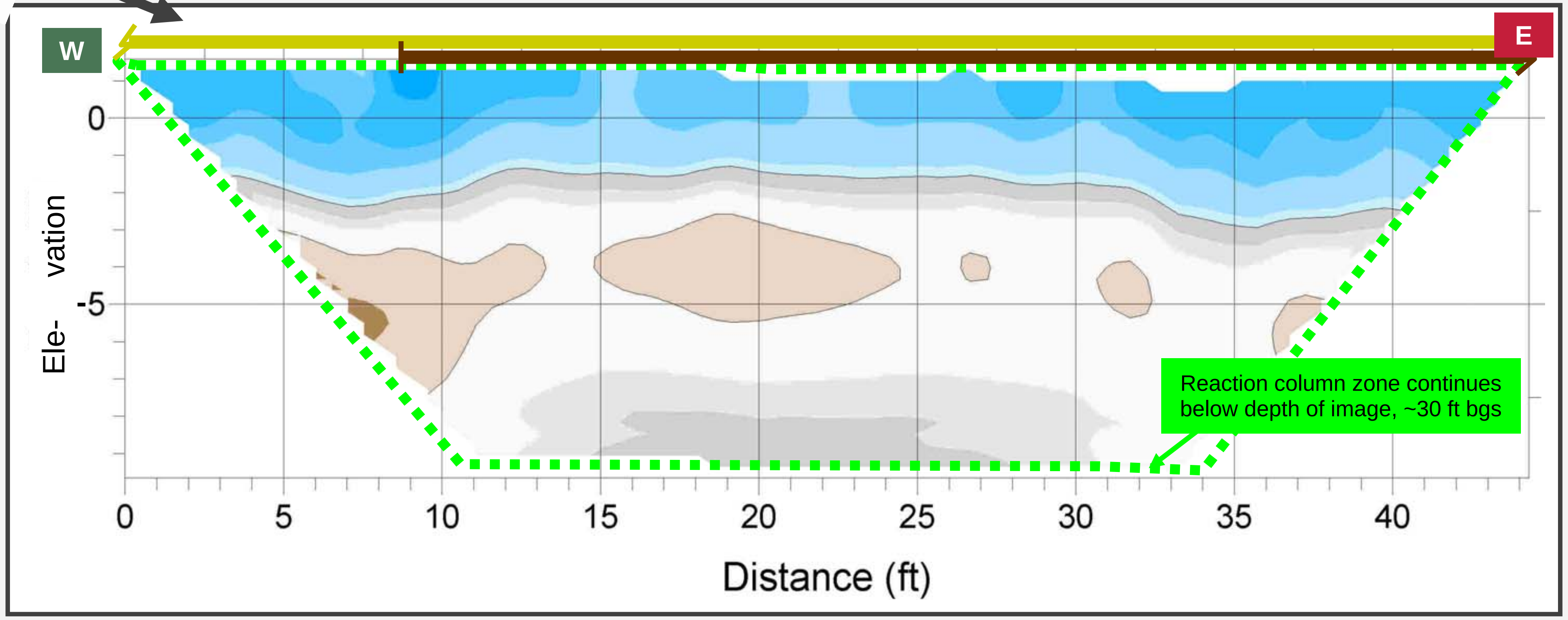


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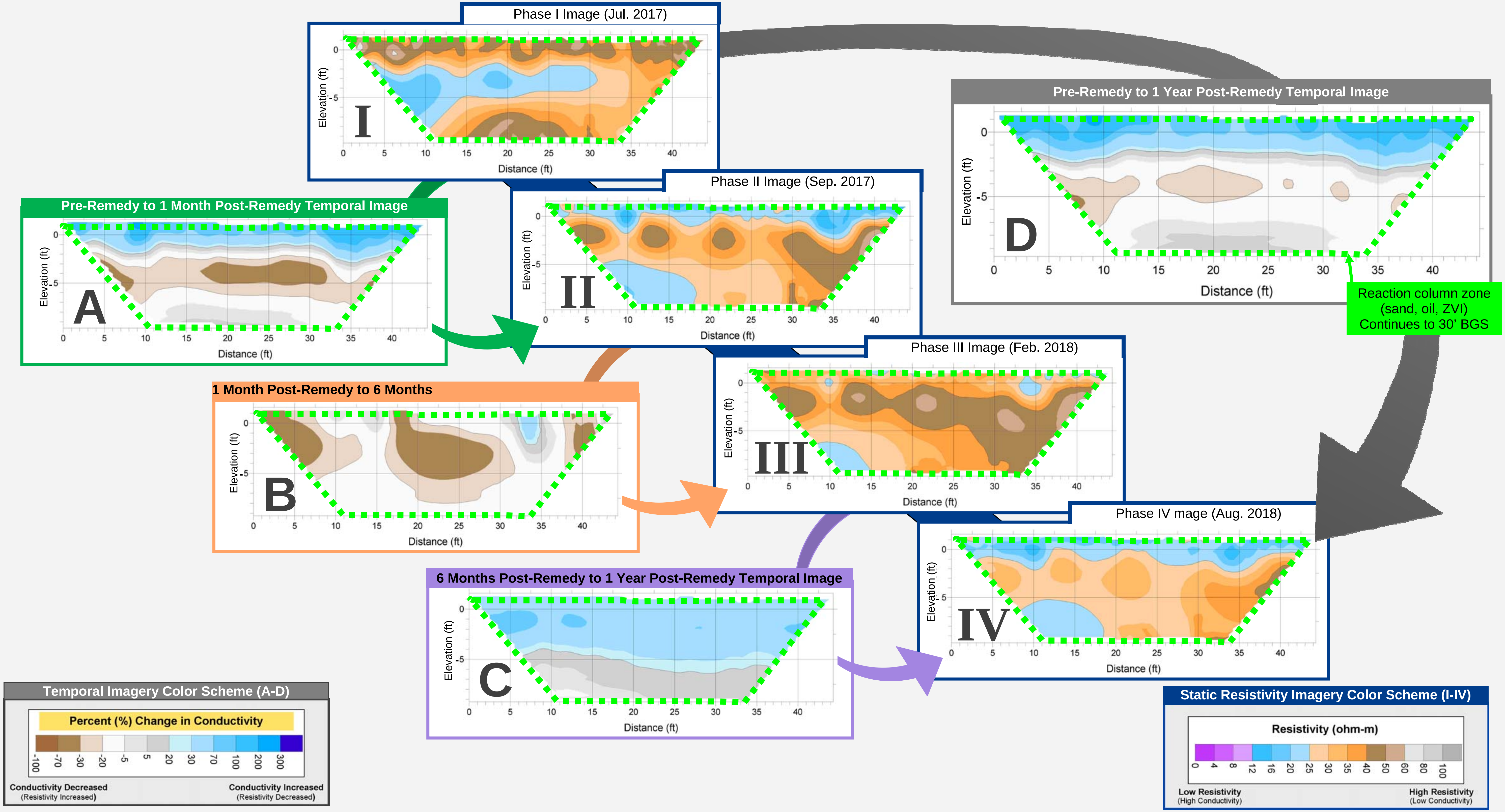
FIGURE
7

Survey Line IND-05 — Phases I, II, III, and IV Resistivity and Temporal Changes



Reaction column zone
(sand, oil, ZVI)
Continues to 30' BGS

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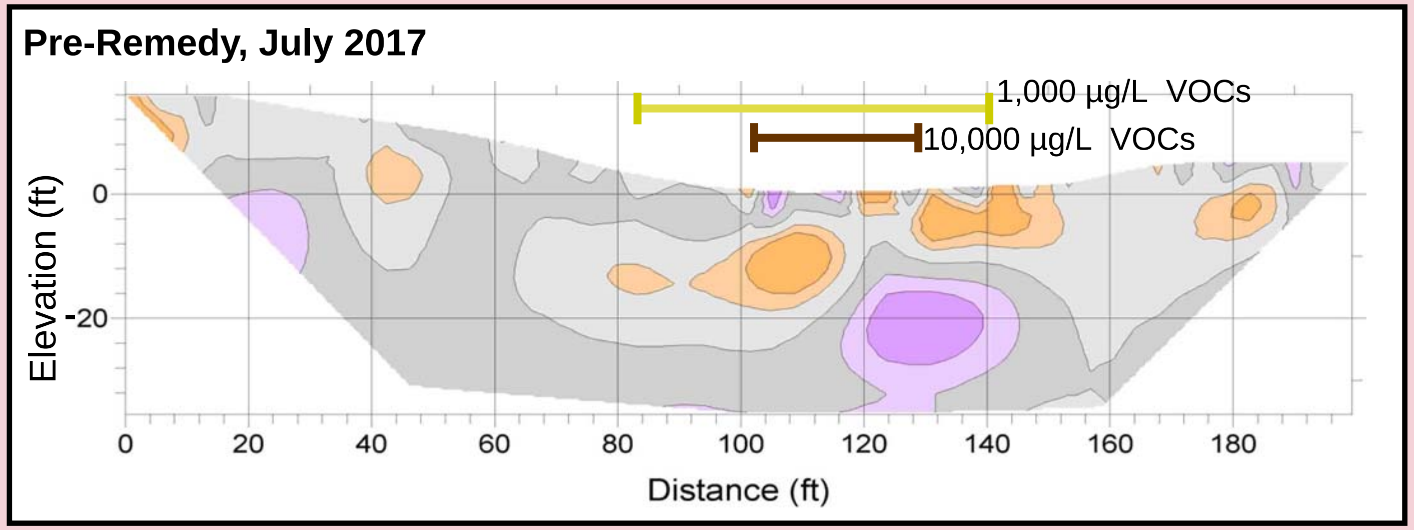
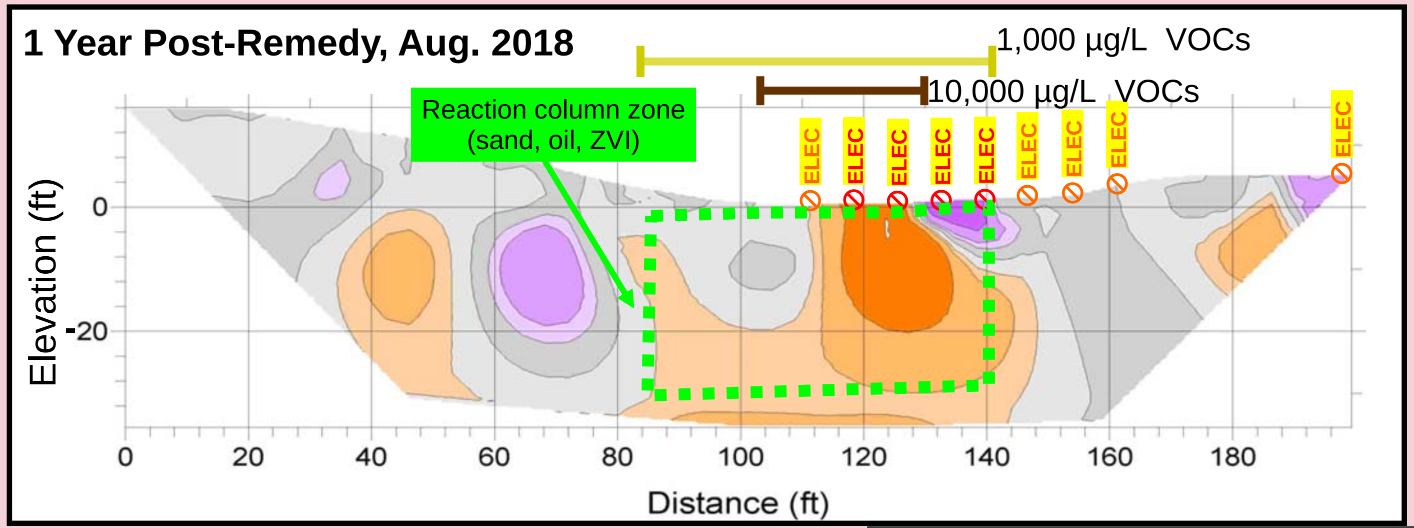
FIGURE
8

Results of Repeat Imaging to Evaluate Precision—Cable Quality Control Imaging

Survey Line IND-01

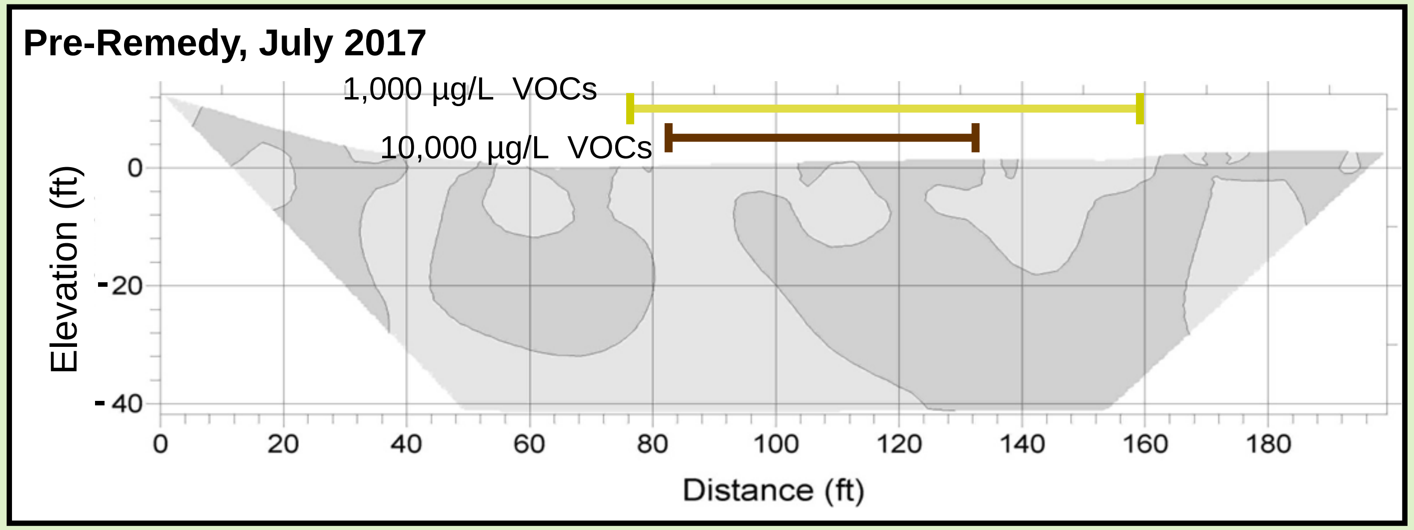
North **South**

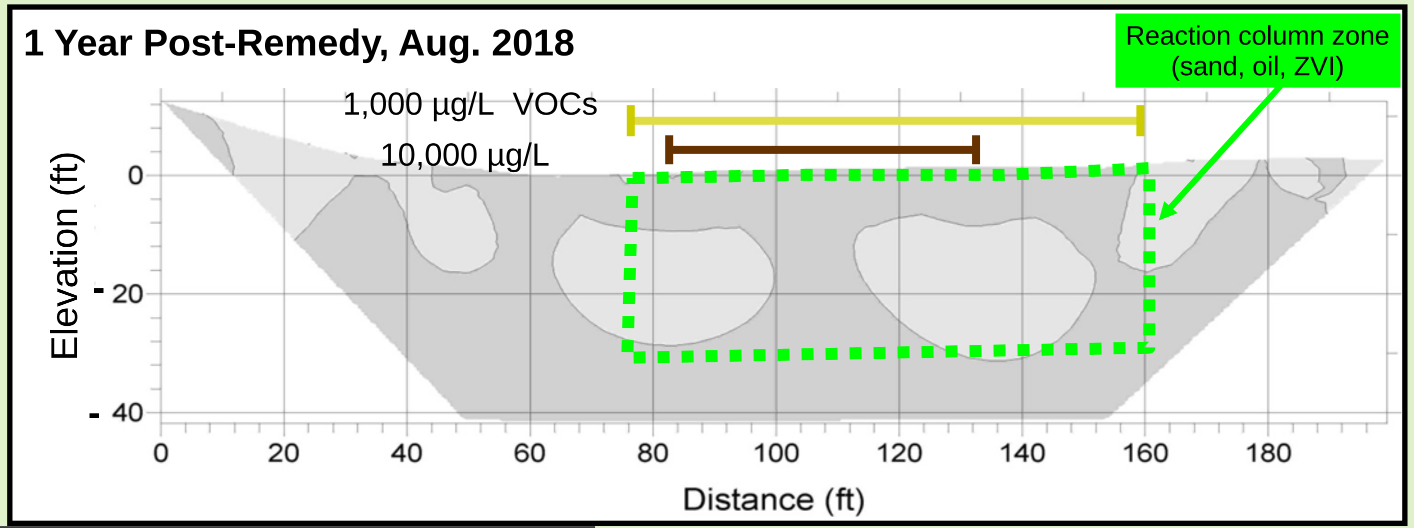




Survey Line IND-04

West **East**

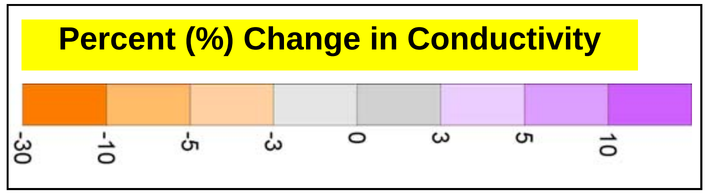




⃠ **Failed Electrode**

⃠ **Noisy Data Point**

Resistivity Decreased
(Conductivity Increased)



Resistivity Increased
(Conductivity Decreased)

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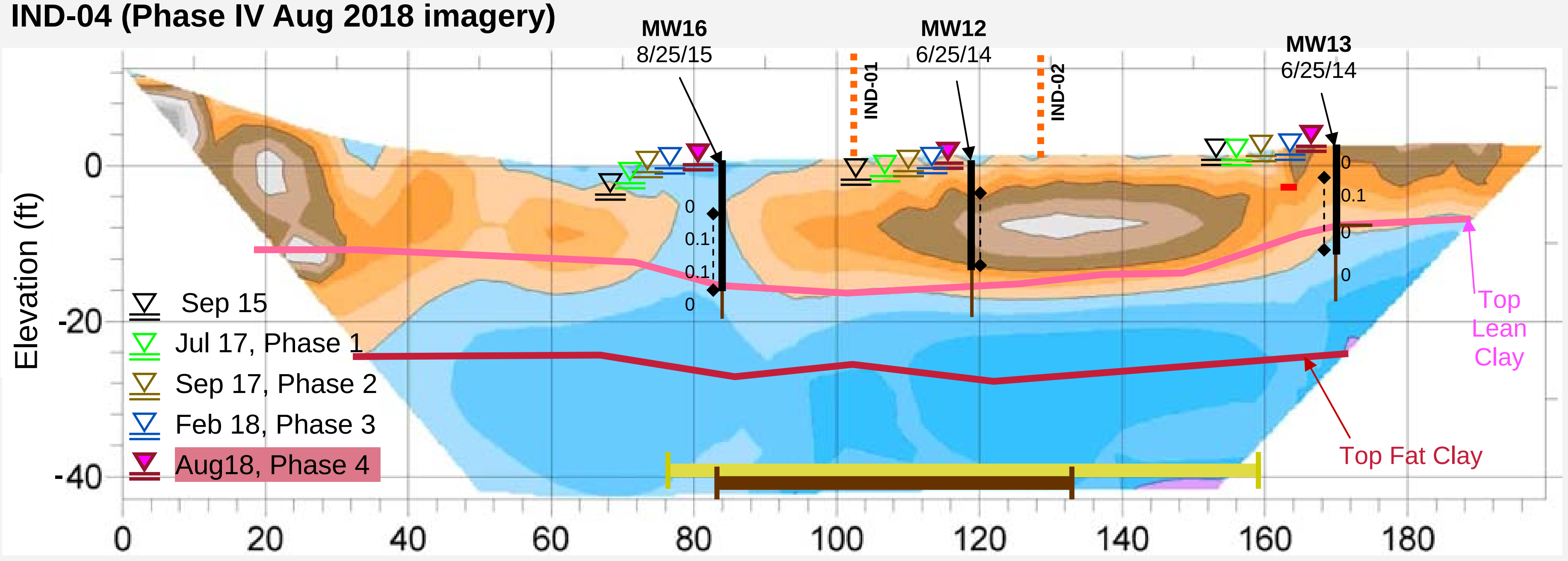
FIGURE
9

Groundwater Elevation Variations

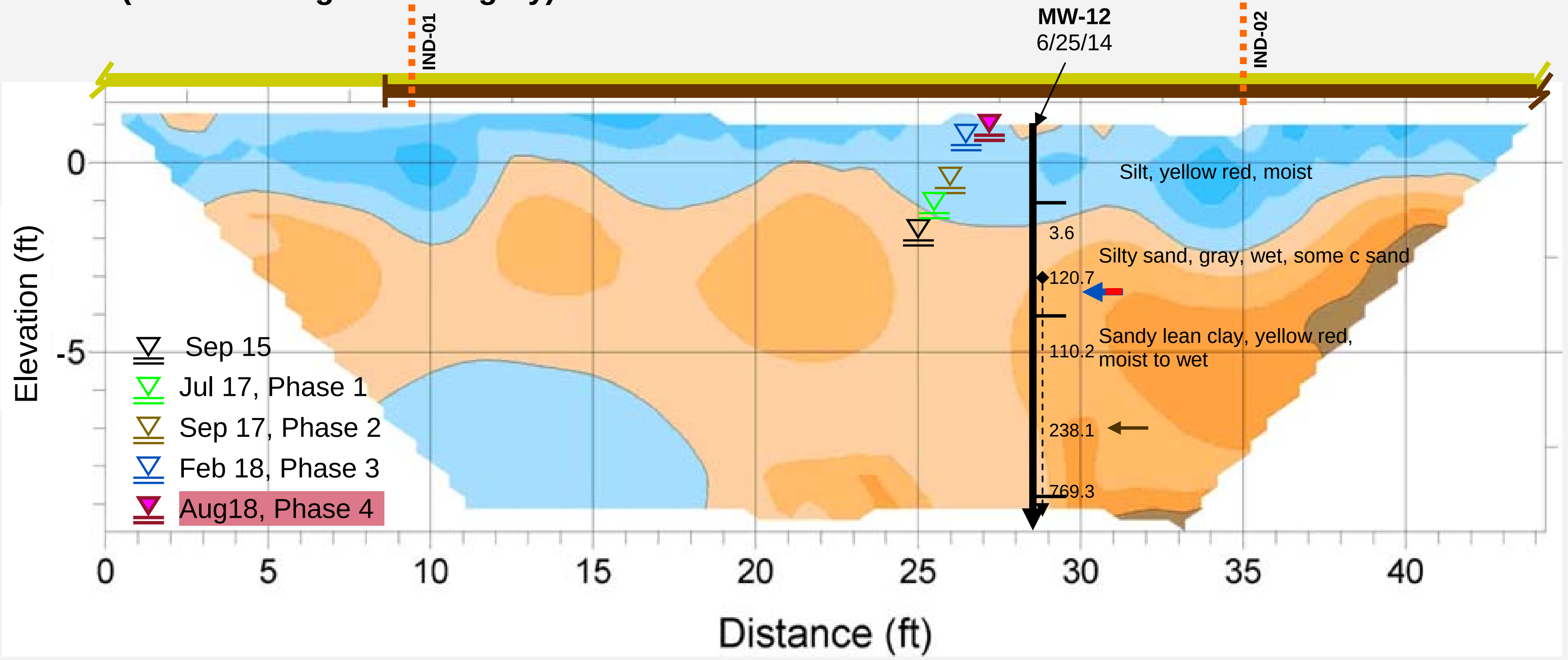
West

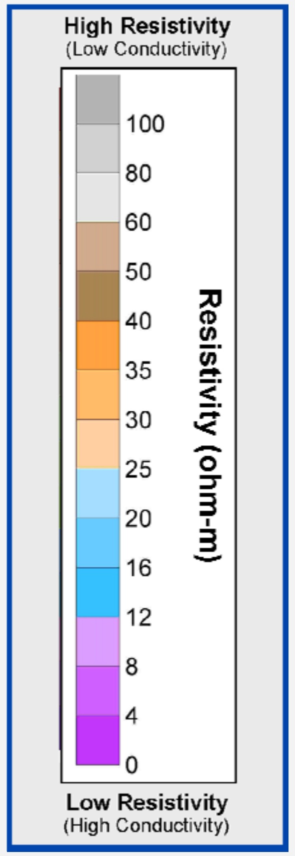
East

IND-04 (Phase IV Aug 2018 imagery)

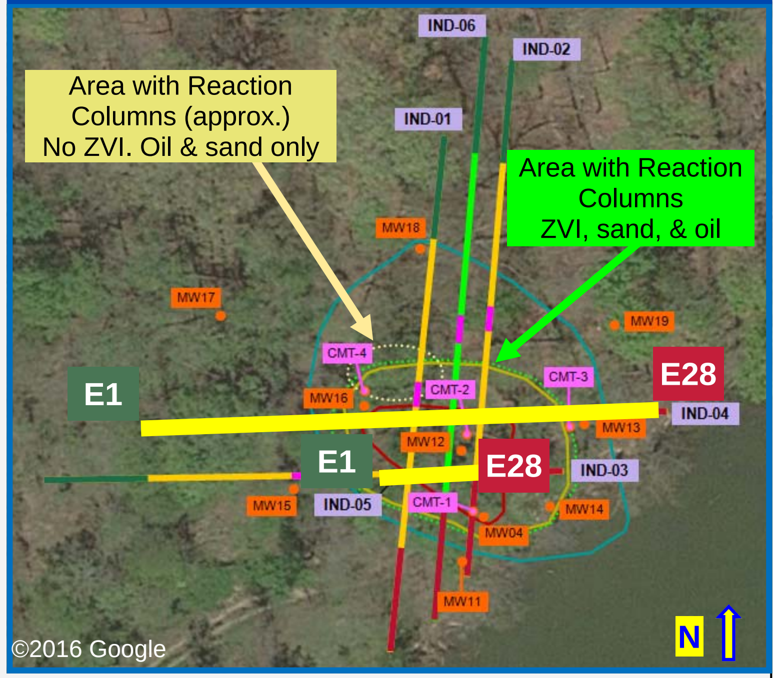


IND-05 (Phase IV Aug 2018 imagery)





GeoTrax Survey ™ Line Location in Plan View



Legend

🟨 1,000 µg/L VOCs

🟫

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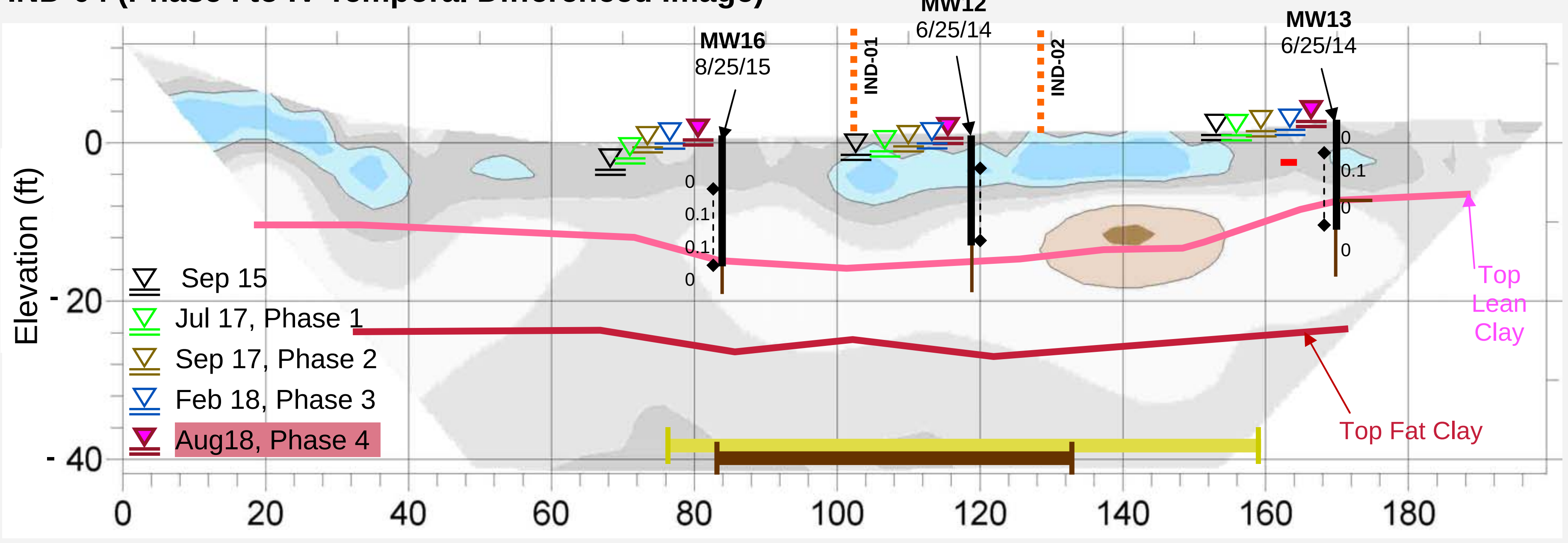
FIGURE
10

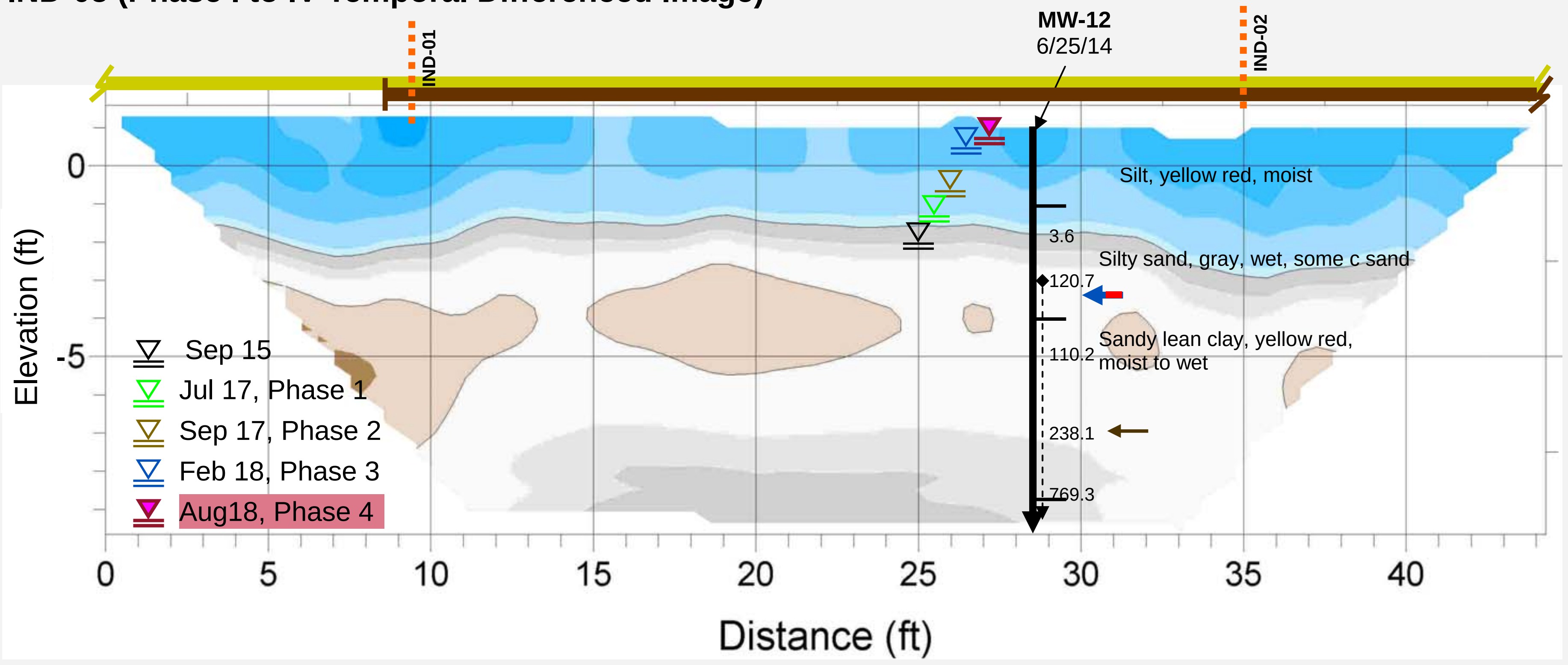
Groundwater Elevation Variations

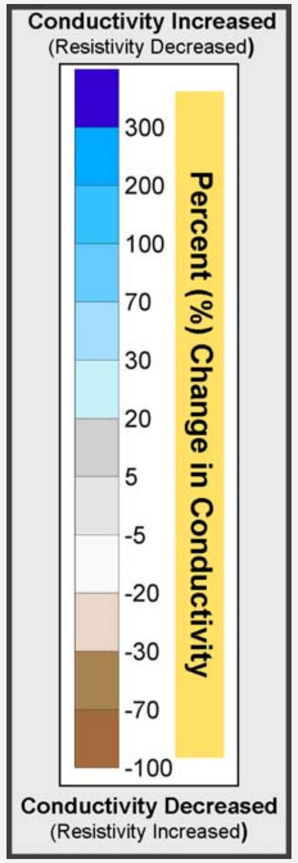
West **East**

IND-04 (Phase I to IV Temporal Differenced Image)



IND-05 (Phase I to IV Temporal Differenced Image)



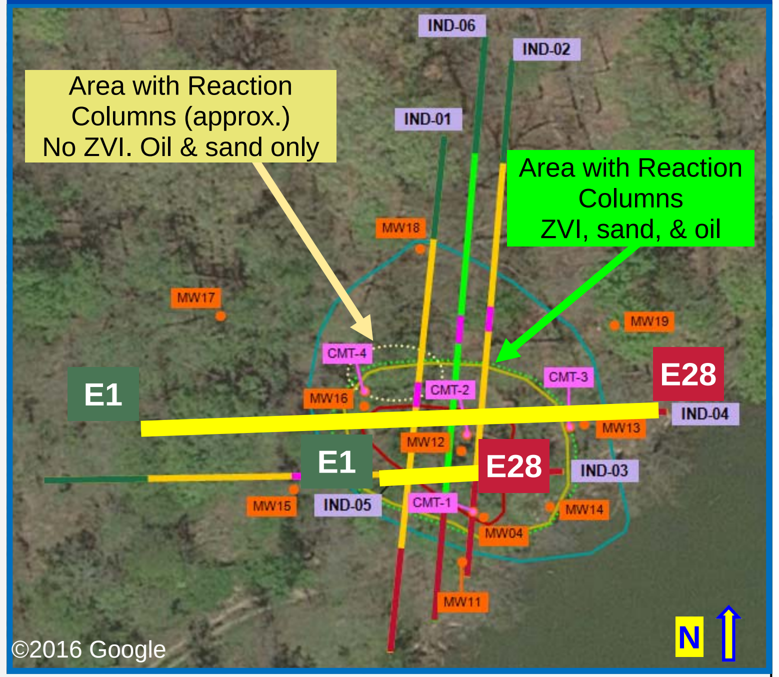


Legend

🟨 1,000 µg/L VOCs

▬

GeoTrax Survey ™ Line Location in Plan View



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Approved By:	SWM
Date:	09-30-19
Project No.:	17-111-06

GeoTrax Survey LTM™ Temporal Monitoring Results
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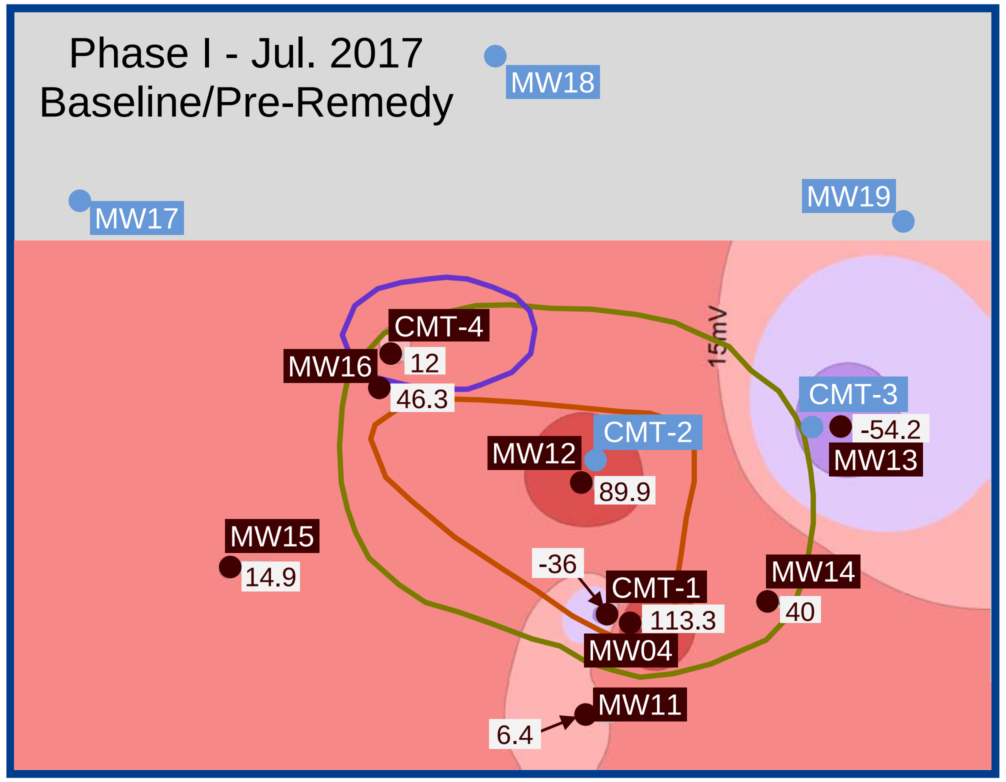
FIGURE

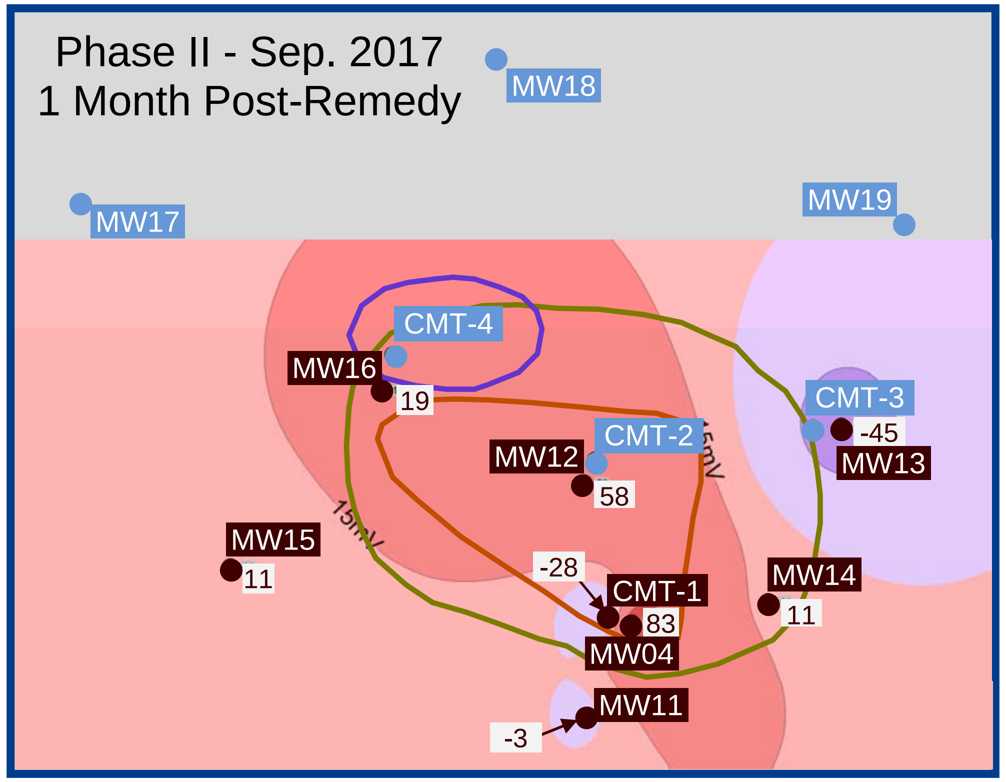
11

Shallow ORP (mV) Data

Data sampled at ~ +3' to –5' amsl



Phase I - Jul. 2017
Baseline/Pre-Remedy

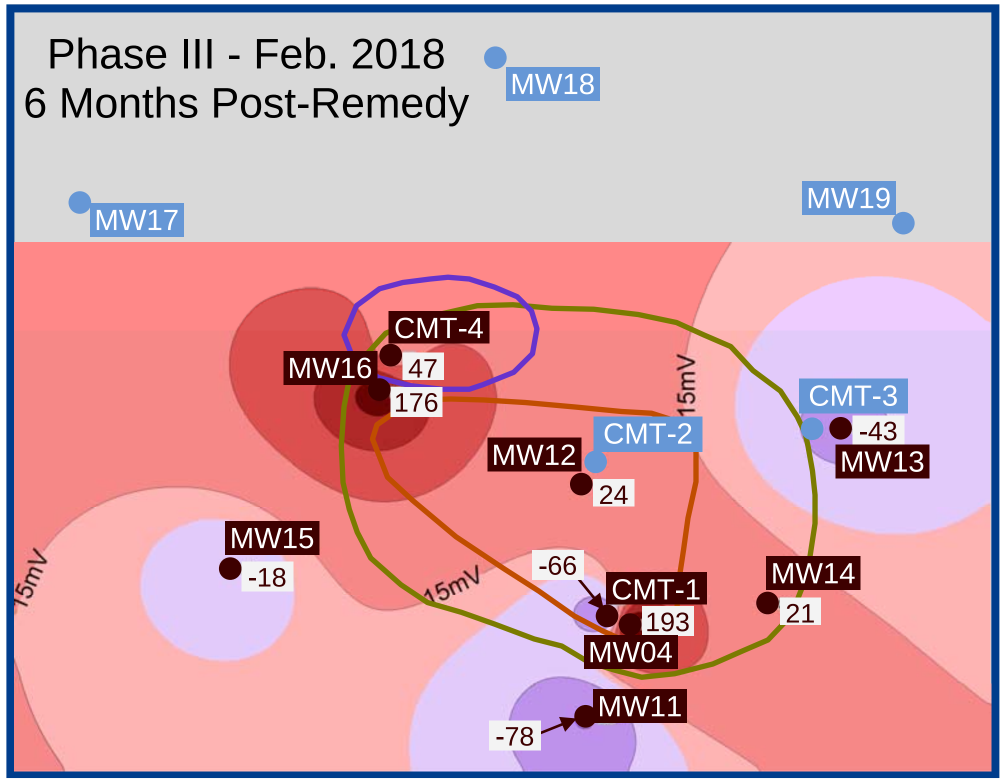


Phase II - Sep. 2017
1 Month Post-Remedy

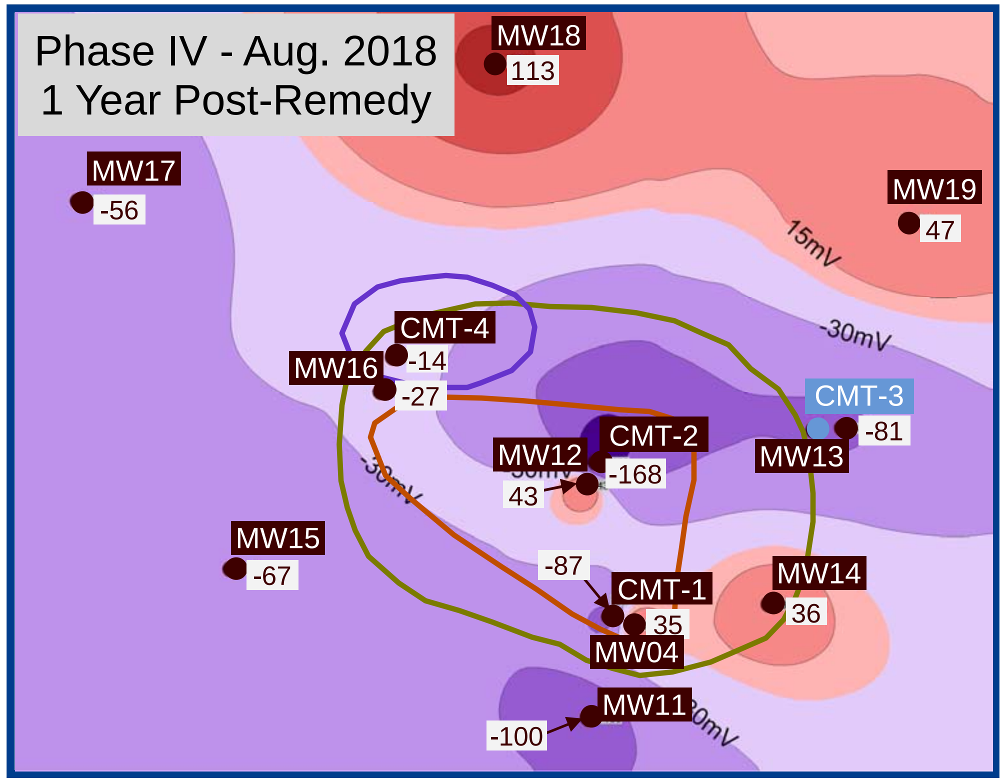
Legend

- 10,000 µg/L VOCs
- 1,000 µg/L VOCs / Remedy Zone
- Oil Only Remedy Zone
- ● Well
- ●

