Source and Plume Sampling and Analysis Plan

Chicago Heights Site

EPA Docket Nos. RCRA-07-2013-001 & CERCLA-07-2013-001

PerkinElmer, Inc.

Project No. 26682

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INDEX AND CERTIFICATION

PerkinElmer, Inc.
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Report Index

Certification

I hereby certify, as a Professional Geologist in the state of Missouri, that the information in this document was assembled under my direct personal charge. This report is not intended or represented to be suitable for reuse by PerkinElmer, Inc. or others without specific verification or adaptation by the Geologist.

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Abbreviation	**Term/Phrase/Name**
AFCEE	Air Force Center for Engineering and Environment
AVS	acid volatile sulfide
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
CMT™	Solinst™ Continuous Multi-channel Tubing
COCs	chemicals of concern
CSIA	Compound Specific Isotope Analysis
CSM	Conceptual Site Model
DCE	dichloroethylene
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOC	dissolved organic carbon
EC	electrical conductivity
FID	Flame Ionization Detector
FPH	free-phase hydrocarbon
H_2	hydrogen
HASLC	Housing Authority of St. Louis County
HASP	Health and Safety Plan
HHBRA	Human Health Baseline Risk Assessment
HPT	Hydraulic Profile Tooling
IDW	investigation derived waste

Abbreviation	Term/Phrase/Name
ISCO	In-situ Chemical Oxidation
$KMnO_4$	potassium permanganate
LL MIP	Low-level Membrane Interface Probe
MCLs	maximum contaminant levels
MDHSS	Missouri Department of Health and Senior Services
MDL	method detection limit
MDNR	Missouri Department of Natural Resources
MIP	Membrane Interface Probe
MMSC	Missouri Metals Shaping Company
MNA	monitored natural attenuation
mS/m	milli-siemens per meter
MS	matrix spike
MSD	matrix spike duplicate
NAPL	non-aqueous phase liquid
O&M	operation and maintenance
Order	Administrative Settlement Agreement and Order of Consent
ORP	oxidation-reduction potential
PA/SI	Preliminary Assessment/Site Inspection
PCE	tetrachloroethene
PerkinElmer	PerkinElmer, Inc.
PID	Photo-ionization detector
ppb	parts per billion
PPE	personal protective equipment

Abbreviation	**Term/Phrase/Name**
ppm	parts per million
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RAE	Response Action Evaluation
RAP	Remedial Action Plan
RASR	Remedial Action Summary Report
RI	Remedial Investigation
RL	reporting limit
SAP	Sampling and Analysis Plan
SDWA	Safe Drinking Water Act
SI	Supplemental Investigation
SIWP	Supplemental Investigation Work Plan
SOP	Standard Operating Procedure
TCE	trichloroethene
TOC	total organic carbon
USEPA	United States Environmental Protection Agency
VC	vinyl chloride
VOCs	volatile organic compounds
XSD	Halogen Specific Detector

1.0 INTRODUCTION

Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) has prepared this *Source and Plume Sampling and Analysis Plan* (SAP) for the Chicago Heights Site, consisting of the Missouri Metals facility and the residential area located southeast of the facility, located near Overland, Missouri (Site) (see Figure 1-1). This SAP has been prepared pursuant to the Administrative Settlement Agreement and Order on Consent (Order) effective on November 26, 2012 (Chicago Heights Site – EPA Docket Nos. RCRA-07-2013-001 & CERCLA-07-2013-001) entered into by the United States Environmental Protection Agency (USEPA) and PerkinElmer, Inc. (PerkinElmer).

In a letter dated June 25, 2013, USEPA requested the submittal of a Source and Plume SAP as outlined in the Order (Task III of the Order). In addition, an updated site-wide *Quality Assurance Project Plan* (QAPP) is being submitted in conjunction with this Source and Plume SAP as stipulated in the Order.

As described in the Task III of the Order, the purpose of the Source and Plume investigation is to define the three-dimensional extent of the contaminant source(s) and the groundwater contaminant plume for site-specific chemicals of concern (COCs) in bedrock and overlying unconsolidated materials, including non-aqueous phase liquids (NAPLs). The Source and Plume investigation has been designed to provide the information required to update the *Human Health Baseline Risk Assessment* (HHBRA) submitted in 2006 (Burns & McDonnell, 2006). In addition, data required to perform a Response Action Evaluation (RAE) following completion of the Source and Plume Investigation will be collected.

As stated in the Order, USEPA anticipates the work required to complete the Source and Plume investigation to occur in phases. A phased investigation approach has been proposed which includes a high-resolution direct-push investigation and discrete analytical sampling in the overburden and upper bedrock prior to any deeper bedrock investigation activities. High-resolution direct-push investigation technologies will be implemented to further define the horizontal and vertical extent of the groundwater source(s) and plume located on the Missouri Metals; and also to locate additional permanent monitoring wells to adequately define and monitor the source(s) and plume. To facilitate the phased approach, this SAP and the updated QAPP have been structured to accommodate amendments describing any additional work required following USEPA's approval of the SAP and QAPP.

The phased approach to overburden/upper bedrock and deeper bedrock investigation has two primary benefits: (1) provides data that can be used to optimize the bedrock investigation, and (2) provides information useful in designing a bedrock investigation that minimizes the risk of unintended contaminant and/or potential NAPL mobilization. Further details regarding the Source and Plume investigation approach and the deeper bedrock investigation methodology is presented in Section 3.0.

2.0 SITE BACKGROUND

This section provides site background information, including a description of previous investigation and remediation activities.

2.1 Site Location and Description

The Chicago Heights Site consists of the Missouri Metals facility and the residential area located southeast of the facility (see Figures 2-1 and 2-2). The Site is located in an area of rolling hills. The overall ground surface in this area slopes to the southeast. The majority of the ground surface at the Missouri Metals facility, approximately 90 percent, is paved with asphalt or concrete with small areas of grass, gravel and bare soil present in portions of the property. The Site and the surrounding area is served by a public water supply system operated Missouri American Water Company which draws water from surface water sources, namely the Meramec and the Missouri Rivers.

The residential area located southeast of the Missouri Metals facility has a surface cover of grass and concrete streets. This area is located in an unincorporated segment of St. Louis County, and includes both single family and multi-family dwellings. Many of the residences have basements and some of the basements include foundation drains equipped with sumps. The residential area lies within a heavily urbanized area, surrounded by various industrial and commercial businesses.

Initial industrial activities at the Missouri Metals facility began in 1957 and were conducted by Missouri Metals Shaping Company (MMSC). In 1979 the property and business were purchased from MMSC by Alco Standard Corporation – Aerospace Division. In 1988 the property and business were purchased by a subsidiary of what is now known as PerkinElmer. PerkinElmer sold the Missouri Metals business in 2001, but retained ownership of the property. The Missouri Metals facility continues to operate at 9970 Page Avenue in Overland, Missouri, near the center of Section 31, Township 46 North, Range 6 East in St. Louis County, Missouri. Structures on the property consist of two manufacturing buildings and two metal storage buildings. The Missouri Metals facility encompasses approximately 3.5 acres and is located in an area that is primarily commercial and/or industrial, with the aforementioned residential area located southeast of the facility. The Missouri Metals facility is illustrated in Figure 2-1.

Data obtained from past soil and groundwater investigations suggests that historical releases of solvents, primarily tetrachloroethene (PCE) and trichloroethene (TCE), into the soil and groundwater have occurred at the Site. These solvents were previously used at the Site but their use was eliminated subsequent to PerkinElmer purchasing the business.

2.2 Chemicals of Concern

As defined in the Order, the primary COCs at the Site are solvents previously used at the Site (PCE and TCE), and their daughter products [1,1-dichloroethylene (DCE), cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride (VC)].

2.3 Site-Specific Screening Levels

Site-specific screening levels related to potential vapor intrusion were calculated as part of the *Supplemental Investigation Work Plan* (SIWP) (Burns & McDonnell, 2012a). A discussion of the site-specific screening levels and the corresponding calculations is discussed in Section 5.1 of the SIWP (Burns & McDonnell, 2012a). The attenuation factors represent the recommended empirically-derived values from *U.S. EPA's Vapor Intrusion Database: Preliminary Evaluation of Attenuation Factors* (USEPA, 2008). The equations and variables used to calculate the screening levels related to potential vapor intrusion are provided on Table 2-1. In addition to the aforementioned site-specific screening levels, the Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs) are applicable groundwater screening levels and are included on Table 2-1.

2.4 Geology & Hydrogeology

The geology and hydrogeology of the Site is presented in Section 2.1 and Section 2.2, respectively, of the recently submitted *Conceptual Site Model (CSM) Update* (Burns & McDonnell, 2013a).

2.5 Investigation and Remediation Timeline

This section provides a summary of previous investigation and remedial activities performed at the Missouri Metals facility. Previous investigation locations within the Missouri Metals facility and the residential neighborhood are illustrated on Figure 2-1 and Figure 2-2, respectively. Monitoring and Injection Well completion details, historical groundwater monitoring well analytical results, and soil sampling analytical results collected at the Missouri Metals facility are presented on Tables 2-2, 2-3, and 2-4, respectively. Previous data collected in the residential area are summarized in the SIWP (Burns & McDonnell, 2012a).

2.5.1 Investigation Activities (Pre-Remedial Action)

The following is a summary of activities conducted through 2002, prior to initial remediation activities at the Site:

- From 1988 through 1992, various site assessments and site characterization activities were performed by OBG, GTI, and Burns & McDonnell. Pre -1992 reports are summarized in the *Remedial Action Report*, dated November 1992. (Burns & McDonnell, 1992b).

- In 1992, a *Remedial Investigation (RI) Report* was submitted to the Missouri Department of Natural Resources (MDNR) (Burns & McDonnell, 1992a).

- In 1992, a *Remedial Action Summary Report* (RASR) was submitted to MDNR (Burns & McDonnell, 1992b).

- From 1994 through 1998, a five-year period of groundwater monitoring was performed as dictated by the Consent Agreement with MDNR (MDNR, 1994).

- From 1998 through 2001, various investigations and evaluations were conducted in the residential neighborhood by MDNR and Burns & McDonnell. These included soil, groundwater, and in-home sampling.

- In 2001, a Health Consultation was conducted by Missouri Department of Health and Senior Services (MDHSS) following in-home sampling activities. MDHSS concluded that based on existing screening levels at that time the contaminant detections were not at levels expected to result in adverse health effects (MDNR and MDHSS, 2001).

- In 2001, a revised *Remedial Alternatives Evaluation* for the Site was prepared and submitted to MDNR (Burns & McDonnell, 2001b).

- In 2001, Burns & McDonnell performed a chemical oxidation treatability study and pilot test at the Site to evaluate the effectiveness of in-situ chemical oxidation (ISCO). The results were presented in the *Chemical Oxidation Treatability Study Report* (Burns & McDonnell, 2002b).

- In 2002, free-phase hydrocarbon (FPH) investigation activities were conducted and results were submitted to MDNR in a letter dated January 18, 2002. These investigation activities were conducted to determine the subsurface extent of FPH encountered down gradient of the hydraulic fluid containment pit located in the west building of the Missouri Metals Facility (see Figure 2-1) (Burns & McDonnell, 2002a).

- In 2002, a *Remedial Action Plan* (RAP) was prepared for the full-scale design and implementation of ISCO at the Site (Burns & McDonnell, 2002c). Results of the ISCO treatability study and pilot test were used to develop the full-scale design and implementation plan.

2.5.2 Summary of Remedial Activities

Burns & McDonnell implemented the full-scale ISCO RAP in 2003 and 2004. Implementation activities included subsurface permanganate distribution via injections wells, fractures, and an injection trench near the former degreasing pit. These activities are summarized below and are detailed in the RASR (Burns & McDonnell, 2005).

Burns & McDonnell conducted the following remediation activities in 2003:

- Groundwater sampling in March and November 2003;
- Monitoring well abandonment and installation;
- Injection well installation;
- Injection trench installation;
- Fracture emplacement and injection of potassium permanganate ($KMnO_4$);
- Oxidant mixing and injection;
- Weekly injection system operation and maintenance (O&M); and,
- FPH skimmer O&M.

Burns & McDonnell conducted the following remediation activities in 2004:

- Groundwater sampling in March, July, November, and December 2004;
- Fracture emplacement and injection of $KMnO_4$;
- Injection trench regeneration;
- Monthly injection system O&M;
- FPH skimmer O&M; and,
- Water injection activities.

Burns & McDonnell conducted the following remediation activities in 2005:

- Injection trench regeneration; and,
- Water injection in the former drum storage area to enhance advective movement of permanganate in this area.

Results of the RAP implementation were summarized in the RASR submitted to MDNR in March 2005 (Burns & McDonnell, 2005). The HHBRA was submitted to MDNR in January 2006 (Burns & McDonnell, 2006).

2.5.3 Recent Activities

The SIWP and corresponding QAPP were prepared for the collection of data used to re-assess potential health risk in the residential neighborhood based on reductions in health risk thresholds for the COCs. The original versions of these documents were submitted to MDNR in January 2010. The second revision of the SIWP and QAPP were conditionally approved by MDNR in April 2012. The Supplemental Investigation (SI) activities are focused in the residential neighborhood and have included the following activities through October 2013:

- In August and September 2011, Burns & McDonnell installed and sampled temporary shallow piezometers. Groundwater samples were also collected from existing groundwater monitoring wells. Temporary piezometers were abandoned following groundwater sampling activities.

- In May and August 2012, Burns & McDonnell performed in-home vapor intrusion sampling as select residential homes and apartment units; activities included installation and sampling of sub-slab monitoring points, sampling of indoor air, and sampling of sump air and water.

- In September 2012, vapor mitigation systems were installed at four residential homes and one apartment unit. Indoor air verification sampling of the vapor mitigation systems was completed in October 2012.

- In November and December 2012, Burns & McDonnell installed and sampled temporary soil gas monitoring points and shallow monitoring wells.

- In January, April, June, and August 2013, Burns & McDonnell performed in-home vapor intrusion sampling, including sub-slab and indoor air sampling, at selected residences within the residential neighborhood.

- In August 2013, an additional vapor mitigation system was installed in the residential neighborhood; Indoor air verification sampling of the vapor mitigation systems was completed in October 2013.

The recently submitted CSM Update provides an update of the site geology and hydrogeology based on information obtained during the Supplemental Investigation activities (Burns & McDonnell, 2013a). The

Supplemental Investigation, which began under MDNR direction in 2011, and continues today under USEPA direction, focuses on in-home sampling (sub-slab vapor and indoor air) within the residential neighborhood. Supplemental investigation data, including analytical results, are being communicated to the USEPA as activities progress.

3.0 SOURCE & PLUME INVESTIGATION APPROACH

Significant investigation activities have been completed at the Site, however, with the advance of technology, more sophisticated data related to geology and hydrogeology, as well as plume sources, characteristics and definition, can now be collected for this complex site. The use of these new investigative tools is expected to provide a much better understanding of the Site Conceptual Model meeting the objectives of the Source and Plume investigation as stated in the Order, and providing the data needed to assess potential remedial actions.

As described in Task III of the Order, and discussed in Section 1.0, the purpose of the Source and Plume investigation is to define the three-dimensional extent of the contaminant source(s) and groundwater contaminant plume for site-specific COCs in bedrock and overlying unconsolidated materials, including NAPLs. The Source and Plume investigation has been designed to provide the information required to update the HHBRA submitted in 2006 (Burns & McDonnell, 2006), and the data required to perform a RAE following completion of Source and Plume investigation. As discussed in Section 1.0, the work required to complete the Source and Plume investigation will occur in phases.

A phased investigation approach has been proposed that focuses the initial phase on the Missouri Metals facility and the adjacent property located east of the facility. This initial phase will be limited to the unconsolidated overburden and upper bedrock and will be completed prior to deeper bedrock investigation activities. As discussed in Section 1.0, this phased approach has two primary benefits: (1) provides data that can be used to optimize the bedrock investigation, and (2) provides information useful in designing a bedrock investigation that minimizes the risk of unintended contaminant and/or potential NAPL mobilization.

The following investigative techniques will be utilized during the initial phase of investigation:

- Geoprobe® Direct Image® Membrane Interface Probe (MIP) technology;
- Geoprobe® Direct Image® Low-Level MIP (LL MIP) technology;
- Geoprobe® Direct Image® Electrical Conductivity (EC) technology;
- Geoprobe® Direct Image® Hydraulic Profile Tooling (HPT) technology;
- Direct-push soil sampling;
- Installation and sampling of temporary groundwater piezometers via direct-push; and,
- Monitoring well groundwater sampling.

The approach for each of the aforementioned techniques is discussed in the following section and details regarding investigation methods, standards, and procedures are presented in Section 4.0. It should be noted that the investigation will be an iterative process subject to change based on results obtained during field activities. As stated above, site investigation activities will be completed in phases and the bedrock investigation design and planning will be developed using data collected during the overburden/upper bedrock investigation. This approach will allow for the review and selection of the most appropriate bedrock investigation technologies and protocols prior to field implementation. The time between investigation phases will be limited to the extent practicable.

3.1 High-Resolution Direct-Push Investigation

High-resolution direct-push investigation technologies will be implemented to further define the horizontal and vertical extent of the groundwater source(s) and plume located on the Missouri Metals facility; and also to locate additional permanent monitoring wells to adequately define and monitor the source(s) and plume. Direct-push investigation borings will be completed on a grid with 50-foot spacing as illustrated in Figure 3-1. The details regarding the specific technologies to be employed during the MIP investigation are provided in the following subsections.

3.1.1 Membrane Interface Probe Technology

MIP is a semi-quantitative field-screening technique for the real-time detection and measurement of volatile organic compounds (VOCs) in the subsurface. The direct-push MIP technology is an in-situ application that uses a modified direct-push probe tip threaded onto the end of a string of direct-push rods. The probe tip is equipped with a membrane permeable to VOCs. As described by Geoprobe®, “The MIP membrane is semi-permeable and comprised of a thin film polymer impregnated into a stainless steel screen for support”. As the probe tip is advanced at a constant rate down through the subsurface materials, the probe heats the surrounding soil to 80-125°C, causing VOCs present in the soil or groundwater to volatilize and pass through the membrane. The VOCs are subsequently conveyed to the surface through the probe rods by a carrier gas, such as nitrogen, where they are analyzed by three in-line detectors, each providing sensitivity to a particular type of contaminant. The three in-line detectors and their respective detection capabilities are as follows:

- Halogen Specific Detector (XSD) – targets halogenated compounds (chlorinated solvents);
- Photo-ionization Detector (PID) – aromatic compounds [Benzene, toluene, ethylbenzene, and xylene (BTEX)] and confirmation of chlorinated ethylene compounds detected by the XSD; and,

- Flame Ionization Detector (FID) – general detector useful for hydrocarbon detections and confirmation of high concentrations of all compounds observed on the PID and XSD.

Analytical detector results are transmitted real-time to a computer that displays the MIP data, plotted with depth, on a graphical log for easy interpretation. Detection limits for the MIP are in the 1 part per million (ppm) concentration range; however, actual detection limits depend on multiple factors (i.e. soil type, temperature, and detector type). The Geoprobe® standard operating procedures (SOP) for the MIP are provided in Appendix A.

The LL MIP probe increases the sensitivity of the detector by a factor of 10, allowing it to detect VOC concentrations lower than those detectable using a standard MIP. Detection limits for the LL MIP are in the 100 part per billion (ppb) concentration range; however, as with the standard MIP, actual detection levels are dependent on multiple factors.

The LL MIP operates similarly to the standard MIP; one exception is that the flow of carrier gas is temporarily interrupted to allow contaminants to pass through the membrane over a set period of time. Once carrier gas flow resumes, it conveys the “slug” of vapors to the surface for analysis. This operational method allows for a larger and narrower contaminant response peak at the detectors, resulting in the ability to detect much lower concentrations than the standard MIP. The Geoprobe® LL MIP Operation Guide is provided in Appendix A.

3.1.2 Electrical Conductivity Technology

EC profiling will be conducted simultaneously with MIP to provide lithological information used to supplement the VOC concentration profile provided by MIP. The EC technology will assist in identifying lithological seams or “stringers” of higher permeability material (e.g. sands and silts) that may constitute preferential migration pathways within the silty clay overburden and upper bedrock. The EC results, in combination with HPT results, will be analyzed to further characterize the horizontal and vertical distribution of permeability across the Site.

EC data will be recorded simultaneously with the MIP data as the probe is advanced into the subsurface. EC technology is based on the principle that different soil types conduct electricity differently depending on particle size and mineralogy (i.e. clays, sands, and gravels). In general, finer grained material produces greater EC signals than coarser grained materials. EC readings are recorded by applying a low-level alternating current voltage across two separated contact points on the probe. As the probe is pushed into the subsurface, current return readings are continuously recorded. The conductivity readings, measured in milli-Siemens per meter (mS/m), show the relative change in subsurface material conductivity with depth. EC logging will provide an assessment of subsurface stratigraphy in the unconsolidated material where more permeable zones or preferential pathway may be present. Continuous soil sampling will be performed at MIP groundwater confirmation locations for visual verification of the EC results. The Geoprobe® EC SOP is provided in Appendix A.

3.1.3 Hydraulic Profiling Tool Technology

HPT technology will provide a vertical profile of the formation permeability with depth at each MIP sampling location. The HPT results, in combination with the EC results, will be analyzed to further characterize the horizontal and vertical distribution of permeability across the Site.

HPT data will be recorded simultaneously with the MIP and EC data as the probe is advanced through the subsurface. The HPT instrument, installed on the direct-push probe tip, measures the pressure required to inject a flow of water into the subsurface at discrete depths to estimate formation permeability. As the probe tip advances down through the subsurface, a flow of water is injected into the soil through a screen on the side of the probe and the pressure required to maintain flow measured by an in-line sensor. In general, more permeable layers require less injection pressure than less permeable layers. The HPT tool provides a log of injection pressure with depth that can be used in combination with EC to identify zones of higher permeability or preferential flow.

A pressure dissipation test, used to determine the static hydrostatic pressure and time to reach equilibrium at a specific depth, is a measurement of pore pressure dissipation as it approaches static equilibrium versus time. At a selected depth, the probe is stopped and the water flow is turned off. Simultaneously, a time log is started to record dissipation of the HPT pressure. The stabilized pressure is the absolute hydrostatic pressure at that depth. A minimum of one pressure dissipation test per location will be performed within the saturated zone. The depth of the dissipation test will be determined based on the real-time HPT log targeting areas of higher permeability. In general, higher permeability formations will require less time to complete the dissipation tests and provide better representative data for estimated hydraulic conductivity values and a static water level prediction. If dissipation tests are conducted in lower permeability zones, it may be necessary to end the test prior to reaching complete equilibrium due to time constraints. The Geoprobe® HPT SOP is provided in Appendix A.

3.1.4 MIP Investigation Approach

As discussed in Section 3.1.1, the MIP and LL MIP technologies indicate the presence of elevated VOC concentrations, including those potentially attributed to NAPL, by measuring “responses” generated by the MIP detectors incorporated into the direct-push probe tips. This MIP response data will be used to identify high concentration source or plume seams or “stringers” within the overburden and upper bedrock as well as overall plume extent. In addition, the MIP investigation will be used to determine the appropriate locations for new permanent monitoring wells to fully delineate the source areas and associated plume(s).

Direct-push borings will continue through the unconsolidated material until refusal is encountered. Based on previous direct-push investigations at the facility, refusal is anticipated to occur within the upper bedrock unit at approximately 25 feet below ground surface (bgs). MIP, EC, and HPT technologies will be employed concurrently at each location using 1.5-inch direct-push rods and a specialized probe tip.

MIP or LL MIP will employed at each of the grid locations presented on Figure 3-1. Some locations have been offset from the grid nodes based on known locations of utilities and obstructions. In addition, a few locations have been added in areas of particular interest (i.e. the vicinity of the former degreaser). Physical accessibility of the proposed grid locations has been field verified; however, facility activities, unknown subsurface obstructions, and/or drilling difficulties may result in adjustment of one or more grid locations. All efforts will be made to complete the investigation locations proposed in the grid layout presented on Figure 3-1.

LL MIP will be used at all grid locations exhibiting non-detectable standard MIP responses, and at locations where historical data indicates COC levels within the detectable range of the LL MIP. At locations exhibiting a non-detectable response using standard MIP, a separate borehole, offset a few feet from the standard MIP borehole, will be required for LL MIP screening.

The margins of the shallow groundwater plume exhibiting concentrations lower than the detection limit of the LL MIP will be delineated using data provided by discrete groundwater sampling. Discrete groundwater samples will be collected from temporary piezometers, installed at an offset location, to confirm the presence or absence of low-level site-specific COC concentrations. It is important to note that discrete samples cannot be collected from MIP or LL MIP boreholes; separate boreholes offset a few feet from the original borehole must be completed for collection of the discrete groundwater samples.

EC profiling will be conducted to provide lithological information used to supplement the VOC concentration profile provided by MIP. The HPT results, in combination with the EC results, will be analyzed to further characterize the horizontal and vertical distribution of permeability across the Site.

The MIP investigation will progress as follows:

- Initial MIP locations will be completed along the known groundwater plume flow path (excluding the known source area), working outward (e.g. in cross-gradient [east/west] directions) on the 50-foot grid until MIP results indicate a non-detectable response or where historical data indicates COC levels within the detectable range of the LL MIP;
- Once the grid locations at the edges of the plume, with COC levels detectable by standard MIP, have been completed, the grid locations surrounding the known source area (i.e. former degreaser source area) will be completed;
- The LL MIP will then be employed at locations where the standard MIP results indicate a non-detectable response or where historical data indicates COC levels are within the range of the LL MIP; and,
- Additional LL MIP locations will be completed between non-impacted and impacted locations, as identified by MIP response results, to further define the limits of impact as necessary.

In order to minimize vertical mixing or migration of contaminants within the overburden and upper bedrock, MIP borings will be properly abandoned immediately following removal of the direct-push tooling. Direct-push and MIP services will be provided by a qualified direct-push contractor in accordance with procedures outlined in the Geoprobe® SOPs provided in Appendix A.

MIP, LL MIP, EC and HPT logs will be generated in the field real-time, allowing for timely field decisions as the investigation progresses. If additional horizontal definition of high concentration zones located on the Missouri Metals facility are deemed necessary, then additional probe locations will be added as permitted by physical accessibility. Likewise, the proposed grid will be extended as needed if contaminants are detected on the edges of the planned grid to fully define the impacted areas. Additional grid locations required within the Missouri Metals facility will be completed during the initial mobilization; however, due to property access limitations, additional off-site locations east and south of the Missouri Metals facility will be completed during a subsequent mobilization. Access agreement notifications and approvals, and/or permit approvals will be required prior to conducting work on the off-site properties. The subsequent mobilization will happen as soon as practical, likely within one month of completing the investigation work included during the initial mobilization.

In order to define the low-level margins of the shallow groundwater plume, discrete shallow groundwater samples will be collected at all LL MIP locations indicating a non-detectable response to confirm the presence or absence of low-level site-specific COC concentrations. Confirmation sampling will also be conducted at a subset of the LL MIP and standard MIP locations where detectable COC concentrations are identified. The discrete groundwater samples will be collected from temporary piezometers installed using direct-push methodology (see Section 3.1.5). As previously noted, discrete samples cannot be collected from MIP or LL MIP boreholes; separate boreholes offset a few feet from the original borehole must be completed for the collection of discrete groundwater samples.

During subsequent phases of overburden and upper bedrock investigation in the residential neighborhood, MIP will be conducted at locations selected based on an evaluation of COC concentration data provided by the initial investigation phase. Groundwater investigation in areas of low-level COC impact, below the detection range of the LL MIP technology, will consist of discrete groundwater sample collection from temporary piezometers installed within the overburden.

3.1.5 Discrete Groundwater Sampling

MIP confirmation groundwater sampling will be performed at a minimum of 10 percent of the MIP profiling locations to semi-quantitatively verify findings of the MIP investigation. Confirmation samples will be collected from temporary piezometers installed in borings offset a few feet from the corresponding MIP borehole. The confirmation sample locations will be strategically chosen based on results of the MIP investigation, access constraints and utility locations, and specific locations of interest (e.g. the former degreaser source area). The MIP confirmation samples will be collected from locations of varying MIP detector response results (low, medium, high, and non-detect) to obtain a confirmation data set that provides an adequate range of concentrations. The actual number of confirmation sample locations will be determined based on a review of the MIP investigation results.

Discrete groundwater sampling will also be performed at all LL MIP locations indicating a non-detectable response to confirm the presence or absence of low-level site-specific COC concentrations. The actual number of discrete groundwater sample locations will be determined based on a review of the MIP investigation results.

Temporary piezometers will be installed for the collection of discrete groundwater samples using standard direct-push equipment. Direct-push soil borings will be completed for piezometer installation, following the procedures discussed in Section 3.3.1 of the QAPP (Burns & McDonnell, 2013b), at an offset location from the corresponding MIP/LL MIP borehole. During boring installation at select locations, continuous soil cores will be collected and boring logs including lithology and contaminant impact observations will be prepared as discussed in Section 3.3.9 of the QAPP (Burns & McDonnell, 2013b) to confirm EC results. If collected, soil cores will be screened for non-specific VOCs using a PID.

Temporary piezometers will be installed in accordance with the procedures presented in Section 3.3.3 of the QAPP (Burns & McDonnell, 2013b). Piezometer screen lengths will range from two to five feet and completion/sampling depths will be determined based on the targeted confirmation depth identified during the MIP investigation.

Discrete groundwater samples will be collected from the piezometers once sufficient time (minimum of 24 hours) has been allowed for water level stabilization. Based on previous investigation activities, a water level stabilization period of greater than 24 hours may be required for temporary piezometers installed within the silty clay overburden. Stabilization will be determined by comparing groundwater elevations measured in the piezometers with those observed in nearby temporary piezometers and/or shallow monitoring wells. Discrete groundwater samples will be collected for laboratory analysis of COCs in accordance with procedures discussed in Section 3.3.4 of the QAPP (Burns & McDonnell, 2013b). Expedited laboratory analysis may be requested to facilitate the comparison of confirmation sample results with MIP results as the investigation progresses. Groundwater analytical methods and procedures are discussed in Section 4.4.

3.2 Direct-Push Soil Sampling

Direct-push soil sampling will be performed as part of the MIP investigation activities. Discrete soil sampling will be conducted at select boring locations in conjunction with MIP groundwater confirmation sampling (see Section 3.1.5). Both vadose zone and saturated zone samples will be collected as detailed below. The soil analytical parameters for these samples are detailed on Table 3-1.

3.2.1 Vadose Zone Soil Sampling

Discrete soil sampling will be conducted adjacent to the four MIP investigation locations surrounding the former degreaser within the Metal Fabrication Building at the Missouri Metals facility (see Figure 3-1). The following soil samples will be collected for laboratory analysis of site-specific COCs:

- One surface soil sample will be collected at each location from zero to two feet below the bottom of the building foundation; and,
- One subsurface soil sampling will be collected in the unsaturated (vadose) zone at each location from the depth of greatest impact as indicated by the highest measured PID response (i.e. PID readings). Based on a minimum soil volume of approximately two to three ounces required for

laboratory analysis for site-specific COCs, soil will be collected from the 0.25 to 0.5 foot interval (approximate) centered on the highest PID reading.

These soil samples will be collected for the purpose of further defining the concentration and horizontal and vertical extent of the source area in the vicinity of the former degreaser within the Metals Fabrication Building. In addition, the soil analytical results will be used to update the HHBRA following completion of all Source and Plume investigation activities. Soil analytical methods and procedures are discussed in Section 4.4.

3.2.2 Saturated Zone Soil Sampling

Discrete soil sampling will be conducted within the saturated zone at select locations along the main flow path of the groundwater plume to assess and characterize current subsurface conditions within the soil matrix of the plume relating to COC degradation extent and processes. Data provided by these analyses will be used in assessing potential remedial alternatives during the future RAE to be performed following completion of the Source and Plume investigation activities, per Task V of the Order – "Remedial Alternatives Evaluation".

Several technical references, including those listed below, were consulted in selecting the proposed saturated soil analyses.

- *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvent, Air Force Center for Engineering and Environment (AFCEE),* August 2004 (AFCEE, 2004); and,
- *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, Office of Research and Development, EPA/600/R-98-128,* September 1998, (USEPA, 1998).

Direct-push borings required for soil sample collection in the saturated zone will be completed in conjunction with MIP groundwater confirmation sampling. Soil samples collected from the saturated zone will submitted for laboratory analysis of COCs in soil and the following soil degradation parameters:

- Bioavailable iron;
- Bioavailable manganese;
- Acid volatile sulfide (AVS); and,
- Total organic carbon (TOC).

Due to the volume of soil required for the analyses listed above, multiple direct-push soil borings may be required at each saturated soil sample location. A summary of data interpretation and relevance for soil degradation parameters is provided in Table 3-1, and soil analytical methods and procedures are discussed in Section 4.4.

3.3 Groundwater Monitoring Well Sampling

Following completion of the MIP investigation, groundwater sampling will be performed at select groundwater monitoring wells to provide additional plume delineation and degradation data. Groundwater samples will be collected for laboratory analysis of COCs from Monitoring Wells GMW-3 through GMW-11, GMW-14, GMW-15, GWM-16, and GMW-17. Monitoring well locations are illustrated on Figure 3-1.

