FINAL REPORT

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-201027

January 2013

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Acronyms

AFB	Air Force Base
AFCEE	Air Force Center for Engineering and the Environment
ASTM	American Society for Testing and Materials
bgs	below ground surface
cis-1,2-DCE	cis-1,2-dichloroethene
COC	Chemical of Concern
CVOC	Chlorinated Volatile Organic Compound
cy	cubic yard
DDD	1,1-dichloro-2,2-bis(p-chlorophenyl)ethane
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane
DHC	Dehalococcoides
DNT	2,4-dinitrotoluene
DoD	Department of Defense
DOT	Department of Transportation
ESTCP	Environmental Security Technology Certification Program
ft	foot
GAC	Granular Activated Carbon
GAO	Government Accountability Office
GEDIT	Gaseous Electron Donor Injection Technology
HASP	Health and Safety Plan
H_2T	Hydrogen-based Treatment
IRCTS	Inactive Rancho Cordova Test Site
LEL	Lower Explosive Limit
LPG	Liquefied Petroleum Gas
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDL	Method Detection Limit
ND	Non-Detect
NDEQ	Nebraska Department of Environmental Quality
NES	National Environmental Systems
NFPA	National Fire Protection Association
O&M	Operation and Maintenance
P&ID	Process and Instrumentation Diagram
PID	Photoionization Detector
PCE	Perchloroethene
ppmv	part per million by volume
PRG	Preliminary Remediation Goal
PSA	Pressure Swing Adsorption
PV	Pore Volume
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance / Quality Control
QAPP	Quality Assurance Project Plan
qPCR	Quantitative Polymerase Chain Reaction
RACER	Remedial Action Cost Engineering and Requirements

RL	Reporting Limit
ROI	Radius of Influence
scfm	Standard cubic foot per minute
SERDP	Strategic Environmental Research and Development Program
SVE	Soil Vapor Extraction
1,1,1-TCA	1,1,1-Trichloroethane
TCE	Trichloroethene
TEP	triethyl phosphate
trans-1,2-DCE	trans-1,2-dichloroethene
USCS	Unified Soil Classification System
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VC	Vinyl Chloride
VOC	Volatile Organic Chemical

Acknowledgments

This project was funded by the Environmental Security Technology Certification Program (ESTCP). The project team wishes to thank Dr. Andrea Leeson and Dr. Jeff Marqusee for the support throughout the demonstration. Mr. Chuck Coyle, Mr. Mark Wichman and their team at USACE Omaha District provided very helpful comments during project execution, also granted access to the demonstration site. Mr. Thomas Georgian from the Omaha District USACE provided an independent expert technical support with several of the statistical analyses. The project team wishes to thank the technical support team for their ongoing support and dedication throughout the project. The technical support team included Dr. David Adamson, Mr. Travis McGuire, Dr. Brian Looney, Dr. Patrick Evans, Dr. Joseph Hughes, Dr. Michelle Simon, Mr. Charles Coyle, and Mr. Thomas Georgian. Contact information for individuals involved in this project is provided in Appendix A.

Executive Summary

Key Points

We tested a new Hydrogen-based Treatment technology (H_2T) where gaseous hydrogen and other gases were injected into a fine-grained vadose zone at a former missile silo site in Nebraska. The hydrogen gas was designed to stimulate biodegradation of the chlorinated solvent contaminants that persisted in this zone even after 3 years of soil vapor extraction (SVE). The process can be thought as a type of "Anaerobic Bioventing" for unsaturated zones containing chlorinated solvents.

Over the 6-month test, we injected a total of 830,000 standard cubic feet of gas with the following average composition: 10% hydrogen, 79% nitrogen, 10% propane, and 1% carbon dioxide. The nitrogen and propane were added to help keep the system anaerobic from oxygen diffusing into the test zone. The propane also served to keep the density of the gas mixture closer to that of nitrogen and air. By doing this the buoyant tendency of hydrogen was alleviated. The carbon dioxide was added to ensure a carbon source for the dechlorinating bacteria. Because of inconclusive sampling results during the test, the total gas flow rate and hydrogen composition were doubled for the last month of the injection phase and the total gas flow rate was increased from 2.5 scfm to 5.0 scfm and hydrogen composition was increased from 10% to 20%. An increase in hydrogen and propane concentrations and decrease in oxygen concentrations were observed at the monitoring points after increase in the flow rate and hydrogen composition.

Mass in Treatment Zone	Pre-Test (grams)	Post-Test (grams)	% Change
TCE	289	127	-56%
cis1,2-DCE+trans1,2-DCE	472	589	+24%
Total	760	717	-6%

The molar mass of chlorinated compounds was unchanged (7.1 moles before vs. 7.1 moles after). Therefore while the system was successful at converting TCE, a "cis-DCE stall" condition at the site appeared to be present at the site.

Key conclusions from the test:

- The H_2T process removed half the TCE from the test zone that was remaining after this zone had been treated with soil vapor extraction for 3 years. This indicates the process may be effective for treating finer-grained units that are difficult to treat with SVE.
- In-test measurements of redox-related parameters (oxygen, methane) indicated that deeply anaerobic conditions were not achieved uniformly through the test zone, a likely contributing factor for the observed cis-DCE stall condition. For example, the average oxygen content in the treatment zone soils during test ranged from 0.1% to 11%, indicating partial anaerobic conditions for most of the treatment zone.
- Lab microcosm work where the gas mixture was added to soil samples from the site indicated that samples that had been bioaugmented with dechlorinating bacteria performed much better than unamended soils, indicated a dechlorinating bacterial limitation at the site. Additional microcosm results indicated that low moisture may have been a contributing

factor to this bacterial limitation. The research team concluded that the system's inability to create deeply anaerobic conditions was likely a major factor in the cis-DCE stall issue.

- Unit cost for a full-scale H_2T system (assumed to be about 50,000 cubic yards) is projected to be **$39 per cubic yard**. This would compare to the following costs per cubic yard: $37 for a new-build soil vapor extraction system; $20 to keep an existing SVE system in operation for another two years; and $97 for excavation.
- It is possible to safely injection the hydrogen, nitrogen, propane, carbon dioxide gas mixture in the test zone. The radius of influence from the injection point was approximately 15 feet.
- In-test vapor VOC monitoring data were not very helpful in evaluating the progress of remediation.
- The H_2T system for this test was more successful than the existing SVE system at removing TCE from the fine-grained soils at this test site, but was not successful at removing a significant fraction of the cis-DCE. To help drive a full-scale H_2T drive a treatment zone to deeply anaerobic conditions, some type of barriers over the top and around the sides of the treatment zone (even something as simple as adding water to reduce the gas permeability of the soils) might help break out of a cis-DCE stall condition.

The pre-test success criteria and outcomes are summarized below:

Performance Objective	***Success Criteria***	***Success Criteria Achieved?***
Achievement of a greater radius of influence (ROI)	ROI that is 50% greater compared to ROI of liquid addition to the unsaturated zone	**YES** • ROI for *He* was 15 feet • Low O_2 concentration in MWs up to 40 feet • H_2, and propane detected in MWs up to 40 feet
Greater reduction in baseline (no action) mass	50% or greater reduction in baseline (no action) mass and/or estimated mass flux	**YES FOR TCE, NO FOR DAUGHTER PRODUCTS** • TCE mass reduced by 56% over six months. (This was TCE remaining in soil after 3 years of SVE operation). • Number of soil samples above 57µg/kg standard dropped from 27% to 10% • Total moles of CVOC unchanged due to apparent cis-DCE stall.
Higher cost savings compared to the continued operation of an SVE system	Greater cost savings compared to the continued operation of a SVE system or use of an injection-based system.	**SOMETIMES** • For full-scale application, H_2T unit costs (in $/cu. yrd) were $39 vs. $97 for excavation vs. $37 for SVE (although continued SVE appeared to be ineffective). • Continued operation of SVE for two years was estimated to be $20/cu. yrd vs. $39/cu. yrd for H_2T. However, the H_2T process was more efficient at removing TCE (but not daughter products) from fine-grained soils than SVE.
Reduction in the carbon footprint compared to SVE	50% reduction in the carbon footprint compared to SVE w/ oxidizer or carbon.	**MOSTLY YES** • H_2T carbon footprint was 8 tons of CO_2 compared to 21tons for SVE (high end) • H_2T CO_2footprint was 43% of SVE (low end)
Safety	Flammabilities of less than 10% of LEL at surface	**YES** • No health and safety incidents occurred • H_2, and propane never detected in ambient air
Ease of Use	Lower time requirement for system setup and operation compared to SVE	**YES** One field technician did the weekly O&M, made the pressure-flow readings and collected the data.

Background and Technology Description

A Hydrogen-based Treatment (H_2T) technology for unsaturated zones contaminated with chlorinated solvents was tested during this project. This technology can be applied when DoD site managers would like to shut down an existing SVE system, but where monitored natural attenuation may not be sufficient to control the groundwater plume that is sourced by the residual contaminants in the unsaturated zone. With such a technology, the cost for remediating these groundwater plumes can be greatly reduced, and a much more sustainable remedy can be implemented. Since the H_2T technology relies on some very important technical criteria that can affect its performance (e.g., radius of influence, bioavailability, etc.), field-scale application of this technology required verification through a treatability study and a field-scale demonstration.

"Anaerobic Bioventing" is an attractive option for unsaturated zone remediation because gases can disperse farther into the unsaturated materials than liquids. Gases can also potentially diffuse more thoroughly through the subsurface, to some extent minimizing the problems of preferential flow pathways that are more common with liquid flow. Previous studies have shown that anaerobic biotreatment of chlorinated volatile organic compounds (CVOCs) in the unsaturated soils (i.e., anaerobic bioventing) has potential as a remediation alternative for unsaturated soils. In H_2T, reductive dechlorination and bioventing are combined to create a remediation technology for sites where the unsaturated zone requires some type of treatment of chlorinated solvents. This approach for bioremediation of unsaturated soils containing chlorinated solvents was originally proposed in a patent by Hughes et al. (1997).

In the H_2T system, a mixture of nitrogen, hydrogen, propane, and carbon dioxide gases are injected into an unsaturated treatment zone. Nitrogen serves to flush oxygen from the soil gas, enhancing conditions for the anaerobic degradation of chlorinated solvents. Propane is used as an electron donor for scavenging oxygen (i.e., aerobic bacteria will use the propane to remove oxygen) and making the gas mixture neutrally buoyant. Hydrogen is used as the electron donor for dechlorinating bacteria. Nitrogen and hydrogen can be purchased and delivered to the site (which are refilled or changed out regularly by the gas provider as part of the gas delivery contract) or generated on-site depending on the size of H_2T application (i.e., total flowrate and treatment time).

The stoichiometry of the dechlorination reaction indicates that for every 1 mg of hydrogen utilized by dechlorinating bacteria, 21 mg of perchloroethene (PCE) can be completely converted to ethene. In the unsaturated zone, the H_2T process relies on a gas injection skid consisting of piping, gages, safety equipment, process control system, and gas supply vessels that could connect to a piping manifold and injection wells at the site. At some sites, one advantageous configuration could be the conversion of a low-performance SVE system to H_2T, where the existing SVE blower and treatment system is decommissioned and replaced by the H_2T injection skid connected to the existing manifold and injection wells.

Performance Objectives and Results

Soil and vapor samples collected prior, during, and after the gas injection to evaluate the system performance at the demonstration site (Atlas Missile Site 10 in Former Lincoln AFB, York, Nebraska). Following completion of the sampling and analysis program, the data was reviewed and analyzed to determine whether the success criteria for each performance objective have been met.

Radius of Influence: The effectiveness of the technology for unsaturated soil remediation is a function of the transport of the gas mixture out from the injection wells through the contaminated source zone. The H_2T system has a larger radius of influence for gas injection than liquid chemical addition such as molasses or permanganate in liquid-based bioremediation of the unsaturated zone. The H_2T system also increases the treatment of lower-permeability units due to the high diffusion coefficient of the hydrogen. Therefore, it is expected that the H_2T system has larger ROI in lower-permeability soils compared to SVE system.

Measurements of different gases at the monitoring points were used to evaluate the ROI of the H_2T system at the demonstration site. Monitoring points were located between 10 to 40 feet from the injection points. Success was defined as ROI that is 50% greater compared to ROI of liquid addition to the unsaturated zone, estimated to be 5 to 10 feet. The ROI achievement was evaluated in two ways:

(1) Tracer test using helium/nitrogen tracer gas. Helium gas reached the 10-ft distance monitoring wells at all depths (i.e., shallow, medium, and deep). Tracer gas reached almost all the monitoring wells including the 15-ft distance monitoring wells after Day 4. However, the levels of helium were not high enough at the monitoring points farther than 15 feet from the injection points (i.e., 50% of the helium concentration in the injection gas) to confirm that the ROI extended beyond approximately 15 feet. The tracer test also generated data that demonstrated the presence of preferential pathways.

(2) Evaluating the ROI by looking at the concentrations of oxygen, hydrogen, and propane gases before, during, and after the gas injection phase in multi-level monitoring points. Average oxygen concentrations were reduced from 16.1% to 0.4% in shallow monitoring points, from 16.8% to 5.7% in medium monitoring points, and from 16.3% to 5.7% in deep monitoring points. The low oxygen concentrations in the shallow monitoring points were observed at distances up to 40 feet away from the point of injection, while for the medium and deep monitoring points, oxygen concentrations increased significantly at around 15 feet distance from the point of injection. While deeply anaerobic conditions never reached at the medium and deep monitoring points, significant reduction in oxygen concentrations was attainable at the medium and deep monitoring intervals.

Hydrogen was detectable at all depths and distances as far as 40 feet from the injection point, exceeding the 15-feet target ROI. As expected hydrogen concentrations never maintained the injected concentration of 10% in the treatment zone. The highest hydrogen concentrations (i.e., approximately 0.5%) were observed at the shallow depths (i.e., 15 ft-bgs) and generally decreased as the depth increased and as the distance from injection point increased. Propane was more easily distributed than hydrogen both with respect to distance from injection and depth. The detected propane concentration before gas injection (i.e., May 2011) ranged from <0.02 ppmv to 4.5 ppmv. Measured propane concentrations after gas injection (i.e., December 2011) ranged from 11.5 ppmv to 85,030 ppmv. Propane was easily distributed at significant distances from the point of injection at the 20, 30, and 40-ft bgs depths. For example, propane concentration of 16,397 ppmv was observed at MW-8D which is 40 feet away from the injection point.

__Baseline Mass Reduction:__ The mass of trichloroethene (TCE) and its daughter products in soil was measured both before and after the demonstration was calculated. This analysis included the change in concentration and mass for 48 sample pairs collected from all of the injection and monitoring well locations during pre- and post-treatment characterization phases. Success was defined as 50% or greater reduction in baseline (no action) mass.

The median TCE concentrations of all 48 samples (i.e., 12 sampling locations and 4 depths) dropped from 8 µg/kg during the pre-treatment characterization phase to 4 µg/kg during the post-treatment characterization phase. The median cis-1,2-dichloroethene (cis-1,2-DCE) concentrations of all 48 samples (i.e., 12 sampling locations and 4 depths) increased from 17 µg/kg during the pre-treatment characterization phase to 40 µg/kg during the post-treatment characterization phase. The median TCE concentration decreased approximately 50% and median cis-1,2-DCE concentration increased approximately 123%.

The number of soil samples with TCE concentrations above 57 µg/kg which is the Nebraska Department of Environmental Quality (NDEQ) soil remediation goal dropped from 13 samples in pre-treatment to 5 samples in post-treatment. The number of soil samples with cis-1,2-DCE concentrations above 400 µg/kg which is the NDEQ soil remediation goal dropped from 10 samples in pre-treatment to 9 samples in post-treatment.

The total estimated TCE mass in the treatment zone (excluding results from MW-9, since this well is located outside the treatment area) dropped from 289 g during the pre-treatment characterization phase to 127 g during the post-treatment characterization phase. The total estimated cis-1,2-DCE mass increased from 464 g during the pre-treatment characterization phase to 573 g during the post-treatment characterization phase. The estimated mass showed that approximately 56% reduction in TCE mass and approximately 24% increase in DCE mass (sum of cis 1,2- and trans 1,2-DCE) were observed, for a total of 6% reduction in total chlorinated compounds. The total moles of chlorinated compound were unchanged during the test, with 7.1 moles pre-treatment and 7.1 moles post-treatment. (Only trace amounts of vinyl chloride were ever observed in any of the sampling conducted for this test). Total estimated CVOC mass in the treatment zone dropped from 760 g during the pre-treatment characterization phase to 717 g during the post-treatment characterization phase.

Several t-test and Mann-Whitney analyses were performed to compare the means of the 48-pair TCE samples from pre- and post-treatment characterization phases. Average TCE concentration dropped from 166 µg/kg during the pre-treatment characterization phase to 74 µg/kg during the post-treatment characterization phase. The t-test conducted on the 48-pair samples resulted in p-value of 0.092 that corresponds to a 91% confidence in support of the hypothesis that the post-treatment TCE concentrations are significantly smaller than the pre-treatment TCE concentrations. The Mann-Whitney analysis also resulted in a similar p-value of 0.104 that corresponds to a 90% confidence in support of the hypothesis that post-treatment TCE concentrations are significantly smaller than the pre-treatment TCE concentrations.

Both t-test and Mann-Whitney analyses show that there is approximately 90% confidence that the post-treatment TCE concentrations are significantly less than the pre-treatment TCE concentrations. The data sets are characterized by large variability (e.g., extreme positive outliers) and a relatively large number of non-detects, which tends to adversely affect the power of statistical tests to detect differences. Similar analyses were performed for cis-1,2-DCE and the results show that there is greater than a 90% but less than a 95% probability that the post-treatment cis-1,2-DCE soil concentrations are significantly greater than the pre-treatment cis-1,2-DCE soil concentrations.

<u>Carbon Footprint:</u> The carbon footprint was estimated for two variations of H_2T (i.e., liquid nitrogen/hydrogen cylinder delivery versus on-site nitrogen and hydrogen generation) and compared to two variations of SVE system operation (i.e., continuous versus pulsed operation at 25% time). Success was defined as 50% reduction in the carbon footprint compared to SVE.

Two carbon footprint cases were studied: (1) high end carbon footprint case where a constant operation of SVE+GAC was compared with direct liquid nitrogen/hydrogen cylinder delivery, and (2) low end cases, where a pulsed operation of SVE+GAC was compared with on-site nitrogen and hydrogen generation.

For the high end carbon footprint case, the carbon footprint was 21.4 tons of CO_2 for SVE+GAC versus 8.1 tons of CO_2 for the H_2T system. For the high end case, the carbon footprint of H_2T system operation is approximately 62% less than SVE system operation. For the low end case, the carbon footprint was 7.7 tons of CO_2 for SVE+GAC versus 4.4 tons of CO_2 for the H_2T system. For the low end case, the carbon footprint of H_2T system operation is approximately 43% less than SVE system operation. Note that the high-end hydrogen case has approximately the same footprint as the low-end SVE case.

The carbon footprint calculations were performed for the demonstration site operating for a year (i.e., a treatment zone with dimensions of approximately 2,200 ft^2 area and 40 foot thickness). There were considerable uncertainties in the calculations. At some sites, use of SVE and activated carbon could result in a lower carbon footprint than the direct hydrogen injection process. The most sensitive parameters included: 1) use of cylinders, gas in cryo-liquid form; tube trailers, or on-site nitrogen and/or hydrogen generators; 2) amount of electricity used by SVE system blower and gas generators; 3) amount of gas used in the direct hydrogen delivery process; and 4) number of trips required to deliver gas to the site.

<u>Safety:</u> One of the potential risks associated with field implementation of the H_2T system is the use of gases (i.e., H_2 and LPG) that are explosive under certain conditions. Although the concentration of the explosive gases in the gas mixture is 20% by volume, it was expected that the H_2T process was considered safe because the flammable gases disperse quite readily in the atmosphere and no detections of flammable gases above ground were observed. It is also expected that the oxygen levels at the injection points below ground surface are close to zero. Nevertheless, standard engineering practices can be used to provide a safe system. As part of H_2T performance objective the concentrations of H_2 and propane were monitored at the surface to maintain levels below the lower explosive levels (LEL) at the surface. The objective was considered to be met if flammabilities of less than 10% of the LEL at surface are achieved. Soil gas monitoring included explosivity measurements using an explosivity meter.

No health and safety incidents occurred during the demonstration, and flammable gas concentrations above the ground surface were not detectable. It should be noted that hydrogen and propane concentrations exceeded the LELs at some points below ground surface, but there was not enough oxygen available at those points to make the system potentially explosive. While concerns regarding safety of hydrogen and propane injections are reasonable, the results of this demonstration indicate the technology can be implemented safely.

Ease of Use: The effectiveness of the H_2T technology is also related to the relatively easy implementation of the H_2T system compared to other technologies such as SVE. It was anticipated that the ease of permitting (no air permits were required for this demonstration) and the ease of operation make the implementation of this technology quick and easy. Success criteria for this performance objective were evaluated qualitatively. It should be noted that a site-specific comparison of H_2T vs. SVE operation should be implemented because the ease of use also depends whether engineering controls for safety is implemented for H_2T or vapor-phase emissions control system is needed for SVE.

Required operator manpower was evaluated for both the existing SVE system and for H_2T system. Feedback from field personnel regarding ease of use of H_2T compared to SVE was also used. The metric for this performance objective was the frequency at which an operator needed to visit the site. The reasons for site visitation during normal operations included gas cylinder change-outs, system leak test, pressure and flow readings, and monitoring. This occurred once per week (i.e., weekly O&M) or every few weeks (i.e., tank re-fill or cylinder replacement), which was considered reasonable.

Implementation Issues

The primary application for H_2T is anticipated to be treatment of contaminants such as TCE in unsaturated soil for the purpose of groundwater protection. A site-specific feasibility study should be conducted to evaluate H_2T compared to other alternatives such as excavation, soil vapor extraction, and thermal treatment. Specific permits for H_2T may be required by local codes and will include drilling, well installation permits and hazardous materials storage permits. Other permits may be necessary and will be dependent on local codes.

A summary of H_2T-specific implementation issues are:

- One of the main safety concerns associated with H_2T application is the flammability of hydrogen and LPG and the potential production of methane gas. Flammable gases were not detected above the ground surface. Thus, release of flammable gas to the atmosphere was not a safety issue. It was shown in this demonstration that the safety concerns could be addressed easily by following the safety codes (e.g., NFPA50A, NFPA55, etc.), placing flammable gas/no smoking placards, and monitor measured gas concentrations and compare them to lower explosive level (LEL) at the surface soil and ambient air.

- Soil permeability and heterogeneity, soil moisture, etc. can greatly affect the performance of H_2T system. Computer modeling as well as pilot tests can be conducted to improve the design basis. These can generate data related to soil gas permeability, radius of influence, hydrogen utilization rates, and oxygen infiltration, all of which are valuable for deciding whether or not H_2T should be applied at a site. For example, for this demonstration, preliminary diffusion modeling conducted by Dr. Brian Looney, indicated significant oxygen diffusion from the sides, and that likely was one of the reasons that deep anaerobic conditions were not achieved in the middle or deep monitoring intervals.
- A suitable population of dechlorinating organisms *(Dehalococcoides)* (DHC*)* is needed to ensure complete conversion of PCE or TCE to non-toxic products (e.g., ethane). Quantitative polymerase chain reaction (qPCR) testing is recommended to quantify and characterize DHC bacteria at a site where H_2T application is considered. qPCR testing can be done with either groundwater or soil samples.
- In-test measurements of redox-related parameters (oxygen, methane) indicated that deeply anaerobic conditions were not achieved uniformly through the test zone, a likely contributing factor for the observed cis-DCE stall condition. Although the H_2T process is best suited for fine-grained soils with a reasonable degree of pneumatic interconnectivity, the structure of silty, loess-like soil at the site may have included some micro-fractures, which probably conveyed the majority of the volume of gas around some areas within the treatment zone. The disconnected zones of low permeability may have retained enough oxygen to inhibit reductive dechlorination within these zones. The research team concluded that the system’s inability to create deeply anaerobic conditions was likely a major factor in the cis-DCE stall issue.
- Lab microcosm work where the gas mixture was added to soil samples from the site indicated that samples that had been bioaugmented with dechlorinating bacteria performed much better than unamended soils, indicated a dechlorinating bacterial limitation at the site. The team strongly recommends that one should understand the bacterial limitation and issues involved with vadose zone bioaugmentation before attempting this technology.
- Additional microcosm results indicated that low moisture may have been a contributing factor to this bacterial limitation. Lab microcosm work showed that a high moisture content (30%) promoted the most complete reductive dechlorination under conditions with high electron donor concentration (10%) and bioaugmentation. However, lower moisture contents (17% to 19%) promoted reductive dechlorination of TCE to cis-1,2-DCE more effectively than a high moisture content (30%) when the electron donor concentration was low (1%). The later condition for moisture content and electron donor concentration was similar to the condition observed in the field.
- Liquid nitrogen was supplied in a commercially available trailer during this demonstration project. Approximately 20-30% of the liquid nitrogen was wasted due to ventilation to the atmosphere. The lost volume of nitrogen from tube trailers should be considered when the decision for using tube trailers versus nitrogen generator is being made.
- Hydrogen was supplied in cylinders and LPG was supplied in a tank during this demonstration project. Using both hydrogen and LPG at the site increases safety concerns, and relevant safety codes must be followed for the distance between LPG tank and the hydrogen cylinders (i.e., 30 feet for this demonstration). For large-scale projects

where an on-site hydrogen generator is used, it is more economical to replace LPG by hydrogen gas.

- If generators are to be used at a site, whether the generators are powered by fuel or electricity, the safety concerns must be addressed with regard to the placement of the generators and their proximity to the treatment area.

Implementation Cost

A cost model was developed for H_2T system. Four scenarios were considered and compared in this cost assessment based on data collected during this H_2T demonstration. In each scenario the H_2T system was compared with an alternative SVE system or soil excavation. All scenarios were based on the system design used in the demonstration and have an ROI of 15 feet. The cost model is based on implementing H_2T, SVE, or excavation of the entire source zone (i.e., area with initial TCE soil concentration above 57 µg/kg). The hypothetical treatment zone is 46,000 cubic yard (i.e., 27,500 ft^2 and 45 feet deep). Both H_2T and SVE costs are based on two-year system operation. The H_2T implementation cost included construction of gas injection skid, injection and monitoring well installation, pre- and post-treatment soil and vapor characterizations, cost of gas using nitrogen and hydrogen generators, and a gas composition of 20% hydrogen and no LPG, and weekly O&M.

For H_2T technology, the cost of potential bioaugmentation and barrier measures including capping or wetting the margins to prevent oxygen intrusion were roughly estimated. Bioaugmentation costs were included as a contingency (assuming bioaugmentation can be done effectively at some sites) to achieve complete dechlorination. It was assumed that water barrier wells were installed at the treatment zone perimeter using 74 temporary holes (i.e., assuming 5-foot ROI). It was assumed that water would be injected at an injection rate of 5 gallons per minute (gpm) per well. Bioaugmentation was implemented to the entire treatment zone area with 10-foot radius of influence. I was assumed that the bioaugmentation was performed in 88 wells (i.e., assuming 10-foot ROI) at an injection rate of 10 gpm per well was assumed.

In Scenarios 1 and 2, the cost of H_2T system operation for two years based on the implemented demonstration design conditions was \$49/cy compared to the entire SVE system operation (i.e., \$37/cy) and soil excavation (i.e., \$97/cy). In Scenario 3, the cost of H_2T system operation based on the implemented demonstration design conditions was \$49/cy compared to the continuation of the existing SVE system operation (i.e., \$20/cy). Finally, in Scenario 4, the cost of H_2T system operation by using the existing SVE wells as gas injection wells was \$46/cy compared to the continuation of the existing SVE system operation (i.e., \$20/cy).

It was concluded that while the cost of H_2T was greater than SVE system operation, the decision to switch to H_2T operation over an SVE system should be made based on the overall performance and not only on the cost assessments. For example, in the demonstration site where an SVE system was operating since 2008, the SVE system was not able to reduce the mass in the vadose zone due to the very low permeability soil (i.e., clayey silt loess material), likely due to preferential removal from a high-permeability layer at the bottom of the treatment interval. Small molecules of hydrogen gas, on the other hand, were able to diffuse into the small pores of the low-permeability soil.

Sensitivity analyses were performed to evaluate the effect of gas flowrate and ROI on the unit cost of H_2T implementation. At a gas injection flowrate of approximately 5 scfm the gas cost using bulk gas versus an on-site generator was similar. For total gas flowrates higher than 5 scfm the use of nitrogen and hydrogen generators are more economical. These cost calculations are for a two-year H_2T system operation. If the H_2T system operation is longer than two years, the cost savings by using gas generators will be increased.

Sensitivity of H_2T operation costs to radius of influence were evaluated for ROI values from 5 to 25 feet in a treatment area of 27,500 ft^2. The number of injection wells was increased dramatically from 15 to 350 when the ROI is decreased from 25 feet to 5 feet. By increasing the ROI from 10 feet to 15 feet, the total cost of H_2T operation is reduced by approximately 23% (i.e., \$64/cy to \$49/cy), while increasing the ROI from 15 ft to 20 feet, the total cost of H_2T operation is reduced by approximately 10% (i.e., \$49/cy to \$44/cy). It was assumed that the total number of pore volumes injected within two years of H_2T operation was similar for all the ROI values and therefore, the gas cost for all different ROI values were the same. The analysis shows that the effect of ROI on the total H_2T cost is significant and an accurate estimate of site ROI is needed.

1.0 INTRODUCTION

1.1 BACKGROUND

As of 2005, the Department of Defense (DoD) has identified nearly 6,000 sites at its facilities that require groundwater remediation and has invested $20 billion for site cleanup over a ten-year period (GAO, 2005). At many of these sites, unsaturated chlorinated volatile organic compounds (CVOCs) source zones located above the water table are producing and sustaining groundwater plumes. Many of these unsaturated sources are currently being treated with soil vapor extraction (SVE) technologies. Long-term SVE projects can be very costly, as the treatment process for the recovered vapors is expensive.

A low-cost, more passive treatment technology for unsaturated zones contaminated with chlorinated solvents was tested during this project. This technology can be applied when DoD site managers would like to shut down an existing SVE system, but where monitored natural attenuation may not be sufficient to control the groundwater plume that is sourced by the residual contaminants in the unsaturated zone. With such a technology, the cost for remediating these groundwater plumes can be greatly reduced, and a much more sustainable remedy can be implemented. “Anaerobic Bioventing” is an attractive option for unsaturated zone remediation because gases can disperse farther into the unsaturated materials than liquids. Gases can also potentially diffuse more thoroughly through the subsurface, to some extent minimizing the problems of preferential flow pathways that are more common with liquid flow.

Several studies have been conducted on the use of hydrogen as an electron donor for the anaerobic bioremediation of saturated and unsaturated porous media (Evans and Trute, 2006; Mihopoulos et al., 2002; Newell et al., 1997; Aziz et al., 2003a; Aziz et al., 2003b; Mihopoulos et al., 2000; Shah et al., 2001; Mihopoulos et al., 2001, Evans et al., 2009). Hydrogen technology using pure H_2 gas has been extensively tested as a treatment technology for groundwater (AFCEE, 2004; GSI, 2003; Fisher et al., 1999; Newell et al., 2001) and showed good performance where H_2 injections alone were able to promote vigorous biodegradation. Details on the laboratory data supporting successful application of anaerobic bioventing are presented below.

The biological reduction of VOCs using hydrogen in groundwater has been pioneered by the Air Force Center for Engineering and the Environment (AFCEE). The AFCEE Principals and Practices guide (AFCEE, 2004) summarized gaseous hydrogen technology in the saturated zone:

> ***“5.5.6.3 Gaseous Hydrogen***
> *Because microorganisms known to completely degrade PCE to ethene use hydrogen as an electron donor, addition of hydrogen is the most direct approach to stimulating anaerobic dechlorination. Although hydrogen is highly combustible, it is an inexpensive substrate that can be delivered safely with the proper engineering controls. Besides direct addition of hydrogen to groundwater, other methods to deploy hydrogen via hydrogen-releasing compounds, hydrogen-generating electrodes, and permeable membranes also are being developed (Newell et al., 2002; Novak et al., 2002). The feasibility of distributing uniform concentrations of gaseous hydrogen throughout large portions of a contaminated aquifer is*

> *still under research and development. In addition, hydrogen does not provide a carbon source for microbial growth and development. While hydrogen may stimulate activity of dechlorinating species, their growth depends on the availability of a carbon source for cell development. Therefore, the use of gaseous hydrogen may be better suited for aquifers with relatively high quantities of organic carbon (i.e., Type 1 and Type 2 sites).*
>
> *The Air Force has conducted two pilot-scale treatability tests involving direct addition of hydrogen to groundwater (Newell et al., 2001 and 2002). The first was a pull-push-pull test of groundwater contaminated with DCE at Offutt AFB, Nebraska, in November 1998. Concentrations of DCE decreased from 430 micrograms per liter (μg/L) to non-detectable levels over the 48-hour period of the test, indicating that anaerobic dechlorination of DCE was achieved. Direct hydrogen injection into the subsurface also was conducted at Launch Complex 15 at CCAFS, Florida (Appendix E.8). The pilot test used low-volume, pulsed biosparging with hydrogen into a sandy aquifer over an 18-month period. Three biosparge points were placed approximately 12 feet apart in a row perpendicular to groundwater flow. Hydrogen gas was sparged into each well at different rates and amounts during the first part of the pilot test. During the final year, most sparge pulses were at 10 to 12 standard cubic feet per minute (scfm) per well for 10 minutes once a week using 100 percent hydrogen gas. To evaluate potential stripping effects of the sparging process, an identically constructed and operated well was sparged with nitrogen. In addition, a side gradient transect of monitoring wells was installed and monitored to evaluate natural attenuation effects. The treatment zone and the natural attenuation and nitrogen sparge control zones were monitored to determine the effectiveness of the hydrogen addition. Concentrations of TCE and DCE decreased, while an increase in VC, ethene, and methane concentrations was observed. These data suggest that dechlorination proceeded to completion under methanogenic conditions. Based on these results, the Air Force is planning additional testing of hydrogen to stimulate anaerobic dechlorination. A similar system is currently being operated at the Old Jet Engine Test Cell Site at Offutt AFB, Nebraska."*

In general, these studies indicate that anaerobic biotreatment of CVOCs in the unsaturated soils (e.g., anaerobic bioventing) has potential as a remediation alternative for unsaturated soils. Since the technology relies on some very important technical criteria that can affect the performance of the technology (e.g., radius of influence, bioavailability, surface cover, etc.), field-scale application of this technology requires verification through a field-scale demonstration.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of this project is to show if **hydrogen-based treatment** (H_2T) can serve as a remediation technology for the unsaturated zone, either as the initial remediation technology applied at a site or as a polishing technology that will allow site managers to shut down expensive, low performance soil vapor extraction systems (SVE) that are no longer cost effective. H_2T is implemented by injecting a primarily inert gas mixture of nitrogen (N_2), propane (C_3H_8), hydrogen (H_2), and carbon dioxide (CO_2) gas through a series of widely spaced injection points to degrade chlorinated organic compounds. The nitrogen (N_2) serves as a non-explosive carrier gas for the process. The propane serves as an inexpensive electron donor that naturally-occurring bacteria can use to remove oxygen from the vadose zone and control gas buoyancy. The hydrogen stimulates dechlorinating bacteria to biodegrade chlorinated organic compounds, forming innocuous daughter products such as ethane or ethane. This demonstration answers key questions about the performance, implementability, and cost of the technology. If successful, the H_2T system can serve as a cost-effective and more sustainable remediation technology (i.e., lower carbon-footprint) for unsaturated soils containing chlorinated solvents.