195	🟥
150	🟥
105	🟥
60	🟥
15	🟥
0	🟪
-30	🟪
-75	🟪
-120	🟪



Phase III - Feb. 2018
6 Months Post-Remedy



Phase IV - Aug. 2018
1 Year Post-Remedy

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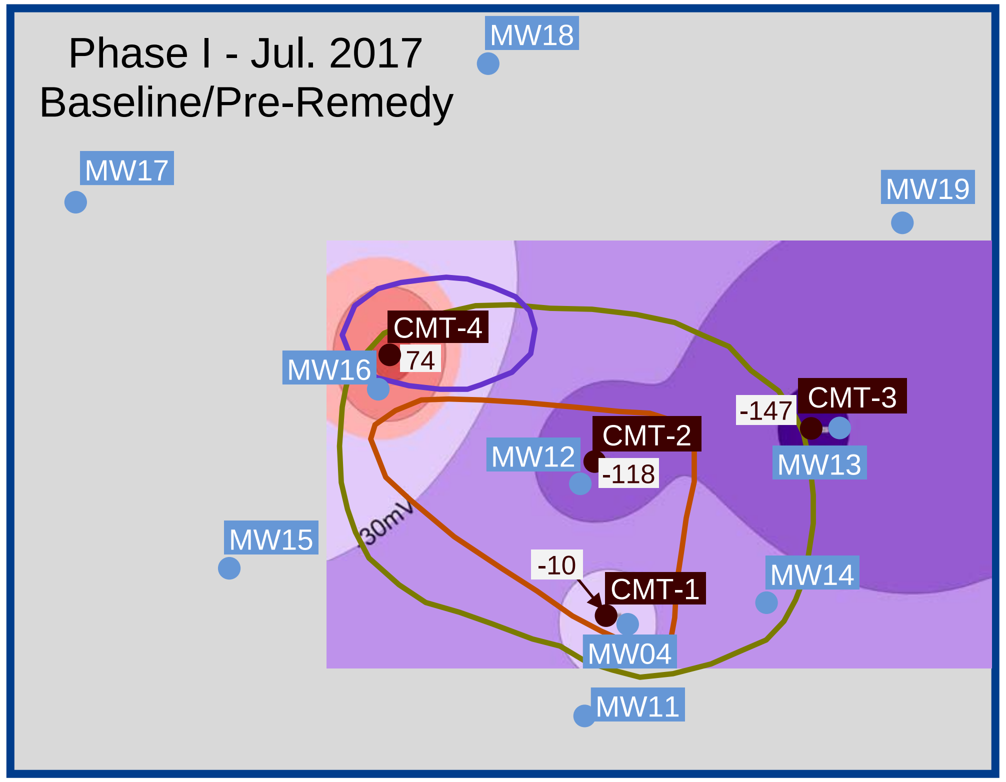
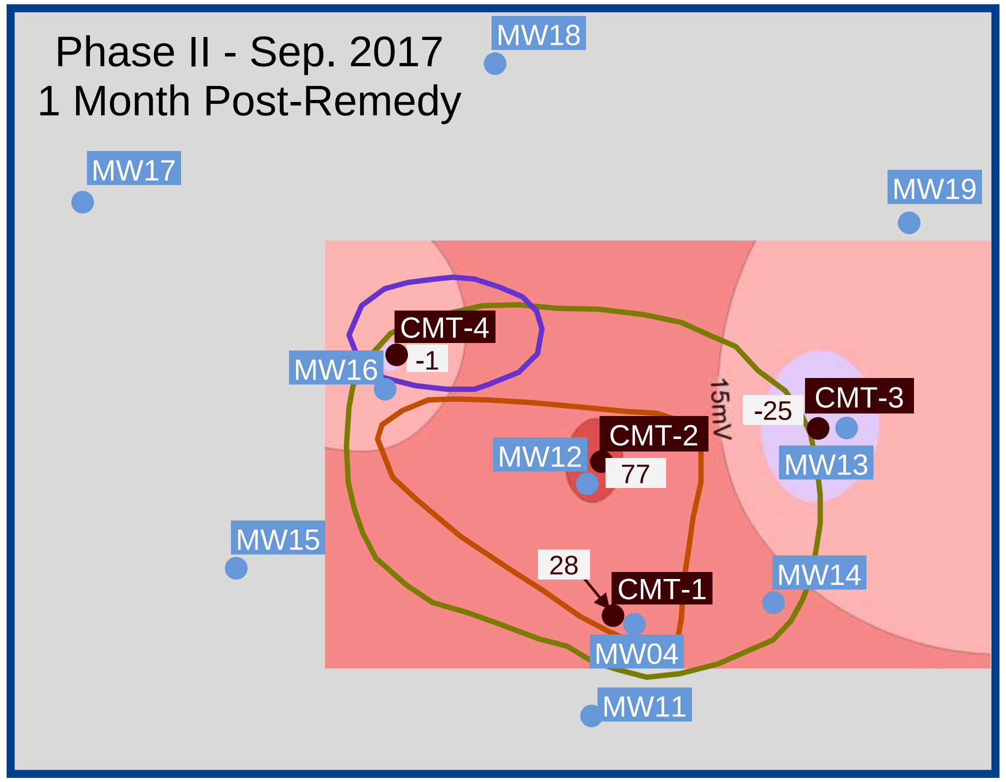
FIGURE
12

Deeper ORP (mV) Data

Data sampled at ~ –13’ to –16.5’ amsl

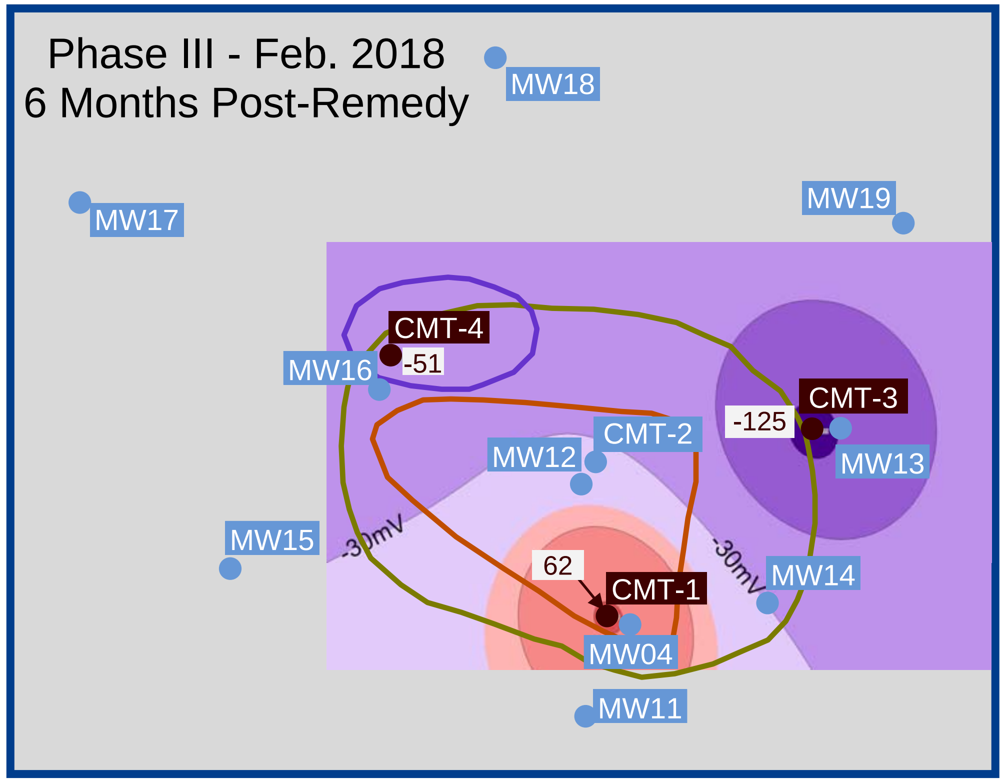

Phase I - Jul. 2017
Baseline/Pre-Remedy


Phase II - Sep. 2017
1 Month Post-Remedy

Legend

- 10,000 µg/L VOCs
- 1,000 µg/L VOCs / Remedy Zone
- Oil Only Remedy Zone
- ● Well
- ●

195	🟥
150	🟥
105	🟥
60	🟥
15	🟥
0	🟪
-30	🟪
-75	🟪
-120	🟪


Phase III - Feb. 2018
6 Months Post-Remedy

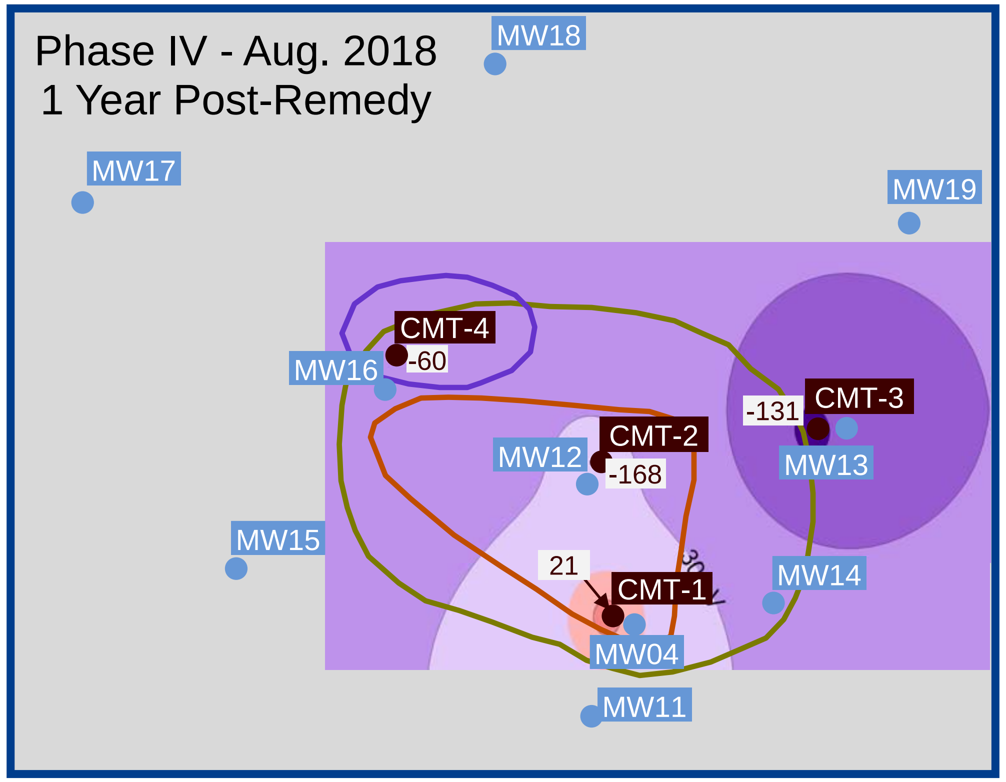

Phase IV - Aug. 2018
1 Year Post-Remedy

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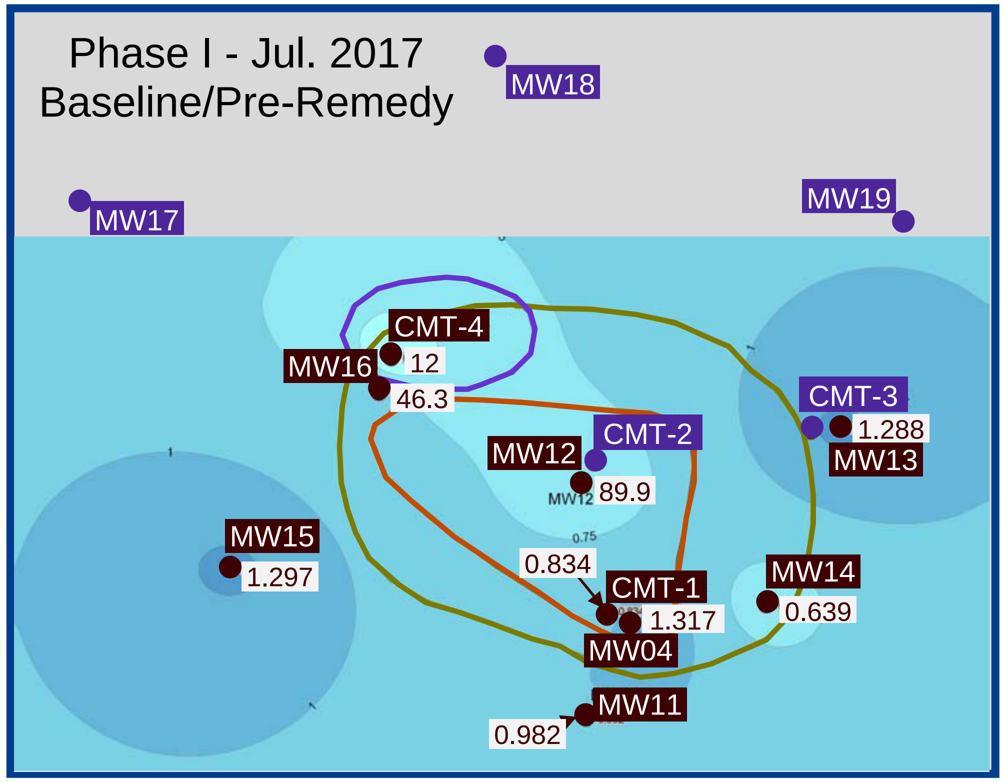
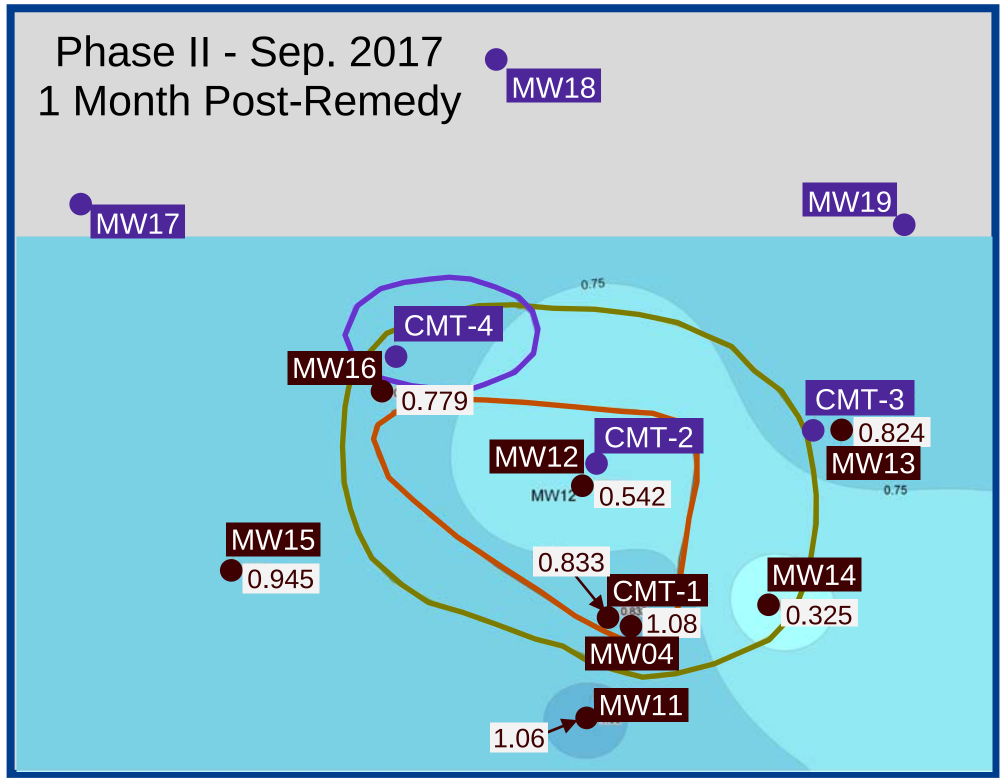
FIGURE
13



Shallow EC (mS/cm) Data

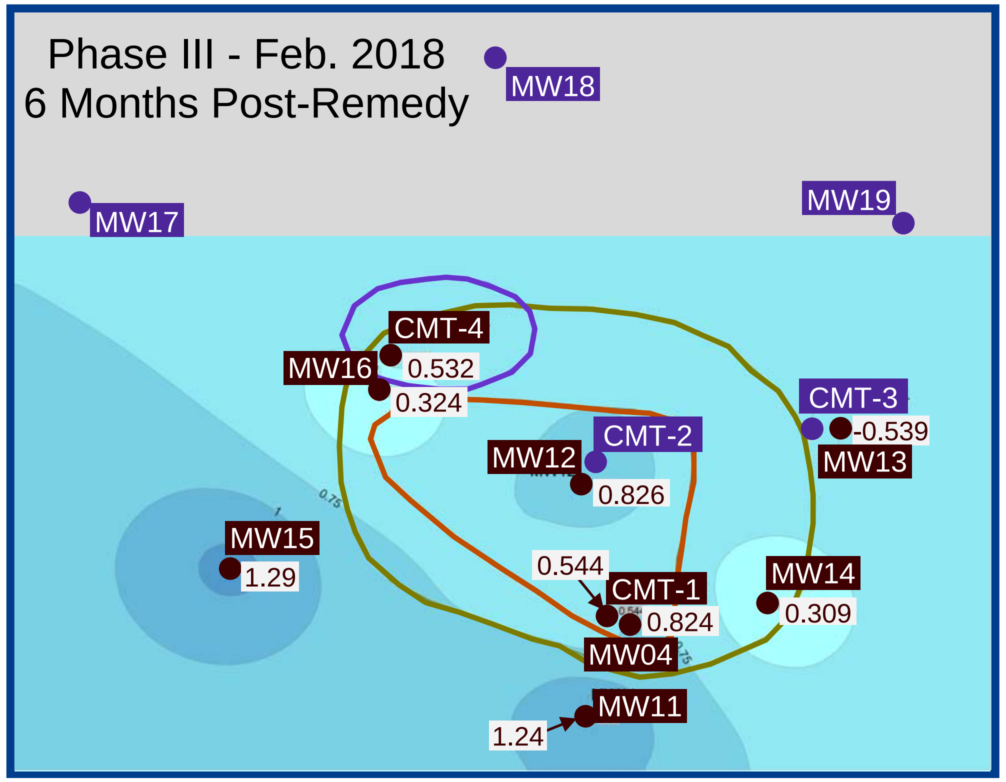
Data sampled at ~ +3' to –5' amsl



Legend

- 10,000 µg/L VOCs
- 1,000 µg/L VOCs / Remedy Zone
- Oil Only Remedy Zone
- ● Well
- ●

2.75	■
2.50	■
2.25	■
2.00	■
1.75	■
1.50	■
1.25	■
1.00	■
0.75	■
0.50	■
0.25	■



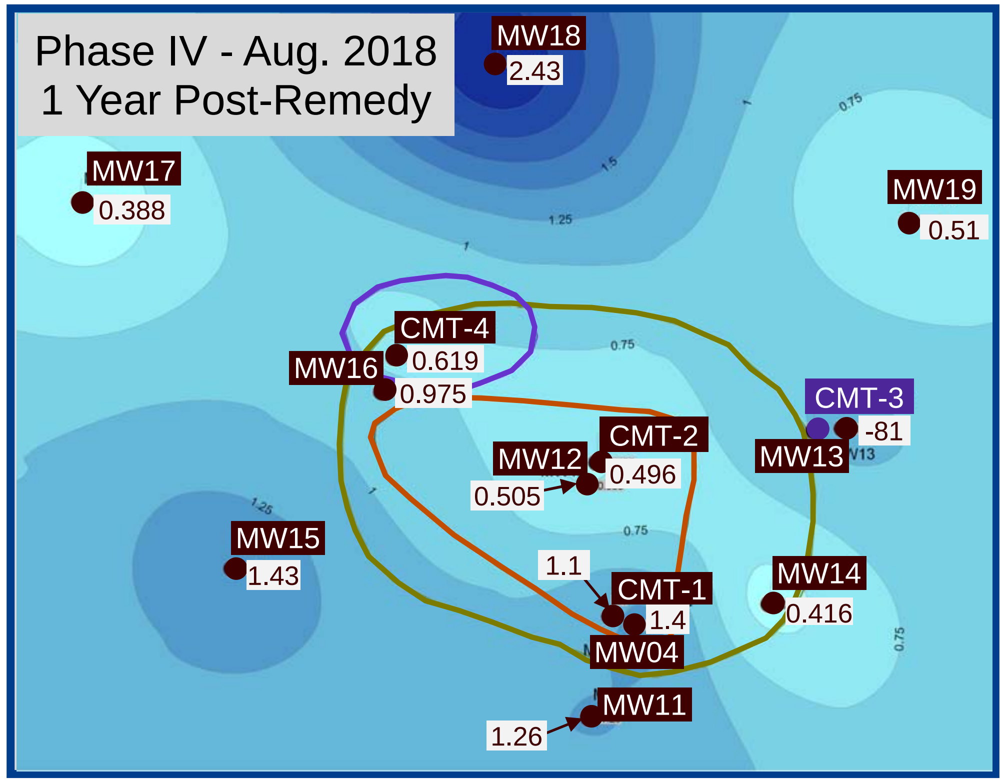


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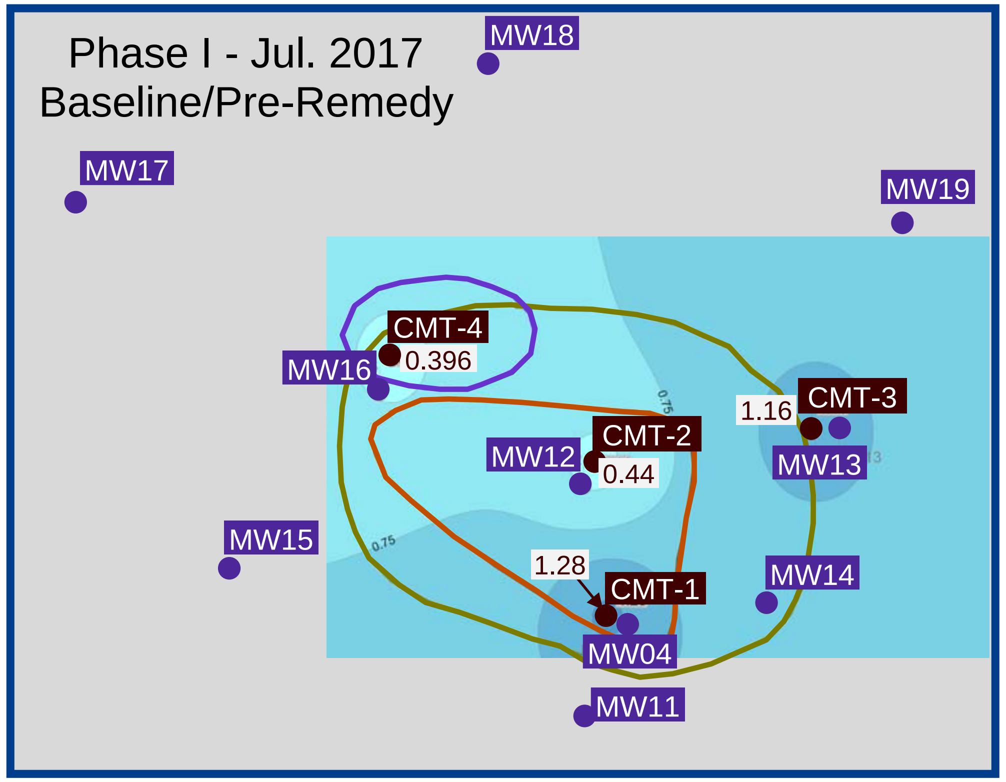
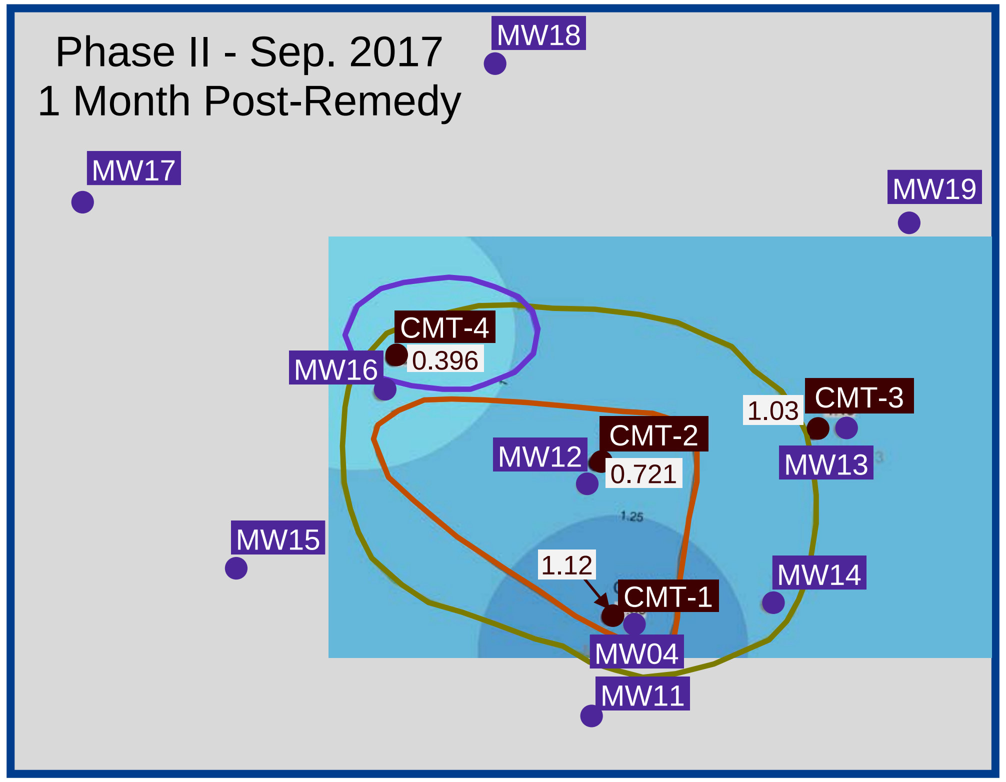
FIGURE
14

Deeper EC (mS/cm) Data

Data sampled at ~ –13' to –16.5' amsl





Legend

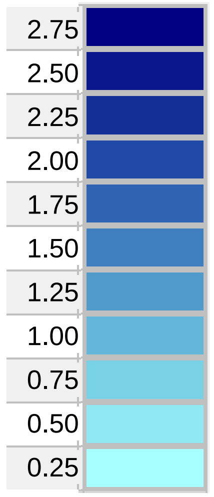
◯ 10,000 µg/L VOCs

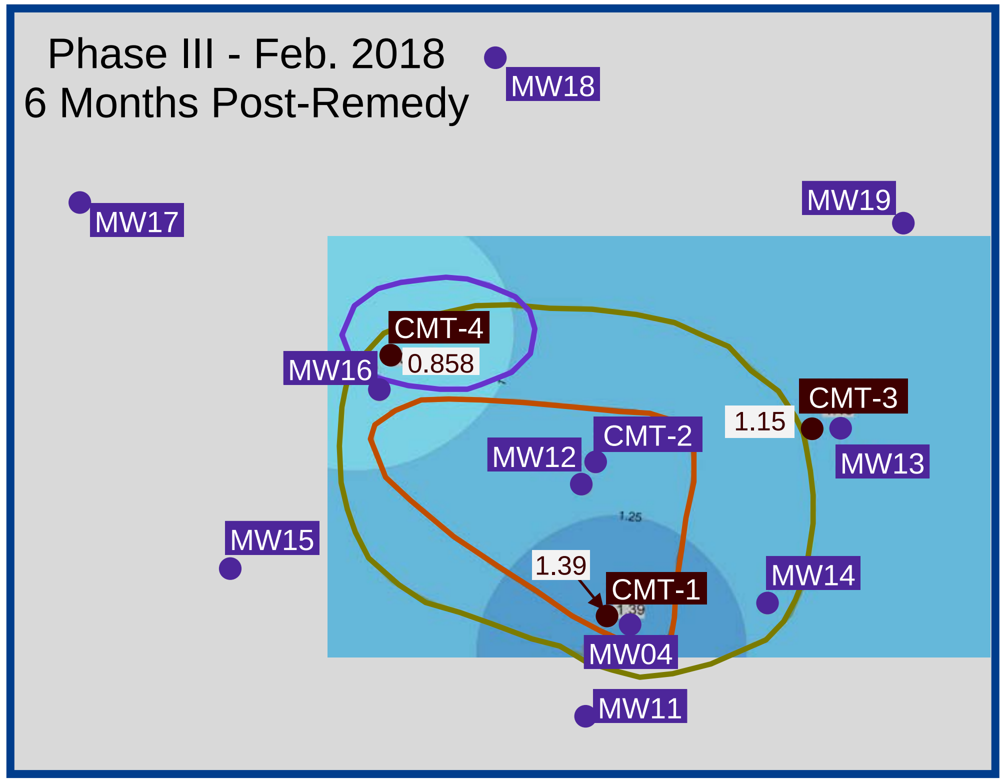
◯ 1,000 µg/L VOCs / Remedy Zone

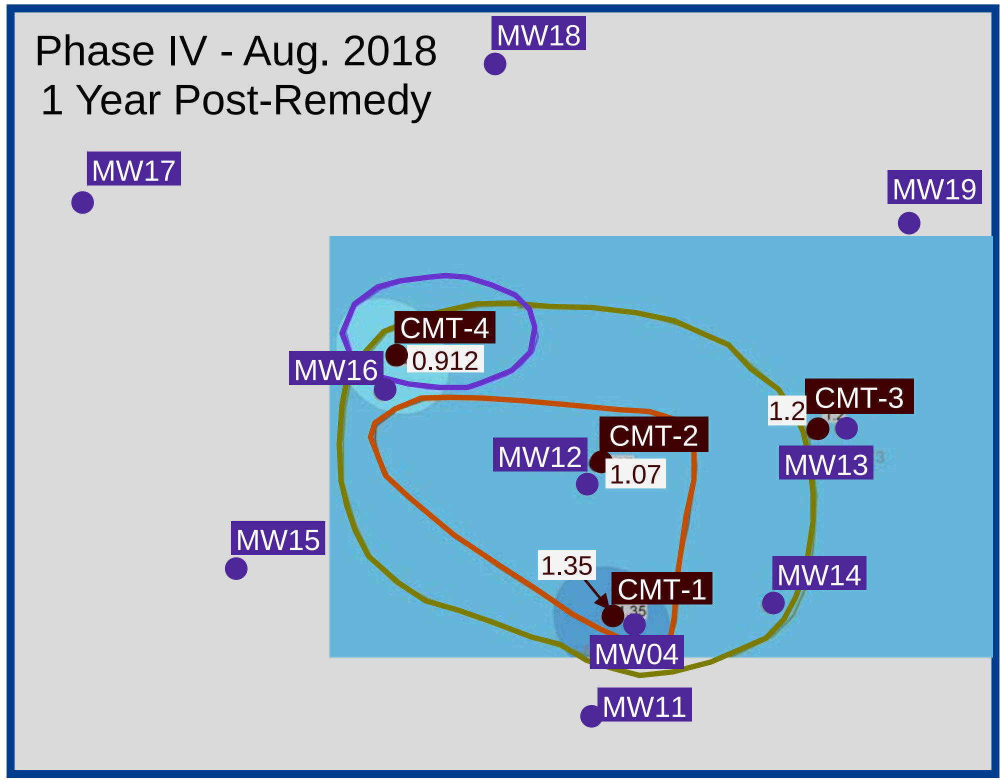
◯ Oil Only Remedy Zone

● Well

●







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Naval Support Facility Indian Head; North Site 17
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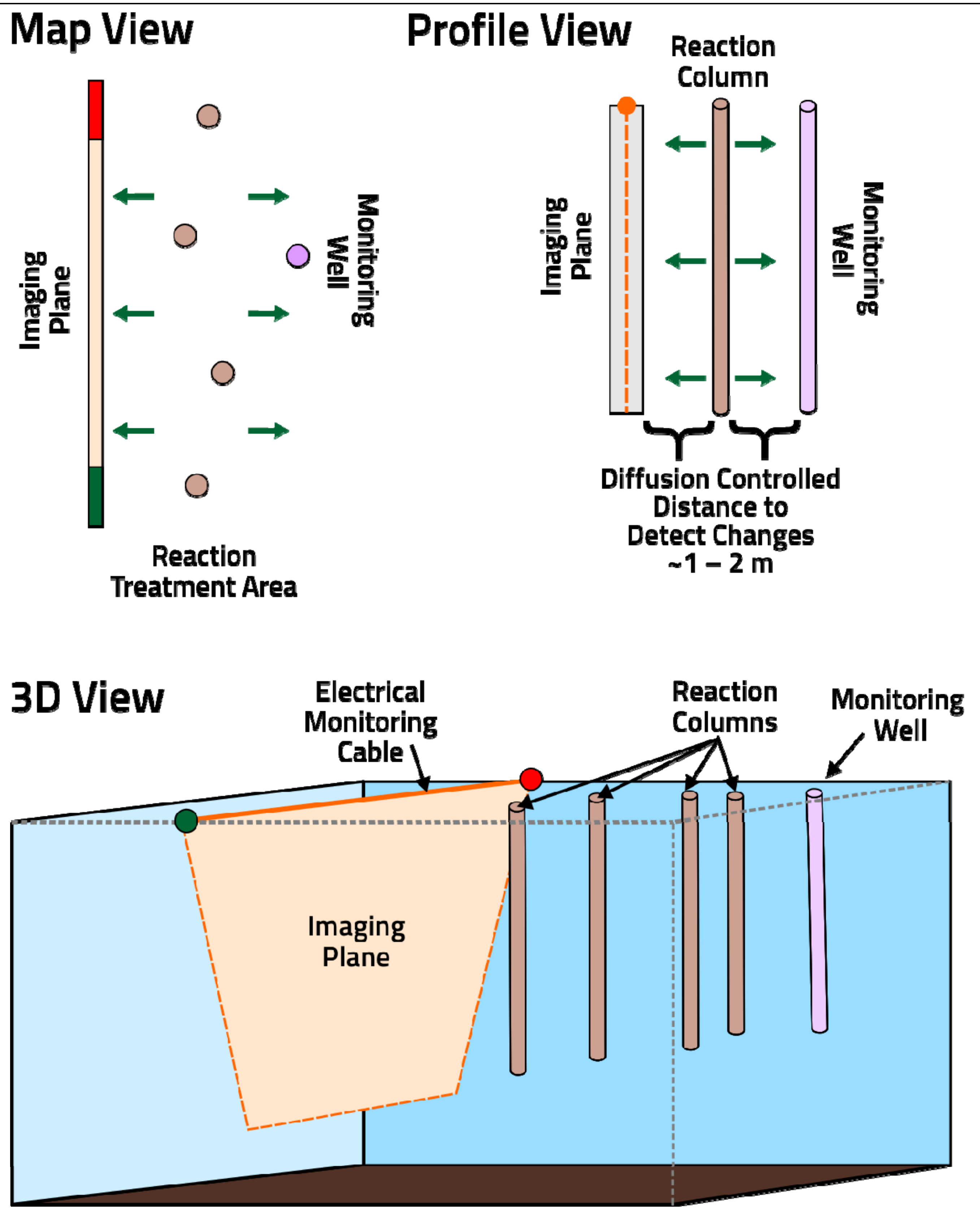
FIGURE

15



Graphic shows location of the reaction columns relative to Aestus GeoTrax Survey™ transect line (2D image) and site monitoring well locations and therefore:

- **GeoTrax Survey™ transect lines will not "see" the reaction columns as they are not located within the vertical 2D image plane**
- **GeoTrax Survey LTM™ temporal monitoring and monitoring wells may take time to see effects from reaction columns based on diffusion controlled mechanisms and typically longer associated timeframes**

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GeoTrax Survey LTM™ Transect Lines and MWs vs. Reaction Column Locations
Naval Support Facility Indian Head; North Site 17
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FIGURE
16

Representative Site Photos*

* All site photos included as an electronic appendix to this report

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Naval Support Facility Indian Head; North Site 17
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FIGURE

17

Electronic Data Transfer

(Sent via email with report transmittal)

Appendix G:	3D Model and Free Viewer (Electronic Data Transfer)
Appendix H	Site Photos (Electronic Data Transfer)
Appendix I-1	Phase I - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)
Appendix I-2	Phase II - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)
Appendix I-3	Phase III - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)
Appendix I-4	Phase IV - GeoTrax Survey™ XYZR Files (Electronic Data Transfer)

Appendix H. ZVI Specifications and Magnetic Separation Test Method

Appendix H. ZVI Specifications and Magnetic Separation Test Method

During the Bomber method field demonstration, two reaction column locations per day were sampled for iron content following the magnetic separation test (MST) method. Three samples were collected from different depths of the first column mixed in each treatment area. After the first week, two samples were collected from one column per day for iron content analysis.

Site 17 dosing criteria required between 28% and 52% fraction of iron. If the iron/sand ratio calculated following step 8 (below) was within that range, then the volume criteria was indicated to have been met.

Water Content Test

1. Weigh out approximately 25 grams of treated soil sample
2. Dry sample on a hot plate at temperature of 105° Fahrenheit for 1 hour.
3. Weigh the dry sample and calculate the water content

Magnetic Separation Test

1. Weigh out approximately 150 grams of treated soil sample
2. Add 150 to 200 milliliters (mL) of deionized water to the treated soil sample
3. Mix solution until soil particles are dispersed
4. Pass a high-powered magnet wrapped in cellophane through the slurry until all magnetic iron is removed
5. Remove the iron from the magnet and dry on a hot plate
6. Grind dry iron with mortar and pestle to remove any remaining soil adhering to iron
7. Use high powered magnet wrapped in cellophane to remove iron from dried soil
8. Weigh the iron and calculate the fraction of iron by dividing by the mass of iron by the dry mass of soil

Zero Valent Iron – 50D

Typical Specifications

Typical bulk density range: 145-195 pounds per cubic foot

All ZVI powders are 100% dry and oil free

Particle Size

Screen Size	% Retained
40	0
50	0-3
80	14
100	10
200	29
325	18
PAN	29
	100

Typical Chemistry

Element	Percentage
Iron	90+
Carbon	1.50-2.50
Silicon	2.00
Manganese	0.60
Sulfur	0.12
Phosphorus	0.14
Nickel	0.20
Chromium	0.20
Molybdenum	0.15
Copper	0.20

MAGNETIC SEPARATION TEST

Sample ID 0727-T1 **Date** 7/27/17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 24 g

Water Content 4%

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 150 g - measured

Volume of ZVI/Sand Sample 60 mL - measured

Water Content Adjusted Sample Weight 144 g 150 - (150)(0.04) = 144 g

Water Content Adjusted Sample Volume 54 mL 150(0.04) = 6g/0.997g/mL = 6 mL 60-6=54 mL

Volume of Water Added 200 mL

Weight of Iron Recovered 75g - measured

Volume of Iron Recovered 26 mL 75g/2.88g/mL **Measured Iron Density** 2.88g/mL

Iron/Sand Volume Ratio 48% $\frac{26\text{ mL}}{54\text{ mL}}$ **Volume Criteria Met?** Yes
(between 28% and 52% ZVI)

Notes:

Density of ZVI 145-195 lbs/ft^3
2.32-3.04 kg/L

Density of Water 0.997 g/mL

MAGNETIC SEPARATION TEST

Sample ID 0727-T2

Date 7-27-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 19 g

Water Content 24 %

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 232 g

Volume of ZVI/Sand Sample 100 mL

Water Content Adjusted Sample Weight 176.32 g

Water Content Adjusted Sample Volume 44.2 mL

Volume of Water Added 200 mL

Weight of Iron Recovered 112 g

Volume of Iron Recovered 38.8 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio 88 %

Volume Criteria Met? No
(between 28% and 52% ZVI)

Notes:

Density of ZVI 145-195 lbs/ft^3
2.32-3.04 kg/L

Density of Water 0.997 g/mL

MAGNETIC SEPARATION TEST

Sample ID 0728-T1

Date 7-28-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 21 g

Water Content 16 %

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 117 g

Volume of ZVI/Sand Sample 50 mL

Water Content Adjusted Sample Weight 98.3 g

Water Content Adjusted Sample Volume 31.2 mL

Volume of Water Added 200 mL

Weight of Iron Recovered 42 g

Volume of Iron Recovered 10.84 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio 34 %

Volume Criteria Met? Yes
(between 28% and 52% ZVI)

Notes:

Density of ZVI 145-195 lbs/ft^3
2.32-3.04 kg/L

Density of Water 0.997 g/mL

MAGNETIC SEPARATION TEST

Sample ID 0809-T1

Date 8-9-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 21 g

Water Content 16 %

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 128 g

Volume of ZVI/Sand Sample 50 mL

Water Content Adjusted Sample Weight 107.5 g

Water Content Adjusted Sample Volume 29.4 mL

Volume of Water Added 350 mL

Weight of Iron Recovered 41 g

Volume of Iron Recovered 14.25 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio 48 %

Volume Criteria Met? Yes
(between 28% and 52% ZVI)

Notes:

Density of ZVI 145-195 lbs/ft^3
2.32-3.04 kg/L

Density of Water 0.997 g/mL

MAGNETIC SEPARATION TEST

Sample ID 0809-T2

Date 8-9-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 21 g

Water Content 16%

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 108 g

Volume of ZVI/Sand Sample 50 mL

Water Content Adjusted Sample Weight 90.72 g

Water Content Adjusted Sample Volume 32.67 mL

Volume of Water Added 350 mL

Weight of Iron Recovered 36 g

Volume of Iron Recovered 12.5 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio 38%

Volume Criteria Met? Yes
(between 28% and 52% ZVI)

Notes:

Density of ZVI	145-195 2.32-3.04	lbs/ft^3 kg/L
Density of Water	0.997	g/mL

MAGNETIC SEPARATION TEST

Sample ID 0810 - T1

Date 8-10-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 20 g

Water Content 20 %

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 137 g

Volume of ZVI/Sand Sample 50 mL

Water Content Adjusted Sample Weight 109.6 g

Water Content Adjusted Sample Volume 22.5 mL

Volume of Water Added 350 mL

Weight of Iron Recovered 53 g

Volume of Iron Recovered 18.4 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio 81 %

Volume Criteria Met? No
(between 28% and 52% ZVI)

Notes:

Density of ZVI 145-195 lbs/ft^3
2.32-3.04 kg/L

Density of Water 0.997 g/mL

GSI Job No. 4460-301

ESTCP WICK DRAIN
FIELD DEMONSTRATION

GSI
ENVIRONMENTAL

MAGNETIC SEPARATION TEST

Sample ID 0810-T2

Date 8-10-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 20 g

Water Content 20 %

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 119 g

Volume of ZVI/Sand Sample 50 mL

Water Content Adjusted Sample Weight 95.2 g

Water Content Adjusted Sample Volume 26.1 mL

Volume of Water Added 350 mL

Weight of Iron Recovered 21 g

Volume of Iron Recovered 7.3 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio 28 %

Volume Criteria Met? Yes
(between 28% and 52% ZVI)

Notes:

Density of ZVI 145-195 lbs/ft^3
2.32-3.04 kg/L

Density of Water 0.997 g/mL

GSI Job No. 4460-301

ESTCP WICK DRAIN
FIELD DEMONSTRATION

GSI
ENVIRONMENTAL

MAGNETIC SEPARATION TEST

Sample ID 0811-T1

Date 8-11-17

WATER CONTENT TEST

Weight of Treated Soil 25 g

Weight of Dry Sample 21 g

Water Content 16%

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample 126 g

Volume of ZVI/Sand Sample 50 mL

Water Content Adjusted Sample Weight 105.8 g

Water Content Adjusted Sample Volume 29.7 mL

Volume of Water Added 350 mL

Weight of Iron Recovered 47g

Volume of Iron Recovered 16 mL

Measured Iron Density 2.88 g/mL

Iron/Sand Volume Ratio ~54%

Volume Criteria Met? No
(between 28% and 52% ZVI)

Notes:

Density of ZVI	145-195	lbs/ft^3
	2.32-3.04	kg/L
Density of Water	0.997	g/mL

MAGNETIC SEPARATION TEST

Sample ID 0811-T2

Date 8-11-17

WATER CONTENT TEST

Weight of Treated Soil	25 g
Weight of Dry Sample	20 g
Water Content	20 %

MAGNETIC SEPARATION TEST

Weight of ZVI/Sand Sample	114 g
Volume of ZVI/Sand Sample	50 mL
Water Content Adjusted Sample Weight	91.2 g
Water Content Adjusted Sample Volume	27.1 mL
Volume of Water Added	350 mL
Weight of Iron Recovered	35 g
Volume of Iron Recovered	12.15 mL
Iron/Sand Volume Ratio	~45 %

Measured Iron Density 2.88 g/mL

Volume Criteria Met? Yes
(between 28% and 52% ZVI)

Notes:

Density of ZVI	145-195 2.32-3.04	lbs/ft^3 kg/L
Density of Water	0.997	g/mL

MAGNETIC SEPARATION TEST

Sample ID 0811-T3

Date 8-11-17

WATER CONTENT TEST

Weight of Treated Soil	25 g
Weight of Dry Sample	21 g
Water Content	16 %

MAGNETIC SEPARATION TEST

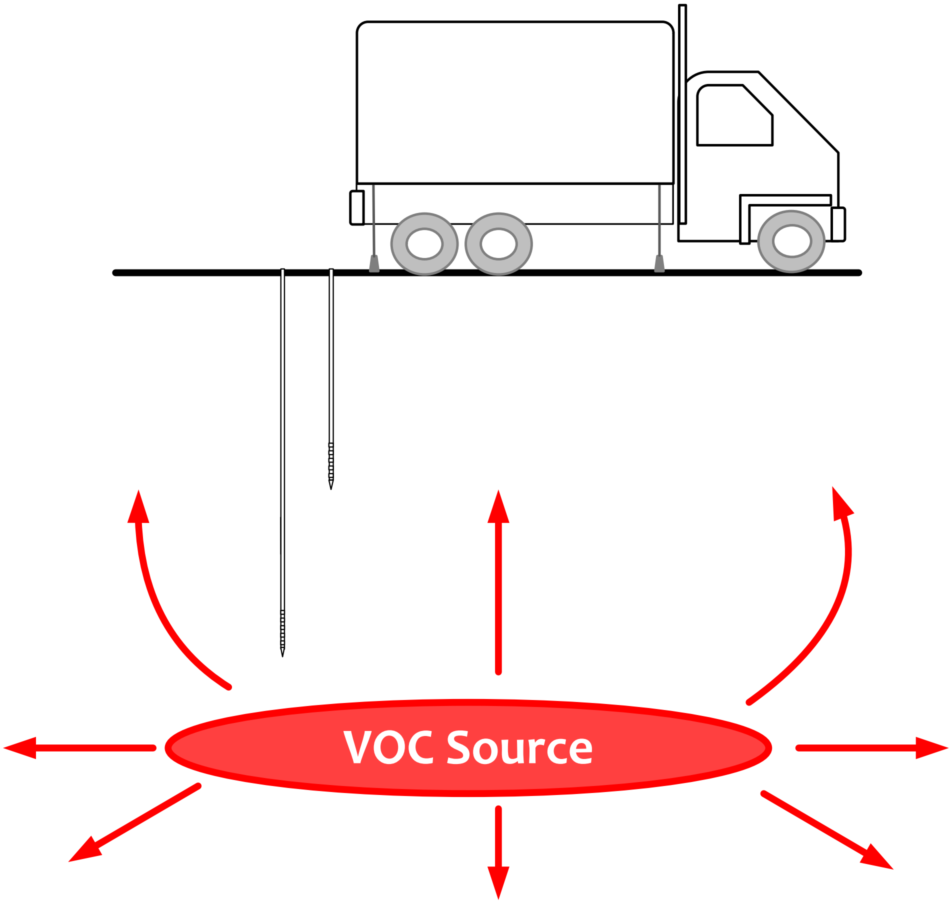
Weight of ZVI/Sand Sample	114 g		
Volume of ZVI/Sand Sample	50 mL		
Water Content Adjusted Sample Weight	95.8 g		
Water Content Adjusted Sample Volume	31.75 mL		
Volume of Water Added	350 mL		
Weight of Iron Recovered	41 g		
Volume of Iron Recovered	14.2 mL	**Measured Iron Density**	2.88 g/mL
Iron/Sand Volume Ratio	~45 %	**Volume Criteria Met?** (between 28% and 52% ZVI)	Yes

Notes:

Density of ZVI	145-195 2.32-3.04	lbs/ft^3 kg/L
Density of Water	0.997	g/mL

Appendix I. Soil Vapor Installation and Sampling Procedures

ADVISORY
ACTIVE SOIL GAS INVESTIGATIONS



California Environmental Protection Agency
Department of Toxic Substances Control
Los Angeles Regional Water Quality Control Board
San Francisco Regional Water Quality Control Board

July 2015

Modified from original; abridged to include relevant sections

Soil gas samples collected immediately above the source of contamination are more likely to be representative of what may be in contact with the building's foundation (Hers et al., 2006; DiGiulio and Cody, 2006; and USEPA, 2012). Likewise, the numerical modeling conducted by Abreu and Johnson (2005), Abreu and others (2006), and Bozkurt and others (2009) also suggests this relationship. Hence, risk estimates may be biased low if quantified with shallow soil gas measurements when using the Johnson and Ettinger (1991) model. Maximum subsurface concentrations, or soil vapor concentrations representative of source conditions, should be used for preliminary vapor intrusion screening evaluations. A five foot deep sample is not appropriate if there is a deeper source. Accordingly, collecting soil gas samples near contaminant sources is recommended for vapor intrusion modeling. Vertical soil gas sampling should be conducted to determine the source of subsurface contamination. Ideally, numerous vertical profiles of soil gas should be developed at the site to accurately locate subsurface sources. Once located, soil gas collection can be targeted at these depths site-wide. Typically, contaminant sources are adjacent to the areas of highest subsurface concentration.