Prior to groundwater sample collection, water level measurements will be recorded in each monitoring well using an electronic water level indicator. Water levels will be measured to the top of the well casing to the nearest 0.01 foot. Monitoring wells will be purged and sampled in accordance with the low-flow sampling techniques discussed in Section 3.3.6.4 of the QAPP (Burns & McDonnell, 2013b). During purging, stabilization parameters (pH, temperature, conductivity, dissolved oxygen [DO], and oxidation-reduction potential [ORP]) will be measured and recorded. In addition to COCs, groundwater samples collected from select monitoring wells will be analyzed for degradation parameters to assess and characterize plume degradation and to define potentially viable remediation alternatives, as necessary. Additional information regarding groundwater degradation parameters is presented in the following subsections and details regarding groundwater analytical methods and procedures are discussed in Section 4.4.

During subsequent phases of field investigation, new permanent monitoring wells will be installed within the overburden and deeper bedrock to facilitate delineation of source areas and the associated plume(s). Locations of new permanent monitoring wells will be determined based on an evaluation of MIP overburden investigation results, laboratory analytical results for discrete groundwater samples, and other existing site data. The time lapse between initial and subsequent phases of investigation will be minimized.

3.3.1 Groundwater Degradation Parameters

Groundwater degradation parameters will be analyzed for samples collected from select monitoring wells along the plume flow path to assess and characterize current plume degradation extent and processes. While the data provided by these sample results could be used in the future to evaluate monitored natural attenuation (MNA) as a remedial alternative, the purpose of the currently proposed degradation parameter sampling and analysis is to establish a baseline and assess current site conditions. Per Task V of the

Order – “Remedial Alternatives Evaluation”, remedial alternatives, including MNA and other “active” alternatives, may be considered following completion of the Source and Plume investigation activities. Consequently, collection of this degradation parameter data during the Source and Plume investigation activities will assist in expediting completion of the RAE.

Several technical references, including those listed below, were consulted in selecting the proposed groundwater degradation parameters.

- *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvent, AFCEE, August 2004* (AFCEE, 2004);
- *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, Office of Research and Development, EPA/600/R-98-128, September 1998,* (USEPA, 1998); and,
- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, OSWER Directive 9200.4-17P, April 21, 1999* (USEPA, 1999).

Groundwater samples will be collected from Monitoring Wells GMW-5 through GMW-11, GMW-14 and GMW-15 for laboratory analysis of the following groundwater degradation parameters:

- Dissolved metals (aluminum, arsenic, barium, calcium, chromium, cadmium, lead, magnesium, manganese, nickel, potassium, sodium, and vanadium);
- Dissolved metals – Ferrous Iron [Fe(II)] ;
- Dissolved organic carbon (DOC);
- Dissolved gases (methane, ethane, and ethene);
- Anions (nitrate, nitrite, sulfate, sulfide, and chloride);
- Total alkalinity;
- Dissolved molecular hydrogen (H_2); and,
- Dissolved ammonium.

In addition to the laboratory degradation parameters listed above, field-measured stabilization parameters measured during low-flow groundwater purging will be used to assess aquifer characteristics and contaminant degradation. A summary of the data interpretation and relevance for groundwater degradation parameters is provided in Table 3-2.

Compound Specific Isotope Analysis

Compound specific isotope analysis (CSIA) will be conducted on groundwater samples collected from a sub-set of the aforementioned monitoring wells selected for degradation parameter sampling and analysis. CSIA measures the ratios of naturally occurring stable isotopes in targeted compounds included in a given groundwater sample. Groundwater samples will be collected for laboratory CSIA analysis from Monitoring Wells GMW-6R through GMW-8, GMW-10, and GMW-11. In addition, one groundwater sample will be collected from a temporary piezometer installed within the source area (former degreaser) located in the Metals Fabrication Building. CSIA results for this sample will be used to determine source area contaminant isotope ratios necessary for completion of the CSIA evaluation. A summary of the data interpretation and relevance for groundwater degradation parameters is provided in Table 3-2.

Microbial Analysis

Based on an evaluation of data collected during the initial phase investigation, future phases of Source and Plume investigation may include microbial analyses. The potential laboratory analyses include the following:

- 16S rRNA Assay;
- vcrA Gene Assay; and,
- bvcA Gene Assay.

If necessary, these microbial analyses will be used to determine if the requisite organisms (e.g. *dehalococcoides*) for biological COC degradation are present and functional. This information will also be used in preparing the forthcoming RAE (Task V of the Order). These potential laboratory analyses are detailed in SOPs provided in Appendix C of the QAPP (Burns & McDonnell, 2013). A summary of the data interpretation and relevance for groundwater degradation parameters is provided in Table 3-2.

3.4 Bedrock Groundwater Investigation

Following completion of the initial phase of the Source and Plume Investigation, the deeper portion of the bedrock unit will be investigated to further delineate the vertical and horizontal extent of impacts at the Site. As with the permanent overburden monitoring wells, bedrock investigation locations will be proposed in a SAP addendum to be prepared and submitted to USEPA for review following an evaluation of the overburden/shallow bedrock investigation data. Temporal differences between overburden/shallow bedrock and deeper bedrock investigation data will be addressed by minimizing the time lapse between the phases of investigation. Also, existing site groundwater data collected over a significantly long period of time indicates relatively stable concentrations within the overburden and deeper bedrock units, thus minimizing the concern for shorter-term temporal effects within the data set.

Initial bedrock investigation (i.e. boring) locations will be within the Missouri Metals Facility and will be chosen based on the results of the initial overburden/upper bedrock investigation. Investigation activities will include bedrock coring, logging, and screening (using a PID), and multi-level discrete groundwater sampling. Details regarding the specific technologies to be employed during the bedrock investigation are provided in the following subsections.

3.4.1 Bedrock Drilling and Sampling

Contaminant source areas that may extend into bedrock, such as the degreaser source area present at the Site, are sensitive in nature, particularly as it relates to NAPL stability and migration potential. For this reason, specific bedrock drilling and sampling methods that minimize the potential for mobilizing NAPL, if present, were selected for the Site. However, based on overburden/shallow bedrock investigation results, the specific bedrock investigation methodologies presented in this SAP may be modified. Such modifications would be proposed for USEPA approval in the aforementioned SAP addendum. It is also important to note that access for deeper drilling in the main source area (former degreaser area) is restricted; larger drilling equipment needed to drill deeper into the bedrock cannot access the former degreaser location.

Roto-sonic is the presumptive methodology for bedrock drilling at the Site. Prior to bedrock drilling, a permanent surface casing will be installed through the unconsolidated overburden to maintain the integrity of the borehole and isolate the bedrock zone from groundwater within the overburden and shallow bedrock while drilling into underlying bedrock. The surface casing will be set into competent bedrock and cemented into place. Following completion of the surface casing, sonic drilling will be used to advance a continuous casing into the bedrock formation, thereby creating a borehole of a specific diameter and depth, while also providing continuous core samples of the formation material. The continuous casing advancement will minimize vertical contaminant migration or mixing within the borehole during drilling. Boreholes will be drilled in accordance with the roto-sonic drilling procedures presented in Section 3.3.2.3 of the QAPP (Burns & McDonnell, 2013b).

Continuous core samples retrieved from the borehole during drilling will be utilized for stratigraphic logging of the bedrock and inspection for zones of high permeability and/or COC-impact. The roto-sonic core barrel sampler provides continuous and relatively undisturbed samples of subsurface materials collected in clear plastic sleeves. The plastic sleeves minimize VOC losses and facilitate field screening for total VOCs using a PID. Borehole logs including lithology, contaminant impact observations, and PID readings will be prepared by a Burns & McDonnell geologist using the continuous core samples. Boring logs will be prepared in accordance with the procedures detailed in Section 3.3.9 of the QAPP (Burns & McDonnell, 2013b). In order to minimize potential NAPL destabilization and/or vertical COC migration, the time between bedrock borehole completion and installation of a properly constructed (sealed) monitoring well will be minimized to the extent practicable.

The total required depth for bedrock investigation borings and monitoring wells is anticipated to be less than 100 bgs. The bedrock unit targeted for site investigation activities is composed of Pennsylvanian-age shale and limestone of relatively low transmissivity. A generalized stratigraphic column for the St. Louis area is provided in *Water Resources St. Louis Area Missouri, Water Resources Report No. 30, MDNR* (Miller, 1974). As discussed in Section 2.1 of the CSM Update (Burns & McDonnell, 2013a), at the Site, the bedrock unit consists of siltstone, with shale, limestone, and sandstone layers intermixed. This unit is underlain by a shallow, Upper Mississippian aquifer formation that is anticipated to be encountered at approximately 100 feet bgs.

3.4.2 Multi-Level Groundwater Sampling

Following completion of each bedrock boring, a multi-level groundwater monitoring system will be installed to vertically define the extent of groundwater impacts in the bedrock unit. The multi-level monitoring technology selected for this application is the Solinst™ Continuous Multichannel Tubing (CMT) system. The CMT system allows for discrete sampling and long-term monitoring of up to seven vertical intervals per borehole location. These vertical sampling intervals can be determined in the field immediately prior to CMT well installation. For the purposes of this bedrock characterization, CMT sample intervals will be determined based on soil core screening data and visual observations performed during borehole completion. The selected sample intervals will target zones of higher bedrock permeability or elevated COC concentration. Each multi-level sampling location will be completed in accordance with Missouri Well Construction Rules, ensuring that the seals between discrete sampling intervals are constructed to prevent vertical cross-contamination or unwanted contaminant migration within the borehole. The Solinst™ CMT system is detailed in Section 3.3.5 of the QAPP (Burns & McDonnell, 2013b).

Low-flow groundwater sampling at each multi-level sampling interval will be performed using a micro double-valve pump and Teflon® tubing in accordance with the procedures presented in Section 3.3.5.2 of the QAPP (Burns & McDonnell, 2013b). The micro double-valve pump will be operated by compressed air driven by an electronic pump control unit. Groundwater analytical methods and procedures are discussed in Section 4.4.

4.0 FIELD SAMPLING AND ANALYSIS PLAN

This section details the Source and Plume investigation field sampling and analysis plan. The investigation approach is detailed in Section 3.0. Detailed information regarding sample collection procedures/methods, decontamination, and handling of investigation derived waste (IDW) is included in this section. All data collected during field activities will be recorded in the field logbook or on designated field forms. All field activities will be performed by properly trained personnel.

A site-wide QAPP, dated August 2013, has been completed for the Site and is being submitted concurrently with this Source and Plume SAP. The purpose of the QAPP is to establish the policies, organization, objectives, functional activities, and specific quality assurance (QA) and quality control (QC) activities for sampling to be performed at the Site. In addition, the QAPP includes procedures for all standard investigation activities, including but not limited to, direct-push soil sampling, temporary piezometer installation, soil and groundwater sampling, and analytical methods and procedures.

4.1 Site Health and Safety Plan

An updated site Health and Safety Plan (HASP) has been prepared in accordance with all applicable OSHA regulations 1910 and 1926 and covers all work activities to be performed. The site HASP is provided in Appendix A of the QAPP (Burns & McDonnell, 2013b). The initial HASP was completed in February 2010 for the SI activities and was updated in September 2013 in concurrence with production of the QAPP. Burns & McDonnell HASP Amendment forms are located following the title page for documentation. A copy of the HASP will be kept on site during the supplemental investigation activities. Health and safety tailgate meetings will be conducted daily by the Site Health and Safety Supervisor.

4.2 Off-Site Access and Permitting

PerkinElmer will obtain an access agreement with the adjacent property owner (Verizon Wireless) located to the east of the Missouri Metals facility prior to performing field activities.

Future phases of the Source and Plume investigation activities may require additional access and permitting within the Chicago Heights neighborhood. PerkinElmer has executed a short-term access agreement with the Housing authority of St. Louis County (HASLC) for access to rental properties for completion of investigation activities. In addition, access to private property will be obtained as needed based on investigation plans.

In the event access is required within the right-of-way along the streets, a special use permit for access to right-of-way locations will be submitted to the St. Louis County Department of Highways and Traffic as needed. A copy of the special use permit application form is provided in Appendix B.

4.3 Utility Clearance

Prior to any field work involving intrusive subsurface activities, utility clearance will be required. Burns & McDonnell personnel will locate utilities with the aid of Missouri One-Call (1-800-DIG-RITE). A 48-hour notification is required for Missouri One-Call prior to commencing intrusive activities. In addition, a private utility locating company will clear locations to be completed within the buildings of the Missouri Metals facility. Due to the presence of underground or overhead utilities, it may be necessary to offset proposed boring locations. Any modification to proposed boring locations will be done with approval of the Burns & McDonnell Project Manager.

4.4 Laboratory Analytical Methods and Procedures

Soil and groundwater samples will be submitted for laboratory analysis in accordance with the field sampling approach specified in Sections 3.1 through 3.3 of this SAP. Analytical laboratories that may be used during the Source and Plume investigation are identified in Section 2.1.5 of the QAPP (Burns & McDonnell, 2013b). A complete list of the soil laboratory analytical parameters is presented in Table 3-1. A complete list of groundwater field and laboratory analytical parameters is presented in Table 3-2.

All laboratory samples will be packaged and shipped within all applicable holding time following collection. The laboratory completing specific analyses, analytical methods, sampling containers, and preservation requirements for soil and groundwater are presented on Table 2-1 and Table 2-2 of the QAPP (Burns & McDonnell, 2013b), respectively. Details regarding chain-of-custody records and custody seals, packaging and shipping are also provided in Section 3.5 of the QAPP (Burns & McDonnell, 2013b). Analytical methods, procedures, and QC requirements are specified in Section 3.6 and 3.7 of the QAPP (Burns & McDonnell, 2013b). Detailed information regarding the laboratory methods are provided in Appendix B and C of the QAPP (Burn & McDonnell, 2013b).

4.4.1 Laboratory Groundwater Analyses

Groundwater samples will be sent for laboratory analysis of site-specific COCs and selected groundwater degradation parameters as detailed in Section 3.1.5 and 3.3 of this SAP. Groundwater samples submitted for laboratory analysis of site-specific COCs will be analyzed using USEPA SW-846 Method 8260. Samples collected for groundwater degradation analytical parameters, as identified on Table 3-2, include the following:

- Dissolved metals (aluminum, arsenic, barium, calcium, chromium, cadmium, lead, magnesium, manganese, nickel, potassium, sodium, and vanadium);
- Dissolved metals – Ferrous Iron [Fe(II)] ;
- DOC
- Dissolved gases (methane, ethane, and ethene)
- Selected anions (nitrate, nitrite, sulfate, sulfide, and chloride)
- Total Alkalinity
- Dissolved molecular hydrogen (H_2)
- Dissolved Ammonium
- CSIA

Samples collected for dissolved metals (excluding ferrous iron), dissolved ammonium and DOC analysis will require field-filtering during collection. Filtering will be performed in accordance with the instructions provided in Section 3.6.1 of the QAPP (Burn & McDonnell, 2013b). In addition, due to the specialized nature of the H_2 groundwater analyses, samples will be collected following a bubble strip method in accordance with Microseeps SOP-SM 9, which is included in Section 3.6.1 of the QAPP (Burn & McDonnell, 2013b).

4.4.2 Laboratory Soil Analysis

Soil samples will be sent for laboratory analysis of site-specific COCs and selected soil degradation parameters as detailed in Section 3.2 of this SAP. Soil samples submitted for laboratory analysis of site-specific COCs will be analyzed using USEPA SW-846 Method 5035/8260. Samples collected for soil degradation analytical parameters, as identified on Table 3-1, include the following:

- Bioavailable iron;
- Bioavailable manganese;
- AVS; and,
- TOC.

Due to the specialized nature of AVS, bioavailable manganese, and bioavailable iron analytical methods, samples will be collected in accordance with Microseeps SOPs discussed in Section 3.6.1 of the QAPP (Burn & McDonnell, 2013b).

4.5 Data Validation

Burns & McDonnell will conduct data validation after receipt of the analytical data package. The quality of the laboratory results will be assessed through evaluation of the results of the submitted QA/QC and the laboratory internal QA/QC samples. Data will be evaluated for analytical precision, analytical accuracy, representativeness, completeness, and comparability. Validation measures are further discussed in Section 5.0 of the QAPP (Burns & McDonnell, 2013b).

4.6 Instrument Calibration and Frequency

Field sampling equipment will be calibrated using known standards supplied by the manufacturer or other reputable vendor. At a minimum, instruments will be calibrated at the beginning of each day, and calibration checks will be performed any time readings appear abnormal. Additionally, calibration checks will be recorded in the field logbook. Further detail on instrument calibration and frequency is discussed in Section 3.9 in the QAPP (Burns & McDonnell, 2013b).

4.7 Decontamination Procedures

All sampling and investigative equipment will be decontaminated prior to beginning investigation activities, between borings, and upon completion of investigation activities. Non-disposable and other non-dedicated equipment which contact the sample will be decontaminated prior to the collection of each sample. This equipment includes, but is not limited to, sampling knives and spoons, direct-push shoes, and containers. Down-hole sampling tools such as drill string, augers, and direct-push rods, as well drill rigs and direct-push trucks/van, will be decontaminated between each borehole. Decontamination procedures are provided in Section 3.3.11 of the QAPP (Burns & McDonnell, 2013b).

4.8 Field Activity Documentation

Each sample, field measurement, and field activity will be properly documented to facilitate timely, correct, and complete analyses, and support actions concerning investigation activities. Details regarding field documentation are discussed in Section 3.4 of the QAPP (Burns & McDonnell, 2013b). Investigation locations will be surveyed following procedures are provided in Section 3.3.13 of the QAPP (Burns & McDonnell, 2013b).

<u>Sample Documentation</u>

All samples and investigation locations will be identified with a unique sample number. Sample numbers will be used on all sample labels, chain-of-custody, field logbooks, and all other applicable documentation. The sample numbering system will be comprised of the sample point, QA/QC designator, if appropriate, and sample depth (if applicable). The general format will be "sample point QA/QC designator(s)/sample depth."

The sample point will be based on the activity being conducted as follows:

- **MIP Investigation Location** – MP followed by a two digit identifying number
- **LL MIP Investigation Location** – LMP followed by a two digit identifying number
- **MIP Confirmation Boring Location** – MPC followed by a two digit identifying number
- **Discrete Groundwater Monitoring Point Samples** – DW followed by a two digit identifying number
- **Soil Boring Samples –** SB followed by a two digit identifying number
- **Monitoring Well Groundwater Samples** – Monitoring well number

The sample designator will be followed by a QA/QC designator for all QA/QC samples including field duplicates, Matrix Spike (MS)/Matrix Spike Duplicate (MSD), and equipment rinsate blanks. The following suffixes will be used:

Abbreviation	**QA/QC Sample Type**
FD	Field Duplicate
MS	Matrix Spike
MSD	Matrix Spike Duplicate

Additional details regarding sample documentation is discussed in Section 3.5 of the QAPP (Burns & McDonnell, 2013b).

4.9 Borehole Abandonment

Temporary groundwater monitoring points will be abandoned within 30 days of installation. Boreholes will be abandoned according to the Missouri Well Construction Rules. In order to minimize vertical mixing or migration of contaminants within the overburden and upper bedrock, MIP and discrete sampling borings will be properly abandoned immediately following removal of the direct-push tooling. Ground surface will be restored to match the surrounding conditions. Abandonment registration records for all sampling locations that exceed 10 feet in depth will be submitted as required by the Missouri Well Construction Rules. Abandonment activities will be completed as discussed in Section 3.3.8 of the QAPP (Burns & McDonnell, 2013b).

4.10 Investigative Derived Waste

Solid and liquid IDW created during investigation activities will be containerized, labeled, and stored on the Missouri Metals facility pending proper disposal by PerkinElmer. Liquid IDW may consist of fluids generated during monitoring well purging and sampling or decontamination activities. Soil IDW consists of soil cuttings generated during subsurface investigations. In addition, IDW consisting of used personal protective equipment (PPE), disposable equipment (acetate liners, tubing, etc.), concrete dust, and other trash will be rendered non-hazardous through the removal of gross contamination and disposed of as a municipal waste in accordance with applicable regulations. Further details regarding IDW are presented in Section 3.3.12 of the QAPP (Burns & McDonnell, 2013b).

5.0 SCHEDULE, DATA ANALYSIS, AND PATH FORWARD

The first phase of field work is anticipated to begin in early January 2014; contingent upon EPA approval of the SAP and QAPP by December 1, 2013. Future phases of work will be added to the schedule and the time lapse between the overburden and bedrock investigation phases will be minimized.

A SAP addendum, including installation details for proposed monitoring wells and deeper bedrock borings, will be prepared and submitted to USEPA for review following an evaluation of data provided by the initial phase of investigation. Discussions with USEPA regarding the overburden/upper bedrock investigation results, including any contaminant concentrations approaching one percent of solubility, will be conducted prior to determining the scope and sequencing of future overburden/upper bedrock investigation phases, the deeper bedrock investigation, and new permanent monitoring well installations.

Following each phase of field activities, Burns & McDonnell will validate, tabulate and evaluate investigation results. Investigation results will be communicated to USEPA via email within 30 days after data validation is complete.

Burns & McDonnell and USEPA will periodically meet to collaboratively review investigation results and discuss the next course of action. If additional investigation activities are required to complete the Source and Plume investigation per the Order, the scope of such activities will be agreed upon and then documented as a SAP addendum in memorandums or letters prior to implementation. If the procedures for implementing the agreed upon activities are not adequately defined in the SAP or QAPP, addenda to these documents will be prepared and submitted to USEPA for approval prior to implementing the activities.

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TABLES

TABLE 2-1
Site-Specific Screening Levels
Chicago Heights Site
Overland, Missouri

Equations:

$C_{SS} = C_{IA} / AF_{SS}$

$C_{SG} = C_{IA} / AF_{SG}$

$C_{Gw} = C_{IA} / (AF_{Gw} \times H \times 1{,}000L/m^3)$

Where:

C_{SS} = Calculated screening level in sub-slab soil gas (µg/m^3)
C_{SG} = Calculated screening level in soil gas (µg/m^3)
C_{Gw} = Calculated screening level in groundwater (µg/L)
C_{IA} = Published screening level in indoor air (µg/m^3)
AF_{SS} = Sub-slab soil gas to indoor air attenuation factor (unitless)
AF_{SG} = Soil gas to indoor air attenuation factor (unitless)
AF_{Gw} = Groundwater to indoor air attenuation factor (unitless)
H = Henry's Law Constant (unitless)

Variable Values:

C_{SS} = Calculated
C_{SG} = Calculated
C_{GW} = Calculated
C_{IA} = Chemical-specific (USEPA, 2013)[1]
AF_{SS} = 1.00E-01 Empirically-derived value (USEPA, 2008)[2]
AF_{SG} = 1.00E-02 Empirically-derived value (USEPA, 2008)[2]
AF_{Gw} = 1.00E-03 Empirically-derived value (USEPA, 2008)[2]
H = Chemical-specific (USEPA, 2013)[1]

Chemical	**C_{IA}[3] (µg/m^3)**	**C_{SS} (µg/m^3)**	**C_{SG} (µg/m^3)**	**H (unitless)**	**C_{GW} (µg/L)**	**Groundwater MCLs[4] (µg/L)**
Volatile Organic Compounc						
1,1-Dichloroethene	2.10E+02	2.10E+03	2.10E+04	1.07E+00	1.97E+02	7.00E+00
cis-1,2-Dichloroethene[3]	7.30E+00	7.30E+01	7.30E+02	1.67E-01	4.38E+01	7.00E+01
trans-1,2-Dichloroethene	6.30E+01	6.30E+02	6.30E+03	1.67E-01	3.78E+02	1.00E+02
1,2-Dichloroethene, total	NA	--	--	1.67E-01	--	--
Tetrachloroethene[3]	9.36E+00	9.36E+01	9.36E+02	7.24E-01	1.29E+01	5.00E+00
Trichloroethene	4.30E-01	4.30E+00	4.30E+01	4.03E-01	1.07E+00	5.00E+00
Vinyl Chloride	1.60E-01	1.60E+00	1.60E+01	1.14E+00	1.41E-01	2.00E+00

Notes:

[1] - Values represent USEPA's Regional Screening Levels for residential indoor air (USEPA, November, 2013).

[2] - Value calculated from USEPA's Vapor Intrusion Database: Preliminary Evaluation of Attenuation Factors, March 4, 2008.

[3] - C_{IA} value calculated following USEPA RSL procedures using updated toxicity information.

[4] - Safe Drinking Water Act (SDWA) Maximum Contaminent Levels (MCLs) for groundwater (http://water.epa.gov/drink/contaminants/#List).

µg/m^3 - micrograms per cubic meter.	IA - indoor air.
µg/L - micrograms per liter.	SS - sub-slab.
NA - Value not available.	SG - soil gas.
-- Value not calculated.	GW - groundwater.

USEPA - United States Environmental Protection Agency.

TABLE 2-2
Well Completion Details
Chicago Heights Site
Overland, Missouri

Monitoring Well	Installation Date	Well Diameter	Total Depth (feet bgs)	Screen Length (feet)	Screened Formation	Screened Interval	Ground Surface Elevation (feet, msl)	Top of Casing Elevation (feet, msl)
GMW-1	Pre-1992	2"	16.5	5.0	Silty Clay	shallow	650.92	650.92
GMW-3	Pre-1992	2"	16.5	5.0	Silty Clay	shallow	635.87	635.83
GMW-4	Pre-1992	2"	16.5	5.0	Silty Clay	shallow	641.60	641.54
GMW-5	Pre-1992	2"	17.5	15.0	Silty Clay	shallow	646.29	646.29
GMW-6R	3/25/2003	2"	15.2	10.0	Silty Clay	shallow	642.61	642.35
GMW-7	Pre-1992	2"	14.0	10.0	Silty Clay	shallow	638.21	638.32
GMW-8	Pre-1992	2"	14.0	10.0	Silty Clay	shallow	636.35	635.91
GMW-10	Pre-1992	2"	16.0	10.0	Silty Clay	shallow	643.06	643.06
GMW-11	Pre-1992	2"	16.0	10.0	Silty Clay	shallow	643.15	643.15
GMW-25R	6/3/2013	2"	20.0	10.0	Silty Clay	shallow	--	624.14
GMW-26	12/11/2012	2"	18.0	5.0	Silty Clay	shallow	--	631.63
GMW-27	12/11/2012	2"	17.0	5.0	Silty Clay	shallow	--	622.81
GMW-28	12/12/2012	2"	17.0	5.0	Silty Clay	shallow	--	616.40
GMW-29	12/12/2012	2"	16.0	5.0	Silty Clay	shallow	--	626.52
GMW-30	12/13/2012	2"	20.0	5.0	Silty Clay	shallow	--	633.90
GMW-31	12/13/2012	2"	22.0	5.0	Silty Clay	shallow	--	635.19
GMW-32	12/13/2012	2"	20.0	5.0	Silty Clay	shallow	--	634.16
INJ-37	5/8/2003	4"	15.0	9.0	Silty Clay	shallow	636.55	636.12
GMW-9	Pre-1992	2"	20.3	10.0	Silty Clay	shallow/inter.	637.57	637.50
INJ-29	4/1/2003	4"	19.0	15.0	Silty Clay	shallow/inter.	646.62	646.29
INJ-30	4/1/2003	4"	19.0	15.0	Silty Clay	shallow/inter.	646.30	646.02
INJ-31	4/2/2003	4"	19.0	15.0	Silty Clay	shallow/inter.	646.08	645.63
INJ-33	4/2/2003	4"	19.0	15.0	Silty Clay	shallow/inter.	645.81	645.39
INJ-35	4/3/2003	4"	19.0	15.0	Silty Clay	shallow/inter.	642.77	642.51
INJ-36	4/2/2003	4"	19.0	15.0	Silty Clay	shallow/inter.	642.26	641.96
GMW-15	4/1/1992	4"	19.9	4.5	Transition	intermediate	642.31	642.31
GMW-14	3/30/1992	4"	23.0	4.5	Transition	intermediate	636.41	636.23
SKM-28	5/14/2002	4"	22.6	19.5	Transition	intermediate	645.19	644.62
INJ-25	11/13/2001	4"	28.5	15.0	Transition	intermediate	645.96	645.66
INJ-26	11/14/2001	4"	26.8	15.0	Transition	intermediate	645.69	645.29
INJ-27R	--	4"	29.8	10.0	Transition	intermediate	646.70	646.32
INJ-32	4/1/2003	4"	29.0	25.0	Transition	intermediate	646.27	645.98

TABLE 2-2
Well Completion Details
Chicago Heights Site
Overland, Missouri

Monitoring Well	Installation Date	Well Diameter	Total Depth (feet bgs)	Screen Length (feet)	Screened Formation	Screened Interval	Ground Surface Elevation (feet, msl)	Top of Casing Elevation (feet, msl)
INJ-34	4/3/2003	4"	29.0	25.0	Transition	intermediate	642.81	642.46
INJ-38	5/7/2003	4"	30.0	26.0	Transition	intermediate	637.27	636.95
INJ-39	5/7/2003	4"	30.0	26.0	Transition	intermediate	638.04	637.66
INJ-40	5/6/2003	4"	30.0	26.0	Transition	intermediate	637.28	636.79
GMW-16	4/7/1992	4"	34.5	5.0	Bedrock	deep	636.49	636.00
GMW-17	4/8/1992	4"	49.7	10.0	Bedrock	deep	646.29	646.29
GMW-19	8/9/2000	2"	33.0	5.0	Bedrock	deep	633.83	633.61
GMW-20	8/10/2000	2"	34.0	5.0	Bedrock	deep	634.29	634.12
GMW-21	2/26/2001	2"	33.8	5.0	Bedrock	deep	627.60	627.29
GMW-22	2/27/2001	2"	38.1	5.0	Bedrock	deep	618.03	617.60
GMW-23	2/28/2001	2"	34.7	5.0	Bedrock	deep	610.06	609.80
GMW-24	3/1/2001	2"	35.5	5.0	Bedrock	deep	618.73	618.37

Notes:
bgs - Below ground surface
msl - Mean sea level
inter. - Intermediate

TABLE 2-3
Historical Groundwater Monitoring Well Analytical Results
Chicago Heights Site
Overland, Missouri

Monitoring Well	Sample Date	PCE (µg/L)	TCE (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)
MCL[1]		**5**	**5**	**7**	**70**	**100**	**2**
Screening Levels for Vapor Intrusion[2]		**12.9**	**1.07**	**197**	**43.8**	**378**	**0.141**
GMW-1	05/05/97	ND	ND	ND	ND	ND	ND
	11/17/97	ND	ND	ND	ND	ND	ND
	06/03/98	ND	ND	ND	ND	ND	ND
	11/18/98	ND	ND	ND	ND	ND	ND
	05/27/99	ND	ND	ND	ND	ND	ND
	03/27/03	ND	ND	ND	ND	ND	ND
	11/24/03	ND	ND	ND	ND	ND	ND
	03/10/04	ND	ND	ND	ND	ND	ND
	07/21/04	ND	ND	ND	ND	ND	ND
	11/23/04	ND	ND	ND	ND	ND	ND
GMW-3	05/05/97	**12.4 J**	**454**	ND	**407**	ND	**16.4 J**
	11/17/97	ND	**385**	ND	**369**	ND	**19.7**
	06/03/98	ND	**370**	ND	**280**	ND	ND
	11/18/98	ND	**880**	ND	**920**	ND	**40 J**
	05/27/99	ND	**860**	ND	**970**	ND	**34 J**
pre-pilot	12/04/01	3.1 J	**138**	1.8 J	**308**	2.6 J	**10.5**
post-pilot	01/10/02	ND	**65.1**	2.3 J	**476**	ND	**19.2**
pre-full	03/28/03	**17 J**	**26 J**	ND	**835**	ND	**22.5**
	11/24/03	**84 J**	**984**	ND	**888**	ND	**36 J**
	03/11/04	**34.9**	**40.3**	ND	**95.4**	ND	**3.3**
	07/20/04	2.5 J	**351**	2.8 J	**652**	6.5	**34.2**
	11/23/04	ND	**120**	ND	**1,010**	ND	**47.9**
	08/24/11	ND	**260**	2.0 J	**600**	3.5 J	**260**
GMW-4	12/05/01	ND	ND	ND	ND	ND	ND
pre-full	03/28/03	2.0 U* J	ND	ND	ND	ND	ND
	11/24/03	2.6 U* J	ND	ND	ND	ND	ND
	03/11/04	ND	ND	ND	ND	ND	ND
	07/20/04	ND	ND	ND	ND	ND	ND
	11/23/04	ND	ND	ND	ND	ND	ND
GMW-5	05/06/97	**10,400**	**4,830**	ND	**3,800**	ND	**713**
	11/17/97	**11,000**	**4,630**	ND	**3,360**	ND	**625 J**
	06/03/98	**7,100**	**5,000**	ND	**4,200**	ND	**740**
	11/18/98	**7,900**	**4,800**	ND	**4,700**	ND	**600**
	05/27/99	**9,100**	**5,900**	ND	**6,500**	ND	**1,100**
pre-pilot	12/04/01	**1,510**	**1,120**	6.3	**2,960**	28.7	**239**
post-pilot	01/11/02	ND	ND	ND	ND	ND	ND
pre-full	03/27/03	**839**	**1,060**	ND	**2,880**	ND	**254**
	11/24/03	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	03/10/04	**706**	**1,170**	ND	**2,860**	40 J	**390**
	07/21/04	**1,250**	**1,680**	ND	**4,670**	38 J	**702**
	11/23/04	**1,140**	**1,670**	ND	**4,820**	ND	**657**
	08/25/11	**4,200**	**3,900**	ND	**10,000**	47 J	**1,200**