1.3 REGULATORY DRIVERS

Two main drivers for cleanup of TCE in soil at many sites is protection of groundwater and/or vapor intrusion. The current maximum contaminant level (MCL) established by U.S. EPA is 5 µg/L, while the maximum contaminant level goal (MCLG) for TCE is zero. Various states also may have drinking water regulations that apply to TCE. The Nebraska Department of Environmental Quality (NDEQ) has established a remediation goal of 57.0 µg/kg for TCE concentration in soil.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

In-situ biodegradation of chlorinated solvents (called reductive dechlorination) and bioventing are two proven remediation technologies with extensive application in groundwater and the unsaturated zone, respectively. Most of the groundwater applications of reductive dechlorination are based on the addition of soluble or semi-soluble substrates (i.e., molasses, lactate, HRC polymers, edible oils) where the substrates ferment to form dissolved hydrogen (as a waste product), and then the dissolved hydrogen is used by dechlorinating bacteria to degrade chlorinated solvents. The role of hydrogen as an electron donor is widely recognized as the key factor governing the dechlorination of chlorinated compounds (Holliger et al., 1993; DiStefano et al., 1992; Maymo-Gatell et al., 1995; Gossett and Zinder, 1996; Smatlak et al., 1996; Hughes et al., 1997; Evans and Trute, 2006; Shah et al., 2001). There have been a wide variety of injection schemes, ranging from direct push of the amendments to groundwater recirculation systems. The addition of liquids to the unsaturated zone is difficult. However, relatively few biodegradation projects of this type have been performed in the unsaturated zone.

Bioventing (where air is injected at slow rates into the unsaturated zone) has proven to be very effective in remediating releases of petroleum products including gasoline, jet fuels, kerosene, and diesel fuel. Several Number of field demonstrations and pilot applications of bioventing were reported in the literature for petroleum sites (for example, Ely and Heffner, 1988; Hinchee et al., 1991a; Hinchee et al., 1991b; Miller and Hinchee, 1990; Thomas and Ward, 1989; Urlings et al., 1990). Bioventing typically is applied in situ to the unsaturated zone and is applicable to any chemical that can be biodegraded rapidly by aerobic processes, and has been implemented primarily at petroleum-contaminated sites. Conventional bioventing using air has not been used for remediating releases of most chlorinated solvents such as PCE, TCE, or other more highly chlorinated compounds because these compounds either do not degrade or degrade relatively slowly in aerobic environments.

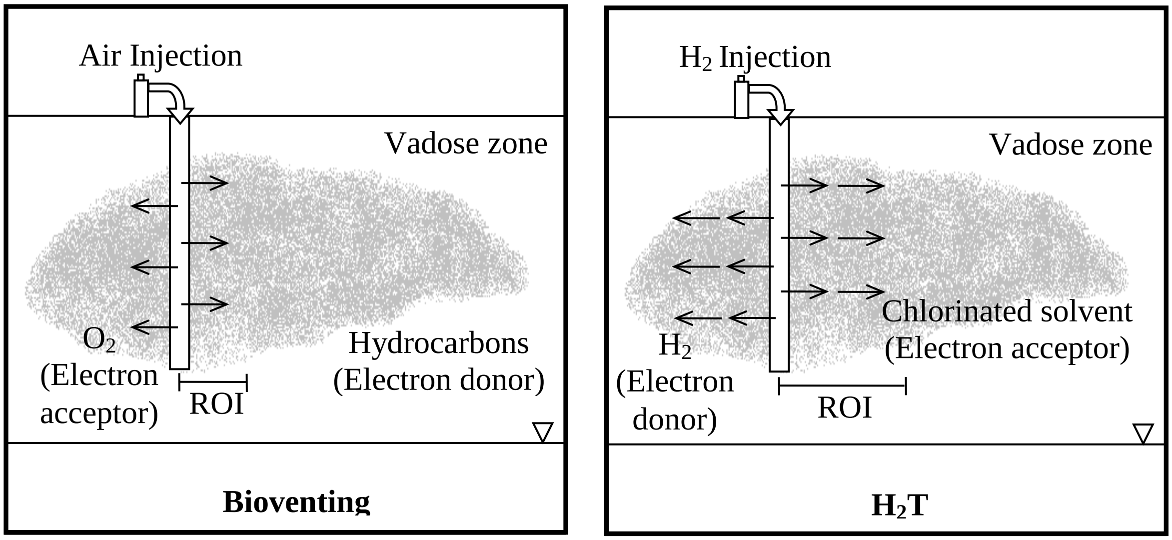


Figure 1: Comparison of H_2T and bioventing

In the H_2T, reductive dechlorination and bioventing are combined to create a remediation technology (hydrogen-based treatment or H_2T) for sites where the unsaturated zone requires some type of treatment of chlorinated solvents. This approach for bioremediation of unsaturated soils containing chlorinated solvents was originally proposed in a patent by Hughes et al. (1997). **Figure** 1 shows the comparison of H_2T and bioventing. Biodegradation of the soil contaminant is facilitated by injection of gaseous oxygen in bioventing or hydrogen gas in H_2T.

The conceptual configuration for gas injection implementation is shown in **Figure 2**. In the H_2T system, a mixture of nitrogen, hydrogen, propane, and carbon dioxide gases are injected into an unsaturated treatment zone. Nitrogen serves to flush oxygen from the soil gas, enhancing conditions for the anaerobic degradation of chlorinated solvents. Propane is used as an electron donor for scavenging oxygen (i.e., aerobic bacteria will use the propane to remove oxygen). Hydrogen is used as the electron donor for dechlorinating bacteria. Nitrogen and hydrogen can be purchased and delivered to the site (which are refilled or changed out regularly by the gas provider as part of the gas delivery contract) or generated on-site depending on the size of H_2T application (i.e., total flowrate and treatment time). The stoichiometry of the dechlorination reaction indicates that for every 1 mg of hydrogen utilized by dechlorinating bacteria, 21 mg of perchloroethene (PCE) can be completely converted to ethene.

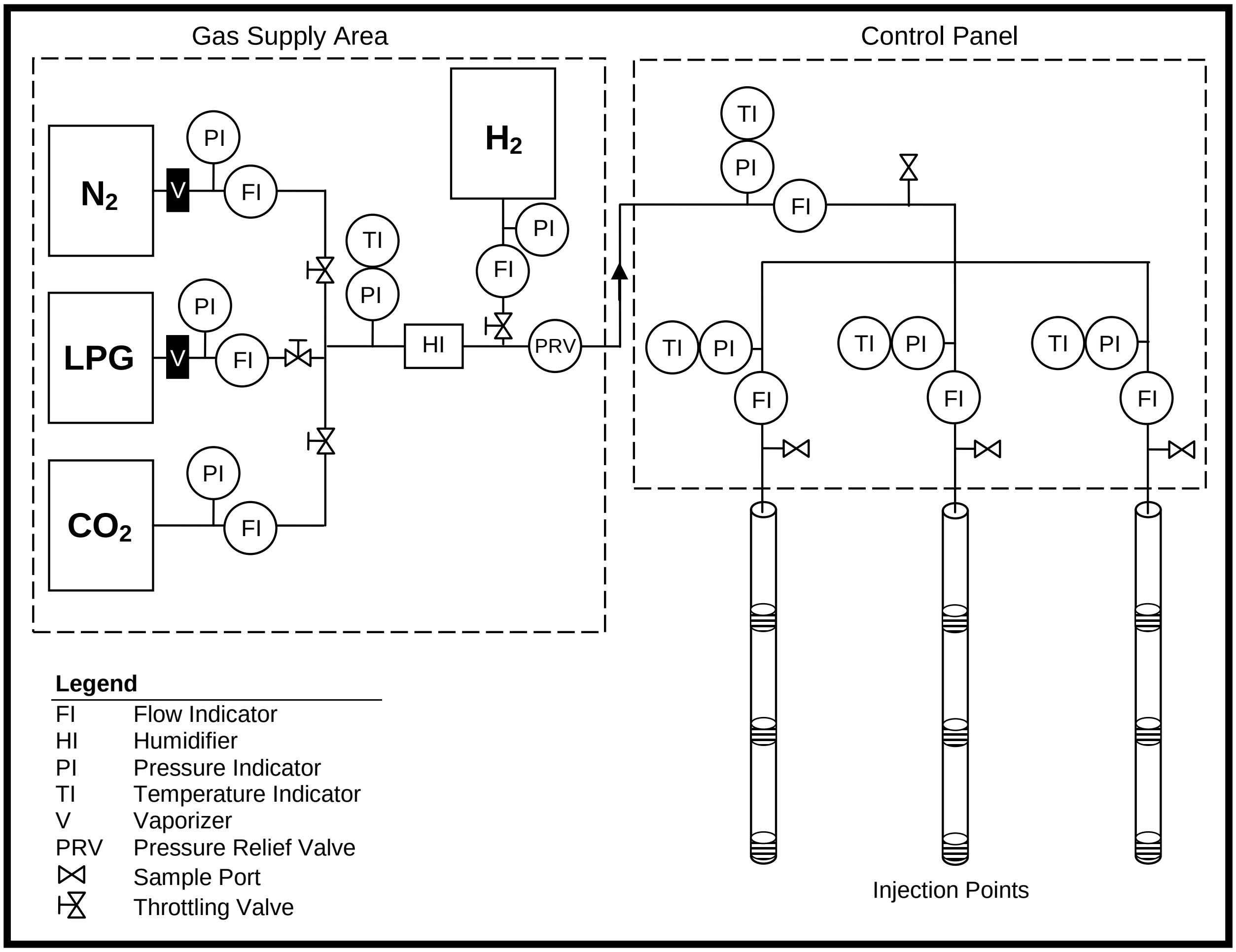


Figure 2: Conceptual configuration for gas injection implementation (tracer not shown)

In the unsaturated zone, the H_2T process relies on a gas injection skid consisting of piping, gages, safety equipment, process control system, and gas supply vessels that could connect to a piping manifold and injection wells at the site. At some sites, one advantageous configuration is conversion of a low-performance SVE system to H_2T, where the existing SVE blower and treatment system is decommissioned and replaced by the H_2T injection skid connected to the existing manifold and injection wells.

Hydrogen-based biodegradation can be applied in three ways:

1) As a replacement for traditional soil treatment technologies (SVE, excavation, liquid-based biodegradation, thermal treatment, or chemical oxidation) at sites where no treatment has yet occurred;
2) As a polishing step to replace expensive SVE systems that are no longer removing large amounts of contaminant mass; and
3) Potentially as a method to eliminate migration of solvent vapors to indoor air. In some cases, the existing SVE system hardware (injection points, manifolds, monitoring points) can be retrofitted to accommodate H_2 injection.

2.2 TECHNOLOGY DEVELOPMENT

H_2T technology development is very similar to the Gaseous Electron Donor Injection Technology (GEDIT) that has been described in detail previously (Evans, et al., 2009; Evans and Trute, 2006; Evans, 2007; Evans et al., 2011). The previous ESTCP project (ER-0511) applied the GEDIT technology for perchlorate and nitrate remediation (Evans et al., 2009). For that perchlorate remediation project, a gas mixture consisting of 79% $N_{2,}$ 10% C_3H_8, 1% CO_2, and 10% H_2 was injected into the subsurface. Because the results of that project demonstrated success in the degradation of perchlorate, a similar gas mixture was used for this demonstration.

Mihopoulos et al., (2000) conducted soil column experiments and studied the dechlorination of vapor phase PCE by lab-scale “anaerobic bioventing”. They used Hydrogen as their electron donor. Using the soil column inoculated with anaerobic dechlorinating bacteria, the experimental results showed that by passing a gas composed of 1% H_2 and >0.1% CO_2 in N_2, methanogenic conditions were established and that PCE was rapidly converted with terminal products VC and trans-1,2-DCE. PCE half-life in the column was 7 minutes. Intermediate product detected but never accumulated in the column were TCE and cis-1,2-DCE. They acknowledged that in order to have a complete dechlorination of PCE to ethane, the bioventing process must be initiated by anaerobic followed by aerobic dechlorination.

Mihopoulos et al., (2001) conducted soil column experiment to study the complete remediation of PCE contaminated unsaturated soils to ethene by sequential anaerobic-aerobic bioventing. Two columns were connected in series. In the first column they injected hydrogen at level of 1% as electron donor for the anaerobic step. In the second column oxygen at 4.2% was used as an electron acceptor in the aerobic step. Experimental results showed complete dechlorination of PCE to ethene with PCE and VC half-lives of less than 10 minutes in anaerobic and aerobic steps, respectively.

The sequential anaerobic-aerobic bioventing can be easily implemented as in some cases anaerobic bioventing may use the same type of gas delivery system as the aerobic bioventing. Since some of the VOCs or SVOCs generated during the anaerobic bioventing may be slow to degrade under anaerobic conditions, the following aerobic treatment may be implemented in two ways: the more volatile compounds may diffuse into the soil surrounding the treatment zone, where aerobic degradation may occur. SVOCs and VOCs remaining in the treatment zone may be treated by following anaerobic bioventing with aerobic bioventing. Since aerobic and anaerobic bioventing share similar gas delivery systems, the switch can be made by simply changing the injected gas.

Tezel et al., (2004) investigated a sequential biotic-abiotic treatment of gaseous TCE where TCE was degraded to ethylene and ethene by passing through an anaerobic column followed with an elemental iron metal (Fe(0)) packed column. The anaerobic condition was reached by injecting H_2, CO_2 and N_2 gas mixture. The only by-product detected from the anaerobic step was cis-1,2-DCE.

Shah et al., (2001) conducted lab-scale experiments to evaluate potential of anaerobic bioventing for the treatment of unsaturated soils contaminated with 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) and 2,4-dinitrotoluene (DNT) using hydrogen as the electron donor. It was observed that by feeding a gas mixture of 1% H_2, 1% CO_2 and N_2, methanogenic conditions were established. DDT was dechlorinated and 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane (DDD) was observed as the intermediate product. The half-life for DDT dechlorination was 8.5 months. DNT completely disappeared after six months and no intermediates could be detected.

Mihopoulos et al., (2002) conducted two-dimensional experimental and numerical studies to investigate the establishment of an anaerobic zone of influence by nitrogen injection in the vadose zone. The oxygen exclusion experiments were performed in a pilot scale flow cell (2m × 1.1m × 0.1m) using different venting flows and two different outflow boundary conditions (i.e., open and partially covered). Results showed that anaerobic conditions were achieved in a reasonable time period. It was shown that use of covers on the surface could significantly reduce the volume of forcing gas used, where an increase in oxygen exclusion efficiency is consistent with a decrease in the outflow area above the injection well.

Evans and Trute (2006) conducted lab-scale column experiments and tested the effectiveness of several electron donors (e.g., hydrogen, ethanol, ethyl acetate, and butyraldehyde) in reducing nitrate and perchlorate. These column studies demonstrated widely varying transport rates of different electron donors through moist soil. Primary factors affecting transport included soil moisture, electron donor Henry's constant, void volume, bulk soil density, bulk gas velocity, soil permeability, and biodegradation rate. The laboratory microcosm studies demonstrated that hydrogen and ethanol promoted nitrate and perchlorate reduction in vadose zone soil and that moisture content was an important factor. Moisture clearly had a positive effect on nitrate and perchlorate reduction when moisture content increased from 8% to 12%. Significant nitrate reduction was observed with hydrogen only when moisture was supplemented.

Evans et al. (2009; 2011), during a field demonstration at the Inactive Rancho Cordova Test Site (IRCTS) near Sacramento, California, injected a mixture of 10% hydrogen, 10% liquefied petroleum gas (LPG or propane), 1% carbon dioxide, and 79% nitrogen into vadose zone soil to validate the gaseous electron donor injection technology (GEDIT) through an ESTCP-funded project. The field demonstration of GEDIT involved injection of a constant low flow rate (about 50 liters per minute) of a gas mixture into soil for three months. Results showed that GEDIT is capable of distributing the electron donors to distances of at least 50 feet from the point of injection. Oxygen concentrations were also depleted which was required for effective nitrate and perchlorate biodegradation. Soil sampling and analysis showed that nitrate concentrations were reduced by 90 percent or more, when compared to pre-injection data. Perchlorate concentrations have also been significantly reduced. Reductions in nitrate and perchlorate concentrations were observed in varying soil moistures and lithologies. Evans et al. (2009) concluded that a complete perchlorate biodegradation required approximately 105 days of gas injection and that the soil moisture content was an important factor affecting the rate of nitrate and perchlorate biodegradation, but nutrient amendment was not important with the particular Site soil.

Several bench-scale and field-scale studies summarized above indicate that anaerobic biotreatment of chlorinated solvents in the unsaturated soils is possible has in unsaturated soils. H_2T can be used in the vadose zone with sufficiently anaerobic conditions to attain reductive dechlorination. In general, any contaminant that can be anaerobically biodegraded is a potential candidate for H_2T.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Advantages: The H_2T system has the following advantages compared to SVE and liquid-based unsaturated zone bioremediation projects:

Advantages compared to an SVE system are:

1) H_2T system does not require costly surface treatment equipment such as thermal oxidizers;
2) H_2T system likely to be more sustainable from an environment perspective than SVE that uses thermal oxidizers or regenerated activated carbon;
3) Easier to permit in areas with stringent air discharge regulations.

Advantages compared to liquid-based bioremediation of the unsaturated zone are:

1) Larger radius of influence for gas injection than liquid chemical addition such as molasses or permanganate, thereby reducing costs;
2) Increased treatment of lower-permeability units due to the high diffusion coefficient of the hydrogen; and
3) Injection equipment operates automatically and requires little space.

Limitations: The main limitations to the H_2T process are:

Safety concerns:

1) Use of hydrogen and LPG can be of concern to some facilities and fire safety personnel on active sites;

2) Special knowledge is required to design the injection skid;
3) Compressed and/or liquefied gases are used, and adequate safety procedures are needed when handling these materials;
4) Another potential issue is injection of gases where there are nearby basements or buildings. This is an issue common to injection-based bioventing that is discussed in the bioventing guidance. Therefore, it is not unique to H_2T.

Efficiency and reaction concerns:

1) Diffusion of oxygen from the surface can reduce the efficiency of the process, as this oxygen will remove electron donor. If oxygen diffusion is significant, then higher rates of nitrogen and electron donor gas addition may be required, thereby increasing costs.
2) At some sites, there may not be adequate dechlorinating bacteria present to completely dechlorinate chlorinated solvents.
3) At some sites, the radius of influence of the gas injection point may be limited due to diffusion of oxygen from the surface.

3.0 PERFORMANCE OBJECTIVES

The technical performance objectives of this project were evaluated through the collection of soil and vapor data within the treatment area. Performance objectives, along with the data collected to meet these objectives and the final performance results, are listed in **Table 1**.

Table 1: Performance objectives and results of H_2T demonstration

Performance Objective	***Performance Monitoring Data Used to Evaluate Objectives***	***Success Criteria***	***Success Criteria Achieved?***
Quantitative Performance Objectives			
Achievement of a greater radius of influence (ROI)	Measure Helium, H_2, O_2 and propane concentration in the monitoring points. Monitoring points were located 10, 15, 20, and 40 feet from injection points.	ROI that is 50% greater compared to ROI of liquid addition to the unsaturated zone	**YES** • ROI for *He* was 15 feet • Low O_2 concentration in MWs up to 40 feet • H_2, and propane detected in MWs up to 40 feet
Greater reduction in baseline (no action) mass	Estimate contaminant mass from volume-weighted TCE and cis-1,2-DCE concentrations in treatment zone soil samples for before (48 samples) and after (48 samples) demonstration.	50% or greater reduction in baseline (no action) mass and/or estimated mass flux	**NO** • TCE mass reduced by 56% • Number of soil samples above 57µg/kg standard dropped from 27% to 10% • Total moles of CVOC unchanged
Higher cost savings compared to the continued operation of an SVE system	Calculate the cost of H_2T application compared to SVE and soil excavation by collecting the following data: ROI to estimate number of injection points; capital Cost (injection skid; manifold system, wells); gas cost; O&M cost (operator cost; electricity); soil and vapor monitoring.	Greater cost savings compared to the continued operation of a SVE system or use of an injection-based system.	**SOMETIMES** • For full-scale application, H_2T unit costs (in $/cy) were $39 vs. $97 for excavation vs. $37 for SVE (although continued SVE appeared to be ineffective). • Continued operation of SVE for two years was estimated to be $20/cy vs. $39/cy for H_2T. However, the H_2T process was more efficient at removing TCE (but not daughter products) from fine-grained soils than SVE.
Reduction in the carbon footprint compared to SVE	Estimate carbon footprint (H_2T: estimate volume of gasoline used by site operators to reach site; compile mass of key materials (PVC, steel, concrete); any electricity use. SVE: same but add natural gas use).	50% reduction in the carbon footprint compared to SVE using thermal oxidizer or activated carbon.	**MOSTLY YES** • H_2T carbon footprint was 8 tons of CO_2 compared to 21tons for SVE (high end) • H_2T carbon footprint was 43% of SVE (low end)
Safety	Measure flammability, H_2 and propane air emission. Soil gas monitoring that includes explosivity measurements using explosivity meter.	Flammabilities of less than 10% of LEL for H_2 /propane mixture at surface	**YES** • No health and safety incidents occurred • H_2, and propane were never detected in ambient air
Qualitative Performance Objectives			
Ease of Use	Required operator manpower records for both SVE system that is used before H_2T and for H_2T system. Feedback from field personnel regarding ease of use of H_2T compared to SVE.	Lower time requirement for system setup and data collection	**YES** One field technician did the weekly O&M, made the pressure and flow readings and collected the data.

3.1 ACHIEVEMENT OF A GREATER RADIUS OF INFLUENCE (ROI)

The effectiveness of the technology for unsaturated soil remediation is a function of the transport of the gas mixture out from the injection wells through the contaminated source zone. First quantitative performance objective to evaluate the success of H_2T technology in remediating the test area was to reach a greater ROI. It is anticipated that The H_2T system compared to liquid-based bioremediation of the unsaturated zone has a larger radius of influence for gas injection than liquid chemical addition such as molasses or permanganate. The H_2T system also increases the treatment of lower-permeability units due to the high diffusion coefficient of the hydrogen. The ROI from H_2T was compared with a typical ROI for a liquid-based technology, estimated to be 5 to 10 feet.

3.1.1 Data Requirements

In order to evaluate the radius of influence, helium, hydrogen, oxygen and propane concentrations was measured in the monitoring points. Monitoring points used for the ROI evaluation were located 10, 15, 20, and 40 feet from injection points.

3.1.2 Success Criteria

The objective was considered to be met if the ROI achieved by the H_2T was greater than or equal to the target ROI of 15 feet.

3.1.3 Results

Success criteria achieved? **YES**

The ROI achievement was evaluated in two ways:

(1) Tracer test using helium/nitrogen tracer gas. Helium gas reached the 10-ft distance monitoring wells at all depths (i.e., shallow, medium, and deep). Tracer gas reached almost all the monitoring wells including the 15-ft distance monitoring wells after Day 4. However, the levels of helium percentage were not high enough at the monitoring points farther than 15 feet from the injection points (i.e., 50% of the helium concentration in the injection gas) to confirm that the ROI extended beyond approximately 15 feet. The tracer test also generated data that demonstrated the presence of preferential pathways.

(2) Evaluating the ROI by looking at the concentrations of oxygen, hydrogen, and propane gases before, during, and after the gas injection phase. Average oxygen concentrations were reduced from 16.1% to 0.4% in shallow, 16.8% to 5.7% in medium, and 16.3% to 5.7% in deep monitoring points. The low oxygen concentrations in the shallow monitoring points were observed at distances up to 40 feet away from the point of injection, while for the medium and deep monitoring points, oxygen concentrations increased significantly at around 15 feet distance from the point of injection. While deeply anaerobic conditions never reached at the medium and deep monitoring points, significant reduction in oxygen concentrations was attainable at the medium and deep monitoring intervals.

Hydrogen was detectable at all depths and distances as far as 40 feet from the injection point, exceeding the 15-feet target ROI. As expected, hydrogen concentrations never maintained the injected concentration of 10% in the treatment zone. The highest hydrogen concentrations (i.e., approximately 0.5%) were observed at the shallow depths (i.e., 15 ft-bgs) and generally decreased as the depth increased and as the distance from injection point increased. Hydrogen was detectable at all depths and distances as far as 40 feet from the injection point exceeding the 15-feet target ROI. Propane was more easily distributed than hydrogen both with respect to distance from injection and depth. The detected propane concentration before gas injection (i.e., May 2011) ranged from <0.02 ppmv to 4.5 ppmv. Measured propane concentrations after gas injection (i.e., December 2011) ranged from 11.5 ppmv to 85,030 ppmv. Propane was easily distributed at significant distances from the point of injection at the 20, 30, and 40-ft bgs depths. For example, propane concentration of 16,397 ppmv was observed at MW-8D which is 40 feet away from the injection point. Overall, the metric for this performance objective was met.

3.2 GREATER REDUCTION IN BASELINE (NO ACTION) MASS

A further measure of the effectiveness of the technology for unsaturated soil remediation is the reduction in the chlorinated solvent mass from the baseline that is set at the initial mass (e.g., no action). Consequently, the second quantitative performance objective for this project was to evaluate if the H_2T technology results in reduction in total mass relative to the baseline (no action) case.

3.2.1 Data Requirements

In order to evaluate the reduction in mass, the volume-weighted chlorinated solvent concentrations were measured in the soil samples collected from four different depths (i.e., 10, 20, 30, and 40 ft-bgs) within the treatment area before (48 samples) and after (48 samples) the field demonstration.

3.2.2 Success Criteria

The objective was considered to be met if a 50% or greater reduction in baseline (no action) mass is achieved.

3.2.3 Results

Success criteria achieved? **YES FOR TCE, NO FOR DAUGHTER PRODUCTS**

The total estimated TCE mass in the treatment zone - excluding results from MW-9, since this well is located outside the treatment area - dropped from 289 gr during the pre-treatment characterization phase to 127 gr during the post-treatment characterization phase. The total estimated cis-1,2-DCE mass increased from 464 gr during the pre-treatment characterization phase to 573 gr during the post-treatment characterization phase. The estimated mass showed that approximately 56% reduction in TCE mass and approximately 24% increase in DCE mass (sum of cis 1,2- and trans 1,2-DCE) were observed, for a total of 6% reduction in total chlorinated compounds. The total moles of chlorinated compound were unchanged during the test, with 7.1 moles pre-treatment and 7.1 moles post-treatment. (Only trace amounts of vinyl chloride were ever observed in any of the sampling conducted for this test). Total estimated

CVOC mass in the treatment zone dropped from 760 gr during the pre-treatment characterization phase to 717 gr during the post-treatment characterization phase.

Several t-test and Mann-Whitney analyses were performed to compare the means of the 48-pair TCE samples from pre- and post-treatment characterization phases. Average TCE concentration dropped from 166 µg/kg during the pre-treatment characterization phase to 74 µg/kg during the post-treatment characterization phase. The t-test conducted on the 48-pair samples resulted in p-value of 0.092 that corresponds to a 91% confidence in support of the hypothesis that the post-treatment TCE concentrations are smaller than the pre-treatment TCE concentrations. The Mann-Whitney analysis also resulted in a similar p-value of 0.104 that corresponds to a 90% confidence in support of the hypothesis that post-treatment TCE concentrations are significantly smaller than the pre-treatment TCE concentrations.

Both t-test and Mann-Whitney analyses show that there is approximately 90% confidence that the post-treatment TCE concentrations are significantly less than the pre-treatment TCE concentrations. The data sets are characterized by large variability (e.g., extreme positive outliers) and a relatively large number of non-detects, which tends to adversely affect the power of statistical tests to detect differences. Similar analyses were performed for cis-1,2-DCE and the results show that there is greater than a 90% but less than a 95% probability that the post-treatment cis-1,2-DCE soil concentrations are significantly greater than the pre-treatment cis-1,2-DCE soil concentrations. The metric for this performance objective was met.

3.3 HIGHER COST SAVINGS COMPARED TO AN SVE SYSTEM

In general, the H_2T system has the potential to reduce treatment cost for these situations:

1) Compared to in-situ technologies such as chemical oxidation/bioremediation or thermal treatment, it is anticipated that the larger radius of influence for gas injection compared to liquid chemical addition would allow the H_2T system to use higher injection point spacing, therefore reducing system capital cost.

2) For sites where SVE is being considered, but expensive off-gas treatment would be required (thermal oxidizers or excessive use of activated carbon), the H_2T system is anticipated to reduce costs because no off-gas treatment would be required.

3) For sites where SVE systems have been operating, but treatment objectives have not been met, it is anticipated that converting the existing SVE extraction well system to a H_2T injection system would result in reduced costs as the hydrogen mixture may be more cost-effective method to treat chlorinated solvents in low-permeability zones that have resisted treatment by SVE.

Four scenarios were considered and compared based on data collected during this H_2T demonstration. In each scenario the H_2T system was compared with an alternative SVE system or soil excavation. All scenarios were based on the system design used in the demonstration and have an ROI of 15 feet. The cost model is based on implementing H_2T, SVE, or excavation of the entire source zone (i.e., area with initial TCE soil concentration above 57 µg/kg). The hypothetical treatment zone is 46,000 cubic yard (i.e., 27,500 ft^2 and 45 feet deep). Both H_2T and SVE costs are based on two-year system operation. The H_2T implementation cost included construction of gas injection skid, injection and monitoring well installation, pre- and post-treatment soil and vapor characterizations, cost of gas using nitrogen and hydrogen generators, and a gas composition of 20% hydrogen and no LPG, and weekly O&M.

SVE Scenario 1: H_2T vs. New SVE System. This scenario represents the comparison of costs associated with the H_2T system with the costs associated with setting up and operating an entire SVE system including the capital cost of well installation and GAC treatment system or soil excavation. Scenario 1 represents the design used in the demonstration where gas injection wells were installed for the H_2T system and the SVE wells were shut down and were not used as gas injection wells.

Excavation Scenario 2: H_2T vs. Soil Excavation. This scenario represents the comparison of costs associated with the H_2T system with the costs associated with soil excavation. Similar to Scenario 1, Scenario 2 represents the design used in the demonstration where gas injection wells were installed for the H_2T system.

SVE Scenario 3: H_2T with New Gas Injection Wells vs. Continuing Operation of an Existing SVE System. This scenario represents the comparison of costs associated with the H_2T system with the costs associated with continuing an existing SVE system operation. Similar to Scenarios 1 and 2, Scenario 3 represents the design used in the demonstration where gas injection wells were installed for the H_2T system and the SVE wells were shut down and were not used as gas injection wells.

SVE Scenario 4: H_2T with Existing SVE Wells vs. Continuing Operation of an Existing SVE System. In scenario 3, the existing SVE wells were used as the gas injection wells for the H_2T system. Scenario 4 represents the conditions where the screen intervals are not very long and the site managers decide to use the existing SVE wells as H_2T gas injection wells.

3.3.1 Data Requirements

In order to evaluate this performance objective, the cost of the H_2T application was compared to SVE and soil excavation. The following data were gathered and used to estimate this cost: radius of influence to estimate number of injection points; capital cost (injection skid; manifold system, wells); gas cost; O&M cost (operator cost; electricity); and soil and vapor monitoring.

3.3.2 Success Criteria

The objective was considered to be met if cost savings are achieved compared to the use of an entire SVE system, soil excavation, and/or the continued operation of an existing SVE system.

3.3.3 Results

Success criteria achieved? **SOMETIMES**

In Scenarios 1 and 2, the cost of H_2T system operation for two years based on the implemented demonstration design conditions was $39/cy compared to the entire SVE system operation (i.e.,

$37/cy) and soil excavation (i.e., $97/cy). In Scenario 3, the cost of H_2T system operation based on the implemented demonstration design conditions was $39/cy compared to the continuation of the existing SVE system operation (i.e., $20/cy). Finally, in Scenario 4, the cost of H_2T system operation by using the existing SVE wells as gas injection wells was $35/cy compared to the continuation of the existing SVE system operation (i.e., $20/cy). **Table 2** summarizes the unit cost comparisons of different scenarios.

Table 2: Unit cost comparisons of different scenarios

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
Technology	**H_2T**	**SVE**	**H_2T**	**Excavation**	**H_2T**	**SVE**	**H_2T**	**SVE**
System Type	entire system	entire system	entire system	entire system	entire system	existing system	existing SVE wells	existing system
Unit Cost ($/cy)	$39	$37	$39	$97	$39	$20	$35	$20

It was concluded that while the cost of H_2T was greater than SVE system operation, the decision to switch to H_2T operation over an SVE system should be made based on the overall performance and not only on the cost assessments. For example, in the demonstration site where an SVE system was operating since 2008, the SVE system was not able to reduce the mass in the vadose zone due to the very low permeability soil (i.e., clayey silt loess material), likely due to preferential removal from a high-permeability layer at the bottom of the treatment interval. Small molecules of hydrogen gas, on the hand, were able to diffuse into the small pores of the low-permeability soil.

Sensitivity analyses were performed to evaluate the effect of gas flowrate and ROI on the unit cost of H_2T implementation. At a gas injection flowrate of approximately 5 scfm the gas cost using bulk gas versus an on-site generator was similar. For total gas flowrates higher than 5 scfm the use of nitrogen and hydrogen generators are more economical. These cost calculations are for a two-year H_2T system operation. If the H_2T system operation is longer than two years, the cost savings by using gas generators will be increased.

Sensitivity of H_2T operation costs to radius of influence were evaluated for ROI values from 5 to 25 feet in a treatment area of 27,500 ft^2. The number of injection wells was increased dramatically from 15 to 350 when the ROI is decreased from 25 feet to 5 feet. By increasing the ROI from 10 feet to 15 feet, the total cost of H_2T operation is reduced by approximately 27% (i.e., $53/cy to $39/cy), while increasing the ROI from 15 ft to 20 feet, the total cost of H_2T operation is reduced by approximately 13% (i.e., $39/cy to $34/cy). It was assumed that the total number of pore volumes injected within two years of H_2T operation was similar for all the ROI values and therefore, the gas cost for all different ROI values were the same. The analysis shows that the effect of ROI on the total H_2T cost is significant and an accurate estimate of site ROI is needed.

3.4 REDUCTION IN THE CARBON FOOTPRINT COMPARED TO SVE

The H_2T system is anticipated to be more sustainable with a lower carbon footprint compared to SVE system using thermal oxidizers and/or large amounts of activated carbon (which require thermal regeneration). The effectiveness of the technology is therefore in its ability to reduce the carbon footprint compared to other alternatives, such as continuing SVE operation or excavation. Thus, the fourth quantitative performance objective that was used to evaluate the success of H_2T was achieving a reduction in the carbon footprint compared to SVE.

The carbon footprint was estimated for two variations of H_2T (i.e., liquid nitrogen/hydrogen cylinder delivery versus on-site nitrogen and hydrogen generation) and compared to two variations of SVE system operation (i.e., continuous versus pulsed operation at 25% time). Success was defined as 50% reduction in the carbon footprint compared to SVE.

3.4.1 Data Requirements

The considered parameters in the H_2T system versus continuation of the existing SVE system at the demonstration TCE site operating for a year included: 1) use of cylinders, gas in cryo-liquid form; tube trailers, or on-site nitrogen and/or hydrogen generators; 2) amount of electricity used by SVE system blower; 3) amount of gas used in the H_2T system operation (i.e., nitrogen, hydrogen, propane, and CO_2); and 4) number of trips required to deliver gas to the site. The mass of key materials for construction of the skids and well installations (e.g., PVC, steel, concrete) were assumed to be similar for all cases.

3.4.2 Success Criteria

The objective was considered met if 50% reduction in the carbon footprint compared to SVE system is achieved.

3.4.3 Results

Success criteria achieved? **YES**

For the high end carbon footprint case, where a constant operation of SVE+GAC was compared with direct liquid nitrogen/hydrogen cylinder delivery, the carbon footprint was 21tons of CO_2 for SVE+GAC versus 8.1 tons of CO_2 for the H_2T system. For the high-end case, the carbon footprint of H_2T system operation is approximately 62% less than SVE system operation. For the low end case, where a pulsed operation of SVE+GAC was compared with on-site nitrogen and hydrogen generation, the carbon footprint was 7.7 tons of CO_2 for SVE+GAC versus 4.4 tons of CO_2 for the H_2T system. For the low end case, the carbon footprint of H_2T system operation is approximately 43% less than SVE system operation. Note that the high-end hydrogen case has approximately the same footprint as the low-end SVE case. Overall, the metric for this performance objective was met. **Table 3** summarizes the carbon footprint comparisons of H_2T system vs. SVE+GAC system for high-end and low-end cases.