3.2 INSTALLATION PROCEDURES

Soil gas well installation procedures are described below. Soil gas well construction should ensure a good seal between the formation and sampling assembly, and minimize ambient air breakthrough. Additional standards may be required by local oversight agencies.

3.2.1 Installation Methods and Design

Soil gas wells may be installed using a variety of drilling methods such as direct push, hollow stem auger or hand auger. Certain drilling methods that significantly disrupt soil gas equilibrium, such as air rotary and rotosonic, may be employed if longer equilibration times are used prior to sampling. The mud rotary drilling method is not acceptable for soil gas probe emplacement under any circumstances. Following is a step-by-step guide to soil gas well (probe) installation after the borehole has been drilled:

1) Sand Pack. Install a sand pack to minimize disruption of airflow to the sampling tip. A tremie pipe should be used for soil gas wells deeper than 15 feet to avoid bridging or segregation during placement of the sand pack and annular seal. Place the probe tip midway in the sand pack, as shown on Figure 1 with at least six inches of sand above and below the probe tip.

2) Transition Seal. Emplace at least six inches of dry granular bentonite on top of each sand pack, as shown on Figure 1. Granular bentonite is preferred over bentonite in powdered or pellet form for the sand pack / annular seal transition. Following the dry bentonite, fill the borehole to the surface with an appropriate annular sealing material (see below). The purpose of the dry granular bentonite between the sand pack and the annular seal is to prevent water and clay from the annular seal infiltrating into the sand pack. A tremie pipe should be used for the emplacement of the transition seal in soil gas wells that are deeper than 15 feet, otherwise the material can be gravity fed (freefall) from the surface.

3) Annular Seal. The composition of the annular seal is a function of the long-term use of the soil gas well, as follows:

- Temporary Soil Gas Wells. For wells that will be sampled for less than one year, the annular seal can be hydrated bentonite or other materials, as appropriate. Studies have shown that bentonite annular seals in the vadose zone desiccate readily and will not rehydrate once damaged (Lackey et al., 2009). Hence, bentonite-only annular seals are discouraged for long-term use. The integrity of a bentonite annular seal can be increased by adding sand to the grout mixture as indicated by Lackey (2009).

- Permanent Soil Gas Wells. For wells that will be used for longer than one year, the annular seal should be neat cement with bentonite. Typically, the bentonite content is 1 – 5 percent. The integrity of a neat cement annular seal can be increased by adding sand to the grout mixture as indicated by Lackey (2009).

When using a bentonite seal on a temporary soil gas well, the bentonite should be hydrated at the surface in a container and then slowly poured or pumped into the borehole. If the borehole is deeper than 15 feet, a tremie pipe should be used to place the hydrated bentonite.[4]

It is important to have a good annular seal to prevent “short circuiting” of air from the upper portions of the borehole into the sample, yielding contaminant concentrations not indicative of the targeted interval. Follow a similar procedure for deep well construction with multiple probe depths, in that one foot of dry granular bentonite should be emplaced on top of the sand pack encasing each probe, followed by the annular sealing material. The annular seal should continue until the next sand pack, as shown on Figure 1. Accordingly, soil gas probe construction should be consistent with California Department of Water Resources Bulletin 74-90 (California Well Standards) (DWR 1991) and the annular seal should be appropriate for the local climate, subsurface conditions, and permanence of the soil gas well.

4) Probe Support Rod. A down-hole rod should be used to support the well tubing in the borehole. A down-hole rod is a support device used in boreholes deeper than 15 feet to ensure that probe tips are placed at appropriate depths. A small diameter PVC pipe that is capped at both ends is the most commonly used material for probe support. The probe support is created by attaching the probe tip and tubing to the exterior of the PVC pipe. Other materials may be used, such as metal, as long as the support rod is free of contaminants. Depending on the depth, centralizers may be necessary to ensure the support rod is in the center of the borehole. Alternative probe support designs with accompanying descriptions may be proposed in the project workplan. Justification should be

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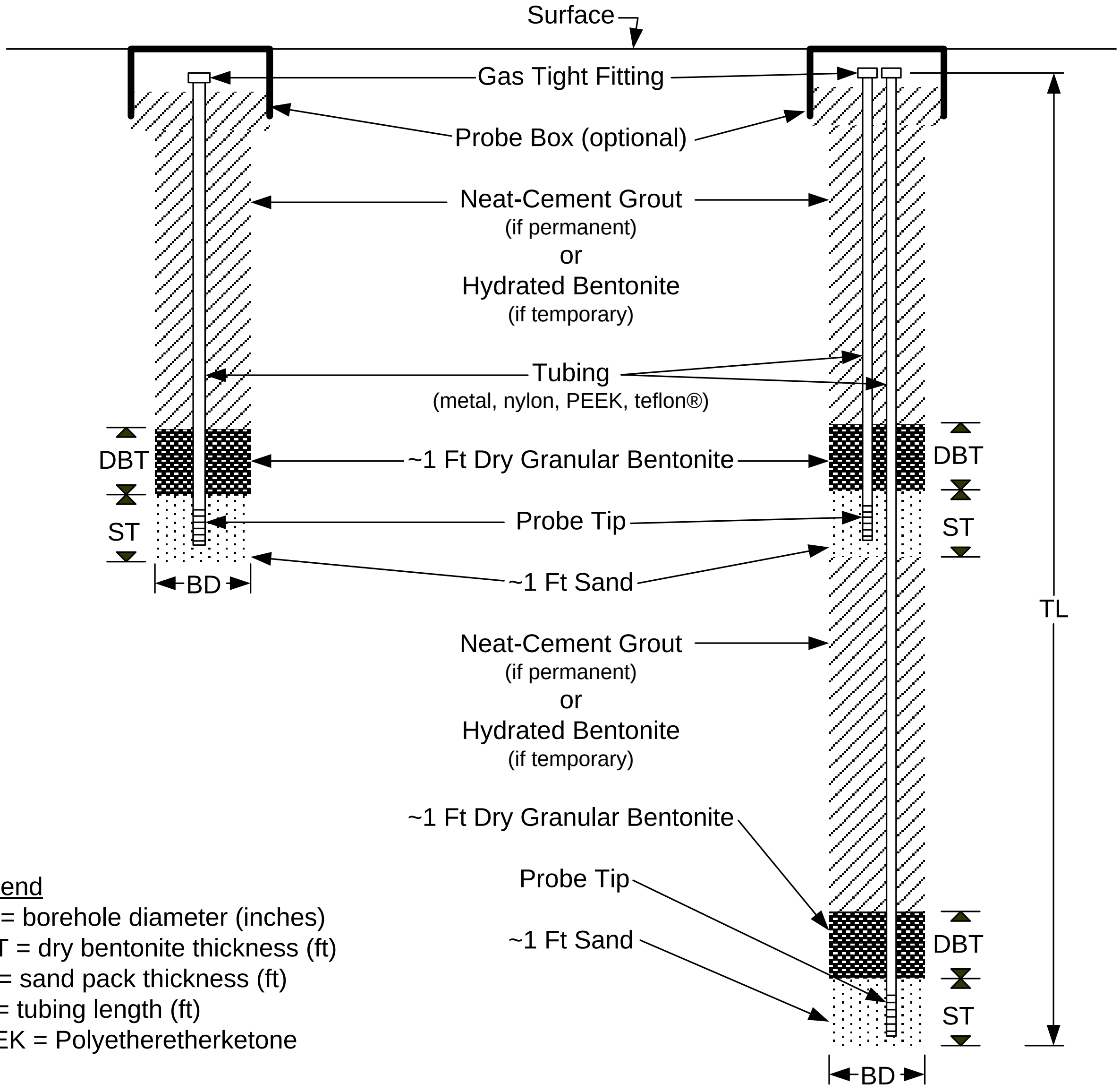
[4] The protocol for the placement of the hydrated bentonite is similar to the approach in USEPA (2014).

included in the project workplan if the project proponent chooses not to use probe support for deep soil gas wells.

Figure 1

Typical Single and Nested Soil Gas Probe Design



Legend
BD = borehole diameter (inches)
DBT = dry bentonite thickness (ft)
ST = sand pack thickness (ft)
TL = tubing length (ft)
PEEK = Polyetheretherketone

Neat-Cement Grout means a mixture in the proportion of 94 pounds of Portland cement and not more than 6 gallons of water. Bentonite up to 5 percent by weight of cement (4.7 pounds of bentonite per 94 pounds of Portland cement) may be used to reduce shrinkage.

3.2.2 Sampling Tubing

Small diameter (1/8 to 1/4 inch) tubing is typically used for probe construction, made of material which will not react or interact with site contaminants. At sites where soil moisture is high and/or finer-grained materials are present, larger diameter tubing, up to 3/4-inch, may also be used. Using larger diameter tubing is less susceptible to plugging by high soil moisture and fine-grained materials. The same soil gas sampling protocols for smaller tubing apply to the larger tubing. The probe tip, probe and probe connectors should all have the same diameter to provide a good seal between the formation and the sampling assembly. The following steps will help ensure a good-quality soil gas sample.

- Clean, dry tubing should be used at all times. If any moisture or unknown material is present in the tubing prior to insertion, decontaminate or replace the tubing;

- The bottom-end of the tubing should be attached to a soil gas probe tip. Downhole equipment (probe screens, tie wires, etc.) or drive heads should be free of cutting oils and other contaminants;

- Metal tubes should not be used to collect hydrogen sulfide samples. Nylaflow®, polyetheretherketone (PEEK), and Teflon® are recommended for soil vapor sampling. Low-density polyethylene (L-D PE) should not be used due to decreased performance relative to other tubing types in both off-gassing of VOCs inherent in the tubing structure (contribution to background) and for decreased contaminant recovery (reactivity). Reduced recovery of naphthalene was observed when using Nylaflow® tubing with small sample sizes. For additional information, see Appendix B;

- Prior to sampling, an assembled soil gas probe, tip and tubing should be blank tested at a frequency of one analysis per new batch of tubing or material used. Demonstration of equipment cleanliness enhances the quality of soil gas data. The need for blank testing of tubing, probe tips, or an assembled soil gas probe should be evaluated through the DQO process. Demonstrating cleanliness is needed because even new, unused, tubing may be stored inappropriately, such as near fuel sources or exhaust ports. Likewise, probe tips may contain residual oils from the manufacturing process. Some common ways of blank testing are as follows:

  a. Coiled Tubing. Spools of tubing can be blank tested by collecting a sample of the dead air within the tubing. The tubing should not be purged prior to sampling and the sampling volume should be less than the dead space within the tubing. The air should be analyzed for site constituents. The air sample from the coiled tubing can be collected by either the field crew or by laboratory personnel prior to taking the tubing to the site.

  b. Assembled Soil Gas Probe. A soil gas probe can be assembled and then blank tested prior to insertion into the subsurface. A length of tubing representative of the maximum sampling depth for the site should be cut from the tubing spool and a probe tip attached to one end. Pressure gauges, fittings and valves can also be attached as appropriate. A sample of dead air from the probe should be collected in the same manner as when collecting a soil gas sample. The sampling volume should not exceed the dead space in the probe. This testing can be conducted in the field or by the stationary or mobile laboratory prior to using the tubing. If conducted by a stationary laboratory, the dead air in the assembled probe may be replaced by zero-grade air and this zero-grade air may be tested;

c. Probe Tips. Probe tips can be blank tested with distilled water. The most common method is to pour distilled water over the tip and through the inside, collecting the water in a container appropriate to the analytical method. The collected water should be tested for all site contaminants.

3.2.3 Drive Point Method

Post-run tubing (PRT) and drive point methods[5] used to create temporary soil gas wells may be used to rapidly acquire soil gas samples when carefully installed. Contractors should ensure that installation includes regularly checking and cleaning of the PRT tip threads and its seat and changing the O-rings on a daily basis. Contractors should use stiff tubing to couple the PRT tip to the connective hose and use ¼ inch outer diameter, thick-wall tubing to ensure sufficient torque is available to screw the tip tightly into the seat. If the O-ring is not seated properly into the drill rod, ambient air from inside the rod could enter into the sampling system, introducing ambient air into the soil gas sample, biasing the sampling results. The integrity of the seal of the O-ring cannot be readily evaluated with a leak check compound, and the inability to evaluate the integrity of the O-ring seal should be evaluated with the DQO process.

Representative soil gas samples may be difficult to obtain with PRT and drive point methods in certain lithologies. Drive point probes may be deflected by consolidated lithologies and strata containing cobbles or boulders, which can create gaps between the outer wall of the drive rod and the subsurface that are difficult to observe and equally difficult to seal. A hydrated bentonite plug at ground surface does not stop communication along the annular space. Samples collected under these circumstances will potentially draw soil gas primarily from the most permeable layer above the probe tip which may introduce a significant bias. Moreover, this condition is difficult to identify by a leak check compound applied at or near ground surface. Collecting representative soil gas samples in these conditions may require alternative sampling methods such as passive soil gas sampling or the installation of permanent sampling wells.

3.3 SOIL GAS WELL COMPLETION

Soil gas wells should be secured, capped and completed to prevent infiltration of water or ambient air into the subsurface, and to prevent accidental damage or vandalism. Mark the tubing at the surface to identify the probe location and depth. For surface completions, the following components may be installed:

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[5] Drive point methods may be appropriate for certain site conditions or circumstances depending on DQOs. The use of post-run tubing should be discussed with the regulating agency prior to inclusion in the workplan.

1) Gas-tight valve or fitting for capping the sampling tube;
2) Utility vault or meter box with ventilation holes and lock;
3) Surface seal; and
4) Guard posts.

3.4 DECOMMISSIONING

When sample collection ceases at a vapor well, properly remove or decommission wells with concurrence from the regulating agency. The decommissioning process should prevent the well and associated borehole from becoming a conduit for the preferential migration of contamination. The decommissioning procedures within the California Well Standards (Bulletin 74-90) should be followed along with any local requirements.

When decommissioning vapor wells with tubing, the following decommissioning steps should be followed:

1) Excavate the borehole down to approximately three feet below grade, exposing the upper portion of the tubing.
2) Either cut the tubing near the bottom of the excavated hole or pull the tubing out of the ground by hand, removing as much tubing as possible.
3) If tubing is still visible in the hole upon removal by hand, cut the tubing near the bottom of the hole, then insert[6] sealant, such as powdered bentonite grout, or silicone caulk, into the exposed tubing, filling it as much as possible;
4) Fill the open hole with cement grout to within one foot of the surface grade;
5) Fill the last foot of the hole with compacted native material; and,
6) Restore pavement and vegetation to original conditions, if needed.

When decommissioning vapor wells constructed with ridged casing, wells can be overdrilled or cement grouted in place pursuant to local requirement. When overdrilling, a casing guide should be used to prevent the drill bit from drifting during the decommissioning. A casing guide will allow the drill bit to remain aligned on the top of the well casing, allowing for effective removal of the well material. Once the well material is removed, the borehole should be filled with cement grout. If vapor wells penetrate clay units, consideration should be given to overdrilling rather than abandonment in place in order to prevent preferential contaminant migration.

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[6] Inserting sealant may be accomplished by using a peristaltic pump or large syringe. Sealant must be free of lumps to freely pass down the tubing.

3.5 DECONTAMINATION

Decontaminate all reusable equipment to prevent cross contamination. Tubing is not reusable and should not be decontaminated. Instead, use new or unused sampling tubing for each probe location.

Decontamination may consist of steam cleaning or a three-stage decontamination process consisting of a wash with a non-phosphate detergent, a rinse with tap water and a final rinse with distilled water. Collect one equipment blank at the beginning of sampling and at least one each day after decontamination. Equipment should be air-dried before reuse.

The most common method of collecting an equipment blank is to pour distilled water over recently decontaminated piece of equipment and collect the water in an appropriate container for analysis of site constituents. Drill rods contacting contaminated soil should be decontaminated before reuse and blank tested as appropriate. If soil gas samplers arrive at the site after drill rig demobilization, equipment blanks should be provided by the drilling contractor. As discussed in Section 3.2.2, an equipment blank is recommended for probe tubing and probe tips. A syringe blank may be collected by sampling ultra-pure air as it passes through the syringe, and a syringe blank is not an acceptable substitute for the driller’s equipment blank. The equipment blanks demonstrate there is no residual contaminant carryover from other sites or the manufacturing process.

3.6 SUB-SLAB INVESTIGATION METHODS

The procedures for collecting sub-slab soil gas samples directly under a building’s foundation are the same as for collecting subsurface soil gas samples. When collecting sub-slab samples, if a building is determined to have a moisture barrier and/or a tension slab, special care should be given when hand-drilling through the concrete slab. In particular, for tension foundation slabs, the tension cables within the slab should be located prior to drilling either through visual observation or through remote-sensing with either a metal detector or ground penetrating radar. The cutting of a tension cable within a slab during drilling could disrupt the integrity of the slab and potentially cause injury to the field crew.

When evaluating sub-slab soil gas for a building, permanent sampling points should be installed so repeated sampling can be conducted, as necessary, to evaluate seasonal or temporal variations.

For sub-slab samples, after removal of the floor covering, a small-diameter hole should be drilled through the concrete of the foundation slab. Typically, holes are 1.0 to 1.25 inches in diameter. Either an electric hand drill or concrete corer is used to drill the holes. All sub-slab utilities, such as water, sewer, and electrical, should be located and clearly marked on the slab prior to drilling. Sub-slab holes should be advanced three to four inches into the engineering fill below the slab. All drill cuttings should be removed from the borehole. A typical sub-slab probe design is shown in Figure 2. The sampling probe should be constructed with the following specifications:

- Vapor probes are typically constructed of 1/8 inch or 1/4 inch diameter tubing, with a permeable probe tip. Alternate sub-slab sampling devices are commercially available. The reviewing agency should be consulted on the vapor probe construction prior to development of the workplan.

- Depending on the type of sub-slab probe construction, install a sand pack to minimize disruption of airflow to the sampling tip. Place the probe tip midway in the sand pack, as shown on Figure 2.

- Dry granular bentonite should be used to fill the borehole annular space to above the base of the concrete foundation.

- Hydrated bentonite should then be placed above the dry granular bentonite. The bentonite for this portion of probe construction should be hydrated at the surface to ensure proper sealing. Care should be used in placement of the bentonite to prevent post-emplacement expansion which might compromise both the probe and cement seal.

- The remainder of the hole should be filled with neat cement mixed with bentonite if the probe is permanent or with hydrated bentonite if the probe will be used for less than a year. Prior to the introduction of this material, the concrete surfaces in the borehole should be cleaned with a damp towel to increase the potential of a good seal and, ideally, all concrete dust should be removed from the borehole.

- All water used in the construction of the probe should be deionized, the cement should be contaminant-free and quick drying, and all metal probe components should be thoroughly cleaned to remove manufacturer-applied cutting oils.

- Each probe should be constructed with a gas-tight fitting and flush-mounted well box so that the probe completion is not a tripping hazard.

- Prior to sampling, at least two hours of time should elapse following installation of a probe to allow the construction materials to cure and allow for the subsurface to equilibrate (USEPA, 2006).

- The collection of sub-slab samples should follow the procedures in this Advisory, which recommends leak testing and shut-in testing. Purging and sampling rates should not exceed 200 milliliters per minute. To avoid air breakthrough from nearby, unobserved foundation cracks within the slab, DTSC recommends using sampling containers with volumes of less than or equal to one liter. If using passivated metal canisters, the canisters should be returned to the laboratory slightly depressurized, such as -2 inches of mercury.

- All laboratory analytical methods should meet the site-specific DQOs and the analytical method reporting limits should be low enough for risk determination.

- A sufficient number of sub-slab sampling events should be conducted to account for seasonal and spatial variability. At a minimum, two sub-slab sampling events are warranted before a final risk determination is made.

- Upon completion of all sampling, the sub-slab probes should be properly decommissioned. The probe tip, probe tubing, bentonite, and grout should be removed by over-drilling. The borehole should be filled with grout and concrete patch material. Surface restoration should include a follow-up visit for final sanding and finish work to restore the floor slab, and associated coverings, to their original condition.

At least two sub-slab probes should be installed at each residential structure, with one probe installed in the center of the building's foundation. The probes should be installed in inconspicuous areas, such as utility closets or beneath stairs. Sub-slab probes should not be installed near the edges of the foundation due to the effects of wind on the representativeness of contaminant concentrations (Luo et al., 2009).

Numerous sub-slab sampling devices, are commercially available. Cal/EPA encourages the use of innovative technologies as long as the devices are capable of meeting project DQOs and established performance criteria. Accordingly, sampling procedures recommended in this Advisory should be followed when using innovative technologies.

3.6.1 High Purge Volume Sub-Slab Sampling

Extracting a large volume of soil gas from beneath a foundation may provide representative average concentrations that minimize spatial variability in the data and can minimize the possibility of missing an area of elevated concentrations when using multiple discrete sampling points. Unlike conventional sub-slab sampling, high purge volume (HPV) testing provides information over a broader area by removing a larger volume of soil gas. The volume of gas beneath a typical residence in the engineered subgrade fill is a few thousand liters. In this context, the volumes of sub-slab soil gas samples currently collected for vapor intrusion assessments are very small, and larger samples may provide more spatially averaged concentrations. Examples of high purge volume methods can be found in Lewis and others (2004) and McAlary and others (2010).

HPV sampling consists of extracting sub-slab soil gas at a slow, constant rate of five to ten liters per minute, or higher if warranted, and collecting a soil gas sample after about two hours. Hence, over five hundred liters of sub-slab gas can be removed prior to sample collection using the HPV technique. The use of HPV sampling should be based on the site conditions and the project DQOs. All HPV sampling should follow the recommendations in this Advisory concerning leak checking, shut-in testing, and DQOs. As HPV sampling becomes further developed, quantitatively accurate results for contaminant concentrations can be achieved and the HPV samples can be used in quantitative risk assessments.

When utilizing HPV at a site, the protocols within McAlary and others (2010) should be followed. Some items to consider when using HPV are as follows:

- Vacuum during purging should not exceed 100 inches of water.

- The anticipated spatial influence of the HPV should not extend beyond the building's footprint, otherwise, ambient air may enter into the sample from the edges of the foundation. This situation can be alleviated by installing probes subject to HPV in the interior portions of the building.

- A leak check compound should be used during the purging and sampling.

- The amount of purge volume should be measured with a calibrated extraction pump.

- During the purging, site contaminants should be measured with a field instrument, such as a photoionization detector capable of reading in the parts per billion range, at the start of purging and then every 30 minutes thereafter, at a minimum.

- Fixed gases, such as oxygen and carbon dioxide, should be monitored every 10 minutes during purging to evaluate potential ambient air breakthrough into the sample system. Typically, oxygen and carbon dioxide should remain constant during the purging of sub-slab soil gas. Changes of fixed gas concentrations may be indicative of unacceptable leakage through the foundation slab.

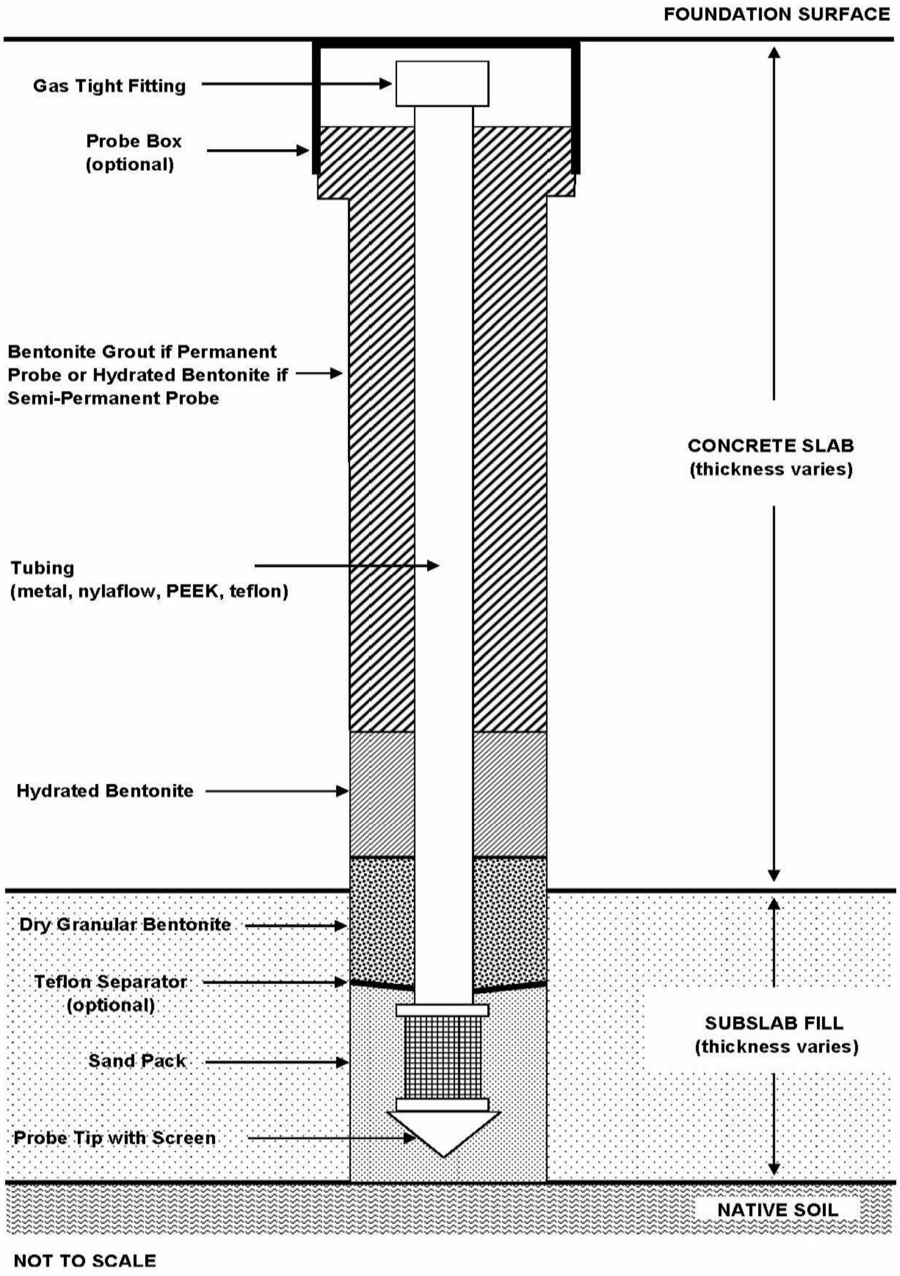
- To evaluate the radial influence of the HPV sampling, vacuum measurements should be continuously monitored at a nearby sub-slab probe locations. These data, along with all other field data, should be reported to the oversight agency.

- As an additional line of evidence for the integrity of the final laboratory sample, the leakage of air through the foundation slab should be quantified by the methods within McAlary and others (2010).

If ambient air breakthrough from the foundation slab occurs, the contaminant data collected upon completion of the purging should not be used for risk assessment purposes. Data indicating breakthrough include the detection of the leak check compound, significant increases of oxygen and/or significant decreases in carbon dioxide while purging. Likewise, significant decreases in VOC concentrations, as collected with a field instrument during purging, may be indicative of breakthrough.

FIGURE 2

Sub-Slab Vapor Probe Typical Diagram



4.0 SOIL GAS SAMPLE COLLECTION

4.1 EQUILIBRATION TIME

Subsurface conditions are disturbed during drilling and probe placement. To allow for the subsurface to equilibrate back to representative conditions, the following equilibration times are recommended before proceeding with soil gas sampling:

1) For soil gas wells installed with the direct push method, do not conduct the purging, leak testing and soil gas sampling for at least two hours following vapor probe installation. Finer-grained material may take longer, up to 48 hours, to equilibrate;

2) The equilibration time for sub-slab probes is two hours (see Section 3.6);

3) For soil gas wells installed with hollow stem or hand auger drilling methods, do not conduct purging, leak testing and soil gas sampling for at least 48 hours after soil gas probe installation;

4) For soil gas wells installed with a combination of hand auger drilling or hollow stem auger and direct push methods, do not conduct purging, leak testing and soil gas sampling for at least two hours following vapor probe installation provided that at least five feet of the borehole was drilled by direct push technology. The five feet of direct push borehole should be drilled after the completion of hand augering or hollow stem augering. The well screen should be located below this five-foot interval. If the well screen is located above the five-foot interval, do not conduct purging, leak testing and soil gas sampling for at least 48 hours after soil gas probe installation; and

5) For soil gas wells installed with the rotosonic or air rotary method, do not conduct purging, leak testing, and soil gas sampling until it can be empirically demonstrated that the subsurface equilibrium time is sufficient to collect representative samples. Due to site-specific conditions, the re-establishment of equilibrium could vary from a few days to a few weeks.

Note: The best option to verify that equilibrium has re-established is to collect time-series data. Soil gas samples for VOC analysis, along with oxygen and carbon dioxide measurements, should be collected shortly after installation, and then at a frequency that will demonstrate the time needed to attain representative samples. A field instrument may be used to analyze the soil gas samples to evaluate representativeness. If the subsurface lithology is homogeneous, one monitoring point could serve as a surrogate for all others when installing multiple sampling probes.

Soil gas well installation method and equilibration time should be recorded in the field log book or field form.

4.2 SOIL GAS ASSEMBLY TESTS

Complete shut-in, leak test and purging before collecting soil gas samples after the soil gas well has equilibrated.

4.2.1 Shut-In Test

Prior to purging or sampling, a shut-in test should be conducted to check for leaks in the above-ground sampling system. To conduct a shut-in test, assemble the above-ground valves, lines and fittings downstream from the top of the probe. Evacuate the system to a minimum measured vacuum of about 100 inches of water using a purge pump. The test is conducted while the sampling canister, if used, is attached with its valve in the closed position. Observe the vacuum gauge connected to the system with a “T”-fitting for at least one minute or longer. If there is any observable loss of vacuum, the fittings are adjusted until the vacuum in the sample train does not noticeably dissipate. After a successful shut-in test, the sampling train should not be altered. The vacuum gauge should be calibrated and sensitive enough to indicate a water pressure change of 0.5 inches. A shut-in test is not a replacement for a leak test.

4.2.2 Leak Test

A leak test is used to evaluate whether ambient air is introduced into the soil gas sample during the collection process. Atmospheric leakage occurs in three ways:

1) Advection through voids in the probe packing material and along the borehole sidewall;
2) Advection directly through the soil column; and
3) Through the fittings in the sampling train at the surface (Banikowski et al, 2009).

A leak test should be conducted at every soil gas well each time a soil gas sample is collected to evaluate the integrity of the sample. Introducing ambient air may result in an underestimation of actual site contaminant concentrations or, alternatively, may introduce external contaminants into samples from ambient air.

The two types of leak check compounds available for use when soil gas sampling are liquid compounds and gaseous compounds. Both types have their advantages and disadvantages, and practitioners should select a leak check compound based on their project’s DQOs. See Appendix C for quantitative leak testing.

4.2.2.1 LEAK CHECK COMPOUNDS (LIQUID)

Liquid tracer compounds, such as hexane, pentane, diflouroethane and n-propanol, can be used to evaluate sample integrity. Other compounds not listed here may also be appropriate. Typically, liquid tracer compounds are applied to towels or clean rags and placed around all connections in the sampling train in order to evaluate potential leaks of ambient air into the sampling train. The liquid tracer should not be directly sprayed or poured onto a fitting, but rather applied to a cloth which should be placed near the connection. Towels or rags with the liquid tracer should also be placed on the ground adjacent to the probe to evaluate soil column and probe construction breakthrough. The leak check compound selected should not be a suspected site-specific contaminant. Seal integrity is confirmed by analyzing the soil gas sample for the tracer compound. Alternatively, each connection can be individually checked by placing the tracer cloth in a plastic bag and then using the bag to enclose individual connections. Instruments can be used in the field to evaluate whether leakage is occurring rather than waiting for the mobile or stationary laboratory results. Liquid leak check compounds should be included in the laboratory analyte list. The laboratory reports should quantify and annotate all detections of the leak check compound at the reporting limit of the target analytes. If the concentration of the leak check compound is greater than or equal to 10 times the reporting limit for the target analyte(s), then corrective action is necessary as discussed below.

4.2.2.2 LEAK CHECK COMPOUNDS (GASEOUS)

Gaseous tracer compounds, such as helium and sulfur hexafluoride, can be used along with a shroud or tent placed over all the sampling equipment. Other compounds not listed here may also be appropriate. Procedures for conducting a quantitative leak test are described in Appendix C. An ambient air leak up to 5 percent is acceptable if quantitative tracer testing is performed by shrouding.

4.2.2.3 LEAK CHECK CONSIDERATIONS

A soil gas well should be decommissioned if the leak cannot be corrected. Replacement soil gas wells should be installed at least five feet from the location where the original soil gas well was decommissioned due to a confirmed leak. The leak check compound concentrations detected in the soil gas samples should be included in the laboratory report and the ambient air breakthrough should be discussed in the site characterization report.

The intent of the leak check compound is to enhance the integrity of the soil gas sample by demonstrating that minimal or no ambient air breakthrough during sampling is occurring. Although it is preferable not to have any tracer gas breakthrough, minor amounts of breakthrough may be acceptable if the breakthrough is appropriate for the site’s DQOs. Detecting leak check compounds indicate potential field problems. Some potential sources of leaks in sampling trains are poor quality fittings, stripped, over tightened, dirty or worn threads, and excessive sampling train connections. Regardless of the cause of the leak, a data adjustment factor based upon the concentration of the leak check compound to compensate for the inability to collect representative samples is inappropriate.

Note that if a passivated stainless steel canister is used to collect a sample that is later analyzed at a stationary laboratory and there is a significant leak, it will typically not be identified until after demobilization of the field crew. Therefore, field screening prior to laboratory analysis is recommended.

Commercially available leak check compounds, both liquid and gaseous, may contain unanticipated impurities. Therefore, laboratories should analyze the leak check compound to aid in the interpretation of the data.

When designing a field study, the tracer compound should be carefully selected. The following items should be considered when choosing a tracer compound.

- Excessive concentrations of the tracer can elevate analytical detection limits;
- Tracer compounds can cause interference with target analytes;
- Field detectors may produce biased results in the presence of water vapor or other compounds;
- The tracer compound may be naturally occurring;
- Field detectors may not be routinely calibrated; and
- Pressurized canisters of tracer gas may be dangerous to transport.

4.2.3 Purging

The purpose of purging is to remove stagnant air from the sampling system so that representative samples can be collected from the subsurface. A default of **three purge volumes** should be used. Purge volume testing is no longer recommended.

One purge volume includes the following:

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

No distinction should be made between new and old probes or whether probes are shallow or deep. All probes should be subject to similar procedures.

Purging should commence after the shut-in test. Sample containers are not included in the purge volume calculation except when non-evacuated glass bulbs are used. In those instances, the volume of the non-evacuated glass bulbs should be added to the purge volume to account for mixing and dilution of gasses inside the glass bulb.

Shallow soil gas and sub-slab probes, where screens and associated sand packs are less than five feet below surface grade, are subject to purging. For shallow soil gas probes, sample collection containers should be less than or equal to one liter to avoid excessive air removal, avoiding the possibility of ambient air entering the subsurface and into the sample. All permanent probes should have an air-tight seal or cap to prevent ambient air from entering the tubing or casing.

Include the purg ing data in the report to verify an adequate volume of air was removed prior to sampling. The soil gas report data set should include the purged volume as well as the flow rate, and vacuum exerted on the formation. Additionally, dependent on the objectives of the characterization activities, collecting pneumatic data during purging may be warranted to determine the air permeability of the subsurface (see Appendix D for more information).

4.3 PURGE/SAMPLE FLOW RATE AND APPLIED VACUUM

Flow rates between 100 to 200 milliliters per minute (mL/min) and vacuums less than 100 inches of water should be maintained during purging and sampling to minimize stripping (partitioning of vapors from pore water to soil gas), to prevent ambient air from diluting the soil gas samples, and to reduce variability between contractors. Maintaining these flow rates and vacuums will increase the likelihood that representative samples will be collected. A flow rate greater than 200 mL/min may be used when purging times are excessive, such as for deep wells with larger-diameter tubing. However, a vacuum of 100 inches of water or less must be maintained during sampling whenever a higher flow rate is used. The pressure gauge used to measure vacuum should be calibrated and in good working order. When purging at rates of greater 200 mL/min, reduce the flow rate to 200 mL/min for sampling.

A vacuum gauge should be used between the soil gas sample tubing and the soil gas purging device to verify that 100 inches of water or less is maintained during sampling. Gas-tight syringes may also be used to qualitatively determine if a high vacuum soil condition is present. If a high vacuum condition is present due to low permeability soil, the sampling technician can feel the suction while the plunger on the syringe is being withdrawn. If low permeability conditions are encountered where 100 inches of water is exceeded, the well can be sampled using the techniques in Appendix D (Soil Gas Sampling in Low Permeability Soil).

4.3.1 Vacuum Pump

When a vacuum pump is used, collect samples on the intake side to prevent potential contamination from the internal parts of the pump. To collect the sample in a polymer gas sampling bag, a lung box[7] is required. Record the vacuum readings and corresponding flow rates on field data sheets for each sample. If the pump is battery-operated, the batteries should be checked before and during the operation to ensure that a proper charge is maintained. As batteries lose charge the flow rate is lowered, effectively changing the purge rate.

5.0 SAMPLE HANDLING AND TRANSPORT

5.1 SAMPLE CONTAINERS

Collect samples in gas-tight containers and handle in a manner that will prevent photodegradation of the target analytes. Sample containers should not compromise the integrity of the samples.

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[7] A lung box is a small airtight chamber into which the polymer gas sampling bag is placed. The connective tubing to the bag protrudes out a hole in the chamber. The sealed chamber is evacuated by a pump, causing the bag to expand, drawing the soil gas from the probe into the bag.