TABLE 2-3
Historical Groundwater Monitoring Well Analytical Results
Chicago Heights Site
Overland, Missouri

Monitoring Well	Sample Date	PCE (µg/L)	TCE (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)
	MCL[1]	5	5	7	70	100	2
Screening Levels for Vapor Intrusion[2]		12.9	1.07	197	43.8	378	0.141
GMW-6	05/06/97	**47,400**	**25,200**	ND	**25,200**	ND	ND
	11/17/97	**15,800**	**12,400**	ND	**18,600**	ND	ND
	06/03/98	**67,000**	**26,000**	ND	**22,000**	ND	ND
	11/18/98	**53,000**	**21,000**	ND	**21,000**	ND	ND
	05/27/99	**72,000**	**26,000**	ND	**25,000**	ND	ND
pre-pilot	12/04/01	**64,100**	**19,800**	**48 J**	**19,400**	69 J	**797**
post-pilot	01/11/02	**57,000**	**17,100**	ND	**16,400**	ND	ND
GMW-6R pre-full	03/27/03	**46,400**	**19,300**	ND	**22,500**	ND	ND
	11/24/03	**36,500**	**13,100**	ND	**10,600**	ND	ND
	03/10/04	**54,400**	**23,100**	ND	**23,300**	ND	**582**
	07/20/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	11/24/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	04/11/06	**18,600**	**12,700**	ND	**28,500**	ND	**1,100 J**
	06/14/06	**18,400**	**13,600**	ND	**31,700**	ND	**1,050**
	08/25/11	**34,000**	**23,000**	ND	**34,000**	**330 J**	**1,000**
GMW-7	05/05/97	ND	**2,180**	ND	**401**	ND	ND
	11/17/97	ND	**2,120**	ND	**346**	ND	ND
	06/03/98	ND	**2,300**	ND	**410**	ND	ND
	11/18/98	ND	**3,200**	ND	**460**	ND	ND
	05/27/99	ND	**2,200**	ND	**490**	ND	ND
pre-full	03/28/03	**25 J**	**612**	ND	**347**	ND	**23.2**
	11/24/03	**52 J**	**487**	ND	**282**	ND	ND
	03/10/04	**7.6**	**468**	1.7 J	**302**	1.6 J	**14.1**
	07/20/04	**9.7**	**534**	1.8 J	**270**	ND	**13.1**
	11/23/04	**5.7 J**	**335**	ND	**220**	ND	**8.8 J**
	08/26/11	1.9	**67**	0.47 J	**92**	0.50 J	**11.0**
GMW-8	05/05/97	ND	**8,120**	ND	**24,500**	ND	**2,450**
	11/17/97	**835 J**	**8,260**	ND	**27,600**	ND	**2,770**
	06/03/98	ND	**7,100**	ND	**26,000**	ND	**1,800**
	11/18/98	ND	**7,900**	ND	**32,000**	ND	**2,700**
	05/27/99	ND	**5,300**	ND	**22,000**	ND	**1,400**
pre-pilot	12/04/01	**1,140**	**7,110**	ND	**25,800**	64 J	**2,030**
post-pilot	01/10/02	ND	**6,880**	ND	**22,400**	ND	**1,900**
pre-full	03/28/03	**200 J**	**3,640**	ND	**14,100**	ND	**731**
	11/25/03	**920 J**	**2,400 J**	ND	**15,100**	ND	**710 J**
	03/11/04	ND	**1,310**	ND	**8,380**	ND	**459**
	07/20/04	ND	**2,190**	ND	**12,000**	ND	**380**
	11/23/04	ND	**3,030**	ND	**19,000**	ND	**889**
	08/24/11	ND	**1,200**	ND	**7,600**	31 J	**310**
GMW-9	05/05/97	ND	**8,810**	ND	**571**	ND	ND
	11/17/97	ND	**9,220**	ND	**577**	ND	ND
	06/03/98	ND	**8,300**	ND	**500**	ND	ND
	11/18/98	ND	**8,800**	ND	**650**	ND	ND
	05/27/99	ND	**7,300**	ND	**570**	ND	ND
post-pilot	01/10/02	ND	ND	ND	ND	ND	ND
pre-full	03/28/03	**8.0**	**148**	ND	**97**	ND	**3.2**
	11/25/03	**83 J**	**980**	ND	**831**	ND	ND
	03/11/04	ND	**592**	ND	**1,020**	ND	ND

TABLE 2-3
Historical Groundwater Monitoring Well Analytical Results
Chicago Heights Site
Overland, Missouri

Monitoring Well	Sample Date	PCE (µg/L)	TCE (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)
	MCL[1]	**5**	**5**	**7**	**70**	**100**	**2**
Screening Levels for Vapor Intrusion[2]		**12.9**	**1.07**	**197**	**43.8**	**378**	**0.141**
GMW-9	07/20/04	ND	**591**	ND	**1,150**	ND	ND
(Continued)	11/23/04	ND	**676**	ND	**655**	ND	**13 J**
	08/26/11	**5.8 J**	**320**	ND	**1,000**	3.9 J	**11 J**
GMW-10	05/22/96	**187**	**543**	ND	**533**	ND	**30.1**
pre-full	03/28/03	**66.4**	**50.3**	ND	45.2	ND	ND
	11/25/03	**28.8**	**20.1**	ND	36.1	ND	ND
	03/11/04	**5.5**	**5.7**	ND	38	1.1 J	**4.0**
	07/21/04	**5.6**	4.9 J	ND	40.6	ND	**4.7**
	11/24/04	4.7 J	**6.9**	ND	38.6	ND	**2.6**
	08/26/11	0.67 J	1.8	ND	16	ND	0.31 J
GMW-11	05/05/97	ND	**258**	ND	**1,290**	ND	ND
	11/17/97	ND	**257**	ND	**1,780**	ND	ND
	06/03/98	ND	**150**	ND	**1,200**	ND	ND
	11/18/98	ND	**460**	ND	**1,600**	ND	ND
	05/27/99	ND	**540**	ND	**1,800**	ND	ND
pre-full	03/28/03	4.5 U* J	**60.6**	1.7 J	**173**	2.2 J	**3.1**
	11/25/03	4.0 U* J	**44.7**	1.6 J	**195**	1.9 J	**4.6**
	03/11/04	2.2 J	**49.5**	1.2 J	**171**	2.1 J	**6.4**
	07/21/04	ND	**12.2**	ND	**77**	ND	**11.3**
	11/24/04	ND	**8.8**	ND	**76**	ND	**10.2**
	08/26/11	0.24 J	**5.1**	ND	50	0.56 J	1.4
GMW-14	05/05/97	**103,000**	**123,000**	ND	ND	ND	**11,700**
	11/17/97	ND	**43,800**	ND	**72,200**	ND	**7,040**
	06/03/98	ND	**50,000**	ND	**72,000**	ND	**5,100**
	11/18/98	ND	**57,000**	ND	**84,000**	ND	**6,900**
	05/27/99	**2,600 J**	**58,000**	ND	**85,000**	ND	**7,200**
pre-pilot	12/04/01	**3,580**	**39,600**	**68.4**	**69,700**	ND	**6,180**
post-pilot	01/10/02	ND	ND	ND	ND	ND	ND
pre-full	03/28/03	**4,640**	**50,700**	ND	**64,400**	ND	**2,400**
	11/24/03	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	03/11/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	07/20/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	11/23/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	08/26/11	ND[3]	ND[3]	ND[3]	ND[3]	ND[3]	ND[3]
GMW-15	05/06/97	**39,200**	**9,030**	ND	**13,500**	ND	ND
	06/03/98	**53,000**	**10,000**	ND	**17,000**	ND	ND
	11/18/98	**67,000**	**18,000**	ND	**24,000**	ND	ND
	05/27/99	**74,000**	**23,000**	ND	**22,000**	ND	ND
pre-pilot	12/04/01	**65,200**	**14,500**	**34.5**	**23,800**	ND	**940 J**
post-pilot	01/11/02	**66,500**	**27,200**	ND	**19,300**	ND	ND
pre-full	03/27/03	**68,100**	**17,600**	ND	**21,900**	ND	ND
	11/24/03	**64,300**	**67,900**	ND	**13,700**	ND	ND
	03/10/04	**73,800**	**25,500**	ND	**27,600**	ND	**500 J**
	07/20/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	11/23/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	08/25/11	**76,000**	**17,000**	ND	**33,000**	**450 J**	**880**

TABLE 2-3
Historical Groundwater Monitoring Well Analytical Results
Chicago Heights Site
Overland, Missouri

Monitoring Well	Sample Date	PCE (µg/L)	TCE (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)
MCL[1]		5	5	7	70	100	2
Screening Levels for Vapor Intrusion[2]		12.9	1.07	197	43.8	378	0.141
GMW-16	05/05/97	ND	**48**	ND	32.8	ND	ND
	11/17/97	3.0	**56.3**	ND	20.5	ND	ND
	06/03/98	ND	**150**	ND	**90**	ND	ND
	11/19/98	3.0	**36**	ND	20	ND	ND
	05/27/99	4.0 J	**60**	ND	38	ND	ND
pre-pilot	12/04/01	**18.0 J**	**158**	ND	**176**	2.5 J	ND
post-pilot	01/10/02	1.6 J	**89.3**	ND	**97**	ND	ND
pre-full	03/28/03	**390 J**	**5,390**	ND	**14,100**	ND	**82 J**
	04/08/03	**360 J**	**5,750**	ND	**13,000**	ND	ND
	11/24/03	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	03/11/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	07/20/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	11/23/04	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$	$KMnO_4$
	08/26/11	**89**	**990**	ND	**1,200**	**110**	ND
GMW-17	05/06/97	ND	**386**	ND	ND	ND	ND
	11/17/97	ND	**513**	ND	ND	ND	ND
	06/03/98	ND	**340**	ND	ND	ND	ND
	11/18/98	ND	**560**	ND	ND	ND	ND
	05/27/99	ND	**460**	ND	ND	ND	ND
pre-pilot	12/05/01	**50.9**	**664**	ND	28 J	ND	ND
post-pilot	01/11/02	**90.3**	**673**	ND	34	ND	ND
pre-full	03/27/03	**339**	**772**	ND	**132**	ND	ND
	11/24/03	**1,530**	**2,620**	ND	**450 J**	ND	ND
	03/10/04	**100 J**	**2,020**	ND	64 J	ND	ND
	07/21/04	**119**	**1,300**	ND	67 J	ND	ND
	11/23/04	**100 J**	**1,060**	ND	60 J	ND	ND
	08/26/11	ND	**880**	ND	17	ND	ND
GMW-19	08/18/00	ND	**11,000**	ND	**2,900**	ND	ND
	03/02/01	**260 J**	**4,300**	ND	**1,200**	ND	ND
pre-pilot	12/05/01	**200 B**	**7,180**	3.1 J	**2,460**	8.1	**3.3**
post-pilot	01/10/02	ND	**622**	ND	**944**	ND	ND
pre-full	03/28/03	**362**	**9,060**	ND	**3,100**	ND	ND
	11/25/03	**670 J**	**11,600**	ND	**4,320**	ND	ND
	03/11/04	**280 J**	**9,690**	ND	**3,720**	ND	ND
	07/20/04	**200 J**	**8,070**	ND	**3,030**	ND	ND
	11/23/04	**180 J**	**7,870**	ND	**3,030**	ND	ND
	08/26/11	**380**	**6,300**	ND	**1,500**	39 J	ND
GMW-20	08/18/00	ND	**2,000**	ND	ND	ND	ND
	03/02/01	ND	**1,700**	ND	**400**	ND	ND
pre-pilot	12/05/01	**44.0**	**2,260**	1.3 J	**521**	1.8 J	ND
post-pilot	01/10/02	ND	**117**	ND	**176**	ND	ND
pre-full	03/28/03	**62 J**	**1,900**	ND	**524**	ND	ND
	11/25/03	**170 J**	**1,860**	ND	**591**	ND	ND
	03/11/04	**95 J**	**2,910**	ND	**663**	ND	ND
	07/20/04	**34 J**	**2,400**	ND	**622**	ND	ND
	11/23/04	**28 J**	**2,500**	ND	**656**	ND	ND
	08/25/11	**21**	**970**	ND	**280**	6.6 J	ND

TABLE 2-3
Historical Groundwater Monitoring Well Analytical Results
Chicago Heights Site
Overland, Missouri

Monitoring Well	Sample Date	PCE (µg/L)	TCE (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)
	MCL[1]	**5**	**5**	**7**	**70**	**100**	**2**
Screening Levels for Vapor Intrusion[2]		**12.9**	**1.07**	**197**	**43.8**	**378**	**0.141**
GMW-21	03/02/01	**170**	**360**	ND	ND	ND	ND
	12/22/04	**24.5**	**66.7**	ND	3.2 J	ND	ND
	08/26/11	**9.6**	**22**	ND	2.1	ND	ND
GMW-22	03/02/01	2.0	**6.0**	ND	ND	ND	ND
	12/22/04	**273**	**380**	ND	7.6 J	ND	ND
	08/26/11	**440**	**330**	ND	10	ND	ND
GMW-23	03/02/01	**8.0**	**26.0**	ND	0.8 J	ND	ND
	12/22/04	**640**	**1,010**	ND	ND	ND	ND
	08/26/11	**1,500**	**1,100**	ND	52	ND	ND
GMW-24	03/02/01	4.0	**17.0**	ND	2	ND	ND
	12/22/04	**700**	**1,900**	ND	**110 J**	ND	ND
	08/25/11	**1,700**	**1,900**	ND	**120**	11 J	ND
GMW-25	12/19/12	0.21 J	**5.7**	ND (1.0)	3.2	ND (1.0)	ND (1.0)
GMW-25R	--	--	--	--	--	--	--
GMW-26	12/19/12	**14 J**	**2,100**	**ND (34)**	**180**	ND (34)	**ND (34)**
GMW-27	12/19/12	**41 J**	**3,900**	**ND (59)**	**2,700**	ND (59)	**ND (59)**
GMW-28	01/09/13	ND (1.0)	0.22 J	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
GMW-29	12/19/12	1.9	**46**	ND (1.0)	6.4	ND (1.0)	ND (1.0)
GMW-30	12/19/12	**110**	**4,100**	**ND (57)**	**1,500**	ND (57)	**32 J**
GMW-31	12/19/12	**7.4 J**	**540 J**	ND (9.8)	**260**	ND (9.8)	**15.0**
GMW-32	12/19/12	**59**	**48**	0.30 J	**82**	1.1	**2.7**

Notes:

[1] - United States Environmental Protection Agency (USEPA) Regional Screening Levels for Chemical Contaminants at Superfund Sites (Revised May 2013).

[2] - Maximum Continment Levels identified in the 1994 Consent Agreement.

[3] - Permanganate Present During Sampling.

4 - ND is bolded/highlighted if 1/2 RL exceeds screening level

MCL - Maximum contaminant level for drinking water

U* - Qualified as undetected

KMnO$_4$ - Potassium permanganate

PCE - Tetrachloroethylene

TCE - Trichloroethylene

DCE - Dichloroethylene

µg/L - Micrograms per liter

ND - Not detected

J - Qualified as estimated

\- **Bolded Values** - Exceeds MCLs identified in the 1994 Consent Agreement and Site-Specific Screening Levels[1]

▨ - Exceeds Site-Specific Screening Levels[2]

TABLE 2-4
Historical Soil Analytical Results
Chicago Heights Site
Overland, Missouri

Date	Soil Sample Location	Sample Depth (feet)	Compound Concentrations				
			TCE mg/kg	PCE mg/kg	DCE mg/kg	Vinyl Chloride mg/kg	Methylene Chloride mg/kg
2/1988[1]	OB-1	3.5-5.0	<1.2	1.31	<1.0	NA	NA
	OB-2	3.5-5.0	12.85	21.30	<1.0	NA	NA
	OB-3	2.5-4.0	<1.2	11.03	9.34	NA	NA
	OB-4	3.0-4.5	<1.2	<0.3	<1.0	NA	NA
	OB-6	3.0-4.5	<1.2	<0.3	<1.0	NA	NA
	OB-7	2.5-4.0	<1.2	6.73	<1.0	NA	NA
	OB-9	2.5-4.0	<1.2	<0.3	<1.0	NA	NA
	OB-11	2.5-4.0	<1.2	<0.3	<1.0	NA	NA
	OB-13	3.0-4.5	<1.2	1.35	<1.0	NA	NA
	OB-15	3.5-5.0	<1.2	2.65	<1.0	NA	NA
	OS-1	surface	<1.2	<0.3	<1.0	NA	NA
	OS-2	surface	<1.2	<0.3	1.57	NA	NA
	OS-3	surface	<1.2	<0.3	<1.0	NA	NA
	OS-4	surface	<1.2	<0.3	<1.0	NA	NA
	OS-5	surface	<1.2	<0.3	<1.0	NA	NA
7/1990[2]	SB-1G	6.0-9.0	<0.04	<0.04	<0.04	<0.06	<0.18
	SB-2G	2.0-3.0	0.08	0.13	0.07	<0.06	<0.18
	SB-3G	1.0-3.0	0.33	290	<0.04	<0.06	<0.18
	SB-4G	3.0-6.0	<0.04	0.17	<0.04	<0.06	<0.18
	GMW-5	3.0-6.0	<0.04	<0.04	<0.04	<0.06	<0.18
	GMW-6	6.0-9.0	0.56	7.30	0.23	<0.06	<0.18
	GMW-7	6.0-9.0	<0.04	<0.04	<0.04	<0.06	<0.18
	GMW-8	6.0-9.0	0.10	<0.04	0.27	<0.06	<0.18

TABLE 2-4
Historical Soil Analytical Results
Chicago Heights Site
Overland, Missouri

Date	Soil Sample Location	Sample Depth (feet)	Compound Concentrations				
			TCE mg/kg	PCE mg/kg	DCE mg/kg	Vinyl Chloride mg/kg	Methylene Chloride mg/kg
3/1992[3]	GMW-14	1.0-1.5	215	656	426	<1.000	<0.500
	SB-1	19.0-19.4	<0.005	<0.005	<0.005	<0.010	<0.005
	SB-2	1.4-1.8	<0.005	0.0143	<0.005	<0.010	<0.005
		19.0-19.4	<0.005	<0.005	<0.005	<0.010	<0.005
	SB-3	6.6-7.0	<0.005	<0.005	<0.005	<0.010	<0.005
	SB-6	2.0-2.6	0.157	1.73	0.133	<0.010	<0.005
		7.2-7.8	<0.005	<0.005	<0.005	<0.010	<0.005
		13-14	0.0198	0.126	0.0744	<0.010	<0.005
4/1992[3]	GMW-15	1.2-1.5	0.0698	2.30	0.101	<0.010	<0.005
		3.8-4.4	0.025	4.26	0.0072	<0.010	<0.005
		9.0-9.6	0.0763	1.16	0.0822	<0.010	<0.005
	GMW-16	19.0-19.4	0.0156	<0.005	0.0734	<0.010	<0.005
	GMW-17	0.8-1.3	304	1900	0.490	<0.500	<0.250
	SB-4	1.1-1.4	<1.250	684	<1.250	<2.500	<1.250
		5.5-5.7	<0.005	<0.005	0.197	<0.010	<0.005
		10.6-11	0.0334	0.137	1.100	0.184	<0.005
7/1992[3]	AS-3	4.0-4.4	<0.005	<0.005	0.001 J	<0.010	0.013 B
	AS-7	1.3-1.8	0.320 J	0.200 J	2.80	0.007 J	0.011 B
	AS-8	3.3-3.9	<0.005	<0.005	0.06	0.004 J	0.016 B
	AS-9	3.0-3.7	0.012	0.019	0.140	0.007 J	0.014 B

Notes:

[1] Burns & McDonnell Engineering Company, Inc., November 1992. *Remedial Investigation EG&G KT Aerofab Missouri Metals Site.* Appendix B and J. Borings completed by O'Brien and Gere.

[2] Burns & McDonnell Engineering Company, Inc., November 1992. *Remedial Investigation EG&G KT Aerofab Missouri Metals Site.* Appendix B. Borings completed by GTI and Burns & McDonnell.

[3] Burns & McDonnell Engineering Company, Inc., November 1992. *Remedial Investigation EG&G KT Aerofab Missouri Metals Site.* Sections 3 and 4. Borings completed by Burns & McDonnell.

NA = not analyzed
▨ = saturated zone
J = estimated value
B = analyte detected in method blank

TABLE 3-1
Proposed Soil Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use
Soil (Lab Analysis)	AVS	Extractable Sulfide	SOP-WC43 (Microseeps)	Sulfide is a direct indicator of sulfate reduction, and as such, is used as an indicator of the redox state and the extent of sulfate reduction. Free sulfide can also be toxic to dechlorinating microbes, so quantifying the extent of sulfide sequestration is important	Sulfide is a direct indicator of sulfate reduction, and as such, is used as an indicator of the redox state and the extent of sulfate reduction. AVS is used to quantify the sulfide that has precipitated with metals such as ferrous iron, and provides an indication of the extent of sulfate reduction in soil. The total sulfide in-situ is determined by summing groundwater AVS and soil AVS.
	Bioavailable Manganese (MnO_2 and $MnCO_3$)	MnO_2 [oxidized Mn(IV)] and $MnCO_3$ [reduced Mn(II)]	SOP-WC45 (Microseeps)	Mn(IV) (present primarily as solid phase MnO_2) serves an electron acceptor during manganese reduction. Manganese reduction is closely related to iron reduction as many known Fe(III) reducers are also Mn(IV) reducers, and virtually all known Mn(IV) reducers are Fe(III) reducers. Mn(IV) may or may not compete with the targeted COCs as an electron acceptor and will likely assist PCE and TCE reduction as many Mn(IV) reducers also reduce PCE and TCE. Mn(IV) reduction, like Fe(III) reduction, can increase pH.	Mn(IV) contributes to the overall electron acceptor balance that must be considered in a bioremediation strategy. Its importance is elevated at the subject site due to the historical use of permanganate during in-situ chemical oxidation treatments. These ISCO treatments may have left behind residual soild phase MnO_2, a strongly oxidizing electron acceptor for Mn(IV)/Fe(III)-reducing microorganisms.
	Bioavailable (Total) Iron	Bioavailable Ferric Iron [BAFe(III)]	SOP-WC45 (Microseeps)	A total metals analysis quantifies all iron present in the system including ferric iron that is not available to microorganisms as a terminal electron acceptor; this assay specifically targets the fraction of ferric iron that can be microbially reduced. Fe(III) serves an electron acceptor during iron reduction. Iron and manganese reduction are closely related as virtually all known Mn(IV) reducers are Fe(III) reducers. Depending on factors such as Fe(III) concentration, electron donor concentration, and concentrations of all available electron acceptors, Fe(III) may or may not compete with the targeted COCs as an electron acceptor. In addition, Fe(III) reduction can actually promote chlorinated VOC degradation by promoting the steady state molecular hydrogen levels most amenable to complete dechlorination. Fe(III) reduction, like Mn(IV) reduction, can increase pH.	Fe(III) contributes to the overall electron acceptor balance that must be considered in a bioremediation strategy. Its importance is elevated at the subject site due to the historical use of permanganate that may have left behind residual soild phase MnO_2, a strongly oxidizing electron acceptor for Mn(IV)/Fe(III)-reducing microorganisms.
	TOC	Same	EPA 9060	An indicator of native carbon available for use as an energy source for reductive dechlorination.	An indicator of the extent to which chlorinated VOCs, PCE and TCE in particular, will adsorb to subsurface material. Also used to indicate whether or not the conditions may support reductive dechlorination via natural attenuation.
	VOCs	PCE, TCE, cis-DCE, vinyl chloride	SW-846 5035/8260	Although dissolved-phase VOCs in water is the primary health concern, the adsorbed VOC fraction in soil is the "source" of contamination. Identification of soil hot spots, in both the saturated and unsaturated zones, will be used to target remediation strategies that address source(s) of VOCs as well as the dissolved-phase plume.	Chemical of concern. Soil analysis provides concentration of VOCs adsorbed to organic carbon. Can be used to indicate VOC source mass.

Notes:
VOC - volatile organic compound.
AVS - acid volatile solids.
TOC - total organic carbon.
ISCO - in-situ chemical oxidation.
pH - negative log of the hydrogen ion concentration.
PCE - tetrachloroethylene
TCE - trichloroethylene
SOP - standard operating procedures.
COCs - chemicals of concern.
EPA - United States Environmental Protection Agency
AFCEE - Air Force Center for Engineering and Environment

References:

AFCEE, 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvent, August 2004.
USEPA, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, Office of Research and Development, September 1998.

TABLE 3-2
Proposed Groundwater Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use
Water Field Analysis)	pH	Same	Field-Analysis	The optimal pH range for PCE and TCE reduction (generating cis-DCE) is 5 < pH < 9; The optimal pH range for Dehalococcoides-like organisms to grow and proliferate is 6.2 < pH < 7.5.	Used to monitor the favorability of site conditions for biodegradation. Aerobic and anaerobic biological processes are pH-sensitive. pH also controls the speciation of metals, which influences their bioavailability. Biological proccesses themselves can also influence pH.
	ORP	Same		The ORP of groundwater is controlled by microbial reactions relative to the availability of key electron acceptors; while negative ORP indicates reducing conditions, this parameter alone is not enough to determine whether PCE or TCE (and their respective daughter products) will be reduced either by biological or abiotic processes.	Key parameter for determining whether aquifer is aerobic (oxic) or anaerobic (anoxic). Also used to monitor the favorability of site conditions for biodegradation. ORP trends are monitored following the addition of a chemical oxidant or reductant for remediation purposes.
	Conductivity	Same		Conductivity provides an estimate of TDS/ionic strength in groundwater	Conductivity is monitored to track changes in TDS that may affect degradation processes.
	Temperature	Same		Groundwater temperature affects the concentration of DO and can influence the activity of bacteria and chemicals. A groundwater temperature greater than 20 degrees Centigrade (68 degrees Fahrenheit) is favorable, but not required, for biological activity.	Temperature can be monitored to detect changes that may positively or negatively affect biodegradation processes.
	DO	Same		DO levels less than 0.5 mg/L are considered favorable for anaerobic biodegradation, a primary mechanism of dechlorination (USEPA, 1998).	Key parameter for determining whether aquifer is aerobic (oxic) or anaerobic (anoxic). Also used to monitor the favorability of site conditions for biodegradation.

TABLE 3-2
Proposed Groundwater Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use
Water (Laboratory Analysis)	VOCs	PCE	SW-846 8260B	Chemical of Concern. In addition, some ferrous iron mediated reactions will convert chloroethanes to PCE.	Decreasing concentrations demonstrate direct contaminant degradation if daughter products are also quantified; mass loss alone may indicate degradation or dilution-dispersion. May also indicate incomplete degradation pathway and suggests the predominance of ferrous iron mediated reactions relative to reductive dechlorination.
	VOCs	TCE	SW-846 8260B	Chemical of Concern. Also a breakdown product of PCE.	Decreasing concentrations demonstrate direct contaminant degradation if daughter products are also quantified; mass loss alone may indicate degradation or dilution-dispersion.
	VOCs	cis-DCE, vinyl chloride	SW-846 8260B	Breakdown products of TCE	Increasing concentration demonstrates microbial reductive dechlorination of TCE; the increase/decrease patterns in the reduction series TCE > cis-DCE > VC > ethene can be used to quantify chlorinated solvent mass balances.
	Dissolved Metals (Field-Filtered)	Aluminum, Barium, Calcium, Chromium, Magnesium, Nickel, Potassium, Sodium, and Vanadium	SW-846 6010	Total metals quantifies all potential metal electron acceptors irrespective of the fraction of each metal that may be available to microorganisms based on metals speciation (i.e. the amount available as an electron acceptor may be less than the total). This analysis also provides an indication of potential metals mobility and toxicity issues, such as those associated with chromium and arsenic.	Dissolved metals data is required for assessing substrate demand (associated with enhanced biodegradation), potential metals mobility issues (associated with chemical and biological remediation methods), and attenuation mechanisms.
	Dissolved Metals (Field-Filtered)	Manganese, Arsenic, Lead, and Cadmium	SW-846 6010	Increased dissolved manganese demonstrates microbial Mn(IV) reduction or microbial Fe(III) reduction [since Mn(VI) will abiotically oxidize Fe(II) to Fe(III), in turn generating Mn(II)]. Free arsenic indicates Fe(III) reduction since most arsenic is adsorbed to Fe(III) in-situ. Lead and cadmium will limit microbial activity at excessive concentrations.	Initial total iron and manganese concentrations will provide an indication of the redox state of the aquifer and favorability for degradation of targeted chlorinated ethene compounds. Subseqent data will be used to identify changes in aquifer conditions that may affect contaminant degradation. Lead and Cadmium concentrations will be used to assess potential microbial toxicity associated with these metals.
	Dissolved Metals	Ferrous Iron	SM 3500 FE D	Ferrous iron is a key indicator of reducing conditions, and as such, is used as an indicator of redox state and the extent of iron reduction. Ferrous iron concentrations greater than 1 mg/L generally considered favoarable for biological and chemical reduction of chlorinated compounds (USEPA, 1998).	Initial ferrous iron concentrations will provide an indication of the redox state of the aquifer and favorability for degradation of targeted chlorinated ethene compounds. Subseqent data will be used to identify changes in aquifer conditions that may affect contaminant degradation.

TABLE 3-2
Proposed Groundwater Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use
Water (Laboratory Analysis)	DOC (Field-Filtered)	Same	SW-846 9060	An indicator of native carbon available for use as an electron donor for reductive dechlorination	Used as an indicator of native carbon available for use as an electron donor for reductive dechlorination of contaminants.
	Dissolved Gases	Ethane, Ethene	RSK-175	Breakdown products of chlorinated ethanes/ethenes.	Ethene is the terminal product of complete reductive dechlorination; ethane may be produced from ethene or chlorinated ethanes. Ethene, even at very low levels in TCE-contaminated material, can be used to infer the presence of an appropriate microbial community.
	Dissolved Gases	Methane	RSK-175	Methane concentrations greater than 500 µg/L are indicative of reducing conditions, potentially favorable for reductive dechlorination. However, highly elevated methane concentrations (greater than 5 to 10 mg/L) may indicate that the electron donors are being consumed by methanogens at the expense of dechlorinating organisms (AFCEE, 2004).	Used as an indicator of redox state and the extent of methanogenesis. Elevated methane concentrations may also indicate excessive electron donor addition.
	Dissolved Ammonium (Field-Filtered)	Ammonium	EPA 350.1	Reduction product of nitrate respiration	Dissolved ammonium, along with nitrite, indicates nitrate reduction as a dominant metabolism.
	Anions	Chloride	IC 9056	Chloride can be correlated with complete dechlorination.	Indicator parameter. Chloride is produced by anaerobic dechlorination of chlorinated aliphatic hydrocarbons.
	Anions	Sulfate	IC 9056	Sulfate is a key indicator of reducing conditions and potential for reductive dechlorination. Sulfate levels less than 20 mg/L are considered favorable for anaerobic biodegradation, a primary mechanism of dechlorination (USEPA, 1998).	Sulfate is the preferred electron acceptor in the absence of oxygen, nitrate, manganese, and ferric iron. Initial sulfate concentrations will provide an indication of the redox state of the aquifer and favorability for biodegradation of targeted chlorinated ethene compounds. Subseqent data will be used to identify changes in aquifer conditions that may affect contaminant degradation.
	Anions	Nitrite	IC 9056	Nitrite is both a reduction product of nitrate and itself an electron acceptor.	Initial nitrite concentrations will provide an indication of the redox state of the aquifer and favorability for biodegradation of targeted chlorinated ethene compounds. Subseqent data will be used to identify changes in aquifer conditions that may affect contaminant degradation.