Table 3: Carbon footprint comparisons of H_2T vs. SVE+GAC

	High-End Case		**Low-End Case**	
Technology	**SVE+GAC**	**H_2T**	**SVE+GAC**	**H_2T**
System Type	Continuous Operation	Bulk Gas Delivery	Pulsed Operation	On-Site Gas Generation
CO_2 Emission (tons)	21.4	8.1	7.7	4.4
Reduction in CO_2 emission	-	62%	-	43%

3.5 SAFETY

One of the potential risks associated with field implementation of the H_2T system is the use of gases (i.e., H_2 and LPG) that are explosive under certain conditions. Although the concentration of the explosive gases in the gas mixture is 20% by volume, it was expected that the H_2T process was considered safe because the flammable gases disperse quite readily in the atmosphere and no detections of flammable gases above ground were observed. It is also expected that the oxygen levels at the injection points below ground surface are close to zero. Nevertheless, standard engineering practices can be used to provide a safe system. As part of H_2T performance objective the concentrations of H_2 and propane were monitored at the surface to maintain levels below the lower explosive levels (LEL) at the surface. The effectiveness was a function of satisfying all of the compressed gas safety codes (i.e., NFPA50A, NFPA55). As part of H_2T performance objective the lower explosive level (LEL) of H_2 and propane were monitored at the surface to maintain levels below the LEL at the surface.

3.5.1 Data Requirements

In order to evaluate the safety concerns associated with the technology, flammability relative to explosivity limits were assessed along with H_2 air emissions. Soil gas monitoring was included explosivity measurements using an explosivity meter.

3.5.2 Success Criteria

The objective was considered to be met if flammabilities of less than 10% of the lower explosive limit (LEL) at surface are achieved.

3.5.3 Results

Success criteria achieved? **YES**

No health and safety incidents occurred during the demonstration and flammable gas concentrations above the ground surface were not detectable. It should be noted that hydrogen and propane concentrations exceeded the LELs at some points below ground surface, but there was not enough oxygen available at those points to make the system potentially explosive. While concerns regarding safety of hydrogen and propane injections are reasonable, the results of this demonstration indicate the technology can be implemented safely. The metric for this performance objective was met.

3.6 EASE OF USE

The effectiveness of the technology is also related to the relatively easy implementation of the H_2T system compared to other technologies such as SVE. It was anticipated that the ease of permitting (no air permits were required for this demonstration) and the ease of operation make the implementation of this technology quick and easy. Success criteria for this performance objective were evaluated qualitatively.

3.6.1 Data Requirements

Required operator manpower was evaluated for both the existing SVE system and for H_2T system. Feedback from field personnel regarding ease of use of H_2T compared to SVE was also used.

3.6.2 Success Criteria

The objective will be considered met if the proposed technology results in a lower time requirement for system setup and data collection.

3.6.3 Results

Success criteria achieved? **YES**

The metric for this performance objective was the frequency at which an operator needed to visit the site. The reasons for site visitation during normal operations included gas cylinder change-outs, system leak test, pressure and flow readings, and monitoring. This occurred once per week (i.e., weekly O&M) or every few weeks (i.e., tank re-fill or cylinder replacement), which was considered reasonable. The metric for this performance objective was met. It should be noted that a site-specific comparison of H_2T vs. SVE operation should be implemented because the ease of use also depends whether engineering controls for safety is implemented for H_2T or vapor-phase emissions control system is needed for SVE.

4.0 SITE DESCRIPTION

This demonstration involves field validation of the H_2T system. In this section, the site selection criteria used to select the appropriate site are described. The information presented in this section is based on previous site characterizations and two vapor sampling events conducted in July and August of 2010. A Site Selection Memorandum was prepared as part of this project and submitted to ESTCP.

4.1 SITE SELECTION

A summary of the site selection criteria data for these two sites are shown in **Table 4**. The following criteria were used to identify potential demonstration sites:

a. Concentration range. Moderate to relatively low concentrations (e.g., TCE soil concentrations < 100 μg/kg) was preferred for this parameter so that a clear removal of the chlorinated solvent can be demonstrated.

b. Presence of relatively permeable media in vadose zone. Sand or silty sand soil type with an average hydraulic conductivity, *K*, of greater than 0.05 ft/day in the vadose zone was preferred for this parameter. Relatively permeable site where hydrogen gas can be readily injected is required.

c. Moisture content in vadose zone. Moisture content values between 5% and 40% were preferred for this parameter. Moisture content below 5% will limit biodegradation processes and moisture content more than 40% will prevent the gas flow.

d. Thickness of vadose zone. A vadose zone with a thickness of greater than 20 feet was preferred for this parameter.

e. Source zone well-characterized. Preferred sites will include those with baseline source area characterization data identifying potential hot-spots. This is important to calculate the initial chlorinated solvent mass and estimate the initial mass flux in the source zone.

f. Presence of anaerobic environment in vadose zone. An anaerobic or anoxic environment was preferred. Nevertheless, the N_2 gas will be injected to deplete oxygen in the system before starting the gas mixture injection.

g. Presence of long-term contaminant monitoring data. To compare the H_2T performance with the SVE system, and estimate the mass removal and mass flux reduction, soil and soil vapor concentrations during SVE application were required.

h. Presence of surface cover. A surface cover or confining layer in the source area that prevents the air intrusion into the treatment zone and hydrogen loss to the surface was preferable.

i. Presence of DHC bacteria. If DHC is not present or not abundant at a site, then TCE dechlorination may be limited or may stall at cis-1,2-dichloroethene (cis-1,2-DCE) or vinyl chloride (VC).

Table 4: Site selection data for the two candidate sites

Criteria	Preferred Value(s)	Relative Importance (1-5, with 1 being highest)	Site 1: Offutt AFB, Omaha, NE (Site OT-18)	Site 2: Former Lincoln AFB, York, NE (Atlas Missile Site 10)
Presence of chlorinated ethenes as primary COC?	Yes	1	Yes (TCE)	Yes (TCE)
Presence of relatively permeable media in vadose zone?	Yes: Soil type: sand or silty sand K > 0.05 ft/day Thickness >20 ft	1	Yes. Silty Clay Loess. Average K = 0.5 ft/day (1.8×10^{-4} cm/s) ~45 ft thick	2 units in vadose zone: upper loess and lower fine sand - Loess: 50 ft thick (K~ 0.005 ft/day (1.8×10^{-6} cm/s)) - Sand: 15 ft thick, located between bottom of loess unit and water table (K~ 95 ft/day (3.3×10^{-2} cm/s))
Thickness of vadose zone	Thickness > 20 to 100 ft	1	45 ft	65 ft
Presence of DHC bacteria?	Yes	1	Not Tested	It is possible that there could be DHC at some locations in the lower reaches of the vadose zone because bioaugmentation was performed in the saturated zone.
SVE system status?	SVE system available	1	Yes	Yes, full-scale SVE system was started up in the Sept/Oct 2008 timeframe, and has been operating since then.
Moisture content (M.C.) in vadose zone	5% < M.C. < 40%	1	10 to 30 %	Not measured, would likely be 10-15% for loess and sand layer
Source and plume well-characterized?	Yes	1	Yes	Yes
Presence of surface cover?	Yes: Asphalt, concrete or clay, etc.	1	Concrete	Limited area of pavement near the missile silo
Presence of building(s) with residents?	No	1	Yes	No
Concentration range	moderate to relatively low concentrations (soil concentrations < 100 µg/kg)	2	Maximum of 500 µg/kg unsaturated	Maximum of 2000 µg/kg unsaturated - The range span was from about 1 to 2000 µg/kg, but concentrations likely to be lower now due to operation of the SVE system.
Presence of anaerobic environment in vadose zone?	Yes	2	No	To the best of our knowledge, oxygen concentrations in soil gas have not been measured.
Presence of long-term contaminant monitoring data?	Yes: Soil and soil vapor concentrations during another application (i.e., Soil Vapor Extraction)	3	Yes. Subslab soil vapor concentrations up to 29,000 ug/m^3	Yes, VOC levels in air extracted from SVE wells.
Daughter product formation	No preference	5	No: < 1% of TCE concentration	Generally below detection limits
Presence of confining layer?	No preference	5	No	Loess unit overlying sand layer

j. Presence of building(s) with residents. To prevent any safety issues during the H_2T demonstration a source area that is far (>50-100 feet) from any building with residents was preferred.

k. SVE system operation status. Since existing SVE system hardware (injection points, manifolds, monitoring points) can be easily retrofitted to accommodate H_2 injection, a site where SVE is currently operating or the system hardware is still in place was preferred.

Three sites were offered by DoD personnel for the H_2T demonstration. One of these three sites was located in Alaska and was removed from consideration due to extensive travel costs. The two remaining sites were evaluated in more detail, including focused vapor sampling:

1) Offutt AFB (Site OT-18) in Omaha NE
2) Former Lincoln AFB (Atlas Missile Site 10) in York NE

The initial site screening process indicated that the York site had several favorable characteristics relative to the Offutt site:

- The treatment zone for the Offutt site is underneath a building used by base personnel.
- Conditions were assumed to be anaerobic in the unsaturated zone at the York site due to the low permeability of the loess and the presence of cis-1,2-DCE in the effluent from the SVE system.

Both sites had conditions that would reduce oxygen diffusion. Specifically, the Offutt site has a parking lot and building, while the York site has a relatively low permeability loess soil over the treatment zone.

To further evaluate the sites, soil vapor monitoring and sampling events were conduct at both Nebraska sites and additional data (e.g., oxygen in soil vapor) and supplement existing COC data (e.g., TCE, DCE, and VC soil vapor concentrations) were collected. At both sites, the data collection program consisted of turning off the SVE system for approximately 10 days prior to the first sampling event and collecting soil vapor samples from all of the existing extraction wells. The first soil vapor sampling event was conducted in July 27, 2010 approximately 10 days after turning off the SVE system. The second soil vapor sampling event was conducted in August 30-31, 2010, approximately 45 days after the SVE system shut down.

The data for the York site (described in detail in Section 4.4) indicated that this site was better suited for the H_2T demonstration project than the Offutt site. Specifically, the York site had:

- Lower oxygen levels (8.4 to 20.9 % for York compared to 18.7 to 20.8 % for Offutt);
- Presence of cis-1,2-DCE vapors in the unsaturated zone at York, but not at Offutt.

Based on the soil vapor sampling data, the area east-northeast of the Silo (e.g., LA10-SVE08-07, LA10-SVE08-08, LA10-SVE08-11, LA10-SVE08-14, and LA10-SVE08-18) was selected.

4.2 SITE LOCATION AND HISTORY

Based on the selection criteria described above, Atlas Missile Site 10 in Former Lincoln AFB was selected for the demonstration located in York, Nebraska (**Figure 3**).

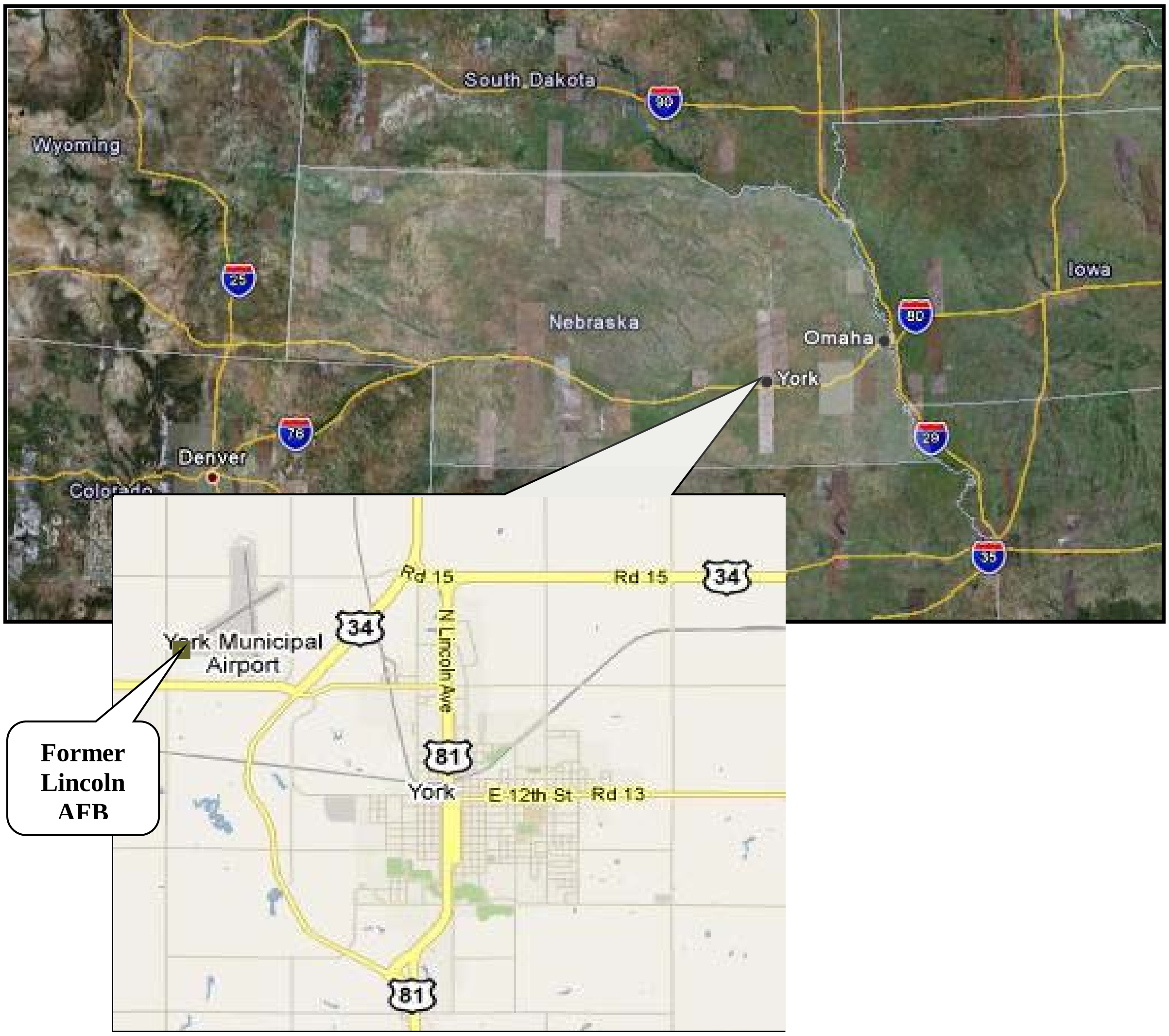


Figure 3: Former Lincoln atlas missile site map, York, Nebraska

Site 10 is the former Atlas "F" missile facility operated by the Former Lincoln AFB from 1960 to 1964, which is illustrated in **Figure 4**. The major structure at the site is the underground missile silo, which is 174 ft in depth and 52 ft in diameter. Historic operations at the former missile silo have resulted in TCE concentrations in soil and groundwater which exceed Nebraska Department of Environmental Quality regulatory standards for chlorinated volatile organic compounds (CVOCs). Site 10 was deactivated and conveyed to a private individual in 1965.

Between 1999 and 2005, soil investigations were conducted to determine the levels of TCE concentrations in soil. These investigations were primarily focused on the pathway from the septic tank to the leach field. The septic system investigation revealed an area measuring approximately 8,978 square feet with TCE soil concentrations above the Nebraska Department of Environmental Quality (NDEQ) remediation goal of 57.0 µg/kg. In 2006, a series of soil borings were completed at the site by Kemron Environmental Services, Inc. (Kemron) to investigate TCE concentrations in soil. The locations of these soil borings and their associated TCE and cis-1,2-DCE concentrations are in soil vapor extraction pilot test report (Kemron, 2007).

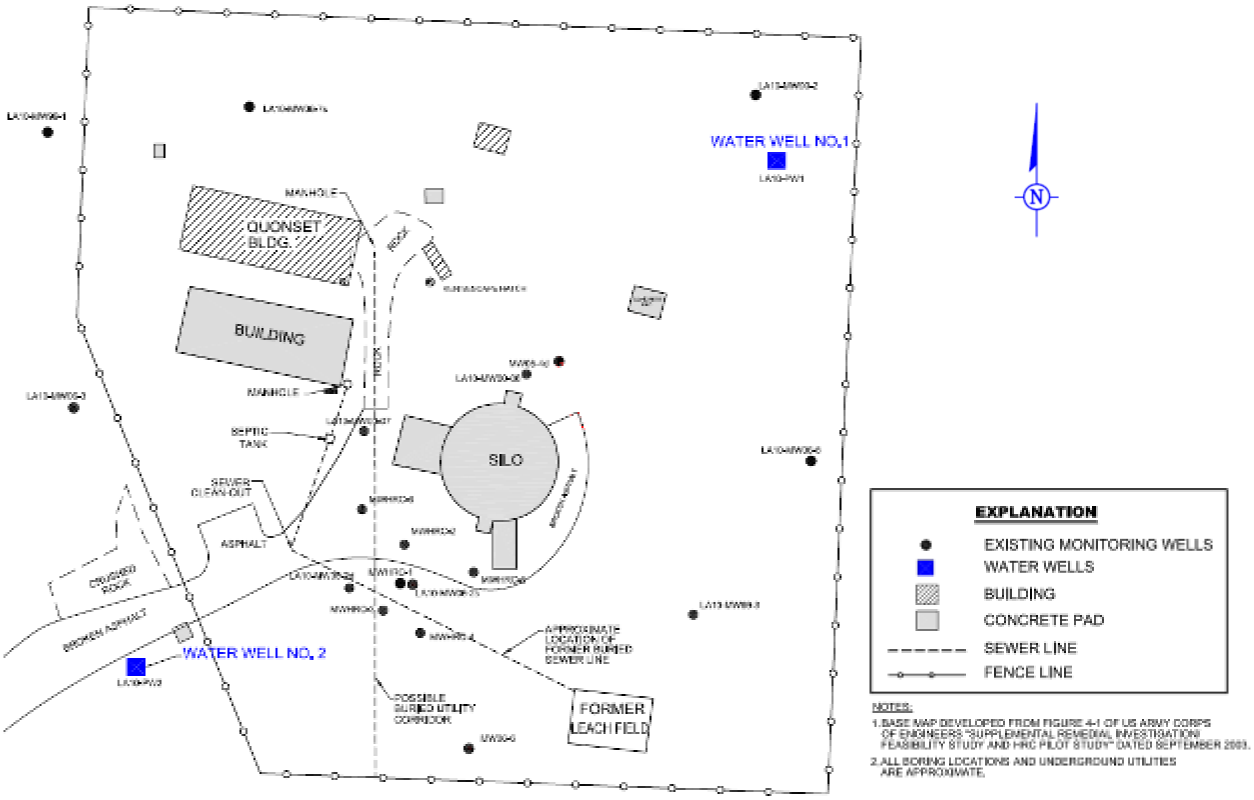


Figure 4: Former atlas missile site map, York, Nebraska (Source: *Kemron, 2007*)

In August 2007, Kemron installed a soil vapor extraction (SVE) well along with eight observation wells (Kemron, 2007) as part of a pilot test at the site. The vapor extracted from the wells was passed through an air/water separator. Generated fluids from the vapor separator were pumped to a holding tank and from the holding tank to a nearby groundwater treatment system, which is associated with the same overall remediation effort. Effluent vapors were discharged into the atmosphere (Kemron 2007; Kemron 2009). This pilot test was conducted in an area approximately 50 ft northeast of the former missile silo where the greatest TCE concentrations were found in soil.

Following the pilot test, a full-scale SVE system was completed by installing 39 SVE wells in September-October 2008, and this system has been operating continuously since this period (Kemron, 2009). Due to relatively low levels of VOCs extracted by the SVE system, it was believed that State emissions criteria for VOCs would not be exceeded, which allowed for direct discharge of emissions to the atmosphere and therefore the SVE system was never equipped with vapor-phase granular activated carbon (GAC) or any other type of emissions control system.

Figure 5 shows the area that TCE soil concentrations are above NDEQ remediation goal of 57.0 µg/kg (red line) and the full-scale SVE well locations.

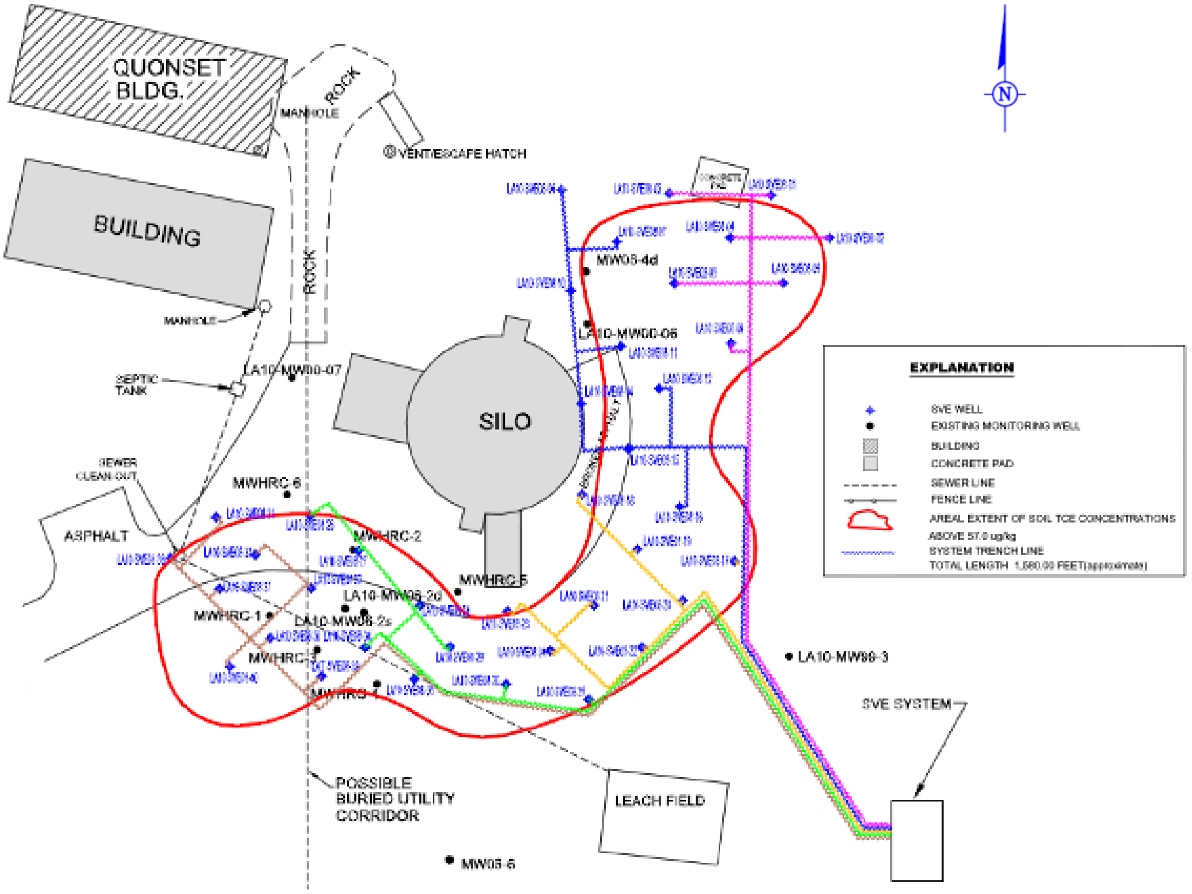


Figure 5: Soil vapor extraction system map (Source: *Kemron, 2009*)

4.3 SITE GEOLOGY/HYDROGEOLOGY

Selected figures and tables from previous site reports in cluding the soil boring logs and SVE well construction details are summarized in Appendix C. There are four distinct stratiographic layers typically found onsite:

1) Peorian loess (relatively low permeability)
2) Loveland loess (relatively low permeability)
3) Grand Island Formation (relatively high permeability)
4) glacial deposits (relatively high permeability)

There are four distinct stratiographic layers typically found onsite: Peorian loess, Loveland loess, the Grand Island Formation, and glacial deposits. During the silo construction, an open cut excavation was used until groundwater was encountered. This resulted in a bowl shaped excavation which was approximately 49.5 feet in depth and 325 feet in diameter. Once construction was complete, the inferred backfill was the stockpiled soil from the excavation. The resulting composition of the soils around the silo is a mixture of silty clays with lenses of fine to coarse sands. Two units exist in the vadose zone: upper loess and lower fine sand. The loess layer is approximately 50 feet thick with a hydraulic conductivity, *K*, of approximately 0.005ft/day (1.8×10^{-6} cm/s). The sand layer is approximately 15 feet thick, located between bottom of loess unit and water table with a hydraulic conductivity, *K*, of approximately 95 ft/day (3.3×10^{-2} cm/s)).

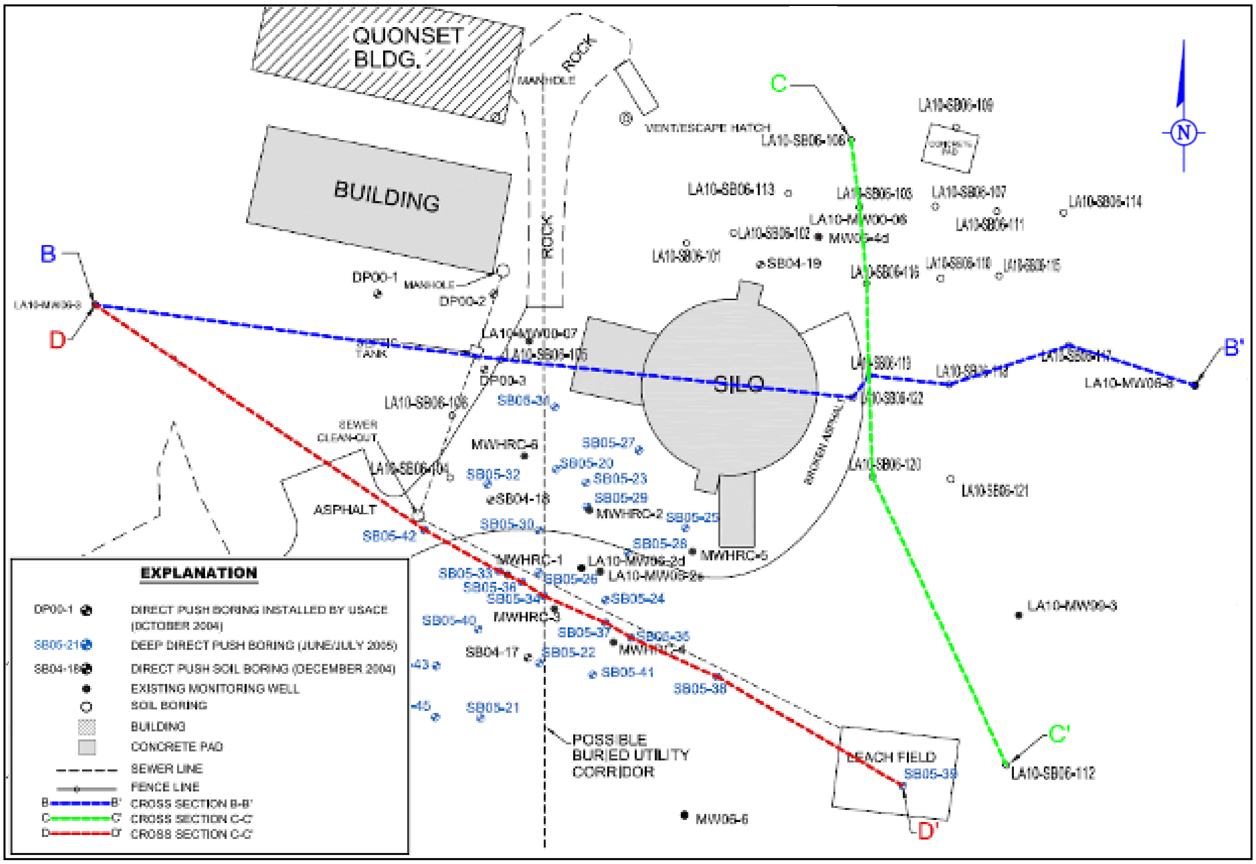


Figure 6: Site cross section location map (Source: *Kemron, 2007*)

During the silo construction, an open cut excavation in the loess was used until groundwater was encountered. This resulted in a bowl-shaped excavation which was approximately 49.5 feet in depth and 325 feet in diameter. Once construction was complete, the inferred backfill was the stockpiled soil from the excavation. The resulting composition of the soils around the silo is a loess mixture comprised of silty clays with lenses of fine to coarse sands. **Figure 6** shows the cross section location map. The open cut excavation and generalized soil cross sections are shown in **Figure 7** and **Figure 8**.

4.4 CONTAMINANT DISTRIBUTION

Detected TCE concentrations in soil ranged from about 1 to 2,000 μg/kg based on the soil investigations conducted between 1999 and 2006. However, TCE concentrations were expected to be lower due to operation of the SVE system (Kemron, 2007). The majority of the remaining mass was believed to be located in the lower permeability loess unit, and concluded that removal by SVE from these lower-permeability zones was relatively inefficient.

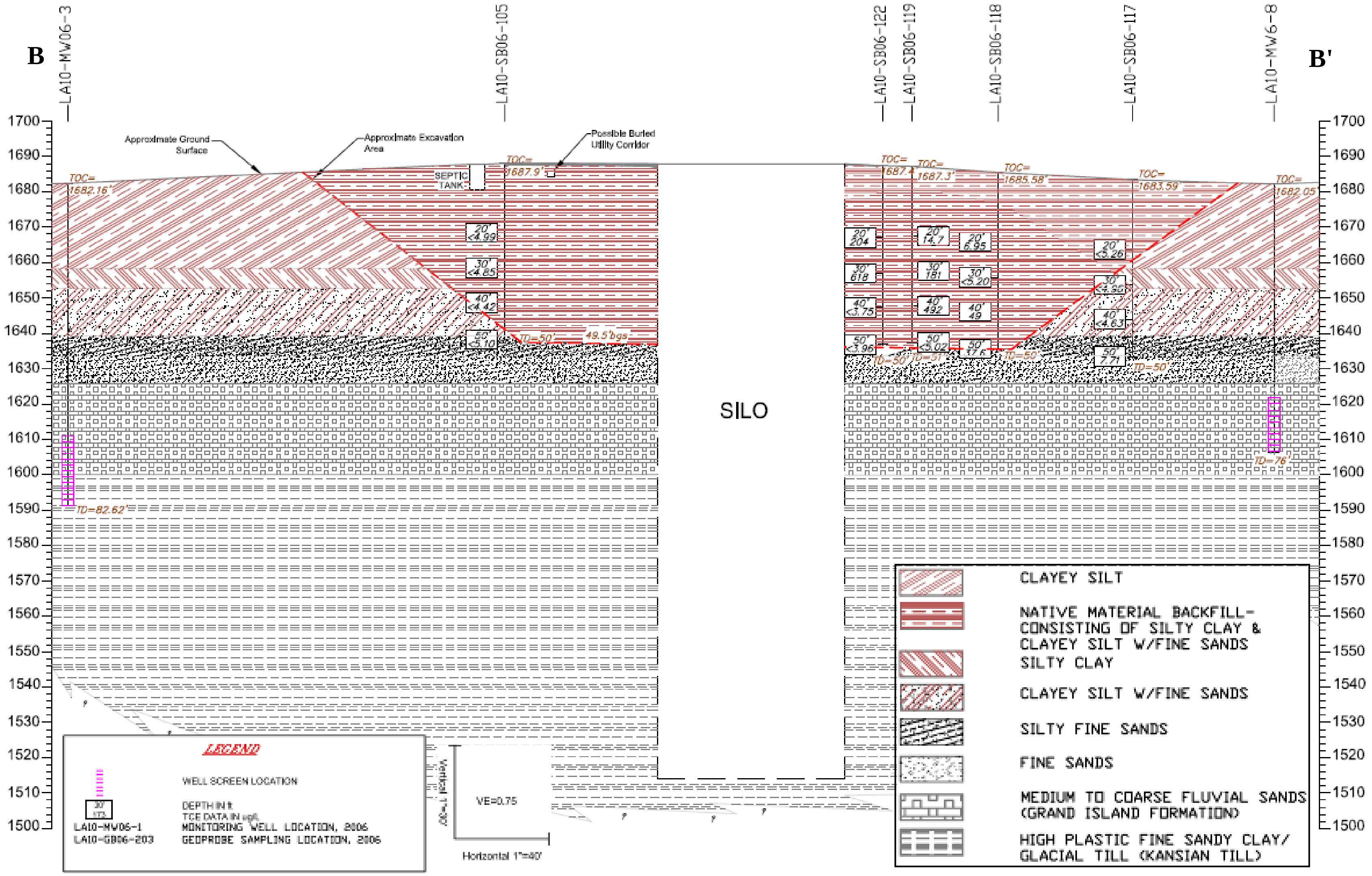


Figure 7: Geological cross section B-B' (Source: *Kemron, 2007*)

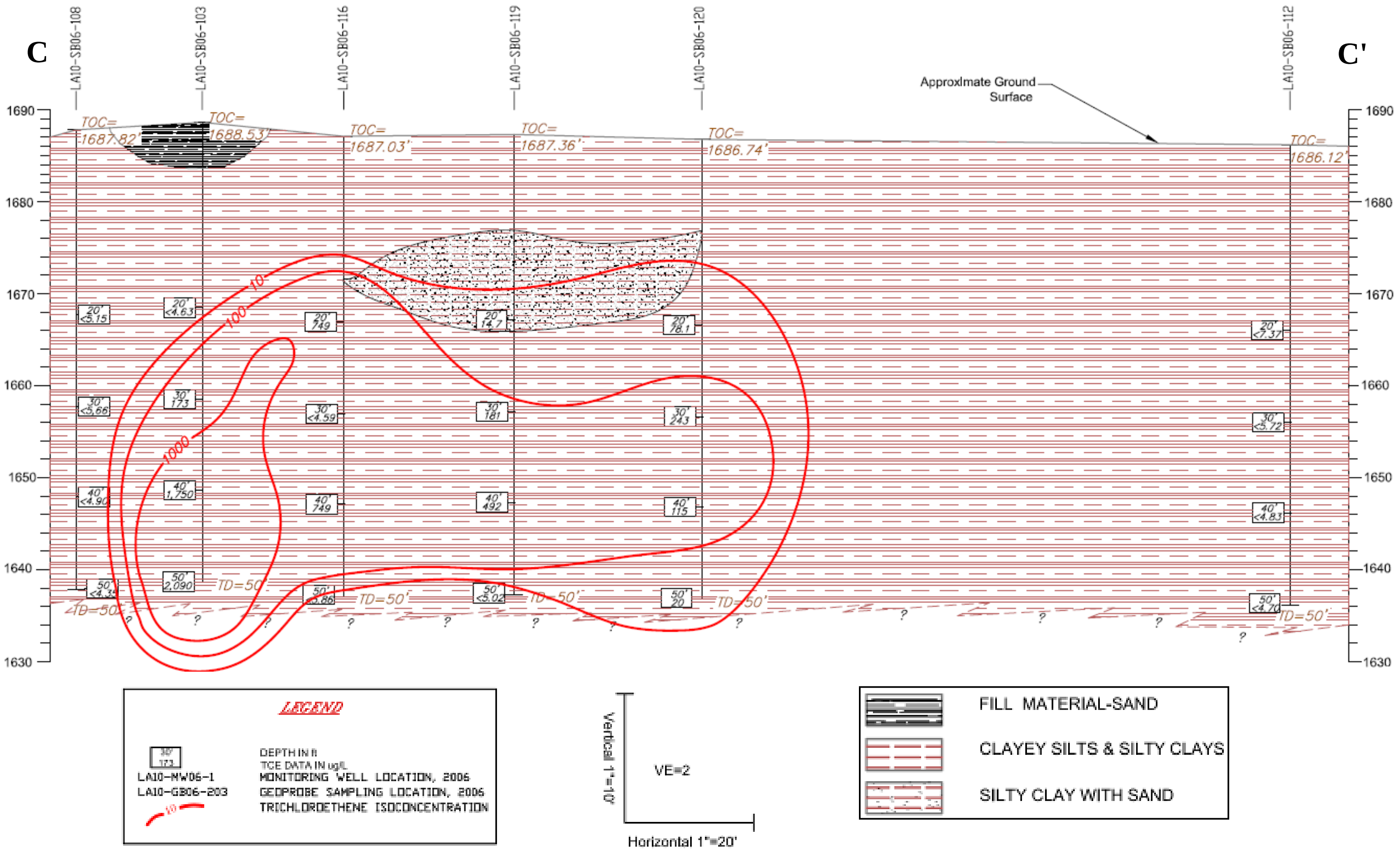
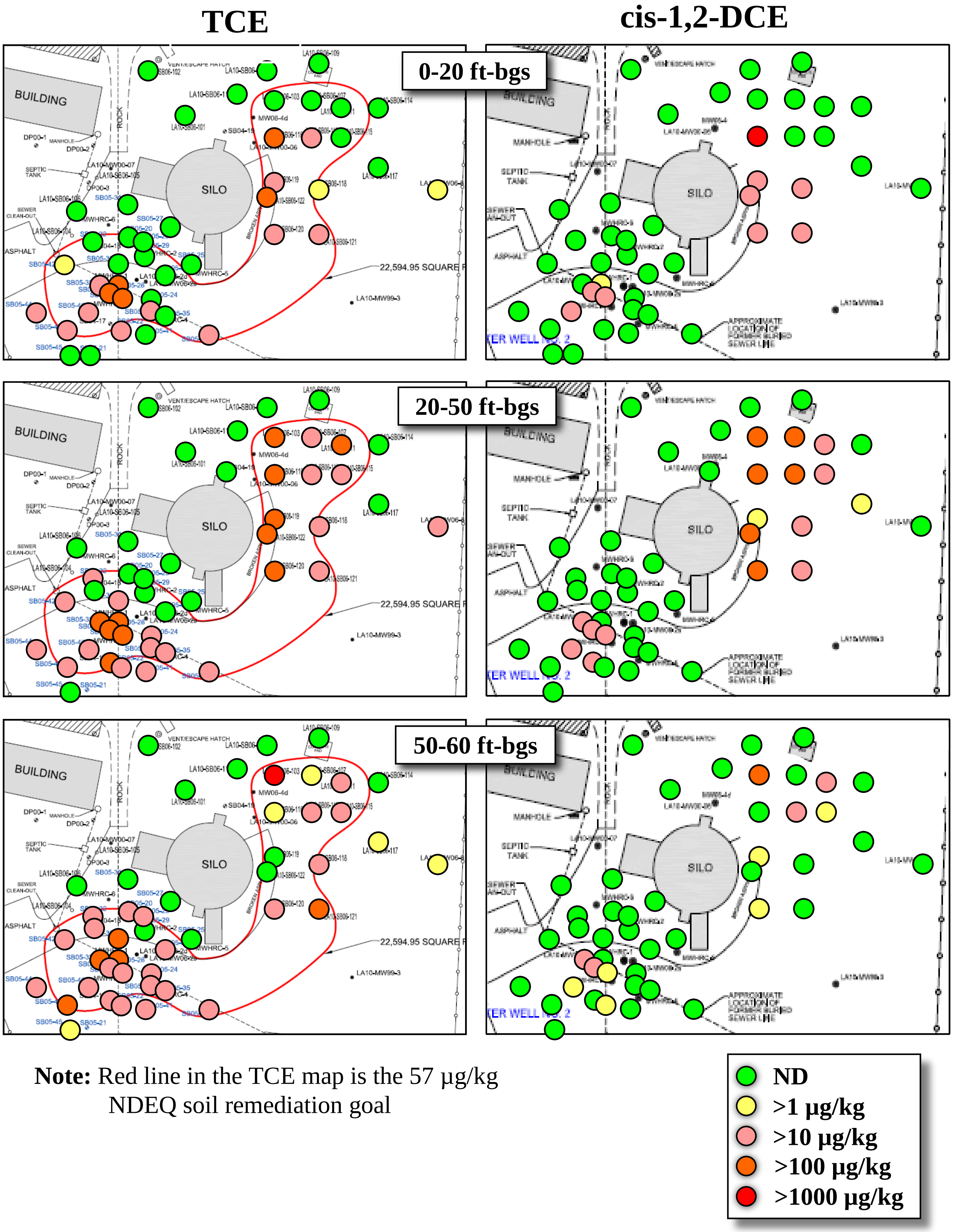


Figure 8: Geological cross section C-C' (Source: *Kemron, 2007*)



Note: Red line in the TCE map is the 57 µg/kg NDEQ soil remediation goal

Figure 9: 2006 soil concentrations of TCE (left) and cis-1,2-DCE (right) at three depth intervals

In addition to the site investigations completed between 1999 and 2005, a series of soil borings were completed at the site in 2006 by Kemron to further investigate TCE concentrations in soil. The locations of these soil borings and their associated TCE concentrations are shown in Appendix C. Soil concentrations of TCE and cis-1,2-DCE at three depth intervals are illustrated in **Figure 9**.