GSI
ENVIRONMENTAL

HAPSITE FIELD LOG: ANALYZE (GC/MS) MODE PRELIMINARY RESULTS

Project: 4460-601
Location: Indian Head Site 17
HAPSITE Instrument: H8
Operator: DMH

HAPSITE Method: SIM_LO_CVOC_10 & SCAN_LO_CVOC_10
Sample Date: 26 April 2019
Calibration Curve:
Time Zone: CST

GSI Job No. 4460-601
Page: 1 of

SAMPLING INFORMATION

Sample/Location Description	Start Time	Run No.	Type (N, Dup, BL, CCV)	Results (ppbv)¹											Notes
				VC	DCE11	DCE12 t	DCA11	DCE12 c	TCLME (chloroform)	DCA12	CTCL	TCE	PCE		
SVP-01 19x Dilution	1530	001		–	–	–	1.2	–	–	12	0.103	–	0.047		dilution w/ office air
SVP-04 19x Dilution	1540	002		–	–	–	–	–	0.996	25	0.104	–	0.032		" "
SVP-01 no dilution	1548	003		3	–	–	212	–	7.9	–	–	–	0.125		
50 ppb CVOC STD	1606	004		–	184	–	–	187	131	–	–	104	145		
Office air	1620	005		–	–	0.741	–	0.423	0.164	–	0.150	0.140	0.121		
SVP-04 no dilution	1627	006		–	–	–	190	–	–	67	–	–	0.166		SIM_LO_CVOC_10
SVP-01 19x Dilution	1653	001													SCAN_LO_CVOC_10 method
SVP-04 19x Dilution	1702	002													
SVP-01 no dilution	1710	003													
SVP-04 no dilution	1720	004													
50 ppb CVOC STD	1730	005													
Office Air	1738	006													

Notes: 1) Results are preliminary and have not been through quality assurance review.
2) Sample collected for 2 minutes on each run

Review of Scans

GSI ENVIRONMENTAL

HAPSITE FIELD LOG: ANALYZE (GC/MS) MODE PRELIMINARY RESULTS

Project: 4460
Location:
HAPSITE Instrument:
Operator: VHB

HAPSITE Method: SCAN-LO-CVOC_10-2019-0426
Sample Date: 4/26/19
Calibration Curve:
Time Zone:

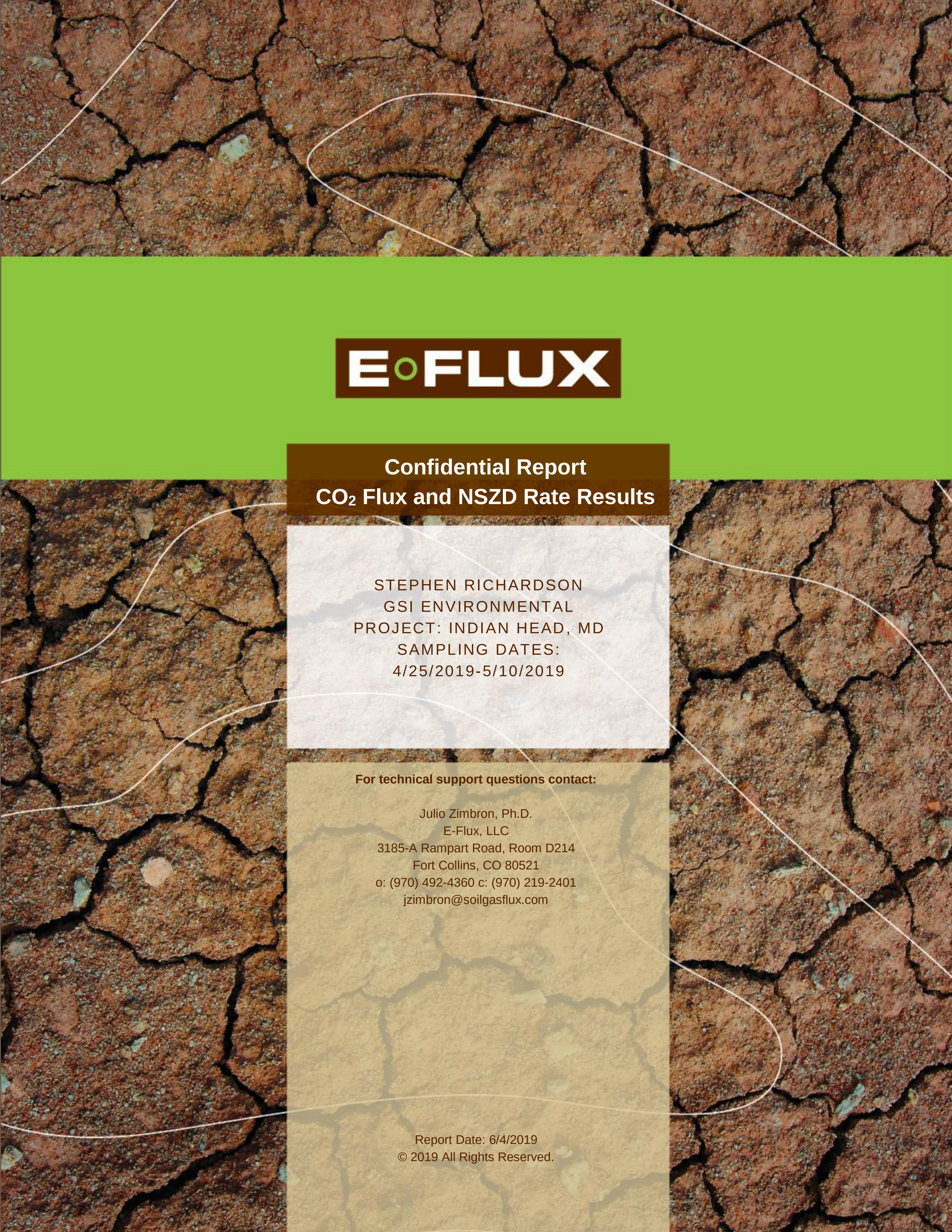
GSI Job No. 4460
Page: 1 of 1

SAMPLING INFORMATION

Sample/Location Description	Start Time	Run No.	Type (N, Dup, BL, CCV)	Results (ppbv)¹			Notes
Scan_Lo-CVOC_10_2019_0426_001				41* (1:27.4) = 1-methylcyclopropanemethanol (41) 56* (1:42.9) = pentane (78.7)	74 (2:01.5) = 1-hexene, 4,5-dimethyl (15.1) 80* (2:07.7) = 1-pentene, 2-methyl (15.9)	85* (2:12.9) = hexane (74.4) 92 (2:20.1) = 3-hexanol, 5-methyl (20.8)	
LEGEND Peak ID (retention time) =				97 (2:25.4) = 3-hexanol (?) (9.4) 114 (2:42.8) = 1-octene, 4-methyl (19.5)	119 (2:48.0) = hexane, 3-methyl (73.2) 124 (2:53.2) = cyclopentane, 1,2-dimethyl-cis (14.7)	130* (2:59.4) = heptane (69%) 166* (3:36.6) = heptane, 4-methyl (72.4)	
NIST result/s	(% prob.)						
* = distinct peaks				41* (1:27.3) = 1-methylcyclopropane methanol (51.2) 56* (1:42.8) = pentane (75.8)	74 (2:01.4) = butane, 2,3-dimethyl (31.8) 1-pentanol, 2-methyl (7.3) 80* (2:07.6) = pentane, 3-methyl (35.5)	86* (2:13.7) = hexane (58.5) 115 (2:43.8) = hexane, 2-methyl (37.8)	
-002				119 (2:47.9) = hexane, 3-methyl (75.4) heptane (17.5) 130* (2:59.3) = heptane (68) hexane, 3-methyl (22.8)	166* (3:36.5) = heptane, 4-methyl (62.9%) hexane, 2,3-dimethyl (15.8%)		
-003				130 (2:59.3) = butanal, 2-ethyl (16.4) heptane (9.95) 163 (3:33.4) = benzene, (2-methloctyl) (27.6)	169 (3:39.6) = hexane, 3-ethyl (30.3) 183* (3:54.0) = hexane, 3-ethyl (14.6)	113 (2:41.7) = 1-pentanol, 2-ethyl (14.7) 1-octene, 4-methyl (13.0)	
poor TIC							
-004							
poor TIC							

Notes: 1) Results are preliminary and have not been through quality assurance review.

Appendix J. Carbon Trap Results: Laboratory Report (E-Flux, LLC)



E·FLUX

Confidential Report
CO_2 Flux and NSZD Rate Results

STEPHEN RICHARDSON
GSI ENVIRONMENTAL
PROJECT: INDIAN HEAD, MD
SAMPLING DATES:
4/25/2019-5/10/2019

For technical support questions contact:

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o: (970) 492-4360 c: (970) 219-2401
jzimbron@soilgasflux.com

Report Date: 6/4/2019

The purpose of this document is to provide sample calculations for the reported results and to explain the method for differentiating petroleum hydrocarbon-derived CO_2 from that produced from natural soil respiration processes. The value of the ^{14}C analysis, site-specific study results and applicable notes, calculation explanations, and references are included.

The Value of the ^{14}C Analysis

How to differentiate between petroleum hydrocarbon-derived CO_2 and natural process-derived CO_2 using CO_2 flux traps:

Unimpacted soils naturally produce CO_2 due to microbial root zone activity and/or the degradation of natural organic matter. Thus, the total measured CO_2 flux at an impacted location is a function of the rates of both natural soil respiration and LNAPL degradation (Sihota and Mayer, 2012). The latter, which is caused by Natural Source Zone Depletion (NSZD), can be estimated by subtracting measured CO_2 fluxes at unimpacted locations from the total measured CO_2 fluxes at LNAPL-impacted locations (Sihota and Mayer, 2012). This spatial "background correction" assumes that bio-based CO_2 fluxes are similar at both impacted and unimpacted locations. This approach is complicated to implement, given that at many industrial facilities it is difficult to find unimpacted areas and vegetation cover can vary across a site. Alternatively, carbon isotope analysis can be used to carry out a location-specific correction for total measured CO_2 fluxes, and this approach effectively overcomes the limitations of the background correction.

Theory of Carbon Isotope Analysis:

Our method for NSZD rate estimation relies on the analysis of ^{14}C, an unstable carbon isotope with an absolute half-life of 5,730 years. ^{14}C is generated by cosmic rays in the atmosphere and is quickly oxidized to $^{14}CO_2$; thus, bio-based living carbon is ^{14}C-rich, while ancient fossil fuel carbon is completely ^{14}C-depleted. Additionally, bio-based organic carbon and the atmosphere have the same characteristic amount of ^{14}C. The short half-life of ^{14}C only allows for dating of samples younger than 60,000 years using accelerator mass spectrometry (Stuiver and Polach, 1977). ^{14}C analysis can therefore be used to differentiate between anthropogenic (i.e., fossil fuel) and natural sources of atmospheric carbon (see Klouda and Connolly, 1995; Levin et al., 1995; Avery et al., 2006), and this analysis is the basis for ASTM D6866-18.

For samples that contain both bio-based and fossil fuel-derived carbon, such as E-Flux's fossil fuel traps, measurement of ^{14}C enables quantitation of *both* source contributions. The fossil fuel-derived percentage of the sample (ff_{sample}) and the bio-based percentage ($1\text{-}ff_{sample}$, or bb_{sample}) are related by the following two-component mass balance (modified from Avery, Jr. et al., 2006):

$$Fm_{sample} = (ff_{sample})(Fm_{ff}) + (1 - ff_{sample})(Fm_{atm})$$

Here, Fm_x represents the fraction modern, a measure of how close the present $^{14}C/^{12}C$ ratio of the sample is to the ratio from 1950, which is derived from a pre-industrial era standard. Fm_{sample} is the total measured fraction modern of the sample. Fm_{ff} is the fraction modern of only the fossil fuel portion of the sample. This number is 0, as there is no ^{14}C in fossil fuel-derived CO_2. Fm_{atm} is the fraction modern of the part of the sample derived from natural soil respiration processes. This value, currently equal to **1.02** (Cerling et al., 2016, Larsen et al., 2018), has been experimentally determined and is a fixed value at each point in time. By convention, the results of carbon isotope analysis are reported based on a 1950 NBS oxalic acid standard, and so Fm_{sample} is reported as if the analysis took place in 1950. Due to nuclear testing, current ^{14}C atmospheric levels are now higher than they were in 1950. This means that Fm_{atm} is counter-intuitively larger than 1, as the $^{14}C/^{12}C$ sample ratio is higher now than it would have been in 1950.

^{14}C Calculations:

Conversion of Fraction Modern Carbon to Fossil Fuel Carbon:

The equation for calculating the percentage of fossil fuel carbon (ff_{sample}) is derived from the following mass balance:

$$Fm_{sample} = (ff_{sample})(Fm_{ff}) + (1 - ff_{sample})(Fm_{atm})$$

Solving for ff_{sample} yields:

$$ff_{sample} = 1 - \frac{Fm_{sample}}{Fm_{atm}}$$

Fraction modern (Fm_{sample}, from ^{14}C analysis) is reported by convention based on ^{14}C levels from 1950. Because of atomic testing, current environmental ^{14}C levels are approximately 2% higher than they were in 1950 (Cerling et al., 2016, Larsen et al., 2018) and Fm_{atm} is equal to 1.02. This equation then becomes:

$$ff_{sample} = 1 - \frac{Fm_{sample}}{1.02}$$

As percentages must add to 1, the percentage of bio-based carbon ($bb_{sample.}$) can then be calculated using the following equivalence:

$$bb_{sample} = 1 - ff_{sample} = 1 - \left(1 - \frac{Fm_{sample}}{1.02}\right) = \frac{Fm_{sample}}{1.02}$$

Converting Carbon Flux to Equivalent LNAPL Loss Rate:

The intermediate reactions for LNAPL mineralization include methanogenesis, leading to production of methane and CO_2, and the subsequent aerobic oxidation of methane into CO_2:

$$C_8H_{18} + 3.5\ H_2O \rightarrow 6.25\ CH_4 + 1.75\ CO_2 \text{ (methanogenesis)}$$

$$6.25\ CH_4 + 12.5\ O_2 \rightarrow 6.25\ CO_2 + 12.5\ H_2O \text{ (methane oxidation)}$$

$$C_8H_{18} + 12.5\ O_2 \rightarrow 9H_2O + 8\ CO_2 \text{ (overall reaction)}$$

Assuming a conservative LNAPL density of 0.77 g mL^{-1} (upper range of gasoline) and using the molecular weight of C_8H_{18} (octane, 114.23 g mol^{-1}), µmol m^{-2} s^{-1} of CO_2 can then be converted into gal. $acre^{-1}$ yr^{-1} of LNAPL:

$$1\ \frac{\mu\text{mol CO}_2}{\text{m}^2\ \text{s}} \cdot \left(\frac{1\ \mu\text{mol C}_8\text{H}_{18}}{8\ \mu\text{mol CO}_2}\right)\left(\frac{1\ \text{mol C}_8\text{H}_{18}}{1 \times 10^6\ \mu\text{mol C}_8\text{H}_{18}}\right)\left(\frac{114\ \text{g C}_8\text{H}_{18}}{1\ \text{mol C}_8\text{H}_{18}}\right)\left(\frac{1\ \text{mL C}_8\text{H}_{18}}{0.77\ \text{g C}_8\text{H}_{18}}\right)$$
$$\left(\frac{1\ \text{L}}{1000\text{mL}}\right)\left(\frac{1\ \text{gal.}}{3.785\ \text{L}}\right)\left(\frac{4{,}046\ \text{m}^2}{1\ \text{acre}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)\left(\frac{24\ \text{h}}{1\ \text{d}}\right)\left(\frac{365\ \text{d}}{1\ \text{yr}}\right).$$

$$= 625.2\ \frac{\text{gal. C}_8\text{H}_{18}}{\text{acre} \cdot \text{yr}}$$

Note that both the LNAPL formula and its density are assumed, and so this conversion is subject to uncertainty. However, site-specific data can be used if available. Using alternative representative hydrocarbon formulas and densities generally results in conversion factors that are within 10-15% of 625.2 gal. $acre^{-1}$ yr^{-1}. Therefore, the uncertainty associated with these values does not preclude an acceptable estimate.

Expected Results and Recommendations:

^{14}C-based techniques offer a built-in, location-specific correction as an alternative to the standard background location correction. Early work on a limited number of samples suggested that ^{14}C-corrected results are equivalent to background-corrected results (Sihota and Mayer, 2012; McCoy et al., 2015). However, a more recent comparison spanning 4 different sites suggests that measured carbon fluxes can differ by up to five times among different locations within the same site (Zimbron and Kasyon, 2015). Depending on the location, the resulting difference between background-corrected and ^{14}C-corrected NSZD rate estimates can be up to one order of magnitude. In contrast, the background correction assumes that the non-fossil fuel CO_2 flux is constant across an entire site; large errors in final estimated NSZD rates might therefore be introduced if the background correction is used. Because the ^{14}C measurement is co-located with the CO_2 flux measurement, it is unbiased by spatial uncertainties related to the background location(s) (e.g., vegetation, lithology, unknown impacts, different gas transport regimes, soil moisture).

The fossil fuel CO_2 content of unexposed sorbent as used in the traps is typically around 30% (as of today) and likely results from material processing and handling (e.g., exposure to fossil fuel fumes). This small mass of fossil fuel CO_2 is removed from samples by carrying out a ^{14}C travel blank correction. ^{14}C analysis is performed on CO_2 sorbent sub-samples after homogenization of the entire bottom sorbent layer (see McCoy et al., 2015). The mass of fossil fuel CO_2 in the unexposed travel blank trap (TB) is then subtracted from the mass of fossil fuel CO_2 in each field-deployed trap.

The results in this report are based on proprietary technology used to measure soil gas efflux. All information contained herein is strictly confidential to the customer.

Easy set-up. Expert results.

This report contains Confidential Information and is to be delivered only to the indicated Customer.

Project: Indian Head, MD
Customer: GSI Environmental
Customer Contact: Stephen Richardson
Report Date: 4-May-19

Sample ID	**Sampling Information**			**Raw Results[a]**				**Final CO_2 Results[b]**			**^{14}C Results[a]**			**NSZD Results[b]**				
	Deployed	**Retrieved**	**Days in Field**	**Moisture content (%)**	**Dry Sorbent Mass (g)**	**Avg. % CO_2[c]**	**CV[d] CO_2 (%)**	**CO_2 content (%)**	**CO_2 mass (g)**	**CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)**	***Fm_{sample}* As Reported[e]**	***bb_{sample}* As of Today[f]**	***ff_{sample}* As of Today[f]**	**Bio-based CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)**	***ff_{sample}* As of Today (TB-corrected)**	**Fossil Fuel CO_2 (g)**	**Fossil Fuel CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)**	**Equivalent NSZD Rate (gal. $acre^{-1}\ yr^{-1}$)**
IHMD-R1-CO2-TB	NA	NA	0.0	16.7%	40.860	1.12%	0.38%	-	-	-	69.48%	68.12%	31.88%	-	-	-	-	-
IHMD-R1-CO2-01	4/25/19 9:38	5/10/19 11:56	15.1	21.9%	40.480	1.73%	2.88%	0.61%	0.24	0.53	82.46%	80.84%	19.16%	0.55	ND	ND	ND	ND
IHMD-R1-CO2-02	4/25/19 9:39	5/10/19 12:04	15.1	22.7%	41.860	7.08%	3.47%	5.95%	2.49	5.35	99.04%	97.10%	2.90%	5.49	ND	ND	ND	ND
IHMD-R1-CO2-03	4/25/19 9:47	5/10/19 12:22	15.1	22.1%	41.550	2.26%	1.32%	1.14%	0.47	1.02	88.56%	86.82%	13.18%	1.07	ND	ND	ND	ND
IHMD-R1-CO2-04	4/25/19 9:42	5/10/19 12:14	15.1	22.6%	40.850	1.86%	5.00%	0.73%	0.30	0.64	84.50%	82.84%	17.16%	0.68	ND	ND	ND	ND
IHMD-R1-CO2-05	4/25/19 9:51	5/10/19 12:43	15.1	39.3%	44.870	2.48%	1.15%	1.36%	0.61	1.31	93.72%	91.88%	8.12%	1.46	ND	ND	ND	ND
IHMD-R1-CO2-06	4/25/19 9:53	5/10/19 12:48	15.1	22.3%	43.450	11.01%	4.83%	9.88%	4.29	9.21	102.98%	100.96%	-0.96%	9.65	ND	ND	ND	ND

- The flux equivalence is **1** µmol m^{-2} s^{-1} = **625.2** gallons $acre^{-1}$ yr^{-1}, assuming a representative hydrocarbon density of **0.77** g mL^{-1} with the formula **C_8H_{18}**.Trap cross-sectional area is **8.11×10^{-3}** m^2 (based on a **4-inch** receiver pipe).
- Carbonate analysis of each trap/sample is based on method ASTM 4373-14, which does do not provide acceptable variability (CV) standards. Similar methods (e.g., ASTM D513-16) allow typical errors of ≤ 20%. Analysis is therefore conducted in duplicate if the coefficient of variation (CV) of the duplicates is < 5%. If CV ≥ 5%, duplicate analyses are repeated until CV < 5%.
- NA = Not Applicable; ND = Not Detectable.

a. Results are not TB-corrected.
b. Results are TB-corrected.
c. Refers to the measured weight percentage of CO_2 with respect to the total dry sorbent mass.
d. Refers to the coefficient of variation of CO_2 measurements for each sample: CV = [standard deviation of %CO_2 measurements] / [average %CO_2 measurement]
e. Refers to the reported fraction modern (*Fm_{sample})*. As is standard in radiocarbon reporting, this value has not been corrected to account for present-day ^{14}C atmospheric levels. This number is originally reported as pMC (percent modern carbon) and is converted into *Fm* for our calculations using the relation 100.0 pMC = 1.0 *Fm* = 100% *Fm*.
f. "As of Today" means that the value has been adjusted to account for the difference between atmospheric ^{14}C levels from the 1950s and today (Stenström et al., 2011). *bb_{sample}* is the percentage of the total CO_2 that is derived from bio-based (non-fossil fuel) sources. *ff_{sample}* refers to the percentage of CO_2 that is derived from fossil fuels. These values are not TB-corrected.

Results Snapshot:

- The Travel Blank (TB) concentration is **1.12%**; typically, this number is < 2%.
- Trap tops are not saturated with CO_2 (sorbent saturation is 30%). The maximum measured (raw) top concentration is ***3.18%*** (sample **IHMD-R1-CO2-03.1**).
- Bio-based carbon fluxes represent the CO_2 contributions from natural soil respiration processes to the total carbon flux; the ^{14}C analysis corrects for this contribution. Average bio-based CO_2 flux is **3.67** μmol m^{-2} s^{-1}, and the coefficient of variation is **105%**. The range of bio-based CO_2 fluxes is between **0.68** and **9.65** μmol m^{-2} s^{-1}. If these interferences were not removed using the results of the radiocarbon analysis, the errors in the NSZD rate estimates would be between **424** and **6030** gallons $acre^{-1}$ yr^{-1}.
- **All samples** show non-detectable (ND) fossil fuel CO_2 flux. The entire CO_2 flux for these sample(s) is likely derived from non-fossil fuel sources.

Site-specific Sample Calculations:

Grams of Fossil Fuel CO_2:

The mass of fossil fuel-derived CO_2 in each trap is calculated by subtracting the total fossil fuel CO_2 in the travel blank (TB) from the total fossil fuel CO_2 in the trap. Only data that are ***not*** TB-corrected (i.e., ff_{sample} As of Today and raw % CO_2) are used in this calculation. Using Sample 1 as an example:

$$\left(\mathrm{g\ CO_{2(ff)}}\right)_{sample\ 1} = \mathrm{g_{sorbent}} \cdot \left[\left((\%\ \mathrm{CO_2})_{\mathrm{sample}}\left(ff_{sample}\right)\right) - \left((\%\ \mathrm{CO_2})_{\mathrm{TB}}\left(ff_{TB}\right)\right)\right]$$

$$\left(\mathrm{g\ CO_{2(ff)}}\right)_{sample\ 1} = \mathbf{40.48}\ \mathrm{g} \cdot \left[\left(\mathbf{1.7}\ \% \cdot \mathbf{19.2}\ \%\right) - \left(\mathbf{1.12}\ \% \cdot \mathbf{31.88}\ \%\right)\right]$$

$$\left(\mathrm{g\ CO_{2(ff)}}\right)_{sample\ 1} = 0.0\ \mathrm{g}\ \textit{(below detection limit)}$$

Here, $g_{sorbent}$ is the mass of sorbent used in the bottom layer of the trap, $(\%CO_2)_{sample}$ is the average weight percentage of CO_2 in the sample, ff_{sample} is the percentage of carbon in the sample derived from fossil fuels, $(\%CO_2)_{TB}$ is the average weight percentage of CO_2 in the travel blank, and ff_{TB} is the percentage of carbon in the travel blank that is derived from fossil fuels. In this example, Sample 1 contains 0.0 g of fossil-fuel derived CO_2.

Fossil Fuel CO_2 Flux:

Converting grams of CO_2 to CO_2 flux requires the cross-sectional area of the receiver (**8.11×10^{-3}** m^2 for a **4**-inch receiver), the number of days that the trap was deployed in the field, and the molecular weight of CO_2 (44 g mol^{-1}). Using Site 1 as an example:

$$\text{Fossil Fuel CO}_2\text{ Flux} = \frac{\mathrm{g\ fossil\ fuel\ CO_2} \cdot \dfrac{\mathrm{1\ mol\ CO_2}}{\mathrm{44\ g\ CO_2}} \cdot \dfrac{\mathrm{1{,}000{,}000\ \mu mol\ CO_2}}{\mathrm{1\ mol\ CO_2}}}{\mathrm{days\ in\ the\ field} \cdot \dfrac{\mathrm{24\ hr}}{\mathrm{day}} \cdot \dfrac{\mathrm{3600\ s}}{\mathrm{hr}} \cdot \mathrm{(receiver\ area)}}$$

$$\text{Fossil Fuel CO}_2\text{ Flux} = \frac{\mathbf{0.0}\ \mathrm{g\ fossil\ fuel\ CO_2} \cdot \dfrac{\mathrm{1\ mol\ CO_2}}{\mathrm{44\ g\ CO_2}} \cdot \dfrac{\mathrm{1{,}000{,}000\ \mu mol\ CO_2}}{\mathrm{mol\ CO_2}}}{\mathbf{15.1}\ \mathrm{days} \cdot \dfrac{\mathrm{24\ hr}}{\mathrm{day}} \cdot \dfrac{\mathrm{3600\ s}}{\mathrm{hr}} \cdot \left(\mathbf{8.11} \times \mathbf{10^{-3}}\ \mathrm{m^2}\right)}$$

$$\text{Fossil Fuel CO}_2\text{ Flux} = 0.0\,\frac{\mathrm{\mu mol\ CO_2}}{\mathrm{m^2 \cdot s}} \quad \textit{(below detection limit)}$$

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Appendix K. Groundwater Sampling Forms

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Date: 8-16-17
GSI Job No. 4460-301
Page: 1 of 1
Project: Wick Drains - Indian Head
Well Number: 1
Well Depth: 25
Screen Interval: 5, 15, 25
Personnel: JAL
Starting SWL: —
Well Diam: CMT
Volume Purged: —
Sample meth: Low Flow
Tubing Type: Poly
Other:

SAMPLE INFORMATION

	Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/[✓ C])	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
CMT-1-Upper	1050			Silty Black Organic odor	24.5	6.53	0.895	502	0.13	-46	
	1100			Clear org. odor	23.2	6.39	0.845	158	0	-42	
	1110			Clear org. odor	22.2	6.30	0.834	17.5	0	-36	
CMT-1-Middle	1132			Silty tan Slight odor	21.92	6.28	1.28	220	1.81	-10	
	1140	Stopped Producing Water									
CMT-1-Lower	1205	Not enough water for parameters. Only VOCs and Gase									
		initially collected.									

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown) GROUNDWATER SAMPLING RECORD

Client: ESTCP
Date: 8-16-17
GSI Job No. 4460
Page: 1 of 1

Project: Wick Drains - Indian Head
Well Number: CMT-2
Well Depth: 28
Screen Interval: 8, 18, 28

Personnel: JAL
Starting SWL: —
Well Diam: —
Volume Purged: —

Sample meth: Low Flow - Grab
Tubing Type: Poly
Other:

SAMPLE INFORMATION

	Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
CMT-2-Upper	1235	Not able to produce enough H_2O for parameters. Only VOCs									
		+ Gases initially Collected.									
CMT-2-Middle	1305			Silty Brown No odor	25.62	6.95	0.440	OR	2.11	-118	
		Not enough H_2O for 2nd reading.									
CMT-2-Lower		Not enough H_2O for parameters.									

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains
Personnel: JAL
Sample meth: Low Flow - GRAB
Date: 8-16-17 GSI Job No. 4460 Page: 1 of 1
Well Number: CMT-3 Well Depth: 25 Screen Interval: 5, 15, 25
Starting SWL: — Well Diam: — Volume Purged: —
Tubing Type: Poly Other: —

SAMPLE INFORMATION

	Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
CMT-3-~~Upper~~ Middle	1520			Silty tan slight odor	28.36	6.98	1.16	787	3.0	-147	
CMT-3-Upper	1455	Not enough volume.									
CMT-3-Lower	1515	Not enough Volume									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains-Indian Head
Personnel: JAL
Sample meth: Low Flow -Grab

Date: 8/16/17
Well Number: CMT-4
Starting SWL: —
Tubing Type: Poly

GSI Job No. 4460-301
Well Depth: 25'
Well Diam: CMT
Other: —

Page: 1 of 1
Screen Interval: 5, 15, 25
Volume Purged: —

SAMPLE INFORMATION

	Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
CMT-4-Upper (complete)	1624			Silty Tan slight odor	28.36	6.46	0.280	319	4.57	12	
			Out	of H2O							
CMT-4-Middle (complete)	1645			Silty tan No odor	24.38	5.88	0.447	484	2.22	55	
	1650			Sitly tan No odor	23.10	5.56	0.396	742	2.08	74	
										82	
CMT-4-Lower	1715			Silty Tan No odor	22.89	5.85	0.344	643	2.98	82	
	1720			Silty tan No odor	21.85	5.63	0.364	836	3.50	109	

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains
Personnel: MLS
Sample meth: Low Flow

Date: 7/19/17
GSI Job No. 4460
Page: 1 of 1
Well Number: 1517MW04
Well Depth: 15'
Screen Interval: 8-18'
Starting SWL: 6.13
Well Diam: 2"
Volume Purged:
Tubing Type: Teflon-[illegible]
Other: Tubing Depth: 16'

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
1730	12.40	200	clear none	24.10	5.33	1.338	14.7	1.93	90.8	
1735	13.21		clear none	24.18	5.32	1.324	11.2	1.98	104.6	
1740	15.70	200	clear none	24.22	5.30	1.317	10.3	2.12	113.3	slt. sheen on purge water
1742	well dewatered									
1815	collect sample									

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains
Personnel: MLS
Sample meth: Low-flow

Date: 7/19/17
GSI Job No. 4460
Page: 1 of 2
Well Number: 1517MW11
Well Depth: 16.70
Screen Interval: 4-14
Starting SWL: 6.88
Well Diam: 2"
Volume Purged:
Tubing Type: Teflon 1/4"
Other: Tubing Depth = 12'

SAMPLE INFORMATION

Time	SWL	Pumping Rate ml/min	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
1342	7.40	250	clear none	19.46	5.89	1.117	26.6	0.61	-16.9	
1345	7.41	250	clear none	20.76	5.79	1.104	38.0	0.53	-13.7	
1348	7.42	250	clear none	21.18	5.76	1.098	34.0	0.50	-9.3	
1351	7.45	250	clear none	21.46	5.74	1.098	43.3	0.58	-5.1	
1354	7.48	250	clear none	21.71	5.70	1.090	41.0	0.53	-5.7	
1357	7.49	200	clear none	21.66	5.70	1.088	33.2	0.52	-8.1	
1600	7.49	200	clear none	22.04	5.68	1.084	57.0	0.49	-7.9	slight
1605	7.49	200	clear none	22.17	5.66	1.084	37.1	0.52	-5.5	Sheen
1610	7.53	200	clear none	23.09	5.63	1.067	26.4	0.50	2.7	developing
1615	7.55	200	clear none	23.44	5.61	1.058	26.8	0.51	9.4	on purge water
1620	7.56	200	clear none	23.46	5.59	1.043	23.7	0.51	8.7	
1625	7.56	200	clear none	23.46	5.58	1.032	23.5	0.49	8.2	

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: W. Ck Drains
Personnel: MLS
Sample meth:

Date: 7/19/17 GSI Job No. 4460 Page: 2 of 2
Well Number: 1517MW11 Well Depth: Screen Interval:
Starting SWL: Well Diam: Volume Purged:
Tubing Type: Other:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
1630	7.57	200	clear none	~~1.013~~ 23.28	5.55	1.014	19.6	0.49	6.6	
1635	7.58	200	clear none	23.30	5.54	1.012	16.3	0.49	7.8	
1640	7.60	200	clear none	23.44	5.52	1.000	12.2	0.49	8.2	
1645	7.60	200	clear none	23.29	5.51	0.997	11.3	0.48	7.3	
1650	7.60	200	clear none	23.26	5.50	0.990	14.1	0.48	6.8	
1655	7.60	200	clear none	22.62	5.49	0.982	9.7	0.48	6.4	
1700	collect sample									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains
Personnel: M. Schofield
Sample meth: Low Flow

Date: 7/25/17
Well Number: 1517MW12
Starting SWL: 5.65
Tubing Type: Teflon C

GSI Job No. 4460
Well Depth:
Well Diam: 2"
Other:

Page: 1 of
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
1032	6.38	200	clear none	18.42	5.55	0.625	20.8	1.57	64.2	
1037	6.41	200	clear none	19.30	5.28	0.623	15.4	0.93	81.0	
1042	6.48	200	clear none	19.55	5.20	0.604	12.8	0.63	89.0	
1047	6.55	200	Clear none	19.58	5.20	0.560	9.6	0.69	89.9	
1050	collect sample									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains
Personnel: MLS
Sample meth: low flow

Date: 7/20/17 GSI Job No. 4460 Page: 1 of
Well Number: 1517MW13 Well Depth: Screen Interval:
Starting SWL: 5.35 Well Diam: 2" Volume Purged:
Tubing Type: Teflon Other:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
0905	5.85	200	clear none	19.32	6.21	1.403	42.4	0.90	-34.7	
0910	6.02	200	clear none	21.02	6.16	1.400	22.7	0.48	-27.1	
0915	6.05	200	clear none	20.81	6.14	1.380	15.5	0.45	-35.7	
0920	6.09	200	clear none	21.01	6.13	1.362	14.0	0.41	-42.2	
0925	6.14	200	clear none	21.14	6.12	1.321	13.2	0.36	-51.0	
0930	6.22	200	clear none	20.98	6.12	1.301	11.0	0.34	-52.6	
0935	6.26	200	clear none	20.94	6.12	1.288	9.7	0.37	-54.2	
0940	collect sample									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: W.ck Drains
Personnel: MLS
Sample meth: low flow

Date: 7/20/17
GSI Job No. 4460
Page: 1 of
Well Number: 1517MW14
Well Depth:
Screen Interval:
Starting SWL: 5.31
Well Diam: 2"
Volume Purged:
Tubing Type: Teflon
Other:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
0747	5.86	200	clear / none	19.14	5.62	0.661	25.7	1.17	37	
0752	5.90	200	clear / none	20.06	5.51	0.652	11.0	0.81	40.2	
0757	5.94	200	clear / none	20.34	5.36	0.644	8.28	0.67	45.6	
0800	5.97	200	clear / none	20.07	5.33	0.640	4.77	0.58	40.7	
0803	6.01	200	clear / none	20.04	5.31	0.639	3.81	0.51	40.0	
0810	collect sample									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Wick Drains
Personnel: M. Schofeld
Sample meth: low-flow

Date: 7/20/17
GSI Job No. 4460
Page: 1 of
Well Number: 1S17MW15
Well Depth: 22.01
Screen Interval:
Starting SWL: 6.41
Well Diam: 2"
Volume Purged:
Tubing Type: Poly
Other:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
1050	7.25	200	clear none	22.28	6.05	1.298	34.0	0.61	5.1	
1055	8.15	200	clear none	22.32	6.04	1.299	31.1	0.52	7.7	
1100	9.20	200	clear none	23.32	6.03	1.296	24.7	0.46	9.6	
1105	9.31	200	clear none	23.42	6.02	1.298	4.23	0.47	12.9	
1110	9.80	200	clear none	23.36	6.01	1.297	6.12	0.46	14.9	
1115	collect sample									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP

Project: Wick Drains

Personnel: M. Schofeld

Sample meth: Low Flow

Date: 7/25/17

Well Number: 1517MW16

Starting SWL: 5.95

Tubing Type: Teflon

GSI Job No. 4460

Well Depth:

Well Diam: 2"

Other:

Page: 1 of

Screen Interval:

Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance/Odor	Temp. (°F/C)	pH	Spec. Cond. (mS/cm)	Turbidity (NTU)	Diss.Oxygen (mg/L)	Redox (mV)	Remarks
1040	7.18	200	clear none	18.36	5.81	0.888	72.0	0.96	46.7	
1145	7.48	200	clear none	19.78	5.83	0.912	41.0	0.69	42.3	
1150	8.11	200	clear none	20.12	5.79	0.928	32.0	0.60	43.0	
1155	8.44	200	clear none	20.78	5.78	0.932	21.2	0.57	43.5	
1200	8.71	200	clear none	20.08	5.76	0.933	16.6	0.41	45.5	
1205	8.93	200	clear none	20.35	5.79	0.935	9.8	0.41	46.3	
1215	collect sample									

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 - IH
Personnel: JAL
Sample meth: Low - Flow

Date: 9-27-17
Well Number: MW04
Starting SWL: 5.22'
Tubing Type: Poly

GSI Job No. 4460
Well Depth: 21.1'
Well Diam: 2"
Other:

Page: 1 of 1
Screen Interval: 8-18'
Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
1043	9.30	300	Clear no odor	26.18	6.03	1.07	4.8	0.75	86	
1046	10.90	250	Clear no odor	26.19	5.89	1.08	4.8	0.15	83	
1049 → Well dewatered - let recharge										
Sampled @ 1300										

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 IH
Personnel: JAL
Sample meth: Low-flow

Date: 9-26-17
Well Number: MW11
Starting SWL: 5.96' btoc
Tubing Type: Poly

GSI Job No. 4460
Well Depth: 16.17
Well Diam: 2"
Other:

Page: 1 of 1
Screen Interval: 4-14'
Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
1602	6.35	300	Clear No odor	21.56	6.11	1.170	3.0	0.00	-3	
1605	6.47	300	" "	21.70	6.01	1.110	2.6	0.00	-1	
1608	6.60	300	" "	21.52	5.97	1.070	3.3	0.00	-1	
1611	6.66	300	" "	21.68	5.96	1.070	4.5	0.00	-2	
1614	6.73	300	" "	21.69	5.95	1.060	4.8	0.00	-3	
Sampled @ 1615										

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber-Site 17-IH
Personnel: JAL
Sample meth: Low Flow

Date: 9-27-17
Well Number: MW12
Starting SWL: 4.99' btoc
Tubing Type: Poly

GSI Job No. 4460
Well Depth:
Well Diam: 2"
Other:

Page: 1 of 1
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
0818	5.76	300	Reddish/orange slight odor	20.54	5.67	0.638	OR	0.0	120	
0821	6.16	300	Slight Red tint no odor	20.36	5.82	0.571	225	0.0	84	
0824	6.42	300	" " no odor	20.49	5.84	0.560	20.5	0.0	73	Water color Clearing
0827	6.71	300	" " " "	20.58	5.85	0.554	22.1	0.0	67	Slug of reddish Water came through
0830	6.90	300	Clear " "	20.52	5.85	0.546	18.2	0.0	63	
0835	7.21	300	Clear " "	20.51	5.85	0.544	9.4	0.0	59	
0838	7.26	300	" " " "	20.56	5.84	0.542	5.7	0.0	58	
Sampled @ 0840										
Collect Dup-2										

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 IH
Personnel: JAL
Sample meth: Low Flow
Date: 9-26-17
Well Number: MW13
Starting SWL: 4.57' btoc
Tubing Type: Poly
GSI Job No. 4460
Well Depth: 16.85' btoc
Well Diam: 2"
Other:
Page: 1 of 1
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
0838	5.2	350	Clear sulfur Odor	21.39	6.95	0.829	25.6	0.02	-60	
0841	5.51	300	Clear " "	21.13	6.48	0.830	23.4	0.0	-52	
0844	5.65	300	Clear " "	20.93	6.36	0.833	20.7	0.0	-46	
0847	5.80	300	Clear " "	20.88	6.32	0.827	15.7	0.0	-44	
0850	5.96	300	Clear " "	20.87	6.31	0.824	7.2	0.0	-45	
Sampled @ 0855										

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client:	ESTCP	Date:	9-26-17	GSI Job No.	4460
Project:	Bomber - Site 17 - IH	Well Number:	MW14	Well Depth:	16.85
Personnel:	JAL	Starting SWL:	4.43' btoc	Well Diam:	2"
Sample meth:	Low Flow	Tubing Type:	Poly	Other:	

Page: 1 of 1

Screen Interval:

Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance / Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
1400	4.70	300	Clear / Slight Sulfur odor	27.50	5.78	0.306	3.4	0.08	61	
1403	4.77	300	Clear / " "	26.62	5.77	0.309	3.1	0.00	47	
1406	4.77	300	Clear / " "	26.18	5.76	0.311	3.4	0.00	37	
1409	4.77	300	Clear / " "	26.02	5.76	0.313	3.3	0.00	29	
1412	4.77	300	Clear / " "	25.81	5.76	0.314	3.7	0.00	24	
1415	4.82	300	Clear / " "	25.60	5.76	0.315	4.1	0.00	20	
1418	4.84	300	Clear / " "	25.41	5.76	0.318	3.8	0.00	17	
1421	4.85	300	Clear / " "	25.29	5.76	0.320	3.7	0.00	15	
1424	4.87	300	Clear / " "	25.25	5.76	0.322	3.6	0.00	14	
1427	4.87	300	Clear / " "	25.20	5.76	0.323	3.6	0.00	12	
1430	4.88	300	Clear / " "	25.16	5.77	0.324	3.6	0.00	11	
1433	4.88	300	Clear / " "	25.11	5.77	0.325	3.7	0.00	11	

Sampled @ 1435

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 - IH
Personnel: k JAL
Sample meth: Low Flow

Date: 9-26-17
Well Number: MW15
Starting SWL: 5.64' btoc
Tubing Type: Poly

GSI Job No. 4460
Well Depth: 22'
Well Diam: 2"
Other:

Page: 1 of 1
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

Time	SWL	Pumping Rate	Sample Appearance / Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
1502	6.50	300	Clear / No odor	25.34	6.46	0.905	17.4	1.14	21	
1505	7.05	300	Clear / No odor	24.89	6.65	0.916	15.9	1.38	14	
1508	7.60	300	" / "	24.52	6.72	0.926	11.5	2.03	12	
1511	8.10	300	" / "	24.56	6.72	0.927	8.0	1.89	12	
1514	8.50	300	" / "	23.96	6.44	0.938	5.3	1.85	12	
1517	9.00	300	" / "	23.90	6.42	0.938	3.1	1.87	12	
1520	9.55	300	" / "	23.50	6.40	0.945	5.1	1.88	11	
Sampled @ 1525										

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 - IH
Personnel: JAL
Sample meth: Low Flow

Date: 9-26-17
Well Number: MW16
Starting SWL: 4.73' BTOC
Tubing Type: Poly

GSI Job No. 4460
Well Depth: 17.55 btoc
Well Diam: 2"
Other:

Page: 1 of 1
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

Time	SWL	ML/min Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
1110	4.80	300	Clear No odor	21.49	6.40	0.835	38.3	0.00	-16	
1113	4.88	300	Clear No odor	21.67	6.25	0.823	37.5	0.00	-14	
1116	5.20	300	Clear No odor	21.94	6.19	0.803	35.0	0.00	-3	
1119	5.79	300	Clear No odor	22.10	6.17	0.787	31.2	0.00	6	
1122	6.40	300	Clear No odor	22.16	6.16	0.779	26.1	0.00	10	
1125	6.90	300	Clear No odor	22.20	6.16	0.778	18.2	0.00	13	
1128	7.53	300	Clear No odor	22.23	6.15	0.779	15.4	0.00	16	
1131	8.11	300	Clear No odor	22.19	6.14	0.779	13.5	0.00	17	
1135	8.75	300	Clear No odor	22.10	6.14	0.779	9.7	0.0	19	
Sampled @ 1140										

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 - IH
Personnel: JAL
Sample meth: Low Flow - Grab

Date: 9-27-17
Well Number: CMT-1
Starting SWL: —
Tubing Type: Poly

GSI Job No. 4460
Well Depth: 8.96'Btoc 18.65'Btoc 28.7'Btoc.
Well Diam: CMT
Other: Near MW-04

Page: 1 of 1
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

	Time	SWL	Pumping Rate	Sample Appearance / Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
Upper	1100	4.35	—	Clear / No odor	24.86	6.38	0.828	48	0.10	8	
	1130	6.30	—	Clear / No odor	24.44	6.39	0.827	35.3	0.0	-25	
	1135	7.90	—	Clear / No odor	23.99	6.41	0.833	70.2	0.0	-28	
			Sampled @ 1100								
Middle	1155	4.61	—	yellow tint / strong organic odor	23.24	6.22	1.12	33.7	1.13	28	sheen on surface
			Well dewatered during 2nd round of field parameters								
			Sampled @ 1155								
Lower	1230	5.22	Unable to collect parameters - Dewatered								
			Sample collected @ 1230								
			* Dup-2 collected for VOCs + Gases (no ~~ma~~ Iron)								

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 - IH
Personnel: JAL
Sample meth: Low flow - Grab
Date: 9-27-17
Well Number: CMT - 2
Starting SWL: —
Tubing Type: Poly
GSI Job No. 4460
Well Depth: 8.34' btoc, 19.84 btoc'
Well Diam: CMT
Other: Near MW-12
Page: 1 of 1
Screen Interval: 28.65' btoc
Volume Purged: —

SAMPLE INFORMATION

	Time	Initial SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
Upper	0925	4.56'	—	Silty Black	Unable to collect field parameters - Well						
					dewatered. Sample collected @ 0925 for						
					VOCs and gases only (no metals)						
Middle	0945	4.35'	—	Reddish orange tint slight organic odor	22.11	6.58	0.721	854	0.12	77	Sample tubing in port 6,
			Sampled @ 0945. Well dewatered after first round of field								WL in port 2.
					parameters.						
Lower	1010	4.32'		Yellowist tint slight organic odor	Unable to collect field parameters - Well dewatered						
					Sampled @ 1010						

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Date: 9-26-17
GSI Job No. 4460
Page: 1 of 1
Project: Bomber - Site 17 - IH
Well Number: CMT-3
Well Depth: 7.47 btoc
Screen Interval:
Personnel: JAL
Starting SWL:
Well Diam: 18.1 btoc 27.95 btoc
Volume Purged:
Sample meth: Low Flow - Grab
Tubing Type: Poly
Other: Near MW-14

SAMPLE INFORMATION

	Time	Initial SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
Upper	0925	3.94'	Sampled @ 0925 : Unable to collect field parameters - well								
				silty gray	went dry. Only VOCs & MEE Collected (no metals).						
Middle	1000	4.00	—	Clear No odor	20.58	6.82	1.03	35	0.82	-25	
			Sampled @ 1000 for all analytes; Final WL = 15.31'								
Lower	1035	8.43	Unable to collect field parameters - well dewatered								
			Sampled @ 1035 for all analytes (Filtered Diss. Iron limited volume								
								~150 mL)			

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

Client: ESTCP
Project: Bomber - Site 17 - IH
Personnel: JAL
Sample meth: Low Flow - Grab
Date: 9-26-17
Well Number: CMT - 4
Starting SWL:
Tubing Type: Poly
GSI Job No. 4460
Well Depth: 7.23 btoc 16.75' btoc 26.8 btoc
Well Diam: CMT
Other: Near MW-16
Page: 1 of 1
Screen Interval:
Volume Purged:

SAMPLE INFORMATION

	Time	Initial SWL	Pumping Rate	Sample Appearance Odor	Temp. (°F/C)	pH	Spec. Conduct (m mhos/cm)	Turbidity (NTU)	Disolved Oxygen (mg/L)	Redox (mV)	Remarks
Upper	1225	5.34'	—	Strong sulfur Odor	~~Unde~~ Unable to Collect field parameters - Well dewatered.						
			Sampled @ 1225								
Middle	1255	4.40 8.43	—	Strong sulfur odor	23.14	5.94	0.418	60.9	0.67	3	
	1310	14.47	—	" "	22.63	5.80	0.396	82.9	0.34	-1	
			Sampled @ ~~[illegible]~~ 1255 for all constituents.								
Lower	1325	—	—	Strong sulfur odor	22.15	5.68	0.410	266	0.20	-10	
			Sampled @ 1325 for all analytes. Dewatered after parameters.								