TABLE 3-2
Proposed Groundwater Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use
Water (Laboratory Analysis)	Anions	Nitrate	IC 9056	Nitrate is a key indicator of reducing conditions and potential for reductive dechlorination. Nitrate levels less than 15 mg/L are considered favorable for anaerobic biodegradation, a primary mechanism of dechlorination (USEPA, 1998).	Nitrate is the preferred electron acceptor in the absence of oxygen. Initial nitrate concentrations will provide an indication of the redox state of the aquifer and favorability for biodegradation of targeted chlorinated ethene compounds. Subseqent nitrate data will be used to identify changes in aquifer conditions that may affect contaminant degradation.
	Anions	Sulfide	EPA 376.1	Sulfide is a direct indicator of sulfate reduction, and as such, is used as an indicator of redox state and the extent of sulfate reduction. Sulfide concentrations greater than 1 mg/L generally indicate that sulfate is being reduced and that chlorinated compounds may also be reduced (USEPA, 1998).	Initial sulfide concentrations will provide an indication of the redox state of the aquifer and favorability for biodegradation of targeted chlorinated ethene compounds. Subseqent data will be used to identify changes in aquifer conditions that may affect contaminant degradation.
	Total Alkalinity	Same	SM2320B	Alkalinity is the acid neutralizing capacity of aquifer material.	Used to indicate the buffering capacity of aquifer which is imporant given the criticality of pH (see above).
	CSIA	Carbon ($^{13}C/^{12}C$) and Chlorine ($^{37}Cl/^{36}Cl$) Isotopes for PCE & TCE	SOP-AM24 (Microseeps)	CSIA is an analysis of the ratio of heavy stable isotopes to lighter stable isotopes. Light isotopes enter biological and chemical reactions much faster than heavy isotopes due to intramolecular forces such as bond strength. Therefore, as a contaminant degrades, the relative amount of the heavy isotope becomes "enriched" in the parent compound. Degradation reactions enrich the parent compounds in the heavy isotopes, while "non-reactive" attenuation proceses such adsorption, dilution, and dispersion do not enrich the heavy isotopes. Trends in isotope ratios can be observed long before changes in contaminant mass because shifts in isotope ratios occur on the molecular scale.	Primarily used to assess the extent of current degradation, the potential for future biodegradation (natural and/or enhanced), and degradation rates. Under the right conditions, CSIA can also be used for source identification; however this is at best a correlation between sample locations and a known source, interpreted using statistical tools and compared to other data collected at the site. Past permanganate treatments at the subject site will complicate these interpretations.

TABLE 3-2
Proposed Groundwater Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use
Water (Laboratory Analysis)	Hydrogen	Dissolved molecular hydrogen (H_2)	AM20Gax (Microseeps)	H_2 is an indicator of both general microbial acitvity and the specific terminal electron accepting process that is dominant for specific site location(s). H_2 is the primary electron donor for cis-DCE and VC reduction.	The terminal electron accepting processes that arise and the respective H_2 steady-state thresholds are: • O_2 reduction (aerobic metabolism), <0.1 nM H_2 • NO_3- reduction (dissimilatory or denitrification),0.1 - 0.5 nM H_2 • Fe(III) and/or Mn(IV) reduction, >0.5 nM – 4.0 nM H_2 • SO_4^{2-} reduction, >4.0 nM – 6.0 nM H_2 - Complete dechlorination aligns with this range • CO_2 reduction (methanogenic metabolism), >6.0 nM H_2
	VFAs	Acetic Acid, Butyric Acid, Formic Acid, Lactic Acid, Propionic Acid, and Pyruvic Acid	SOP AM23G (Microseeps)	All VFAs are electron donors for microbial reduction of PCE and TCE; indicates the available "native" carbon sources.	Fermentation of VFAs produces molecular hydrogen for anaerobic dechlorination. VFAs act as direct electron donors for Mn(IV) reduction. Low levels than expected levels may be a result of native geochemistry plus residual manganese from permanganate treatment.
	bvcA Gene	Same	QPCR with functional gene specific primers (use Microbial Insight); no EPA method	Determine if dehalococcoides are capable of degrading VC to ethene.	This assay will determine if the appropriate *dehalococcoides* strains are present to convert VC to ethene; its absence does not mean that activity will be absent, as it is often present at very low abundance; however, a positive result indicates that TCE will be completely reduced to ethene.
	vcrA Gene	Same	QPCR with functional gene specific primers (use Microbial Insight); no EPA method	Determine if *dehalococcoides* are capable of degrading cis-DCE to ethene via vinyl chloride.	This assay will determine if the appropriate *dehalococcoides* strains are present to convert is-DCE to ethene via vinyl chloride; its absence does not mean that activity will be absent, as it is often present at very low abundance; however, a positive result indicates that TCE will be completely reduced to ethene.
	16S rRNA	Same	Standard PCR assay using Dehalococcoides specific primer primers; can be qualitative or quantitative	This assay will determine if *dehalococcoides* strains are present.	This assay will determine if any *dehalococcoides* strains are present. Absence of the *dehalococcoides* strains suggest that complete reduction of TCE to ethene may not occur. Used to determine the potential need for bioaugmentation.

TABLE 3-2
Proposed Groundwater Analytical Parameters
Chicago Heights Site
Overland, Missouri

Matrix	Analytical Group	Analytes	Analytical Method	Interpretation	Relevance / Data Use

Notes:

PCE - tetrachloroethylene
TCE - trichloroethylene
VOC - volatile organic compound.
TDS - total dissolved solids
mg/L - milligrams per liter.
µg/L - micrograms per liter.
VC - vinyl chloride.
DCE - dichloroethene.
ORP - oxidation-reduction potential.
DO - dissolved oxygen.
H_2 - dissolved molecular hydrogen
DOC - dissolved organic carbon.
CSIA - Compound Specific Isotope Analysis.
pH - negative log of the hydrogen ion concentration.
MNA - monitored natural attenuation
USEPA - United States Environmental Protection Agency
AFCEE - Air Force Center for Engineering and Environment
RNA - ribonucleic acid
VFA - volatile Fatty Acid

References:

AFCEE, 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvent, August 2004.
USEPA, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, Office of Research and Development, September 1998.

FIGURES

LEGEND

— SITE BOUNDARY

N

NOT TO SCALE

Burns & McDonnell
SINCE 1898

FIGURE 1-1
SITE LOCATION MAP
CHICAGO HEIGHTS SITE
OVERLAND, MISSOURI

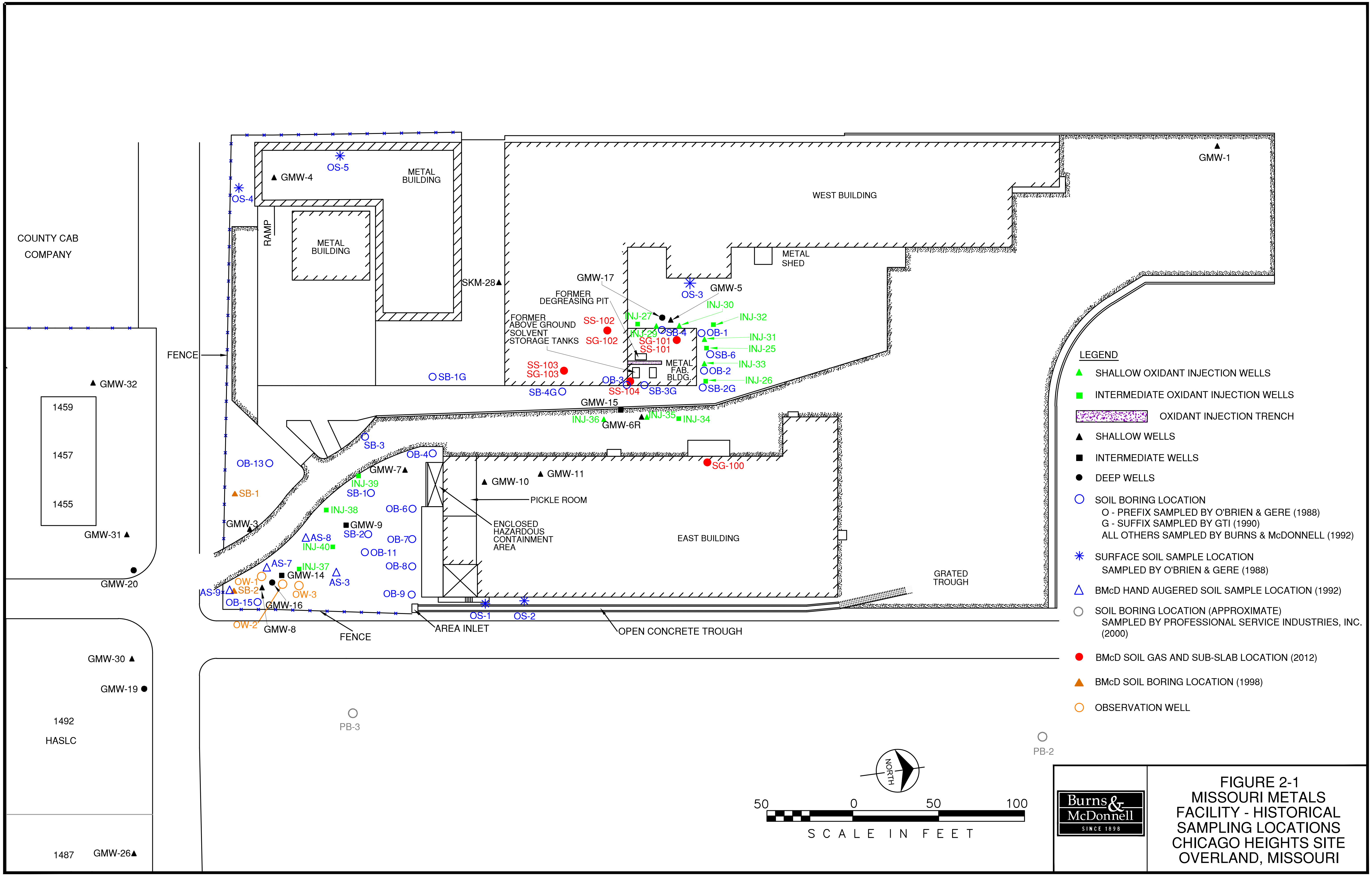

FIGURE 2-1
MISSOURI METALS
FACILITY - HISTORICAL
SAMPLING LOCATIONS
CHICAGO HEIGHTS SITE
OVERLAND, MISSOURI

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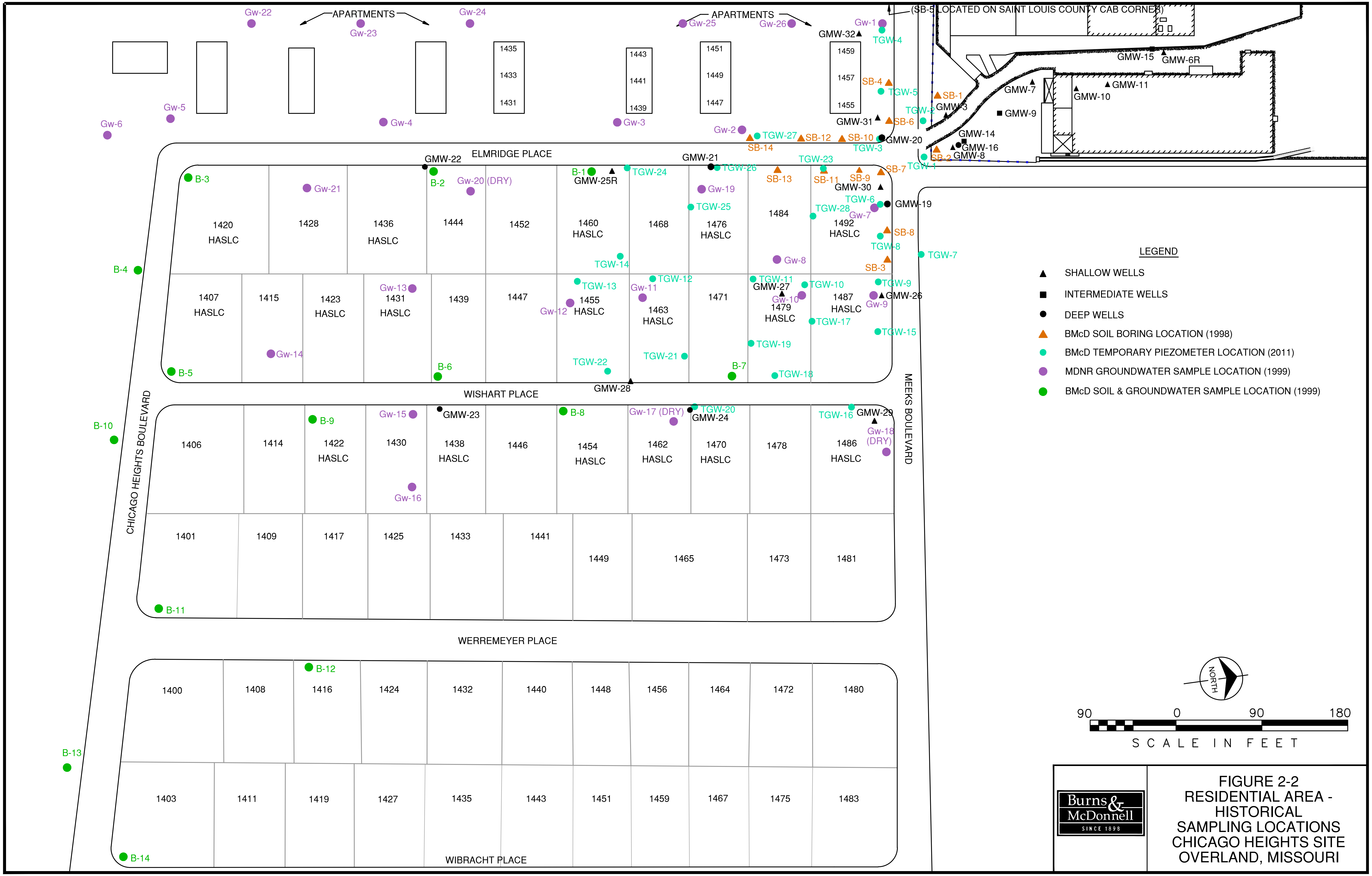
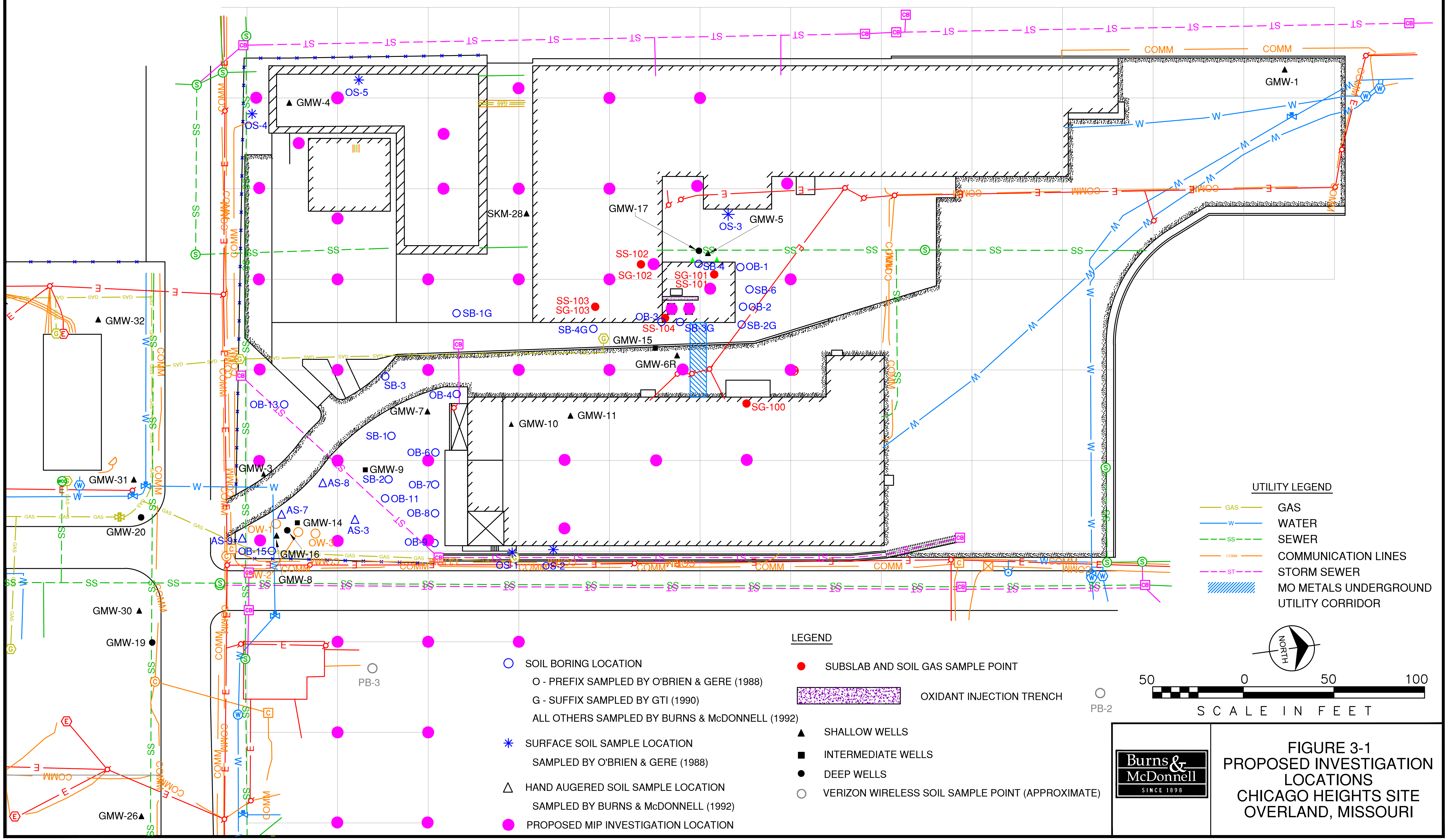


Burns & McDonnell
SINCE 1898

FIGURE 2-2
RESIDENTIAL AREA - HISTORICAL SAMPLING LOCATIONS
CHICAGO HEIGHTS SITE
OVERLAND, MISSOURI



UTILITY LEGEND

GAS	GAS
W	WATER
SS	SEWER
COMM	COMMUNICATION LINES
ST	STORM SEWER
▨	MO METALS UNDERGROUND UTILITY CORRIDOR

LEGEND

○ SOIL BORING LOCATION
O - PREFIX SAMPLED BY O'BRIEN & GERE (1988)
G - SUFFIX SAMPLED BY GTI (1990)
ALL OTHERS SAMPLED BY BURNS & McDONNELL (1992)

✳ SURFACE SOIL SAMPLE LOCATION
SAMPLED BY O'BRIEN & GERE (1988)

△ HAND AUGERED SOIL SAMPLE LOCATION
SAMPLED BY BURNS & McDONNELL (1992)

● PROPOSED MIP INVESTIGATION LOCATION

● SUBSLAB AND SOIL GAS SAMPLE POINT

▨ OXIDANT INJECTION TRENCH

▲ SHALLOW WELLS

■ INTERMEDIATE WELLS

● DEEP WELLS

○ VERIZON WIRELESS SOIL SAMPLE POINT (APPROXIMATE)

50 0 50 100
SCALE IN FEET

Burns & McDonnell
SINCE 1898

FIGURE 3-1
PROPOSED INVESTIGATION LOCATIONS
CHICAGO HEIGHTS SITE
OVERLAND, MISSOURI

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APPENDIX A - HIGH-RESOLUTION DIRECT-PUSH STANDARD OPERATION PROCEDURS

Geoprobe Systems®

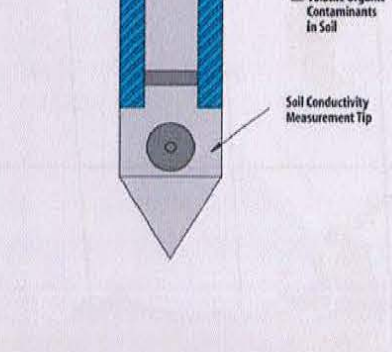
ENVIRONMENTAL • GEOTECHNICAL • GEOTHERMAL • EXPLORATION

Direct Image®

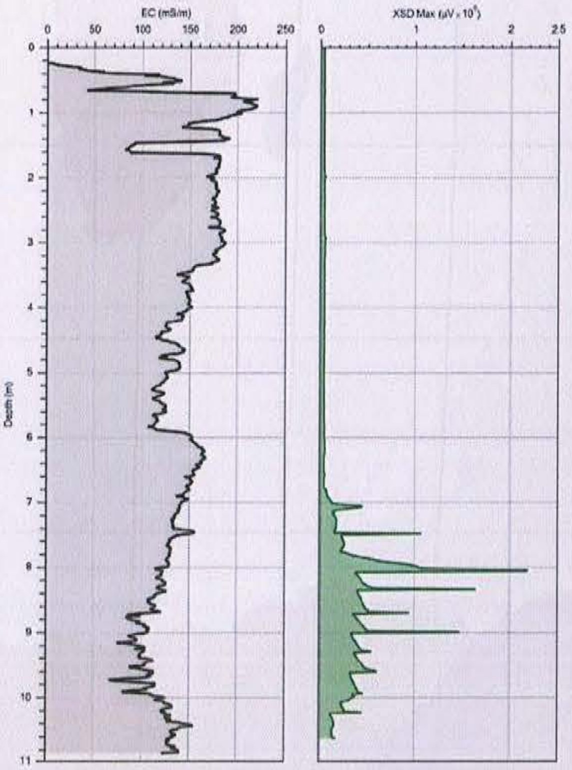
Membrane Interface Probe (MIP)

The MIP was developed by Geoprobe Systems® (U.S. Patent No. 5,639,956) and is presently manufactured and sold exclusively by Geoprobe Systems® and its distribution agents. The MIP has been used extensively in the U.S. and Europe for mapping the extent of VOC contamination in the subsurface. As a logging tool, the MIP offers many benefits to site investigators:

- Useful for detecting and logging both chlorinated and non-chlorinated VOC contaminants.
- Able to detect contaminants in both coarse and fine grained soils.
- Works in both saturated and unsaturated soils.
- The MIP can be either pushed or driven to depth.
- Standard tool configurations combine the MIP with other sensors for lithology or permeability logging.
- Real time contaminant screening information is generated, allowing field adjustment of the site investigation.



An MIP log showing an EC soil log (left) with MIP-XSD contaminant log (right).

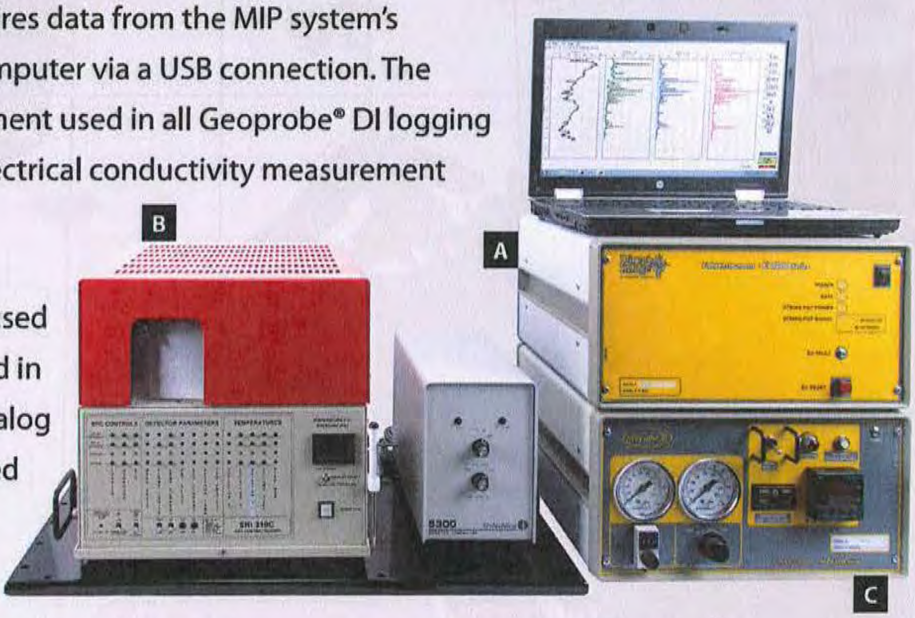


The MIP Principle of Operation. The downhole, permeable membrane serves as an interface to a detector at the surface. Volatiles in the subsurface diffuse across the membrane and partition into a stream of carrier gas where they can be swept to the detector. The membrane is heated so that travel by VOCs across this thin film is almost instantaneous. MIP acquisition software logs detector signal with depth.

Membrane Interface Probe (MIP)

A) FI6000: Data acquisition instrument, acquires data from the MIP system's detectors and sensors and relays it to the computer via a USB connection. The FI6000 is the general data acquisition instrument used in all Geoprobe® DI logging systems (EC and HPT). It also provides the electrical conductivity measurement system associated with MIP.

B) GC1000: This is the platform of detectors used in the MIP System. Standard detectors offered in this system include the PID, FID, and XSD. Analog data outputs from this instrument are directed to the FI6000.



C) MP6500 Series MIP Controller: This instrument regulates and measures gas pressure and flow to the MIP probe and controls heating of the probe. Data from this controller is sent to the FI6000 via a data cable.

Purchasing an MIP System

The MIP system is available exclusively from Geoprobe Systems® and its authorized distributors. Please contact Geoprobe Systems® (800-436-7762) for a quotation for this equipment. Quotations for MIP equipment will include equipment and services in

the following categories:
- MIP controller and data acquisition system.
- MIP detectors.
- Probes, trunklines, and push hardware.
Training.

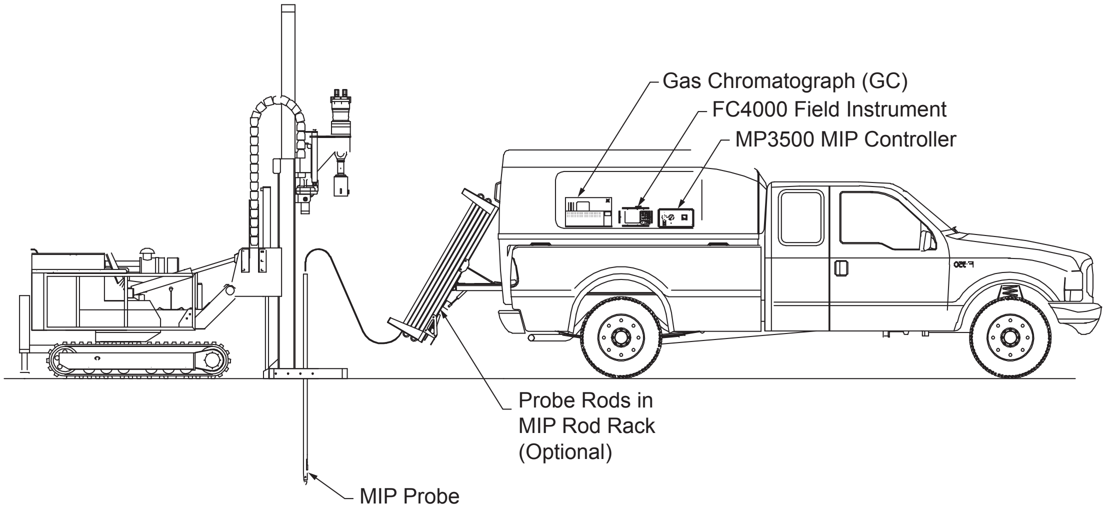
Companies who already operate Geoprobe® EC or HPT systems may already have some of the instrumentation required to operate an MIP system (such as the FI6000 and various probe pushing hardware). Geoprobe Systems® is adamant that all MIP operators receive proper training. This training is designed to teach proper set-up and operation of the MIP system, practice of log Quality Assurance (QA) and Quality Control (QC) procedures, field trouble shooting, and log interpretation. Training is typically designed to include field exercises in MIP logging.

GEOPROBE® MEMBRANE INTERFACE PROBE (MIP)

STANDARD OPERATING PROCEDURE

Technical Bulletin No. MK3010

PREPARED: May, 2003
REVISED: November, 2006



THE MIP SYSTEM MAY BE DEDICATED TO A SINGLE CARRIER VEHICLE FOR USE IN TANDEM WITH MULTIPLE GEOPROBE® DIRECT PUSH MACHINE MODELS

Geoprobe Systems®

A DIVISION OF KEJR, INC.

Geoprobe Systems®

1.0 OBJECTIVE

This document serves as the standard operating procedure for use of the Geoprobe Systems® Membrane Interface Probe (MIP) to detect volatile organic compounds (VOCs) at depth in the subsurface.

2.0 BACKGROUND

2.1 Definitions

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

Membrane Interface Probe (MIP): A system manufactured by Geoprobe Systems® for the detection and measurement of volatile organic compounds (VOCs) in the subsurface. A heated probe carrying a permeable membrane is advanced to depth in the soil. VOCs in the subsurface cross the membrane, enter into a carrier gas stream, and are swept to gas phase detectors at ground surface for measurement.

2.2 Discussion

The MIP is an interface between contaminates in the soil and the detectors at ground surface. It is a screening tool used to find the depth at which the contamination is located, but is not used to determine concentration of the compound. Two advantages of using the MIP are that it detects contamination in situ and can be used in all types of soil conditions.

Refer to Figure 2.1. The MIP is a logging tool used to make continuous measurements of VOCs in soil. Volatile compounds outside the probe diffuse across a membrane and are swept from the probe to a gas phase detector at ground surface. A log is made of detector response with probe depth. In order to speed diffusion, the probe membrane is heated to approximately 100° C (212° F).

Along with the detection of VOCs in the soil, the MIP also measures the electrical conductivity of the soil to give a probable lithology of the subsurface. This is accomplished by using a dipole measurement arrangement at the end of the MIP probe so that both conductivity and detector readings may be taken simultaneously. A simultaneous log of soil conductivity is recorded with the detector response.

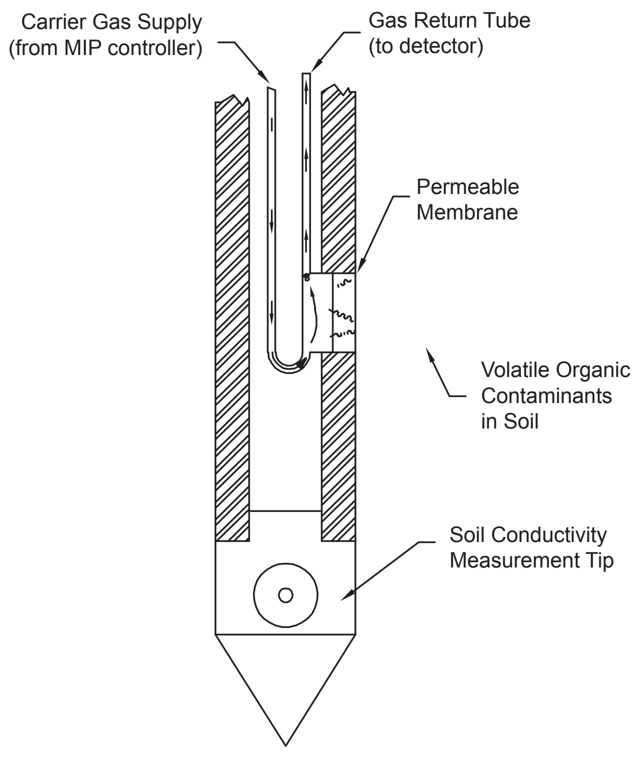


Figure 2.1
Schematic drawing of the MIP probe

3.0 Tools and Equipment

The following equipment is needed to perform and record an MIP log. Basic MIP system components are listed in this section and illustrated in Figure 3.1. Refer also to Appendix I for more required tools as determined by your specific model of Geoprobe® direct push machine.

3.1 Basic MIP System Components

Description	Quantity	Part Number
Field Instrument	(1)	FC4000 / FC5000
MIP Controller	(1)	MP3500 / MP6500
MIP/EC Acquisition Software	(1)	MP3517
MIP Probe	(1)	MP4510 / MP6510
Replacement Membrane	(1)	MP3512
Membrane Wrench	(1)	16172
LB Sample Tube (MP4510)	(1)	AT6621
Stringpot (linear position transducer)	(1)	SC160
Stringpot Cordset	(1)	SC161
MIP O-ring and Service Kit	(1)	MP2515
MIP Trunkline, 100-ft (30 m) length	(1)	MP2550
Extension Cord, 25-ft (8 m) length	(1)	SC153
Needle Valve	(1)	13700
24-in. Nafion Dryer Tube	(1)	12457
Drive Cushion*	(1)	23321
MIP Connection Tube (MP6510)	(1)	20701

3.2 Anchoring Equipment

Description	Quantity	Part Number
Soil Anchor, 4.0-in. OD flight	(3)	10245
Anchor Foot Bridge	(1)	10824
Anchor Plate	(3)	10167
GH60 Hex Adapter (if applicable)	(1)	10809
Chain Vise	(3)	10075

3.3 Optional Accessories

Description	Quantity	Part Number
MIP Trunkline, 150-ft (46 m) length	(1)	13999
MIP Trunkline, 200-ft (61 m) length	(1)	15698
FID Compressed Air System	(1)	AT1004
Hydrogen Gas Regulator	(1)	10344
Nitrogen Gas Regulator	(1)	13940
Cable Rod Rack, for 48-in. rods	(1)	18355
Rod Cart Assembly, for 1.25-in. OD rods	(1)	SC610
Rod Cart Hitch Rack, for SC610	(1)	SC650K
Rod Cart Carrier, for SC610	(1)	SC675
Rod Wiper, for 5400 Series foot	(1)	AT1255
Rod Wiper, for 66 Series foot	(1)	18181
Rod Grip Pull Handle, for GH40 hammer	(1)	GH1255
Rod Grip Pull Handle, for GH60 hammer	(1)	9641
Water Transport System	(1)	19011

*For Geoprobe® 66- and 77-Series Direct Push Machines only.