Highest soil TCE concentration of 2,090 µg/kg was found at depth of 50 ft-bgs in boring LA10-SB06-103 at the northeast of the silo. Subsequently, the area around soil boring LA10- SB06-103 was further delineated to reveal an area of approximately 10,275 square feet which has TCE soil concentrations above the NDEQ remediation goal of 57.0 µg/kg. During the soil investigation, samples were collected at 20, 30, 40, and 50 feet below ground surface (bgs). A majority of the TCE soil exceedences were found in samples collected between 40 and 50 feet bgs, which is the transition zone between loess layers and the high permeability Grand Island formation. This data is illustrated in **Figure C2** and **Table C1**.

Based on TCE and cis-1,2-DCE concentrations in soil during 2006 investigation (**Table C1**), two areas around the Silo were identified as potentially appropriate locations for further investigation: one at the east-northeast of the Silo (for example, see LA10-SB06-110, LA10-SB06-116, and LA10-SB06-122) and one around the southwest side of the Silo (for example, see SB05-33, SB05-34, and SB05-36).

To determine which of the two candidate locations were best suited for the current demonstration, additional soil vapor monitoring and sampling programs were conducted on July 27 and August 30, 2010. Soil vapor monitoring consisted of recording oxygen, carbon dioxide, methane, and LEL readings on-site using a GEM2000 landfill gas monitor. Soil vapor sampling consisted of the collection of vapor samples in Tedlar bags for off-site analysis. Off-site analysis included VOC analysis using HAPSITE ER portable Gas Chromatograph/Mass Spectrometer (GC/MS). Samples were collected from all 39 SVE wells.

The data showed that:

- the highest soil vapor TCE concentrations were found at the east-northeast side of the silo (72,500 ppbv at SVE well LA10-SVE08-07);
- the highest soil vapor cis-1,2-DCE concentration were found at the east-northeast side of the silo (33,900 ppbv at SVE well LA10-SVE08-07);
- typical oxygen concentrations were lowest near the east-northeast side of the silo, and typically ranged from 8.4 to 18.8 % oxygen.

Results of soil vapor sampling programs conducted in July and August 2010 are summarized in Appendix B. The locations of the SVE wells and their associated COC concentrations in soil vapor during July 2010 sampling program are shown in **Figure B1**. **Table B1** and **B3** summarize the analytical data for the samples collected during July and August 2010 sampling programs, respectively. **Table B2** and **B4** summarize the results of the soil vapor monitoring for O_2, CO_2, and CH_4 during July and August 2010 sampling programs, respectively.

Analytical data for the samples collected during August 2010 sampling program (35 days after the SVE system was shut off) generally showed increasing concentrations for TCE and cis-1,2-

DCE concentrations in soil vapor relative to the July 2010 event (10 days after the SVE system was shut off). As expected, higher cis-1,2-DCE concentrations were observed in the same area where oxygen levels were relatively low (e.g., 10-15%). Based on the TCE and cis-1,2-DCE concentrations and lower oxygen levels at York site in the SVE wells on the east-northeastern side of the Silo (e.g., LA10-SVE08-07, LA10-SVE08-08, LA10-SVE08-11, LA10-SVE08-14, and LA10-SVE08-18), the area east-northeast of the Silo was selected as the location to perform H_2T Pilot Test.

5.0 TEST DESIGN

This section provides the detailed description of the H_2T system design and the different phases of testing conducted during the demonstration.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The primary goal of this demonstration was to field-test hydrogen-based treatment (H_2T) of unsaturated zones and determine the cost, regulatory acceptance, safety, and performance of the H_2T process. With H_2T, a mixture of nitrogen (N_2) gas and gaseous electron donors (hydrogen (H_2), propane (C_3H_8), and carbon dioxide (CO_2) was injected through a series of widely spaced injection points. The hydrogen drives in-situ biodegradation by dechlorinating bacteria, transforming contaminants to innocuous daughter products such as ethene or ethane.

An approximately 6-month bench-scale microcosm study was also conducted to better understand the extent to which reductive dechlorination of TCE would occur using the Site vadose-zone soils and increase insight on the optimal gaseous electron donor mixture to be used in the demonstration. The report of the treatability study is in Appendix E.

The demonstration was conducted in four phases as illustrated in **Figure 10**. Pre-treatment characterization was conducted in **Phase 1** using direct push techniques to evaluate the contaminant concentrations and soil characteristics. The baseline characterization activities included drilling of 36 boreholes, collection of soil samples, and installation of multi-level monitoring points. The samples were analyzed for soil characteristics and contaminant concentrations.

Phase 2 involved the design and construction of gas mixture injection skid and underground piping. The injection skid consisted of piping, pressure and flow measurement gages, safety equipment, process control system, and gas cylinders that were connected to the piping manifold on the skid and injection wells at the site. The gas vendor replaced the all gas supply containers (i.e., re-fill the liquid N_2 and LPG tanks and replace the H_2 and CO_2 cylinders) as needed, mostly on the order of every week or every few weeks. Gas mixture was injected in a steady state mode with a constant low-flowrate gas stream (i.e., total flowrate <1 scfm).

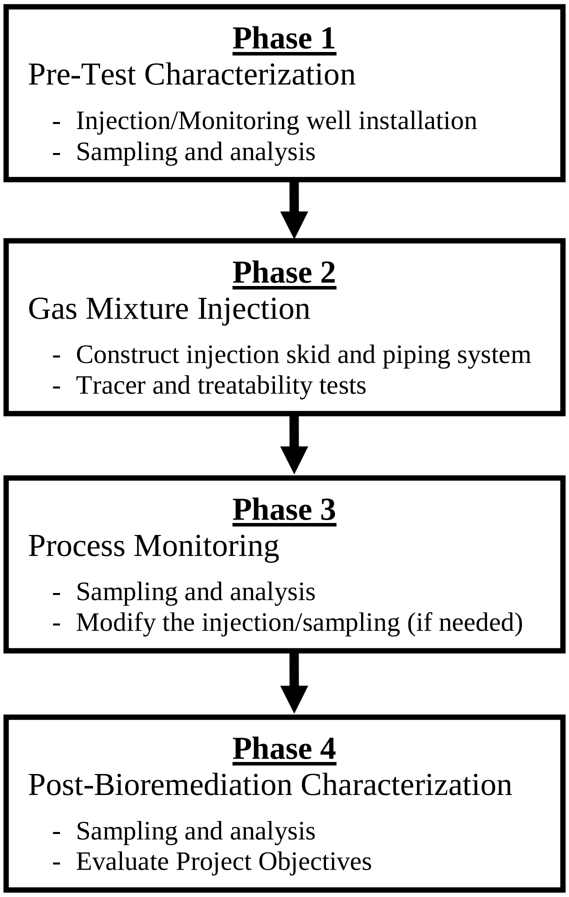


Figure 10: Demonstration phases

Tracer test was conducted in Phase 2 to verify injection and monitoring wells performances and to characterize gas transport in the vadose zone. The tracer gas was a mixture of nitrogen (approximately 90%) and helium (approximately 10%) gases. The generated data from tracer test was used to demonstrate potential ROI without biological uptake, as well as to identify the presence of preferential pathways.

Phase 3 involved an approximately 6-month operation and process monitoring period of the H_2T system. Monitoring of the influence of the hydrogen delivery approach on bioremediation processes relative to the control condition was achieved through the collection of soil vapor samples from all monitoring and injection wells. Sample analysis included concentrations of contaminants, daughter products, oxygen, and hydrogen. Soil gas samples were collected to verify system operation and quantify TCE, cis-1,2-DCE, and VC degradation.

Phase 4 consisted of post-treatment sampling, data analysis tasks, and writing the final project report. Soil samples were collected at the end of the treatment period (as determined based on process monitoring data), to compare to the soil concentrations measured in the pre-treatment (Phase 1) samples. Process monitoring data was evaluated in terms of the stated project objectives. Specifically, the collection of spatial and temporal data provided a means of evaluating the rate of the injected gas mixture transport and distribution within the treatment zone, as well as its effect on the rate of dechlorination. The chlorinated solvent removal rate as well as the duration of the potential enhancement effect provided by the gas mixture was evaluated using this dataset.

5.2 BASELINE CHARACTERIZATION ACTIVITIES

This section presents the baseline characterization activities that occurred in May 2011. These activities included drilling of 36 boreholes, collection of soil and soil vapor samples, and installation of nine injection wells and 27 monitoring points. The samples were analyzed for soil characteristics, nutrient and bacterial concentrations, and VOC concentrations.

5.2.1 Injection and Monitoring Point Installation

Gas injection and vapor monitoring points were installed as shown in **Figure 11** and **Figure 12**. A total of nine injection points (i.e., three clusters of three holes at different depths) and 27 monitoring points (i.e., nine clusters of three holes at different depths) were installed for the demonstration. Well construction details are summarized in **Table 5**.

Injection Point Installation: A total of nine injection points (i.e., three different locations and three holes at three different depths at each location) were installed for the demonstration. The design concept is based on three injection locations arranged in an equilateral triangle with an inter-well spacing of approximately 30 ft. The three injection points in each cluster were approximately 2-3 feet apart. A total of three gas injection points were installed at each cluster location using traditional direct-push technique that generates intact soil cores. The three injection points in each cluster were equally spaced vertically in the vadose zone at depths of 20, 30 and 40 feet below ground surface. The deep gas injection point was logged and soil samples were collected from this borehole. The shallow and intermediate injection points were advanced with no sample collection or logging.

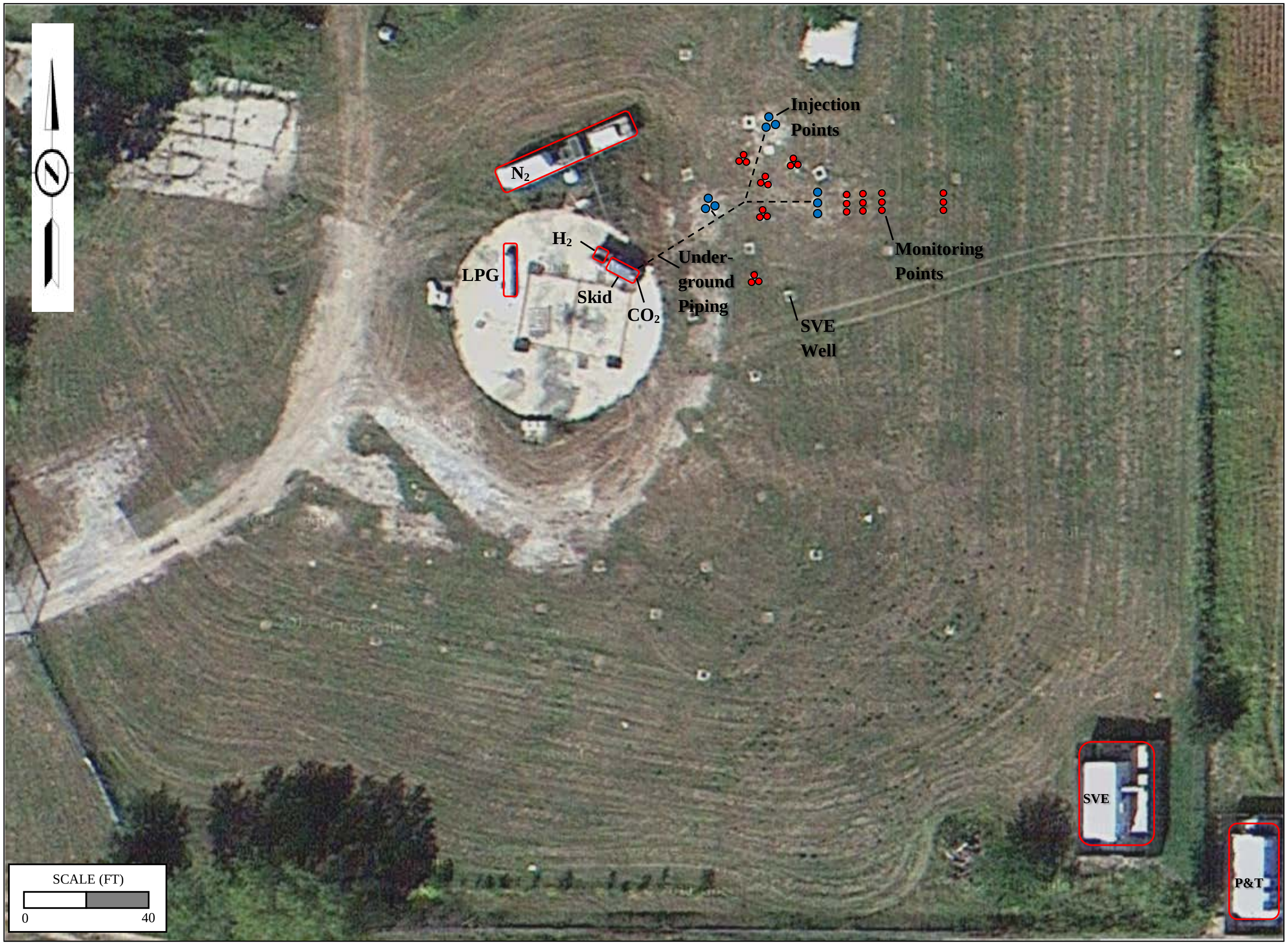


Figure 11: Location map of installed gas injection and vapor monitoring points

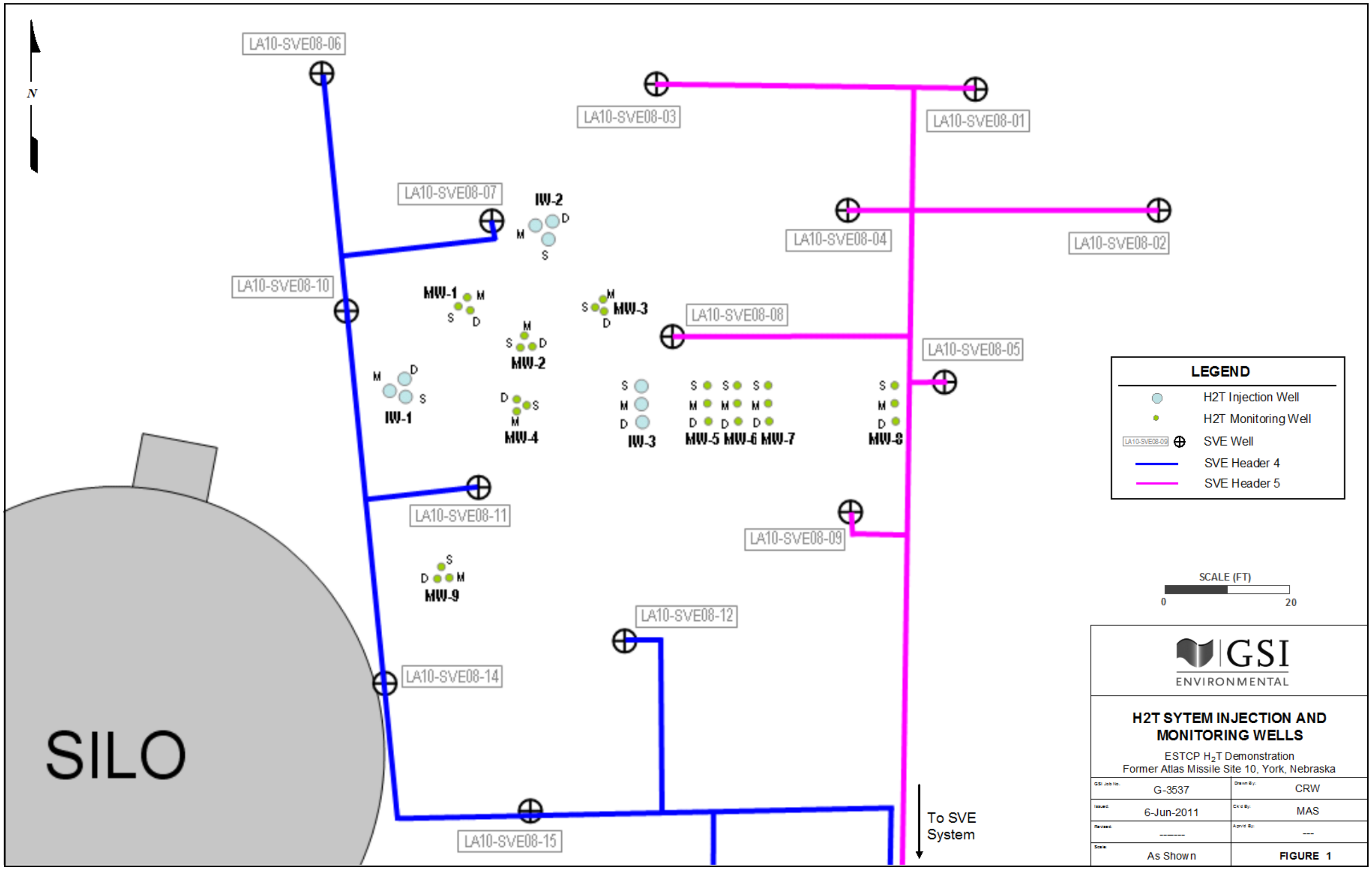


Figure 12: Location of gas injection and vapor monitoring points

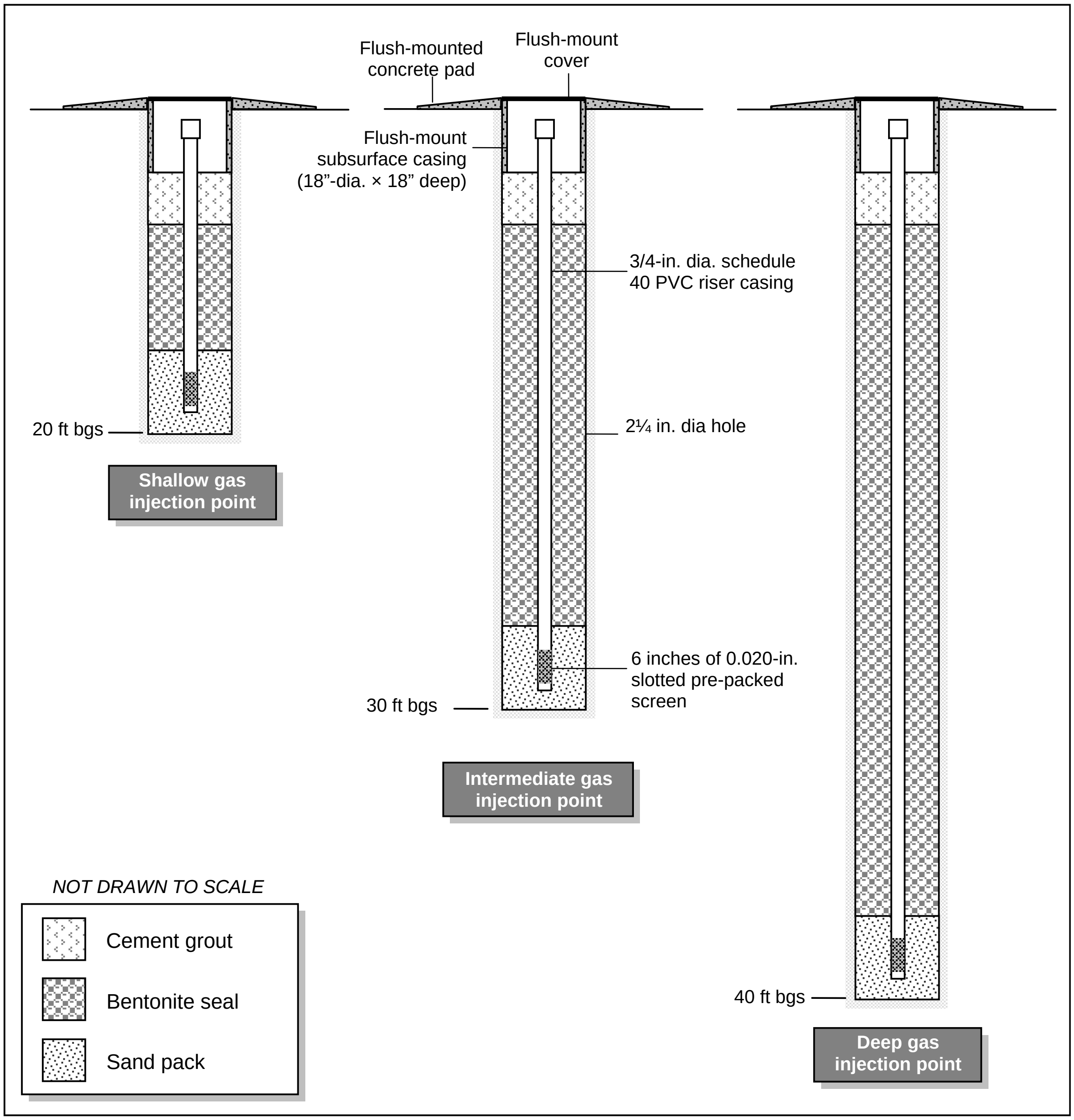


Figure 13: Example construction specifications for multi-level gas injection points

A generalized injection well design is depicted in **Figure 13**. Details of the boring logs and well construction are included in Appendix D. Injection wells were constructed with 3/4-inch diameter schedule 40 PVC with 6 inches of 0.020 inch (0.020") slotted pre-packed well screen. Annular materials included a sand filter pack (No. 3 Monterey Sand or equivalent), a bentonite chip seal, and a cement grout surface seal. Annular materials were installed by pouring the materials into the annular space outside the well casing. The bentonite chips were hydrated to create an annular seal. Depths were tagged periodically to ensure the materials were installed at the specified depths. Each well was completed with an 18”-diameter × 18”-deep flush mount man-way, individually installed with concrete pads. Upon completion, the 3/4-inch PVC casing was sealed from atmospheric air using a tight fitting PVC slip cap that was replace by the injection well-head fitting during the gas injection skid installation.

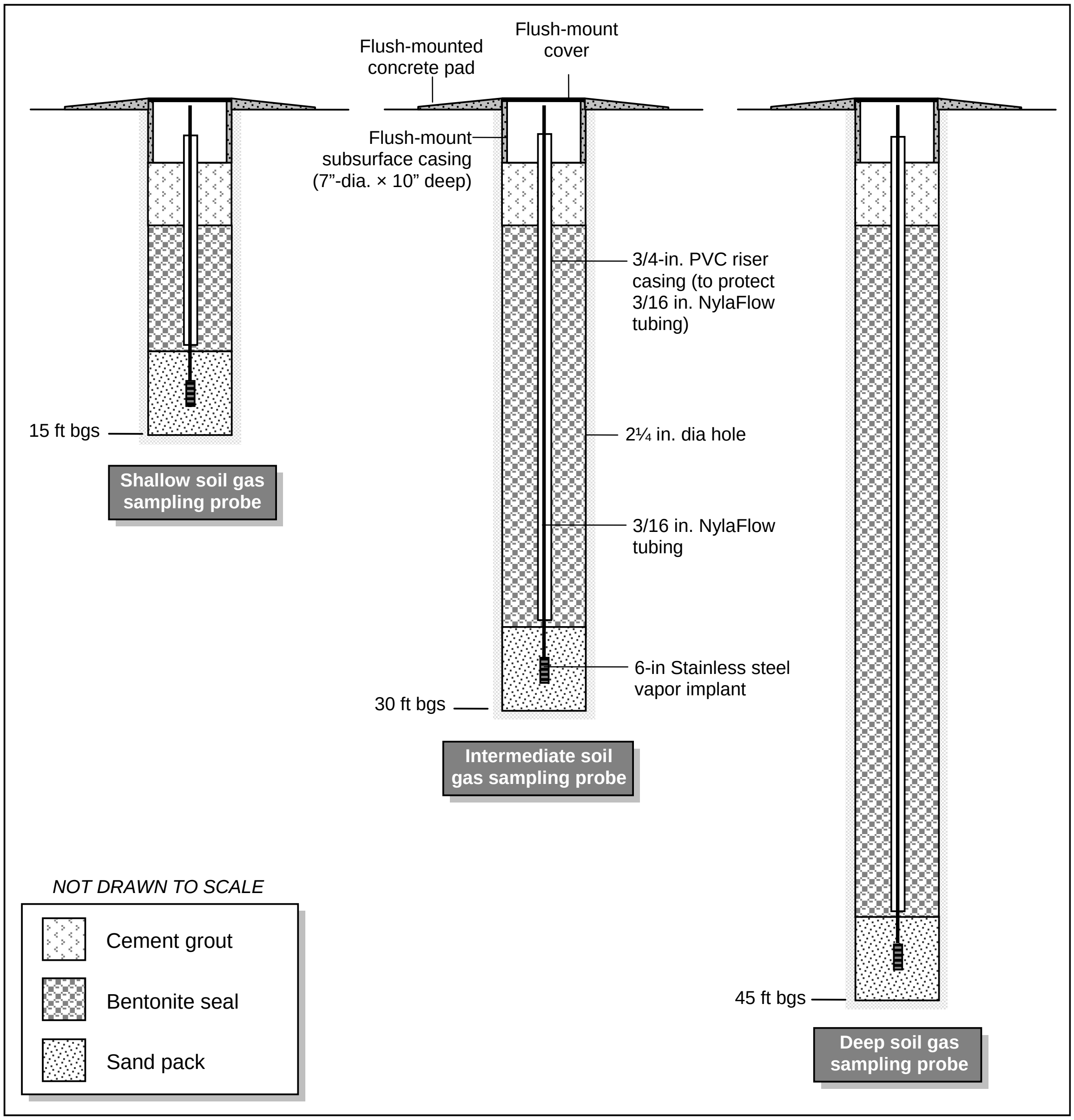


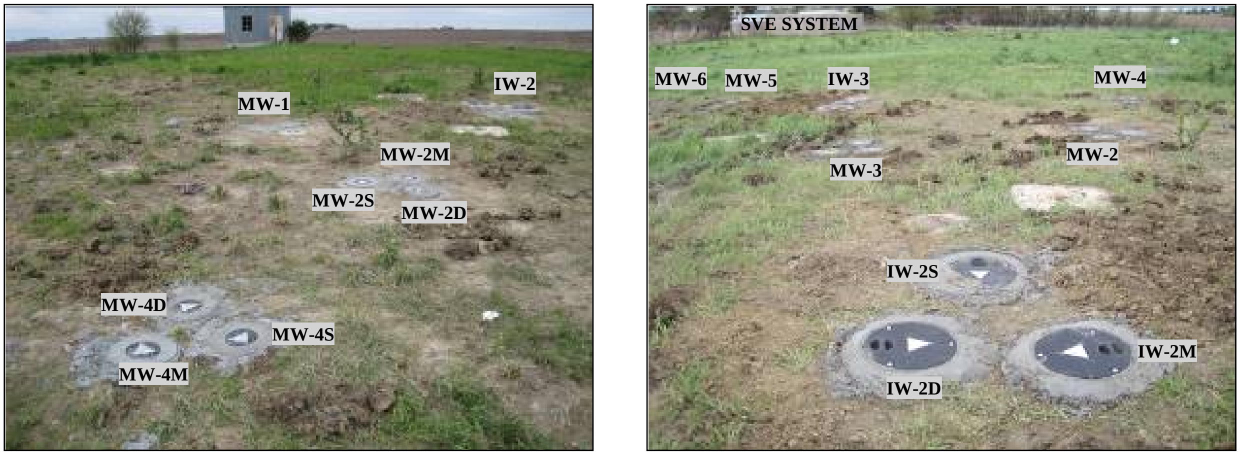
Figure 14: Example construction specifications for multi-level vapor sampling points

Monitoring Point Installation: Soil gas sampling points were installed in the sample point clusters as schematically shown in **Figure 14**. Soil vapor sampling wells were completed at varying depths above the water table (e.g., shallow, intermediate, deep). A total of three soil gas points were installed at each cluster using traditional direct-push technique that generates intact soil cores. The three soil gas points in each cluster were equally spaced vertically in the vadose zone at depths of 15, 30 and 45 feet below ground surface. The deep soil gas sampling point was logged and soil samples were collected. The shallow and intermediate soil gas sampling points were advanced with no sample collection or logging. Injection and monitoring well construction details are summarized in **Table 5**.

Table 5: Summary of well construction details

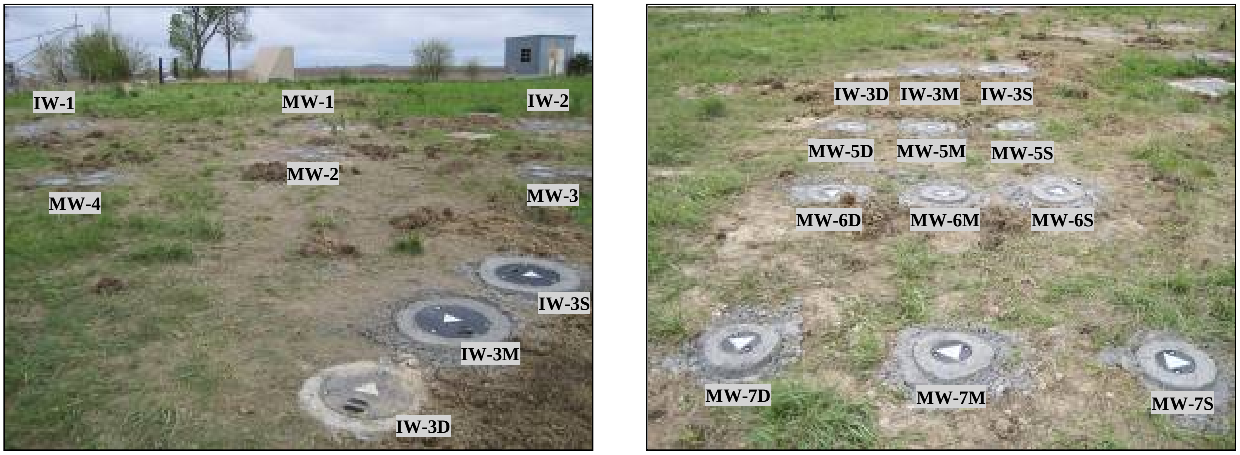
Well ID	Date	Injection/ Monitoring Zone	Well Type	Total Depth (ft-bgs)	Diameter (inches)	Sand Pack (ft-bgs)	Screen Interval (ft-bgs)
IW-1S	05/10/12	Shallow	Injection	20	3/4	18.5 -20	19-19.5
IW-1M	05/10/12	Intermediate	Injection	30	3/4	28.5-30	29-29.5
IW-1D	05/10/12	Deep	Injection	40	3/4	38.5-40	39-39.5
IW-2S	05/10/12	Shallow	Injection	20	3/4	18.5-20	19-19.5
IW-2M	05/10/12	Intermediate	Injection	30	3/4	28.5-30	29-29.5
IW-2D	05/10/12	Deep	Injection	40	3/4	38.5-40	39-39.5
IW-3S	05/10/12	Shallow	Injection	20	3/4	18.5-20	19-19.5
IW-3M	05/10/12	Intermediate	Injection	30	3/4	28.5-30	29-29.5
IW-3D	05/10/12	Deep	Injection	40	3/4	38.5-40	39-39.5
MW-1S	05/09/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-1M	05/09/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-1D	05/09/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-2S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-2M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-2D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-3S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-3M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-3D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-4S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-4M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-4D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-5S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-5M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-5D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-6S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-6M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-6D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-7S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-7M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-7D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-8S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-8M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-8D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5
MW-9S	05/10/12	Shallow	Monitoring	15	3/16	13.5-15	14-14.5
MW-9M	05/10/12	Intermediate	Monitoring	30	3/16	28.5-30	29-29.5
MW-9D	05/10/12	Deep	Monitoring	45	3/16	43.5-45	44-44.5

The soil gas sampling points were constructed of stainless steel vapor implant points attached securely to 3/16-inch Nylaflow tubing and lowered to the bottom of the borehole. A sand pack using U.S. mesh interval 20/40 sand were installed to approximately 6 inches above the vapor implant point. The remainder of the borehole was filled with bentonite chips to the ground surface and hydrated to create an annular seal. To protect the Nylaflow tubing, the tubing was encased within schedule 40 PVC pipe above the sand pack. Annular materials were installed by pouring the materials into the annular space between the well casing and the wash-over casing as well as inside the PVC casing around the Nylaflow tubing. Upon completion, the 3/16-inch Nylaflow tubing was sealed from atmospheric air using a three-way syringe valve that was used later for vapor sampling. Each well was completed with a 7”-diameter × 10”-deep flush mount man-way, individually installed with concrete pads. For all the injection and monitoring points, the temperature of the new concrete pads was kept above 50°F (10°C) during the curing period. Locations of the installed injection and monitoring points are shown in **Figure 15**.