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8/7/18 - 8/8/18

Well ID: MW-04
Weather: Sunny ~80° F
Personnel: OMH JAL
Site Conditions: Damp, grassy

WELL INFORMATION

Well Depth (ft btoc) 21.51' ~~[illegible]~~ ~~w/ tubing~~
Well Diameter: 1"
Well Material: PVC
Starting SWL (ft btoc): 3.98' w/ tubing
Ending SWL (ft btoc): 20.10

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~ Peri pump tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
0916	10.20	250	Clear slight sweet	22.30	6.62	1.42	6.47	-2	15.0	SWL Dropping Quickly
0919	13.55	250	" " " "	21.14	6.16	1.43	0.75	-9	14.0	SWL Dropping
0922	18.22	250	" "	21.10	6.13	1.40	0.00	12	13.5	" "
0925	—	250	" "	21.17	6.06	1.40	3.50	35	14.4	Air bubbles dry
0848	13.82	→	8/8/18		Sample TS17MW04 @ 0910					
0919	16.37						8/8/18			
					(VOCs & Dissolved Gas)					
1325					Sample TS17MW04 @ 1330					
							8/8/18			
					(Microbial & Chloride/Nitrate)					
					* Dry @ 1345 : limited volume available					
					for chloride/nitrate sample ~150 mL					

Remarks: Dry @ 0925

Sample ~~TSMW~~ TS17MW04 @ 0910 (8/8/18)
for VOCs + Dissolved Gas

Page 1 of 1

Sample @ 1330 for microbial & chloride/Nitrate (lim. volume)

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: ISMW11
Weather: Sunny ~90° F
Personnel: JAL + OMH
Site Conditions: Fluvial bank, dry-damp, veg.

WELL INFORMATION

Well Depth (ft btoc)
Well Diameter: 2''
Well Material: PVC
Starting SWL (ft btoc): 5.49'
Ending SWL (ft btoc): 6.63'

Sampling Method: Low Flow
Tubing Type: 1/4'' Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1240	6.06	300	clear / no odor	22.18	6.76	1.52	3.43	-101	35.0	
1244	6.32	250	↓	20.31	6.72	1.43	0.00	-99	17.5	
1247	6.35	250		20.18	6.72	1.39	0.00	-98	17.6	
1250	6.38	250	" / "	20.13	6.69	1.38	0.00	-97	17.5	
1253	6.46	250		20.11	6.72	1.34	0.00	-99	18.9	
1256	6.49	250		20.20	6.73	1.30	0.00	-99	20.9	
1259	6.58	250		20.26	6.74	1.26	0.00	-100	21.4	

Remarks:

Sampled @ 1300

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: IS17MW12
Weather: Partial Clouds ~85° F
Personnel: JAL + DMH
Site Conditions: Ponded water, grass

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.15'
Ending SWL (ft btoc): 6.35'

Sampling Method: Low Flow
Tubing Type: Poly 1/4" OD
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1600	3.97	300	orangish musty sweet	26.47	6.86	0.617	0.65	22	79.0	
1605	4.69	300		24.37	6.59	0.556	0.00	42	72.7	
1608	5.20	300		24.00	6.59	0.524	0.00	47	69.7	
1611	5.66	250	yellowith organic odor	23.91	6.54	0.517	0.00	45	67.2	
1614	5.82	250		23.90	6.59	0.505	0.00	43	67.0	

Remarks: Sample IS17MW12 @ 1620

come back tmrw 8-8-18 for chloride, nitrate, & MI samples

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: IS17 MW13
Weather: Sunny, hot ~95° F
Personnel: DMH + JAL
Site Conditions: Damp, ponded water, leaves

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.25
Ending SWL (ft btoc): 4.88

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1447	4.19	380	orangish	31.15	7.29	1.19	1.01	-116	94.3	
1450		300	Clear no odor	29.85	7.19	1.19	0.00	-112	61.1	
1453	4.67			29.56	7.16	1.15	0.00	-103	70.5	
1456	4.69	250	" "	29.36	7.11	1.08	0.00	-92	74.7	Pump dying flow slowing
1459										Pump died...
										Switch out for JAL's pump
1504	4.51	250	Clear no odor	29.71	7.03	1.10	0.00	-83	57.7	
1507	4.68	250	" "	29.69	7.01	1.07	0.00	-81	46.5	
1510	4.73	250	" "	29.62	7.01	1.06	0.00	-82	43.0	
1513	4.79	250	" "	29.72	7.01	1.05	0.00	-81	40.8	

Remarks: Pump battery dies @ 1459, start back up w/ JAL's @ 1502

Sample @ 1515

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: ISMW14
Weather: Sunny ~90°F
Personnel: DMH + JAL
Site Conditions: bank of Potomac R.; veg. + debris

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 4.00
Ending SWL (ft btoc): 4.67

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~ Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1333	4.30	250	Clear / no odor	26.79	6.66	0.555	7.69	12	30.2	
1336		250	" " / " "	25.71	6.51	0.477	5.76	30	26.7	
1339	4.55	250	" / "	25.24	6.48	0.451	4.96	37	32.4	
1344		250	" / "	25.02	6.51	0.440	3.47	39	35.5	
1349	4.60	250		24.89	6.60	0.426	2.50	36	33.8	
1354		250	" / "	24.94	6.59	0.418	1.73	36	33.3	
1357	4.64	250	" / "	24.99	6.62	0.416	1.55	36	31.3	

Remarks: Sampled @ 1400

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: MW-17
Weather: Sunny, ~85°F
Personnel: DMH + JAL
Site Conditions: Damp-wet, vegetated

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
~~1027~~				~~20.16~~	~~10.~~					Flow thru not full
1030				19.36	9.03	0.782	10.58	-342	40.9	pH falling from >10.00
1033				19.32	7.67	0.543	9.88	-242	38.8	
1036				19.41	6.90	0.440	8.95	-141	31.7	
1039				19.60	6.56	0.398	8.11	-86	17.6	
1042				19.61	6.45	0.383	7.51	-64	14.0	
1045				19.78	6.44	0.388	6.90	-58	12.6	
1048				19.97	6.46	0.388	6.50	-56	12.8	

Remarks: Parameters for Aestus; NO sample
Initially alkaline pH - JAL thinks possible bentonite leaching

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: MW-18
Weather: Sunny ~80° F
Personnel: DMH + JAL
Site Conditions: Dry - damp, vegetated

WELL INFORMATION

Well Depth (ft btoc) ~22'
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1013				20.85	5.90	0.261	1.46	135	159	
1016				20.97	5.69	0.249	0.00	132	133	
1019				21.01	5.65	.246	0.00	126	120	
1022				21.02	5.63	0.243	0.00	113	115	

Remarks: Field parameters for Aestus ; No Sample

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GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: MW-19
Weather: Sunny ~80° F
Personnel: DMH, JAL
Site Conditions: Dry, leaves + deadfall

WELL INFORMATION

Well Depth (ft btoc): ~29' (soft bottom)
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to bottom of hole (TD)

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
0953			Yellowish	18.59	6.26	0.628	4.58	28	560	
0958				17.07	6.12	0.525	0.00	51	152	
1001			Clear	16.95	6.15	0.515	0.00	52	84.4	
1004				17.05	6.26	0.510	0.00	47	62.0	

Remarks: Field parameters for Aestus, no sample

Soft bottom, obstruction @ ~15' bgs

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8/8/18

Well ID: CMT - 4
Weather: Sunny / Warm
Personnel: DMH + JAL
Site Conditions: Muddy + Standing Water

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter:
Well Material:
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~ Tubing to Channel TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
	CMT-4-UPPER			Sampled @ 1015					ch. 1	
1025	*	1st Reading		24.22	5.81	0.621	2.48	-1	98.9	
1028	*	2nd		24.70	5.89	0.619	1.32	-14	102	
	CMT-4-MIDDLE			Sampled @ 1040					Ch. 2	
1045				25.58	6.36	0.855	0.45	-53	24.7	
1051				21.56	6.06	0.925	0.42	-59	28.1	
1054				21.45	6.11	0.914	0.40	-61	68.4	
1057				21.92	6.05	0.912	0.00	-60	77.2	
	CMT-4-LOWER			Sampled @ 1105						Ch. 3
1115		* NOT ENOUGH		VOLUME FOR READING						

Remarks:
CMT-4-UPPER @ 1015 Ch. 1
CMT-4-MIDDLE @ 1040 Ch. 2
CMT-4-LOWER @ 1105 Ch. 3

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: CMT-3
Weather: Sunny / Hot
Personnel: DMH + JAL
Site Conditions: Muddy + standing water

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: CMT
Well Material:
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~
Tubing to channel T D

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
CMT-3-UPPER				Sampled		@	1650			Ch. 1
	*	Limited volume available;				Total Iron	bottle	filled	to	~50 mL
		- no volume left for reading								
CMT-3-MIDDLE				Sampled	@	1710				
	*	1st Reading @ 1717								
1717				22.45	7.52	1.18	6.22	-130	24.4	
1721	*	2nd Reading @ 1721		23.17	7.66	1.20	1.79	-131	18.6	
		- No volume for		3rd Reading						
CMT-3-UPPER				Sample	@	1720				
	*	No volume left for reading								

Remarks:
CMT-3-UPPER @ 1650 Ch. 1
CMT-3-MIDDLE @ 1710 Ch. 2
CMT-3-LOWER @ 1720 Ch. 3

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date:

Well ID: CMT-2
Weather: Sunny/Hot
Personnel: JAL/DMH
Site Conditions: Muddy/Standing Water

WELL INFORMATION

Well Depth (ft btoc)
Well Diameter:
Well Material:
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: Pump set at

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
CMT-2-Upper Sampled @ 1500										
Reading 1:			Yellow Tint organic odor	25.28	7.78	0.496	0.00	-168	187	
			Only volume for 1 reading							
CMT-2-Middle Sampled @ 1535										
Reading 1:			slight yellow tint organic odor	23.77	7.65	1.07	1.48	-21	27.5	
			Only volume for 1 reading							
CMT-2-Lower Sampled @ 1610										
		Not enough volume for field parameter readings								
		* ~~We~~ Sample water appeared to react with preservative								
		creating many small bubbles in VOA vial – may have								
		some headspace.								

Remarks:

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: CMT-1
Weather: Sunny/hot
Personnel: JAL/DMH
Site Conditions: Muddy/Standing Water

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: CMT
Well Material: Poly
Starting SWL (ft btoc): 493'
Ending SWL (ft btoc):

Sampling Method: ~~Low Flow~~ Grab
Tubing Type: Poly
Screened Interval (ft bgs):
Other: Pump set at

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
CMT-1-Upper :			Sampled @ 1245							
Reading 1 :			yellow tint No odor	26.69	6.90	1.19	0.22	-103	58	
	4.13' 2 :		" " " "	24.86	6.96	1.12	0.58	-91	63.5	
	6.11' 3 :			24.72	6.92	1.10	0.12	-87	49.5	
CMT-1-Middle			Sampled @ 1400							
	3.93		orange/ yellow No odor	25.29	6.65	1.35	1.15	21	616	
			Only Volume for 1 Reading							
CMT-1-Lower			Sampled @ 1430							
Reading 1 :			clear No odor	30.61	7.12	1.48	1.49	17	17.5	
			Only Volume for 1 reading							

Remarks:

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-7-18

Well ID: IS17MW15
Weather: Sunny/Hot
Personnel: JAL/DMH
Site Conditions: Muddy/Standing Water

WELL INFORMATION

Well Depth (ft btoc) 18
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.4' BTOC
Ending SWL (ft btoc): 10.4' BTOC

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs): 8-18'
Other: Pump set at 14'

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1745	5.1	0.300	Clear No odor	19.74	7.08	1.45	1.26	-67	9.5	
1748	6.0	0.300	Clear No odor	19.52	7.04	1.44	0.0	-66	8.3	
1751	6.78	0.275	" " " "	19.31	7.04	1.44	0.0	-66	9.8	
1754	7.43	0.275	" " " "	19.40	7.05	1.43	0.0	-67	9.7	
1757	8.27	0.275	" " " "	19.36	7.07	1.43	0.0	-67	9.5	
	Sample time = 1800									
	Dup-1 also Collected									

Remarks:

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GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 8-8-18

Well ID: IS17MW16
Weather: Sunny/Hot
Personnel: JAL/DMH
Site Conditions: Wet/Muddy

WELL INFORMATION

Well Depth (ft btoc) 16
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.86' Btoc
Ending SWL (ft btoc): 4.0

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs): 6-16'
Other: Pump set at 12'

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
0926	3.98'	150	Clear / No odor	23.0	5.88	0.973	0.00	-21	0.0	
0929	4.01'	200	" " / " "	22.5	5.89	0.973	0.00	-24	0.0	
0932	4.02'	200	" " / " "	22.19	5.80	0.972	0.00	-21	0.0	
0935	4.01'	200	" " / " "	22.22	5.80	0.973	0.00	-23	0.0	
0938	4.01'	200	" " / " "	22.27	5.86	0.975	0.00	-27	0.0	
	Sample @ 0940									
	Dup-2 also Collected									
	MS/MSD also Collected									
	Microbial also Collected									

Remarks:

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DAILY FIELD ACTIVITY LOG

GSI ENVIRONMENTAL

GSI Job No.: 4951

Date: 8-8-18

Project: Indian Head, MD

Personnel: JAL/DMH

TIME	***ACTIVITY*** Sample Summary
0940	Sampled ISI7MW16 for : VOCs, MEE, Acetylene, Microbial,
	Total Iron, Dissolved Iron, Chloride, and Nitrate
	Also collected : Dup-2 (VOCs, MEE + Acet., + Total Iron)
	MS/MSD (VOCs only)
0930	Sampled ISI7MW12 for : Microbial; Nitrate; Chloride
0910	Sample ISI7MW04 for : VOCs, Dissolved Gases + Acetylene
1035	Sampled ISI7MW11 for : Nitrate; Chloride
1015	Sampled CMT-4-Upper for : VOCs; MEE + Acet.; Total Iron
1040	Sampled CMT-4-Middle for : VOCs; MEE + Acet; Total Iron
1105	Sampled CMT-4-Lower for : VOCs, MEE + Acet; Total Iron
1130	Field Parameters from Mattawoman Creek
	R1 : Temp : 31.86 °C R2 : Temp. 33.69 °C
	pH : 8.37 pH : 9.10
	ORP : -116 ORP : -90
	Cond : 0.213 mS/cm Cond : 0.215 mS/cm
	DO : 13.3 mg/L DO : 10.05 mg/L
	Turb : 31.5 NTU Turb : 341 NTU
1300	Collect Sample at ISI7MW15 for : Nitrate; Chloride; Dissolved Iron

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown) GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/11-12/2018
Well ID: MW04
Weather: ~ 40° F Sunny
Personnel: DMH
Site Conditions: Damp, snow

WELL INFORMATION

Well Depth (ft btoc): 21.2
Well Diameter: 1"
Well Material: PVC
Starting SWL (ft btoc): 4.83
Ending SWL (ft btoc): 21.2
Sampling Method: Low Flow Per. pump
Tubing Type: Poly
Screened Interval (ft bgs): 8 - 18
Other: ~~Pump~~ set at ~ 17 ft
Tubing

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/°C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
12/11/18 1208	12.12	300	Clear	14.5	5.60	1.386	3.09	23.8	0	
1213	21.2			14.9	5.76	1.305	4.73	48.4	7.6	Dry
12/12/18 1245	14.40									
1445	14.0									~1100 mL
	* VOC, & MEE									
	* MICROBIAL									
12/13 1600	* Chlor. Total + Diss. Fe									

Remarks: Pumped Dry @ 1213 on 12/11/18

12/12/18 Sampled @ 1500 for VOCs + MEE
@ 1640 for Microbial
12/13/18 @ 1600 for Chloride, Total + Diss. Fe

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/11/18

Well ID: MW 11
Weather: ~40°F Sunny
Personnel: DMH
Site Conditions: Damp, grass

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 5.82
Ending SWL (ft btoc): 6.89

Sampling Method: Low Flow Peri pump
Tubing Type: Poly dedicated
Screened Interval (ft bgs): 3.6 - 13.6
Other: Pump set at TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1333	5.89	300	Clear / no odor	14.3	5.92	1.244	0.79	-96.5	13.3	
1338	6.17	100	" / "	13.8	5.92	1.328	0.43	-97.1	20.5	
1342	6.19	100	" / "	13.8	5.99	1.333	0.28	-95.8	17.3	
1346	6.26	200	" / "	13.8	6.02	1.333	0.17	-89.0	12.0	
1350	6.31	200	" / "	14.0	6.02	1.338	0.12	-85.9	11.7	
1353	6.35	200	" / "	14.0	6.03	1.339	0.09	-83.8	13.5	
1356		200	" / "	14.1	6.03	1.340	0.07	-79.2	13.5	
1359	6.39	200	" / "	14.1	6.03	1.340	0.05	-79.3	14.0	

Remarks: Sample @ 1400

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/13/18

Well ID: IS17 MW12
Weather: ~45° F, Sunny
Personnel: DMH
Site Conditions: Wet, Muddy

WELL INFORMATION

Well Depth (ft btoc)
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.85
Ending SWL (ft btoc): 5.90

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 3.6 - 13.6
Other: ~~Pump~~ set at TD
Tubing

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1220	3.85	200	Clear	14.7	5.45	0.618	0.57	49.7	16.8	
1225	4.61	200	Orange sandy No odor	15.0	5.27	0.564	0.14	74.6	500	
1228				14.9	5.41	0.511	0.06	59.9	176.1	
1232	5.29	200	Clear	15.1	5.39	0.502	0.04	58.2	252	Flow thru turb. higher
1235				15.1	5.39	0.493	0.01	59.8	OR	Flow thru build up
1236									Clean out Flow thru cell	
1241	5.75	300	Clear	15.1	5.37	0.428	0.14	68.5	35.8	
1244	5.99	200		15.0	5.37	0.423	0.02	74.1	13.2	
1247		200	Clear	14.9	5.37	0.422	0.02	76.7	14.6	
1250	6.14	200		14.5	5.37	0.416	0.02	78.9	30.4	

Remarks: Sample IS17MW12 @ 1250
* DUP-1 also collected (All 11 bottles)
* MS/MSD also collected (VOCs)

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/12/18

Well ID: IS17 MW13
Weather: Cold, Sunny
Personnel: DMH
Site Conditions: Wet, muddy

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.02
Ending SWL (ft btoc): 4.55

Sampling Method: Low Flow
Tubing Type: Poly 1/4"
Screened Interval (ft bgs): 3.6 - 13.6
Other: ~~Pump~~ set at TD
Tubing

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1022	3.55	200	Cloudy	13.0	6.41	1.237	2.32	-42.8	48.9	
1026	4.03	200	Clear No odor	13.5	6.47	1.258	2.24	-55.3	31.0	
1030	4.13			13.5	6.47	1.259	1.21	-56.0	24.5	
1035	4.36	200	Clear	13.0	6.48	1.254	1.57	-58.2	23.2	
1039	4.38	200		12.9	6.48	1.242	1.90	-57.5	20.6	
1043	4.43	200		12.8	6.49	1.227	1.73	-57.0	21.1	
1046	4.49	200		13.0	6.38	1.212	1.40	-55.9	18.6	
1050	4.55	200		13.1	6.47	1.219	1.09	-56.5	16.0	
1053	4.57	200		13.1	6.44	1.216	0.97	-55.4	15.2	
1056	4.59	200		13.1	6.43	1.213	0.85	-56.8	14.5	
1101				13.4	6.47	1.197	1.93	-61.6	13.4	
1106	4.63	200		13.3	6.47	1.199	1.92	-59.6	11.3	
1109	4.63	200		13.4	6.43	1.194	1.90	-58.8	10.5	

Remarks: Sample @ 1110

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/12/18

Well ID: IS17 MW14
Weather: Sunny, cold
Personnel: DMH
Site Conditions: Damp, grass

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.83
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type:
Screened Interval (ft bgs): 3.6 - 13.6
Other: ~~Pump~~ set at TD
Tubing

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
0919	4.32	200	orangish turbid	11.4	6.29	0.533	3.32	40.2	176	
0924	4.45	200	Clear / No odor	13.3	6.15	0.468	3.25	42.7	6.3	
0928	4.48	200	↓	13.7	6.07	0.449	2.83	21.8	0	
0931	4.51			13.7	5.91	0.452	2.40	35.2	0.2	
0935	4.49	200		14.5	5.91	0.456	2.43	33.3	2.6	
0938	4.50	200		14.8	5.92	0.452	2.34	32.1	10.1	

Remarks: Sample at 0940

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/13/18

Well ID: IS17MW15
Weather: Cloudy ~40° F
Personnel: DMH
Site Conditions: Wet, Muddy

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.79
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 8 - 18.0
Other: Pump set at TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1345	4.66	200	Orangish - clear	13.0	6.18	1.433	0.83	13.5	75.6	
1349	5.62	200	" "	13.9	6.28	1.363	0.12	-26.8	123.2	
1352				13.9	6.32	1.355	0.05	-31.7	112.6	
1355	7.45	200		14.0	6.32	1.355	0.02	-33.7	106.8	
1359				13.4	6.32	1.362	0.00	-35.8	92.1	

Remarks: Sample @ 1400

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/12/18

Well ID: IS17MW16
Weather: ~35°F Sunny
Personnel: DMH
Site Conditions: wet, Muddy

WELL INFORMATION

Well Depth (ft btoc)
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.71
Ending SWL (ft btoc): 3.94

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 6 - 16
Other: Pump set at TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1153	3.97	200	Clear No odor	13.0	6.42	0.973	2.34	-19.1	6.5	
1158				12.9	6.13	0.974	0.23	-1.7	2.0	
1201	4.03	200		12.6	6.12	0.974	0.14	-0.4	4.7	
1205	4.05	200		12.2	6.11	0.975	0.09	0.1	5.7	
1208	4.05	200		11.9	6.13	0.975	0.05	-2.7	9.3	
1211	4.05	200		11.5	6.14	0.971	0 0	-6.0	11.6	

Remarks: Sample @ 1212 VOCs, MEE, Total + Diss. Fe, Chloride, Microbial

MI for DHC, DHBt, BVC, TCE, VCR + EBAC

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/11/18

Well ID: CMT - 1
Weather: ~40° F Sunny
Personnel: DMH
Site Conditions: Damp, grass snow

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter:
Well Material:
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow Peri
Tubing Type: 1/4" Poly
Screened Interval (ft bgs):
Other: Pump set at TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1500		CMT-1	UPPER		Sampled	for	VOCs,	MEE,	Total + Dissolved	Fe, Chloride
1510			Clear No odor	12.9	6.25	1.034	3.28	-59.3	10.8	
1530		CMT-	1 MIDDLE		Sampled	for	VOCs,	MEE, Total	+ Diss. Fe,	Chloride
	not	enough	water for	parameters						
1600		CMT-1	LOWER		"				↓	No chloride "
	not	enough	water for	parameters						

Remarks:
1500 CMT - 1 UPPER for VOCs, MEE, Total + diss. Fe, Chloride (3/4 VOC VOAs)
1530 MIDDLE for " " 4/4
1600 LOWER for VOC, MEE, Total + diss. Fe 4/4

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown) GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/13/18

Well ID: CMT-2
Weather: ~40°F Partly cloudy
Personnel: DMM
Site Conditions: Wet, Muddy

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter:
Well Material: CMT
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs):
Other: ~~Pump~~ set at Tubing TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
0830	1.97		Clear – Iron/dark particles							
	*	CMT-2 UPPER Sampled @ 0840								Ch. 1
		not enough volume for parameters								
	Collected VOC, MEE, Chloride, Total + Dissolved Fe									
0915	*	CMT-2 MIDDLE Sampled @ 0915								Ch. 6
			Greenish Cloudy Opaque							
0926			Clear	14.2	6.69	1.087	1.39	-87.9	33.5	
0940	*	CMT-2 LOWER Sampled for VOC, MEF, Chloride, Dissolved Iron								
										(~100 mL)
	not enough volume for total Iron or parameters									→ in unpreserved plastic
										Lab Filter
										Ch. 7

Remarks:

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/13/18

Well ID: CMT-3
Weather: ~40° F Cloudy
Personnel: DMH
Site Conditions: Wet, Muddy

WELL INFORMATION

Well Depth (ft btoc) CMT
Well Diameter:
Well Material:
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs):
Other: Pump set at TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1450	*		CMT 3 UPPER			Sample collected				Ch. 1
			for: VOC, (4) MEE(3), ~100 mL of unpres. plastic							=10 bottles
1515	*		CMT-3 MIDDLE			–	All 11 Bottles collected			
1523				12.7	6.95	1.272	1.11	-38.2	32.2	ch. 2
1535	*		CMT-3 LOWER							ch. 3
			partial fill (~100 mL) on HNO3 preserved Bottle for total Fe							
			Not enough volume for params							

Remarks: 1450 CMT-3 Upper 9 bottles + partial fill dissolved Fe
1515 CMT-3 MIDDLE 11 bottles
1535 CMT-3 LOWER 10 bottles + partial fill total Fe

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 12/13/18

Well ID: CMT-4
Weather: ~40° F P. Cloudy
Personnel: DMH
Site Conditions: Wet, Muddy

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: CMT
Well Material:
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs):
Other: Pump set at TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1015		* Sample CMT-4 Upper - All 11 Bottles								Ch. 1
1030			Rust color clear	10.5	6.36	0.757	2.16	-47.0	93.3	
1033				10.4	6.26	0.728	1.91	-46.2		
1040		* Sample CMT-4 MIDDLE - All 11 Bottles								Ch. 2
1058				14.3	6.14	0.832	1.10	-38.6		
1101				15.3	6.07	0.814	0.58	-36.5		
1115		* Sample CMT-4 LOWER								Ch. 7
				collected VOCs (4), MEE (3), Chlor (2), partial diss. Fe (1) ~50 mL						
		Not enough volume for Parameters							= 10 bottles	

Remarks:

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 4-24-19

Well ID: CMT-1
Weather: Sunny
Personnel: DMH/JAL
Site Conditions: Muddy/Wetlands

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter:
Well Material:
Starting SWL (ft btoc): 4.23/
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: 1/4" OD Poly
Screened Interval (ft bgs):
Other: ~~Pump set at~~ Tubing @ TD each interval

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1805	4.23'	Sample CMT-1-Upper								Ch. 1
1825	6.70	–	Clear/particulates No odor	20.08	6.23	1.18	0.24	-94	114	
1831	7.0	–	Clear No odor	18.63	6.10	1.26	0.74	-79	20.9	
	↳	Collected Dup-2 @1835 ("Untreated Sample")								
4/25 0840	5.42	→ collected Dup-3 @ 0840 (12hr treatment)								
4/25 0815	4.32	Sample CMT-1-MIDDLE								Ch. 2
0825	dry	–		15.77	5.25	1.33	0.88	159	89.7	
1025		*collected Dup-4 @ 1025 (2-hr treatment)								
		↳ only 1 bottle (40 mL VOCs voa) not enough volume								
0905	4.09									
0910		Sample CMT-1-LOWER								Ch. 3
0925	Dry	no volume for parameters								
~~1045~~		~~* Dup-5 failure → <40 mL recharged~~								

Remarks:
4/24 CMT-1-Upper Collected @ 1805 & Dup-2 collected @1835
4/25 CMT-1-MIDDLE collected @ 0815 + Dup-4 @ 1025 (one 40 mL VOCs Voa)
4/25 CMT-1-LOWER collected @ 0910

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4/25 CMT-1-UPPER / Dup-3 collected @ 0840 (VOCs + AMDOGAX)

GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 4-24-19

Well ID: CMT-2
Weather: Sunny
Personnel: DMH, JAL
Site Conditions: wet, muddy wetland

WELL INFORMATION

U/M/L Well Depth (ft btoc): 8.34 /
Well Diameter:
Well Material:
U/M/L Starting SWL (ft btoc): 1.43 / clog / clog
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: ~~Pump~~ set at
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
* 1245	1.43	Sample	CMT-2-UPPER							
	*	Not enough	volume	for	params ;			partial	(1) HNO$_3$ plastic 250 mL	
	Dry								(total Fe)	
1320		Sample	CMT-2	MIDDLE						
1340	Dry			26.52	6.72	1.09	1.13	-128	34.0	
1355		Sample	CMT-2-LOW							
1415	Dry									

Remarks: CMT-2-UP - Ch. 1 - Sample @ 1245 all 11 bottles
CMT-2 MD - Ch. 6 - Sample @ 1320 " "
CMT-3, LOW - Ch. 3 - Sample @ 1355 8-5 bottles

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown) GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 4-24-19

Well ID: CMT-3
Weather: Sunny
Personnel: DMH/JAL
Site Conditions: Wet/Muddy/Wetland

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter:
Well Material:
M/M/L Starting SWL (ft btoc): 2.94/3.38/2.20
Ending SWL (ft btoc): dry/dry/dry

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs):
Other: Pump set at

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1545	2.94	Sample CMT-3-Upper								
	* Not enough volume for field parameters - filled 3 VOC VOA, 3 Diss Gas VOAs,									
	2 Cl⁻ VOAs, and half unpreserved 250 mL (no HNO₃ 250 mL)									
1630	3.38	Sample CMT-3-Middle								
1650		—	clear No odor	25.51	7.05	1.23	1.24	-142	36.4	
			" " "	23.21	6.91	1.19	0.83	-124	37.5	
		Well purged Dry - All bottles filled								
1720	2.20	Sampled CMT-3-Lower								
	* Not enough volume for field parameters - limited volume									
		for unpreserved 250 mL bottle (all other bottles filled)								

Remarks: CMT-3-Upper sampled @ 1545
CMT-3-Middle sampled @ 1630
CMT-3-Lower sampled @ 1720

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4951
Project: Indian Head, MD
Location: Indian Head, MD
Date: 4/24/19

Well ID: CMT-4- UPPER/MIDDLE/LOWER
Weather: Partly Cloudy
Personnel: DMH, JAL
Site Conditions: Wet, muddy, wetland grass

WELL INFORMATION

U/M/L Well Depth (ft btoc) 7.23/16.75/26.8
Well Diameter: CMT
Well Material:
U/M/L Starting SWL (ft btoc): 2.21/5.75/10.53
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly 1/4"
Screened Interval (ft bgs): 6.73 - 7.23 (upper)
Other: ~~Pump set at~~
Tubing to TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
* CMT-4 -UPPER				Sampled @ 0945						
0940	2.21									
1005	4.99									
1008	5.56		Particulates ZVI?	20.20	6.13	0.697	0.35	-73	95.4	
* CMT-4- MIDDLE				Sampled @ 1020						
1020	5.75									
1053	7.3			19.32	6.16	0.880	0.18	-54	79.4	SWL 7.3 (Ch. 4 blocked at 7.3)
* CMT-4-LOWER										
1115	10.53									
1130			ZVI particulates	22.53	6.24	0.832	0.73	-57	276	

Remarks: CMT Channel 1 - UPPER 0945
Channel 2 - MID 1020
Ch. 3 - Lower 1115

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GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460-601
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 8-9, 2019

Well ID: MW-04
Weather: Cloudy ~60° F
Personnel: DMH
Site Conditions: Grass

WELL INFORMATION

Well Depth (ft btoc) 21.25
Well Diameter: 1"
Well Material: PVC
Starting SWL (ft btoc): 5.25
Ending SWL (ft btoc):

Sampling Method: Purge Dry - Sample
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): ~~1/4"~~ 8-18 ft
Other:

SAMPLE INFORMATION

	Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
10/8	1525	5.25	250	Yellowish Chemical smell	19.69	5.88	1.34	1.11	28	47.3	
	1528	11.72	250		19.68	5.79	1.34	0.45	36	42.9	
	1532	15.90		Chemical Smell	19.69	5.84	1.33	0.20	37	41.6	
	1536	19.00			19.73	5.83	1.32	0.30	31	42.3	
	1537	Dry									
10/9	1055	16.45			< 20%		recharge				
	1220	16.10									
10/10	1015	12.7									
	1500	11.01									

Remarks: Tubing set @ TD = 21.25

* Sampled VOCs & DGs @ 1515 (grab)
& Microbial
MW-04

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 7 2019

Well ID: MW-11
Weather: Cloudy
Personnel: DMH
Site Conditions: Grassy, banks of Mattawoman Creek

WELL INFORMATION

Well Depth (ft btoc) MW-11
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 5.98
Ending SWL (ft btoc):

Sampling Method: Low flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 3.6 - 13.6
Other:

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1528	6.55	500	Rust color cloudy / –	23.19	6.03	1.43	0.82	-65	65.3	
1535	6.77	250	" / "	22.53	6.04	1.43	0.13	-83	46.9	
1540			" / "	22.61	6.04	1.42	0.07	-85	52.6	
1543	6.85		" / "	22.55	6.04	1.41	0.01	-86	70.6	
1546				22.44	6.04	1.41	0.00	-87	82.1	
* 1550	6.94	250	" / "	22.41	6.04	1.41	0.00	-88	78.8	

Remarks: Bot. of tubing set at ~13 ft btoc

* Sampled @ 1550

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 9 2019

Well ID: MW-12
Weather: Cloudy, ~70°F
Personnel: JMH
Site Conditions: Tall grass

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 5.05
Ending SWL (ft btoc): 7.37

Sampling Method: Low Flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 3.6 - 13.6
Other: Bot. Tubing set ~ 12.5 ft btoc (~ 8.5 ft bgs)

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1115	6.02	250	Yellowish clear / Sulfur Smell	19.98	5.83	0.571	1.33	52	11.2	
1120			" / "	20.02	5.78	0.570	0.44	38	8.8	
1125	6.87	250	" / "	20.12	5.78	0.566	0.26	30	0.0	
1130				20.25	5.78	0.564	0.13	28	0.0	
1133	7.18	250	" / "	20.31	5.78	0.563	0.10	27	0.0	
1136	7.			20.38	5.78	0.562	0.13	27	0.0	
1140	7.41			20.49	5.77	0.560	0.10	27	0.0	

Remarks: Sampled @ 1140

★ Note: will return to sample Microbial on last day (24-hr hold)

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 8, 2019

Well ID: MW-13
Weather: Cloudy, ~60°F
Personnel: DMH
Site Conditions: Damp, grassy

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 3.61
Ending SWL (ft btoc): 4.95

Sampling Method: Low flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 3.6-13.6
Other:

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ °C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1322	3.61	400	clear	18.85	6.22	1.04	0.55	-48	4.6	
1332	4.94	250	clear	19.23	6.27	1.05	0.28	-68	0.0	
1335	~~5.10~~			19.45	6.29	1.04	0.24	-71	0.0	
1338	5.10	250	Clear	19.55	6.31	1.04	0.19	-72	0.0	
1341				19.64	6.31	1.04	0.16	-73	0.0	
1344	5.23	250	clear No odor	19.69	6.31	1.04	0.13	-74	0.0	

Remarks: Tubing set @ 12 ft btoc (~8 ft bgs)

* Sampled @ 1345

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 7 2019

Well ID: MW-14
Weather: Sunny
Personnel: DMH
Site Conditions: Grass, banks of Mattawoman Creek

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 4.00
Ending SWL (ft btoc): 4.84

Sampling Method: Low Flow
Tubing Type:
Screened Interval (ft bgs): 3.6 - 13.6
Other:

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1630	4.64	200	Rust color - clear cloudy metallic/Iron odor	26.30	5.80	0.574	0.68	-4	19.4	
1638	4.79	250	Clear oil smell?	26.41	5.75	0.565	0.07	-7	17.8	
1642			Clear " "	24.43	5.76	0.586	0.00	-10	10.0	
1645	4.81	250	Clear	24.16	5.75	0.588	0.01	-11	9.6	
1648	4.81			23.85	5.76	0.580	0.01	-13	9.1	
1652	4.83	300	Clear	23.95	5.75	0.577	0.00	-15	8.9	
* 1655	4.84			23.92	5.76	0.577	0.00	-15	8.6	

Remarks: Tubing set @ ~13 ft btoc (~9 ft bgs)

*Sampled @ 1655

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 2019

Well ID: MW-15
Weather: Partly Cloudy, Sun ~80°F
Personnel: DMH
Site Conditions: Wetland grasses overgrown, damp

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2-in
Well Material: 2" PVC
Starting SWL (ft btoc): 6.14
Ending SWL (ft btoc): 13.69

Sampling Method: Low flow
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 8 - 18'
Other:
bot. Tubing @ ~13 ft

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1345	6.52	400	Clear	25.23	6.35	1.35	1.70	-91	5.1	
1355		250		22.61	6.46	1.36	0.11	-115	5.8	
1358	10.23	250	Clear	22.51	6.51	1.37	0.13	-119	7.1	
1401	10.71	200		22.44	6.54	1.36	0.22	-121	8.1	
1404				22.44	6.62	1.35	0.56	-115	10.4	
1407	12.05	200		22.49	6.65	1.34	0.83	-110	13.4	
1411		200		22.54	6.70	1.34	1.13	-103	13.8	
1415	12.45			22.58	6.75	1.33	1.54	-99	14.4	
1418	12.61			22.58	6.72	1.33	1.62	-93	11.5	
1423	12.89	150		22.53	6.56	1.34	1.01	-91	8.9	
1428	12.99			22.50	6.52	1.35	0.63	-93	6.3	
1431			Clear	22.44	6.51	1.36	0.49	-94	5.8	
1434				21.98	6.49	1.36	0.25	-94	7.0	
1437	13.38	150		21.90	6.50	1.36	0.12	-96	10.3	
1440				21.97	6.51	1.36	0.09	-98	9.4	

Remarks: @ 1430 Tubing dropped down to ~14-15 ft btoc

* Sampled @ 1440

- VOCs (3)
- Diss. Gases (3)
- Cl⁻ (2)
- Total + Dissolved Fe (2)

= 10 bottles

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GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 8, 2019

Well ID: MW-16
Weather: Cloudy ~ 68°F
Personnel: DMH
Site Conditions: Overgrown grass, damp

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 2"
Well Material: PVC
Starting SWL (ft btoc): 6.16
Ending SWL (ft btoc):

Sampling Method: Low Flow
Tubing Type: Poly
Screened Interval (ft bgs): 6-16
Other:

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1425	7.65	450	Clear	19.24	6.27	0.863	1.16	-9	0.0	
1430	9.73	300	Sulfur Smell	19.47	6.15	0.845	0.20	-16	0.0	
1435				19.59	6.09	0.821	0.31	-12	0.0	
1440	10.36	250		19.66	6.05	0.798	0.23	-6	0.0	
1443				19.70	6.04	0.786	0.16	-4	0.0	
1446	10.35	200	Clear Sulfur smell	19.71	6.03	0.789	0.17	-5	0.0	
1449				19.72	6.04	0.796	0.16	-8	0.0	

Remarks: Bot. Tubing set @ 15 ft btoc (~11 ft bgs)

* Sampled @ 1450

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 9 2019

Well ID: CMT- 1
Weather: Sunny ~70°F
Personnel: DMH
Site Conditions: Tall grass, Dry

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 7-Channel CMT
Well Material:
Starting SWL (ft btoc): 5.38 (up)
Ending SWL (ft btoc):

Sampling Method: Grab Sample
Tubing Type: Dedicated 1/4" Poly
Screened Interval (ft bgs): UP: 7.96-8.46; MID: 18.15-18.65; Low 28.2-28.7
Other:

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
UPPER 1440	5.38									Ch. 1
1507	7.95	200		24.50	6.35	1.15	1.15	-98	45.5	
1503	Dry									
			* Sampled	CMT-1-		UPPER	@	1455		(all bottles)
1515	6.20		* Sampled	DUP-1-CMT-1-UP				@	1515	(VOCs + MEE, Ac)
1520				23.05	6.24	1.18	3.44	-86	19.7	
MID 1540			* Sampled	CMT-1-MIDDLE			@	1540		Ch. 2
1555	18.95 -	Dry	* all	bottles	filled +	channel dry	before	parameters		could be meas.
1558	5.62									
LOW 1610			* Sample	CMT-1-LOWER				@ 1610		Ch. 3
1615	28.15 -	Dry					(all bot)			

Remarks: CMT-1-UPPER @ ~~1515~~ 1455 (10 bot) & DUP-1-CMT-1-UP (VOCs DGs only)
CMT-1- MIDDLE @ 1540
CMT-1- Lower @ 1610