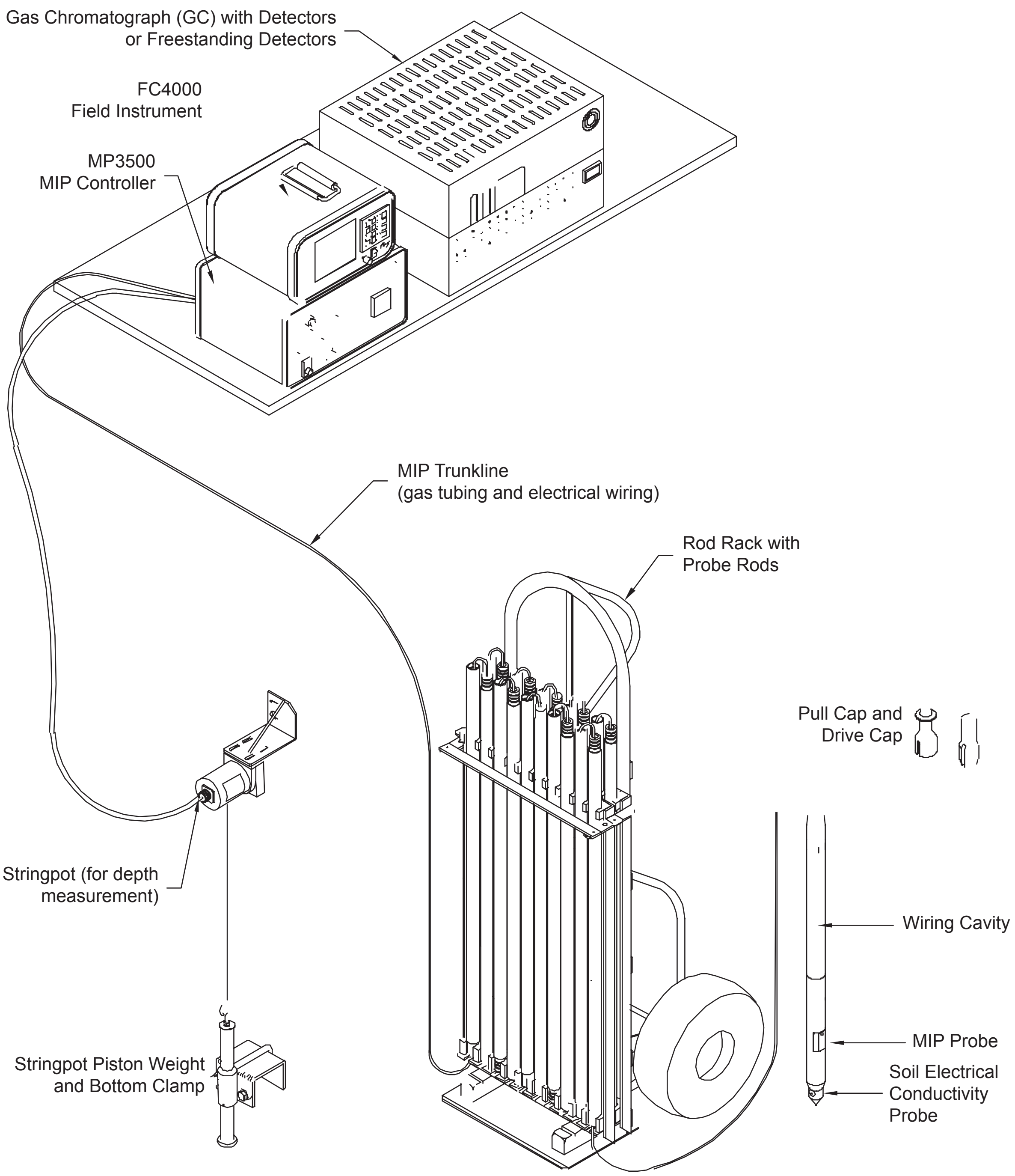


Figure 3.1
MIP system components

4.0: Quality Control - Response Testing

Response testing is an important quality control measure used to validate each log by proving that the integrity of the system is intact. Without running a response test, the operator will not know if the system is detecting the correct compounds or even if the system is working.

4.1 Preparation for Response Testing

Response testing is a necessary part of the MIP logging process because it ensures that the entire system is working correctly and also enables the operator to measure the trip time. Trip time is the time it takes for the contaminant to go from the probe, through the trunk line, and to the detectors. This time will need to be entered into the MIP software for depth calculations as described later in this document.

The following items are required to perform response testing:

- Neat sample of the analyte of interest (i.e.: benzene, TCE, PCE, etc.) purchased from chemical vendor
- Microliter syringes
- 25- or 50-mL Graduated cylinder
- Several 40-mL VOC vials with labels
- Testing cylinder made from a nominal 2-in. PVC pipe with a length of 24 in.
- 0.5 L plastic beaker or pitcher
- 25 mL Methanol
- Supply of fresh water, 0.5 L needed per test
- 5-gallon bucket filled with fine sand and water
- Stopwatch

Preparation of the stock standard is critical to the final outcome of the concentration to be placed into the testing cylinder.

1. Pour methanol into graduated cylinder to the 25 mL mark.

2. Pour 25 mL of methanol from graduated cylinder into 40-mL VOC vial.

3. Mix appropriate volume of desired neat analyte into 40-mL VOC vial containing 25 mL of methanol. The required volume of neat analyte for five common compounds is listed in Column 3 of Table 4.1. Use the equation at the then of this section to calculate the appropriate neat analyte volume for other compounds of interest.

4. Label the vial with name of standard (i.e. TCE, PCE, Benzene), concentration (50 mg/mL), date created, and created by (your name). This is the Stock Standard.

The equation used for making a stock standard is shown on the following page.

Table 4.1
Density and required volumes of neat compounds used to make a 50 mg/mL working standard into 25 ml of methanol

Compound	Density (mg/uL)	Volume of Neat Analyte Required to Prepare a Working Standard (uL)
Benzene	0.8765	1426
Toluene	0.8669	1442
Carbon Tetrachloride	1.594	784
PCE	1.6227	770
TCE	1.4642	854

4.0: Quality Control - Response Testing

Response testing is an important quality control measure used to validate each log by proving that the integrity of the system is intact. Without running a response test, the operator will not know if the system is detecting the correct compounds or even if the system is working.

4.1 Preparation for Response Testing

Response testing is a necessary part of the MIP logging process because it ensures that the entire system is working correctly and also enables the operator to measure the trip time. Trip time is the time it takes for the contaminant to go from the probe, through the trunk line, and to the detectors. This time will need to be entered into the MIP software for depth calculations as described later in this document.

Table 4.2
Volume of 50 mg/mL working standard and final concentration in 0.5 L test sample volume

Volume of 50 mg/mL Standard	Final Concentration of 0.5 L Sample (mg/L or ppm)
1000 uL	100
100 uL	10
10 uL	1

The following items are required to perform response testing:

- Neat sample of the analyte of interest (i.e.: benzene, TCE, PCE, etc.) purchased from chemical vendor
- Microliter syringes
- 25- or 50-mL Graduated cylinder
- Several 40-mL VOC vials with labels
- Testing cylinder made from a nominal 2-in. PVC pipe with a length of 24 in.
- 0.5 L plastic beaker or pitcher
- 25 mL Methanol
- Supply of fresh water, 0.5 L needed per test
- 5-gallon bucket filled with fine sand and water
- Stopwatch

Preparation of the stock standard is critical to the final outcome of the concentration to be placed into the testing cylinder.

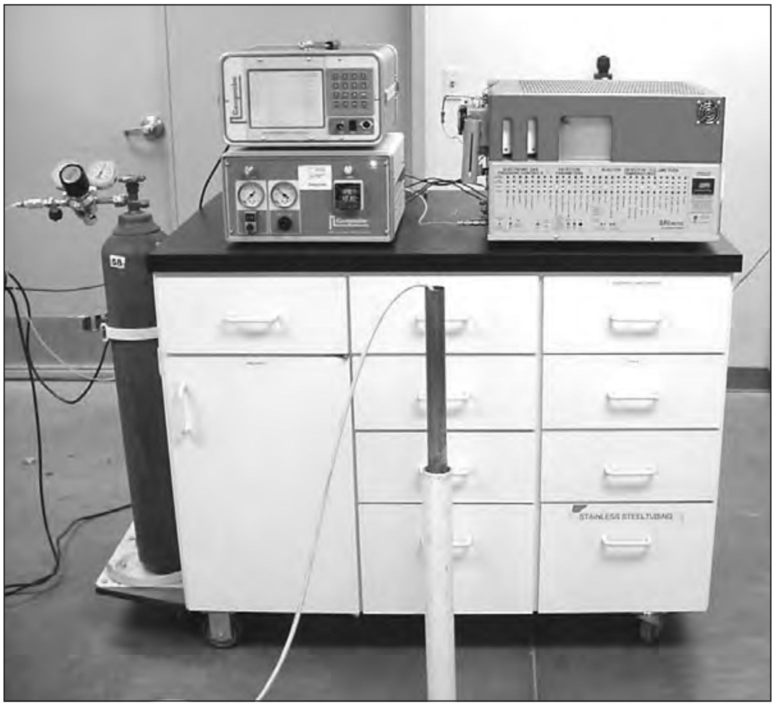


Figure 4.1
The MIP probe is placed in a PVC pipe containing the standard solution.

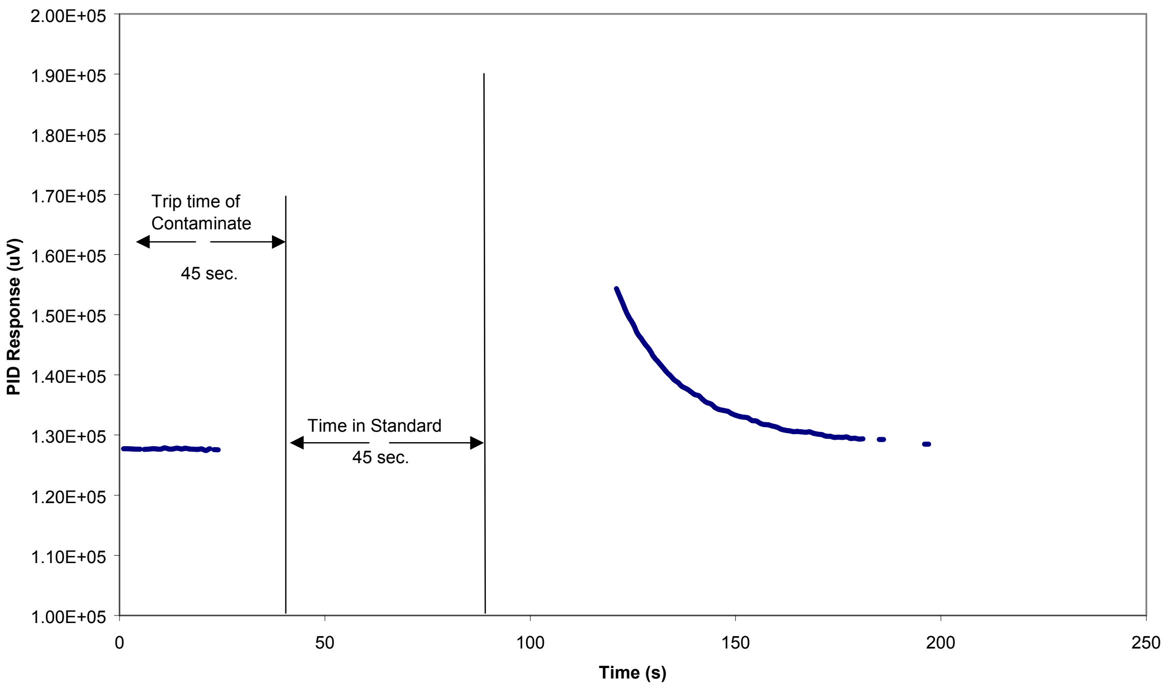


Figure 4.2
SRI PID Response Test - 10 ppm Benzene

5.0 Field Operation

1. Power on the generator.

2. Turn on any gases that will be used for the MIP system (i.e. nitrogen carrier gas, hydrogen for the FID, etc.). Check the flow rate of the system and psi on the mass flow controller. Compare these numbers to previous work.

3. Power on the detector or detectors and allow to warm up to set temperature (approximately 30 minutes).

4. Power on the MIP Controller.

5. Power on the computer or the Field Instrument.

6. Advance a pre-probe 3 to 4 feet into the subsurface at the location to be logged.

7. Remove the pre-probe and raise the probe foot of the direct push machine.

8. If advancing the MIP with percussion, raise the probe foot enough to slide the rod wiper plate underneath.

9. If pushing only, turn the desired amount of anchors into the subsurface and return the probe foot to the position from which the pre-probe was advanced. Leave the probe foot raised sufficiently to allow sliding the rod wiper underneath.

10. Place the rod wiper plate under the foot such that the opening is directly over the pre-probed hole. Lower the foot firmly onto the rod wiper.

11. If pushing only, position the anchoring bridge over the foot of the machine such that the anchors extend through the holes in the bridge (fig. 5.1). Install a chain vise at each anchor to secure the bridge.

12. With the software loaded, run a response test (Section 4.0) and record the height of the peak response and the trip time into a field notebook. Refer to Figure 4.2.

13. Enter the trip time obtained during response testing.

14. Attach a slotted drive cap to the MIP drive head.

15. Insert the MIP point into rod wiper opening and drive it into the soil until the membrane of the probe is at ground level.

16. Connect the stringpot cable to the stringpot weight located on the probe foot and pull keeper pin so the weight drops to the ground.

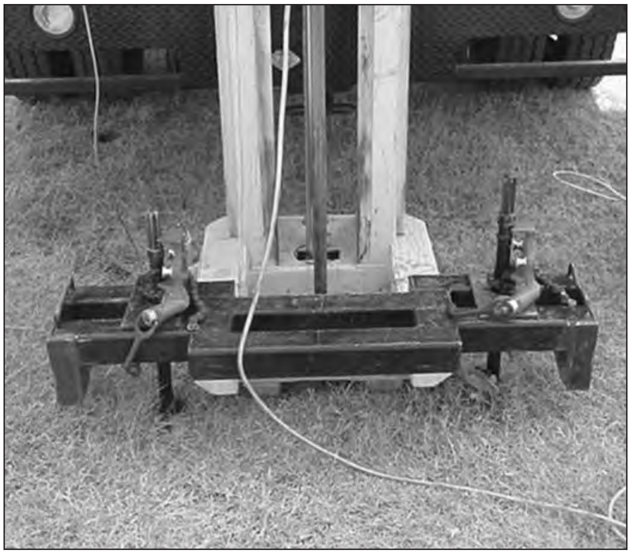


Figure 5.1
Anchor the probe foot to allow advancement of MIP probe by push only (no percussion).

NOTE: **Do not allow the stringpot cable to retract into the stringpot housing at a high rate. This will ultimately damage the stringpot.**

17. Record the system parameters in a field notebook at this time (i.e.. mass flow, trip time).

NOTE: **If the mass flow reading drops or rises more than one psi, turn off the flow at the primary controller and remove the probe from the ground. If the temperature monitor quits heating or gives an error, remove the probe from the ground.**

18. Place the trigger switch in the "ON" position.

19. Advance the probe at a rate of 1 ft/min to the predetermined log depth or until refusal is attained.

20. When the MIP log is complete, turn the trigger off and slowly return the stringpot cable into the stringpot housing.

21. Pull the probe rod string using either the Geoprobe® rod grip pull system or a slotted pull cap.

22. When the MIP reaches the surface, clean the face with water and run a response test. This response test should be written down in the field notes and compared to the initial test. This system check ensures the data for that log is valid.

23. Save the data to a 3.5-inch floppy disk or CompactFlash® card and exit the MIP software.

24. Data from the MIP can now be graphed with Direct Image® MIP Display Log or imported into any spreadsheet for graphing.

6.0 Replacing a Membrane on the MIP Probe

A probe membrane is considered in good working condition as long as two requirements are met: 1) The butane sanity test result is greater than 1.0E+06 uV response, 2) Flow of the system has not varied more than 3 mL/min from the original flow of the system (a flow meter or bubble flow meter should be kept with the system at all times). If either one of these requirements are not met, a new face must be installed as follows.

1. Turn the heater off and allow the block to cool to less than 50° C on the control panel readout.
2. Clean the entire heating block with water and a clean rag to remove any debris.
3. Dry the block completely before proceeding.
4. Remove the membrane using the membrane wrench (Fig. 6.1). Keep the wrench parallel to the probe while removing the membrane to ensure proper engagement with socket head cap screw.

NOTE: Do Not leave the membrane cavity open for extended periods. Debris can become lodged in the gas openings in the plug.

5. Remove and discard the copper washer as shown in Figure 6.2. Each new membrane is accompanied by a new copper washer. **Do not reuse the copper washer**.
6. Inspect the open cavity for any foreign objects. Remove any objects present and clean the inside of cavity of any soil that was deposited on the wall of the block.
7. Insert the new copper washer around the brass plug making sure that it sits flat on the surface of the block.
8. Install the new membrane by threading it into the socket. Use the membrane wrench to tighten the membrane to a snug fit. Do not overtighten.
9. Turn the gas on and leave the heater off. Apply water to the membrane and surrounding area to check for leaks. If a leak is detected (bubbles are formed in the water), use the membrane wrench to further tighten the membrane.
10. Use a flow meter/bubble flow meter to check flow to the detectors. Record this value in a field notebook.

Figure 6.1
Unthread the membrane from the probe block.

Figure 6.2
Remove and discard the copper washer.

Appendix I: Tools for Various Direct Push Machines

Model 5400 and 54DT Direct Push Machines

Description	*Part Number*
Stringpot Mounting Bracket	SC110
Stringpot Bottom Clamp	SC111
Stringpot Piston Weight	SC112
Slotted Drive Cap, for 1.25-in. rods	AT1202
Slotted Pull Cap, for 1.25-in. rods	AT1203
MIP Drive Adapter, for 1.25-in. rods	MP2512
MIP Drive Head	GW1516
Probe Rod, 1.25-in. x 48-in.	AT1248

Model 54LT Direct Push Machine

Description	*Part Number*
Stringpot Mounting Bracket	11433
Stringpot Bottom Clamp	SC111
Stringpot Piston Weight	SC112
Slotted Drive Cap, for 1.25-in. rods	AT1202
Slotted Pull Cap, for 1.25-in. rods	AT1203
MIP Drive Adapter, for 1.25-in. rods	MP2512
MIP Drive Head	GW1516
Probe Rod, 1.25-in. x 48-in.	AT1248

Model 5410 Direct Push Machine

Description	*Part Number*
Stringpot Piston Weight	SC112
Slotted Drive Cap, for 1.25-in. rods	AT1202
Slotted Pull Cap, for 1.25-in. rods	AT1203
MIP Drive Adapter, for 1.25-in. rods	MP2512
MIP Drive Head	GW1516
Probe Rod, 1.25-in. x 48-in.	AT1248

Model 6600, 66DT and 6610DT Direct Push Machines

Description	*Part Number*
Stringpot Mounting Bracket	16971
Stringpot Bottom Clamp	11751
Stringpot Piston Weight	SC112
Slotted Drive Cap, for 1.5-in. rods	15607
Slotted Pull Cap, for 1.5-in. rods	15164
Drive Cap Adapter, for GH60 and 1.25-in. rods	15498
MIP Drive Adapter, for 1.5-in. rods	18563
MIP Friction Reducer	18564
Probe Rod, 1.5-in. x 48-in.	13359

Geoprobe Systems®

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Geoprobe Systems®

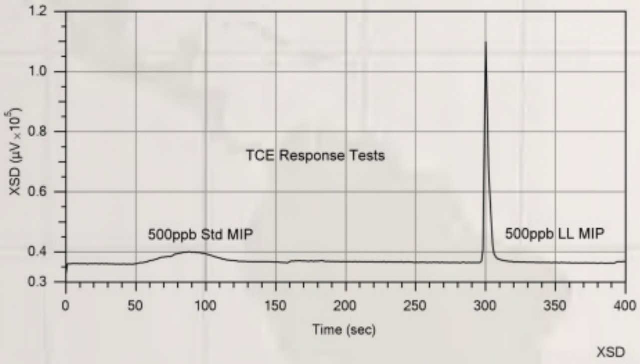
ENVIRONMENTAL • GEOTECHNICAL • GEOTHERMAL • EXPLORATION

Direct Image®

Low Level Membrane Interface Probe (LLMIP)

Low Level MIP (LL MIP) is a technology developed by Geoprobe Systems® that greatly increases the sensitivity (and therefore utility) of the MIP logging tool. The primary feature of LL MIP technology is that the carrier gas stream that sweeps the internal surface of the MIP membrane is pulsed. This results in an increase in the concentration of VOC contaminant delivered to the MIP detectors.

Low Level MIP can be performed with standard MIP probes, MiHpt probes or with MIP-CPT probes. To perform this method an operator will need to add the MP9000 Pulse Flow Controller along with an updated version of the FI6000 acquisition software to the current MIP system. The addition of the MP9000 to the system is simple and requires only the rearrangement of gas line connections. This controller can then be easily removed from the system to return to standard MIP logging. Switching between methods requires only a few minutes of time.



Comparison of 0.5ppm TCE response between standard (50-100s) and Low level (300s) MIP methods

MP9000 Pulse flow controller (patent pending)

The LL MIP method will greatly increase the sensitivity of a MIP system but the resulting detection limits are dependent on the sensitivity of the detectors. To achieve the lowest possible detection limits the probe and trunkline need to be new or verified clean with a system blank. The detectors also need to be fully current within their maintenance program and sensitivity should be tested prior to mobilization. Equipment that has been used to map high level contaminants will result in false positive results due to contaminant desorption from the membrane and return carrier gas line.

Low Level MIP Operation

Description

The low level (LL) MIP method works due to special management and control of the trunkline system carrier flows. In standard MIP operation, the carrier gas continually sweeps across the membrane transporting contaminates to the detectors at the surface. In the LL MIP method, the trunkline sweep flow is temporarily stopped when the MIP probe is brought to rest at a discrete depth in the soil. Stopping the sweep gas flow allows the contaminant concentration to build behind the membrane. This results in a larger and narrower contaminant response peak at the detectors for a given chemical concentration (Figure 1). Switching valves located inside the MP9000 create separate flow paths for the MIP trunkline and detectors; trunkline flow can be stopped and restarted without impacting detector baseline or stability. When the trunkline flow is restarted the contaminant mass (peak) is quickly swept to the surface with a trunkline flow rate of approximately 60ml/min. and is routed to the detectors via a sample loop located in the MP9000. Figure 1 shows the difference of standard and LL MIP response levels.

In the LL MIP mode the trunkline carrier gas is vented out most of the time, only during a very short period is the carrier gas present in the trunkline diverted to the sample loop and then redirected to the detectors.

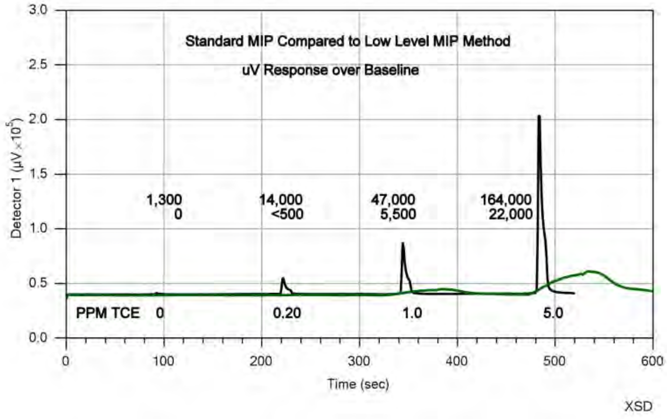


Figure 1: Standard vs. Low level MIP Response

Explanation of Times: These times all refer to the trunkline carrier gas and the position of the contaminant peak.

No Flow Time: The no-flow time is the amount of time you choose to wait at each sampling interval with the trunkline flow turned off. During this time the sample is being collected as contaminants diffuse through the membrane and build into a large contaminant "slug". The no flow time is typically set between 30-45 seconds. When the rig operator reaches the interval to sample and the ROP goes to zero for the set amount of time the software will start the LL cycle. This can also be accomplished in manual mode by turning the TL flow switch off and back on after the desired no wait time has expired.

Load Loop Time: This is the amount of time that the sample loop is exposed to the trunkline carrier gas. The load loop time is typically set to 10 seconds for a 30 foot sample loop since it will take the peak approximately 6 seconds to travel through the sample loop at 60ml/min. The sample loop will be opened to the trunkline carrier gas for the last 10 seconds of the inject time, just prior to the arrival of the peak and then when the peak is inside the loop the gas inside will be "injected" to the GC. This can be accomplished in manual mode by turning the sample valve switch to loop 10 seconds prior to the expiration of the inject time (20sec after the trunkline flow has been restarted). With a load loop time set at 10seconds the valve will always open the sample loop up to the trunkline 10 seconds before the end of the inject time regardless of what the inject time is set to.

Inject Time: This is the amount of time after the trunkline flow has been restarted that the valve switches back to the inject mode and directs the contents of the sample loop to the detectors. This is the most important time setting since if this is not set correctly you will not "see" the response because. In manual mode this is done by turning the sample valve switch back to vent 30second after the restart of trunkline flow.

Setup

Setup of the low level system is all done with management of the gas line connections which are located on the back of the instrument (Figure 2). There is a section for trunkline gas connections and a section specific for detector connections. Also the rear of the instrument has connections for power and USB communication to the operator's laptop.

Figure 2: MP9000 Controller – Back of instrument

Trunkline Connections-

- MIP Supply Gas In: A 1/8" Swagelok bulkhead that is connected to the MIP controller regulated output.
- Trunkline Out: A 1/16" Swagelok bulkhead that either connects directly to the trunkline supply line or to the supply line via a transfer line.
- Trunkline In: A 1/16" Swagelok bulkhead that either connects directly to the trunkline return line or via a transfer line.

Detector Connections-

- Detector In: A 1/8” Swagelok bulkhead that is connected to a regulated Nitrogen source, typically from a pressure controller in the gas chromatograph. The flow rate should be set between 20-30ml/min. This provides a constant gas flow to the detectors and provides for a stable baseline.
- Detector Out: A 1/16” Swagelok bulkhead that connects the LL MIP controller to the gas chromatographs inlet to the detectors, typically leading into the Nafion Dryer.

Figure 3: MP9000 Controller – Front of instrument

Front panel switches and buttons:

- Auto/Manual Switch: This switch is located on the line between auto and manual blocks on the front of the MP9000 controller (Figure 3). To operate LL MIP in automated mode making use of the automated features in the DI Acquisition software this switch must be to the left with the auto light lit. When the controller is powered up and this is in auto mode, the operator can start the LL Mode by opening the DI Acquisition software and before starting a log, open the sensors tab on the top of the page and click ‘Low level mode”
- Sample Valve Switch will switch the 6 port valve between its 2 positions. In vent mode the trunkline carrier gas is being vented and the detector gas is sweeping through the sample loop on its way to the detectors. In Loop mode the trunkline gas is directed to the sample loop.
- Trunkline Flow Switch manually shuts off and turns back on the trunkline flow.
- Bypass switch diverts the all trunkline carrier gas from being vented to go through the sample loop and onto the detectors. The function of the bypass mode is to ensure a path where all trunkline gas is delivered to the detectors which will allow us determine when the peak will be inside the sample loop. The sample valve is not changed during this mode which is used for peak timing in the LL method.

Both the sample valve switch and the trunkline flow switch only operate in manual mode. No connection is made with these switches during automated operation. The bypass switch is operational in both the automated and manual modes.

Manual Operation:

To operate in manual mode the MIP operator will be stuck at the control panel of the MP9000 with a stopwatch in hand and the MP9000 will be set to manual mode with the trunkline flow on and the sample valve in the vent position. When the rig operator reaches the target sample depth the trunkline flow switch will be flipped to the “off” position. After a no flow time of 35-45 seconds the trunkline flow switch is turned “on” and the stopwatch started. Using the times listed for a 100’ Peek trunkline and 60ml/min TL flow rate, the sample valve switch changed to the “loop” position after 20 seconds and back to vent after 30 seconds have passed since the restarting of the trunkline flow. This process will be repeated at each sampling interval.

Setting Flows

Typical flow rates for the trunkline when operating the LL MIP method would be 60ml/min when using a 100’ TL. Higher TL flows rates will lower the window times and the optimal injection time. Lower TL flow rates will raise the window times and the optimal GC injection times. There is some benefit – reduced injection time (Table 1) which means less time on the hole but not as much as with the longer trunklines. 150’ trunklines or especially 200’ trunklines would see a good reduction in the injection time for the software and reduced time spent waiting on the hole. Also note that increasing the trunkline flow will reduce the amount of time the contaminant slug will be in the sample loop which reduces the sample loop window.

The detector gas flow should be set to between 20-30ml/min. This is the carrier gas stream that is continually flowing across the detectors whether or not the TL gas is flowing.

	100’ Peek TL			150’ PEEK TL	
TL Flow Rates	Sample Loop Window	Optimal Inject Time		Sample Loop Window	Optimal Inject Time
60	27-33sec	30sec		42-48sec	45sec
80	24-27sec	25sec		30-35sec	33sec

Table 1: Approximate injection times for the 100’ and 150’ PEEK trunklines.
Use only as a guide and determine your own injection window.

Setting your timing Based upon 60ml/min TL flow and 100’ PEEK TL

No Flow Time	30-45 sec
Load Loop Time	10 sec
Inject Time	30 sec

Table 2: LL MIP Timing Guide

Using the times above:

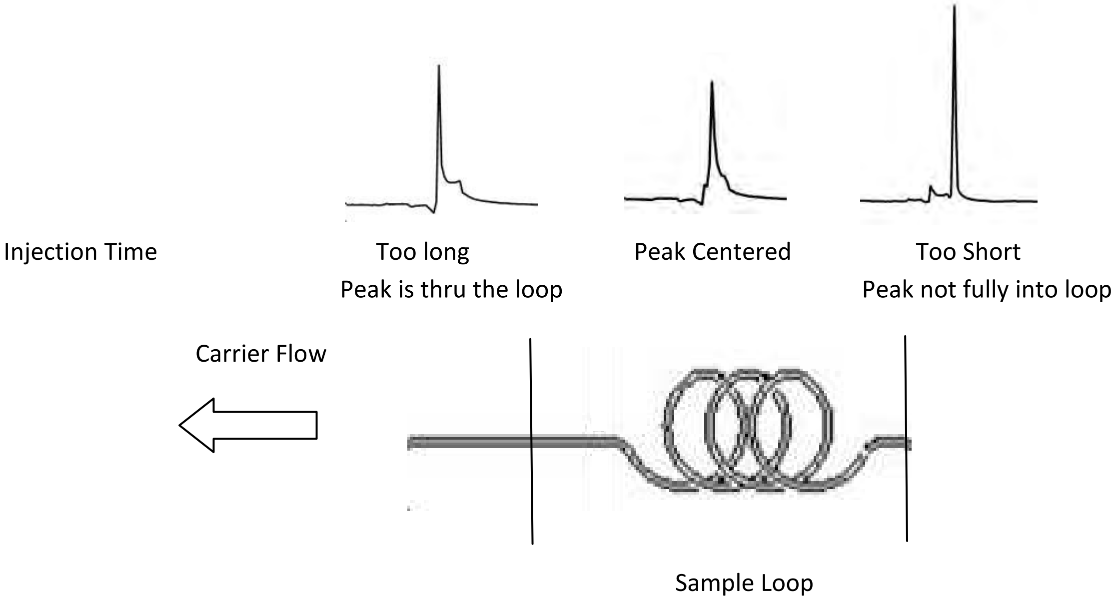
Input the times from Tables 1&2 into the LL MIP software input screen for the appropriate trunkline and carrier flow rate and validate them. Now run a response test (1ppm is a good level to start with) and see if you get a response, if you get a response you will need to determine your specific response window so you can know your optimal injection time. If you do not get a response or the peak shape looks strange use the sample loop window determination guide below to help decide how much time to add or subtract from the inject time setting.

Using the bypass mode:

To set the times, have the system set to automatic mode and bypass off. Set the no flow time to 35seconds, TL Load Loop 10seconds, and inject time 30seconds. Expose the membrane to a standard and hit the start button (have a stopwatch ready). When the trunkline flow restarts – start the stopwatch. Now flip the bypass switch from off to on which ensures that all of the trunkline flow goes to the detectors and is not vented off. Stop the timer when the response reaches the detectors. From this time you will need to subtract approximately 12seconds, when a 30’ sample loop is used – this will be your inject time. (12 seconds is the approximate additional time from the center of the loop to the detectors) If the timer read 42seconds then your inject time to try would be 30seconds. Reset the bypass switch to the off position and re-run the response test fully using your set times. If you do not get a response or the peak shape looks strange use the sample loop window determination guide below to help decide how much time to add or subtract from the inject time setting.

Sample loop Injection time window determination:

You will want to make sure you know your response time window so that you can ensure the peak will be centered in the sample loop when you switch to inject to the GC. This can be done by adjusting with the inject times so you can observe the back side of the peak with mostly a peak tail shorten the injection time by about 6-7seconds and then just the peak front will be observed. These will be the outer limits of your injection time window, split these and your peak will be centered for greatest logging confidence. Be sure to record what your trunkline supply flow is and keep a close eye on this, making adjustments when needed. If the trunkline carrier flow lowers by a >5 ml/min the peak will eventually fall outside of the sample loop window and the peak will be missed.