North facing view

South view



North-west facing view

West facing view

Figure 15: Location of the installed injection and monitoring wells

Based on historic generator knowledge (previous analytical data) the soils were not hazardous waste (>10,000 µg/kg). In the state of Nebraska, any soils that are below the Preliminary Remediation Goal (PRG) of 80 µg/kg of TCE may be disposed directly on the surface. The soil cuttings were characterized and managed in accordance with applicable regulations. Both gas injection and vapor monitoring points were registered in the state of Nebraska.

5.2.2 Soil and Vapor Sampling and Analysis

The deep soil gas injection and monitoring points in each cluster were logged and soil samples were collected from this borehole. Each deep borehole was continuously cored from ground surface to total depth. The cores were logged by a GSI geologist in accordance with ASTM D 2488 standard. Soil cores were logged in accordance with the USCS classification guidelines. During soil core logging, special attention was given to the soil type and moisture content of the vadose soils. The shallow and intermediate soil gas sampling points were advanced with no sample collection or logging. **Figure 16** shows a sample picture of the soil cores used for soil logging and sample collection.

Figure 16: Logging and soil sample collection

Soil samples collected during monitoring point installation were representative of baseline conditions before gas injection. Core samples were screened in the field for volatile organic compounds (VOCs) by placing a portion of the sample into a zip-lock bag, waiting approximately 10 minutes, placing the tip of a photoionization detector (PID) into the bag, and then taking a measurement. Results of the PID readings can be found in the boring log sheets in Appendix D. Soil samples for VOC and moisture content analyses were collected from all 12 soil borings. Soil samples from each of the 12 Geoprobe holes were collected at 10-foot intervals (i.e., 4 soil samples from each hole) at depths of approximately 10, 20, 30, and 40 ft-bgs. Samples were placed in 4-oz glass jars (total of 48 samples) to be tested for VOC and moisture content. **Figure 19** and **Figure 20** show the cross-sections from the pre-characterization phase.

5.2.3 Baseline Characterization Results

Soil Samples: Analytical results from the soil sampling are summarized in **Table 6**. **Figure 17** illustrates the ratio of TCE to cis-1,2-DCE throughout the H_2T demonstration area. Analytical results (e.g., five VOCs and moisture content) from the soil sampling are summarized in **Figure 18**.

The primary constituents of concern are chlorinated solvents, including TCE and cis-1,2-DCE. These constituents are present in soil, and ranged from <6.0 to 1,200 µg/kg for TCE and from <5.9 to 2,100 µg/kg for cis-1,2-DCE. These results are consistent with the results of the previous soil investigation during the SVE pilot study from 2004-2006 (Kemron, 2007), that generally ranged from <3.7 to 2,090 µg/kg for TCE and from <3.6 to 1,560 µg/kg for cis-1,2-DCE, with the difference that cis-1,2,-DCE was found at higher concentrations than TCE in the most recent sampling. 26 out of 48 soil samples (e.g., 12 points and 4 depths each) have TCE concentrations above the Nebraska Department of Environmental Quality (NDEQ) remediation goal of 57.0 µg/kg. Soil samples were also tested for trans-1,2-DCE, Vinyl Chloride, and 1,1,1-trichloroethane (1,1,1-TCA). trans-1,2-DCE concentrations ranged from <5.9 to 73 µg/kg. Vinyl Chloride and 1,1,1-TCA were not detected in any of the soil samples.

Three of the Geoprobe borings (i.e., IW-3, MW-2, and MW-5) were selected to collect soil samples for further analyses of grain size distribution, soil pH, nutrients (i.e., NO3-N, P), and quantitative polymerase chain reaction (qPCR) testing (i.e., Gene-Trac Dhc and Gene-Trac VC). Soil samples from each of the selected three Geoprobe borings were collected at 15-foot intervals (i.e., 3 soil samples from each hole) at depths of approximately 10, 25, and 40 ft-bgs. Samples were placed in 4-oz plastic jars (9 samples for qPCR testing), 4-oz plastic jars (9 samples for grain size distribution analysis), and 8-oz plastic jars (9 samples for pH and Nutrient tests).

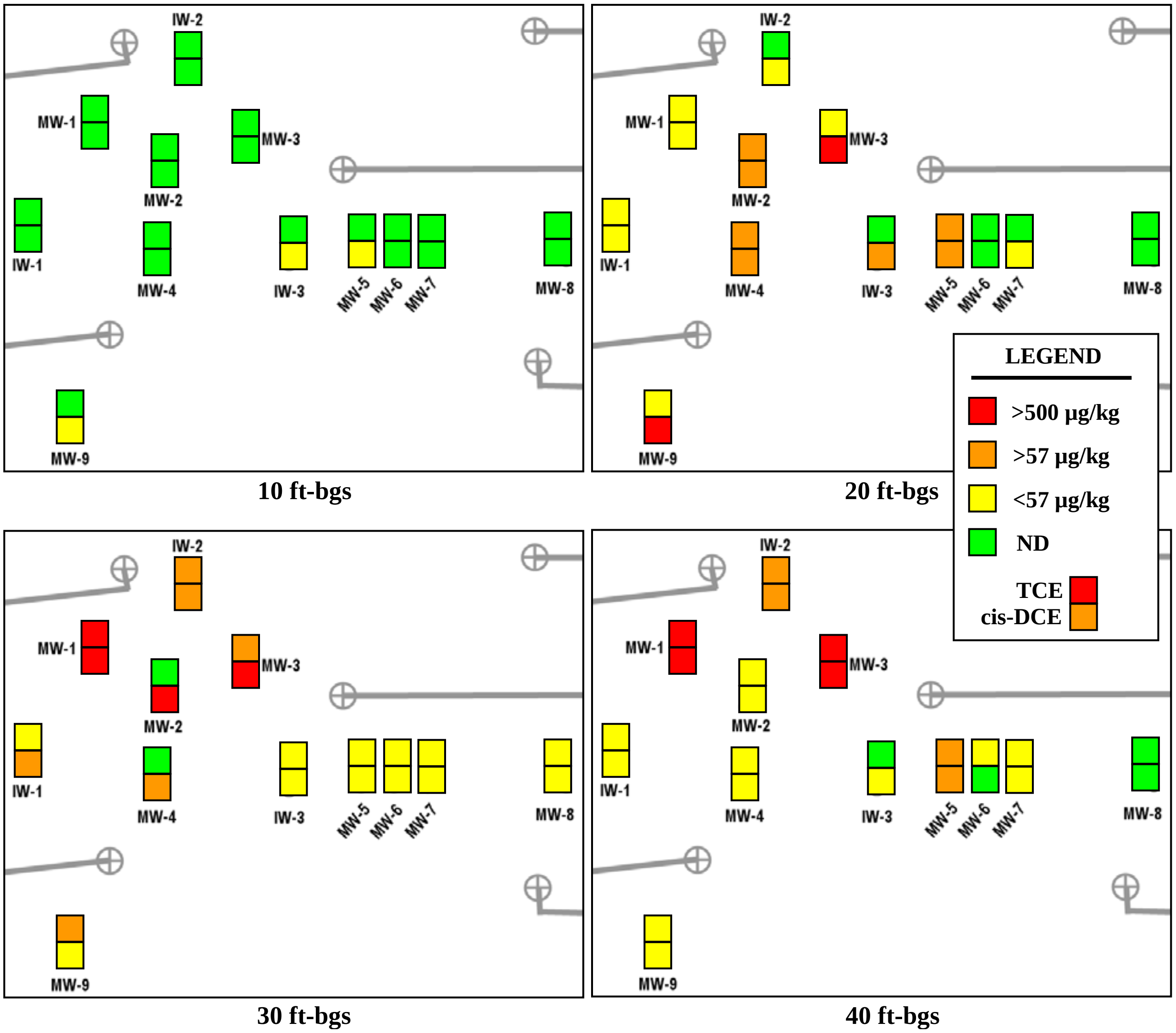


Figure 17: Soil sampling results – TCE and cis-1,2-DCE

Table 6: Soil analytical results, pre-treatment characterization phase, May 2011

Sample ID	**Date**	**Depth** (ft-bgs)	**TCE**	**cis-1,2-DCE**	**trans-1,2-DCE**	**VC**	**1,1,1-TCA**	**Moisture Content** (%)
IW-1-10	09-May-11	10	<0.59	<0.59	<0.59	<0.59	<0.59	15.8
IW-1-20	09-May-11	20	10	15	<0.6	<0.6	<0.6	16.7
IW-1-30	09-May-11	30	71	450	<0.63	<0.63	<0.63	20.6
IW-1-40	09-May-11	40	11	9.5	<0.6	<0.6	<0.6	17.1
IW-2-10	09-May-11	10	<0.59	<0.59	<0.59	<0.59	<0.59	15.3
IW-2-20	09-May-11	20	<0.6	4.2 J	<0.6	<0.6	<0.6	16.4
IW-2-30	09-May-11	30	190	410	21	<0.63	<0.63	21.0
IW-2-40	09-May-11	40	210	140	<0.62	<0.62	<0.62	19.3
IW-3-10	09-May-11	10	<0.6	25	<0.6	<0.6	<0.6	16.6
IW-3-20	09-May-11	20	<0.62	470	15	<0.62	<0.62	19.6
IW-3-30	09-May-11	30	34	35	<0.61	<0.61	<0.61	18.1
IW-3-40	09-May-11	40	<0.6	1.5 J	<0.6	<0.6	<0.6	16.2
MW-1-10	09-May-11	10	<0.59	<0.59	<0.59	<0.59	<0.59	15.8
MW-1-20	09-May-11	20	2.4	3.7 J	<0.61	<0.61	<0.61	18.4
MW-1-30	09-May-11	30	1,000	640	14	<0.63	<0.63	20.4
MW-1-40	09-May-11	40	1,200	1,300	7.8	<0.63	<0.63	21.0
MW-2-10	10-May-11	10	<0.6	<0.6	<0.6	<0.6	<0.6	16.3
MW-2-20	10-May-11	20	67	120	5	<0.6	<0.6	16.8
MW-2-30	10-May-11	30	<0.63	610	2.8	<0.63	<0.63	21.0
MW-2-40	10-May-11	40	14	5.0 J	<0.61	<0.61	<0.61	17.9
MW-3-10	10-May-11	10	<0.61	<0.61	<0.61	<0.61	<0.61	17.5
MW-3-20	10-May-11	20	24	470	9.1	<0.61	<0.61	18.2
MW-3-30	10-May-11	30	57	730	11	<0.62	<0.62	19.0
MW-3-40	10-May-11	40	960	620	7.3	<0.63	<0.63	20.3
MW-4-10	09-May-11	10	<0.6	<0.6	<0.6	<0.6	<0.6	16.1
MW-4-20	09-May-11	20	95	220	<0.61	<0.61	<0.61	18.2
MW-4-30	09-May-11	30	<0.64	230	<0.64	<0.64	<0.64	22.0
MW-4-40	09-May-11	40	8.4	7.4	<0.61	<0.61	<0.61	18.5
MW-5-10	10-May-11	10	<0.6	8.1	<0.6	<0.6	<0.6	16.6
MW-5-20	10-May-11	20	110	73	9.5	<0.59	<0.59	15.2
MW-5-30	10-May-11	30	23	38	<0.61	<0.61	<0.61	18.5
MW-5-40	10-May-11	40	190	65	<0.63	<0.63	<0.63	20.1
MW-6-10	10-May-11	10	<0.6	<0.6	<0.6	<0.6	<0.6	16.2
MW-6-20	10-May-11	20	<0.62	<0.62	<0.62	<0.62	<0.62	19.7
MW-6-30	10-May-11	30	21	38	<0.62	<0.62	<0.62	19.6
MW-6-40	10-May-11	40	12	<0.61	<0.61	<0.61	<0.61	17.7
MW-7-10	10-May-11	10	<0.61	<0.61	<0.61	<0.61	<0.61	17.5
MW-7-20	10-May-11	20	<0.61	19	<0.61	<0.61	<0.61	17.4
MW-7-30	10-May-11	30	7.3	38	<0.61	<0.61	<0.61	18.3
MW-7-40	10-May-11	40	61	24	<0.62	<0.62	<0.62	19.5
MW-8-10	10-May-11	10	<0.62	<0.62	<0.62	<0.62	<0.62	18.8
MW-8-20	10-May-11	20	<0.61	<0.61	<0.61	<0.61	<0.61	17.9
MW-8-30	10-May-11	30	3.5	2.6 J	<0.63	<0.63	<0.63	20.2
MW-8-40	10-May-11	40	<0.61	<0.61	<0.61	<0.61	<0.61	18.1
MW-9-10	10-May-11	10	<0.6	2.9 J	<0.6	<0.6	<0.6	16.8
MW-9-20	10-May-11	20	37	2,100	73	<0.6	<0.6	16.4
MW-9-30	10-May-11	30	62	19	<0.61	<0.61	<0.61	18.1
MW-9-40	10-May-11	40	10	6.6	<0.62	<0.62	<0.62	19.8

Note: Soil concentrations are in µg/kg-dry.

Sample jars were sealed in zip-lock bags which were placed in an ice-chilled cooler prior to shipment to the lab. **Table 7** summarizes the analytical results of soil samples tested for grain size distribution, pH, nutrients (NO_3-N, Phosphorus), and DHC bacteria.

Table 7: Soil sampling results, pre-treatment characterization phase, May 2011

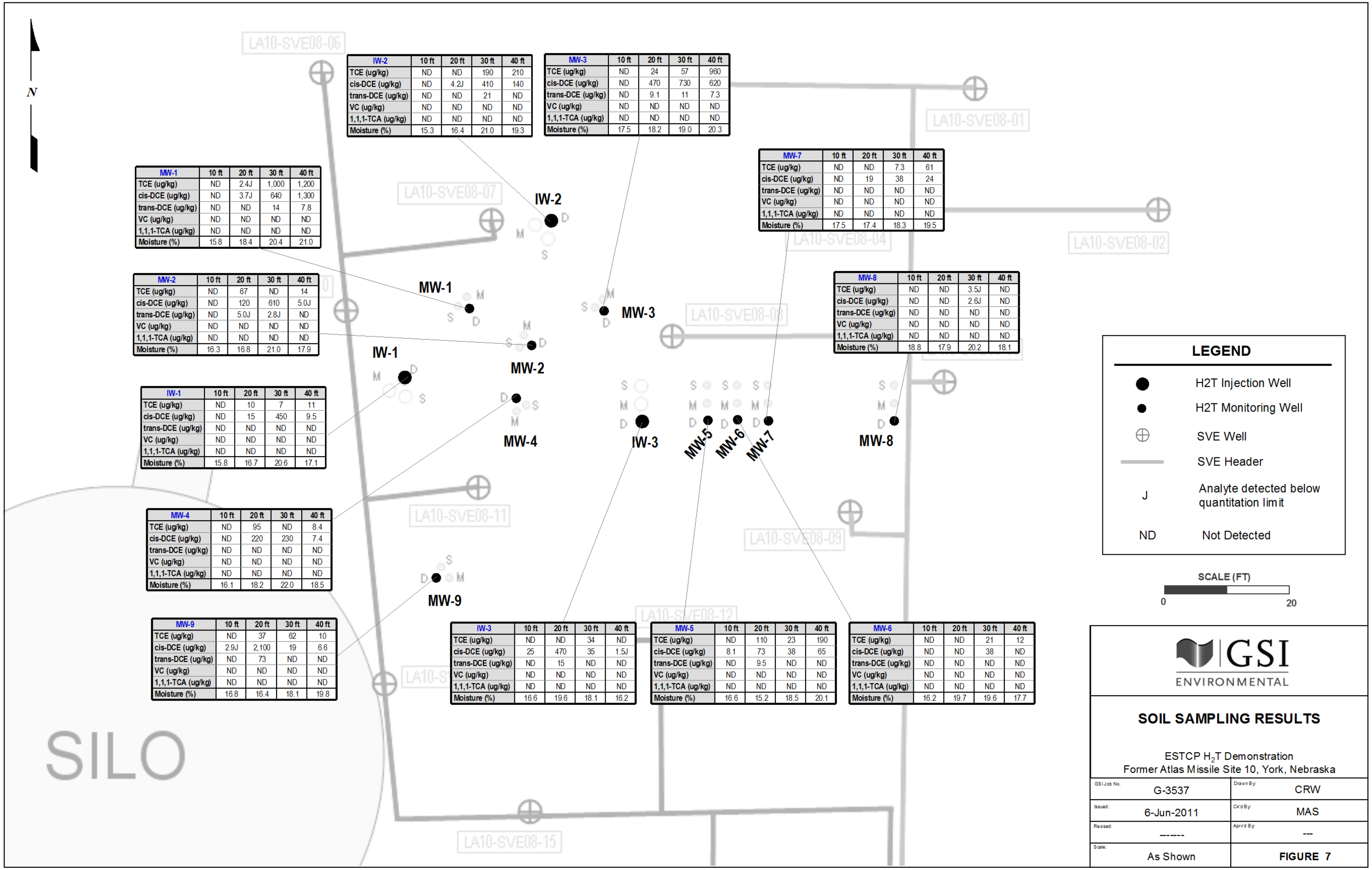
Sample ID	**IW-3-10**	**IW-3-25**	**IW-3-40**	**MW-2-10**	**MW-2-25**	**MW-2-40**	**MW-5-10**	**MW-5-25**	**MW-5-40**
Depth, ft	10	25	40	10	25	40	10	25	40
Soil Type	Silt	Silt	Silt	Silt	Silt	Silt	Silt	Silt	Silt
%Fine Sand	8.27	2.64	8.77	5.19	5.97	0.80	9.35	2.37	1.27
% Silt	70.54	72.38	68.16	72.73	72.49	76.40	68.88	72.86	75.90
% Clay	21.19	24.99	23.07	22.08	21.54	22.80	21.75	24.77	22.83
Median Grain Size, mm	0.023	0.018	0.021	0.022	0.024	0.021	0.023	0.018	0.021
Mean Grain Size, mm	0.016	0.013	0.015	0.015	0.016	0.014	0.016	0.013	0.014
pH	7.8	7.9	7.9	7.6	8.2	8.1	8.0	8.2	7.7
Organic Matter (%)	1.3	1.0	1.0	1.2	1.2	1.2	1.1	1.1	1.2
Nitrate-N, ppm	0.8	0.4	0.5	1.4	0.7	0.5	0.5	0.6	0.7
Phosphorus (P1), ppm****	18	15	15	15	10	10	14	14	16
Phosphorus (Bicarb), ppm	11	8	9	10	6	6	8	7	9
Phosphorus (P2), ppm	169	256	92	200	237	256	190	204	277
Phosphorus (M2), ppm	17	17	15	14	10	11	13	14	17
Phosphorus (M3), ppm	25	40	21	25	24	25	25	18	40
% Dhc*	NA	NA	0.00008-0.0002	NA	NA	NA	NA	NA	0.0004-0.001
Dehalococcoides Enumeration/Gram	8×10^3 U	9×10^3 U	1×10^3 J	7×10^3 U	1×10^4 U	1×10^4 U	9×10^3 U	9×10^3 U	4×10^3 J
DNA Concentration in Sample (extractable), ng/g	3371	3344	2859	2563	4397	3127	3005	2145	2131
PCR Amplifiable DNA	Detected	ND	Detected	Detected	Detected	Detected	Detected	ND	Detected
% vcrA***	-	-	NA	-	-	-	-	-	0.0003-0.001
Vinyl Chloride Reductase (vcrA) Gene Copies/Gram	-	-	1×10^4 U	-	-	-	-	-	3×10^3 J
DNA Concentration in Sample (extractable), ng/g	-	-	2859	-	-	-	-	-	2131
PCR Amplifiable DNA	-	-	Detected	-	-	-	-	-	Detected

* Percent *Dehalococcoides* (Dhc) in microbial population. This value is calculated by dividing the number of Dhc 16S ribosomal ribonucleic acid (rRNA) gene copies by the total number of bacteria as estimated by the mass of DNA extracted from the sample. Range represents normal variation in Dhc enumeration and U corresponds to below detection limit for qPCR.

** Based on quantification of Dhc 16S rRNA gene copies. Dhc are generally reported to contain one 16S rRNA gene copy per cell; therefore, this number is often interpreted to represent the number of Dhc cells present in the sample.

*** Percentage of bacteria in the microbial population that harbor the *vcrA* gene. This value is calculated by dividing the measured number of cells haboring the vinyl chloride reductase A (*vcrA*) gene by the total number of bacteria in the sample estimated using the mass of DNA extracted from the sample. Range represents normal variation in enumeration of *vcrA*.

**** Phosphorous (P1) or weak Bray test measures phosphorus which is readily available to the plants, Phosphorus (Bicarb) test measures the amount of readily available phosphorus in slightly basic (pH of 7.0 - 7.2) to highly basic soils (pH >7.3r), Phosphorus (P2) or strong Bray test measures readily available phosphorus plus a part of the reserve phosphorus in soil, Phosphorus (M2) and Phosphorus (M3) use a number of acids to extract the soil phosphorus whereas the Bray test uses weak HCl.



IW-2	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	190	210
cis-DCE (ug/kg)	ND	4.2J	410	140
trans-DCE (ug/kg)	ND	ND	21	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.3	16.4	21.0	19.3

MW-3	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	24	57	960
cis-DCE (ug/kg)	ND	470	730	620
trans-DCE (ug/kg)	ND	9.1	11	7.3
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.5	18.2	19.0	20.3

MW-1	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	2.4J	1,000	1,200
cis-DCE (ug/kg)	ND	3.7J	640	1,300
trans-DCE (ug/kg)	ND	ND	14	7.8
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.8	18.4	20.4	21.0

MW-7	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	7.3	61
cis-DCE (ug/kg)	ND	19	38	24
trans-DCE (ug/kg)	ND	ND	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.5	17.4	18.3	19.5

MW-2	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	67	ND	14
cis-DCE (ug/kg)	ND	120	610	5.0J
trans-DCE (ug/kg)	ND	5.0J	2.8J	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.3	16.8	21.0	17.9

MW-8	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	3.5J	ND
cis-DCE (ug/kg)	ND	ND	2.6J	ND
trans-DCE (ug/kg)	ND	ND	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	18.8	17.9	20.2	18.1

IW-1	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	10	7	11
cis-DCE (ug/kg)	ND	15	450	9.5
trans-DCE (ug/kg)	ND	ND	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.8	16.7	20.6	17.1

MW-4	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	95	ND	8.4
cis-DCE (ug/kg)	ND	220	230	7.4
trans-DCE (ug/kg)	ND	ND	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.1	18.2	22.0	18.5

MW-9	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	37	62	10
cis-DCE (ug/kg)	2.9J	2,100	19	6.6
trans-DCE (ug/kg)	ND	73	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.8	16.4	18.1	19.8

IW-3	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	34	ND
cis-DCE (ug/kg)	25	470	35	1.5J
trans-DCE (ug/kg)	ND	15	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.6	19.6	18.1	16.2

MW-5	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	110	23	190
cis-DCE (ug/kg)	8.1	73	38	65
trans-DCE (ug/kg)	ND	9.5	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.6	15.2	18.5	20.1

MW-6	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	21	12
cis-DCE (ug/kg)	ND	ND	38	ND
trans-DCE (ug/kg)	ND	ND	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.2	19.7	19.6	17.7

Figure 18: Results of soil sample collected during pre-characterization phase

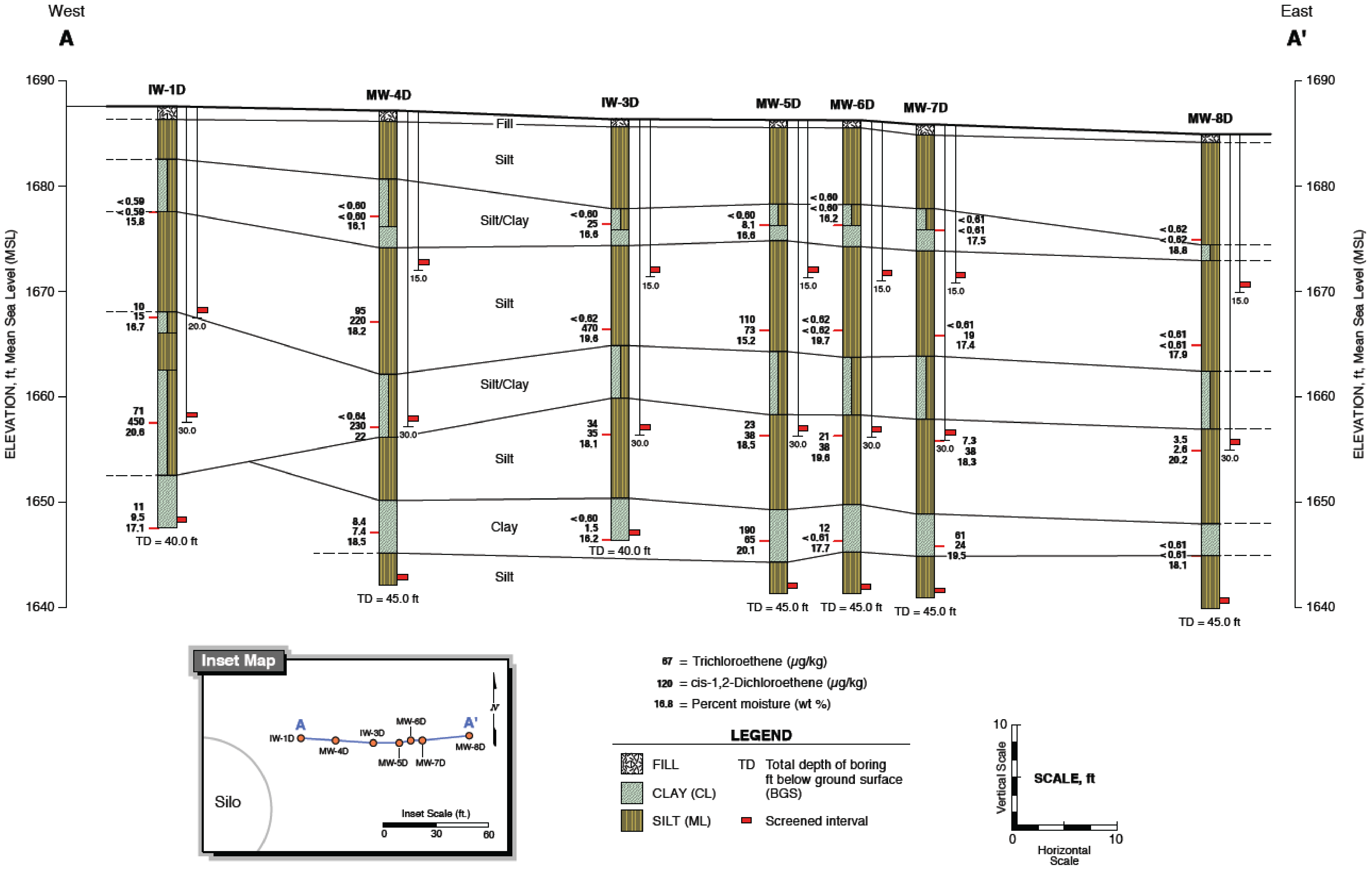


Figure 19: Geologic cross section A-A' west-east orientation

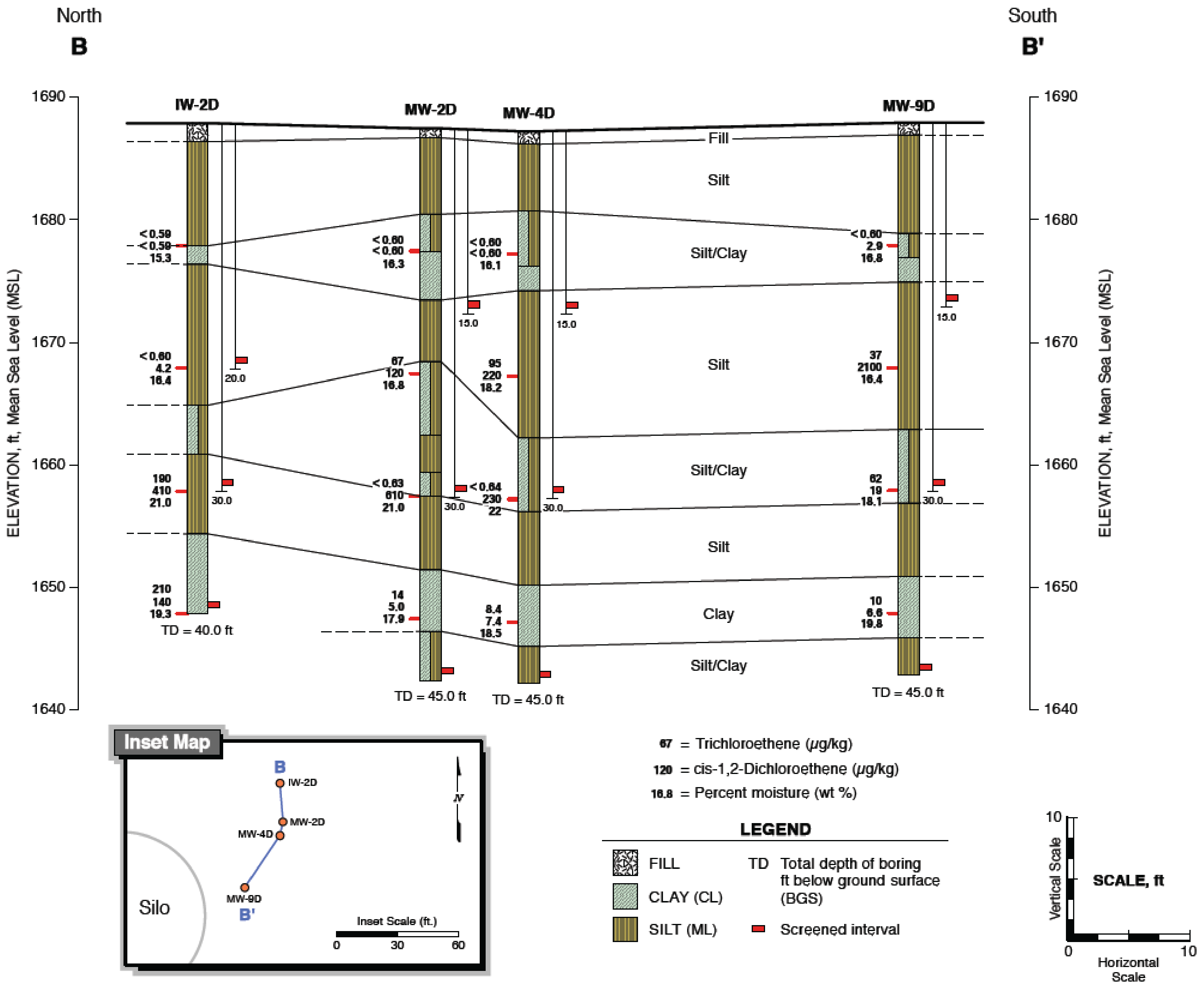


Figure 20: Geologic cross section B-B' north-south orientation

Vapor Samples: Samples of soil gas from the 27 monitoring points were collected and analyzed for oxygen, carbon dioxide, methane, LEL, relative humidity, and temperature using field instruments. Temperature and relative humidity were measured using an Amprobe THWD-5 relative humidity and temperature meter. Barometric pressure and atmospheric (above-ground) concentrations of flammable gases were monitored with GEM2000 landfill gas monitor. **Figure 21** shows the vapor sampling and monitoring. Results of soil vapor monitoring are summarized in **Table 8**. The soil vapor monitoring results were consistent with the results of the previous two soil vapor monitoring events in July and August of 2010.

Samples of gas from the monitoring points were collected in three 22-ml glass vials per sampling point using sampling kit (vials and syringes) provided by Vaportech. Total of 27 vapor samples from the monitoring points, 6 vapor sample duplicates (i.e., MW-1 and MW-9), and two field blanks (ambient air from upwind and downwind) were collected. The soil vapor samples, duplicates, and blanks were shipped to Vaportech lab to be analyzed for concentrations of contaminants and daughter products. During the well completion and prior to sampling, the soil gas points were fitted with a sealing device (three-way syringe valve) to prevent atmospheric air from entering the tubing.

Figure 21: GEM2000 readings and vapor sampling

Analytical results of the soil vapor sampling are summarized in **Table 9**. Soil vapor samples were tested for TCE, cis-1,2-DCE, trans-1,2-DCE, Vinyl Chloride, and 1,1,1-TCA. TCE concentrations ranged ND-180.9 ppmv and cis-1,2-DCE concentrations ranged ND-157.9 ppmv. Vapor samples were also tested for trans-1,2-DCE, Vinyl Chloride, and 1,1,1-TCA. trans-1,2-DCE concentrations ranged between ND-8.6 ppmv. Vinyl Chloride was not detected in any of the samples and 1,1,1-TCA was only found in MW-2D at a concentration of 0.006 ppmv. **Figure 22** illustrates the ratio of TCE to cis-1,2-DCE in the H_2T monitoring wells.