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 9 2019

Well ID: CMT-1
Weather: Sunny ~ 70° F
Personnel: DMH
Site Conditions: Tall grass, Dry

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter:
Well Material:
Starting SWL (ft btoc): 5.47 (UPPER)
Ending SWL (ft btoc):

Sampling Method: Bubble Strip - Microseeps cell
Tubing Type: 1/4" Dedicated Poly
Screened Interval (ft bgs): 7.96-8.46 (Upper)
Other:

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
1621	5.47	–								
1645	5.44	–	→		6.25	1.18	1.52	-35	39.0	
1650		250	* Begin pumping - flow thru microseeps cell							
				for Bubble Strip Sampling Method						
				for Acetylene						
1700	Dry		→ air bubbles from CMT well entered microseeps							
			cell; Increased bubble size by 2X (now ~40 mL)							
			* Botched sample [diluted w/ atmospheric air							
				prior to recommended EQ time]						
1722			* Start again w/ 20 mL bubble							
			→ Flow until SWL falls below 9.0; Stop							
			→ Allow recharge to > 7.0; Flow							
1740-1743		≈ 3 min	recharge time							
1744		≈ 1 min flow time ; 1744-1750 = 6 min recharge to 6.02 ft btoc								
1750	6.02	160								
1752	9.0	—	Stop flow							

1756 6.31 180

Remarks:
1801 Stop flow & sample bubble

* Sample CMT-1-Upper for acetylene @ 1800
two vials 15 mL & 10 mL

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note: additional 10 mL of bubble leftover ⇒ total 30 mL Bubble size @ end

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: ~~4851~~ 4460-601
Project: Indian Head, MD
Location: Indian Head, MD
Date: 10/10/19

Well ID: CMT-2-Lower
Weather:
Personnel: DMH
Site Conditions: Hot + Sunny, Grassy

WELL INFORMATION

Well Depth (ft btoc) 28.55
Well Diameter: 7-Ch. CMT
Well Material:
Starting SWL (ft btoc): 5.61, 5.18, 6.85 (U, M, L)
Ending SWL (ft btoc): Dry

Sampling Method: ~~Low Flow~~ Grab
Tubing Type: Replaced dedicated 1/4" Poly
Screened Interval (ft bgs): 28.14-28.64 (Low)
Other: ~~Pump set at~~
Tubing @ TD

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
LOW 1335	6.85									
1340			* Sample CMT-2-Lower @ 1340							Ch. 7
(ch.7) 1345	Dry		→ VOCs, DGs, Total Fe, partial diss. Fe, NO Cl⁻							
(ch.3) 1345	7.0		(8 bottles)							(Ch.3 connected?)
			*Insufficient volume for params							
UP 1400	5.61		* Sample CMT-2-UPPER @ 1400							Ch. 1
1404	Dry		→ VOCs (2) & DGs (3) = 5 bottles							
	See page 2 for CMT-2-MIDDLE (Bubble strip)									

Remarks: Water level unchanged in channel 3 (& 4) following ch. 7 drying up (Lower)
* CMT-2-Lower @ 1340 (8)
* CMT-2-Upper @ 1400 (5)

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GSI
ENVIRONMENTAL

Low-Flow (Minimal Drawdown)
GROUNDWATER SAMPLING RECORD

GSI Job No.: ~~4951~~ 4460-601
Project: Indian Head, MD
Location: Indian Head, MD
Date: 10/10/19

Well ID: CMT-2-MIDDLE
Weather: Sunny ~75°F
Personnel: DMH
Site Conditions: Tall grass, Dry

WELL INFORMATION

Well Depth (ft btoc): 19.84 → Meas 20.2 C
Well Diameter: 7-channel CMT
Well Material: CMT
Starting SWL (ft btoc): ~~4.90~~ → 5.18
Ending SWL (ft btoc):

Sampling Method: ~~Low Flow~~ Bubble Strip Sampling Microseeps
Tubing Type: 1/4" Poly (replaced)
Screened Interval (ft bgs): 19.34 - 19.84
Other: ~~Pump set at~~
Ch. 6

SAMPLE INFORMATION

Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
Start 1221	5.18									
1225	13.70	150								
1229	19.2	STOP								Approx 1 Liter prod
1235	18.0	150	*	Sample 1 vial VOCs & DGs (GW) from						
1240	20.10	STOP		effluent of Microseep cell						
			★	→ Stop/start sample CMT-2-MIDDLE						
				for VOCs & DGs (6 bottles)						
				from microseeps cell effluent						
1246			* Sample	15 mL (1) & 6 mL (1) gas						
				for acetylene analysis						
				CMT-2-MIDDLE-01						

Remarks: 20 mL atmospheric air bubble injected to bubble strip cell @ 1221
★ CMT-2-MIDDLE @ 1240 [VOCs & DGs (6)]
★ CMT-2-MIDDLE-01 @ 1246 [gas 15 mL & 6 mL (acetylene)]

Page 2 of 2

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown) GROUNDWATER SAMPLING RECORD

GSI Job No.: ~~4951~~ 4460-601
Project: Indian Head, MD
Location: Indian Head, MD
Date: 10/10/19

Well ID: CMT-3
Weather: Sunny ~ 70°F
Personnel: DMH
Site Conditions: Tall grass

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: 7-Channel CMT
Well Material:
Starting SWL (ft btoc): 3.79 (low)
Ending SWL (ft btoc):

Sampling Method: ~~Low Flow~~ Grab
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): Low: 27.45-27.95; MID: 17.6-18.1; UP: 6.97-7.47
Other: ~~Pump set at~~ Peri pump

SAMPLE INFORMATION

	Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/[✓ C])	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
Low	1040	3.79		* Sample	CMT-3	- Lower			VOCs,	DGs,	Total & Diss Fe
				* Insufficient	vol. for		Cl^-	sample	or	Parameters	(8)
											Ch. 3
MID	1100	3.68		* Sample	CMT-3-	MIDDLE		(10 bot)			Ch. 2
	1108	17.95			18.58	6.79	1.18	0.84	-94	23.8	
	1110	Dry									
	1126 1130	13.35 12.49									
UP	1120	3.50		* Sample	CMT-3-	LOWER		[VOCs &		DGs	Only (6)]
		7.78 ≈ DRY		* Insufficient	volume			for other	bottles &		Parameters

Remarks: * 1040 CMT-3-Lower (8 bot)
* 1100 CMT-3-MIDDLE (10 - all)
* 1120 CMT-3-UPPER (6 VOCs & DG only)
* 1140 DUP-2-CMT-3-MID (CMT Recharge Dup - VOCs only)

GSI ENVIRONMENTAL

Low-Flow (Minimal Drawdown) GROUNDWATER SAMPLING RECORD

GSI Job No.: 4460
Project: Site 17 NSFIH
Location: North Plume, Site 17
Date: October 9, 2019

Well ID: CMT-4
Weather: Partly Cloudy ~70°F
Personnel: DMH
Site Conditions: Tall grass

WELL INFORMATION

Well Depth (ft btoc):
Well Diameter: CMT
Well Material: 7-Channel
Starting SWL (ft btoc):
Ending SWL (ft btoc):

Sampling Method: Grab sample
Tubing Type: 1/4" Poly
Screened Interval (ft bgs): 6.73 - 7.23 (up); 16.25-16.75 (mid); 26.3-26.8 (Low)
Other:

SAMPLE INFORMATION

	Time	SWL (ft btoc)	Pumping Rate (mL/min)	Sample Appearance/ Odor	Temp. (°F/C)	pH	Spec. Conduct (mS/cm)	Diss. Oxygen (mg/L)	Redox (mV)	Turbidity (NTU)	Remarks
UPPER *	1245	5.61		* Sample CMT-4-UPPER @ 1245							upper = ch. 1
	1250	7.52		* VOCs & Diss. Gases collected (6 bottles)							SWL ch. 1
		Dry		→ insufficient volume for other samples / parameters							
MID	1300	7.48		* Sample CMT-4-MIDDLE @ 1300							
	1310	9.94		* VOCs, Diss. Gas, Total & Diss Fe, Cl⁻ (10 bottles)							
	~~1319~~										
	1319	16.30			22.72	6.32	0.804	1.05	-33	135	
	1321	Dry			22.33	6.36	0.808	0.72	-50	146	
Low	1326	16.34									
	1300	7.48									Not hydraulically independent
	1335	* Sample CMT-4-LOWER @ 1335									
	1345	23.85		* VOCs, Diss Gases, Total Fe, Partial Diss. Fe							(8)
		Dry									

Remarks: CMT-4-UPPER @ 1245 VOCs & Diss Gases (6 bot)
-MIDDLE @ 1300 VOCs, Diss. Gases, Total · Diss. Fe, Cl⁻ (10)
-LOWER @ 1335 VOCs, DGs, Total & Diss Fe (8)
↳ Partial

Page 1 of 1

Appendix L. Chain-of-Custody Documentation

Pace Analytical®
www.pacelabs.com

220 William Pitt Way
Pittsburgh, PA 15238
412-826-5245

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

23586

30227882

Page: of

009442

Section A
Required Client Information:

Company:	GSI Environmental
Address:	9600 Great Hills Trail Suite 350E
Email To:	sdr@gsi-net.com
Phone:	512-346-4474
Fax:	
Requested Due Date/TAT:	Standard

Section B
Required Project Information:

Report To:	SDR@gsi-net.com
Copy To:	JAL@gsi-net.com MLS@gsi-net.com
Purchase Order No.:	4460-301
Project Name:	ESTCP Wick Drains
Project Number:	4460-301

Section C
Invoice Information:

Attention:	Justin Long
Company Name:	GSI Environmental
Address:	acct.pay@gsi-net.com
Pace Quote Reference:	
Pace Project Manager:	
Pace Profile #:	

REGULATORY AGENCY

NPDES [✓ GROUND WATER] DRINKING WATER
UST RCRA OTHER

Site Location
STATE: MD

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Matrix Codes
MATRIX / CODE
Drinking Water DW
Water WT
Waste Water WW
Product P
Soil/Solid SL
Oil OL
Wipe WP
Air AR
Tissue TS
Other OT

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	⬇Analysis Test⬇ Y/N	VOCs-8260B	MEE-AM20GAX	Acetylene AM20GAX	Dissolved Iron	Total Iron	Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1	CMT-1-upper	WT	G	~~8/16/17~~		8/16/17	1055	8				X	X	X					X	X	X	X		N	
2	CMT-1-Middle	WT	G			8/16/17	1130	8				X	X	X					X	X	X	X		N	
3	CMT-1-Lower	WT	G			8/16/17	1200	6					X	X					X	X	X			N	2x VOAs for AMG20GAX
4	CMT-2-Upper	WT	G			8/16/17	1230	7					X	X					X	X	X			N	
5	CMT-2-Middle	WT	G			8/16/17	1300	9				X	X	X					X	X	X	X	X	N	
6	CMT-2-Lower	WT	G			8/16/17	1325	6					X	X					X	X	X			N	2x VOAs for AM20
7	CMT-3-Upper	WT	G			8/16/17	1455	8				X	X	X					X	X	X	X		N	
8	CMT-3-Middle	WT	G			8/16/17	1510	9				X	X	X					X	X	X	X	X	N	
9	CMT-3-Lower	WT	G			8/16/17	1545	6					X	X					X	X	X			N	2x VOAs for AM20
10	CMT-4-Upper	WT	G			8/16/17	1610	9				X	X	X					X	X	X	X	X	N	
11	CMT-4-Middle	WT	G			8/16/17	1635	9				X	X	X					X	X	X	X	X	N	
12	CMT-4-Lower	WT	G			8/16/17	1700	9				X	X	X					X	X	X	X	X	N	

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
	/GSI	8/17/17	1600	J McGrath/PACES	8/18/17	8:30	BR	Y	N	Y
							Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

Page 46 of 48

ORIGINAL

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Justin Long
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 08/17/17

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

REPORT TO:
Name: Justin Long
Company: GSI Environmental
Address: 9600 Great Hills Trail
Suite ~~3E~~ 350E
Austin, Tx 78759
email: SDR@gsi-net.com; JAL@gsi-net.com
Phone: 512-346-4474
Fax:

INVOICE TO: (For invoices paid by a third party it is imperative that all information be provided)
Name:
Company:
Address:
email: acct.pay@gsi-net.com
Phone:
Fax:

microbialinsights

10515 Research Dr
Knoxville, TN 37932
865-573-8188
www.microbe.com

Project Manager: Steve Richardson
Project Name: ESTCP Wick Drains
Project No.: 4460-301

Purchase Order No. 4460-301
Subcontract No.
MI Quote No.

Please Check One:
☐ More samples to follow
☒ No Additional Samples

Report Type: ☒ Standard (default) ☐ Microbial Insights Level III raw data(15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (30%)

EDD type: ☒ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information					**Analyses**					**CENSUS: Please select the target organism/gene**																							
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	**PLFA**	**DGGE+3ID**	**DGGE+5ID**	**QuantArray Chlor**	**QuantArray Petro**	DHC (Dehalococcoides)	DHC Functional genes bvc, tce, vcr)	DHBt (Dehalobacter)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AOB (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	add. qPCR:	RNA (Expression Option)*	Other:	Other:	Other:
DL080H1	MW04	8/17/17	0700	W						X	X	X			X																		
2	MW12	8/17/17	0730	W						X	X	X			X																		

Relinquished by: 8/17/17

Received by: **Date** 8/18/17 900

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

REPORT TO:
Name: Justin Long
Company: GSI Environmental Inc.
Address: 9600 Great Hills Trail
Suite 350E
Austin, TX 78759
email: jalong@gsi-net.com
Phone: 512-346-4474
Fax:

INVOICE TO: (For Invoices paid by a third party it is imperative that all information be provided)
Name: Stephen Richardson
Company: GSI Environmental
Address:
email: acct.pay@gsi-net.com
Phone:
Fax:

mi microbialinsights
10515 Research Dr
Knoxville, TN 37932
865-573-8188

www.microbe.com

Project Manager: Justin Long
Project Name: Bomber-Site 17 - Indian Head
Project No.: 4460-301

Purchase Order No.
Subcontract No.
MI Quote No.

Please Check One:
☐ More samples to follow
☒ No Additional Samples

Report Type: ☒ Standard (default) ☐ Microbial Insights Level III raw data(15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (35%)

EDD type: ☒ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information						Analyses				CENSUS: Please select the target organism/gene						
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	PLFA	NGS	QuantArray Chlor	QuantArray Petro	DHC (Dehalococcoides)	DHC Functional genes (bvc, tce, vcr)	DHBt (Dehalobacter)	DHG (Dehalogenimonas)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)
1090I1	MW-12	9-27-17	0840	WT	1					X	X	X				X
2	MW-04	9-27-17	1300	WT	1					X	X	X				X
3	MW-16	9-27-17	1310	WT	1					X	X	X				X

MI ID (Laboratory Use Only)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AMO (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	RNA (Expression Option)*	Other:	Other:	Other:
1090I1																	
2																	
3																	

Relinquished by: Date 9-27-17 Received by: Date 9/28/17

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

* additional cost and sample preservation are associated with RNA samples.

**Saturday delivery: See sampling protocol for alternate shipping address.

Pace Analytical®

CHAIN-OF-CUSTODY RECORD

Phone: (412) 826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

SEND TO: Pace

DUE DATE: 10/10/2017

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.com

Lab Proj. # 24061

Invoice to: ruth.welsh@pacelabs.com

Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin: MD

Preservatives
1 -Unpreserved
2- H2SO4
3- HNO3
4-HCL
5-NaOH+Zn Ace.

WO# : 30231546

30231546

	Sample Type						Parameters Requested											
							12	12	56									
Sample ID	Water	Solid	Date	Time	# Bottles	Preservatives	8260 VOAs	Total Iron 6010	TCLP ZHE - 8260	TCLP Metals	pH							Remarks:
240610001 DUP-1	X				4	3, 4	X	X										001
240610002 DUP-2	X				4	4	X											002
240610003 MW-12	X		9/27/17	8:40	2	3, 4	X	X										003
240610004 CMT-2-UPPER	X		9/27/17	9:25	3	4	X											004
240610005 CMT-2-MIDDLE	X		9/27/17	9:45	4	3, 4	X	X										005
240610006 CMT-2-LOWER	X		9/27/17	10:10	2	3, 4	X	X										006
240610007 CMT-1-UPPER	X		9/27/17	11:00	2	3, 4	X	X										007
240610008 CMT-1-MIDDLE	X		9/27/17	11:55	4	3,4	X	X										008
240610009 CMT-1-LOWER	X		9/27/17	12:30	2	3, 4	X	X										009
240610010 MW-04	X		9/27/17	13:00	4	3, 4	X	X										010
240610011 WASTE-1	X		9/27/17	15:40	4	1			X	X	X							011

Relinquished by: L.McGrath	Company: PAES	Date: 9/29/2017	Time: 9;00	Received by:	Company: Pace	Date: 9-29-17	Time: 1811
Relinquished by:	Company: Pace	Date: 9-29-17	Time: 1600	Received by:	Company: Pace	Date: 9-29-17	Time: 1600
Relinquished by:	Company:	Date:	Time:	Received by:	Company:	Date:	Time:

30231391

Pace Analytical

CHAIN-OF-CUSTODY RECORD

Phone: (412) 826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

SEND TO: Pace

DUE DATE: 10/9/2017

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.cor

Invoice to: ruth.welsh@pacelabs.com

Lab Proj. # 24040

Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin: MD

Preservatives
1-Unpreserved
2- H2SO4
3- HNO3
4-HCL
5-NaOH+Zn Ace.

	Sample Type						Parameters Requested				
Sample ID	Water	Solid	Date	Time	# Bottles	Preservatives	12 8260 VOAs	12 Dissolved Iron 6010	56 Total Iron 6010	Remarks:	
240400001 MW-13	X		9/26/17	8:55	4	3, 4	X	X	X	Samples were field filtered	001
240400002 CMT-3-UPPER	X		9/26/17	9:25	4	3, 4	X				002
240400003 CMT-3-MIDDLE	X		9/26/17	10:00	2	4	X	X	X		003
240400004 CMT-3-LOWER	X		9/26/17	10:35	3	3, 4	X	X	X		004
240400005 MW-16	X		9/26/17	11:40	4	3, 4	X	X	X		005
240400006 CMT-4-UPPER	X		9/26/17	12:25	2	4	X	X	X		006
240400007 CMT-4-MIDDLE	X		9/26/17	12:55	2	4	X	X			007
240400008 CMT-4-LOWER	X		9/26/17	13:25	4	3,4	X	X			008
240400009 MW-14	X		9/26/17	14:35	2	4	X	X			009
240400010 MW-15	X		9/26/17	15:25	4	3, 4	X	X			010
240400011 MW-11	X		9/26/17	16:15	4	3, 4	X	X			011

WO# : 30231391
30231391

Relinquished by: L.McGrath	Company: PAES	Date: 9/28/2017	Time: 11:05	Received by:	Company: PACE	Date: 9/28/17	Time: 15:00
Relinquished by:	Company: PACE	Date: 9/28/17	Time: 16:00	Received by:	Company: Pace	Date: 9/28/17	Time: 1600
Relinquished by:	Company:	Date:	Time:	Received by:	Company:	Date:	Time:

Pace Analytical™

CHAIN-OF-CUSTODY RECORD

Phone: (412) 826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

SEND TO: Pace

DUE DATE: 3/5/2018

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.com

Lab Proj. # 25766

Invoice to: ruth.welsh@pacelabs.com

WO#: 30244497
30244497

Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin: MD

Preservatives:
1-Unpreserved
2- H2SO4
3- HNO3
4-HCL
5-NaOH+Zn Ace.

Parameters Requested

Sample ID	Sample Type: Water	Sample Type: Solid	Date	Time	# Bottles	Preservatives	12 8260 VOAs	12 Total Iron 6010	12 Diss Iron 6010	Remarks:
257660001 IS17GW040218	X		2/21/18	14:30	4	3, 4	X			001
257660002 IS17GW110218	X		2/20/18	11:00	4	3, 4	X	X	X	002
257660003 IS17GW120218	X		2/21/18	14:45	4	3, 4	X	X	X	003
257660004 IS17GW130218	X		2/20/18	13:15	4	3, 4	X	X	X	004
257660005 IS17GW140218	X		2/20/18	11:25	4	3, 4	X	X	X	005
257660006 IS17GW150218	X		2/20/18	13:20	4	3, 4	X	X	X	006
257660007 IS17GW160218	X		2/21/18	12:50	4	3, 4	X	X	X	007
257660008 TB022218GW	X		2/22/18	11:00	4	3,4	X			008

Relinquished by: L.McGrath	Company: PAES	Date: 2/23/2018	Time: 13:00	Received by:	Company: Pace	Date: 2/23/18	Time: 1355
Relinquished by:	Company: Pace	Date: 2/23/18	Time: 1655	Received by:	Company: Pace	Date: 2-23-18	Time: 1658
Relinquished by:	Company:	Date:	Time:	Received by:	Company:	Date:	Time:

Pace Analytical®
www.pacelabs.com

220 William Pitt Way
Pittsburgh, PA 15238
412-826-5245

25785

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Page: 1 of 2

010781

Section A
Required Client Information:

Company: CH2M
Address:
Email To:
Phone:
Fax:
Requested Due Date/TAT:

Section B
Required Project Information:

Report To: JUAN ACARON
Copy To: JUAN.ACARON@CH2M.COM
352-214-2814
Purchase Order No.:
Project Name:
Project Number:

Section C
Invoice Information:

Attention:
Company Name:
Address:
Pace Quote Reference:
Pace Project Manager:
Pace Profile #:

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER ____________

Site Location
STATE: ________

Requested Analysis Filtered (Y/N)

Section D
Required Client Information

Matrix Codes
MATRIX / CODE

Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	Y/N ➡ / ⬇Analysis Test ➡	MEE+ACETYLENE												Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1	IS17CMT01A0218	WT	G			2/20	1445		3					X					X													
2	01A A					2/20	1455		3					X					X													
3	01B					2/21	0815		3					X					X													
4	01C					2/21	0840		3					X					X													
5	~~01CP A~~					~~2/21~~	~~0845~~		INSUFFICIENT VOLUME																							
6	02A					2/21	0840		3					X					X													
7	02B					2/21	0940		3					X					X													
8	02C					2/21	1030		3					X					X													
9	03A					2/21	0950		3					X					X													
10	03B					2/21	1005		3					X					X													
11	03C					2/21	1030		3					X					X													
12	04A					2/21	1120		3					X					X													

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
		2/22	1200	Dave PACE	2-23	1130	3	Y	Y	

ORIGINAL

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER:

SIGNATURE of SAMPLER:

DATE Signed (MM/DD/YY):

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

F-ALL-Q-020rev.07, 15-May-2007

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25785

CHAIN-OF-CUSTODY / Analytical Request Document

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Page: 2 of 2

010782

Section A
Required Client Information:

Company: CH2m	
Address:	
Email To:	
Phone:	Fax:
Requested Due Date/TAT:	

Section B
Required Project Information:

Report To: JUAN ACARON
Copy To: JUAN-ACARON@CH2m.com
352-214-2814
Purchase Order No.:
Project Name:
Project Number:

Section C
Invoice Information:

Attention:
Company Name:
Address:
Pace Quote Reference:
Pace Project Manager:
Pace Profile #:

REGULATORY AGENCY

NPDES	GROUND WATER	DRINKING WATER
UST	RCRA	OTHER ________

Site Location
STATE: ________

Section D
Required Client Information

Matrix Codes
MATRIX / CODE

Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	Y/N ➡ Analysis Test ➡	MEE+ACETYLENE												Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1	IS17CMT04B0218	WT	G			2/21	1150		3					X					X													
2	↓ 04C ↓	↓	↓			2/21	1200		3					X					X													
3																																
4																																
5																																
6																																
7																																
8																																
9																																
10																																
11																																
12																																

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
		2/22	1200	PACE	223	1130	3	Y	Y	

ORIGINAL

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER:

SIGNATURE of SAMPLER:

DATE Signed (MM/DD/YY):

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

REPORT TO:

Name: Justin Long
Company: GSI Environmental
Address: 9600 Great Hills Trail
Suite 360E
Austin, TX 78759
email: jalong@gsi-net.com
Phone: 512-346-4474
Fax:

Project Manager: Justin Long
Project Name: NSF-IH Site 17
Project No.: 4951-000

INVOICE TO: (For Invoices paid by a third party it is imperative that all information be provided)

Name: Justin Long / Accounts Payable
Company: GSI Environmental
Address: 9600 Great Hills Trail
Suite 350E
Austin, TX 78759
email: acct.pay@gsi-net.com
Phone: 512-346-4474
Fax:

Purchase Order No.
Subcontract No.
MI Quote No.

microbialinsights
10515 Research Dr
Knoxville, TN 37932
865-573-8188

www.microbe.com

Please Check One:
☐ More samples to follow
☒ No Additional Samples

Report Type: ☒ Standard (default) ☐ Microbial Insights Level III raw data(15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (35%)

EDD type: ☒ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information						**Analyses**				**CENSUS: Please select the target organism/gene**																							
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	**PLFA**	**NGS**	**QuantArray Chlor**	**QuantArray Petro**	**DHC (Dehalococcoides)**	DHC Functional genes (bvc, tce, vcr)	DHBt (Dehalobacter)	DHG (Dehalogenimonas)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AMO (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	**RNA (Expression Option)***	Other:	Other:	Other:
	TS17MW12	8/8/18	0930	GW	1			X		X	X	X				X																	
	TS17MW16	8/8/18	0940	GW	1			X		X	X	X				X																	
	TS17MW04	8/8/18	1330	GW	1			X		X	X	X				X																	

Relinquished by: Justin Long **Date** 8-8-18 **Received by:** **Date**

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

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CHAIN-OF-CUSTODY / Analytical Request Document

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Page: 1 of 3

011648

Section A
Required Client Information:

Company: GSI Environmental
Address: [illegible]
[illegible]
Email To: JALONG@GSI-NET.COM
Phone: [illegible]
Fax:
Requested Due Date/TAT: Standard

Section B
Required Project Information:

Report To: JALONG@GSI-NET.COM
Copy To: [illegible]@GSI-NET.COM
Purchase Order No.:
Project Name: NSF[illegible]
Project Number: 4451

Section C
Invoice Information:

Attention: [illegible]@GSI-NET.COM
Company Name: GS[illegible]
Address: [illegible]
Pace Quote Reference:
Pace Project Manager: Megan Meyers
Pace Profile #:

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER ______

Site Location STATE: MD

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Matrix Codes MATRIX	CODE
Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COMPOSITE START TIME	COMPOSITE END/GRAB DATE	COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	Analysis Test / Y/N	Total Iron	Dissolved Iron (Y)	VOCs - 8260	MEE [illegible]	[illegible]		Chl[illegible]						Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1	DUP-1	W	G	8-[illegible]		8-8-18			10	X		X	X	X					X	X	X	X			X							
2	IS17 MW11				1300				9	X		X	X	X					X	X	X	X										
3	IS17 MW14				1400				9	X		X	X	X					X	X	X	X										
4	IS17 MW13				1515				9	X		X	X	X					X	X	X	X										
5	IS17 MW12				1620				9	X		X	X	X					X	X	X	X										
6	CMT-3-UPPER				1650				8			X	X	X					X		X	X										
7	CMT-3- MIDDLE				1710				9										X		X	X										
8	CMT-3- LOWER				1730				8										X		X	X										
9	IS17MW15				1800				8										X		X	X										
10	CMT-2 - UPPER				1500				8										X		X	X										
11	CMT-2 - MIDDLE				1555				8										X		X	X										
12	CMT-2 - LOWER				1610				8										X		X	X										

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS
Lab filter dissolved Iron	Dylan Hart	8/8/18	1710				
	Justin Long	8/8/18	1710				

3

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Justin Long
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 8/8/18

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

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Page: 2 of 3

011651

Section A
Required Client Information:
Company: GST Environmental
Address: 9600 Great Hills Trail
Austin, TX 78759
Email To: JALONG@GSI-NET.COM
Phone: 512 346-4474
Fax:
Requested Due Date/TAT: Standard

Section B
Required Project Information:
Report To: JALONG@GSI-NET.COM
Copy To: DMHART@GSI-NET.COM
Purchase Order No.: 495
Project Name: NSF IH
Project Number: 4951

Section C
Invoice Information:
Attention: DMHART@GSI-NET.COM
Company Name: GSI Environmental
Address: 9600 Great Hills Trail STE 350E
Pace Quote Reference:
Pace Project Manager: MEGAN MEYERS
Pace Profile #:

REGULATORY AGENCY
NPDES
GROUND WATER
DRINKING WATER
UST
RCRA
OTHER

Site Location
STATE: MD

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Matrix Codes
MATRIX / CODE
Drinking Water DW
Water WT
Waste Water WW
Product P
Soil/Solid SL
Oil OL
Wipe WP
Air AR
Tissue TS
Other OT

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives Unpreserved - [illegible]	Preservatives H_2SO_4	Preservatives HNO_3 - [illegible]	Preservatives HCl - VOCs	Preservatives TSP - MEE [illegible]	Preservatives BAK	Preservatives Zinc Acetate & NaOH	Preservatives Other - ICE	Analysis Test	Total Iron	Dissolved Iron	VOCs - 8260	MEE Acetylene	by AM20GAX		Chloride, Sulfate	by Method 300					Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
	Requested Analysis Filtered (Y/N)																	Y/N →		Y												
1	CMT-1-UPPER			8-7-18	1245				8			X	X	X					X		X	X										
2	CMT-1-MIDDLE			8-7-18	1400				8			X							X		X	X										
3	CMT-1-LOWER			8-7-18	1430				8										X		X	X										
4	IS17 MW04			8-8-18	0910	&	1330		8				X								X	X			X							Limit values for Method 300
5	IS17 MW12			↓	0930				1	X															X							
6	CMT-4-UPPER				1015				8	X		X	X	X					X		X	X										
7	CMT-4-MIDDLE				1040				8			X	X	X					X		X	X										
8	CMT-4-LOWER				1105				8			X	X	X					X		X	X										
9	IS17 MW14				1310				1	X															X							
10	IS17 MW13				1325				1	X															X							
11	IS17 MW16				0940				10	X		X	X	X					X	X	X	X			X							
12	IS17 MW11				1035				1	X															X							

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
Lab filter dissolved iron	Dylan Hart / GST	8/8/18	1710			
	Justin Long / GST	8/8/18	1710			

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

3

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Dylan Hart
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 8/8/18

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

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CHAIN-OF-CUSTODY / Analytical Request Document

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Page: 3 of 3

011649

Section A
Required Client Information:

Company: GSI Environmental
Address: 9600 Great Hills Trail
Austin, TX 78759
Email To: JALONG@GSI-NET.com
Phone: 512 346 4474
Fax:
Requested Due Date/TAT: standard

Section B
Required Project Information:

Report To: JALONG@ ~~GSI~~ GSI-NET.com
Copy To: DMHART@GSI-NET.com
Purchase Order No.: 4451
Project Name: NSF IH
Project Number: 4451

Section C
Invoice Information:

Attention:
Company Name:
Address:
Pace Quote Reference:
Pace Project Manager:
Pace Profile #:

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER ____

Site Location
STATE: MN

Section D
Required Client Information

Matrix Codes
MATRIX / CODE

Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	↓Analysis Test↓ (Y/N →)	Total Iron	VOCs by 8260	MEE + Acetylene	↳ AM20GAx	Dissolved Iron (Y)	Chloride	Nitrate						Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1	Dup-2	W	G	8-8-18					8			X	X	X					X	X	X											
2	Trip Blank 1	|	|	|					2				X							X												
3	Trip Blank 2	|	|	|					2				X							X												
4	~~Trip~~ MS/MSD	|	|	|					4				X							X												
5	IS17MW15	W	G	8-8-18	1320				2	X													X	X	X							
6																																
7																																
8																																
9																																
10																																
11																																
12																																

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
Lab filter dissolved iron	Dylan Hart GSI	8/8/18	1710							
	Justin Long GSI	↓	↓							
							Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Justin Long
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 8/8/18

3

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

REPORT TO:
Name: Justin Long
Company: GSI Environmental
Address: 9600 Great Hills Trail
Suite 350E
Austin, TX 78759
email: jalong@gsi-net.com
Phone: 512-346-4474
Fax:

Project Manager: Justin Long
Project Name: NSF-IH Site 17
Project No.: 4951-000

INVOICE TO: (For Invoices paid by a third party it is imperative that all information be provided)
Name: Justin Long / Accounts Payable
Company: GSI Environmental
Address: 9600 Great Hills Trail
Suite 350E
Austin, TX 78759
email: acct.pay@gsi-net.com
Phone: 512-346-4474
Fax:

Purchase Order No.
Subcontract No.
MI Quote No.

microbialinsights
10515 Research Dr
Knoxville, TN 37932
865-573-8188

www.microbe.com

Please Check One:
☐ More samples to follow
☒ No Additional Samples

Report Type: ☒ Standard (default) ☐ Microbial Insights Level III raw data(15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (35%)

EDD type: ☒ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information						Analyses				CENSUS: Please select the target organism/gene																							
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	PLFA	NGS	QuantArray Chlor	QuantArray Petro	DHC (Dehalococcoides)	DHC Functional genes (bvc, tce, vcr)	DHBt (Dehalobacter)	DHG (Dehalogenimonas)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AMO (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	RNA (Expression Option)*	Other:	Other:	Other:
031PH1	IS17MW12	8/8/18	0930	GW	1			X		X	X	X				X																	
2	IS17MW16	8/8/18	0940	GW	1			X		X	X	X				X																	
3	IS17MW04	8/8/18	1330	GW	1			X		X	X	X				X																	

Relinquished by: Justin Long
Date 8-8-18
Received by: Bailey [illegible]
Date 8/9/18

It is vital that chain of custody is filled out correctly & that all relative information is provided.

Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

Chain of Custody

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☐ Samples were sent directly to the Subcontracting Laboratory.

State Of Origin: MD

Workorder: 30262083 **Workorder Name:** 27698

Owner Received Date: 8/10/2018 **Results Requested By:** 8/21/2018

Report To	**Subcontract To**
David A. Pichette Pace Analytical Pittsburgh 1638 Roseytown Road Suites 2,3,4 Greensburg, PA 15601 Phone (724)850-5617	Pace Analytical Indianapolis 7726 Moller Road Indianapolis, IN 46268 Phone (317)228-3100

Item	**Sample ID**	**Sample Type**	**Collect Date/Time**	**Lab ID**	**Matrix**	Preserved Containers: HNO3	Preserved Containers: Unpreserved	Requested Analysis: Sub Chloride & Nitrate Method 300	50203401 LAB USE ONLY
1	276980001 DUP-1	PS	8/7/2018 00:01	30262083001	Water	1		X	001
2	276980016 IS17 MW04	PS	8/8/2018 13:30	30262083016	Water		1	X	002
3	276980017 IS17 MW12	PS	8/8/2018 12:30	30262083017	Water		1	X	003
4	276980021 IS17 MW14	PS	8/8/2018 13:10	30262083021	Water		1	X	004
5	27698002 IS17 MW13	PS	8/8/2018 13:25	30262083022	Water		1	X	005
6	276980023 IS17 MW16	PS	8/8/2018 09:40	30262083023	Water	1		X	006
7	276980024 IS17 MW11	PS	8/8/2018 10:35	30262083024	Water		1	X	007
8	276980028 IS17 MW15	PS	8/8/2018 13:20	30262083028	Water		1	X	008

Transfers	**Released By**	**Date/Time**	**Received By**	**Date/Time**
1			Fedex	
2	Fedex		Hayden Pruitt	8/15/18 0835
3				

Comments

Cooler Temperature on Receipt 3.1 °C **Custody Seal** [✓ Y] or N **Received on Ice** [✓ Y] or N **Samples Intact** [✓ Y] or N

****In order to maintain client confidentiality, location/name of the sampling site, sampler's name and signature may not be provided on this COC document. This chain of custody is considered complete as is since this information is available in the owner laboratory.*

WO#:30262083

[redacted]

30262083

30262083

CHAIN-OF-CUSTODY RECORD

Pg 1 of Pg 1 of 3

826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.cor

SEND TO: Pace **DUE DATE:** 8/21/2018

Invoice to: ruth.welsh@pacelabs.com

Lab Proj. # 27698

Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin: MD

Preservatives
1-Unpreserved 4-HCL
2- H2SO4 5-NaOH+Zn Ace.
3- HNO3

	Sample Type						Parameters Requested												
							12	16	60	35									
Sample ID	Water	Solid	Date	Time	# Bottles	Preservatives	Total Iron	Dissolved Iron	TCL VOAS	Chloride & Nitrate Mtd 300								Remarks:	
276980001 DUP-1	X		8/7/18	0:01	6	1, 3, 4	X	X	X	X									001
276980002 IS17 MW11	X		8/7/18	13:00	5	1, 3, 4	X	X	X									Dissolved iron needs lab filtered	002
276980003 IS17 MW14	X		8/7/18	14:00	5	1, 3, 4	X	X	X										003
276980004 IS17 MW13	X		8/7/18	15:15	5	1, 3, 4	X	X	X										004
276980005 IS17 MW12	X		8/7/18	16:20	5	1, 3, 4	X	X	X										005
267980006 CMT-3-UPPER	X		8/7/18	16:50	4	3,4	X		X										006
276980007 CMT-3-MIDDLE	X		8/7/18	17:10	4	3,4	X		X										007
276980008 CMT-3-LOWER	X		8/7/18	17:20	4	3,4	X		X										008
276980009 IS17 MW15	X		8/7/18	18:00	4	3,4	X		X										009
276980010 CMT-2-UPPER	X		8/7/18	15:00	4	3,4	X		X										010
276980011 CMT-2-MIDDLE	X		8/7/18	15:35	4	3,4	X		X										011
276980012 CMT-2-LOWER	X		8/7/18	16:10	4	3,4	X		X										012

Relinquished by:	**Company:** PAES	**Date:**	**Time:**	**Received by:**	**Company:** PACE	**Date:** 8/10/18	**Time:** 1610
Relinquished by:	**Company:** Pace	**Date:** 8/10/18	**Time:** 1730	**Received by:**	**Company:** PACE	**Date:** 8/10/18	**Time:** 1730
Relinquished by:	**Company:**	**Date:**	**Time:**	**Received by:**	**Company:**	**Date:**	**Time:**

30262083 2 of

Pg 2 of 3

Pace Analytical

CHAIN-OF-CUSTODY RECORD

Phone: (412) 826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.com

SEND TO: Pace

DUE DATE: 8/21/2018

Invoice to: ruth.welsh@pacelabs.com

Lab Proj. # 27698

Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin
MD

Preservatives	
1-Unpreserved	4-HCL
2- H2SO4	5-NaOH+Zn Ace.
3- HNO3	

	Sample Type						Parameters Requested					
							12	16	60	35		
Sample ID	Water	Solid	Date	Time	# Bottles	Preservatives	Total Iron	Dissolved Iron	TCL VOAS	Chloride & Nitrate Mtd 300	Remarks:	
276980013 CMT-1-UPPER	X		8/7/18	12:45	4	3,4	x		X			013
276980014 CMT-1-MIDDLE	X		8/7/18	14:00	4	3,4	X		X		Dissolved iron needs lab filtered	014
276980015 CMT-1-LOWER	X		8/7/18	14:30	4	3,4	X		X			015
276980016 IS17 MW04	X		8/8/18	13:30	4	1, 4			X	X		016
276980017 IS17 MW12	X		8/8/18	12:30	1	1				X		017
276980018 CMT-4-UPPER	X		8/8/18	10:15	4	3,4	X		X			018
276980019 CMT-4-MIDDLE	X		8/8/18	10:40	4	3,4	X		X			019
276980020 CMT-4-LOWER	X		8/8/18	11:05	4	3,4	X		X			020
276980021 IS17 MW14	X		8/8/18	13:10	1	1				X		021
27698002 IS17 MW13	X		8/8/18	13:25	1	1				X		022
276980023 IS17 MW16	X		8/8/18	9:40	5	1,3,4	X		X	X		023
276980024 IS17 MW11	X		8/8/18	10:35	1	1				X		024

Relinquished by:	Company: PAES	Date:	Time:	Received by:	Company: PACE	Date: 8/10/18	Time: 1600
Relinquished by:	Company: PACE	Date: 8/10/18	Time: 1700	Received by:	Company: PACE	Date: 8/14/18	Time: 1730
Relinquished by:	Company:	Date:	Time:	Received by:	Company:	Date:	Time:

3026208 3 Pg 3 of

Pg 3 of 3

Pace Analytical

CHAIN-OF-CUSTODY RECORD

Phone: (412) 826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.con

SEND TO: Pace

DUE DATE: 8/21/2018

Invoice to: ruth.welsh@pacelabs.com

Lab Proj. # 27698

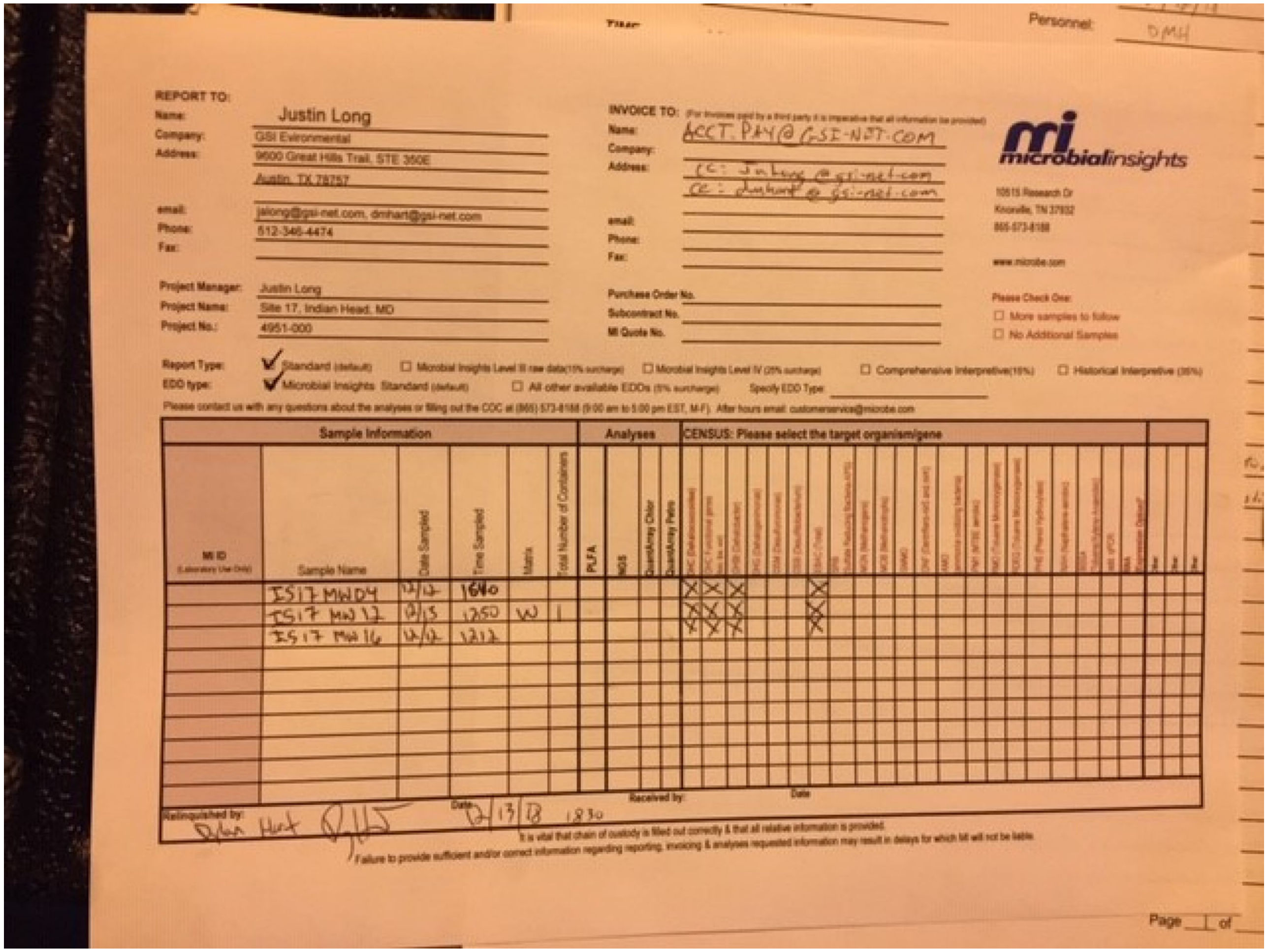
Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin
MD