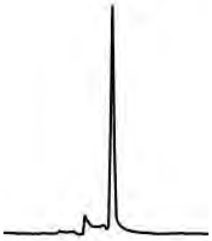


Example peaks where the injection time is set too short – the peak is not in or centered in the sample loop

⇦ Carrier Flow


No Peak not in loop at all
Increase Inj. Time 3-4 sec

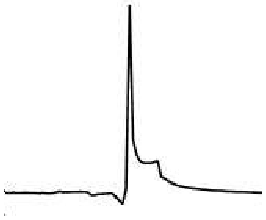
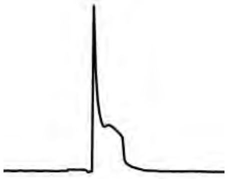

Peak just entering loop
Increase Inj. Time 3 sec


Peak in loop but on the edge
Increase Inj. Time 2-3 sec

If there appears to be a peak tail response, the peak moved through the sample loop and we are seeing the peak remnants. You will need to subtract 3-4 seconds off of the current inject time and re-run the response test.

Example peaks where Injection time is set too long – the peak is through the sample loop

⇦ Carrier Flow

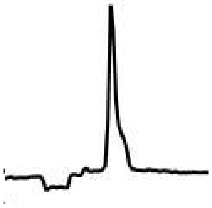


Peaks have mostly past thru loop
Reduce Inj. Time 3 sec
Reduce Inj. Time 3 sec


Peak thru loop only tail showing
Reduce Inj. Time 4 sec

Example peaks with a properly set Injection time resulting in a peak centered in the sample loop

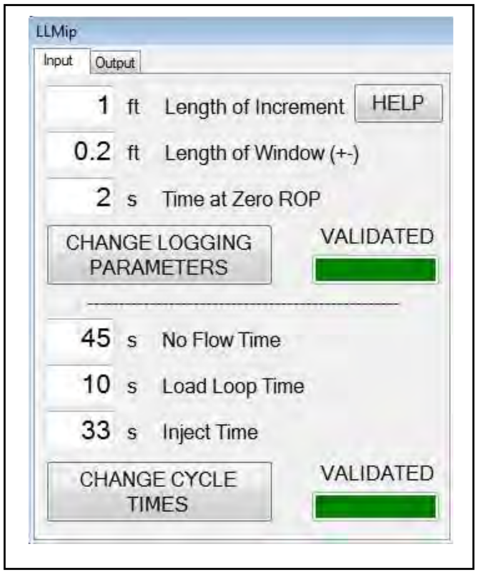
⇦ Carrier Flow





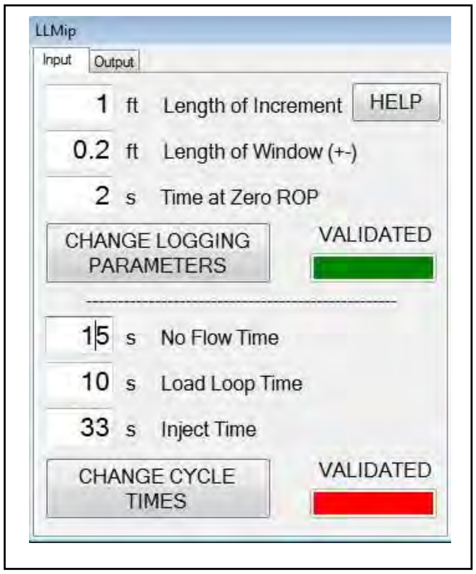
LL MIP DI Acquisition Software

LL MIP Input screen



1 ft Length of Increment
0.2 ft Length of Window (+-)
2 s Time at Zero ROP
VALIDATED 🟩
45 s No Flow Time
10 s Load Loop Time
33 s Inject Time
VALIDATED 🟩

Figure 4: LL MIP Input Screen



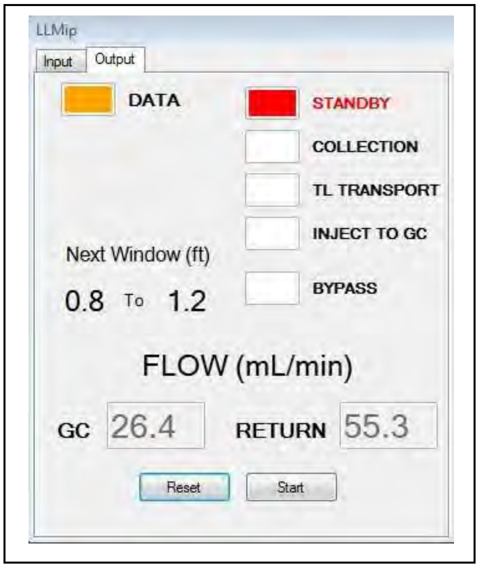
1 ft Length of Increment
0.2 ft Length of Window (+-)
2 s Time at Zero ROP
VALIDATED 🟩
15 s No Flow Time
10 s Load Loop Time
33 s Inject Time
VALIDATED 🟥

Figure 5: LL MIP Input Screen

The top parameters of the LL MIP input screen are for the frequency of the sampling event. In this case (Figure 4) the system is running the LL cycle every 1’. When the probe is advanced to 1’ ± 0.2’ and the probe advancement stops for 2 seconds in that window the LL cycle will run.

The lower section of the input screen displays the LL MIP timing events as described before. The “no flow time” is the sample collection at the probe membrane with the trunkline carrier flow turned off (45sec). The “load loop time” is the time after the restarting of the trunkline flow that the sample loop is opened to the trunkline (20 sec). The “inject time” is the amount of time after the restarting of the trunkline flow when the valve is switched to inject the contents of the sample loop to the detectors.

Any of these values can be changed so long as the software is not in the middle of a cycle. To change the values, simply type over the entered values, this will create a red code on the validation (Figure 5), when the changes are complete click on the “change cycle times” button and the validated sign will turn from red to green.



DATA
STANDBY
COLLECTION
TL TRANSPORT
INJECT TO GC
BYPASS
Next Window (ft)
0.8 To 1.2
FLOW (mL/min)
GC 26.4
RETURN 55.3

The output screen is where you can see the status of the LL cycle. These status descriptions all refer to the position of the contaminant slug.

- Standby - ready start next cycle
- Collection - TL flow off – collection at the membrane
- TL transport - TL flow on sample moving up the trunkline.
- Inject to GC - valve switched sending the contaminant slug to the detectors.
- Bypass – sends all of the gas in the trunkline to the detectors.

When the data light blinks orange the system is in communication with the control box. The next window indicates the depth window to target for the next sample collection. Gas flows of GC detector flows and the trunkline return flows can be observed here.

Setting the Trip Time of the log:

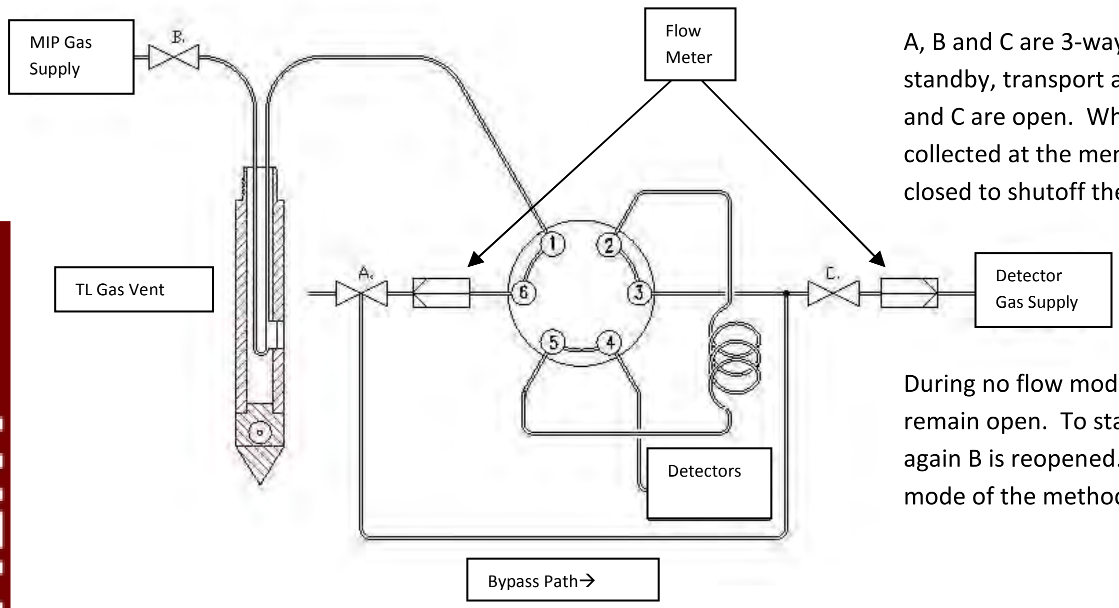
Regardless of the length of trunkline used the trip time should be set to about 45seconds. It will take approximately 20seconds for the sample to be transported from the sample loop to the detectors. The MIP probe advancement to the next sampling interval may begin prior to the completion of the low level cycle as described in the next section, so setting the contaminant trip time to 45seconds will ensure that the contaminant response gets assigned to the depth that it was acquired from. If the trip time is set too long, say from the beginning of the sample collection or no flow time until the detector response then the peak response will begin off and not result in a sharp, typical low level peak. The overall time from the beginning of the no flow time until the detector response may be in the 100 second range, if this value is entered as the trip time then the response likely get assigned by the software at the sample depth previous to the actual depth it was taken from and stretched out to the actual depth.

Probe Advancement:

The MIP probe will be advanced to the sampling interval which begins the low level MIP cycle when the probe is stopped inside the sampling window for the time set in the acquisition software as described previously. The MIP probe must be kept at that interval for the sample collection or no flow time as well as the trunkline transport until the valve switching begins. When the operator hears the first valve switch, opening the sample loop to the trunkline, the direct push operator can begin the probe advancement to the next sampling interval. Not waiting for the cycle to return to standby will provide for some reduction in the overall logging time.

6 Port Valve/Sample Loop Configurations

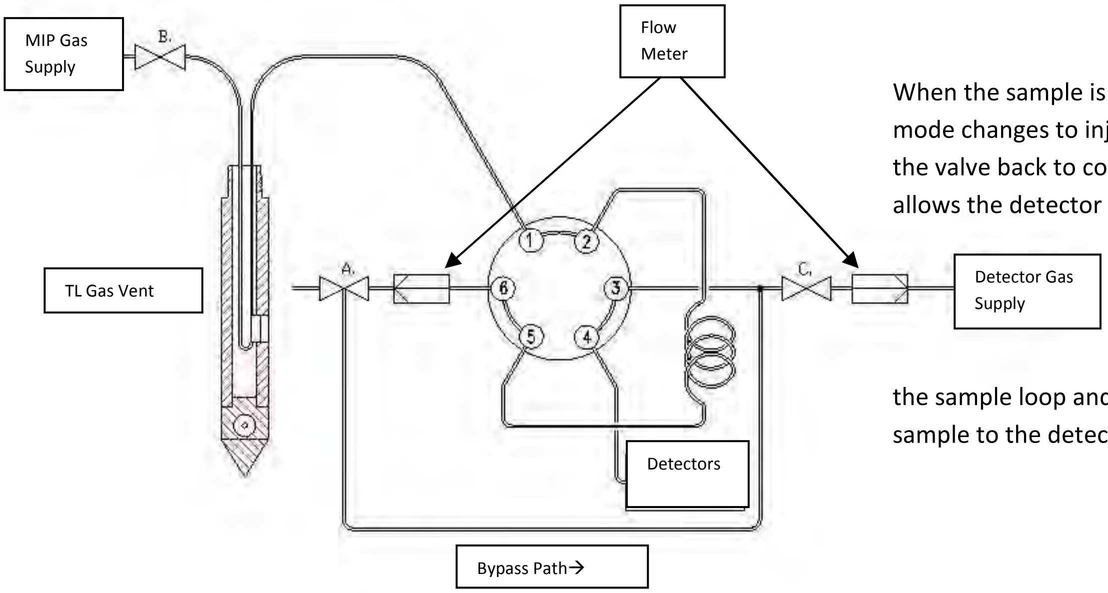
Configuration #1: The trunkline carrier gas is venting out 6-port valve positions 2-1 and exiting out the 3-way shutoff valve A. Clean carrier gas from GC is cycling through the valve positions 3-4, through the sample loop and then valve positions 6-5 to the detectors. This configuration is for modes: standby, no flow, transport and inject.



A, B and C are 3-way shutoff valves. In standby, transport and inject modes A, B and C are open. When samples are collected at the membrane, valve B is closed to shutoff the trunkline gas flow.

During no flow mode shutoff valves A and C remain open. To start the trunkline flow again B is reopened. This is the transport mode of the method.

Configuration #2: As the sample approaches in the trunkline, the 6-port valve is switched allowing the trunkline carrier gas to enter into the sample loop through 6-port valve ports 2-3, the clean carrier gas from the GC is sent directly to the detectors through 6-port valve positions 4-5. This configuration is for the collect mode (sample into sample loop) only.

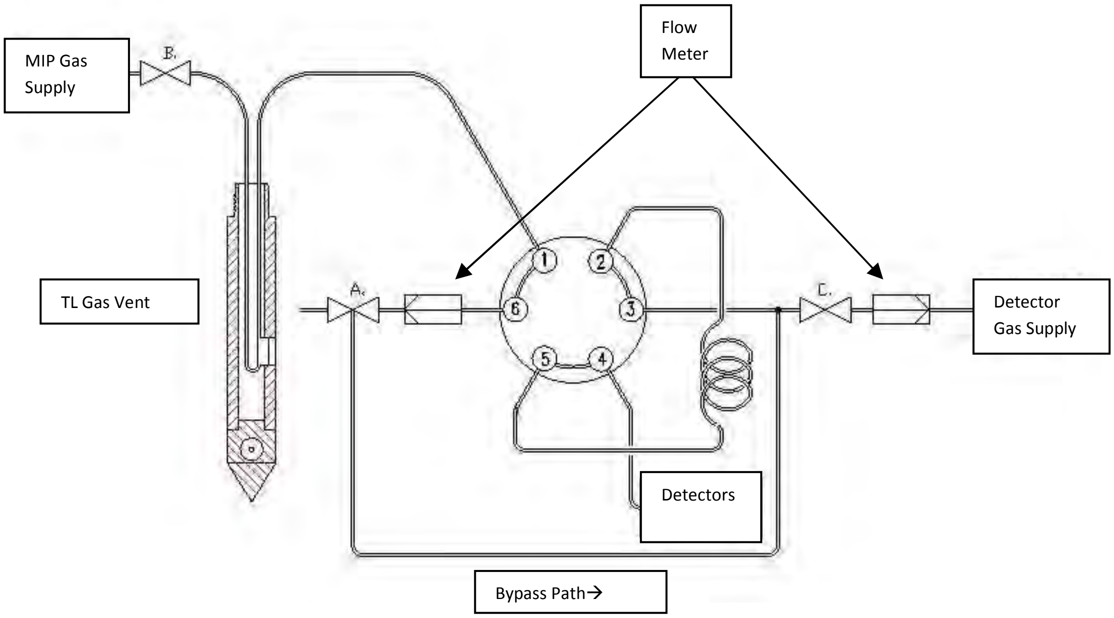


When the sample is in the sample loop the mode changes to inject which will switch the valve back to configuration 1. This allows the detector gas supply to reenter

the sample loop and carry the subsurface sample to the detectors.

6 Port Valve/Sample Loop Configurations

In the bypass mode, 3-way shutoff valves A and C are closed and B is opened. The carrier flow from the trunkline is then sent from shutoff valve A to the bypass path entering the 6-port valve position 4 to 3 then into the sample loop and then through valve positions 6-5 and off to the detectors. The bypass mode allows for easy TL gas timing measurements to be taken.



Direct Image® Electrical Conductivity System (EC) –

Obtain Accurate and Reliable Lithology Information

- Descriptive Log naming via alpha/numeric key pad
- Lithologic logging of unconsolidated soils and sediments in 20 to 30 percent of the time as conventional methods
- ASCII formated data file
- Measures soil conductivity and probing speed simultaneously
- Real time or "On Screen" data logging

Cost-Effective Alternative to Borehole Logging or Cone Penetrometers

- Limited soil sampling required to verify log response
- No drill cuttings generated during the logging process

FI6000 Field Instrument Specifications

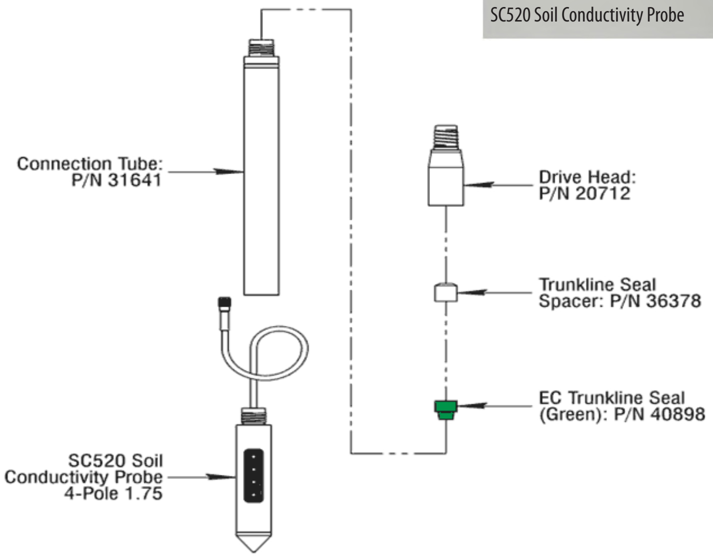
Vertical Resolution	0.05 ft	0.02 m
Data Rate	20 samples per second	
Maximum Depth (with standard cordset)	80 ft.	24 m
Power Requirements	90-230 VAC @ 3A	
Operating System	Embedded DOS	
Dimensions	17 in. x 7.5 in. x 13.5 in. 432 mm x 191 mm x 343 mm	
Weight	18.5 lbs. (8 Kg)	

Finish: Gray molded ABS plastic with yellow front and back overlays. Gray molded ABS plastic front and back transport covers with carrying handles.

SC520 Soil Conductivity Probe

Field Applications

- Determination of the thickness and lateral extent of aquifers, aquitards, and other lithologic units based on electrical conductivity logs
- Construction of geologic cross sections based on EC logs
- Delineation of aquifers and aquitards in the subsurface based on EC logs
- Assist in locating appropriate lateral and vertical placement of wells and well screens
- Construct contour maps on the upper surface of sand formations
- Construct contour maps on the surface of an aquitard or impermeable bedrock contact based on EC logs to determine potential DNAPL flow paths and collection points.
- Construction of isopach maps (thickness) for lithologic units based on EC logs.



Conductivity Probe Specifications

SC520 Array.... Wenner Probe for 1.5 inch probe rods
1.75 in. (44 mm) probe diameter
Wenner - 4 electrodes, 3 in. (76 mm) length
Dipole - 2 electrodes, 1 in. (25 mm) length

SC400 Array.... Wenner Probe for 1.25 inch probe rods
1.5 in. (38 mm) probe diameter
Wenner - 4 electrodes, 3 in. (76 mm) length
Dipole - 2 electrodes, 1 in. (25 mm) length

SC300 Array ... Dipole Button Probe, 1.0 in. thread
1.1 in. (28 mm) probe diameter
Dipole - 2 electrodes, 0.5 in. (12.7 mm) length

SC310 Array ... Expendable Button Probe, unthreaded
1.1 in (28 mm) probe diameter
Dipole - 2 electrodes, 0.5 in. (12.7 mm) length

Direct Image®
By Geoprobe Systems®

ELECTRICAL CONDUCTIVITY (EC) LOGGING

Standard Operating Procedure
Prepared: December 2008

1.0 Objective

This document is to be used as the standard operating procedure for use of the Geoprobe Systems® Electrical Conductivity Logging System for the determination of soil conductivity.

2.0 Background

2.1 Definitions

Electrical Conductivity (EC): A measure of the ability of a material to transmit or conduct electricity.

2.2 Discussion

The field computer injects a current across electrical contacts placed in the soil. The system measures electrical current and voltage and from these parameters, calculates electrical conductivity. Higher electrical conductivities typically are representative of finer grained sediments, such as silts and clays, while sands and gravels have distinctively lower conductivities. Ionic contaminants can increase the conductivity of the soil.

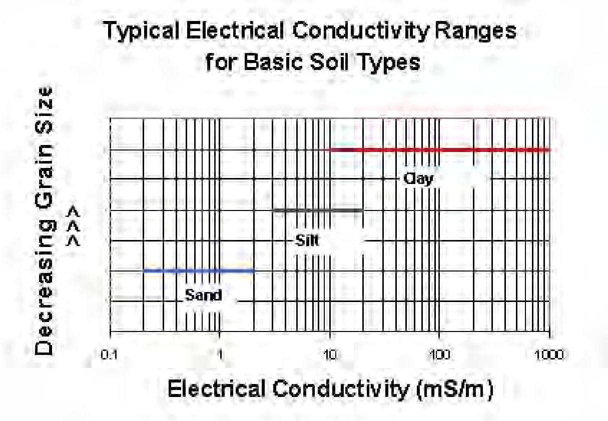


Figure 1: General Conductivity Ranges

Interpretation of EC logs comes with field experience and an initial core sample to confirm lithologic changes. As a generalization, a high conductivity reading indicates a smaller particle size and a low conductivity reading indicates a larger particle size (Figure 1).

The EC probe comes in two different configurations, Dipole Array and Wenner Array. Both configurations have the same theory of operation. A current is sent through the formation between two probe contacts. This current is measured along with the voltage that results (Figure 2). The conductivity is a ratio of current to voltage times a constant. The resulting reading is in milli-Siemens per meter (mS/m).

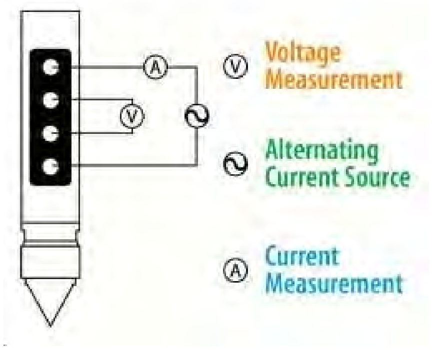


Figure 2: Wenner Array for Conductivity Measurements

3.0 Tools and Equipment

The following equipment is needed to perform, save and print electrical conductivity logs. EC system components are listed and illustrated in section 3.1.

3.1 Basic EC System Components

Description	**Part Number**
Field Instrument	FC5000
EC Probe (Figure 3)	SC500
Conductivity Cordset	SC164
Stringpot (linear position transducer)	SC160
Stringpot Cordset (30m)	SC161
Probe Test Jig	SC463
EC Test Load	37785
<u>Model 5400 and 54DT Series</u>	
Stringpot Mounting Bracket	SC110
Stringpot Bottom Clamp	SC111
Stringpot Piston Weight	SC112
<u>Model 54LT Series</u>	
Stringpot Mounting Bracket	11433
Stringpot Bottom Clamp	SC111
Stringpot Piston Weight	SC112
<u>Model 6600 Series</u>	
Stringpot Mounting Bracket	16791
Stringpot Piston Weight Bracket	11751
Piston Weight	SC112
Drive Cushion	23321
Slotted Drive Cap (1.5 in. rods)	15607
Power Inverter	SC652
Generator	User Preference
Computer	
SD Memory card reader	
Printer	

Figure 3: FC5000 and SC500

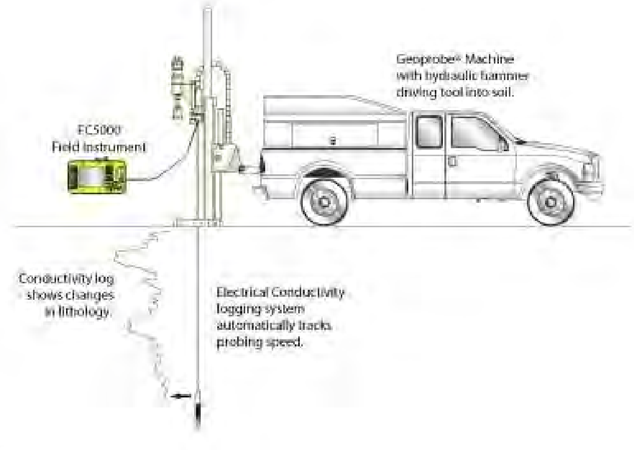


Figure 4: EC Setup and Deployment

4.0 EC Logging Field Operation

1. Power up the generator or connect the power inverter.

2. Power up the FC5000.

3. Place the SC-500 in the test jig with the test load connected for the QA test (Figure 6).

4. On the FC5000, select 1-EC for conductivity logging.

5. On the FC5000, select the proper stringpot configuration.
   1 – 100 inch
   2 – 80 inch
   (Stringpot length is located on the side of the stringpot body.)

6. On the FC5000, enter the log name (a maximum of 8-character space limit).

7. On the FC5000, select the probe type #4 – SC500

8. On the FC5000, select #1 to test the instrument or #2 to bypass the QA tests (see section 5.0).
   Results of the QA Tests are saved in the information file of the log.
   (Geoprobe requires that the QA tests are run before each log and after the last log of the day to validate data quality).

9. On the FC5000, select the rod length (i.e. #4 for 4 foot rods).

10. On the FC5000, select the dipole array 1-Wenner (optimum). The instrument will tell which array can be used based on the results of the QA test. 1-Wenner, 2- Top Dipole, 3- Middle Dipole and 4-Bottom Dipole.

11. At the direct push rig, advance a preprobe 3' into the subsurface at the location to be logged. Remove.

12. Insert the EC probe through a rod wiper and into the preprobed log location.

13. With the drive cushion on, advance the SC500 into the ground so that ground surface is level with the center of the four pole array.

14. With the direct push rig drive hammer or cushion on the rods, turn the trigger of the FC5000 system to the "on" position to begin the log.

15. Begin advancing the rod string into the ground at a medium and steady speed (i.e., 2-3 cm/sec).

16. When you reach the end of the log press the trigger button on the FC5000 again to turn the trigger off. The trigger may be turned off at any time to make adjustments w/o recording any probe movement. With the trigger turned "off", the cable may be disconnected to add rods or to add an additional cable.

17. Using a slotted pull cap or rod grip puller retract the rods and place in the rod rack.

18. Remove the memory card from the front of the FC5000 and place into a card reader connected to the computer. Transfer the 2 files (.dat and .inf files) into an appropriate project folder on the computer.

19. Using the Direct Image Viewer open up the EC log, make any adjustments for depth, EC and rate of push measurements.

20. Print log (Figure 5).

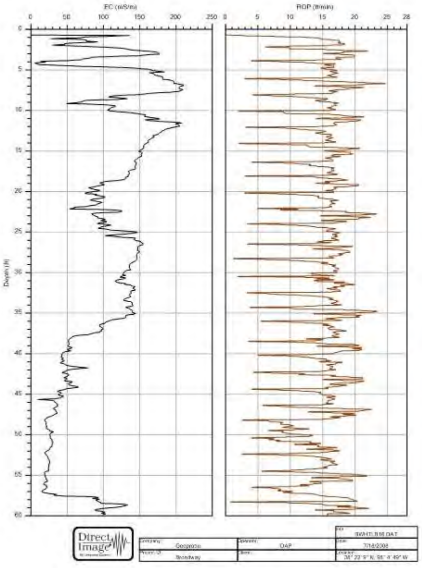


Figure 5: Example Log

5.0 Electrical Conductivity System
QA/QC

The EC system must be tested using the following QA procedures before and after each log. Adhering to these requirements ensures that the system was performing correctly and validates the data quality. Since all logs must be "bounded" by passing QA, a final log must be started after the last log of the day has been performed and the QA parameters must be completed for the assurance that the system was performing correctly at the end of the last log.

Instrument Calibration Test ± 5%

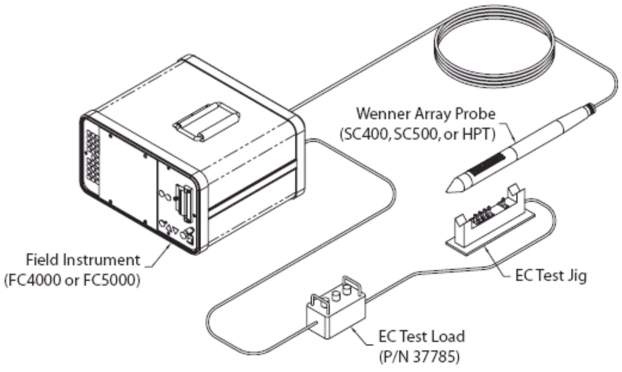


Figure 6: QA System Configuration

Continuity Check (this test looks at the continuity of each of the wires within the system for all 4 dipole arrays)
Probe Resistance should be <8 Ohms

Red R-R, White W-W, Green G-G, Black B-B

If all dipoles are good use the Wenner array.
If the first QA attempt fails, reposition the SC500 on the test jig and rerun the QA test. If 2 QA runs fail, use whichever dipole array the system allows or change your probe. If the system does not allow any of the four dipole arrays change conductivity probes. If the red is out, use middle or bottom dipole. If white is out use bottom dipole. If green is out use top dipole. If black is out use top or middle dipole. If red & green are out probe is no longer usable.

Probe Isolation Test (this test makes sure that each dipole is isolated from the others)
Resistance should be >15 Kilo Ohms

R-N, R-W, R-G, R-N, W-N, W-G, W-B, G-N, G-B, B-N

If the resistance falls below 15 KO on any of the isolation tests, it may signal water is getting into the probe or perhaps some corrosion is present. This will cause your soil magnitudes to be off and you will not want to use the probe or you can attempt to use a different dipole array other than Wenner to avoid using the bad dipole.

EC Test Load ± (this test applies 3 different loads to the system that correlate to low, medium and high conductivity readings that the system will see in the subsurface).
When in the logging screen, depress the test load level 1, 2, and 3 and make sure that the resulting conductivity load values are within 5% of the values listed on the side of the load device. This test provides the best information of how the system is calibrated and how it will map the encountered lithology.

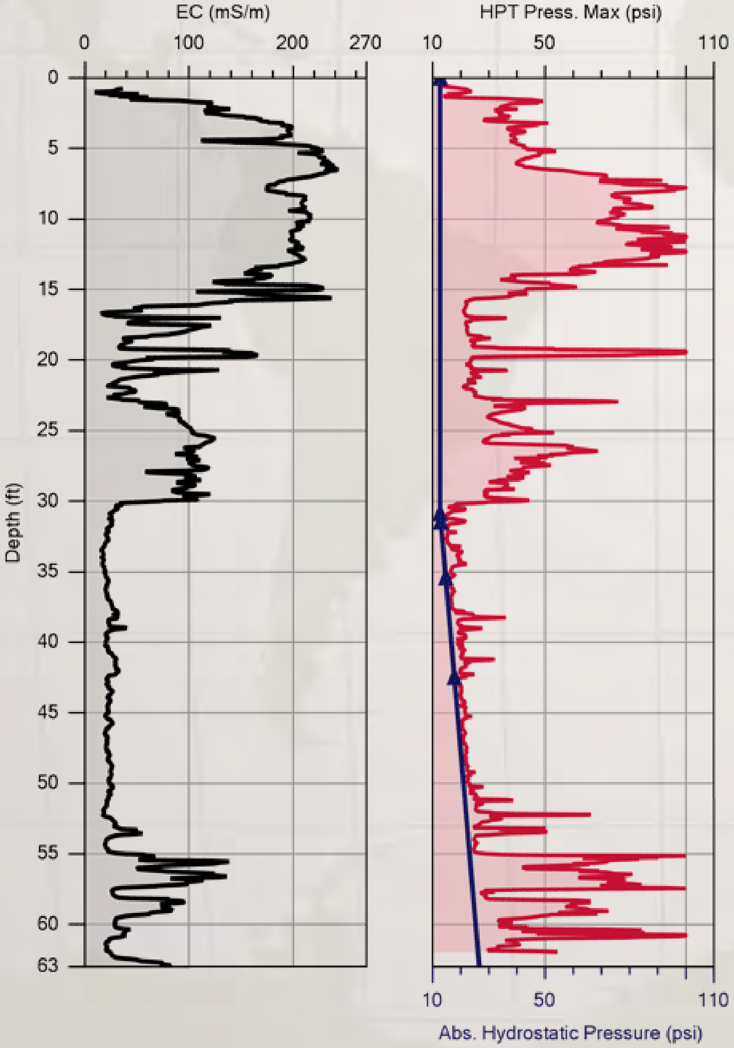
System QC:

After the logs have begun to be generated, your QC will be to compare the logs to either discrete sample or continuous log soil cores, at EC locations, to verify the lithology represented by the electrical conductivity values at the site. Other QC measures include running duplicate logs to confirm repeatability and displaying multiple logs in a cross-section view to observe distinct lithology patterns and transitions.