Table 8: Soil vapor monitoring results using GEM2000 LGM, pre-treatment characterization phase, May 2011

Well ID	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure	Temperature	Relative Humidity	Ambient Temperature	Ambient Rel. Humidity
	%	%	%	%	%	inches Hg	In- H2O	Deg. F	[-]	Deg. F	[-]
MW-1S	0.0	3.8	15.2	81.0	0.0	28.10	-0.29	70.5	56.0	66.2	42.8
MW-1M	0.0	2.2	16.5	81.3	0.0	28.10	-0.30	72.6	60.7	66.7	42.6
MW-1D	0.2	6.0	5.9	87.9	4.0	28.10	-0.30	72.8	57.2	66.1	42.9
MW-2S	0.0	4.3	14.9	80.8	0.0	28.15	-0.21	72.1	57.0	64.9	43.9
MW-2M	0.1	1.6	13.2	85.1	2.0	28.15	-0.24	73.2	55.1	65.2	42.4
MW-2D	0.2	3.0	14.1	82.7	4.0	28.16	-0.26	73.6	56.9	65.0	42.5
MW-3S	0.0	4.7	14.9	80.4	0.0	28.14	-0.40	73.2	56.8	66.7	43.4
MW-3M	0.1	1.6	17.6	80.7	2.0	28.14	-0.46	73.1	56.2	66.3	44.0
MW-3D	0.0	2.3	18.0	79.7	0.0	28.15	-0.50	76.2	57.8	66.5	42.4
MW-4S	0.0	3.1	13.7	83.2	0.0	28.16	-0.32	73.0	56.8	65.4	43.9
MW-4M	0.1	1.2	15.7	83.0	2.0	28.15	-0.35	74.8	57.2	65.4	43.6
MW-4D	0.2	2.7	15.2	81.9	4.0	28.14	-0.36	75.5	60.0	65.5	42.7
MW-5S	0.0	3.6	17.1	79.3	0.0	28.14	-0.55	74.3	56.2	66.4	42.2
MW-5M	0.2	0.9	16.3	82.6	4.0	28.13	-0.55	75.0	58.5	66.0	43.3
MW-5D	0.0	2.0	17.9	80.1	0.0	28.13	-0.56	76.6	59.2	66.0	43.2
MW-6S	0.0	3.2	17.4	79.4	0.0	28.13	-0.58	73.2	55.4	66.5	42.6
MW-6M	0.1	1.9	18.3	79.7	2.0	28.13	-0.54	73.5	58.6	66.8	43.1
MW-6D	0.0	1.4	19.1	79.5	0.0	28.13	-0.50	73.8	57.9	67.1	43.7
MW-7S	0.0	1.1	18.5	80.4	0.0	28.12	-0.46	70.1	57.6	68.2	43.7
MW-7M	0.0	1.0	17.6	81.4	0.0	28.12	-0.44	72.8	57.1	68.4	42.3
MW-7D	0.0	1.2	18.9	79.9	0.0	28.12	-0.44	74.9	59.2	67.9	42.2
MW-8S	0.0	0.7	19.3	80.0	0.0	28.10	-0.29	68.2	59.5	67.2	42.7
MW-8M	0.0	2.1	19.4	78.5	0.0	28.10	-0.30	69.7	55.5	67.4	43.0
MW-8D	0.0	0.2	19.5	80.3	0.0	28.11	-0.30	71.4	55.7	67.3	42.9
MW-9S	0.0	2.9	13.6	83.5	0.0	28.10	-0.19	69.4	55.3	66.3	42.1
MW-9M	0.1	0.5	16.7	82.7	2.0	28.10	-0.19	69.8	55.6	65.7	43.8
MW-9D	0.0	2.0	17.8	80.2	0.0	28.11	-0.22	70.8	56.4	65.0	43.4

Typical Accuracy:	0-5% volume	5-15% volume	15%-FS	Range
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table 9: Soil vapor monitoring results, pre-treatment characterization phase, May 2011

SAMPLE NAME	TCE	PQL	cis-1,2-DCE	PQL	trans-1,2-DCE	PQL	VC	PQL	1,1,1-TCA	PQL
MW-1S	ND	0.005	ND	0.01	ND	0.01	ND	1	ND	0.005
MW-1M	180.865	0.005	145.74	0.01	5.21	0.01	ND	1	ND	0.005
MW-1D	132.940	0.005	46.77	0.01	8.62	0.01	ND	1	ND	0.005
MW-1S-DUP	ND	0.005	ND	0.01	ND	0.01	ND	1	ND	0.005
MW-1M-DUP	179.424	0.005	141.65	0.01	5.17	0.01	ND	1	ND	0.005
MW-1D-DUP	123.057	0.005	43.32	0.01	8.02	0.01	ND	1	ND	0.005
MW-2S	0.010	0.005	0.23	0.01	0.05	0.01	ND	1	ND	0.005
MW-2M	8.404	0.005	157.93	0.01	6.03	0.01	**ND	3	ND	0.005
MW-2D	18.590	0.005	21.42	0.01	1.08	0.01	ND	1	0.006	0.005
MW-3S	0.014	0.005	0.46	0.01	0.08	0.01	ND	1	ND	0.005
MW-3M	67.374	0.005	117.76	0.01	4.22	0.01	**ND	2	ND	0.005
MW-3D	35.876	0.005	13.54	0.01	0.68	0.01	ND	1	ND	0.005
MW-4S	0.493	0.005	53.85	0.01	4.16	0.01	ND	1	ND	0.005
MW-4M	1.747	0.005	69.64	0.01	2.61	0.01	**ND	2	ND	0.005
MW-4D	14.890	0.005	15.08	0.01	1.07	0.01	ND	1	ND	0.005
MW-5S	ND	0.005	7.75	0.01	0.69	0.01	ND	1	ND	0.005
MW-5M	13.782	0.005	24.44	0.01	0.89	0.01	ND	1	ND	0.005
MW-5D	2.915	0.005	0.93	0.01	0.13	0.01	ND	1	ND	0.005
MW-6S	0.045	0.005	9.92	0.01	1.01	0.01	ND	1	ND	0.005
MW-6M	3.003	0.005	18.21	0.01	0.92	0.01	ND	1	ND	0.005
MW-6D	0.178	0.005	0.02	0.01	ND	0.01	ND	1	ND	0.005
MW-7S	0.010	0.005	1.41	0.01	0.20	0.01	ND	1	ND	0.005
MW-7M *	2.256	0.010	16.75	0.02	0.74	0.02	ND	2	ND	0.010
MW-7D	1.467	0.005	0.54	0.01	0.06	0.01	ND	1	ND	0.005
MW-8S	ND	0.005	ND	0.01	ND	0.01	ND	1	ND	0.005
MW-8M	0.575	0.005	0.40	0.01	0.03	0.01	ND	1	ND	0.005
MW-8D	0.024	0.005	0.02	0.01	ND	0.01	ND	1	ND	0.005
MW-9S	ND	0.005	93.04	0.01	4.39	0.01	ND	1	ND	0.005
MW-9M	16.946	0.005	10.85	0.01	2.45	0.01	ND	1	ND	0.005
MW-9D	7.554	0.005	2.97	0.01	0.53	0.01	ND	1	ND	0.005
MW-9S DUP *	0.005	0.010	107.05	0.02	4.91	0.02	ND	2	ND	0.010
MW-9M DUP	17.764	0.005	10.98	0.01	2.49	0.01	ND	1	ND	0.005
MW-9D DUP	5.945	0.005	9.76	0.01	0.63	0.01	ND	1	ND	0.005
FB#1-UPWIND	ND	0.005	ND	0.01	ND	0.01	ND	1	ND	0.005
FB#2-DOWNWIND	ND	0.005	ND	0.01	ND	0.01	ND	1	ND	0.005

TCE: Trichloroethene, cis-1,2-DCE: cis-1,2-Dichloroethene, trans-1,2-DCE: trans-1,2-Dichloroethene, VC: Vinyl Chloride, 1,1,1-TCA, 1,1,1-Trichloroethane. All concentrations are in ppmv.

PQL - denotes lower 'Practical Quantitation Limit'

ND - 'Not Detected' at or above the lower practical quantitation limit

* Sample received with insufficient pressure for analysis. The sample was repressurized diluting the sample by a factor of 2. Analytical results were then multipiled to correct for the dilution.

** PQL was raised due to interfering unidentified compound.

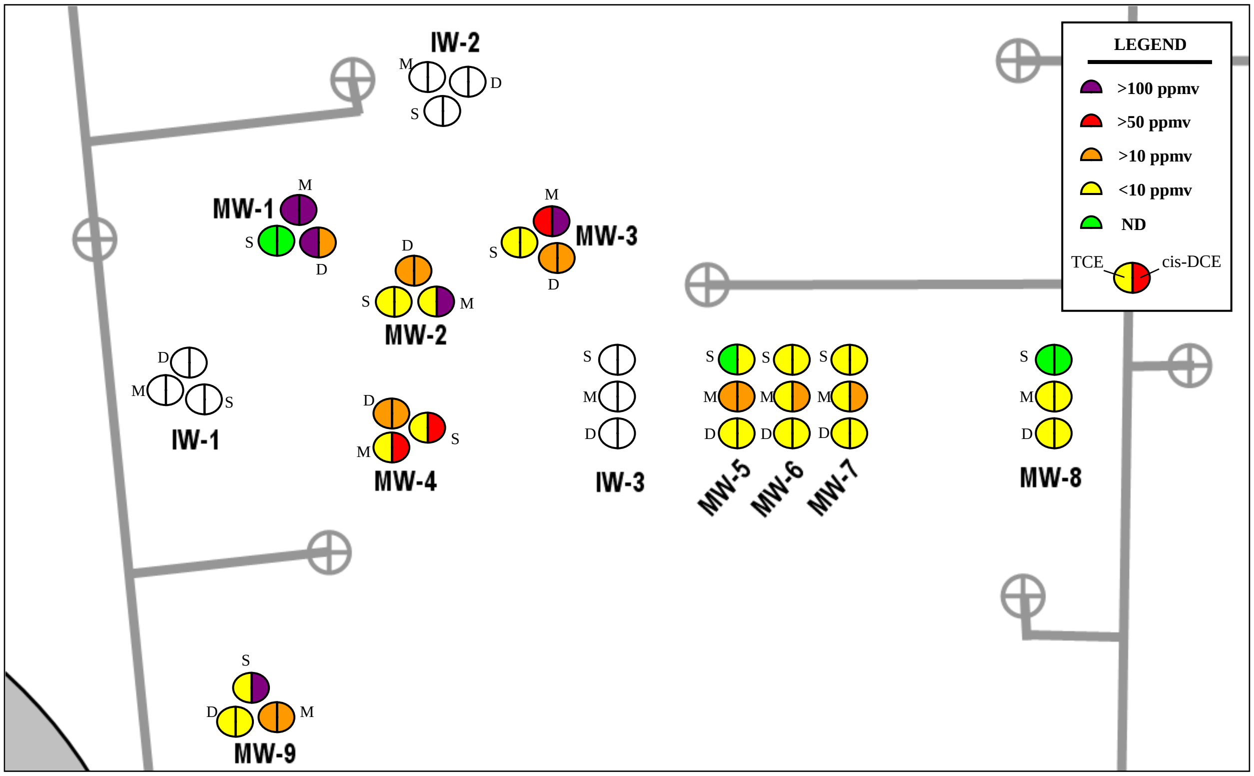


Figure 22: Soil vapor sampling results – TCE and cis-1,2-DCE

5.3 DESIGN AND INSTALLATION OF GAS INJECTION SYSTEM

The injection skid consisted of piping, gages, safety equipment, process control system, and gas cylinders that were connected to the piping manifold and injection wells at the site. Gas vendors replaced the gas supply containers (either compressed gas cylinders or liquid gases), as needed based on the readings during the weekly operation and maintenance (O&M), typically on the order of every week or every few weeks. Adjustments to these design parameters were made if necessary based on site-specific conditions and the review of the system performance. Gas mixture was injected in a steady state mode with a constant low-flowrate gas stream (i.e., approximately 0.28 scfm per injection point).

Table 10 lists gas supply equipment and general specifications. The gas injection system was designed to allow injection of a mixture of nitrogen, hydrogen, propane, and carbon dioxide. Provisions for injection of helium as a tracer were also included.

Table 10: Gas supply equipment

Tag	Description	Specification
1	Liquid nitrogen	Trailer, 150,000 cubic feet gas capacity
2	Compressed hydrogen	Two 16-clusters of K cylinders; 3,200 cubic feet gas capacity each 16-pack
3	Liquid petroleum gas, odorized	1000 gallon, 30,000 cubic feet gas capacity
4	Compressed carbon dioxide	Four K cylinders , 1,200 cubic feet gas capacity
5	Compressed helium	Three T cylinders, 900 cubic feet gas capacity

Figure 23: Gas mixing (left side) and injection (right side) skid for the H_2T system

The injection skid was built by National Environmental Systems (NES) and shipped to the site. Details of H_2T skid operation and maintenance (O&M) manual are in Appendix J. A front view of the gas mixing and injection skid is shown in **Figure 23**. Photos that show the system configuration are shown in **Figure 24**. The gas injection system was designed to be operated without any electrical requirements because of the remoteness of the site and the safety concerns. Each gas flow was controlled using manual pressure regulators and flow control valves along with rotameters to measure flow and gauges to monitor pressure. The gases were mixed in-line prior to distribution to the injection wells. The process and instrumentation diagram (P&ID) for the H_2T system is shown in **Figure 25**.

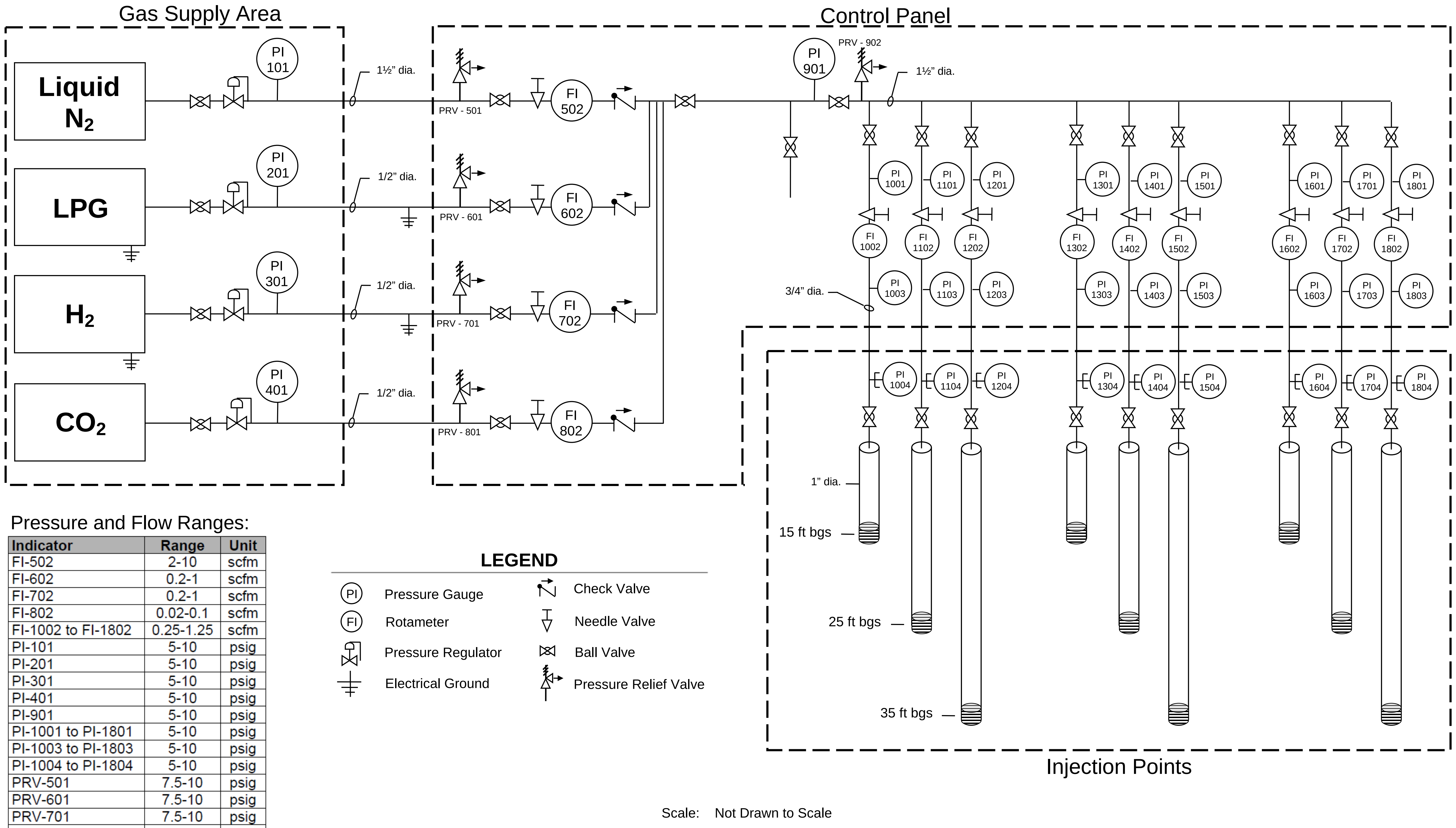
5.3.1 Skid Installation and Piping

After placement on the northeast part of the missile silo, the skid was bolted to the concrete slab using concrete expansion bolts. The piping from the skid to the injection wells were buried under ground to prevent damage during mowing (**Figure 26**).

Placement of Pure Gases: Auto-switch boxes for the hydrogen and carbon dioxide manifolds were mounted on the outside wall of the skid enclosure. Nitrogen and propane pipes and connections were installed. Since NFPA 55 requires the propane tank and hydrogen cylinders to be at least 15 feet apart if the propane supply is bulk, the propane tank was placed on the western part of the silo concrete slab to be approximately 30 feet away from the hydrogen cylinders to comply with the required separation regulations.

Delivery of Gases to Skid: Copper tubing was used for the gas lines from the gas supplies to the skid. Propane lines were routed from the tank through high pressure hose, and through PVC conduit, from the tank to the skid. Nitrogen lines were similarly protected and the entire system was grounded.

Figure 24: H_2T system



Pressure and Flow Ranges:

Indicator	Range	Unit
FI-502	2-10	scfm
FI-602	0.2-1	scfm
FI-702	0.2-1	scfm
FI-802	0.02-0.1	scfm
FI-1002 to FI-1802	0.25-1.25	scfm
PI-101	5-10	psig
PI-201	5-10	psig
PI-301	5-10	psig
PI-401	5-10	psig
PI-901	5-10	psig
PI-1001 to PI-1801	5-10	psig
PI-1003 to PI-1803	5-10	psig
PI-1004 to PI-1804	5-10	psig
PRV-501	7.5-10	psig
PRV-601	7.5-10	psig
PRV-701	7.5-10	psig
PRV-801	7.5-10	psig
PRV-902	7.5-10	psig

Figure 25: Process and instrumentation diagram (P&ID) for the H_2T system

Delivery of Mixed Gas to Injection Wells: High pressure well hoses were placed inside the PVC conduit inside the trenches to ensure continuous protection from the skid to the well sites. The hoses were connected to the installed wellheads.

After the wellheads were glued in place and connected to the high pressure hoses (**Figure 27**), leak tests were performed using soapy water. After the leak test of all gas lines, the excavated areas were filled using the excavated soil. Additionally, Hazard/Warning and NFPA decals were placed on the skid and propane lines to alert site vistors of potential hazards.

5.3.1 Leak Test

After the skid installation and piping to both gas supply and injection wells were completed, and before the injection PVC lines were buried, the entire injection system was tested for any potential leak. Leak check was done in two ways: After the skid enclosure was secured to the ground and the high pressure hoses were connected to the skid and the installed well-heads, using the helium gas the pressure in the injection system was increased to approximately 7 psig. While the valves at the well-head were shut off, the pressure in the piping from the skid to the injection wells (i.e., high pressure hoses) was increased one well at a time by opening the valve to each injection well on the skid.

Figure 26: Trenching, piping and wellhead installation for injection wells

Figure 27: Injection wellhead design

A spray bottle was filled with a few drops of hand soap and water and sprayed all the connections on the skid and the well-heads with the helium gas on. During the leak test we looked for any sign of bubbles - even a small amount of gas would cause these to form. In a few cases where the leak was identified, the connection was re-tightened or re-connected using Teflon tape. To do the leak test for the gas supply to the skid, the gas at the gas supply source was used. The same procedure was followed for each gas line (i.e., copper tubing). After the leak test using soapy water was successfully finished, the pressure in the injection lines to the well-heads were left at approximately 7 psig using the helium gas to do an overnight leak check (about 12 hours). The pressure in the lines after 12 hours was at about 5.5 psig, with the slight pressure drop attributable to the overnight temperature drop.

The subcontractor technician was trained on-site. During the on-site training the locations of the injection and monitoring wells, the skid, and the gas supply tanks/cylinders were showed to the subcontractor, the skid O&M manual provide by NES was reviewed, the weekly O&M check-list provided by GSI was reviewed, and all safety issues, GSI Health & Safety Plan (HASP), and MSDS sheets for all the injecting gases as well as Chemicals of Concern at the site were reviewed. The subcontractor helped GSI with performing weekly O&M during H_2T operation phase, and conducted some of the vapor monitoring at the monitoring points on behalf of GSI. A general GSI Health & Safety Plan (HASP) is shown in Appendix I.

5.4 FIELD TESTING

The field treatability study and demonstration consisted of four phases as described in Section 5.1 (**Figure 10**). The Gantt chart illustrated in **Table 11** summarizes the demonstration schedule for each phase conducted over the period of demonstration project. Detailed descriptions of each of the field testing phases are described below.

5.4.1 Tracer Test

After the leak test was successfully completed, the nitrogen/helium gas mixture at the injection well-head sampling ports and soil vapor from the 27 monitoring points were monitored for helium and oxygen using field instruments. The purpose of the tracer test was to verify injection

Table 11: Schedule of activities for H_2T demonstration project

Task	2010						2011												2012							
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Pre-Treatment Sampling																										
1. Soil vapor sampling from SVE wells	🟥	🟥																								
2. Draft Demonstration Plan submittal			🟥	🟥																						
3. Final Demonstration Plan submittal					🟥	🟥																				
4. Soil boring installation										🟥																
5. Soil and soil vapor sampling and analysis										🟥	🟥															
Startup H_2T System																										
6. Injection skid Design and construction							🟥	🟥	🟥	🟥																
7. Injection skid shipment and installation											🟥															
Operate H_2T Test, Process Monitoring																										
8. Soil vapor sampling												🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥							
Treatability Study																										
9. Microcosm tests															🟥	🟥	🟥	🟥	🟥	🟥						
Post-Treatment Sampling																										
10. Soil boring installation																			🟥							
11. Soil and soil vapor sampling and analysis																			🟥	🟥	🟥					
Data Analysis and Review																						🟥	🟥	🟥		
Draft technical and cost & performance reports																									🟥	🟥

and monitoring wells performances and to characterize gas transport in the vadose zone. The tracer test generated data that was used to demonstrate potential radius of influence (ROI) without biological uptake, as well as to identify the presence of preferential pathways. The tracer gas was a mixture of nitrogen (approximately 90%) and helium (approximately 10%) gases. During the tracer test monitoring events the helium concentration (or %) was verified at the well-head sampling ports using MGD-2002 meter. Flexible tubing was placed at the end of the MGD-2002 probe and connected to the sampling port of the well-head. The helium flow rate was adjusted if the helium percentage was different from the original helium percentage in the mixture.

Helium levels were monitored at both the injection and monitoring wells using a Dielectric MGD-2002 Helium & Hydrogen Detector. Oxygen levels were monitored at the monitoring points using a GEM2000 landfill gas monitor. Helium and oxygen levels were monitored at the monitoring points for a total of three events (Day 1, Day 4, and Day 7 of the tracer injection startup). The ROI for the tracer gas (i.e., helium) was estimated to be the distance from the injection well to the monitoring well where 50 percent of the injected helium concentration (i.e., approximately 9-10% helium in the gas mixture) was observed in the monitoring well (i.e., 4.5-5% helium in the mixture).

5.4.2 Gas Mixture Injection

The H_2T gas injection operation and process monitoring period was started after the tracer test. Over the 6-month test, a total of 830,000 standard cubic feet of gas was injected with the following average composition: 10% hydrogen, 79% nitrogen, 10% propane, and 1% carbon dioxide. The nitrogen and propane were added to help keep the system anaerobic from oxygen diffusing into the test zone. The carbon dioxide was added to ensure a carbon source for the dechlorinating bacteria. Weekly operation and maintenance (O&M) was performed during H_2T system operation phase. O&M activities included the following activities:

- Inspection of the gas mixture and injection skid (50 pressure and flow gauges were read and recorded/week)
    - a) record system pressures and flow rates,
    - b) adjust valves as needed to meet specifications provided by GSI,
    - c) record site/equipment conditions and note any problems
- Oversee tank re-fill and gas cylinder exchange (approximately once every two weeks)
    - a) verify number of cylinders exchanged,
    - b) verify tanks and cylinders pressure and gas flow,
- Provide GSI with a brief report on system performance via call or email.

Figure 28: Vapor monitoring equipment: GEM2000 Landfill Gas Monitor (left) and Dielectric MGD-2002 Helium & Hydrogen Detector (Right)

Tanks refill and cylinders replacements were performed by the gas vendor (Praxair). The injection system was designed so that it did not need to be shut down for tank refill and cylinder replacements. The on-site subcontractor (EA Engineering, Science, and Technology, Inc.) verified the number of cylinders replaced and tank refill, and recorded the cylinder pressure and gas flow. The gas replacement and refill work was done concurrent with weekly O&M task to the extent possible. The subcontractor used the weekly O&M checklist prepared by GSI to record the pressure and flow readings and describe any problems, leaks, unusual noises, vibrations, wear, or damage and described any corrective actions taken or planned. Summary of temperature, pressure, and flow readings as well as a sample filled weekly O&M checklist are shown in Appendix F. **Figure 28** shows the vapor monitoring equipment used by subcontractor throughout the H_2T system operation.

Based on the hydrogen concentrations at the monitoring points and the treatability test results, the total gas flow rate and hydrogen composition were doubled for the last month of the injection phase. The total gas flow rate was increased from 2.5 scfm to 5.0 scfm and hydrogen composition was increased from 10% to 20%. The major additional cost for the gas flowrate and hydrogen composition increase was the additional gas cost. Increasing the flow rate and hydrogen composition required more frequent travels to the site for both the gas vendor and the O&M subcontractor, but the associated costs were minimal compared to the gas cost.

Pros and cons of this option were discussed with the technical support team and the ESTCP office. This option did not change any of the original milestones and required no additional monitoring. Flow and hydrogen composition were increased for the last month of the injection phase to evaluate whether increasing the flow rate would lower the oxygen levels in medium and deep zones.

5.4.3 Process Monitoring

Monitoring of the influence of the gas mixture delivery and the system performance during the gas injection phase was achieved through the collection of soil vapor samples from the monitoring points. Sample analysis included concentrations of VOCs, H_2, O_2, and CO_2. The process monitoring period was approximately 9 months. Soil gas was measured every two months to determine progress and to evaluate if modifications to the sampling frequency or an extension of this monitoring period would provide valuable performance data. Also based on the evaluation of vapor sampling results, the gas injection rate and gas mixture composition were adjusted for the last month of the demonstration.

Process monitoring data was evaluated in terms of the stated project objectives. Specifically, the collection of spatial and temporal data provided a means of evaluating the rate of the injected gas mixture transport and distribution within the treatment zone, as well as its effect on the rate of dechlorination. Data validation for the process monitoring sample set was provided by the inclusion of adequate controls in the design of the demonstration. The scattered placement of the monitoring served to minimize the contribution of small-scale heterogeneities on the performance of the technology.

5.4.4 Post-Bioremediation Characterization

Post-treatment characterization phase started by collecting vapor samples. Nitrogen gas only was flushed for approximately two weeks. Soil sampling was conducted using the direct-push method. All of the soil cores were logged and four soil samples were collected from each borehole at 10, 20, 30, and 40 feet below ground surface (i.e., total of 64 samples) and sent to the lab for analysis. The location of each soil sampling point was approximately 1-2 feet from the location of the deep well for each injection or monitoring points (i.e., total of 12 locations). In addition, soil samples were collected from four additional locations (i.e., 16 additional soil samples) around SVE wells SVE-7 and SVE-8 inside and outside the treatment area. **Figure 39** shows the soil sampling locations.

The 16 additional samples were collected after it was noticed that some of the injected gas had entered SVE wells 7 and 8 (i.e., high H_2 concentrations at these two wells), and the soil samples were collected from "inside" and "outside" of the treatment zone around SVE wells to show (if any) the difference in the TCE mass reduction. These additional samples were not included in the H_2T performance analyses since they were only collected during the post-treatment characterization phase and do not have a pair sample from the pre-treatment characterization phase.

Similar to pre-treatment characterization phase, three of the Geoprobe borings (i.e., IW-3, MW-2, and MW-5) were selected to collect soil samples for further analyses of grain size distribution, soil pH, nutrients (i.e., NO3-N, P), and quantitative polymerase chain reaction (qPCR) testing (i.e., Gene-Trac Dhc and Gene-Trac VC). Soil samples from each of the selected three Geoprobe borings were collected at 15-foot intervals (i.e., 3 soil samples from each hole) at depths of approximately 10, 25, and 40 ft-bgs. Samples were placed in 4-oz plastic jars (9 samples for qPCR testing), 4-oz plastic jars (9 samples for grain size distribution analysis), and 8-oz plastic jars (9 samples for pH and Nutrient tests). Sample jars were sealed in zip-lock bags which were placed in an ice-chilled cooler prior to shipment to the lab.

The post-treatment characterization data was evaluated in terms of the stated project objectives. Specifically, the chlorinated solvent removal rate as well as the duration of the potential enhancement effect provided by the gas mixture was evaluated using this dataset. The latter was assessed through analyses CVOC concentrations as well as by the abundance and/or increase/decrease in Dehaloccoides species in the treatment zone. The effect on the extent of biodegradation was measured by calculating the percent reduction in mass achieved in the treatment zone, the reduction in source strength, and the relative percentage of intermediates (DCE, VC) and end products (ethene). Details on sampling and analysis procedures are presented in Section 5.5.

5.4.5 Demobilization

After the completion of the post-treatment characterization phase, gas mixture at a low flow rate was injected for approximately two months while the post-treatment characterization results were to be evaluated and a decision were to be made to extend the gas injection. Gas storage and delivery equipment was removed from the site upon completion of the demonstration. The injection kid, injection and monitoring points may be left in place upon request of ESTCP or site managers. The injection and monitoring points may be abandoned or ESTCP or site managers may take ownership and responsibility of the infrastructure. If the Site 10 project team decides to have some of the injection/monitoring points abandoned, then the abandonment methods will comply with State regulations (i.e., Title 122, Ch.35 Nebraska Department of Environmental Quality (NDEQ)).

5.4.6 Investigation-Derived Waste

Excess soil was collected during the well construction and confirmation boring drilling events. Based on historic generator knowledge (previous analytical data) the soils were not hazardous waste (>10,000 µg/kg). In the state of Nebraska, any soils that are below the Preliminary Remediation Goal (PRG) of 80 µg/kg of TCE may be disposed directly on the surface. Composite soil samples were collected and sent to lab to determine if the soil concentrations are above or below the 80 µg/kg. While soils were pending analysis, they were containerized in drums to prevent rainwater or dispersal. Since the soils were not hazardous waste (>10,000 up/kg), the bungs on the very dark DOT drums was cracked and in essence allowed to vent without allowing infiltration of rainwater. Since the TCE concentrations were below 80 µg/kg in all composite soil samples, the soils were emptied on site on the ground.

5.5 SAMPLING PLAN

This section summarizes the methods for soil and soil gas sampling and analysis.

5.5.1 Soil Sampling and Analysis

Soil samples were collected during monitoring point installation and confirmation boring drilling events. Soil samples collected during monitoring point installation were representative of baseline conditions before gas injection. Confirmation borings were conducted during Phase 4 and were located as close to the initial deep borings as practical. The Phase 4 confirmation borings were used to assess TCE removal kinetics and overall TCE removal. The number of samples collected and the analytical methods are provided in **Table 12** and **Table 13**.

As described in Section 5.2, each deep borehole was continuously cored from ground surface to total depth. The cores were logged by a GSI geologist in accordance with ASTM D 2488 standard. Core samples were screened in the field for volatile organic compounds (VOCs) by placing a portion of the sample into a zip-lock bag, waiting approximately 10 minutes, placing the tip of a photoionization detector (PID) into the bag, and then taking a measurement. Soil samples were collected at 10-foot intervals starting from the depth of 10 ft-bgs and placed in glass and plastic jars and shipped to different labs for analysis. The samples for VOC analysis were sealed in zip-locks bags which were placed in an ice-chilled cooler prior to shipment to the lab.

Table 12: Analytical methods used for sample analysis

Matrix	Analyte	Method	Container	Preservative[1]	Holding Time
Soil	VOC[2]	SW8260	4-oz glass jar	None	14 days
	Moisture content	SW3550	4-oz glass jar	None	28 days
	DHC	In-house[3]	4-oz plastic jar	None	28 days
	Nutrients, pH, Organic carbon	In-house[4]	8-oz plastic jar	None	28 days
	Particle size	ASTM[5]	4-oz plastic jar	None	28 days
Soil gas	VOC[2]	In-house[6]	22-ml vial	None	72 hours
	VOCs screening	PID	NA	NA	NA
	Relative humidity	Field	NA	NA	NA
	Temperature	Field	NA	NA	NA
	Hydrogen	Field	NA	NA	NA
	Oxygen	Field	NA	NA	NA
	Carbon Dioxide	Field	NA	NA	NA
	Helium	Field	NA	NA	NA

[1] Preservatives were not required for these samples; however, all samples were stored and shipped at 4°C.
[2] Soil and vapor samples were tested for TCE, cis-1,2-DCE, trans-1,2-DCE, Vinyl Chloride, 1,1,1-TCA, ethane, ethane, propane, and methane.
[3] Gene-Trac-Dhc and Gene-Trac VC DNA tests were conducted using an in-house method at SiREM laboratory.
[4] Nutrient, pH and organic carbon measurements were conducted using standard methods at Olsen laboratory.
[5] Particle size distribution analysis was conducted using ASTM D422/D4464M methodology.
[6] Soil vapor samples were collected using syringes in 22-ml vials and analyzed using in-house method at Vaportech Services, Inc. laboratory.

Gene-Trac-Dhc and Gene-Trac VC DNA tests were conducted using an in-house method at SiREM laboratory. Nutrient, pH and organic carbon measurements were conducted using standard methods at Olsen laboratory. Particle size distribution analysis was conducted using ASTM D422/D4464M methodology.

Table 13: Total number and types of samples collected

Component	Matrix	Number of Samples	Analyte	Location
Pre-demonstration sampling	Soil	48	VOC[2]	Deep borings at 10, 20, 30, and 40 ft-bgs
	Soil	9	Physical/chemical parameters[1]	Three locations and three points at 10, 25, and 40 ft-bgs
	Soil	9	Nutrients, pH, Organic carbon	Three locations and three points at 10, 25, and 40 ft-bgs
	Soil	9	DHC	Three locations and three points at 10, 25, and 40 ft-bgs
	Soil gas: Field measurement	Bi-monthly	H_2, O_2, CO_2, He, VOC[3]	All subsurface monitoring points
	Soil gas: Laboratory measurement	32	VOC[2], field blanks and duplicates	All subsurface monitoring points
Technology performance sampling	Soil gas: Field measurement	Bi-monthly	H_2, O_2, CO_2, VOC[3]	All subsurface monitoring points
	Soil gas: Laboratory measurement	96 (32 samples every 2 months)	VOC[2], field blanks and duplicates	Same subsurface monitoring wells selected for initial sampling
	Surface emissions	Bi-monthly	H_2, CO_2, VOC[3]	Ground surface and in the flush mounts at injection points
Post-demonstration sampling	Soil	48 (plus 16 samples from around SVE wells)	VOC[2]	Locations near Deep borings at 10, 20, 30, and 40 ft-bgs
	Soil	9	Physical/chemical parameters[1]	Same as pre-demonstration sampling.
	Soil	9	Nutrients, pH, Organic carbon	Three locations and three points at 10, 25, and 40 ft-bgs
	Soil	9	DHC	Same as pre-demonstration sampling.
	Soil gas: Field measurement	Bi-monthly	VOC[3]	Same subsurface monitoring points selected for initial sampling
	Soil gas: Laboratory measurement	32	VOC[2], field blanks and duplicates	All subsurface monitoring points

[1] Physical and chemical parameters measured included USCS soil classification, moisture content, particle size, moisture content, and pH.

[2] Soil and vapor samples were tested for TCE, cis-1,2-DCE, trans-1,2-DCE, Vinyl Chloride, 1,1,1-TCA, ethane, ethane, propane, and methane.

[3] Soil gas and surface emission were screened for VOCs in the field using PID and LEL meter.