Preservatives
1-Unpreserved 4-HCL
2- H2SO4 5-NaOH+Zn Ace.
3- HNO3

Sample ID	Sample Type Water	Sample Type Solid	Date	Time	# Bottles	Preservatives	Parameters Requested 12 Total Iron	15 Dissolved Iron	60 TCL VOAS	35 Chloride & Nitrate Mtd 300	Remarks:	
276980025 DUP-2	X		8/8/18	0:01	4	3,4	X		X			025
276980026 Trip Blank 1	X		8/8/18	0:01	3	4			X		Dissolved iron needs lab filtered	026
276980027 Trip Blank 2	X		8/8/18	0:01	3	4			X			027
276980028 IS17 MW15	X		8/8/18	13:20	2	1		X		X		028
276980029 DUP-2 MS	X		8/8/18	0:01	3	4			X		Use for MS Analysis	029
276980030 DUP-2 MSD	X		8/8/18	0:01	3	4			X		Use for MSD Analysis	030

Relinquished by:	**Company:** PAES	**Date:**	**Time:**	**Received by:**	**Company:** PACE	**Date:** 8/10/18	**Time:** 1613
Relinquished by:	**Company:** PACE	**Date:** 8/10/18	**Time:** 1730	**Received by:**	**Company:** PACE	**Date:** 8/10/18	**Time:** 1730
Relinquished by:	**Company:**	**Date:**	**Time:**	**Received by:**	**Company:**	**Date:**	**Time:**



Time

Personnel: DMH

REPORT TO:
Name: Justin Long
Company: GSI Evironmental
Address: 9600 Great Hills Trail, STE 350E
Austin, TX 78757
email: jalong@gsi-net.com, dmhart@gsi-net.com
Phone: 512-346-4474
Fax:

Project Manager: Justin Long
Project Name: Site 17, Indian Head, MD
Project No.: 4951-000

INVOICE TO: (For invoices paid by a third party it is imperative that all information be provided)
Name: ACCT.PAY@GSI-NET.COM
Company:
Address: cc: jalong@gsi-net.com
cc: dmhart@gsi-net.com
email:
Phone:
Fax:

Purchase Order No.
Subcontract No.
MI Quote No.

microbialinsights
10515 Research Dr
Knoxville, TN 37932
865-573-8188

www.microbe.com

Please Check One:
☐ More samples to follow
☐ No Additional Samples

Report Type: ☑ Standard (default) ☐ Microbial Insights Level III raw data(10% surcharge) ☐ Microbial Insights Level IV (20% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (35%)

EDD type: ☑ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information						Analyses				CENSUS: Please select the target organism/gene																							
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	PLFA	NGS	QuantArray Chlor	QuantArray Petro	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	IS17MW04	12/12	1640							X	X	X				X																	
	IS17 MW12	12/13	1250	W	1					X	X	X				X																	
	IS17 MW16	12/12	1212							X	X	X				X																	

Relinquished by: Dylan Hart
Date: 12/13/18 1830
Received by:
Date

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

Page 1 of

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Pittsburgh, PA 15238
412-826-5245

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

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Page: 1 of 3

013673

Section A
Required Client Information:

Company: GSI Environmental
Address: 9600 Great Hills Trail
STE 350E, Austin, TX 78759
Email To: JALONG@GSI-NET.COM
Phone: 512-346-4474
Fax:
Requested Due Date/TAT: Standard

Section B
Required Project Information:

Report To: JALONG@GSI-NET.COM
Copy To: DMHART@GSI-NET.COM
Purchase Order No.:
Project Name: NAVFAC - Indian Head
Project Number: 4951

Section C
Invoice Information:

Attention: Dylan Hart
Company Name: GSI Environmental
Address: ACCT.PAY@GSI-NET.COM
Pace Quote Reference: 0
Pace Project Manager: RUTH WELSH
Pace Profile #:

REGULATORY AGENCY

NPDES — GROUND WATER — DRINKING WATER
UST — RCRA — OTHER DOD

Site Location STATE: MD

Level 4 Data Pack

Section D
Required Client Information

Matrix Codes
MATRIX / CODE

Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

Requested Analysis Filtered (Y/N) by lab

* Lab filter for all iron samples

ITEM #	SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED Grab ~~COMPOSITE START~~ DATE	TIME	COMPOSITE END/GRAB DATE	TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other ICE	Analysis Test ↓ Y/N →	8260 VOCs	AM20GAX	(MEE + Acetylene)		6010 Dissolved Iron	6010 Total Iron	9056 Chloride		8260 TCLP VOCs	TCLP Metals	TCLP Metals (Hg)	PH	Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
																							Y	Y								
1	IS17MW11	WT	G	12/11	1400				10	X			X	X			X		X	X	X		X	X	X							
2	CMT-1 UPPER	↓	↓	↓	1500				4	2		1	3	3					X	X	X		X	X	X							
3	CMT-1 MIDDLE				1530				10	2		1	4	3					X	X	X		X	X	X							
4	CMT-1 LOWER				1600				9	1		1	4	3					X	X	X		X	X								
5	IS17 MW14			12/12	0940				10	2		1	4	3					X	X	X		X	X	X							
6	IS17 MW13			↓	1110				10	↓		↓	↓	↓					X	X	X		X	X	X							
7	IS17 MW16				1212				10										X	X	X		X	X	V							
8	IS17 MW04				1500				7				4	3					X	X	X											
9	WC01-121218		C		1600				8	3		1	4														X	X	X	X		
10	Trip Blank 1		G	12/11					2				2						X													
11	Trip Blank 2		G	12/12					2				2						X													
12	Trip Blank 3		G	12/13					2				2						X													

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
3 Coolers	Dylan Hart GSI	12/13	1830	PACE	12.14	0830	1	Y	Y	
							Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

ORIGINAL

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER:

SIGNATURE of SAMPLER:

DATE Signed (MM/DD/YY):

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

F-ALL-Q-020rev.07, 15-May-2007

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412-826-5245

CHAIN-OF-CUSTODY / Analytical Request Document

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Page: 2 of 3

013675

Section A
Required Client Information:

Company: G-S I
Address: 9600 Great Hills Trail
STE 350 E Austin TX 78759
Email To: JALONG@GSI-NET.COM
Phone: 512 346-4474
Fax:
Requested Due Date/TAT: Standard

Section B
Required Project Information:

Report To:
Copy To:
Purchase Order No.:
Project Name: NAVFAC - Indian Head
Project Number: 4951

Section C
Invoice Information:

Attention:
Company Name:
Address:
Pace Quote Reference:
Pace Project Manager:
Pace Profile #:

REGULATORY AGENCY

NPDES	GROUND WATER	DRINKING WATER
UST	RCRA	OTHER DoD

Site Location STATE: MD

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Matrix Codes
MATRIX / CODE

Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

Lab Filter all Fe samples

				COLLECTED						Preservatives									Requested Analysis Filtered (Y/N)														
				COMPOSITE START		COMPOSITE END/GRAB												Y/N ↓					Y	Y									
ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	DATE	TIME	DATE	TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	↓ Analysis Test ↓	8260 VOCs	AM20 GAX	(MEE + Acetylene)		6010 Dissolved Fe	6010 Total Fe	9056 Chloride							Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
1	CMT-2 UPPER	WT	G	12/13	0830				11	3		1	4	3					X	X			X	X	X								
2	CMT-2 MIDDLE	↓	↓	↓	0915				11	3		1	4	3					X	X			X	X	X								
3	CMT-2 LOWER				0940				10	3			4	3					X	X			X		X								
4	CMT-4 UPPER				1015				11	3		1	4	3					X	X			X	X	X								
5	CMT-4 MIDDLE				1040				11	↓		↓	↓	↓					X	X			X	X	X								
6	CMT-4 LOWER				1115				11										X	X			X	X	X								
7	IS17MW12				1250				11										X	X			X	X	X								
8	IS17MW15				1400				11										X	X			X	X	X								
9	CMT-3 UPPER *				1450				10	↓		↓	↓	↓					X	X			X		X								Partial Dissolved Fe *
10	CMT-3 MIDDLE				1515				11										X	X			X	X	X								↑ run if possible ↑
11	CMT-3 LOWER *				1535				10										X	X			X	X	X								Partial fill Total Fe *
12	~~ISMW04~~ IS17MW04	WT	G	12/13	1600			4	5	3		1											X	X	X								↑ run if possible ↑

ADDITIONAL COMMENTS

If possible, run analyses on the partially filled bottles; if not, don't.

RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
	12/13	1830	PACS	12/14	0830	1	y	y	
						Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

ORIGINAL

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER:

SIGNATURE of SAMPLER:

DATE Signed (MM/DD/YY):

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

F-ALL-Q-020rev.07, 15-May-2007

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CHAIN-OF-CUSTODY / Analytical Request Document

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28994

Page: 3 **of** 3

013674

Section A
Required Client Information:

Company: GSI
Address: 9600 Great Hills Trail
STE 350E Austin, TX 78759
Email To: JALONG@GSI-NET.com
Phone: 512-346-4474 Fax:
Requested Due Date/TAT: Standard

Section B
Required Project Information:

Report To: Jalong@gsi-net.com
Copy To: Dmhart@gsi-net.com
Purchase Order No.:
Project Name: NAVFAC Indian Head
Project Number: 4951-000

Section C
Invoice Information:

Attention: ACCT.PAY@GSI-NET.com
Company Name:
Address: DMHART@GSI-NET.com
Pace Quote Reference:
Pace Project Manager: RUTH WELSH
Pace Profile #:

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER DoD

Site Location
STATE: MD

Section D
Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Matrix Codes	MATRIX / CODE
Drinking Water	DW
Water	WT
Waste Water	WW
Product	P
Soil/Solid	SL
Oil	OL
Wipe	WP
Air	AR
Tissue	TS
Other	OT

Lab Filter Fe samples

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED COMPOSITE START DATE	COLLECTED COMPOSITE START TIME	COLLECTED COMPOSITE END/GRAB DATE	COLLECTED COMPOSITE END/GRAB TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives Unpreserved	H_2SO_4	HNO_3	HCl	TSP	BAK	Zinc Acetate & NaOH	Other	⬇Analysis Test⬇	8260 VOCs	AM20 GAX	(MEE+Acetylene)		6010 Dissolved Fe	6010 Total Fe	9056 chloride						Residual Chlorine (Y/N)	Pace Project No./ Lab I.D.
																		Y/N➡					Y	Y								
1	Dup-1	WT	G						11	3		1	4	3					X	X			X	X	X							
2	MS/MSD	↓	↓						4				4						X													
3	FB01	↓	↓	12/13	1730				4				4						X													
4																																
5																																
6																																
7																																
8																																
9																																
10																																
11																																
12																																

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
3 coolers		12/13	1830	PAZ	12 14	0830	1	Y	Y	

ORIGINAL

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER:
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY):

*Important Note: By signing this form you are accepting Pace's NET 30 day payment terms and agreeing to late charges of 1.5% per month for any invoices not paid within 30 days.

E-FLUX

CO2 TRAP SHIPMENT AND INSTALLATION LOG
LNAPL NATURAL ATTENUATION STUDY

Date: 4 / 25 /2019

Date Returned to E-Flux: ____________

Contaminant Type	Deployment Location	Retrieval Location	Identification on Outside of Trap Box	Trap Placed in Field		Trap Recovered from Field		Comments	Depth to Ground Water	LNAPL Thickness in Well	Smear Zone Thickness	
4				Date	Time	Date	Time		ft btoc		Vadose Zone	Groundwater
Trap Data												
	lat: lon:	EF-RC-01	IHMD-R1-CO2-01	4/25/19	0938	5/10/19	1156		[illegible]	—		
	lat: [illegible] lon:	EF-B-01	IHMD-R1-CO2-02	↓	0934	↓	1204		1.82	—		
		EF-B-04	IHMD-R1-CO2-03	↓	0947	↓	1222		2.01	—		
		EF-RC-04	IHMD-R1-CO2-04	↓	0942	↓	1214		1.98	—		
		EF-RC-02	IHMD-R1-CO2-05	↓	0951	↓	1243			—		
		EF-B-02	IHMD-R1-CO2-06	↓	0953	↓	1248			–		
Travel Blanks												
				Date Received		Date Returned						
Travel Blank	Cooler in office		IHMD-R1-CO2-TB	4/25/19	1002	5/10/19	1630					

Installation Steps - KEEP TRAPS UPRIGHT - CAUTION, CONTAINS CAUSTIC MATERIAL

1- Find the appropriate trap for the location chosen (see map). Remove housing from over Receiver.
2- Remove screw-in caps (top and bottom). Add rain cover to top. Keep trap upright.
3- Place trap on receiver in ground using 4 in rubber coupler. Tighten hose clamps on rubber coupler.
4- At end of monitoring period, reverse steps. Cap both top and bottom of the trap.
5- Keep upright while handling and shipping.

Return Traps to:
(970) 492-4360

E-Flux, LLC
200 West Lake St, RIC Room D230
Fort Collins, CO 80521-0922
Attn: E-Flux Receiving

Technician Name: Dylan Hart, CSI

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AIR: CHAIN-OF-CUSTOD

The Chain-of-Custody is a LEGAL DOCUMENT. All r

WO#:10474700

10474700

190757

35958

Page: 1 of 1

Section A
Required Client Information:

Company: GSI Environmental
Address: 9600 Great Hills Trl. STE350E
Austin, TX 78759
Email To: DMHart@gsi-net.com
Phone: (512)346-4474
Fax:
Requested Due Date/TAT: Std.

Section B
Required Project Information:

Report To: VPStoynova@gsi-net.com
Copy To: DMHart@gsi-net.com
Purchase Order No.: 4460-601
Project Name: Indian Head
Project Number: 4460-601

Section C
Invoice Information:

Attention: Dylan Hart
Company Name: GSI Environmental
Address: acct.pay@gsi-net.com
Pace Quote Reference:
Pace Project Manager/Sales Rep. Jey Thompson / Scott Unze
Pace Profile #:

Program
☐ UST ☐ Superfund ☐ Emissions ☐ Clean Air Act
☐ Voluntary Clean Up ☐ Dry Clean ☐ RCRA ☐ Other___

Location of Sampling by State: MD

Reporting Units
ug/m³___ mg/m³___
PPBV X PPMV___
Other___

Report Level II. X III.___ IV.___ Other___

Section D Required Client Information

AIR SAMPLE ID
Sample IDs MUST BE UNIQUE

Valid Media Codes

MEDIA	CODE
Tedlar Bag	TB
1 Liter Summa Can	1LC
6 Liter Summa Can	6LC
Low Volume Puff	LVP
High Volume Puff	HVP
Other	PM10

Method:

ITEM #	AIR SAMPLE ID	MEDIA CODE	PID Reading (Client only)	COLLECTED COMPOSITE START DATE	COMPOSITE START TIME	COMPOSITE - END/GRAB DATE	COMPOSITE - END/GRAB TIME	Canister Pressure (Initial Field - in Hg)	Canister Pressure (Final Field - in Hg)	Summa Can Number	Flow Control Number (Not used)	~~PM10~~ PAMS (Acetylene)	~~Fe~~ - Fixed Gas (%) D-1945	TO-3 BTEX	TO-3 (Methane) He	TO-14	TO-15 Full List VOCs	TO-15 Short List BTEX	TO-15 Short List Chlorinated	TO-15 Short List (other)	Pace Lab ID
1	SVP-04 11852~~7~~	6LC	9.4 ppm	5/9/19	1700	5/10/19	1352	-30	-4	1720	0368	X	X		X		X				001
2	* Note: Limited volume available for																				
3	sample. 2400 mL soil gas sampled.																				
4	See #1-4 for priority analyses																				
5												2	3		4		1				
6																					
7																					
8																					
9																					
10																					
11																					
12																					

Comments :

RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
Dylan Hart, GSI	5-10-19	1628	Pace	5/14/19	945
Matt Pace	5-15-19	15:40			
			Rudy Saldana	5/16/19	1020

SAMPLE CONDITIONS

Temp in °C	Received on Ice	Custody Sealed Cooler	Samples Intact
/	Y/[✓ N]	Y/[✓ N]	[✓ Y]/N
	Y/N	Y/N	Y/N
	Y/N	Y/N	Y/N
	Y/N	Y/N	[✓ Y]/N

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER:
SIGNATURE of SAMPLER:
DATE Signed (MM / DD / YY)

ORIGINAL

FX provided [illegible] can

1700 Elm Street SE, Suite 200, Minneapolis, MN 55414 Air Technical Phone: 612.607.6386

FC046Rev.01, 03Feb2010

Pace Analytical®

CHAIN-OF-CUSTODY RECORD

Phone: (412) 826-5245 Pace Analytical Energy Services, LLC - 220 William Pitt Way - Pittsburgh, PA 15238 Fax: (412) 826-3433

SEND TO: Pace

DUE DATE: 5/7/2019

Results to: ruth.welsh@pacelabs.com
mark.mikesell@pacelabs.com

Invoice to: ruth.welsh@pacelabs.com

Lab Proj. # 30144

Company: Pace Analytical Energy Services, LLC
Co. Address: 220 William Pitt Way, Pittsburgh, PA 15238
Phone #: 412-826-5245
Fax #: 412-826-3433

State of Origin: MD

Preservatives
1-Unpreserved 4-HCL
2- H2SO4 5-NaOH+Zn Ace.
3- HNO3

WO# : 30291486
30291486

	Sample Type						Parameters Requested												
							60	12	12		60	75	8						
Sample ID	Water	Solid	Date	Time	# Bottles	Preservatives	8260 VOAs	Total Iron 6010	Diss Iron 6010		TCLP VOAs	TCLP Metals (As, Ca, Cd, Cr, Pb, Hg, Se, Ag)	pH					Remarks:	
301440001 CMT-4-UPPER	X		4/24/19	9:45	4	1,3, 4	X	X	X									All Dissolved Metals need lab filtered	001
301440002 CMT-4-MIDDLE	X		4/24/19	10:20	4	1,3, 4	X	X	X									Project needs data package and Trihydro EDD	002
301440003 CMT-4-LOWER	X		4/24/19	11:15	4	1,3,4	X	x	X										003
301440004 CMT-2-UPPER	X		4/24/19	12:45	4	1,3, 4	X	X	X										004
301440005 CMT-2-MIDDLE	X		4/24/19	13:20	4	1,3, 4	X	X	X										005
301440006 CMT-2-LOWER	X		4/24/19	13:55	3	1,4	X		X										006
301440007 DUP-1	X		4/24/19	14:50	2	4	X												007
301440008 CMT-3-UPPER	X		4/24/19	15:35	3	4	X		X										008
301440009 CMT-3-MIDDLE	X		4/24/19	16:30	4	1,3,4	X	X	X										009
301440010 CMT-3-LOWER	X		4/24/19	17:20	4	1,3,4	X	X	X										010
301440011 CMT-1-UPPER	X		4/24/19	18:05	4	1,3,4	X	X	X										011
301440012 CMT-1-MIDDLE	X		4/25/19	8:15	4	1,3,4	x	X	X										012
301440013 CMT-1-LOWER	x		4/25/19	9:10	4	1,3,4	x	x	x										013
301440014 DUP-2	x		4/24/19	18:35	2	4	x												014
301440015 DUP-3	X		4/25/19	8:40	2	4	X												015

Relinquished by: E.Louis	Company: PAES	Date: 4/26/2019	Time: 14:25	Received by:	Company: Pace	Date: 4/26/19	Time: 1605
Relinquished by:	Company: Pace	Date: 4/26/19	Time: 1655	Received by: PACE	Company: PACE	Date: 04/26/19	Time: 1655
Relinquished by:	Company:	Date:	Time:	Received by:	Company:	Date:	Time:

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CHAIN-OF-CUSTODY Analytical Request Document

Chain-of-Custody is a LEGAL DOCUMENT - Complete all relevent fields

LAB USE ONLY- Affix Workorder/Login Label Here or List Pace Workorder Number or MTJL Log-in Number Here

30291486 44

EJG 4/26/19

ALL SHADED AREAS are for LAB USE ONLY

Company: GSI Environmental
Billing Information:
Address: 9600 Great Hills Trail, STE 350E
Report To: VPS@gsienv.com
Email To: acct.pay@gsi-net.com
Copy To: DMH@gsienv.com
Site Collection Info/Address: Indian Head Site 17
Customer Project Name/Number: 4460-601 Indian Head
State: MD / County/City: Indian Head
Time Zone Collected: [ ] PT [ ] MT [ ] CT [X] ET
Phone: (512) 346-4474
Email:
Site/Facility ID #:
Compliance Monitoring? [ ] Yes [ ] No
Collected By (print): Dylan Hart
Purchase Order #:
Quote #:
DW PWS ID #:
DW Location Code:
Collected By (signature):
Turnaround Date Required: STD Level IV TriHydro Data Package
Immediately Packed on Ice: [X] Yes [ ] No
Sample Disposal: [X] Dispose as appropriate [ ] Return [ ] Archive: ________ [ ] Hold: ________
Rush: [ ] Same Day [ ] Next Day [ ] 2 Day [ ] 3 Day [ ] 4 Day [ ] 5 Day (Expedite Charges Apply)
Field Filtered (if applicable): [ ] Yes [X] No
Analysis: ________

Container Preservative Type **: D | 3 | 1 | U | U

Lab Project Manager:

** Preservative Types: (1) nitric acid, (2) sulfuric acid, (3) hydrochloric acid, (4) sodium hydroxide, (5) zinc acetate, (6) methanol, (7) sodium bisulfate, (8) sodium thiosulfate, (9) hexane, (A) ascorbic acid, (B) ammonium sulfate, (C) ammonium hydroxide, (D) TSP, (U) Unpreserved, (O) Other ________

* Matrix Codes (Insert in Matrix box below): Drinking Water (DW), Ground Water (GW), Wastewater (WW), Product (P), Soil/Solid (SL), Oil (OL), Wipe (WP), Air (AR), Tissue (TS), Bioassay (B), Vapor (V), Other (OT)

Customer Sample ID	Matrix *	Comp / Grab	Collected (or Composite Start) Date	Collected (or Composite Start) Time	Composite End Date	Composite End Time	Res Cl	# of Ctns	AM20GAX (MEE & Acetylene)	VOC by 8260b	Total Iron (lab filter) Method 300	Dissolved Iron (lab filter) Method 300	Anions (Chloride)						Lab Sample # / Comments
CMT-4-UPPER	GW	Grab	4-24-19	0945				11	X	X	X	X	X						
CMT-4-MIDDLE	↓	↓	↓	1020				11	↓	↓	↓	↓	↓						
CMT-4-LOWER	↓	↓	↓	1115				11	↓	↓	↓	↓	↓						
CMT-2-UPPER	↓	↓	↓	1245				11	↓	↓	↓	↓	↓						
CMT-2-MIDDLE	↓	↓	↓	1320				11	↓	↓	↓	↓	↓						
CMT-2-LOWER	↓	↓	↓	1355				3.5	X	X		X	X						Chloride if possible w/ partial fill
DUP-1	↓	↓	↓	1450				2		X									
CMT-3-UPPER	↓	↓	↓	1535				3.5	X	X		\	X						
CMT-3-MIDDLE	↓	↓	↓	1630				11	X	X	X	X	X						
CMT-3-LOWER	↓	↓	↓	1720				10.5	X	X	X	\	X						

Lab Profile/Line:

Lab Sample Receipt Checklist:
Custody Seals Present/Intact [✓ Y] N NA
Custody Signatures Present [✓ Y] N NA
Collector Signature Present [✓ Y] N NA
Bottles Intact [✓ Y] N NA
Correct Bottles [✓ Y] N NA
Sufficient Volume Y [✓ N] NA
Samples Received on Ice [✓ Y] N NA
VOA - Headspace Acceptable Y N [✓ NA]
USDA Regulated Soils Y N [✓ NA]
Samples in Holding Time [✓ Y] N NA
Residual Chlorine Present Y N [✓ NA]
Cl Strips: ________
Sample pH Acceptable Y N NA
pH Strips: ________
Sulfide Present Y N [✓ NA]
Lead Acetate Strips: ________

LAB USE ONLY:
Lab Sample # / Comments:

Customer Remarks / Special Conditions / Possible Hazards:

Type of Ice Used: Wet Blue Dry None
SHORT HOLDS PRESENT (<72 hours): Y N N/A
Packing Material Used:
Lab Tracking #: 48325771 2231 7901
Radchem sample(s) screened (<500 cpm): Y N NA
Samples received via: [✓ FEDEX] UPS Client Courier Pace Courier

Lab Sample Temperature Info:
Temp Blank Received: [✓ Y] N NA
Therm ID#: ________
Cooler 1 Temp Upon Receipt: 1 oC
Cooler 1 Therm Corr. Factor: ______oC
Cooler 1 Corrected Temp: ______oC
Comments:

Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:
Dylan Hart, GSI	4-25-19 1430	Leon PAS	4.26.19 1055

MTJL LAB USE ONLY
Table #:
Acctnum:
Template:
Prelogin:
PM:
PB:

Trip Blank Received: [✓ Y] N NA
[✓ HCL] MeOH TSP Other

Non Conformance(s): [✓ YES] NO

Page: 1 of: 2

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CHAIN-OF-CUSTODY Analytical Request Document

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LAB USE ONLY- Affix Workorder/Login Label Here or List Pace Workorder Number or MTJL Log-in Number Here

30291486 30144

ALL SHADED AREAS are for LAB USE ONLY

ERJ 4/26/19

Company: GSI Environmental	Billing Information:
Address:	
Report To: dmhart@gsi-net.com	Email To:
Copy To: VPStoynova@gsi-net.com	Site Collection Info/Address:
Customer Project Name/Number: 4460-601	State: MD / County/City: Indian Head / Time Zone Collected: ☐ PT ☐ MT ☐ CT ☒ ET

Phone: Email:	Site/Facility ID #:	Compliance Monitoring? ☐ Yes ☐ No
Collected By (print): Dylan Hart	Purchase Order #: Quote #:	DW PWS ID #: DW Location Code:
Collected By (signature): D. Hart	Turnaround Date Required: STD Level IV Trihydro Data Package	Immediately Packed on Ice: ☒ Yes ☐ No
Sample Disposal: ☒ Dispose as appropriate ☐ Return ☐ Archive: ____ ☐ Hold: ____	Rush: ☐ Same Day ☐ Next Day ☐ 2 Day ☐ 3 Day ☐ 4 Day ☐ 5 Day (Expedite Charges Apply)	Field Filtered (if applicable): ☐ Yes ☒ No Analysis: Metals

Container Preservative Type **: D | 3 | 1 | U | U

Lab Project Manager:

** Preservative Types: (1) nitric acid, (2) sulfuric acid, (3) hydrochloric acid, (4) sodium hydroxide, (5) zinc acetate, (6) methanol, (7) sodium bisulfate, (8) sodium thiosulfate, (9) hexane, (A) ascorbic acid, (B) ammonium sulfate, (C) ammonium hydroxide, (D) TSP, (U) Unpreserved, (O) Other ____

* Matrix Codes (Insert in Matrix box below): Drinking Water (DW), Ground Water (GW), Wastewater (WW), Product (P), Soil/Solid (SL), Oil (OL), Wipe (WP), Air (AR), Tissue (TS), Bioassay (B), Vapor (V), Other (OT)

Customer Sample ID	Matrix *	Comp / Grab	Collected (or Composite Start) Date	Collected (or Composite Start) Time	Composite End Date	Composite End Time	Res Cl	# of Ctns	AM20GAX (MEE + Acetylene)	VOC by 8260b	Total Iron * Method 300	Dissolved Iron (lab filter) Method 300	Anions by IC (Chloride)	Lab Sample # / Comments
CMT-1-UPPER	GW	GW	4-24-19	1805				11	X	X	X	X	X	
CMT-1-MIDDLE		Grab	4-25-19	0815				11	X	X	X	X	X	
CMT-1-LOWER			4-25-19	0910				11	X	X	X	X	X	
DUP-2			4-24-19	1835				7	X	X				
DUP-3			4-25-19	0840				7	X	X				
DUP-4	↓	↓	4-25-19	1025				1	X					Analyze if possible
Trip Blank								2	X					

Lab Profile/Line:

Lab Sample Receipt Checklist:

Custody Seals Present/Intact [✓ Y] N NA
Custody Signatures Present [✓ Y] N NA
Collector Signature Present [✓ Y] N NA
Bottles Intact Y [✓ N] NA
Correct Bottles [✓ Y] N NA
Sufficient Volume [✓ Y] N NA
Samples Received on Ice [✓ Y] N NA
VOA - Headspace Acceptable Y N [✓ NA]
USDA Regulated Soils Y N [✓ NA]
Samples in Holding Time [✓ Y] N NA
Residual Chlorine Present Y N [✓ NA]
Cl Strips: ____
Sample pH Acceptable Y N NA
pH Strips: ____
Sulfide Present Y N [✓ NA]
Lead Acetate Strips: ____

LAB USE ONLY:
Lab Sample # / Comments:

Customer Remarks / Special Conditions / Possible Hazards:

Type of Ice Used: Wet Blue Dry None

Packing Material Used:

Radchem sample(s) screened (<500 cpm): Y N NA

SHORT HOLDS PRESENT (<72 hours): Y N N/A

Lab Tracking #: 483257712932 2317902

Samples received via: [✓ FEDEX] UPS Client Courier Pace Courier

Lab Sample Temperature Info:
Temp Blank Received: [✓ Y] N NA
Therm ID#: ____
Cooler 1 Temp Upon Receipt: 1 oC
Cooler 1 Therm Corr. Factor: ____ oC
Cooler 1 Corrected Temp: ____ oC
Comments:

Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:
Dylan Hart D. Hart	4-25-19 1430	Leon Paz	4/26/19 1055
Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:
Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:

MTJL LAB USE ONLY
Table #:
Acctnum:
Template:
Prelogin:
PM:
PB:

Trip Blank Received: [✓ Y] N NA
[✓ HCL] MeOH TSP Other

Non Conformance(s): [✓ YES] / NO

Page: 2 of: 2

Pittsburgh Lab Sample Condition Upon Receipt

Pace Analytical®

30291486

Client Name: Pace Energy

Project #:

Label

LIMS Login

Courier: ☐ Fed Ex ☐ UPS ☐ USPS ☐ Client ☐ Commercial ☑ Pace Other ______

Tracking #: NA

Custody Seal on Cooler/Box Present: ☐ yes ☑ no Seals intact: ☐ yes ☑ no

Thermometer Used: 11 Type of Ice: Wet Blue None

Cooler Temperature Observed Temp: 4.4 °C Correction Factor: 0 °C Final Temp: 4.4 °C

Temp should be above freezing to 6°C

pH paper Lot# 1003581

Date and Initials of person examining contents: 04|24|19JLB

Comments:	Yes	No	N/A	
Chain of Custody Present:	✓			1.
Chain of Custody Filled Out:	✓			2.
Chain of Custody Relinquished:	✓			3.
Sampler Name & Signature on COC:	✓			4.
Sample Labels match COC:	~~✓~~	✓		5. time on labels for 30144007 samples is 1355
-Includes date/time/ID Matrix: WT				JLB 04/24/19
Samples Arrived within Hold Time:	✓			6.
Short Hold Time Analysis (<72hr remaining):		✓		7.
Rush Turn Around Time Requested:		✓		8.
Sufficient Volume:	✓			9.
Correct Containers Used:	✓			10.
-Pace Containers Used:		✓		
Containers Intact:	✓			11.
Orthophosphate field filtered			✓	12.
Hex Cr Aqueous sample field filtered			✓	13.
Organic Samples checked for dechlorination:			✓	14.
Filtered volume received for Dissolved tests		✓		15.
All containers have been checked for preservation.	✓			16.
exceptions: [✓ VOA] coliform, TOC, O&G, Phenolics, Radon, Non-aqueous matrix				
All containers meet method preservation requirements.	✓			Initial when completed: JLB Date/time of preservation: Lot # of added preservative
Headspace in VOA Vials (>6mm):		✓		17.
Trip Blank Present:		✓		18.
Trip Blank Custody Seals Present			✓	
Rad Samples Screened < 0.5 mrem/hr			✓	Initial when completed: Date:

Client Notification/ Resolution:

Person Contacted: ______ Date/Time: ______ Contacted By: ______

Comments/ Resolution: ______

☐ **A check in this box indicates that additional information has been stored in ereports.**

Note: Whenever there is a discrepancy affecting North Carolina compliance samples, a copy of this form will be sent to the North Carolina DEHNR Certification Office (i.e. out of hold, incorrect preservative, out of temp, incorrect containers)

*PM review is documented electronically in LIMS. When the Project Manager closes the SRF Review schedule in LIMS. The review is in the Status section of the Workorder Edit Screen.

J:\QAQC\Master\Document Management\Sample Mgt\Sample Condition Upon Receipt Pittsburgh (C056-9 5April2019)

CHAIN-OF-CUSTODY Analytical Request Document

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LAB USE ONLY- Affix Workorder/Login Label Here or List Pace Workorder Number or MTJL Log-in Number Here

ALL SHADED AREAS are for LAB USE ONLY

Company: GSI

Address:

Billing Information:

Report To:

Email To:

Copy To:

Site Collection Info/Address:

Customer Project Name/Number: 4460 - Indian Head

State: MD/ County/City: Indian Head

Time Zone Collected: ☐ PT ☐ MT ☐ CT ☒ ET

Phone:

Email:

Site/Facility ID #: Site 17

Compliance Monitoring? ☐ Yes ☒ No

Collected By (print): Dylan Hal

Purchase Order #:

Quote #:

DW PWS ID #:

DW Location Code:

Collected By (signature):

Turnaround Date Required: Std

Immediately Packed on Ice: ☒ Yes ☐ No

Sample Disposal:

☒ Dispose as appropriate ☐ Return

☐ Archive: ______

☐ Hold: ______

Rush:

☐ Same Day ☐ Next Day

☐ 2 Day ☐ 3 Day ☐ 4 Day ☐ 5 Day

(Expedite Charges Apply)

Field Filtered (if applicable): ☐ Yes ☒ No

Analysis: ______

* Matrix Codes (Insert in Matrix box below): Drinking Water (DW), Ground Water (GW), Wastewater (WW), Product (P), Soil/Solid (SL), Oil (OL), Wipe (WP), Air (AR), Tissue (TS), Bioassay (B), Vapor (V), Other (OT)

** Preservative Types: (1) nitric acid, (2) sulfuric acid, (3) hydrochloric acid, (4) sodium hydroxide, (5) zinc acetate, (6) methanol, (7) sodium bisulfate, (8) sodium thiosulfate, (9) hexane, (A) ascorbic acid, (B) ammonium sulfate, (C) ammonium hydroxide, (D) TSP, (U) Unpreserved, (O) Other ______

Lab Project Manager:

Lab Profile/Line:

Customer Sample ID	Matrix *	Comp / Grab	Collected (or Composite Start)		Composite End		Res Cl	# of Ctns	Analyses										Lab Sample # / Comments
								Container Preservative Type **	3	O	1	U	U		3	1	U		
			Date	Time	Date	Time			8260 VOCs	AMDGAX (MEE Acetylene)	Total Iron	Dissolved Iron (lab filter)	Chloride		TCLP VOCs	TCLP Metals	pH		
MW-04	GW	Grab	10/10/19	1515				6	X	X									
WC-01	GW	Comp	10/10/19	1745				10							X	X	X		
CMT-1-UP	V	Comp	10/9/19	1722	10/9/19	1800		2		X									
CMT-2-MIDDLE-01	V	Comp	10/10/19	1221	10/10/19	1246		2		X									
TB-01								1	X										
TB-02																			
TB-03																			
TB-04																			
TB-05																			

Lab Sample Receipt Checklist:

Custody Seals Present/Intact Y N NA
Custody Signatures Present Y N NA
Collector Signature Present Y N NA
Bottles Intact Y N NA
Correct Bottles Y N NA
Sufficient Volume Y N NA
Samples Received on Ice Y N NA
VOA - Headspace Acceptable Y N NA
USDA Regulated Soils Y N NA
Samples in Holding Time Y N NA
Residual Chlorine Present Y N NA
Cl Strips: ______
Sample pH Acceptable Y N NA
pH Strips: ______
Sulfide Present Y N NA
Lead Acetate Strips: ______

LAB USE ONLY:
Lab Sample # / Comments:

Customer Remarks / Special Conditions / Possible Hazards:

Bubble Strip Vapor Samples: Extra vial volume sampled in vial #2 • Only analyze if needed/for extra

Type of Ice Used: Wet Blue Dry None

Packing Material Used:

Radchem sample(s) screened (<500 cpm): Y N NA

SHORT HOLDS PRESENT (<72 hours): Y N N/A

Lab Tracking #: 2324229

Samples received via:
FEDEX UPS Client Courier Pace Courier

Lab Sample Temperature Info:
Temp Blank Received: Y N NA
Therm ID#: ______
Cooler 1 Temp Upon Receipt: ______oC
Cooler 1 Therm Corr. Factor: ______oC
Cooler 1 Corrected Temp: ______oC
Comments:

Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:
GSI	10/11/19 1145		

MTJL LAB USE ONLY
Table #:
Acctnum:
Template:
Prelogin:
PM:
PB:

Trip Blank Received: Y N NA
HCL MeOH TSP Other

Non Conformance(s): YES / NO

Page: 3 of: 3

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CHAIN-OF-CUSTODY Analytical Request Document

Chain-of-Custody is a LEGAL DOCUMENT - Complete all relevent fields

LAB USE ONLY- Affix Workorder/Login Label Here or List Pace Workorder Number or MTJL Log-in Number Here

ALL SHADED AREAS are for LAB USE ONLY

Company: GSI Environmental
Address:
Billing Information:
Report To: DMHart@gsi-net.com
Email To:
Copy To: SDRichardson@gsi-net.com
Site Collection Info/Address:
Customer Project Name/Number: 4460 - S.I. 17 Indian Head
State: MD County/City: Indian Head Time Zone Collected: [ ] PT [ ] MT [ ] CT ☒ ET
Phone: 510-346-4474
Email:
Site/Facility ID #: S.I. 17
Compliance Monitoring? [ ] Yes ☒ No
Collected By (print): Dylan Hart
Purchase Order #:
Quote #: 4460-601
DW PWS ID #:
DW Location Code:
Collected By (signature):
Turnaround Date Required: Std
Immediately Packed on Ice: ☒ Yes [ ] No
Sample Disposal: ☒ Dispose as appropriate [ ] Return
[ ] Archive: ____________
[ ] Hold: ____________
Rush: [ ] Same Day [ ] Next Day [ ] 2 Day [ ] 3 Day [ ] 4 Day [ ] 5 Day (Expedite Charges Apply)
Field Filtered (if applicable): [ ] Yes ☒ No
Analysis: ____________

Container Preservative Type **
Lab Project Manager:

** Preservative Types: (1) nitric acid, (2) sulfuric acid, (3) hydrochloric acid, (4) sodium hydroxide, (5) zinc acetate, (6) methanol, (7) sodium bisulfate, (8) sodium thiosulfate, (9) hexane, (A) ascorbic acid, (B) ammonium sulfate, (C) ammonium hydroxide, (D) TSP, (U) Unpreserved, (O) Other ____________

Lab Profile/Line:

```
Lab Sample Receipt Checklist:

Custody Seals Present/Intact  Y N NA
Custody Signatures Present    Y N NA
Collector Signature Present   Y N NA
Bottles Intact                Y N NA
Correct Bottles               Y N NA
Sufficient Volume             Y N NA
Samples Received on Ice       Y N NA
VOA - Headspace Acceptable    Y N NA
USDA Regulated Soils          Y N NA
Samples in Holding Time       Y N NA
Residual Chlorine Present     Y N NA
Cl Strips: ________________
Sample pH Acceptable          Y N NA
pH Strips: ________________
Sulfide Present               Y N NA
Lead Acetate Strips: __________

LAB USE ONLY:
Lab Sample # / Comments:
```

* Matrix Codes (Insert in Matrix box below): Drinking Water (DW), Ground Water (GW), Wastewater (WW), Product (P), Soil/Solid (SL), Oil (OL), Wipe (WP), Air (AR), Tissue (TS), Bioassay (B), Vapor (V), Other (OT)

Customer Sample ID	Matrix *	Comp / Grab	Collected (or Composite Start)		Composite End		Res Cl	# of Ctns	8260 VOCs	AMJOGAX (MEE - Acetylene)	Total Iron	Dissolved Iron (lab filter)	Chloride
			Date	Time	Date	Time							
DUP-1-CMT-1-UP	GW	G	10.9.19	1515				6	X	X			
CMT-1-MIDDLE	↓	↓	↓	1540				10	X	X	X	X	X
CMT-1-LOWER	↓	↓	↓	1610				10	X	X	X	X	X
CMT-3-LOWER	↓	↓	10.10.19	1040				8	X	X	X	X	
CMT-3-MIDDLE	↓	↓	↓	1100				10	X	X	X	X	X
CMT-3-UPPER	↓	↓	↓	1120				6	X	X			
DUP-2-CMT-3-MID	↓	↓	↓	1140				3	X				
CMT-2-MIDDLE	↓	↓	↓	1240				6	X	X			
CMT-2-LOWER	↓	↓	↓	1340				8	X	X	X	X	
CMT-2-UPPER	↓	↓	↓	1400				5	X	X			

Customer Remarks / Special Conditions / Possible Hazards:
5 Coolers

Type of Ice Used: Wet Blue Dry None
Packing Material Used:
Radchem sample(s) screened (<500 cpm): Y N NA
SHORT HOLDS PRESENT (<72 hours): Y N N/A
Lab Tracking #: 2324228
Samples received via: FEDEX UPS Client Courier Pace Courier

Lab Sample Temperature Info:
Temp Blank Received: Y N NA
Therm ID#: ____________
Cooler 1 Temp Upon Receipt: _____oC
Cooler 1 Therm Corr. Factor: _____oC
Cooler 1 Corrected Temp: _____oC
Comments:

Relinquished by/Company: (Signature) GSI	Date/Time: 10/11/19 1145	Received by/Company: (Signature)	Date/Time:
Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:
Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:

MTJL LAB USE ONLY
Table #:
Acctnum:
Template:
Prelogin:
PM:
PB:

Trip Blank Received: Y N NA
HCL MeOH TSP Other

Non Conformance(s): YES / NO

Page: 2 of: 3

Pace Analytical®

CHAIN-OF-CUSTODY Analytical Request Document

Chain-of-Custody is a LEGAL DOCUMENT - Complete all relevent fields

LAB USE ONLY- Affix Workorder/Login Label Here or List Pace Workorder Number or MTJL Log-in Number Here

ALL SHADED AREAS are for LAB USE ONLY

Company: GSI Environmental
Address: 9600 Great Hills Trail STE 350E
Billing Information:
Report To: DMHART@gsi-net.com
Email To: acct.pay@gsi-net.com
Copy To: SDR@gsi-env.com
Site Collection Info/Address: S.R 17
Customer Project Name/Number: [illegible] S.R 17
State: MD / County/City: Indian Head
Time Zone Collected: [ ] PT [ ] MT [ ] CT [☒] ET
Phone: [illegible]
Email: [illegible]
Site/Facility ID #: S.R 17
Compliance Monitoring? [ ] Yes [☒] No
Collected By (print): Dylan Hart
Purchase Order #: 4460-001
Quote #:
DW PWS ID #:
DW Location Code:
Collected By (signature):
Turnaround Date Required: Std
Immediately Packed on Ice: [☒] Yes [ ] No
Sample Disposal: [☒] Dispose as appropriate [ ] Return [ ] Archive: ______ [ ] Hold: ______
Rush: [ ] Same Day [ ] Next Day [ ] 2 Day [ ] 3 Day [ ] 4 Day [ ] 5 Day (Expedite Charges Apply)
Field Filtered (if applicable): [ ] Yes [☒] No
Analysis: Dissolved Fe

Container Preservative Type **
Lab Project Manager:

** Preservative Types: (1) nitric acid, (2) sulfuric acid, (3) hydrochloric acid, (4) sodium hydroxide, (5) zinc acetate, (6) methanol, (7) sodium bisulfate, (8) sodium thiosulfate, (9) hexane, (A) ascorbic acid, (B) ammonium sulfate, (C) ammonium hydroxide, (D) TSP, (U) Unpreserved, (O) Other ______

* Matrix Codes (Insert in Matrix box below): Drinking Water (DW), Ground Water (GW), Wastewater (WW), Product (P), Soil/Solid (SL), Oil (OL), Wipe (WP), Air (AR), Tissue (TS), Bioassay (B), Vapor (V), Other (OT)