Hydraulic Profiling Tool (HPT)

HPT Introduction:

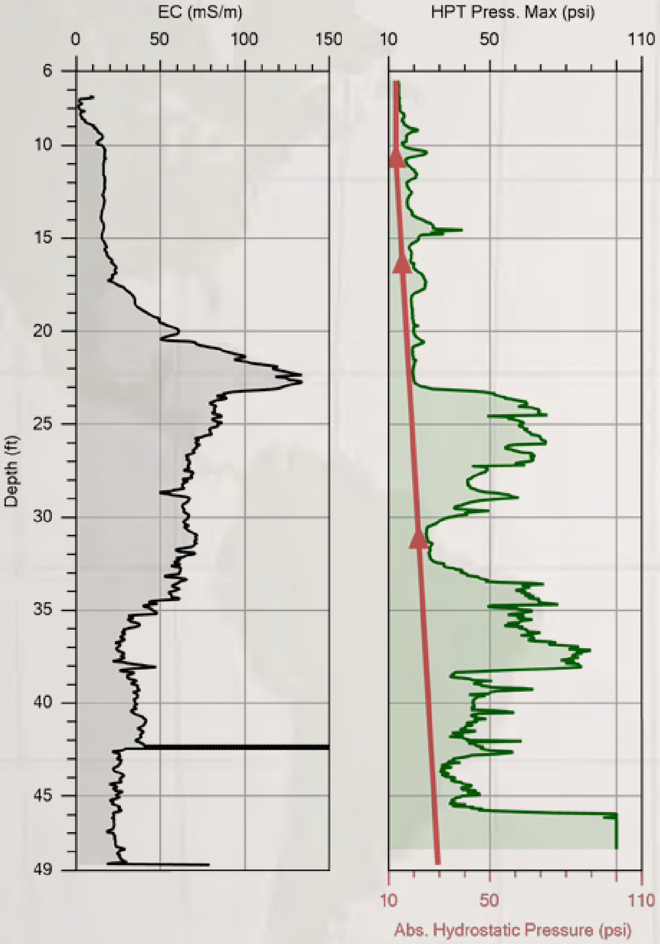
The Hydraulic Profiling Tool is a logging tool that measures the pressure required to inject a flow of water into the soil as the probe is advanced into the subsurface. This injection pressure log is an excellent indicator of formation permeability (Figure 1). In addition to measurement of injection pressure, the HPT can also be used to measure hydrostatic pressure under the zero flow condition. This allows the development of a hydrostatic pressure graph for the log and prediction of the position of the water table.



- HPT produces a detailed hydrostratigraphic log
- Can be used to estimate hydraulic conductivity in the saturated zone
- Logs both HPT injection pressure and electrical conductivity
- Measures hydrostatic pressure and depth to water table
- HPT logging is easy to learn and operate
- Interpretation of HPT logs is straight forward and intuitive

Hydraulic Profiling Tool (HPT)

The HPT is also useful for the detection of brines or other high electrical conductivity fluids in soil. These brines may originate from oilfield production or storage activities. Other high ionic fluids amenable to this technique include road salts and remediation fluids. Detection of these fluids is detected as an anomaly between the EC and HPT log. This occurs when the EC increases, in some cases even above that observed in background logs, while the HPT indicates a zone of high permeability.



An example of the detection of salt or brine contaminated groundwater using the HPT and EC logs. In this case (Left), the EC increases from baseline to maximum value in the 15 to 23 feet interval. At the same time the HPT pressure remains low, indicating that this is a zone of high permeability. The rise in EC in this case is caused by in increase in salt content in the groundwater, yielding specific conductance values in groundwater samples that are several times above background. The shape of the EC curve in this interval is also characteristic of salt contamination.

The equipment to perform HPT logging is simple. In addition to the Field Instrument (FI6000) for data acquisition, HPT requires the use of the K6300 Controller. This instrument provides the pump and pressure and flow measurement required to perform HPT logging.

HPT probes are available in both 1.75 in. (44.5mm) diameter for use with 1.5 inch (38mm) probe rods and 2.25 in. (57mm) diameter probes for use with 2.25 in. probe rods. Tools string diagrams for these probes may be found at: geoprobe.com/hpt-tool-string-diagrams. HPT probes are robust, driveable under all Geoprobe® 54 series and 60 series hammers, and can be factory rebuilt when they wear out (provided remaining thread life is deemed sufficient).

Geoprobe® Hydraulic Profiling Tool (HPT) System

Standard Operating Procedure

Technical Bulletin No. MK3137

Prepared February 6, 2013

1.0 Objective

This document serves as the standard operating procedure for the Geoprobe® Hydraulic Profiling Tool (HPT) system. In this procedure, the HPT system is used to measure the pressure response of soil to injected water for identifying potential flow paths and to assist with characterization of soil type. This document has been updated from Geoprobe Systems® Technical Bulletin No. MK3137 (March 2007) to show the use of an FI6000 field instrument for HPT system control and data acquisition.

2.0 Background

2.1 Definitions

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

**Geoprobe® and Geoprobe Systems® are registered trademarks of Kejr, Inc., Salina, Kansas.*

Hydraulic Profiling Tool (HPT) System: A system manufactured by Geoprobe Systems® to evaluate the hydraulic behavior of subsurface soil. The tool is advanced through the subsurface at a constant rate while water is injected through a screen on the side of the probe. An in-line pressure sensor measures the pressure response of the soil to water injection. The pressure response identifies the relative ability of a soil to transmit water. Both pressure and flow rate are logged versus depth.

2.2 Introduction

The HPT system has been developed by Geoprobe Systems® for the geohydrologic characterization of soils. The HPT probe and logging system is able to quickly provide logs that are easily interpreted. HPT logs are used to indicate hydraulic conductivity, EC, hydrostatic profile, and areas of EC/permeability anomalies.

The HPT system is designed to evaluate the hydraulic behavior of unconsolidated materials. As the probe is pushed or hammered at 2 cm/s, clean water is pumped through a screen on the side of the HPT probe at a low flow rate, usually less than 300 mL/min. Injection pressure, which is monitored and plotted with depth, is an indication of the hydraulic properties of the soil. That is, a low pressure response would indicate a relatively large grain size, and the ability to easily transmit water. Conversely, a high HPT pressure response would indicate a relatively small grain size and the lack of ability to transmit water.

An electrical conductivity measurement array is built into the HPT probe. This allows the user to collect soil electrical conductivity (EC) data for lithologic interpretation. In general, the higher the electrical conductivity value, the smaller the grain size, and vice versa. However, other factors can affect EC, such as mineralogy and pore water chemistry (brines, extreme pH, contaminants). In contrast, HPT pressure response is independent of these chemical and mineralogical factors.

There are four primary components of the HPT system: the probe assembly, trunkline, HPT Flow Module (K6300 Series), and Field Instrument (FI6000 series). These primary components are shown in Figure 2.1.

The probe assembly consists of the HPT probe and connection section. This assembly houses the downhole HPT pressure transducer, water and electrical connections, and the probe body with the injection screen and electrical conductivity array.

Injecting water at a constant rate is integral to system operation. The HPT Flow Module houses the pump and associated hand crank mechanism used for adjusting the output flow of the HPT pump. The flow module also contains the HPT flow measurement and injection line pressure transducers. HPT flow can be adjusted from approximately 50 to 500 ml/min. The HPT pump is a positive displacement pumping device with minimal decrease in flow over the HPT operating pressure range. The flow module is equipped with an internal bypass that is factory set to open and return flow to the supply reservoir at a pressure of 120 psi. When the soil resistance to water injection becomes sufficiently great, the HPT Flow Module bypass will open, returning some or all of the pumped flow to the supply reservoir. The flow meter only measures flow leaving the module to the HPT probe. The HPT Flow Module is connected to the Field Instrument via a data cable.

Water and power are transmitted from the controller to the probe assembly via the HPT trunkline. The probe rods must be pre-strung with the trunkline before advancing the probe.

Data collection occurs in real time by connecting the controller to the field instrument. The field instrument collects, stores and displays transducer pressure, flow rate and electrical conductivity, line pressure, probe rate, and diagnostic parameters, with depth.

Since the HPT pressure response is analogous to the soil's ability to transmit water (and therefore the to the soil's dominant grain size), the HPT system can be used to identify potential contaminant migration pathways. Similarly, it can help identify zones for remedial material injection or provide qualitative guidance on how difficult injection may be in different zones of the formation.

The HPT system may be used to direct other investigation methods, such as soil and groundwater sampling and slug testing. HPT pressure response and EC data can help target zones of geologic and hydraulic interest, minimizing the number of soil and groundwater samples required to adequately develop a site conceptual model. When hydraulic conductivity values are required, the HPT system can also help the user identify zones to slug test, as well as the length of the screen required to adequately test the zone.

The HPT system also can be used to collect static water pressure data at discrete intervals during the logging process. These static pressure data can be used to calculate static water levels or to create a hydrostatic profile for the log.

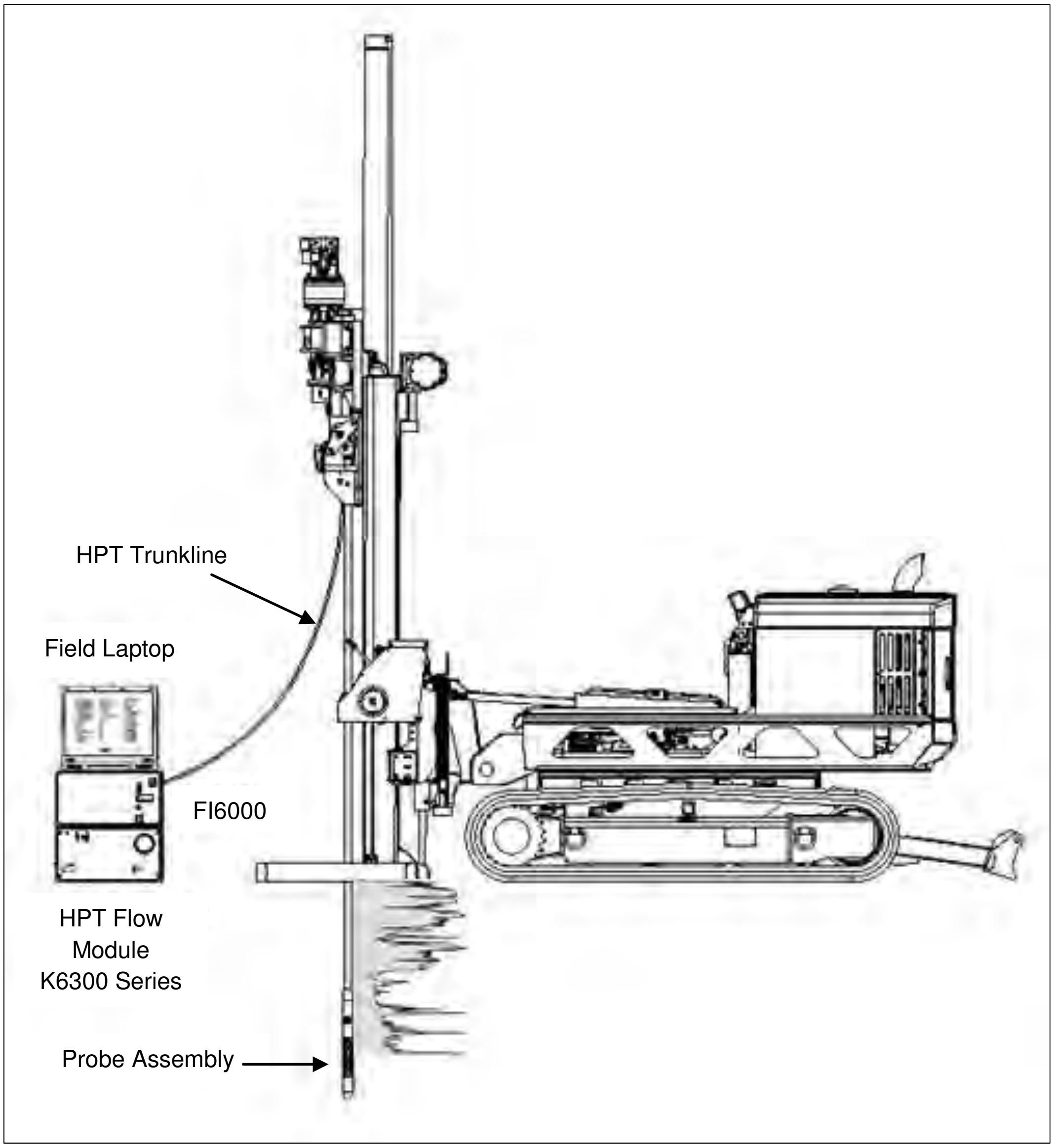


Figure 2.1: HPT Components

3.0 Tools and Equipment

The following equipment is required to perform and record an HPT log using a Geoprobe® 66- or 78-Series Direct Push Machine. Refer to Figures 3.1, 3.2, and 3.3 for identification of the specified parts.

Basic HPT System Components	Quantity	Part Number
Field Instrument, 120V	-1-	FI6000
Field Instrument, 220V	*	FI6003
HPT Acquisition Software	-1-	K6020
HPT Flow Module, 120V	-1-	K6300
HPT Flow Module, 220V	*	K6303
HPT Probe, 1.75 inch	-1-	K6050
MIP/HPT Connection Tube	-1-	31641
MIP/HPT Adapter 1.5 Pin x LB Box	-1-	20712
HPT Probe, 2.25 inch	**	K8050
2.25 Probe Rod, 24 inch	**	32656
2.25 Inch Water Seal Adapter	**	45170
2.25 Inch Water Seal Drive Head	**	48866
HPT Reference Tube 1.75 in HPT Probe	-1-	50344
HPT Reference Tube 2.25 in HPT Probe	**	50344
HPT Trunkline 150 ft.	-1-	K6415
HPT Trunkline 200 ft.	(optional)	K6420
HPT Service Kit *(contains the following)*	-1-	29028
O-Ring Pick	*-1-*	*AT102*
Term Block 4 POS Green	*-4-*	*7700*
Electrical Tape, 0.75-in. x 60-ft.	*-1-*	*6167*
Membrane Ratchet Wrench Asm	*-1-*	*48877*
Coupling 1/8 to 1/8 Tube	*-5-*	*48842*
Oetiker #7 Band Clamp 5.8 x 7mm	*-10-*	*48724*
HPT Sensor Module	*-2-*	*43327*
Silicone Dielectric Compound	*-1-*	*41274*
Butt Connector Red (10 pak)	*-2-*	*39807*
HPT Trunkline Seal Asm.	*-4-*	*37031*
Trunkline Seal Spacer (1 pair)	*-2-*	*36378*
O-Ring 120 BUNA 70	*-10-*	*3537*
HPT Screen Asm	*-4-*	*28895*
HPT Spring Washer (pkg 10)	*-1-*	*52399*
Tube Nylon 0.25 OD x 0.04 W Flexible	*-1-*	*20727*
Tubing 0.125 ID x 0.25 OD Polyur Yellow	*-1-*	*17957*
EC Probe Test Jig	-1-	SC563
EC Test Load	-1-	37785
Stringpot, 100-inch	-1-	SC160-100
Stringpot Cordset, 65-feet (19.8 m)	-1-	16401

*Use in place of 120V components if desired.

**Use in place of 1.75 inch probe and components if desired.

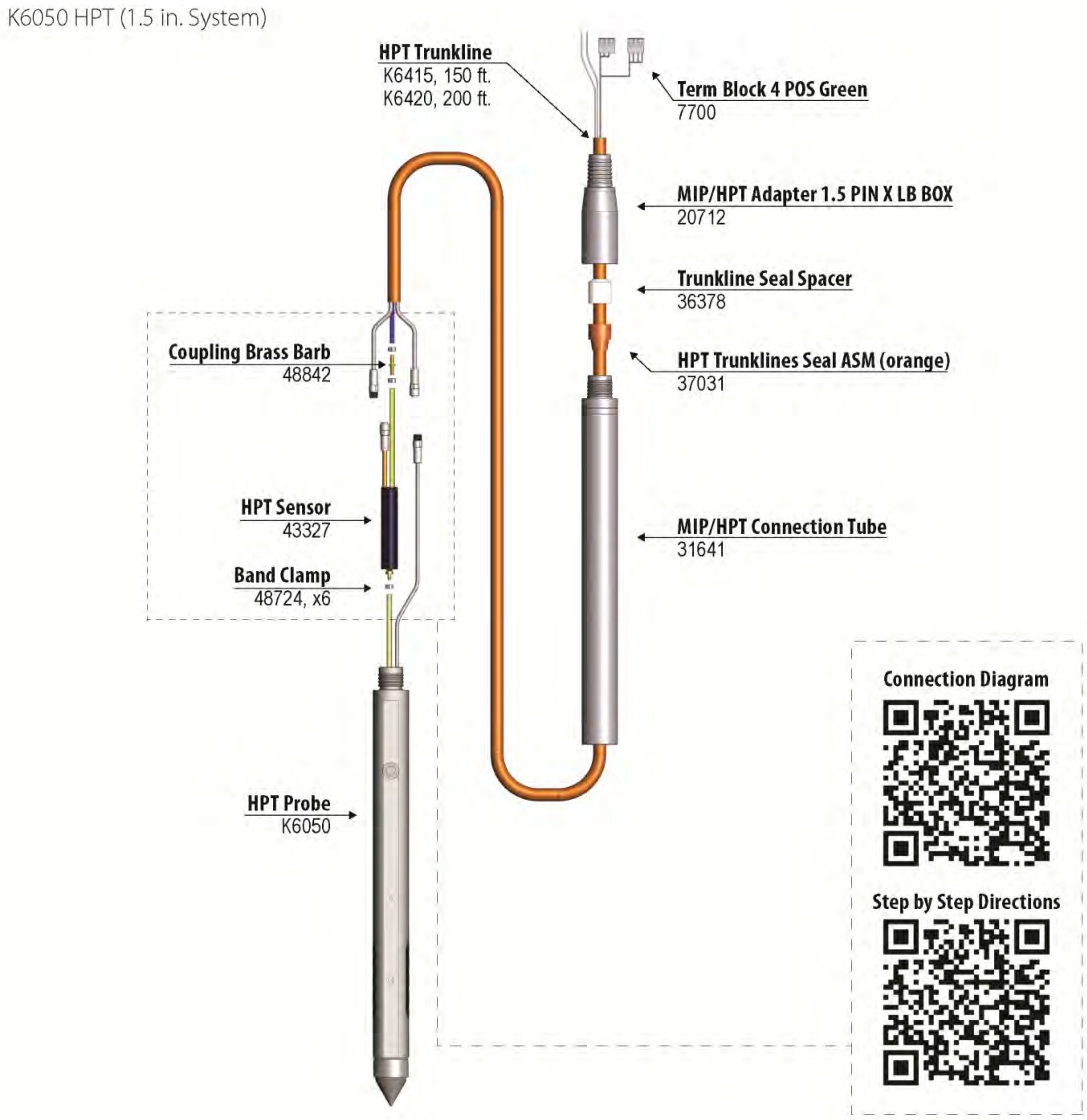


Figure 3.1 PN K6050 1.75 inch HPT Probe and components

http://geoprobe.com/tool-string-diagrams/k6050-hpt

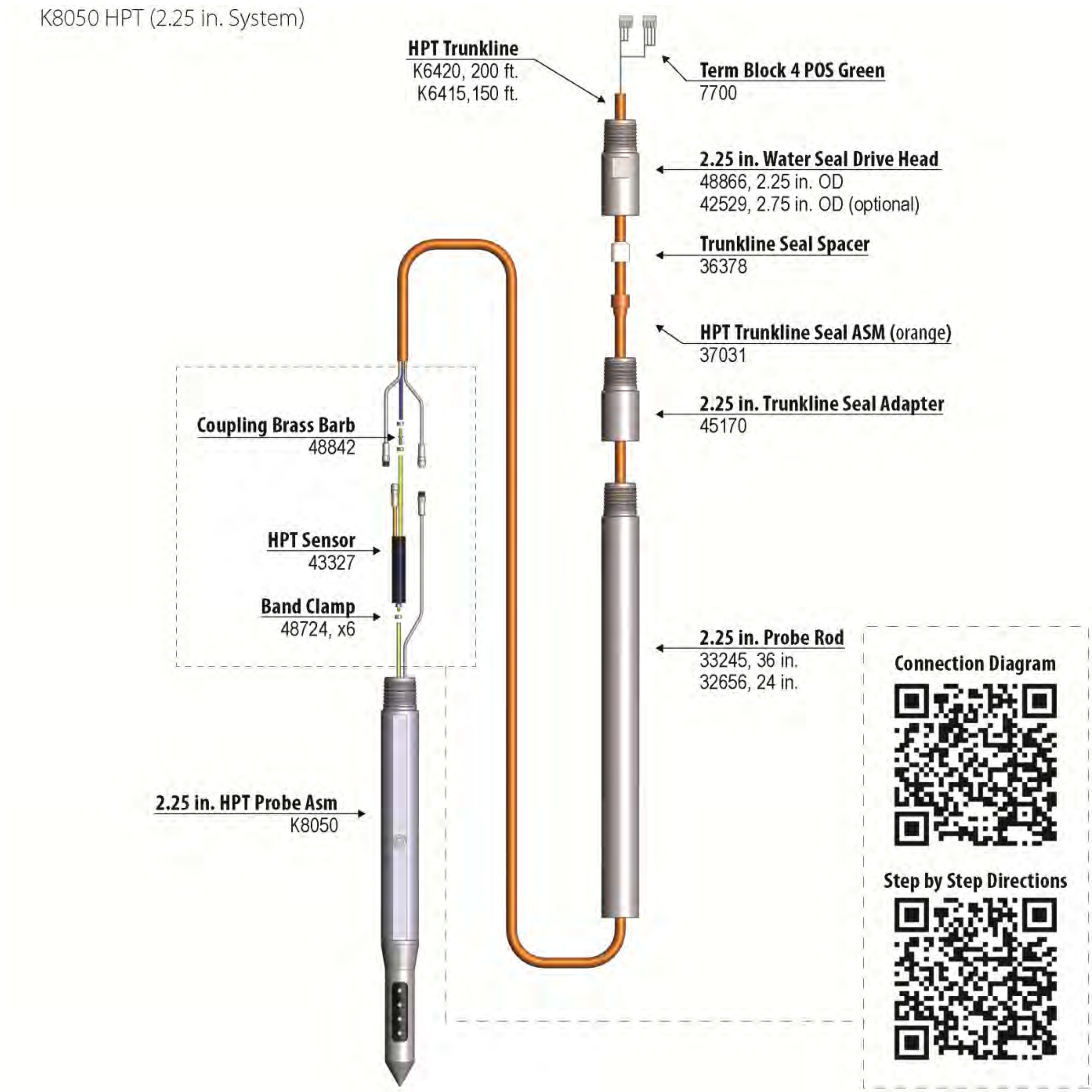
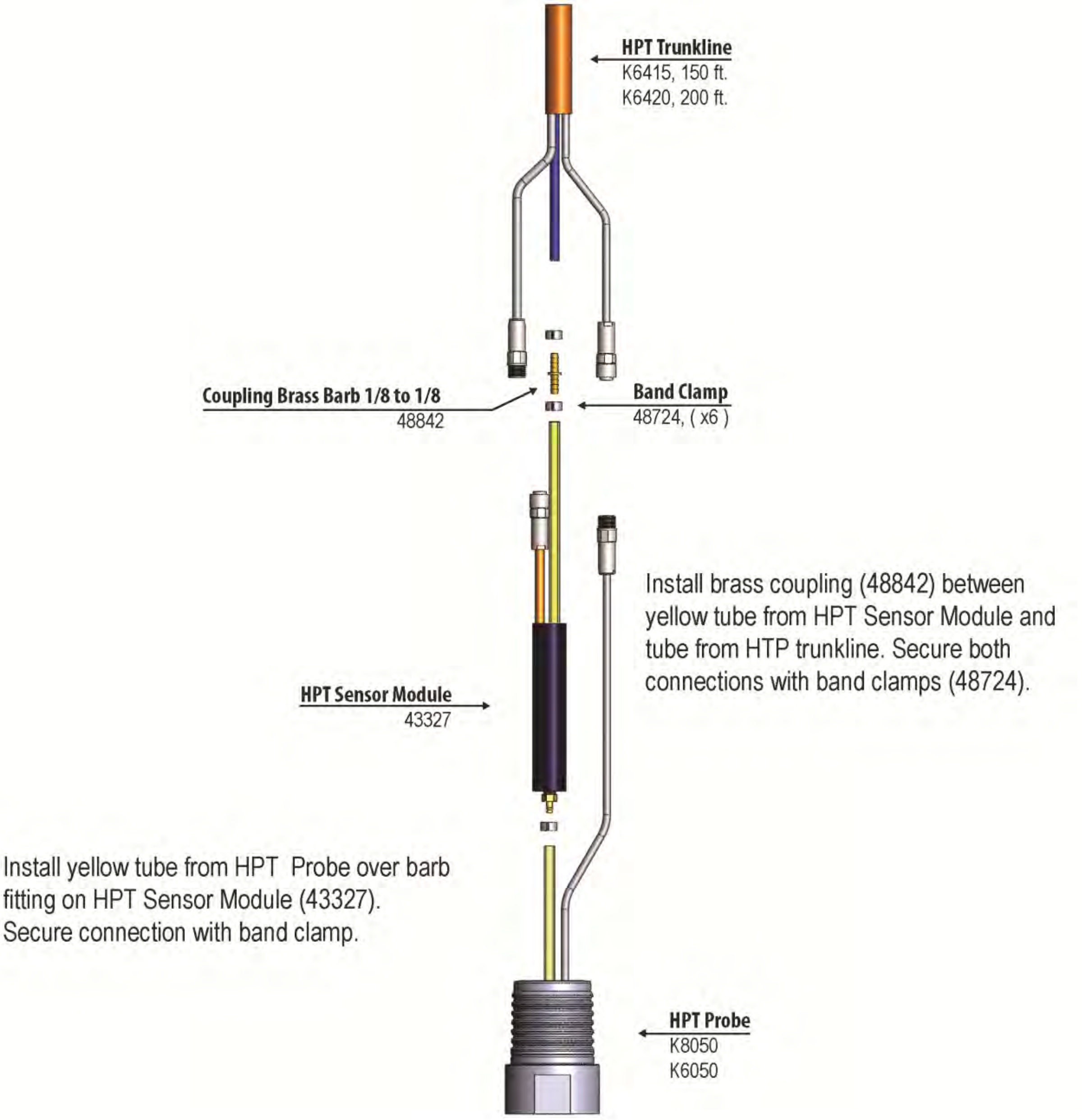


Figure 3.2 PN-K8050 2.25 inch HPT Probe and components

http://geoprobe.com/tool-string-diagrams/k8050-hpt

HPT Sensor Connection Diagram



Install brass coupling (48842) between yellow tube from HPT Sensor Module and tube from HTP trunkline. Secure both connections with band clamps (48724).

Install yellow tube from HPT Probe over barb fitting on HPT Sensor Module (43327). Secure connection with band clamp.

Figure 3.3 PN 43327 HPT Sensor Module Connection Diagram

http://geoprobe.com/tool-string-diagrams/hpt-sensor-connection-diagram

4.0 HPT Assembly

Refer to Appendix A

Threading the Rods

- Protect the end to be threaded through the rods with electrical tape or shrink tubing.
- Probe rods must alternate directions prior to threading the trunkline.
- The end of the HPT trunkline with chrome connectors is the downhole or probe end.
- The probe end of the trunkline will always enter the male end and exit the female end of the probe rods.
- The instrument end (no chrome connectors) will always enter the female end and exit the male end of the probe rods.
- After the trunkline is through the probe rods make sure the downhole end is threaded through the male end of the drive head and connection tube prior to connecting to the probe.
- The trunkline is now ready to connect to the instrument and HPT pressure sensor and probe.

5.0 Field Operation

5.1 Instrument Setup

1. Connect the HPT Controller (K6300), Field Instrument (FI6000) and laptop (Fig. 5.1) to an appropriate power source.

2. Connect the FI6000 to the K6300 using the 62-pin serial cable inserted into the acquisition port of each instrument.

3. Secure the EC wires into the Green terminal block connector and insert into the FI6000. The wires match to the EC dipoles in the following top down order when the probe tip is on the ground – white, black, yellow and blue (Fig 5.2).

Figure 5.1: HPT Instrument Setup

4. Secure the HPT sensor wires to the appropriate inputs on the green terminal block connector and connect to the rear of the K6300. The top down order of the wires which is listed on the back of the instrument is: brown, orange, red and reserved (open).

5. Insert the nylon water line tubing from the trunkline into the water output connector on the back of the K6300.

6. Connect the HPT water supply hose into the input port on the rear of the K6300 and insert the filtered end of the supply line into a water supply tank. The bypass line connects to the bypass port and will follow the supply line back to the supply tank.

Figure 5.2: EC Wire Connections

7. Connect the USB cable between the USB interface port on the rear of the FI6000 to USB input on the field laptop computer.

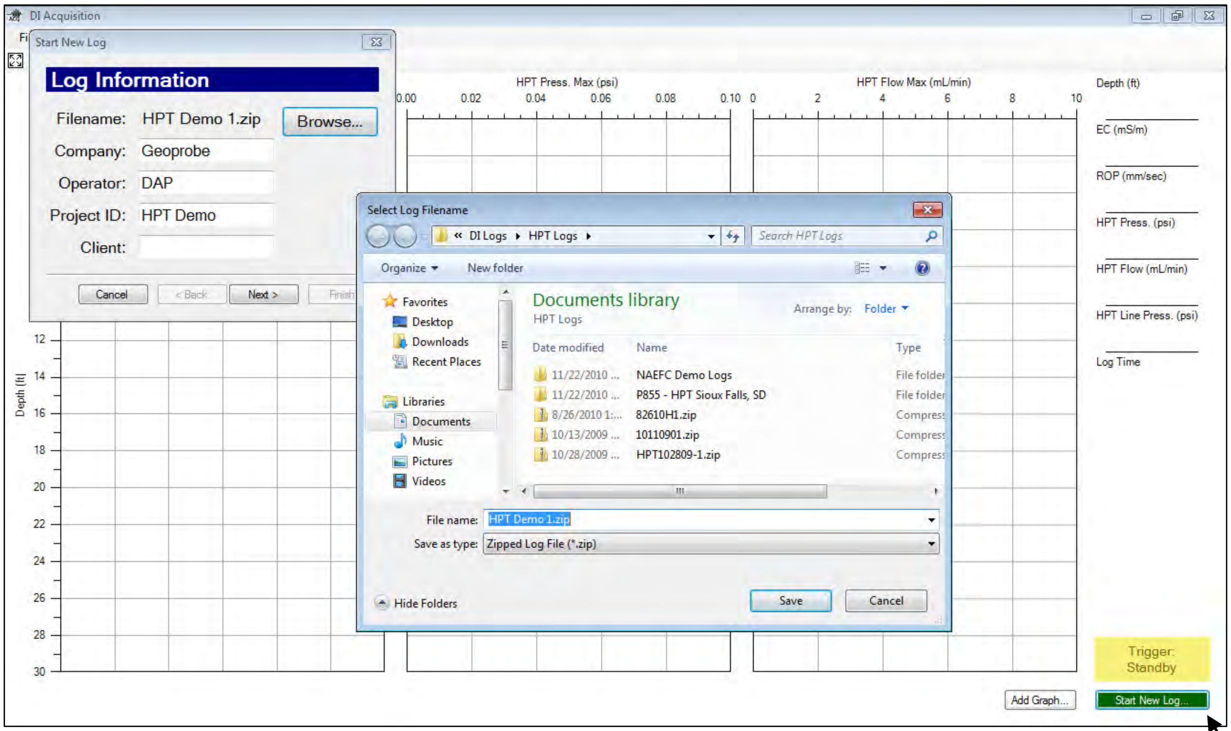
8. A stringpot is required to measure depth. Bolt the stringpot onto the machine and the stringpot onto the bracket. Connect the plastic connector end of the stringpot cable to the "Stringpot" connector on the back of the Field Instrument and the metal connector to the stringpot. Pull the stringpot cable and attach to the stringpot piston weight which should be mounted to the probe machine foot and pull the keeper pin so the weight is free to move.

5.2 Starting the Software

1. Make sure the FI6000 and K6300 are connected together with the 62 pin cable, powered on and connected to the computer by the USB cable for the software to load properly.

2. Start the DI Acquisition Software which should open in HPT mode.

3. Select "Start New Log". The software will request log information and have you browse for a storage location and create and save a file name for the log (Fig. 5.3).



Log Information

Filename: HPT Demo 1.zip
Company: Geoprobe
Operator: DAP
Project ID: HPT Demo
Client:

Date modified	Name	Type
11/22/2010 ...	NAEFC Demo Logs	File folder
11/22/2010 ...	P855 - HPT Sioux Falls, SD	File folder
8/26/2010 1:...	82610H1.zip	Compress
10/13/2009 ...	10110901.zip	Compress
10/28/2009 ...	HPT102809-1.zip	Compress

File name: HPT Demo 1.zip
Save as type: Zipped Log File (*.zip)

Figure 5.3: DI Acquisition Software – Start New Log Sequence

4. Select "Next". If the software has been run before it will show a list of previous settings including Probe Type, EC Configuration, Stringpot length, rod length and HPT Transducer. If any of these have changed or you are unsure select "No" but if they are all the same select "yes". If you select "No" the software will have you select the proper settings after the EC Load Test, if you selected "Yes" the selection of these settings will be bypassed.