5.5.2 Soil Gas Sampling and Analysis

Samples of gas from the monitoring points and the gas injection manifold were collected and analyzed for hydrogen, oxygen, carbon dioxide, relative humidity, and temperature using field instruments (**Table 12** and **Table 13**). Soil gas from the 27 monitoring points was monitored for hydrogen, oxygen, carbon dioxide, methane, and LEL using field instruments. Hydrogen was monitored using Dielectric MGD-2002 Helium & Hydrogen Detector and the rest of the gases were monitored using GEM2000 landfill gas monitor. Barometric pressure and atmospheric (above-ground) concentrations of flammable gases were monitored with GEM2000 landfill gas monitor.

Samples of gas from the monitoring points were collected in three 22-ml glass vials per sampling point using sampling kit (vials and syringes) provided by Vaportech. Total of 27 vapor samples from the monitoring points, 3 vapor sample duplicates (i.e., MW-1S, MW-5M and MW-9D), and two field blanks (ambient air from upwind and downwind) were collected. The soil vapor samples, duplicates, and blanks were shipped to Vaportech lab to be analyzed for concentrations of contaminants and daughter products. Soil vapor samples were tested for TCE, cis-1,2-DCE, trans-1,2-DCE, Vinyl Chloride, and 1,1,1-TCA, as well as ethane, ethane, propane . Samples were also tested for methane to verify the readings from field instruments. Preservatives were not required for these samples; however, all samples were stored and shipped at 4ºC.

In addition to measuring gas concentrations at the monitoring points, gas injection composition, flow rates, and pressures were monitored using the same instruments plus rotameters and pressure gauges. The rotameters in the gas mixing section of the skid were calibrated for each specific gas at 70ºF and 15 psig. The rotameters in the gas injection section of the skid (i.e., after gases were mixed) were calibrated for air at 55ºF and atmospheric pressure (0 psig). Rotameter readings are affected by gas pressure and density and thus the readings will be corrected for gas density and pressure. The flow rate readings were corrected for temperature and pressure based on the weekly O&M measurements.

5.5.3 Quality Assurance Procedures

The integrity of the data generated by this investigation was maintained by adherence to a Quality Assurance Project Plan (QAPP) prepared for this investigation. The QAPP identified the requirements necessary to obtain high quality data and included requirements for QA/QC sampling, detection limits, methods, and field and laboratory performance. In addition to the information provided in the QAPP, the following quality assurance procedures were followed. The QAPP is provided as Appendix H.

- *Calibration of Analytical Equipment.* The majority of project data was generated by fixed analytical laboratories with acceptable quality control programs to assure proper operation of analytical equipment. Measurement of soil gas properties (i.e., temperature, LEL, hydrogen, oxygen and CO_2 levels) were performed using a handheld meter that was properly calibrated before use. The pressure gauges and rotameters were used to measure the pressure and gas flow rates at the injection and monitoring points. Photoionization detector (PID) was used to evaluate VOC levels in the soil and soil vapor sample points and was calibrated per the manufacturer's instructions prior to use.

- *Quality Assurance Sampling.* General quality assurance guidelines of a minimum of one duplicate sample per ten samples collected was followed for all soil and soil gas samples. If less than 10 samples are collected then at least one duplicate sample was collected from each matrix. A field blank sample was collected to demonstrate appropriate sampling techniques for soil vapor, and trip blanks accompanied all soil vapor samples submitted for laboratory analysis.
- *Decontamination Procedures.* During the well installation process, all down-hole boring equipment was decontaminated using water and a suitable detergent to avoid transferring contaminants between borings. All sampling equipment was single-use, disposable material (tubing, sample containers). Re-used vapor sample point materials (compression fittings, sample tubing) were flushed/purged before samples are collected.
- *Sample Documentation.* Field documentation was facilitated by pre-printed tables, labels, and logs that allowed precise notation of sample collection and field conditions. Samples were identified using pre-determined sample IDs that were consistent with date and location of the samples and conducive to assembly of data into databases. Sample labels were prepared prior to the field investigation to minimize errors and keep sample collection orderly. Data collected during the sampling events was recorded on pre-printed data sheets developed specifically for this application. All samples submitted for laboratory analysis were submitted under chain-of-custody control and all laboratory reports included a narrative that discussed any quality control excursions. Photographic documentation of the project activities was collected throughout the project for inclusion in the final report.

5.6 SAMPLING RESULTS

The results of the tracer test, vapor sampling and monitoring, and the soil sampling during the post-remediation characterization are summarized in this section.

5.6.1 Tracer Test

Results of the tracer test monitoring are summarized in **Figure 29** and Appendix L. Helium gas had reached the 10-ft distance monitoring wells (MW-5S, M, and D) after approximately 16 hours. Traces of helium gas were observed at some of the shallow wells within 10-20 feet from the injection wells (e.g., MW-1S, MW-3S, and MW-4S). Also, a trace of helium gas was observed at MW-6M and MW-6D that can potentially be explained by the layers of fine to medium size sand observed during the logging of MW-6 in lower depths. Tracer gas reached the 15-ft distance monitoring wells (MW-3, and MW-6) at Day 4. After 4 and 7 days helium was observed at almost all the monitoring wells, however the levels of helium percentage were not high enough (i.e., 50% of injection helium concentration) to increase the ROI above approximately 15 feet.

The tracer test also generated data that demonstrate the presence of preferential pathways. For example, helium concentrations at MW-8 were higher than helium concentrations at MW-7 for both Day 4 and Day 7 of the test. Also, helium concentrations at MW-9, which is approximately 30 feet away from the closest injection well, were higher than most of the monitoring wells that

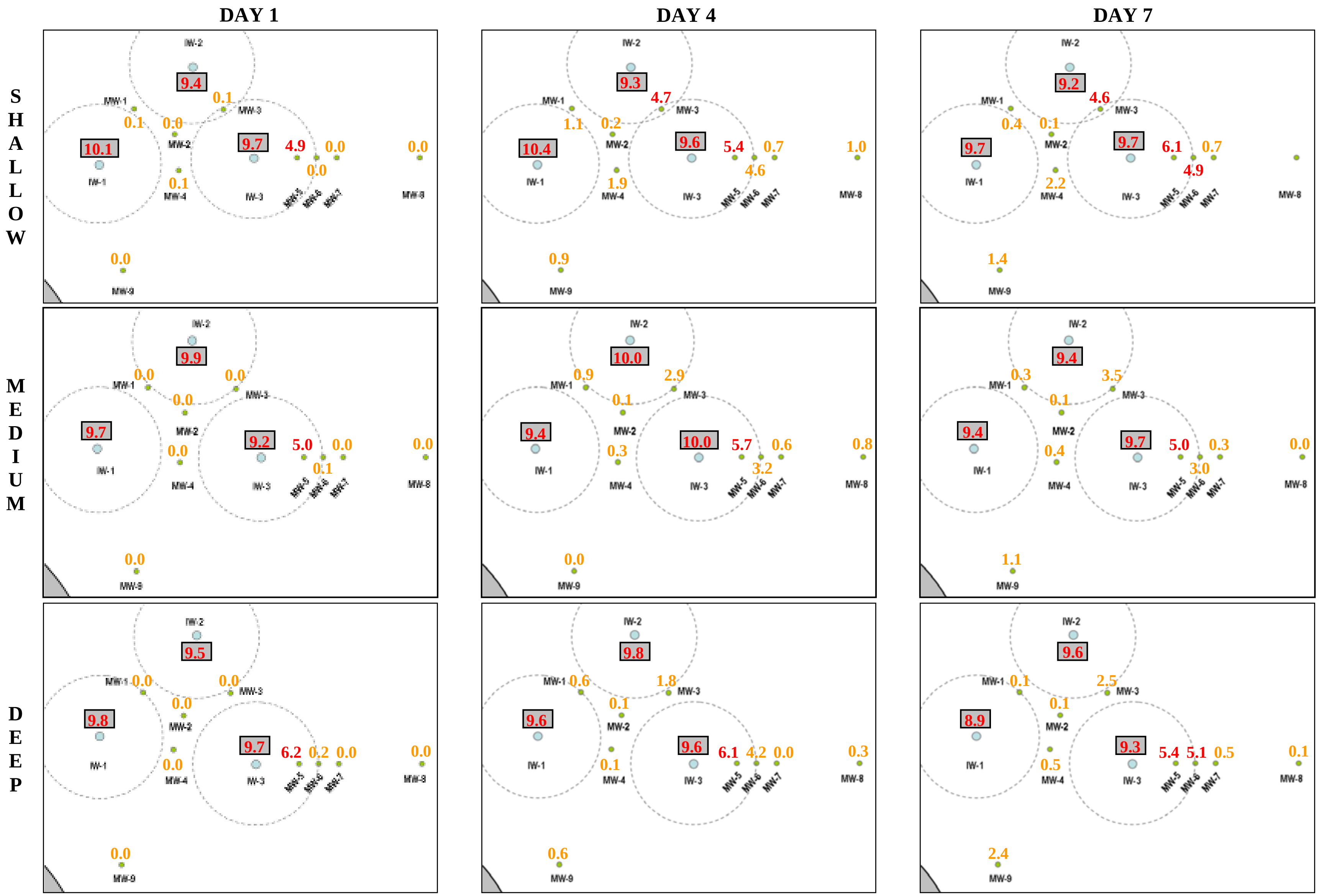


Figure 29: Helium tracer test results - Numbers are % helium in the gas sample. Numbers in the boxes are % helium in the injected gas. Dashed circles are the target ROI of 15 feet.

are in the 15-20 feet distance from the injection wells (for example, compare helium percentages at MW-9 wells with MW-1, MW-2, and MW-7). After 4 days of tracer injection the helium concentrations at MW-3S reached 4.7%, while maximum helium concentrations in the monitoring points MW-3M and MW-3D were 3.5% and 2.5%, respectively.

5.6.2 Weekly O&M

The subcontractor used the weekly O&M checklist prepared by GSI to record the pressure and flow readings and describe any problems, leaks, unusual noises, vibrations, wear, or damage and described any corrective actions taken or planned. The filled weekly O&M checklists are provided in Appendix F.

Corrected injected gas flowrate over time for each injection points is shown in **Figure 30**. As shown in the figure, for IW-1 and IW-2 the flowrates at the deep injection points are approximately 2-3 times lower than the shallow and medium points. The lower flowrates in IW-1D and IW-2D injection points and higher flowrates at IW-3D were consistent with the lithology observations during soil logging and the pressure readings.

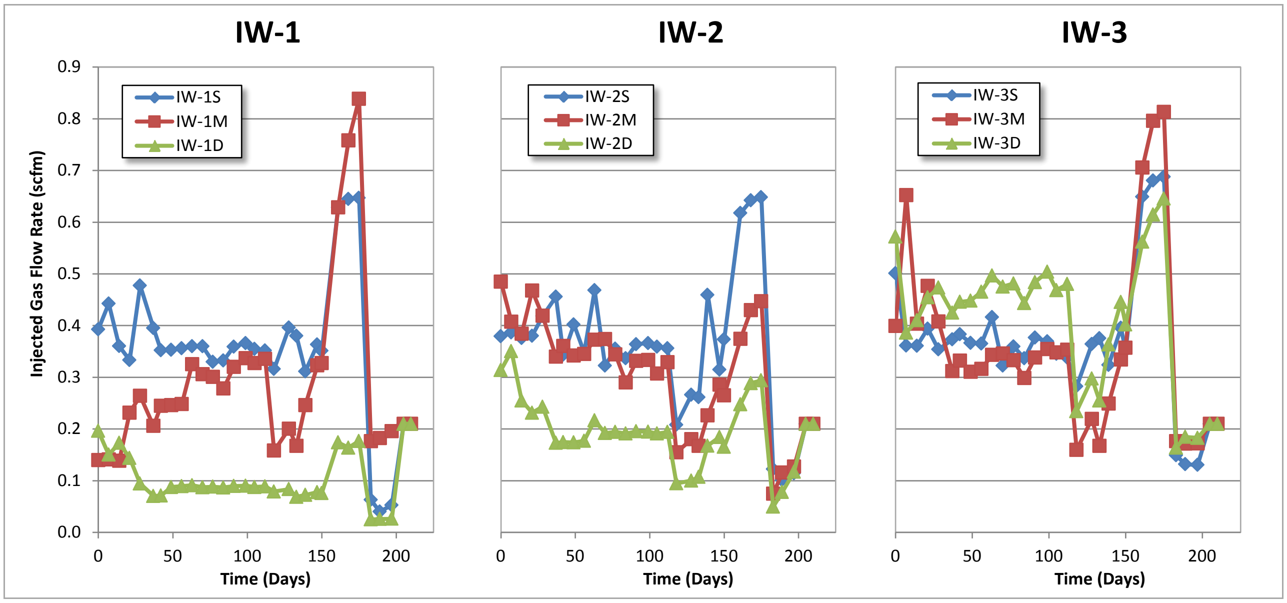


Figure 30: Corrected injected gas flowrates at three injection wells at different depths

Table 14 summarizes the gas mixing (i.e., N_2, H_2, LPG, and CO_2) and injection (i.e., 9 injection wells) flow readings after corrections for temperature and pressure during the 31-weeks system operation.

Because of inconclusive sampling results during the test, the total gas flow rate and hydrogen composition were doubled for the last month of the injection phase and the total gas flow rate was increased from 2.5 scfm to 5.0 scfm and hydrogen composition was increased from 10% to 20%. An increase in hydrogen and propane concentrations and decrease in oxygen concentrations were observed at the monitoring points after increase in the flow rate and hydrogen composition.

Table 14: Flow readings during the weekly O&M corrected for temperature and pressure

Week #	Date	Temp (F)	Gas Mixing Section				Gas Injection Section								
			N_2	LPG	H_2	CO_2	IW-1S	IW-1M	IW-1D	IW-2S	IW-2M	IW-2D	IW-3S	IW-3M	IW-3D
1	14-Jun-11	65-75	2.10	0.26	0.26	0.03	0.39	0.14	0.20	0.38	0.48	0.31	0.50	0.40	0.57
2	21-Jun-11	66	1.91	0.21	0.24	0.02	0.44	0.14	0.15	0.39	0.41	0.35	0.36	0.65	0.39
3	28-Jun-11	75	1.82	0.19	0.21	0.02	0.36	0.14	0.17	0.38	0.38	0.25	0.36	0.40	0.41
4	5-Jul-11	80	2.04	0.24	0.22	0.02	0.33	0.23	0.14	0.38	0.47	0.23	0.39	0.48	0.45
5	12-Jul-11	73	1.98	0.25	0.24	0.03	0.48	0.26	0.09	0.42	0.42	0.24	0.35	0.41	0.47
6	21-Jul-11	86-95	1.75	0.22	0.22	0.02	0.40	0.21	0.07	0.46	0.34	0.17	0.37	0.31	0.42
7	26-Jul-11	93-98	1.76	0.22	0.22	0.02	0.35	0.24	0.07	0.34	0.36	0.17	0.38	0.33	0.45
8	2-Aug-11	83-92	1.76	0.22	0.22	0.02	0.35	0.25	0.09	0.40	0.34	0.17	0.37	0.31	0.45
9	9-Aug-11	81-84	1.79	0.22	0.22	0.02	0.36	0.25	0.09	0.35	0.34	0.18	0.37	0.32	0.47
10	16-Aug-11	77	2.01	0.22	0.23	0.02	0.36	0.33	0.09	0.47	0.37	0.22	0.42	0.34	0.50
11	23-Aug-11	96	1.75	0.22	0.22	0.02	0.36	0.31	0.09	0.32	0.37	0.19	0.32	0.35	0.48
12	30-Aug-11	84	1.77	0.22	0.22	0.02	0.33	0.30	0.09	0.36	0.34	0.19	0.36	0.33	0.48
13	6-Sep-11	73	1.58	0.22	0.22	0.02	0.33	0.28	0.09	0.34	0.29	0.19	0.34	0.30	0.44
14	13-Sep-11	71	1.79	0.22	0.22	0.02	0.36	0.32	0.09	0.36	0.33	0.20	0.38	0.34	0.48
15	21-Sep-11	68	1.80	0.23	0.23	0.02	0.37	0.34	0.09	0.37	0.33	0.19	0.37	0.35	0.50
16	27-Sep-11	78	1.80	0.23	0.23	0.02	0.35	0.33	0.09	0.36	0.31	0.19	0.35	0.35	0.47
17	4-Oct-11	70	1.73	0.22	0.22	0.02	0.35	0.34	0.09	0.36	0.33	0.19	0.34	0.35	0.48
18	10-Oct-11	71	1.79	0.22	0.22	0.02	0.32	0.16	0.08	0.21	0.15	0.09	0.28	0.16	0.23
19	20-Oct-11	58	1.81	0.23	0.23	0.02	0.40	0.20	0.08	0.27	0.18	0.10	0.36	0.22	0.30
20	25-Oct-11	61	1.01	0.10	0.10	0.02	0.38	0.17	0.07	0.26	0.17	0.11	0.38	0.17	0.25
21	31-Oct-11	59	1.31	0.19	0.18	0.02	0.31	0.25	0.07	0.46	0.23	0.17	0.32	0.25	0.36
22	8-Nov-11	46	1.55	0.19	0.19	0.02	0.36	0.32	0.08	0.31	0.29	0.18	0.40	0.33	0.45
23	11-Nov-11	51	1.52	0.20	0.20	0.02	0.35	0.33	0.08	0.37	0.26	0.17	0.35	0.36	0.40
24	22-Nov-11	54	2.76	0.39	0.00	0.04	0.63	0.63	0.17	0.62	0.37	0.25	0.65	0.71	0.56
25	29-Nov-11	47	2.86	0.40	0.41	0.04	0.64	0.76	0.16	0.64	0.43	0.29	0.68	0.80	0.61
26	6-Dec-11	10	3.08	0.31	0.44	0.04	0.65	0.84	0.18	0.65	0.45	0.29	0.69	0.81	0.65
27	14-Dec-11	39	0.63	0.06	0.06	0.01	0.06	0.18	0.03	0.12	0.07	0.05	0.15	0.18	0.16
28	20-Dec-11	30	0.66	0.07	0.07	0.01	0.04	0.18	0.03	0.10	0.12	0.08	0.13	0.17	0.18
29	28-Dec-11	42	0.66	0.07	0.07	0.01	0.05	0.20	0.03	0.11	0.13	0.12	0.13	0.17	0.18
30	5-Jan-12	61	1.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	10-Jan-12	54	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 15: Total injected gas flowrate and cumulative volume

Week #	Date	Temp (F)	Total Flowrate (scfm)	Cumulative Injected Gas Volume (ft^3)			
				Shallow	**Medium**	**Deep**	**Total**
1	14-Jun-11	65 - 75	3.38	0	0	0	0
2	21-Jun-11	66	3.28	12,419	11,210	9,926	33,555
3	28-Jun-11	75	2.86	23,950	21,926	18,622	64,498
4	5-Jul-11	80	3.11	35,061	32,518	27,029	94,608
5	12-Jul-11	73	3.15	46,941	43,940	35,297	126,178
6	21-Jul-11	86 - 95	2.75	62,971	56,561	44,882	164,414
7	26-Jul-11	93 - 98	2.71	71,262	63,019	49,779	184,060
8	2-Aug-11	83 - 92	2.73	82,351	72,266	56,845	211,462
9	9-Aug-11	81 - 84	2.71	93,391	81,373	64,115	238,879
10	16-Aug-11	77	3.09	105,053	91,203	71,862	268,118
11	23-Aug-11	96	2.79	116,394	101,618	79,722	297,734
12	30-Aug-11	84	2.79	126,727	111,709	87,377	325,813
13	6-Sep-11	73	2.59	137,061	121,001	94,866	352,928
14	13-Sep-11	71	2.86	147,675	130,355	102,380	380,410
15	21-Sep-11	68	2.92	160,355	141,954	111,357	413,667
16	27-Sep-11	78	2.79	169,690	150,622	117,996	438,308
17	4-Oct-11	70	2.83	180,300	160,699	125,612	466,610
18	10-Oct-11	71	1.69	188,300	167,134	130,674	486,109
19	20-Oct-11	58	2.11	201,495	174,855	137,081	513,431
20	25-Oct-11	61	1.95	208,853	178,818	140,365	528,036
21	31-Oct-11	59	2.42	217,977	184,099	144,833	546,910
22	8-Nov-11	46	2.72	230,470	193,684	152,385	576,540
23	11-Nov-11	51	2.67	235,114	197,770	155,305	588,189
24	22-Nov-11	54	4.59	258,641	218,813	168,193	645,647
25	29-Nov-11	47	5.02	278,106	237,416	178,529	694,051
26	6-Dec-11	10	5.20	298,014	257,988	189,533	745,534
27	14-Dec-11	39	1.00	311,362	272,537	197,337	781,237
28	20-Dec-11	30	1.03	313,989	276,411	199,616	790,015
29	28-Dec-11	42	1.12	317,278	281,963	203,161	802,401
30	5-Jan-12	61	1.89	322,621	288,441	208,671	819,734
31	10-Jan-12	54	1.89	**327,157**	**292,977**	**213,207**	**833,342**

Table 15 summarizes the cumulative injected gas volumes at each depth (i.e., shallow, medium, and deep), and total injected gas flowrate and cumulative volume. The pore volume (PV) of the treatment zone as well as the total number of pore volumes injected at each treatment depth (i.e., shallow, medium, and deep) and the total treatment zone are summarized in **Table 16**. The total number of 44 PV was injected in the treatments zone during the 6-month gas injection phase. If the numbers of pore volumes are calculated separately for each depth, total gas injected was 51, 46, and 34 PVs, in shallow, medium, and deep intervals, respectively. This is consistent with the flow and pressure readings as well as soil logging observations, which showed the decrease in gas permeability of the soil by depth.

The pore volume calculations assume that the injected gas swept a treatment area of approximately 2,200 ft^2 from 15 ft-bgs to 45 ft-bgs (i.e., 15-25 ft-bgs for shallow, 25-35 ft-bgs for medium, and 35-45 ft-bgs for deep injection points). It should be noted that the pore volume calculations are very approximate and are based on the assumptions that all the injected gas in each depth interval had stayed in that depth interval and swept the entire treatment area uniformly.

Table 16: Number of pore volume of gas injected in each depth interval

Parameter	Units	Value			
		Shallow	**Medium**	**Deep**	**Total**
Radius of influence (ROI)	ft	15	15	15	15
Depth interval	ft	15 - 25	25 - 35	35 - 45	15 - 45
Porosity	-	0.3	0.3	0.3	0.3
Estimated pore volume	ft^3	6,362	6,362	6,362	19,085
Number of injected pore volumes	-	51	46	34	44

The cumulative injected gas volumes at different depths and the total cumulative injected gas is shown in **Figure 31**. The increased flowrate and hydrogen composition are shown in **Table 14** and **Table 15** as well as **Figure 30** and **Figure 31**.

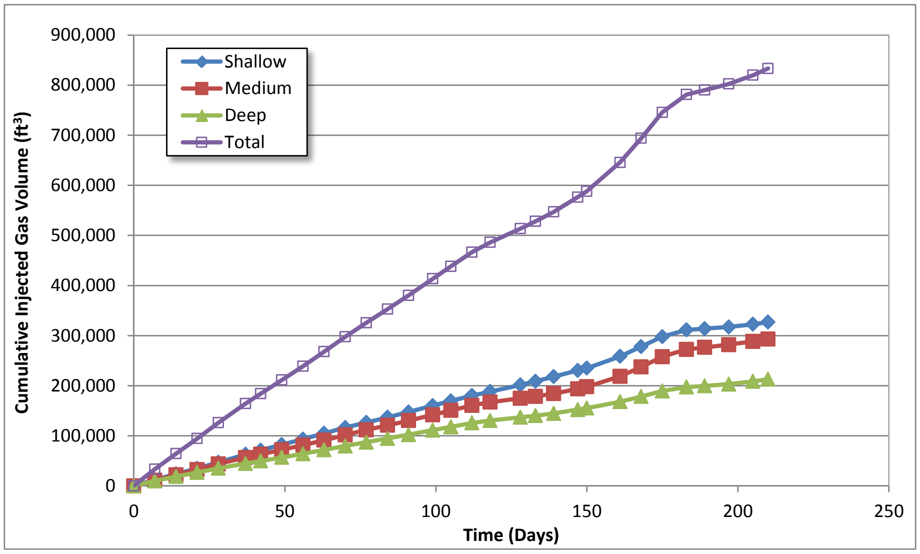


Figure 31: Cumulative injected gas volume at different depths

5.6.3 Vapor Sampling and Monitoring

Analytical results of the soil vapor sampling are summarized in Appendix L. TCE concentrations ranged from <0.005 ppmv to 180.9 ppmv in May 2011, and from 0.005 ppmv to 78.5 ppmv in December 2011. The maximum TCE concentration in the vapor phase decreased by 57%. The median TCE concentration decreased by 78% from 4.47 ppmv to 1.00 ppmv. cis-1,2-DCE concentrations ranged from <0.01 ppmv to 157.9 ppmv in May 2011, and from <0.01 ppmv to 60.8 ppmv in December 2011. The maximum cis-TCE concentration in the vapor phase decreased by 62%. The median cis-TCE concentration decreased by 63% from 14.3 ppmv to 5.22 ppmv.

Figure 32 shows the oxygen concentrations at different depths (i.e., shallow, medium, and deep) measured before and after the gas injection period. The data presented in these figures include data from all monitoring points. Before the gas mixture injection, measured oxygen concentrations ranged from 13.6% to 19.3% in the shallow monitoring points, from 13.2% to 19.4% in the medium monitoring points, and from 5.9% to 19.5% in the deep monitoring points. After gas mixture injection, measured oxygen concentrations ranged from 0.1% to 1.1% in the shallow monitoring points, from 0.1% to 10.7% in the medium monitoring points, and from 0.0% to 10.1% in the deep monitoring points.

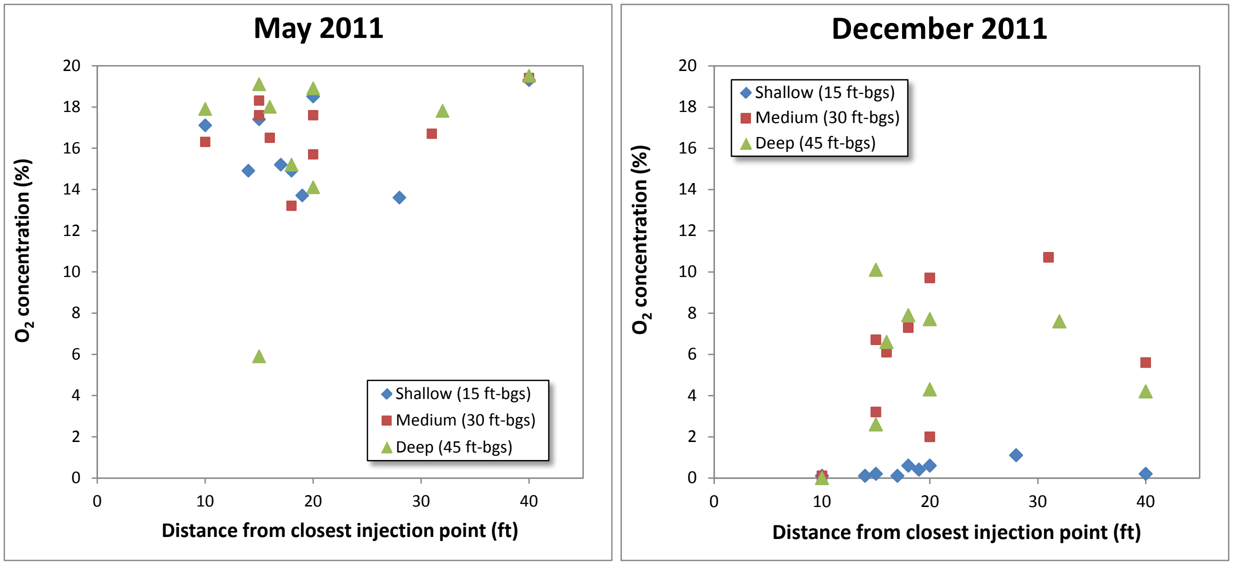


Figure 32: Oxygen concentrations at different depths versus the distance from the closest injection point **before** (left) and **after** (right) gas injection

For the medium and deep monitoring points, oxygen concentrations increased significantly at around 15 feet distance from the point of injection. While deeply anaerobic conditions never reached at the medium and deep monitoring points, significant reduction in oxygen concentrations was attainable at the medium and deep monitoring intervals. Average oxygen concentrations were reduced from 16.1% to 0.4% in shallow, 16.8% to 5.7% in medium, and 16.3% to 5.7% in deep monitoring points. The low oxygen concentrations in the shallow monitoring points were observed at distances up to 40 feet away from the point of injection. However, oxygen concentrations were high at medium and deep monitoring points outside of the 15-ft target ROI.

No significant change in the range and median ethane concentration. No significant change in the range and median trans-1,2-DCE concentration. No vinyl chloride was observed in any of the monitoring points throughout the demonstration. Dramatic change in ethane concentrations was observed. However, ethane concentrations were spatially correlated with propane concentrations. Therefore, the increased concentrations of ethane were due to the ethane that exists as impurity in the LPG. The dramatic increase in the ethane concentrations in the vapor phase occurred right after the start of the gas mixture injection and was observed since the first vapor sampling event in June 2011.

Figure 33 shows the hydrogen concentrations at different depths (i.e., shallow, medium, and deep) measured during and after the gas injection period. Hydrogen concentrations before the gas injection were below the H_2 meter detection limit (i.e., 25 ppmv) at all monitoring points.

Hydrogen concentrations never reached the injected concentration of 10%. The highest hydrogen concentrations were observed at the shallow depths (i.e., 15 ft-bgs). Hydrogen concentrations decreased as the depth increased and as the distance from injection increased. Hydrogen was detectable at all depths and distances as far as 40 feet from the injection point exceeding the 15-feet target ROI.

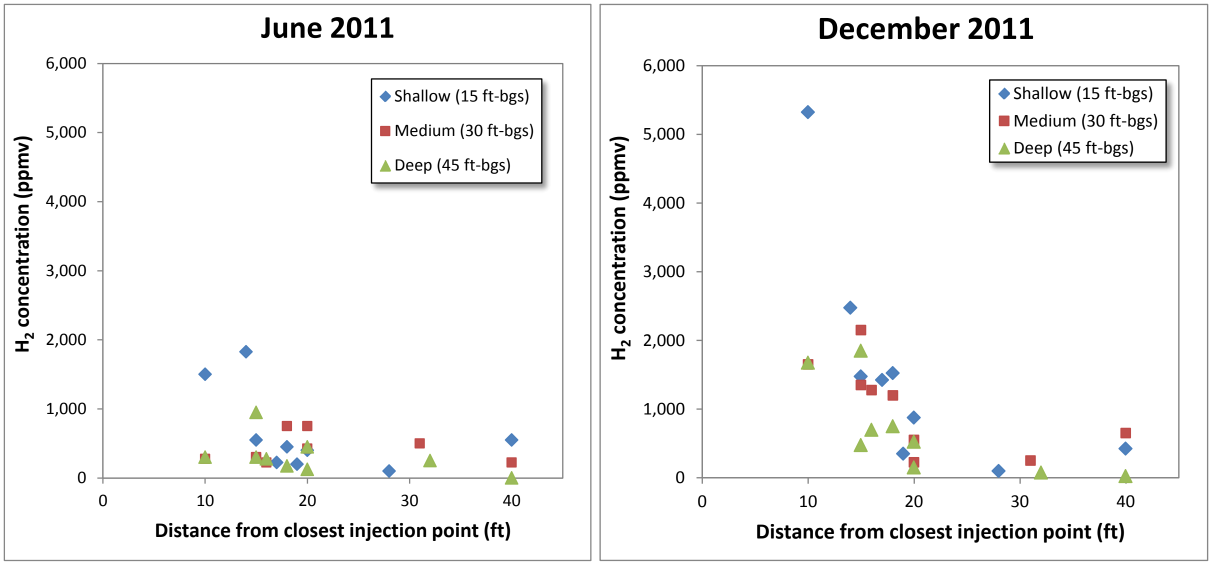


Figure 33: Hydrogen concentrations at different depths versus the distance from the closest injection point at first sampling event (left) and after (right) gas injection. Hydrogen concentration at the injection points was approximately 100,000 ppmv.

At the beginning of the gas mixture injection (i.e., June 2011), hydrogen concentrations ranged from 100 ppmv to 1,825 ppmv at shallow monitoring points (i.e., 15 ft-bgs), from 225 ppmv to 775 ppmv at medium monitoring points (i.e., 30 ft-bgs), and from <25 ppmv to 950 ppmv at deep monitoring points (i.e., 45 ft-bgs). At the end of the gas mixture injection (i.e., December 2011), hydrogen concentrations ranged from 100 ppmv to 5,325 ppmv at shallow monitoring points (i.e., 15 ft-bgs), from 225 ppmv to 2,150 ppmv at medium monitoring points (i.e., 30 ft-bgs), and from 25 ppmv to 1,850 ppmv at deep monitoring points (i.e., 45 ft-bgs). The hydrogen concentrations at almost all monitoring points increased over time. The non-uniform horizontal and vertical distribution of hydrogen concentrations is likely due to lithologic heterogeneities that were also observed during the tracer test and in the soil boring logs. A few of the vapor samples sent to the lab were also analyzed for hydrogen and the hydrogen concentrations from the lab were consistent with the field measurements.

Figure 34 shows the propane concentrations at different depths (i.e., shallow, medium, and deep) measured during and after the gas injection period. Propane was more easily distributed than hydrogen both with respect to distance from injection and depth. Note that the vertical axes for Figure 34 are different. The detected propane concentration before gas injection (i.e., May 2011) ranged from <0.02 ppmv to 4.5 ppmv. Measured propane concentrations after gas injection (i.e., December 2011) ranged from 11.5 ppmv to 85,030 ppmv. Propane was easily distributed at significant distances from the point of injection at the 20, 30, and 40-ft bgs depths. Horizontal and vertical distribution of propane was not consistent with the oxygen and hydrogen distributions. It should be noted that the propane concentrations are from laboratory analysis of vapor samples while the oxygen and hydrogen concentrations are from field measurements.

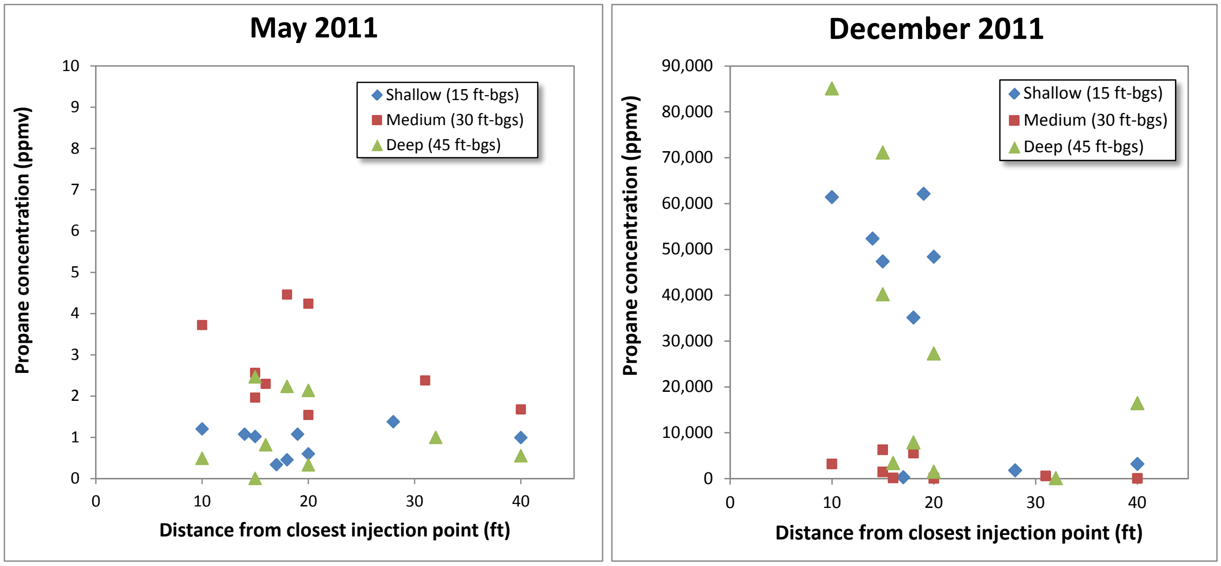


Figure 34: Propane concentrations at different depths versus the distance from the closest injection point, before (left) and after (right) gas injection. Propane concentration at the injection points was approximately 100,000 ppmv.