Customer Sample ID	Matrix *	Comp / Grab	Collected (or Composite Start)		Composite End		Res Cl	# of Ctns	Analyses									
			Date	Time	Date	Time			8260 VOCs	AM20GAx (MEE-Acetylene)	Total Iron	Dissolved Iron (Lab Filter)	Chloride					
MW-15	GW	G	10/7/19	1440				10	X	X	X	X	X					
MW-11	↓	↓	10/7/19	1550				10	↓	↓	↓	↓	↓					
MW-14			10/7/19	1655				10										
MW-13			10/8/19	1345				10										
MW-16			10/8/19	1450				10										
MW-12			10/9/19	1140				10										
CMT-4-UPPER			10/9/19	1245				6	X	X								
CMT-4-MIDDLE			10/9/19	1300				10	X	X	X	X	X					
CMT-4 LOWER			10.9.19	1335				8	X	X	X	X						
CMT-1-UPPER			10/9/19	1455				10	X	X	X	X	X					

Lab Profile/Line:

```
Lab Sample Receipt Checklist:

Custody Seals Present/Intact  Y N NA
Custody Signatures Present    Y N NA
Collector Signature Present   Y N NA
Bottles Intact                Y N NA
Correct Bottles               Y N NA
Sufficient Volume             Y N NA
Samples Received on Ice       Y N NA
VOA - Headspace Acceptable    Y N NA
USDA Regulated Soils          Y N NA
Samples in Holding Time       Y N NA
Residual Chlorine Present     Y N NA
Cl Strips: ___________
Sample pH Acceptable          Y N NA
pH Strips: ___________
Sulfide Present               Y N NA
Lead Acetate Strips: ________

LAB USE ONLY:
Lab Sample # / Comments:
```

Customer Remarks / Special Conditions / Possible Hazards: 5 Coolers

Type of Ice Used: Wet Blue Dry None
Packing Material Used:
Radchem sample(s) screened (<500 cpm): Y N NA
SHORT HOLDS PRESENT (<72 hours): Y N N/A
Lab Tracking #: 2324227
Samples received via: FEDEX UPS Client Courier Pace Courier

Lab Sample Temperature Info:
Temp Blank Received: Y N NA
Therm ID#: ______
Cooler 1 Temp Upon Receipt: ____oC
Cooler 1 Therm Corr. Factor: ____oC
Cooler 1 Corrected Temp: ____oC
Comments:

Relinquished by/Company: (Signature)	Date/Time:	Received by/Company: (Signature)	Date/Time:
GSI	10/11/19 1145		

MTJL LAB USE ONLY
Table #:
Acctnum:
Template:
Prelogin:
PM:
PB:

Trip Blank Received: Y N NA
HCL MeOH TSP Other

Non Conformance(s): YES / NO

Page: 1 of: 3

REPORT TO:
Name: Dylan Hart
Company: GSI Environmental
Address: 4600 Great Hills Trail, STE 350E
Austin, TX 78759

email: dmhart@gsi-net.com
Phone: 512-346-4474
Fax:

Project Manager: Dylan Hart
Project Name: NSFDH Site 17
Project No.: 4460-601

INVOICE TO: (For Invoices paid by a third party it is imperative that all information be provided)
Name: Susan Beadles, AP
Company: GSI Environmental
Address:

email: acct.pay@gsi-net.com
Phone: 713-522-6300
Fax:

Purchase Order No. 4460-601
Subcontract No.
MI Quote No.

microbialinsights
10515 Research Dr
Knoxville, TN 37932
865-573-8188

www.microbe.com

Please Check One:
☐ More samples to follow
☒ No Additional Samples

Report Type: ☒ Standard (default) ☐ Microbial Insights Level III raw data(15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (35%)

EDD type: ☒ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

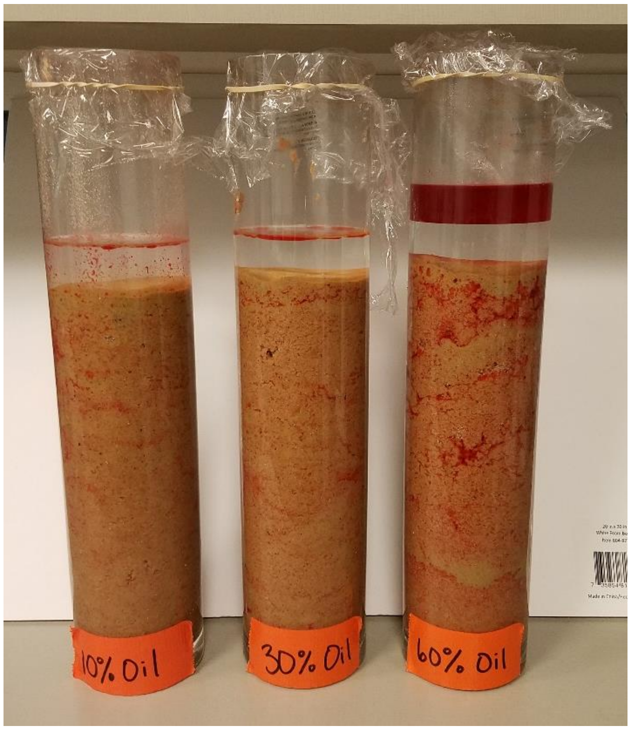
Sample Information						Analyses				CENSUS: Please select the target organism/gene																							
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	**PLFA**	**NGS**	**QuantArray Chlor**	**QuantArray Petro**	DHC (Dehalococcoides)	DHC Functional genes (bvc, tce, vcr)	DHBt (Dehalobacter)	DHG (Dehalogenimonas)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AMO (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	**RNA (Expression Option)***	Other:	Other:	Other:
	MW-04	10/10/19	1515	W	1					X	X	X				X																	
	MW-12	↓	1535	↓	↓					X	X	X				X																	
	MW-16		1545							X	X	X				X																	

Relinquished by: Dylan Hart
Date 10/10/19 1800
Received by:
Date

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

Appendix M. Photo Log

APPENDIX M: SITE PHOTOGRAPHIC LOG



Oil/Sand Column Experiments: 10%, 30%, 60% Oil

Oil/Sand Column Experiments: 40% Oil

APPENDIX M: SITE PHOTOGRAPHIC LOG

Amendment Pilot Test (Denver, CO): Organic Foam Additive

Amendment Pilot Test (Denver, CO): Organic Foam Additive

APPENDIX M: SITE PHOTOGRAPHIC LOG

Amendment Pilot Test (Denver, CO):

Amendment Pilot Test (Denver, CO): Test Mixture 1 - 40% ZVI/Sand, 56% Oil/Water

Amendment Pilot Test (Denver, CO): Test Mixture 2 - 40% ZVI/Sand, 34% Oil/Water

APPENDIX M: SITE PHOTOGRAPHIC LOG

Amendment Pilot Test (Denver, CO): Test Mixture 3 - 40% ZVI/60% Sand, 0% Oil

Amendment Pilot Test (Denver, CO): Test Mixture 4 - 34% Oil/Sand

APPENDIX M: SITE PHOTOGRAPHIC LOG

Amendment Pilot Test (Denver, CO): Test Mixture 5 - 68% Oil/Sand

Amendment Pilot Test (Denver, CO): Test Mixture 6 - 34% Oil/Sand, 5% topsoil

APPENDIX M: SITE PHOTOGRAPHIC LOG

Amendment Pilot Test (Denver, CO): Test Mixture 7 - 40% Oil/Sand

Amendment Pilot Test (Denver, CO): Test Mixture 8 - 40% ZVI/Sand, 15% Foam/Water

APPENDIX M: SITE PHOTOGRAPHIC LOG

Amendment Pilot Test (Denver, CO): Test Mixture 9 - 5% Oil/Sand with Organic Foam Additive

Field Demonstration: Prior to Site Clearance (Facing North)

APPENDIX M: SITE PHOTOGRAPHIC LOG

Field Demonstration: After Site Clearance (Facing South)

Field Demonstration: After Site Clearance (Facing South); Column Locations Marked in Preparation for Installation (blue flags)

APPENDIX M: SITE PHOTOGRAPHIC LOG

Field Demonstration, ZVI mixing in Elkin Mixer

Field Demonstration: Grout Bomber column installation

APPENDIX M: SITE PHOTOGRAPHIC LOG

August 2017 Field Demonstration: After rain delay

August 2017 Field Demonstration (Facing North)

APPENDIX M: SITE PHOTOGRAPHIC LOG

August 2017 Field Demonstration (Facing West)

August 2017 Field Demonstration (Facing Southeast)

APPENDIX M: SITE PHOTOGRAPHIC LOG

July 2017 GeoTrax LTM Electrode Installation (Facing Southeast)

July 2017 GeoTrax LTM Electrode Installation (Facing North)

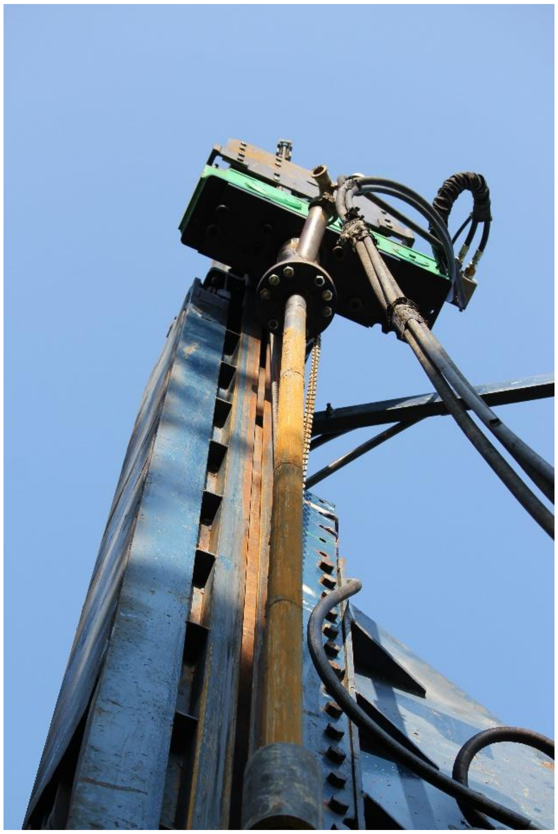
APPENDIX M: SITE PHOTOGRAPHIC LOG

July 2017 GeoTrax LTM Electrode Installation (Facing South)

July 2017 GeoTrax LTM Electrode Installation (Facing North)

APPENDIX M: SITE PHOTOGRAPHIC LOG

Site 17 - column materials at South Plume storage area (covered to keep dry during rain)



Grout Bomber mandrel

APPENDIX M: SITE PHOTOGRAPHIC LOG

GSI / Hayward Baker Field Demonstration to NAVFAC personnel

Grout Bomber Field Demonstration: South Plume Storage and Preparation Area

APPENDIX M: SITE PHOTOGRAPHIC LOG

Field Demonstration of CMT construction using Grout Bomber (September 2017)

Reaction column excavated during soil vapor probe (SVP) installation (April 2019)

APPENDIX M: SITE PHOTOGRAPHIC LOG

April 2019 Performance Monitoring and SVP Installation

Chunks of ZVI material from “dogpiles” excavated during April 2019 SVP installation

APPENDIX M: SITE PHOTOGRAPHIC LOG

Loose ZVI reaction column / native soil interface (April 2019)

Composite soil sample from ZVI reaction column material for field screening (October 2019):
33.59 ppm measured using ppbRAE PID

APPENDIX M: SITE PHOTOGRAPHIC LOG

SVP-01 location showing E-Flux installation directly over reaction column (left), E-Flux installation over native material (mid) and soil vapor probe directly over reaction column (right)

SVP-02 location E-Flux carbon trap installations (top) and soil vapor probe (bottom)

APPENDIX M: SITE PHOTOGRAPHIC LOG

Deployed E-Flux carbon traps: directly over reaction column (left) and native material (right)

Site 17 North Plume, Facing South (April 2019)

APPENDIX M: SITE PHOTOGRAPHIC LOG

Site 17 North Plume, Facing Northwest (April 2019)

SVP-RC-01 at location RGM-01 (October 2019)

APPENDIX M: SITE PHOTOGRAPHIC LOG

6-Liter Summa Canister with 8-hr Flow Controller (October 2019)

Bubble Strip Sampling using MicroSeeps Cell (October 2019)

APPENDIX M: SITE PHOTOGRAPHIC LOG

Bubble Strip Sampling using MicroSeeps Cell (October 2019)

SVP-B-01 Time-Integrated Soil Vapor Sampling

APPENDIX M: SITE PHOTOGRAPHIC LOG

SVP-B-04 (not over reaction column)

October 2019 Time-Integrated SVP Sampling; SVP-B-01 (middle) and SVP-RC-01 (right)

Appendix N. Groundwater Elevations and Potentiometric Surface Maps

TABLE N-1
STATIC WATER LEVEL MEASUREMENTS
Site 17 North Plume, NSFIH, Indian Head, Maryland

Location ID	Screened Interval (ft bgs)	Top of Casing Elevation (ft msl)	Date Measured	Time Interval	Depth To Water (ft btoc)	Static Water Level (ft msl)
Monitoring Wells						
IS17MW04	8-18	6.47	6/17/2013	-	4.75	1.72
			8/27/2013	-	5.78	0.69
			12/4/2013	-	5.43	1.04
			3/19/2014	-	4.43	2.04
			6/23/2014	-	4.95	1.52
			12/1/2014	-	5.4	1.07
			3/23/2015	-	4.3	2.17
			6/15/2015	-	5.6	0.87
			9/14/2015	-	6.47	0
			11/30/2015	-	5.55	0.92
			4/25/2016	-	5.52	0.95
			4/24/2017	-	5.07	1.4
			7/1/2017	Baseline	6.13	0.34
			9/1/2017	t>0	5.22	1.25
			2/1/2018	7-Month	5.2	1.27
			4/16/2018	9-Month	5.36	1.11
			8/1/2018	12-Month	4.43	2.04
			12/11/2018	16-Month	4.83	1.64
			4/23/2019	20-Month	-	-
			10/7/2019	26-Month	5.25	1.22
IS17MW11	3.6-13.6	7.06	7/14/2014	-	6.49	0.57
			12/1/2014	-	5.75	1.31
			3/23/2015	-	5.11	1.95
			6/15/2015	-	6.38	0.68
			9/14/2015	-	7.13	-0.07
			11/30/2015	-	6.3	0.76
			4/25/2016	-	6.09	0.97
			4/24/2017	-	5.74	1.32
			7/1/2017	Baseline	6.88	0.18
			9/1/2017	t>0	5.96	1.1
			2/1/2018	7-Month	5.8	1.26
			4/16/2018	9-Month	4.72	2.34
			8/1/2018	12-Month	5.47	1.59
			12/11/2018	16-Month	5.82	-5.82
			4/23/2019	20-Month	5.58*	1.48*
			10/7/2019	26-Month	6.15	0.91
IS17MW12	3.6-13.6	6.04	7/14/2014	-	5.12	0.92
			12/1/2014	-	4.83	1.21
			3/23/2015	-	3.58	2.46
			6/15/2015	-	4.85	1.19
			9/14/2015	-	6.56	-0.52
			11/30/2015	-	5.29	0.75
			4/25/2016	-	4.69	1.35
			4/24/2017	-	4.38	1.66
			7/1/2017	Baseline	5.65	0.39
			9/1/2017	t>0	4.99	1.05
			2/1/2018	7-Month	3.97	2.07
			4/16/2018	9-Month	3.61	2.43
			8/1/2018	12-Month	2.8	3.24
			12/11/2018	16-Month	3.14	2.9
			4/23/2019	20-Month	2.87*	3.17*
			10/7/2019	26-Month	5.36	0.68

TABLE N-1
STATIC WATER LEVEL MEASUREMENTS
Site 17 North Plume, NSFIH, Indian Head, Maryland

Location ID	Screened Interval (ft bgs)	Top of Casing Elevation (ft msl)	Date Measured	Time Interval	Depth To Water (ft btoc)	Static Water Level (ft msl)
IS17MW13	3.6-13.6	5.42	7/14/2014	-	4.77	0.65
			12/1/2014	-	4.44	0.98
			3/23/2015	-	3.5	1.92
			6/15/2015	-	4.89	0.53
			9/14/2015	-	5.49	-0.07
			11/30/2015	-	4.75	0.67
			4/25/2016	-	4.49	0.93
			4/24/2017	-	4.25	1.17
			7/1/2017	Baseline	5.35	0.07
			9/1/2017	t>0	4.57	0.85
			2/1/2018	7-Month	4.36	1.06
			4/16/2018	9-Month	2.93	2.49
			8/1/2018	12-Month	3.25	2.17
			12/11/2018	16-Month	3.01	2.41
			4/23/2019	20-Month	NS	NS
			10/7/2019	26-Month	3.28	2.14
IS17MW14	3.6-13.6	5.69	7/14/2014	-	4.79	0.9
			12/1/2014	-	4.56	1.13
			3/23/2015	-	3.81	1.88
			6/15/2015	-	5.2	0.49
			9/14/2015	-	5.69	0
			11/30/2015	-	4.82	0.87
			4/25/2016	-	4.4	1.29
			4/24/2017	-	3.96	1.73
			7/1/2017	Baseline	5.31	0.38
			9/1/2017	t>0	4.43	1.26
			2/1/2018	7-Month	4.64	1.05
			4/16/2018	9-Month	3.15	2.54
			8/1/2018	12-Month	3.91	1.78
			12/11/2018	16-Month	3.74	1.95
			4/23/2019	20-Month	3.81*	1.88*
			10/7/2019	26-Month	4.13	1.56
IS17MW15	8-18	6.62	9/14/2015	-	8.11	-1.49
			11/30/2015	-	5.45	1.17
			4/25/2016	-	5.23	1.39
			4/24/2017	-	4.67	1.95
			7/1/2017	Baseline	6.41	0.21
			9/1/2017	t>0	5.64	0.98
			2/1/2018	7-Month	3.96	2.66
			4/16/2018	9-Month	3.4	3.22
			8/1/2018	12-Month	3.55	3.07
			12/11/2018	16-Month	3.63	2.99
			4/23/2019	20-Month	3.81*	2.81*
			10/7/2019	26-Month	8.8	-2.18
IS17MW16	6-16	6.58	9/14/2015	-	7.59	-1.01
			11/30/2015	-	5.64	0.94
			4/25/2016	-	5	1.58
			4/24/2017	-	4.56	2.02
			7/1/2017	Baseline	5.95	0.63
			9/1/2017	t>0	4.73	1.85
			2/1/2018	7-Month	3.88	2.7
			4/16/2018	9-Month	3.79	2.79
			8/1/2018	12-Month	3.86	2.72
			12/11/2018	16-Month	3.7	2.88
			4/23/2019	20-Month	3.37*	3.21*
			10/7/2019	26-Month	6.43	0.15

TABLE N-1
STATIC WATER LEVEL MEASUREMENTS
Site 17 North Plume, NSFIH, Indian Head, Maryland

Location ID	Screened Interval (ft bgs)	Top of Casing Elevation (ft msl)	Date Measured	Time Interval	Depth To Water (ft btoc)	Static Water Level (ft msl)
Continuous Multi-Level Tubing (CMT) Wells						
CMT-01-MIDDLE	18.15-18.65	-	9/1/2017	t>0	4.61	NA
			2/1/2018	7-Month	4.6	NA
			8/1/2018	12-Month	3.93	NA
			12/11/2018	16-Month	5.18	NA
			10/7/2019	26-Month	5.4	NA
CMT-02-MIDDLE	19.34-19.84	-	9/1/2017	t>0	4.35	NA
			2/1/2018	7-Month	3.38	NA
			8/1/2018	12-Month	2.12	NA
			12/11/2018	16-Month	2.74	NA
			10/7/2019	26-Month	5.18	NA
CMT-03-MIDDLE	17.6-18.1	-	9/1/2017	t>0	4	NA
			2/1/2018	7-Month	3.18	NA
			8/1/2018	12-Month	2.29	NA
			12/11/2018	16-Month	3.19	NA
			10/7/2019	26-Month	3.68	NA
CMT-04-MIDDLE	16.25-16.75	-	9/1/2017	t>0	4.4	NA
			2/1/2018	7-Month	3.18	NA
			8/1/2018	12-Month	1.88	NA
			12/11/2018	16-Month	2.96	NA
			10/7/2019	26-Month	NS	NA

Notes:
1. CMT wells have not been surveyed. Only CMT middle interval measurements are reported, which correspond to monitoring well screens.
2. "-" = Not Surveyed;   NA = Not applicable
3. ft bgs = feet below ground surface; ft msl = feet above mean sea level; ft btoc = ft below top of casing
4. * = water level was recorded using a pressure transducer reading rather than a manually measured depth to water. MW-04 and CMT wells do not contain pressure transducers, and thus no measurement was recorded during the April 2019 sampling event for those wells.

N

LEGEND

●	Monitoring well location
3.67	Groundwater elevation measured in ft amsl

Notes

1. ft amsl = feet above mean sea level.
3. Background Imagery: Downloaded from United States Geological Survey, February 2014.

Feet
0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

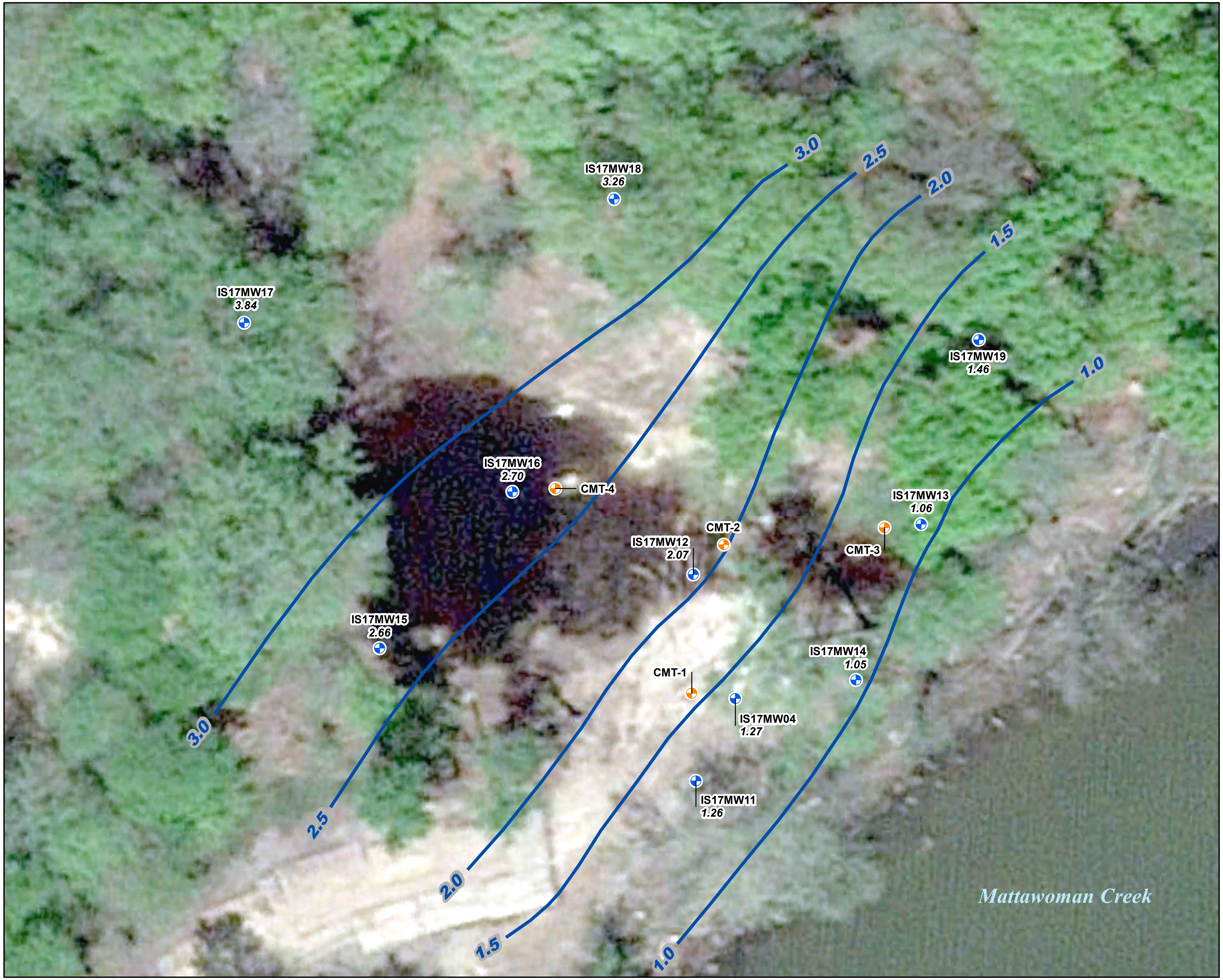
GSI
ENVIRONMENTAL

SITE 17 NORTH PLUME APRIL 2017 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No.	4460	Drawn By:	CDM
Issued:	6-Feb-2020	Chk'd By:	DMH
Map ID:	**002_01**	Appv'd By:	

Figure N-1



LEGEND

● Monitoring well location

● CMT well location

3.84 Groundwater elevation measured in ft amsl

Notes

1. CMT wells have yet to be surveyed, and locations indicated are approximate.
2. CMT = continuous multilevel tubing; ft amsl = feet above mean sea level.
3. Background Imagery: Extracted from GoogleEarth Pro on 5 Feb 2020; Historical image date: 4/30/2018.

Feet
0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

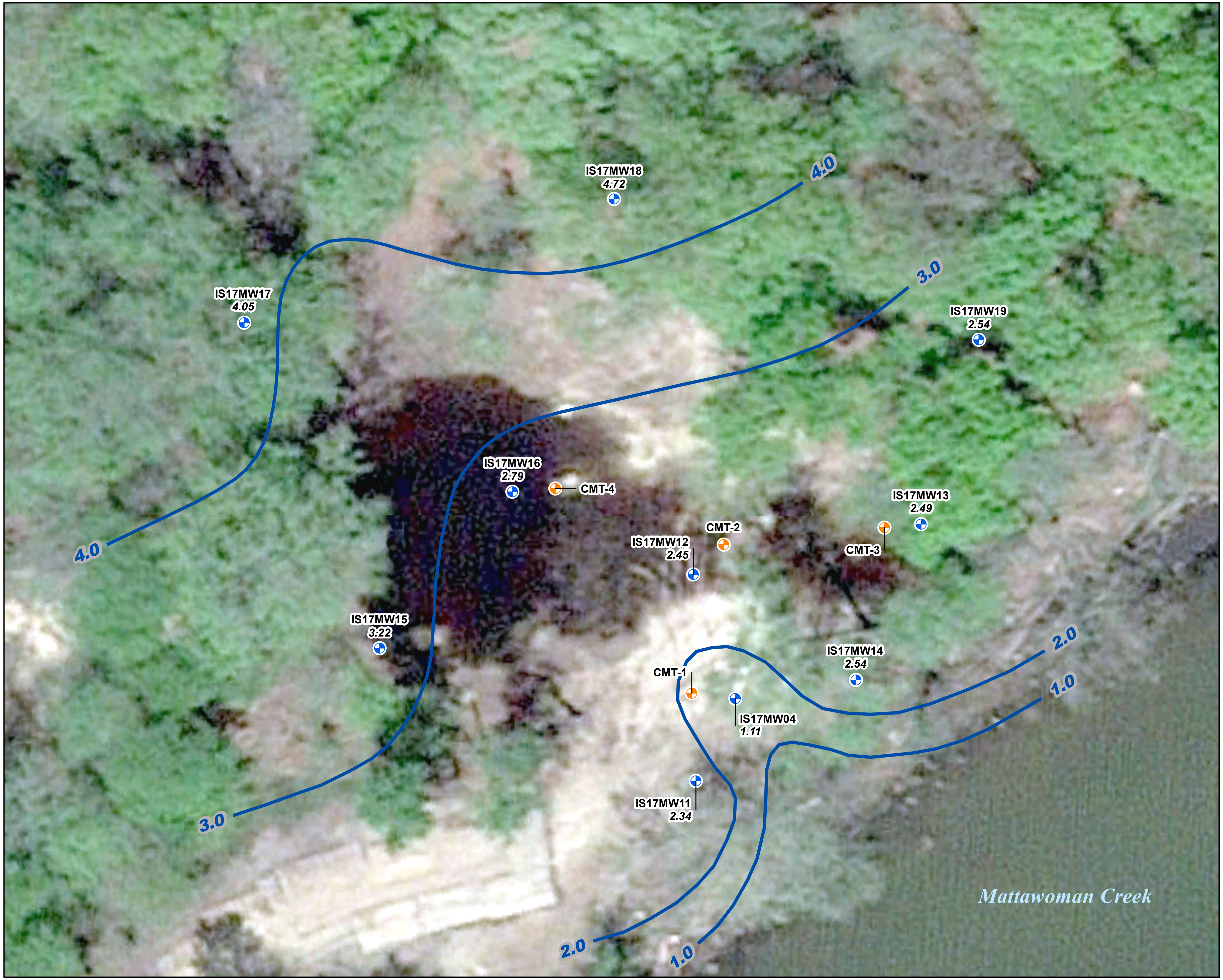
GSI
ENVIRONMENTAL

SITE 17 NORTH PLUME FEBRUARY 2018 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No.	4460	Drawn By:	CDM
Issued:	5-Feb-2020	Chk'd By:	DMH
Map ID:	**002_02**	Appv'd By:	

Figure N-2



LEGEND

● Monitoring well location

● CMT well location

4.72 Groundwater elevation measured in ft amsl

Notes

1. CMT wells have yet to be surveyed, and locations indicated are approximate.
2. CMT = continuous multilevel tubing; ft amsl = feet above mean sea level.
3. Background Imagery: Extracted from GoogleEarth Pro on 5 Feb 2020; Historical image date: 4/30/2018.

Feet
0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

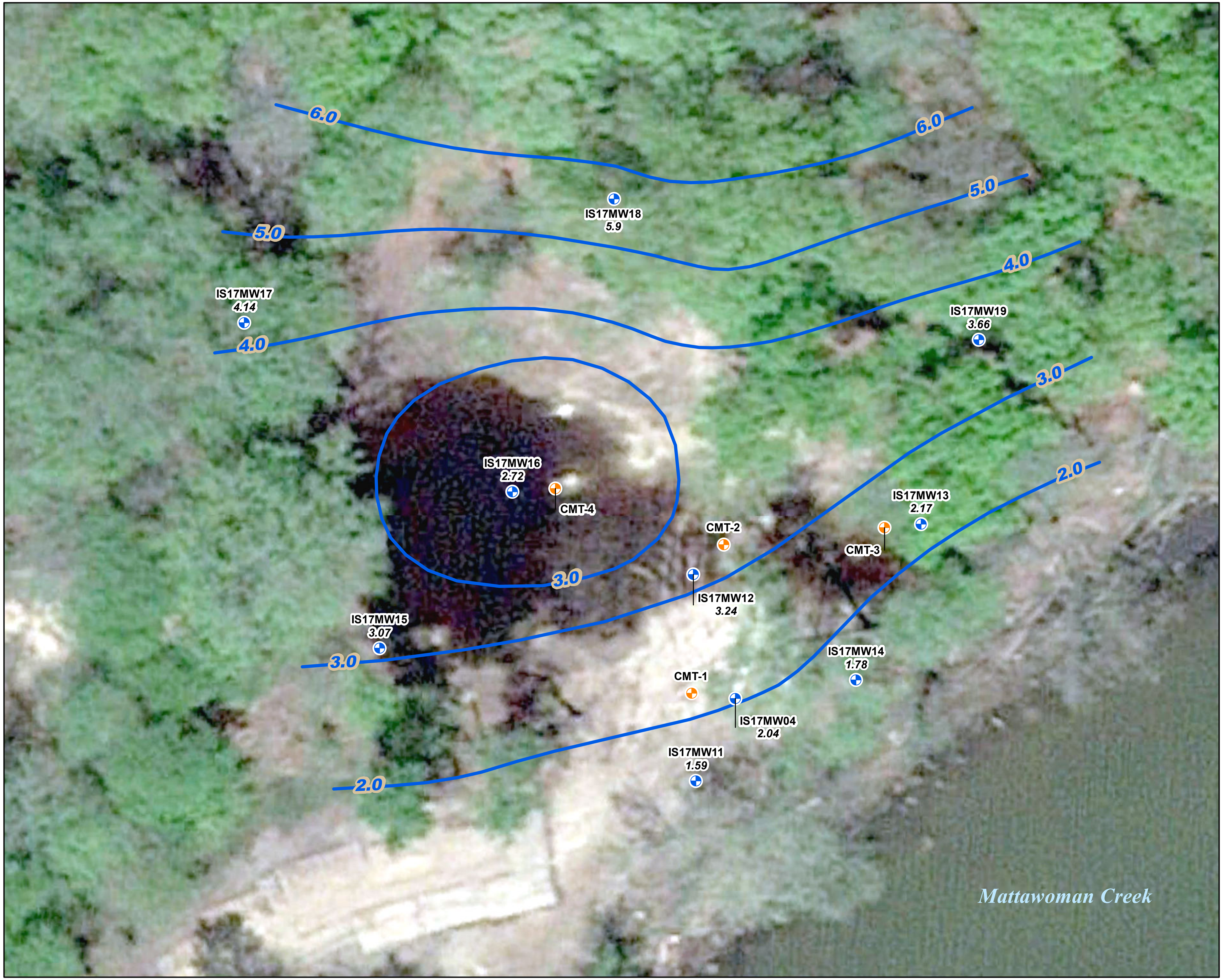
GSI
ENVIRONMENTAL

SITE 17 NORTH PLUME APRIL 2018 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No.	4460	Drawn By:	CDM
Issued:	6-Feb-2020	Chk'd By:	DMH
Map ID:	**002_03**	Appv'd By:	

Figure N-3



N

LEGEND

● Monitoring well location

● CMT well location

4.14 Groundwater elevation measured in ft amsl

Notes

1. CMT wells have yet to be surveyed, and locations indicated are approximate.
2. CMT = continuous multilevel tubing; ft amsl = feet above mean sea level.
3. Background Imagery: Extracted from GoogleEarth Pro on 5 Feb 2020; Historical image date: 4/30/2018.

Feet

0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

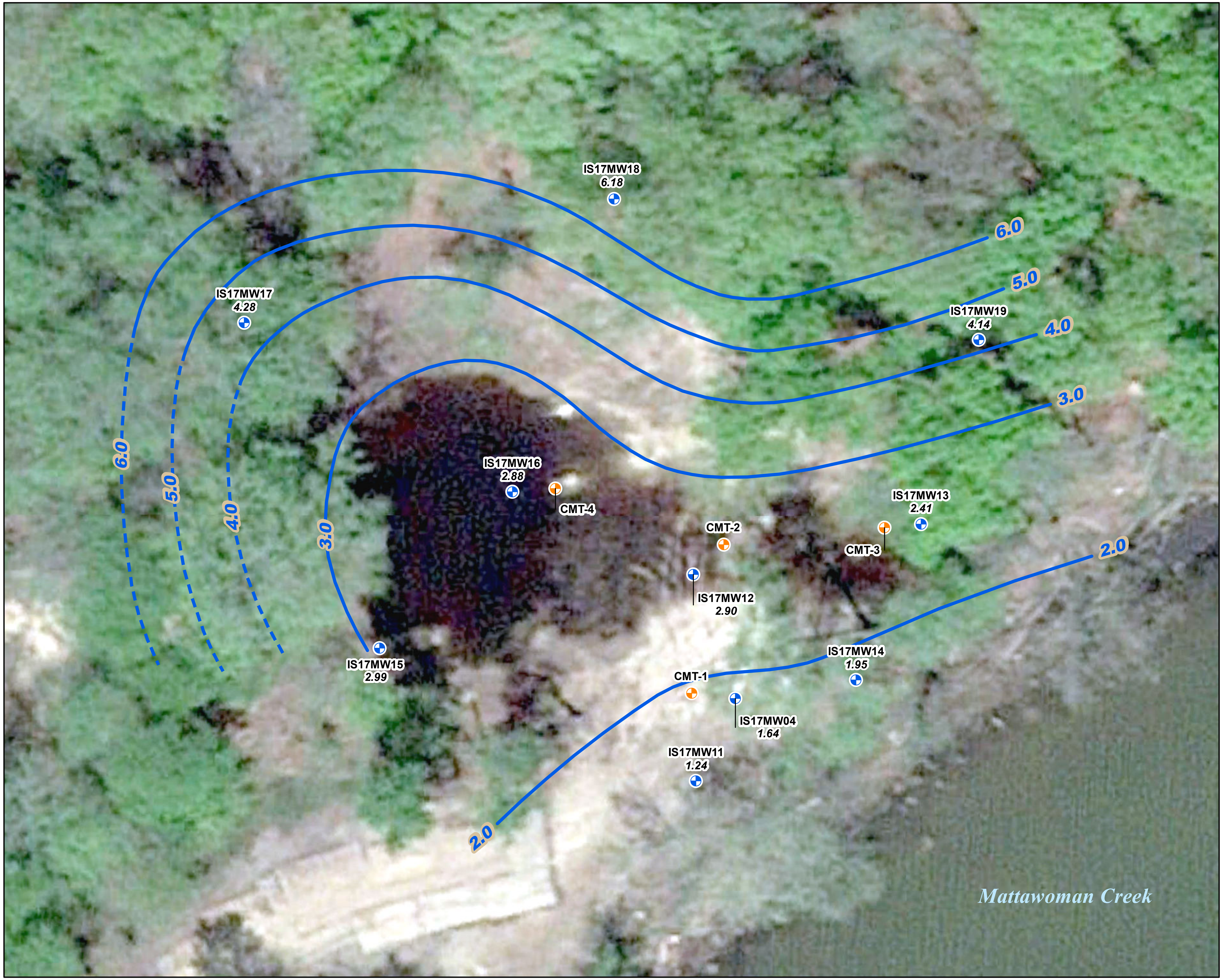
GSI ENVIRONMENTAL

SITE 17 NORTH PLUME AUGUST 2018 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No. 4460	Drawn By: CDM
Issued: 5-Feb-2020	Chk'd By: DMH
Map ID: **002_04**	Appv'd By:

Figure N-4



N

LEGEND

● Monitoring well location

● CMT well location

4.28 Groundwater elevation measured in ft amsl

Notes

1. CMT wells have yet to be surveyed, and locations indicated are approximate.
2. CMT = continuous multilevel tubing; ft amsl = feet above mean sea level.
3. Background Imagery: Extracted from GoogleEarth Pro on 5 Feb 2020; Historical image date: 4/30/2018.

Feet
0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

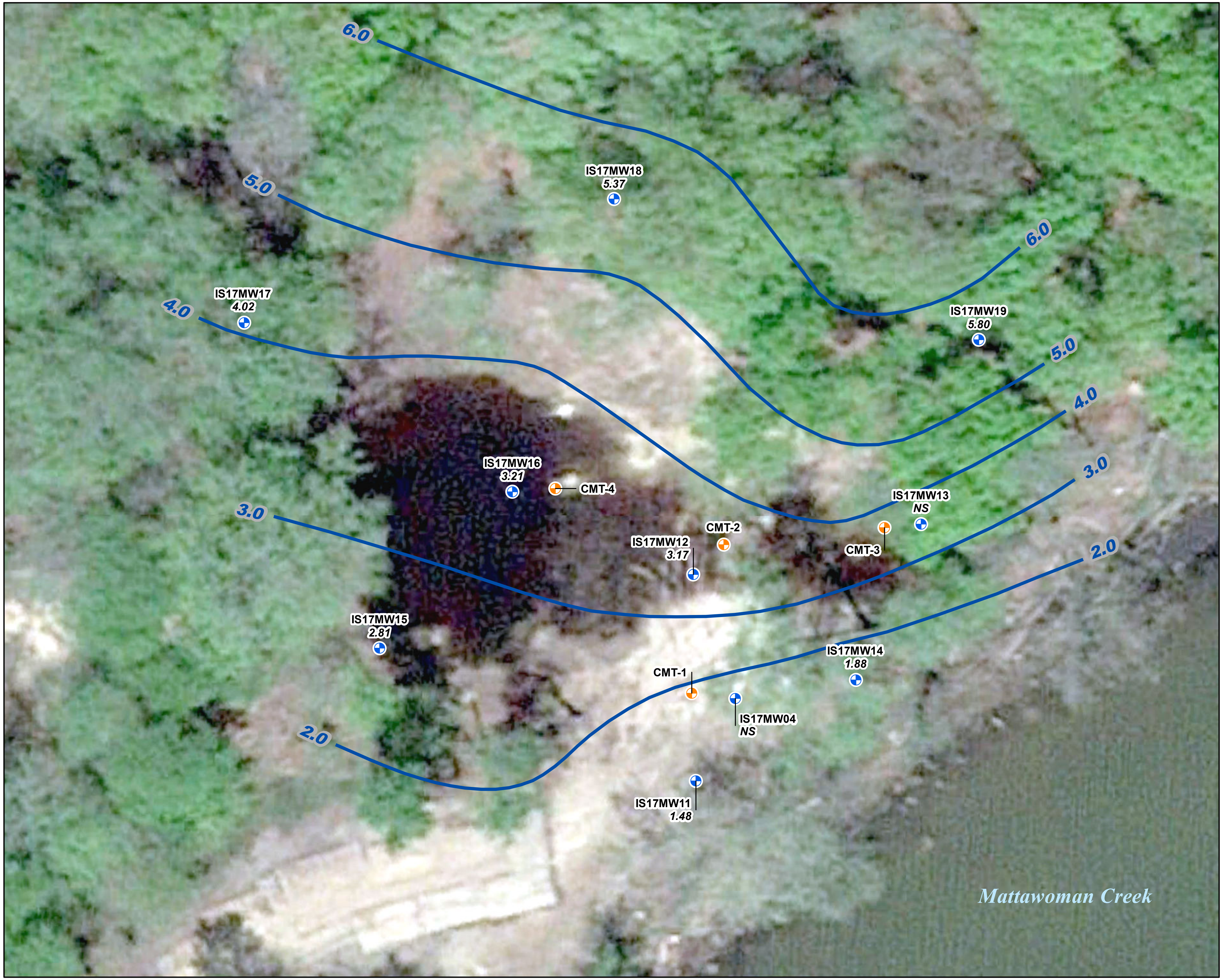
GSI
ENVIRONMENTAL

SITE 17 NORTH PLUME DECEMBER 2018 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No.	4460	Drawn By:	CDM
Issued:	5-Feb-2020	Chk'd By:	DMH
Map ID:	002_05	Appv'd By:	

Figure N-5



N

LEGEND

⊕	Monitoring well location
⊕	CMT well location
5.80	Groundwater elevation measured in ft amsl

Notes

1. Groundwater elevations were determined using pressure transducer data logged on 4/23/19 and downloaded on 10/10/2019.
2. CMT wells have yet to be surveyed, and locations indicated are approximate.
3. CMT = continuous multilevel tubing; ft amsl = feet above mean sea level; NS = not surveyed.
4. Background Imagery: Extracted from GoogleEarth Pro on 5 Feb 2020; Historical image date: 4/30/2018.

Feet
0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

GSI
ENVIRONMENTAL

SITE 17 NORTH PLUME APRIL 2019 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No.	4460	Drawn By:	CDM
Issued:	6-Feb-2020	Chk'd By:	DMH
Map ID:	**002_06**	Appv'd By:	

Figure N-6

LEGEND

- ⊕ Monitoring well location
- ⊕ CMT well location
- *2.14* Groundwater elevation measured in ft amsl

Notes

1. CMT wells have yet to be surveyed, and locations indicated are approximate.
2. CMT = continuous multilevel tubing; ft amsl = feet above mean sea level.
3. Negative groundwater elevation values represent a static water level value below the mean sea level datum.
4. Background Imagery: Extracted from GoogleEarth Pro on 5 Feb 2020; Historical image date: 4/30/2018.

Feet
0 10 20

Projected Coordinate System
Datum: NAD 83
STP: Maryland, FIPS 1900 (ft)

GSI
ENVIRONMENTAL

SITE 17 NORTH PLUME OCTOBER 2019 POTENTIOMETRIC SURFACE MAP

Site 17 North Plume, NSFIH, Indian Head, Maryland
ESTS CTO 033 Remedy Optimization Support

GSI Job No.	4460	Drawn By:	CDM
Issued:	5-Feb-2020	Chk'd By:	DMH
Map ID:	002_07	Appv'd By:	

Figure N-7