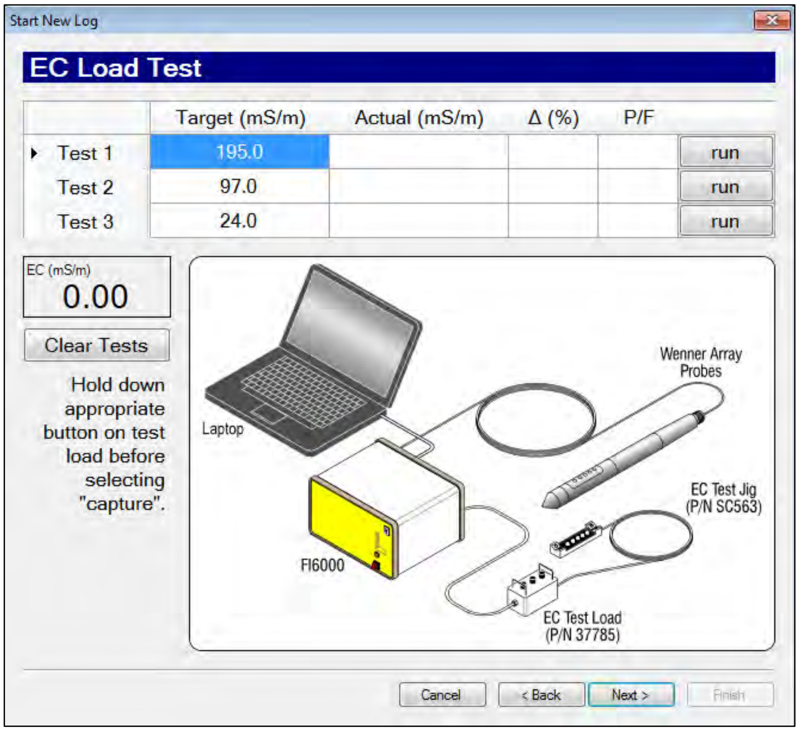
5.3 QA Testing the EC and HPT Systems

Both the EC and HPT components must be tested before and after each log. This is required to ensure that the equipment is working properly and capable of generating good data before and after the log.

A. Electrical Conductivity Load Test

1. Secure the EC 3 position test load connector (37785) to the test input jack on the back of the Field Instrument.

2. Secure the EC Probe Test Jig into the input on the EC 3 position test load.



Start New Log

EC Load Test

	Target (mS/m)	Actual (mS/m)	Δ (%)	P/F	
▸ Test 1	195.0				run
Test 2	97.0				run
Test 3	24.0				run

EC (mS/m)
0.00

Hold down appropriate button on test load before selecting "capture".

Figure 5.4: EC Load Test Screen

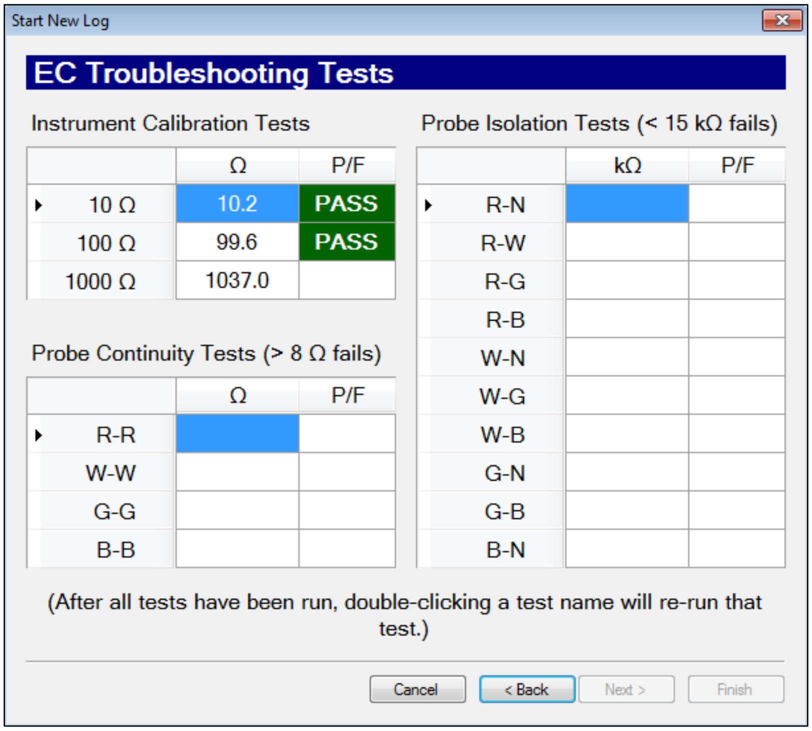
3. Clean and dry the EC dipoles as well as several inches of the probe body above the pins.

4. Place the EC Test Jig (SC563) so that the four springs on the test jig touch the four dipoles of the Wenner EC array (Fig. 5.4). Make sure the trunkline and test jig wires go in the same direction. The other spring on the test jig will ground the probe body above the Wenner array. Make sure the springs are pulled out far enough to make a solid contact on the dipoles.

5. When you get to the EC Load Test Screen and the EC test load and test jig are in place on the probe press down on the test 1 button on the test load and select “run” of Test 1 (Fig. 5.4). After 5 seconds the actual value will acquire and will pass if within 10% of the target value. Continue on with Test 2 and 3.

6. If any of the EC load tests fail do not pass within the allowed 10% acceptance range you can make adjustments on the test jig and rerun the test by just re-clicking the "run" button for an individual test.

7. If the tests continue to fail, select "Next" and the software will conduct the "EC Troubleshooting Tests." The Instrument Calibration Tests (Fig. 5.5) checks of the calibration within the FI6000. If these are far out of range it will influence the EC Test load values and will need to return to Geoprobe® for repair. The "Probe Continuity and Isolation Tests" confirm each of the wires is a complete circuit and is fully isolated from one another. If a probe continuity test fails just outside the target range of <8ohms this is typically a contact issue with the test jig and the dipoles. If the continuity is in the thousands of ohms this is a break in the EC wire circuit – either in the probe, the trunkline or the connection between them.



EC Troubleshooting Tests

Instrument Calibration Tests

	Ω	P/F
10 Ω	10.2	PASS
100 Ω	99.6	PASS
1000 Ω	1037.0	

Probe Continuity Tests (> 8 Ω fails)

	Ω	P/F
R-R		
W-W		
G-G		
B-B		

Probe Isolation Tests (< 15 kΩ fails)

	kΩ	P/F
R-N		
R-W		
R-G		
R-B		
W-N		
W-G		
W-B		
G-N		
G-B		
B-N		

(After all tests have been run, double-clicking a test name will re-run that test.)

Figure 5.5: EC Troubleshooting Test Screen

8. When these tests are complete select next. In the next screen, the software will provide an EC option, if one is available. The EC Load Test will only work if EC can be operated in Wenner array meaning all of the EC wires in the continuity test pass with results <8ohms on the individual circuits. EC can be operated and collect good data in one odf the dipole areas: top, middle or bottom dipole. If the R-R test fails but the others pass the software will provide the option in the next screen to run either middle dipole or bottom dipole arrays. If R-R and G-G are both an incomplete circuit then no EC array is available to run and a new probe must be connected or the problem fixed. In the Wenner configuration it requires 2 adjacent dipoles to operate in dipole mode. If an EC array is chosen and run in this last manner then all of the EC information collected will be bad data.

B. HPT Reference Testing

Reference testing is done to ensure that the HPT pressure sensor is in working order and to evaluate the condition of the HPT injection screen. The HPT reference test calculates atmospheric pressure which is required to obtain static water level readings and to determine the estimated K values for the log in our post log processing software the DI Viewer.

Reference Test Procedure

1. Connect a clean water source to the HPT controller and turn on the pump.

2. Allow water to flow through the system long enough so that no air remains in the trunkline or probe (air in the system can cause inaccurate flow and pressure measurements).

3. Insert the probe into the HPT reference tube and allow the water to flow out the valve adjusting the flow rate to between 250-300ml/min (Fig. 5.5). Ensure that the reference tube is close to vertical.

4. With a stable pressure reading and the water flowing out of the valve select “capture” - bottom with flow (Fig. 5.6)

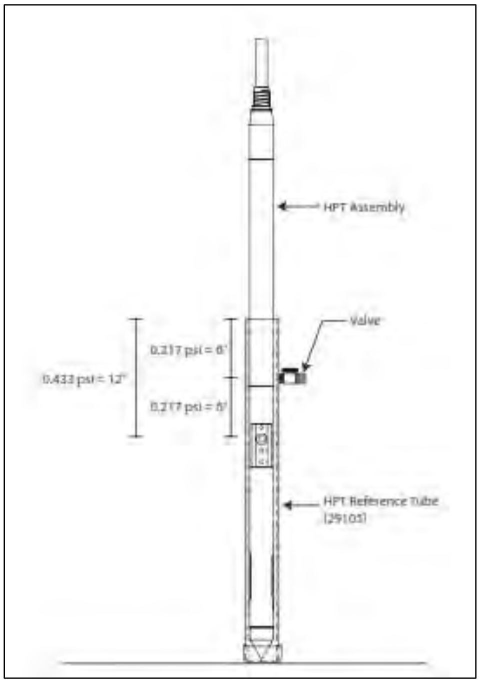
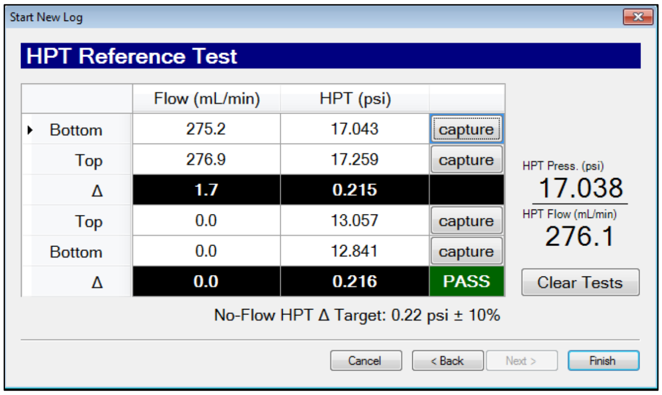


Figure 5.5: HPT Reference Test Setup

5. Close the valve and allow the water to overflow the top of the tube. When the pressure stabilizes select “capture” - top with flow.

6. Shut off the water flow. When the pressure stabilizes select “capture” - top flow = 0.

7. Open the valve and allow the water to drain out. When the pressure stabilizes select “capture” - bottom flow = 0.



HPT Reference Test

	Flow (mL/min)	HPT (psi)	
▸ Bottom	275.2	17.043	capture
Top	276.9	17.259	capture
Δ	1.7	0.215	
Top	0.0	13.057	capture
Bottom	0.0	12.841	capture
Δ	0.0	0.216	PASS

HPT Press. (psi) 17.038

HPT Flow (mL/min) 276.1

No-Flow HPT Δ Target: 0.22 psi ± 10%

Figure 5.6: HPT Reference Test Screen

The HPT reference test reading flow = 0 is the true test of the condition of the pressure sensor and is the only sensor test to have a pass/fail reading on it. Ideally, the pressure difference between the top and bottom values will be 0.22 psi (1.52kPa). Typical pressure readings of the sensor will be in the 12PSI-15PSI (83kPa-104kPa) range.

5.4 Running an HPT Log

1. Place the rod wiper on the ground over the probing location and install the drive cushion in place of the anvil of the probing machine.

2. Place the probe tip in the center of the rod wiper, and place the slotted drive cap on top of the HPT probe.

3. Start the HPT water flow. **Note**: It is important that there is always water flowing when the probe is advanced to avoid soil particles from moving through the screen and causing problems with the pressure readings or causing a blockage behind the screen.

4. Adjust the probe so that it is vertical and advance the probe until the HPT screen is at the ground surface.

5. Click the trigger button in the lower right hand corner of computer screen. (The Trigger label will flash and the background will change from yellow to green).

9. Advance the probe at a rate of 2 cm/s. If necessary, feather the hammer to maintain this advance rate.

10. Perform a dissipation test (Section 5.4) in a zone of higher permeability indicated by lower HPT pressure.

11. After completing the log, press the trigger button again and select “Stop Log”.

12. Pull the rod string using either the rod grip pull system or a slotted pull cap. Run a post-log EC test and HPT response test (Section 5.2).

5.5 Performing a Dissipation Test

At least one dissipation test must be performed in order to calculate the static water level and estimated K readings from the log. Dissipation tests need to be performed below the water table and are best in zones of high permeability where the injection pressure can dissipate off quickly once the flow is shut off.

1. Stop in a zone of higher permeability which is indicated by lower HPT inject pressure.

2. Switch the DI Acquisition display view from the depth screen to the time screen by pressing the F10 key (F9 and F10 toggle between the depth and time screen of the acquisition software).

3. The screen will be grayed out which means that the data up to that point has not been saved. Select “Start Dissipation Test” which will turn the screen from gray to a white background indicating that you are now saving the time data.

4. Now shut the pump switch off and when the line pressure reaches zero, turn the flow valve off.

5. The HPT Pressure will begin to drop (dissipate the hydrostatic increase) and allow it to stabilize so very little visible drop in pressure is seen. When the pressure has fully dissipated turn the flow valve and the pump switch back on. When the flow and pressure are reestablished select “End Dissipation test.”

6. Select F9 to return to the depth screen and advancing the tool into the ground.

   Note: Performing a dissipation test in zones of higher permeability may only take 30 seconds or so but if the HPT pressure was higher to start with it may take a long time up to several hours to dissipate off to equilibrium. This is why targeting the most permeable zone to perform the dissipation tests is most desirable.

6.0 HPT Log Interpretation

Below is a typical HPT log, which consists of both the HPT pressure response and electrical conductivity. In general, both HPT pressure and EC values increase with decreasing grain size, and decrease with increasing grain size. The log in Figure 6.1 shows good consistency between EC and HPT pressure for the majority of the log. It is only between 32’-42’bgs that we see some divergence of the graphs with higher HPT pressure while the EC readings remained low. This can happen for reasons such as poor mineralogy of the soil. Refusal was encountered in a shale layer beginning at 75’bgs and it can be noted that as we enter this layer the HPT flow gets suppressed as the pressure reaches a maximum value of 100PSI (690kPa). The second graph of the log shows the hydrostatic profile on the secondary series of the graph. The hydrostatic profile has 2 black triangles which indicate where dissipation tests were run and used to calculate the profile. The red circle indicates the calculated water table based upon where the hydrostatic profile intersects atmospheric pressure. The fourth graph is the estimate K or groundwater flow graph. This is calculated based upon HPT pressure and HPT flow relationships. Less permeable soil will have less groundwater flow.

It is fairly common to see zones where EC readings and HPT pressure contradict one another. In cases where EC readings are low and HPT pressure trends higher as in the log in Figure 6.1 the following are possible reasons:

- Poor mineralogy of the soil particles resulting in silt and clay soils with very low EC readings. This is seen in many locations along the east coast of the United States.
- Silts intermixed with sand particles.
- Weathered bedrock may have low EC but would have low permeability.

Where we have cases of higher EC and lower HPT pressure typically is due to an ionic influence in the soil or groundwater. These higher EC readings can range from very slight to higher than typical soil readings. Very high EC readings can occur when the probe contacts metallic objects in the soil which will ground them out and typically will cause hard sharp spikes in the EC data.

- Chloride or other ionic contaminant (sea water, injection materials)
- Sea Water intrusion
- Wire, metal objects or Slag

In cases where HPT and EC do not confirm one another it is important to take confirmation soil and/or groundwater samples to help understand the difference between the two graphs.

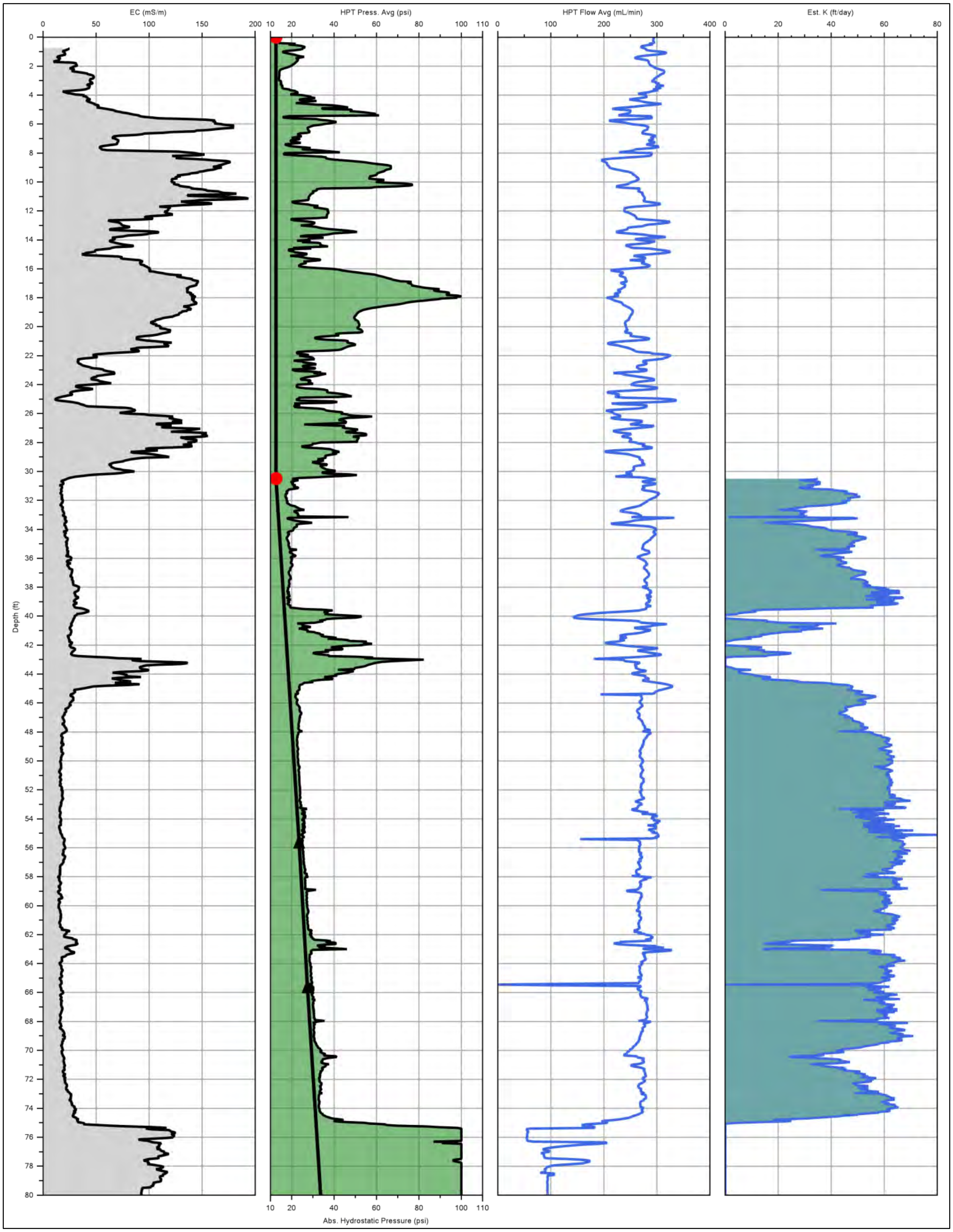


Figure 6.1: HPT Log file showing (left to right):
Electrical Conductivity (EC), HPT Injection Pressure with Hydrostatic Profile, HPT Flow, and Estimated K

7.0 Troubleshooting

7.1 Using the HPT Controller Test Load

The HPT Controller Test Load (32441) is included with the HPT Controller to help troubleshoot the HPT pressure sensor, trunkline, and controller. If there is a major problem with the HPT pressure sensor or the system wiring the system will not read anywhere close to atmospheric pressure with the probe at the surface. Commonly if the HPT sensor has broken the software will read either a maximum or minimum value which would be 100PSI or 0PSI (690kPa or 0KPa). If there is damaged wiring or nothing is connected to the controller the system typically reads 50PSI (345kPa).

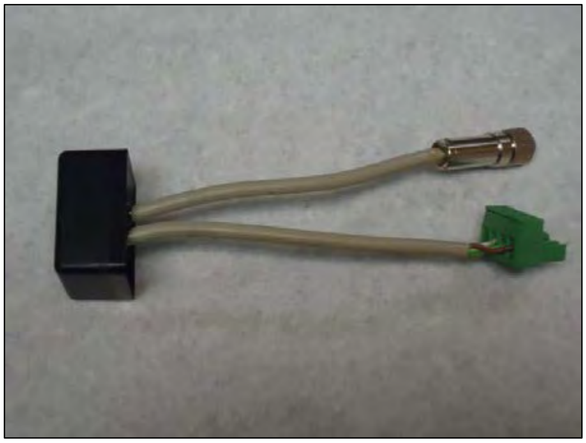


Figure 7.1: HPT Test Load PN32441

When connected to either the trunkline (in place of the pressure sensor), or the controller (in place of the trunkline and pressure sensor), the test load will cause the pressure sensor value to read a pressure ranging from approximately 25PSI-35PSI (172kPa – 241kPa).

To use the test load, set up the system as previously described. Turn on both the field instrument and HPT controller and start the HPT software. Plug the green wire connector of the test load into the HPT sensor connector on the back of the HPT controller. If the pressure sensor value reads somewhere around 30PSI (207kPa), the controller is able to properly read pressures so the problem is in the trunkline or the HPT sensor. If HPT controller has not moved from what it was reading or is way out from the expected value of the load test the HPT controller may require servicing. Contact Geoprobe Systems® for service.

Next, connect the HPT sensor wires of the trunkline to the controller with the green connector and then connect the test load to the female chrome connector on the downhole end of the trunkline in place of the pressure sensor. Again, the pressure value displayed on the field instrument should be somewhere around 30PSI (207kPa) and should be the same as what was seen with the load test connected into the controller. If the load test through the trunkline is around 30PSI (207kPa), then both the trunkline and the controller are working properly and the problem is in the HPT sensor. If it is not, the trunkline may be defective and should be replaced. Before restringing another HPT trunkline, first connect the new trunkline sensor wires into the HPT controller and the downhole end into the test load. If the system now reads in the expected test load range the trunkline needs replacing.

Finally, connect the pressure sensor to the trunkline. If it reads atmospheric pressure, approximately 12PSI-15PSI (83kPa-104kPa), then the pressure transducer is functioning properly. However, if it does not, replace the sensor with a new one and re-check the pressure reading. Be sure to enter the new sensor calibration values into the software prior to starting the new log. Additional pressure sensors purchased from Geoprobe®.

7.2 Common Problems

Problem: The pressure transducer is hooked up to the trunkline, but the software is reporting a reading of ~ 50PSI (345kPa).
Solution: Make sure that the trunkline wires are secured to the green terminal blocks and plugged in to the back of the HPT controller. Check components using the HPT Controller Test Load (Section 7.1).

Problem: The pressure transducer is hooked up to the trunkline, but the software is reporting a reading of 100PSI or 0PSI (690kPa or 0KPa).
Solution: Make sure all of the connections are good and recheck the pressure reading. If still bad connect a new HPT pressure sensor onto the trunkline and see if it reads atmospheric pressure. If not check all the components using the HPT Controller Test Load (Section 7.1).

Problem: The pressure with flow values keep drifting when water is flowing out the port or over the top of the reference tube.
Solution 1: If the trunkline was just connected and flow was just started air may still be in the lines. Allow the water to continue to flow through system which will purge out the remaining air. When it appears that most of the air is out of the lines pressing your finger over the injection screen for a few seconds can help to drive out any remaining air from the trunkline.
Solution 2: There may be debris behind the screen. Remove the HPT injection screen with the membrane wrench and turn the water flow on, place your finger over the open port to drive out debris. Replace the screen and retry the reference test with flow.
Solution 3: If the with flow pressure values continue to not settle down and provide close to the expected difference for a 6" water column then the problem may be inside the HPT control box. When you remove the cover of the HPT controller there will be a brass filter located on the left side when viewing from the front of the instrument (Fig 7.2). Particulates and precipitates can collect inside this filter causing problems with HPT pressure stability. Remove this filter and open up using appropriate wrenches. The filter can be easily cleaned by rinsing water over the screen. Reassemble and return to its proper location inside the control box. Resume reference testing the system.

Figure 7.2: Location of Inline Filter in K6300 and buildup of particulates in filter.

Problem: EC won't pass the QA tests.

Solution: Check the trunkline to probe EC connections ensuring they are tight. Run the troubleshooting tests (Section 4.3A), test EC on a new probe.

APPENDIX A

Making HPT Probe, Sensor and Trunkline Connections

http://geoprobe.com/literature/hpt-sensor-connection-tutorial

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www.geoprobe-DI.com

APPENDIX B - SPECIAL USE PERMIT

Saint Louis COUNTY HIGHWAYS & TRAFFIC

APPLICATION FOR SPECIAL USE PERMIT

TO THE DIRECTOR OF HIGHWAYS AND TRAFFIC, ST. LOUIS COUNTY, MISSOURI
41 South Central Avenue, 6th Floor, Clayton, Missouri 63105
Phone: (314) 615-8515 Fax: (314) 615-7084

1) Name of Applicant: ______________________________

2) Address of Applicant: ______________________________

City: ______________ State: _______ Zip: __________ Phone No.: (   ) _____ - _________ Ext: _______

Emergency Contact: ______________________________ Emergency No.: (   ) _____ - _________

Contractor (if applicable): ______________________________

3) Type of Development (check boxes): ☐ New ☐ Existing ☐ Residential ☐ Commercial ☐ Industrial

4) Description of Work:

5) Location of Work: ______________________________

6) Master Drainlayers Name: ____________________ License Number: ***D-***____________ ***P-***____________

7) Proposed Starting Date: __________________ 8) Days Required to Complete: __________________

9) SL #______________ WL #______________ 10) Plumbing Permit Number: __________________

11) PAC Number: __________________ 12) MLD Number: __________________

13) Applicant hereby agrees to restore and replace such street, avenue, boulevard, road, alley, public easement or highway disturbed or affected, and to conduct all work in accordance with the conditions of this permit. Permit Inspection Section shall be notified **24 hours prior** to commencement of work at (314) 615-1102.

14) Applicant hereby acknowledges its responsibility to incur all costs which may result from damages to applicant's facilities at the location described herein, which may be caused by maintenance, construction, reconstruction, signing and any other work performed by the St. Louis County Department of Highways and Traffic employees upon the County right-of-way over, under or across the location described herein.

15) Applicant agrees to perform all work in accordance with this permit and to indemnify and hold harmless St. Louis County, its officers, agents and employees from all liability, judgments, costs, expenses and claims growing out of damage, or alleged damages of any nature to any person or property arising out of performance or non-performance of said work or the existence of facilities and/or appurtenances thereof.

16) By typing or signing my name, I acknowledge that I have read and understand the above conditions and attached general provisions.

____________________	____________________	____________
Company Name	**Applicant's Signature**	**Date**

- THE FOLLOWING IS FOR OFFICE USE ONLY -

☐ Arterial Road System ☐ County Road System

Fees Collected: ___________ Number of Units:_______ Grading: ________ Date: ___________ By: ________

Special Use Permit Number: ____________________ Map Location: ______________________________

Special Use Permit General Provisions

SECTION 1 The Department as referred to herein is the St. Louis County Department of Highways and Traffic.

SECTION 2 The Director as referred to herein is the Director of the Department of Highways and Traffic or his authorized representative.

SECTION 3 The Applicant shall be the owner of the individual or legal entity having the legal right to the control of the facilities being constructed and repaired herein: provided, however, in the case of reshaping back slopes, the Applicant shall be the owner or the individual of legal entity having the legal right to the possession and control of the property adjacent to the Right-of-Way.

SECTION 4 If the Special Use Permit Application is countersigned by Applicant's contractor, or the authorized representative of the Applicant's contractor. The contractor shall be held jointly responsible with all the requirements of this permit until the Director releases it.

SECTION 5 At all times while any work is under construction with in the County's Right-of-Way, Applicant shall display applicable warning signs, barricades, lights, and flares as described in the Manual of Uniform Traffic Control Devices ASA D6, 1-2000, which has been adopted by the Department, and shall provide flagman and/or other warning devices satisfactory to the Director.

SECTION 6 All work shall be performed without unreasonable delay and in a workmanlike manner.

SECTION 7 Applicant agrees to perform all work in accordance with this permit and to indemnify and hold harmless St. Louis County, it's officers, agents and employees from all liability, judgments, costs, expenses and claims growing out of damages, or alleged damages of any nature to any persons so property arising out of performance or non-performance of said work of the existence of facilities and/or appurtenances thereof.

SECTION 8 All utility facilities shall be installed and located and all other work performed in accordance with the policies of the St. Louis County Department of Highways and Traffic. All work shall be as directed by the Director or his authorized representatives.

SECTION 9 The vertical clearance of overhead installation shall be no less than fifteen (15) feet - six (6) inches from the road surface.

SECTION 10 All underground water lines installation shall have a minimum cover of 42 inches. All other underground installation shall have a minimum cover of 30 inches, except parallel direct burial underground telephone cable, which may have a minimum of 24 inches of cover. The Director may request greater minimums.

SECTION 11 The Director, when deemed necessary may specify encasement requirements.

SECTION 12 Cable, wire, small diameter pipe and other such appurtenances extending from the surface of the ground shall be equipment with covers or guards to improve their visibility, as permitted by this Department.

SECTION 13 Roadway ditches, culvert and other such devices used to carry surface run-off shall be kept open, free and clean of debris, growth or other materials at all times.

SECTION 14 All crossing of classified county roads shall be bored of pushed. Any voids occurring as a result of boring or pushing castings or other facilities under roadways or approached shall be filled to the satisfaction of the Director by a method and with material approved by the Director.

SECTION 15 Open cuts in pavements or stabilized shoulders shall be made only of specifically authorized by the Director.

SECTION 16 Granular backfill to comply with the Standard Aggregate Specifications for Highway and Structures of St. Louis County and graded to comply with size No. 4 of said specifications shall be used under pavement, stabilized shoulders and compacted by mechanical tamping methods on the lifts no greater than six inches, when pavement cuts are allowed.

SECTION 17 Pavement replacement shall comply with the St. Louis County Department of Highways and Traffic's Construction Specifications and Standards for Temporary Openings in Roadway Pavement and Details for concrete patches. Other improved surfaces shall be a material equal to or better than the type removed.

SECTION 18 Frame and cover for manholes shall conform to the transverse and longitudinal pavement, slope and the top shall be on the exact finish grade.

SECTION 19 Applicant shall protect roadway plant material, including trees and shrubs. Such materials and turf that are disturbed shall be restored as directed by the Director. Trees and scrubs shall not be trimmed, cut, moved or sprayed without specific permission from the Director.

SECTION 20 All sidewalks, steps, driveway approaches, drainage facilities, erosion protection and/or roadway appurtenances in general which are removed of damaged as a result of the herein shall be repaired to the satisfaction of the Director. Applicants shall be responsible for such repairs.

SECTION 21 In case of damage to other facilities located on County Right-of-Way that are placed with the permission of the Director. Applicant shall repair or replace such property to the satisfaction of the owner. In all cases, Applicant shall notify the owner of such damage immediately

SECTION 22 Construction materials and equipment shall not be stored on the roadway pavement, shoulders, of any portions of the Right-of-Way. If the Applicant is performing work on or has a right to the property adjacent to the County's Right-of-Way, all materials and equipment shall be stored on that property.

SECTION 23 Utility poles shall be allowed in medians of canalization islands.

SECTION 24 The total cost of all construction, maintenance and removal of facilities and their appurtenances installed or placed under this permit shall be borne by the Applicant, his grantees, successors, heirs, and assigns.

SECTION 25 The issuance of this permit by the Department does not relieve the Applicant of the responsibility obtaining other permits required by this or any other agency having jurisdiction.

SECTION 26 No public way shall obstructed or closed so as to inconvenience traffic, whether vehicular of pedestrian, contrary to these provisions, without specific permission of the Director.

SECTION 27 Surety bonds are required for oversize and/or over weight applicants and other major operations. The Director shall establish Bond amounts and other requirements.

SECTION 28 Except as otherwise provided by state law, Applicant and any Contractors shall maintain in effect from the beginning of construction continuously throughout the term of the Special Use Permit general liability insurance, with limits of not less that Two Million ($2,000,000) per occurrence, covering bodily injury and property damage. Such insurance obligation may be satisfied from either a primary or an excess liability policy. Such insurance shall provide liability coverage for both the Applicant and County as additional insured and shall be so endorsed as to create the same liability coverage on the part of the insurer as though separate policies had written for the Applicant and County. Applicant shall provide the County with an updated Certificates of Insurance on an annual basis. The Certificate shall indicate the County as additional insured. Applicants shall increase the limits of liability of required by state statutory limits of liability for public entities. If any part of the work is sublet, similar insurance shall be provided by or in behalf of the Subcontractor to cover their operations.

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Burns & McDonnell: Making our clients successful for more than 100 years