The vapor sampling and monitoring results indicated that continuous injection of the gas mixture resulted in oxygen depletion and electron donor distribution within the 15-ft target ROI especially at the shallow depths. While hydrogen was detected at all depths and reached as far as 40 feet from the injection point, the concentrations were pretty low and ranged from 0.01% to 0.6% by volume (i.e., 1,000,000 ppmv = 100%). Oxygen depletion and electron donor distribution outside of the 15-ft target ROI was observed; however, the results were variable. Heterogeneities in the soil lithologic conditions resulted in a non-uniform horizontal and vertical distribution of the all gases throughout the treatment zone. For example, greater oxygen depletion and electron donor distribution were observed in monitoring points of MW-9 that are located approximately 30 feet from the closest injection point, while some of the closer monitoring points to the injection points (e.g., MW-2) did not experience similar oxygen depletion and electron donor distribution. While propane was readily distributed at all depths, hydrogen was preferentially distributed at shallower depths. This could be explained by the density of hydrogen and propane causing the propane to sink and the hydrogen gas to rise after injection.

Methane concentrations ranged from 4.5 ppmv to 3,731 ppmv in May 2011 and from 13.0 ppmv to 12,330 ppmv in December 2011. Between these two monitoring events, the maximum methane concentration in the vapor phase increased by 230%., and the median methane concentration increased by 30% from 248.5 ppmv to 319.3 ppmv. Increases in methane were generally observed in the Shallow and Medium monitoring points, which correlates with the vertical distribution of hydrogen gas. **Figure 35** shows the correlation between hydrogen concentrations and methane concentrations at the monitoring point based on a linear regression analysis. The correlation coefficient between the hydrogen and methane concentrations was 0.6

in October 2011 (i.e., second sampling event) and 0.54 in December 2011 (i.e., third sampling event).

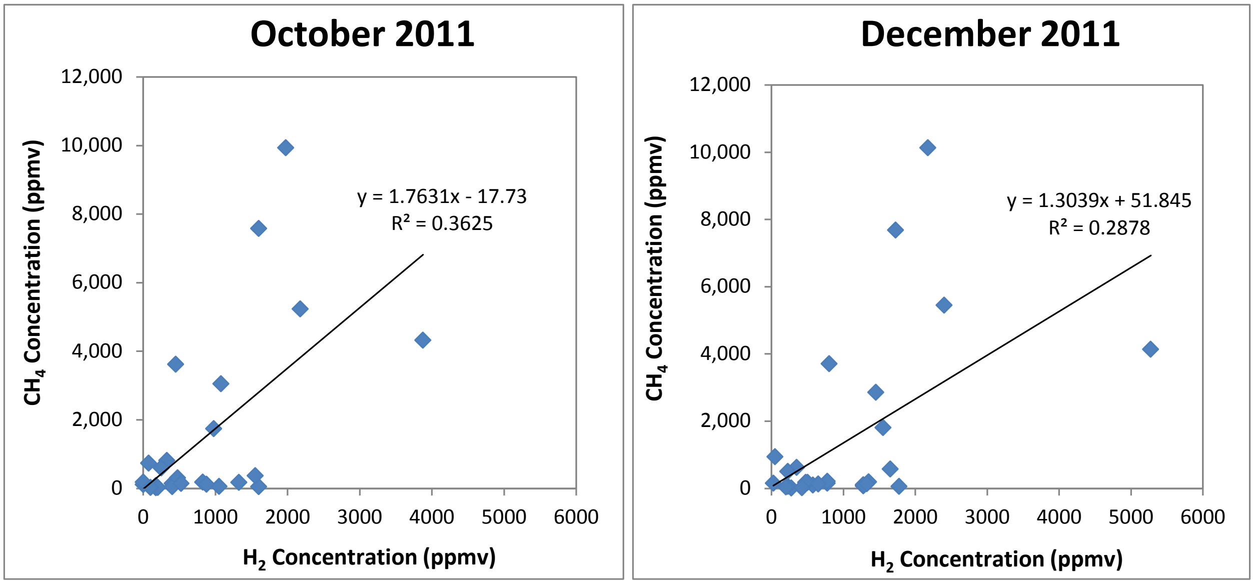


Figure 35: Correlation between hydrogen and methane vapor phase concentrations

Figure 36 shows the correlation between hydrogen concentrations and propane concentrations at the monitoring point. The correlation coefficient between the hydrogen and propane concentrations was 0.47 in October 2011 (i.e., second sampling event) and 0.48 in December 2011 (i.e., third sampling event).

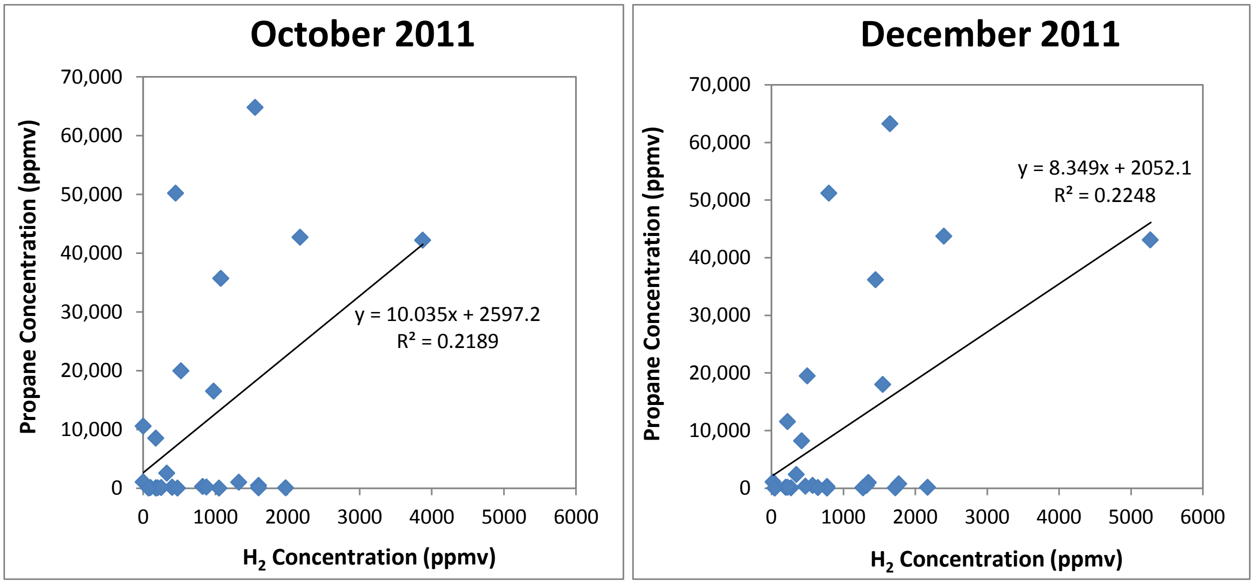


Figure 36: Correlation between hydrogen and propane vapor phase concentrations

Figure 37 illustrates the comparison of TCE and cis-1,2-DCE, and hydrogen and methane in the H_2T monitoring wells before (i.e., pre-treatment characterization phase, May 2011) and after (i.e., post-treatment characterization phase, December 2011) gas injection phase.

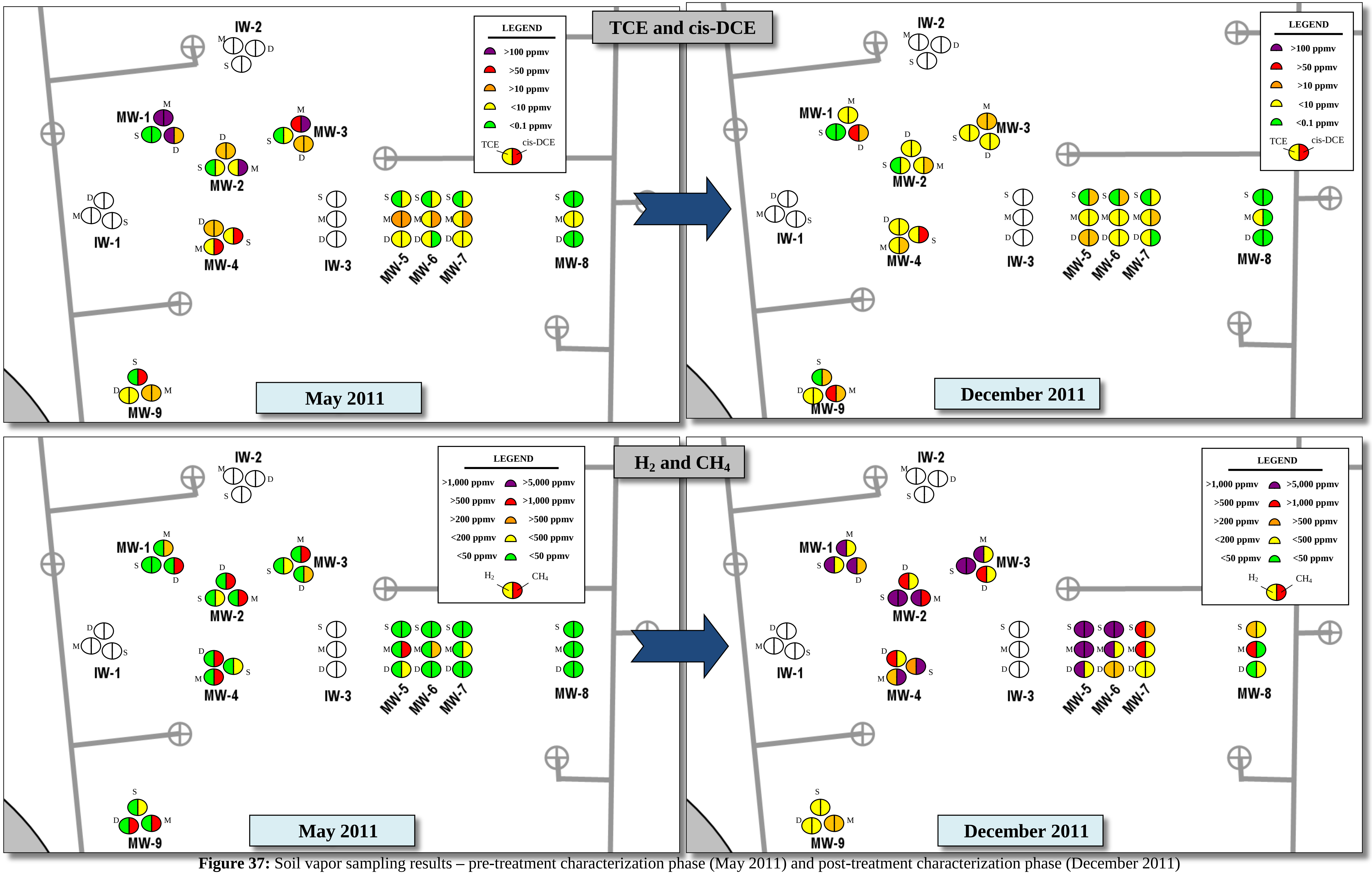


Figure 37: Soil vapor sampling results – pre-treatment characterization phase (May 2011) and post-treatment characterization phase (December 2011)

5.6.4 Soil Sampling during Post-Treatment Characterization

Soil sampling results from the post-treatment characterization phase and the comparison to the results from pre-treatment characterization phase are summarized in **Table 17** and **Table 18**. The change in concentration and mass was calculated for 48 sample pairs collected from all of the injection and monitoring wells during pre- and post-treatment characterization phases. Analytical results from the post-treatment soil sampling are summarized in **Table 19**.

The median VOC concentrations of all 48 samples (i.e., 12 sampling locations and 4 depths) during pre- and post-treatment characterization phases are summarized in **Table 17**. The median TCE concentration decreased approximately 50% and median cis-1,2-DCE concentration increased approximately 123%. Note that Non-Detect (ND) concentrations were assumed to be equal to 50% of Reporting Limit (RL). The statistical parameters were calculated with ND equal or 0, 50%, and 75% of Reporting Limits (RL) and median results did not change significantly.

The estimated mass showed that approximately 56% reduction in TCE mass and approximately 24% increase in cis-1,2-DCE mass were observed. An increase in the total mass of trans-1,2-DCE was also observed. **Table 18** shows the change in the total VOC mass (**Table 18a**) and moles (**Table 18b**) for all the samples.

Table 17: Statistics of 48 soil samples (pre- and post-treatment)

Median Concentration (µg/kg)	Pre	Post	% Change
TCE	7.85	3.95	-50%
cis-1,2-DCE	17	39.5	132%
trans-1,2-DCE	0.31	1.4	359%

Note: Non-Detect (ND) concentrations were assumed to be equal to 50% of Reporting Limit (RL).

Table 18: Change in (a) the total VOC mass and (b) moles for all the samples

(a)

Mass (g)	Pre	Post	% Change
TCE	289.0	127.2	-56%
cis-1,2-DCE	463.7	573.1	24%
trans-1,2-DCE	8.0	16.2	102%
Total	**760.7**	**716.6**	**-5.8%**

(b)

Moles	Pre	Post	% Change
TCE	2.2	1.0	-56%
cis-1,2-DCE	4.8	5.9	24%
trans-1,2-DCE	0.1	0.2	102%
Total	**7.06**	**7.05**	**-0.2%**

1) The concentrations of the ND samples were assumed to be equal to 50% of Reporting Limits (RL)
2) MW-9 was excluded for mass calculations

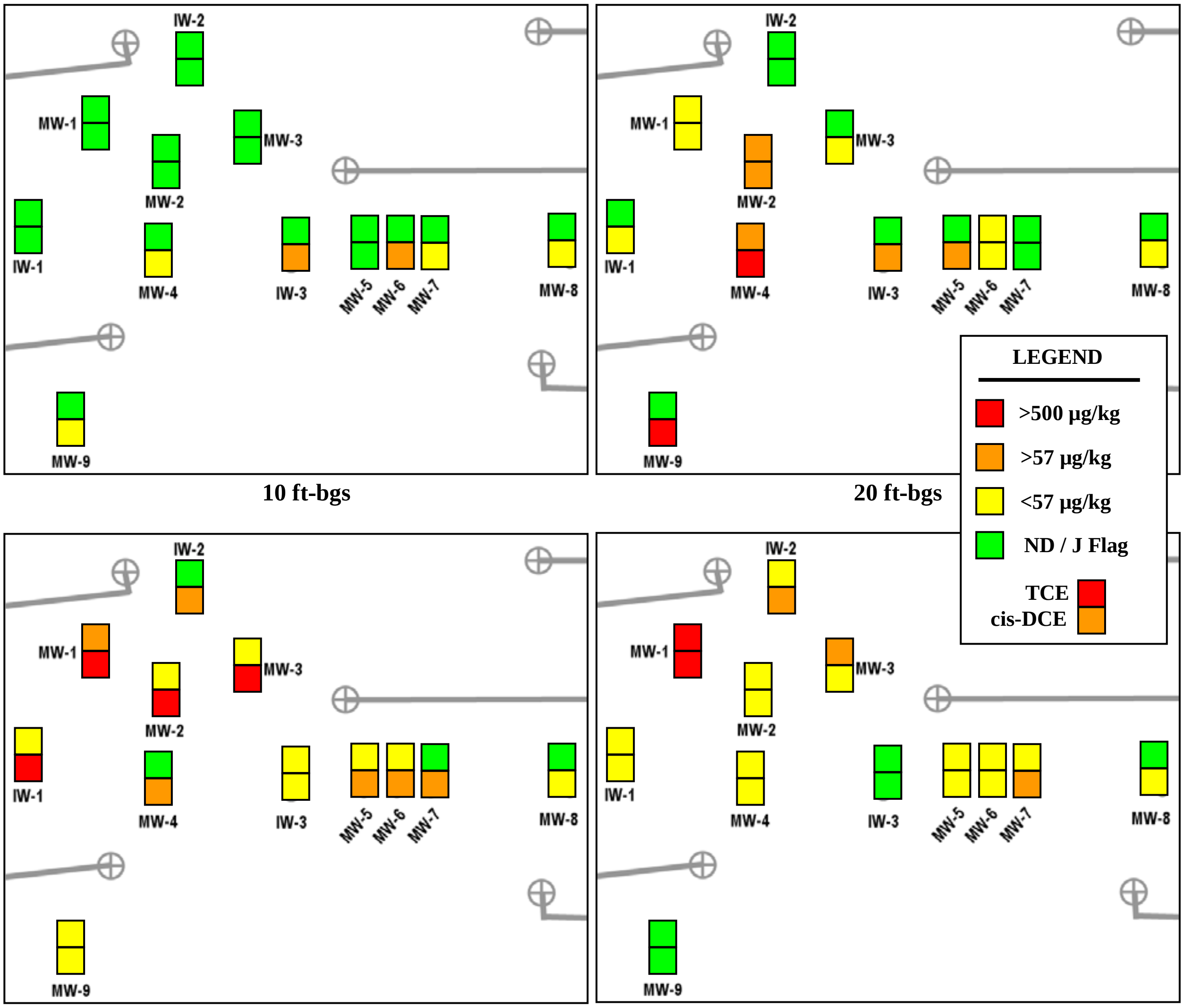
Soil analytical results of the post-treatment characterization phase are summarized in **Table 19**. Soil samples were collected from depths of 10, 20, 30, and 40 ft-bgs and were tested for TCE, cis-1,2-DCE, trans-1,2-DCE, VC, and 1,1,1-TCA as well as soil moisture content. **Figure 38** illustrates the comparison between TCE and cis-1,2-DCE concentration in the soil samples collected during the post-treatment characterization phase.

For the 48-pair samples, mean detected TCE concentration was 166 µg/kg for the pre-treatment characterization phase and 74 µg/kg for the post-treatment characterization phase. The t-test conducted on the 48-pair samples resulted in p-value of 0.092 that corresponds to a 91% confidence in support of the hypothesis that the post-treatment TCE concentrations are smaller than the pre-treatment TCE concentrations. The Mann-Whitney analysis also resulted in a similar

Table 19: Soil analytical results, post-treatment characterization phase, January 2012

Sample ID	Date	Depth (ft-bgs)	TCE	cis-1,2-DCE	trans-1,2-DCE	VC	1,1,1-TCA	Moisture Content (%)
IW-1-10	19-Jan-12	10	<1.9	<1.8	<1.1	<1.2	<2.1	17.2
IW-1-20	19-Jan-12	20	4.1	6.6	<1.1	<1.2	<2.1	17.5
IW-1-30	19-Jan-12	30	18	1,200	8.7	<1.2	<2.1	18.3
IW-1-40	19-Jan-12	40	17	13	<1.1	<1.2	<2.0	17.0
IW-2-10	18-Jan-12	10	<1.9	<1.8	<1.1	<1.2	<2.0	15.7
IW-2-20	18-Jan-12	20	<1.9	<1.8	<1.1	<1.2	<2.1	17.3
IW-2-30	18-Jan-12	30	6	98	1.4	<1.2	<2.1	18.6
IW-2-40	18-Jan-12	40	19	130	<1.1	<1.2	<2.0	16.6
IW-3-10	18-Jan-12	10	<2.0	140	29	<1.2	<2.1	18.9
IW-3-20	18-Jan-12	20	3.8	75	1.3	<1.2	<2.1	18.1
IW-3-30	18-Jan-12	30	11	15	<1.1	<1.2	<2.1	17.7
IW-3-40	18-Jan-12	40	<1.9	<1.7	<1.0	<1.2	<2.0	13.6
MW-1-10	19-Jan-12	10	2.5	3.8	<1.1	<1.2	<2.0	15.0
MW-1-20	19-Jan-12	20	27	21	2.6	<1.2	<2.1	18.5
MW-1-30	19-Jan-12	30	460	1,100	13	<1.3	<2.1	20.1
MW-1-40	19-Jan-12	40	710	580	27	<1.2	<2.1	17.8
MW-2-10	18-Jan-12	10	<2.0	<1.8	<1.1	<1.2	<2.1	18.4
MW-2-20	18-Jan-12	20	62	350	24	<1.2	<2.1	17.1
MW-2-30	18-Jan-12	30	12	1,300	21	3.5	<2.1	20.7
MW-2-40	18-Jan-12	40	11	34	<1.1	<1.2	<2.1	17.8
MW-3-10	18-Jan-12	10	<1.9	<1.8	<1.1	<1.2	<2.0	15.7
MW-3-20	18-Jan-12	20	<1.9	48	<1.1	<1.2	<2.0	17.0
MW-3-30	18-Jan-12	30	19	550	11	<1.2	<2.1	18.8
MW-3-40	18-Jan-12	40	440	980	3	<1.2	<2.1	17.9
MW-4-10	19-Jan-12	10	<1.9	7.6	<1.1	<1.2	<2.1	17.2
MW-4-20	19-Jan-12	20	70	520	28	<1.2	<2.1	17.5
MW-4-30	19-Jan-12	30	<2.0	460	5.1	<1.3	<2.2	21.4
MW-4-40	19-Jan-12	40	11	24	1.1	<1.2	<2.1	18.0
MW-5-10	18-Jan-12	10	<1.9	<1.8	<1.1	<1.2	<2.0	16.2
MW-5-20	18-Jan-12	20	2.8	110	3.4	<1.2	<2.0	16.1
MW-5-30	18-Jan-12	30	16	130	1.8	<1.2	<2.1	17.8
MW-5-40	18-Jan-12	40	14	51	<1.1	<1.2	<2.1	19.0
MW-6-10	19-Jan-12	10	<1.9	110	7.9	<1.2	<2.1	17.3
MW-6-20	19-Jan-12	20	11	44	5.2	<1.2	<2.1	17.7
MW-6-30	19-Jan-12	30	13	110	1.4	<1.2	<2.1	18.4
MW-6-40	19-Jan-12	40	7.1	24	<1.1	<1.2	<2.1	18.7
MW-7-10	19-Jan-12	10	<1.9	20	2	<1.2	<2.0	15.6
MW-7-20	19-Jan-12	20	<1.9	3.8	<1.1	<1.2	<2.0	14.9
MW-7-30	19-Jan-12	30	<2.0	170	6	<1.2	<2.1	19.4
MW-7-40	19-Jan-12	40	8.7	230	16	<1.2	<2.0	16.2
MW-8-10	19-Jan-12	10	<2.0	11	<1.1	<1.2	<2.1	19.6
MW-8-20	19-Jan-12	20	<2.0	10	2.1	<1.2	<2.1	18.6
MW-8-30	19-Jan-12	30	<2.0	22	<1.1	<1.3	<2.1	20.6
MW-8-40	19-Jan-12	40	<2.0	11	6.9	<1.2	<2.1	18.2
MW-9-10	19-Jan-12	10	<2.0	35	5.8	<1.2	<2.1	19.3
MW-9-20	19-Jan-12	20	<2.0	1,200	120	<1.3	<2.1	20.3
MW-9-30	19-Jan-12	30	14	54	3.9	<1.2	<2.1	18.8
MW-9-40	19-Jan-12	40	4.2	<1.8	<1.1	<1.2	<2.1	17.3

Note: Soil concentrations are in µg/kg-dry.



10 ft-bgs

20 ft-bgs

30 ft-bgs

40 ft-bgs

Figure 38: Post-treatment characterization phase soil sampling results – TCE and cis-1,2-DCE

p-value of 0.104 that corresponds to a 90% confidence in support of the hypothesis that post-treatment TCE concentrations are significantly smaller than the pre-treatment TCE concentrations.

Similar analyses were performed for cis-1,2-DCE and the results show that there is greater than a 90% but less than a 95% probability that the post-treatment cis-1,2-DCE soil concentrations are significantly greater than the pre-treatment cis-1,2-DCE soil concentrations. The median cis-1,2-DCE concentration increased from approximately 17 µg/kg to 40 µg/kg. The difference between the pre-treatment and post-treatment median concentrations ranges from 0 to 35 µg/kg.

Both t-test and Mann-Whitney analyses show that there is approximately 90% confidence that the post-treatment TCE concentrations are significantly less than the pre-treatment TCE concentrations. Although the median TCE concentration decreased from approximately 8 µg/kg to some value less than the Reporting Limit (RL), which equals about 6 µg/kg, the difference between the medians is relatively small. The 95% confidence interval for the difference is about 0 to 10 µg/kg. The data sets are characterized by large variability (e.g., extreme positive outliers) and relatively large number of non-detects, which tends to adversely affects the power of statistical tests to detect differences.

The number of soil samples with TCE concentrations above 57 µg/kg which is the NDEQ soil remediation goal dropped from 13 samples in pre-treatment to 5 samples in post-treatment. The number of soil samples with cis-1,2-DCE concentrations above 400 µg/kg which is the NDEQ soil remediation goal dropped from 10 samples in pre-treatment to 9 samples in post-treatment. For the 13-pair samples, the mean detected TCE concentration was 329 µg/kg for the pre-treatment characterization phase and 51 µg/kg for the post-treatment characterization phase. The median TCE concentration decreased from approximately 110 µg/kg to 14 µg/kg (i.e., approximately 87% reduction in TCE concentrations in the samples where the initial TCE concentration was above NDEQ soil remediation goal of 57 µg/kg).

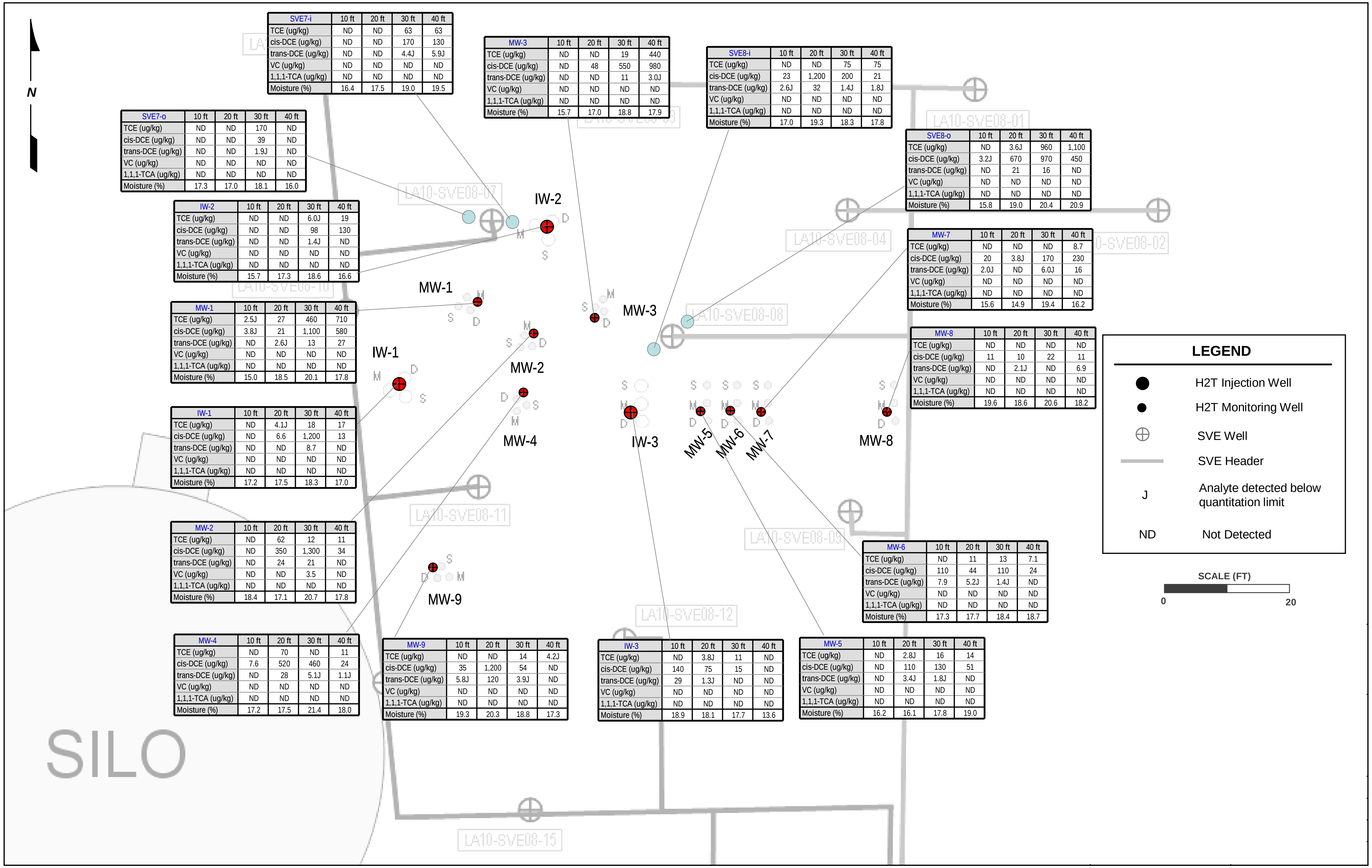
It should be noted that for the small source zone treated during this demonstration, the samples below standards or with reduction in TCE concentrations were not in any one area and the total treatment volume (i.e., size of the source zone with TCE concentrations above 57 µg/kg) did not appear to get any smaller.

Additional soil samples were collected from four additional locations (i.e., total of 16 additional soil samples) around SVE wells SVE-7 and SVE-8 inside and outside the treatment area. These soil samples were collected to investigate the TCE mass reduction inside the treatment area where the gas mixture had reached and TCE treatment was expected and compare the mass reduction to the TCE mass reduction in the outside treatment area where gas was intercepted by fully screened SVE wells and TCE treatment was not expected. **Figure 39** shows the soil sampling locations and VOC analytical results. **Table 20** summarizes the results of TCE and cis-1,2-DCE concentrations from the soil samples collected from depths 10, 20, 30, and 40 feet bgs.

Several t-test and Mann-Whitney analyses were performed to compare the means of the 48-pair TCE samples from pre- and post-treatment characterization phases, and the 8-pair TCE samples collected from SVE wells inside versus outside treatment area. The complete statistical analyses of pre- and post-treatment soil data for TCE and cis-1,2-DCE are in Appendix K. (We thank the significant contributions of Mr. Thomas Georgian of the USACE Omaha District for the help on this statistical evaluation).

Table 20: Soil VOC concentrations around the SVE wells from different depths

	TCE		cis-1,2-DCE	
Sample ID	**Inside**	**Outside**	**Inside**	**Outside**
SVE7-10	<1.9	<1.9	<1.8	<1.8
SVE7-20	<1.9	<1.9	<1.8	<1.8
SVE7-30	63	170	170	39
SVE7-40	63	<1.9	130	<1.8
SVE8-10	<1.9	<1.9	23	3.2 J
SVE8-20	<2.0	3.6 J	1,200	670
SVE8-30	75	960	200	970
SVE8-40	75	1,100	21	450



SVE7-i	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	63	63
cis-DCE (ug/kg)	ND	ND	170	130
trans-DCE (ug/kg)	ND	ND	4.4J	5.9J
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.4	17.5	19.0	19.5

MW-3	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	19	440
cis-DCE (ug/kg)	ND	48	550	980
trans-DCE (ug/kg)	ND	ND	11	3.0J
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.7	17.0	18.8	17.9

SVE8-i	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	75	75
cis-DCE (ug/kg)	23	1,200	200	21
trans-DCE (ug/kg)	2.6J	32	1.4J	1.8J
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.0	19.3	18.3	17.8

SVE7-o	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	170	ND
cis-DCE (ug/kg)	ND	ND	39	ND
trans-DCE (ug/kg)	ND	ND	1.9J	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.3	17.0	18.1	16.0

SVE8-o	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	3.6J	960	1,100
cis-DCE (ug/kg)	3.2J	670	970	450
trans-DCE (ug/kg)	ND	21	16	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.8	19.0	20.4	20.9

IW-2	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	6.0J	19
cis-DCE (ug/kg)	ND	ND	98	130
trans-DCE (ug/kg)	ND	ND	1.4J	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.7	17.3	18.6	16.6

MW-7	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	ND	8.7
cis-DCE (ug/kg)	20	3.8J	170	230
trans-DCE (ug/kg)	2.0J	ND	6.0J	16
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.6	14.9	19.4	16.2

MW-1	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	2.5J	27	460	710
cis-DCE (ug/kg)	3.8J	21	1,100	580
trans-DCE (ug/kg)	ND	2.6J	13	27
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	15.0	18.5	20.1	17.8

MW-8	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	ND	ND
cis-DCE (ug/kg)	11	10	22	11
trans-DCE (ug/kg)	ND	2.1J	ND	6.9
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	19.6	18.6	20.6	18.2

IW-1	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	4.1J	18	17
cis-DCE (ug/kg)	ND	6.6	1,200	13
trans-DCE (ug/kg)	ND	ND	8.7	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.2	17.5	18.3	17.0

MW-2	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	62	12	11
cis-DCE (ug/kg)	ND	350	1,300	34
trans-DCE (ug/kg)	ND	24	21	ND
VC (ug/kg)	ND	ND	3.5	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	18.4	17.1	20.7	17.8

MW-6	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	11	13	7.1
cis-DCE (ug/kg)	110	44	110	24
trans-DCE (ug/kg)	7.9	5.2J	1.4J	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.3	17.7	18.4	18.7

MW-4	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	70	ND	11
cis-DCE (ug/kg)	7.6	520	460	24
trans-DCE (ug/kg)	ND	28	5.1J	1.1J
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	17.2	17.5	21.4	18.0

MW-9	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	ND	14	4.2J
cis-DCE (ug/kg)	35	1,200	54	ND
trans-DCE (ug/kg)	5.8J	120	3.9J	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	19.3	20.3	18.8	17.3

IW-3	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	3.8J	11	ND
cis-DCE (ug/kg)	140	75	15	ND
trans-DCE (ug/kg)	29	1.3J	ND	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	18.9	18.1	17.7	13.6

MW-5	10 ft	20 ft	30 ft	40 ft
TCE (ug/kg)	ND	2.8J	16	14
cis-DCE (ug/kg)	ND	110	130	51
trans-DCE (ug/kg)	ND	3.4J	1.8J	ND
VC (ug/kg)	ND	ND	ND	ND
1,1,1-TCA (ug/kg)	ND	ND	ND	ND
Moisture (%)	16.2	16.1	17.8	19.0

Figure 39: Results of soil sample collected during post-characterization phase

Table 21: Soil sampling results, post-treatment characterization phase, January 2012

Sample ID	**IW-3-10**	**IW-3-25**	**IW-3-40**	**MW-2-10**	**MW-2-25**	**MW-2-40**	**MW-5-10**	**MW-5-25**	**MW-5-40**
Depth, ft	10	25	40	10	25	40	10	25	40
Soil Type	Silt	Silt	Silt	Silt	Silt	Silt	Silt	Silt	Silt
%Fine Sand	10.07	2.30	0.66	3.39	0.30	7.59	4.23	7.03	11.36
% Silt	66.86	76.83	74.18	75.14	77.41	71.58	73.75	72.60	68.02
% Clay	23.07	20.87	25.16	21.47	22.29	20.83	22.02	20.37	20.63
Median Grain Size, mm	0.021	0.023	0.018	0.022	0.021	0.023	0.022	0.024	0.024
pH	7.8	7.9	7.6	7.8	7.9	7.7	8.0	8.0	7.8
Organic Matter (%)	1.4	0.9	1.5	1.0	0.9	0.8	1.0	0.8	0.8
Nitrate-N, ppm	0.9	1.4	0.7	0.6	0.5	0.4	0.6	0.5	0.5
Phosphorus (P1), ppm****	10	17	14	17	10	15	14	12	16
Phosphorus (Bicarb), ppm	10	13	12	14	7	14	12	11	13
Phosphorus (P2), ppm	202	204	63	249	286	127	186	259	110
Phosphorus (M2), ppm	14	25	15	20	12	23	15	23	19
Phosphorus (M3), ppm	18	34	19	32	19	27	21	35	22
% Dhc*	NA	NA	0.0002-0.0006	NA	NA	NA	NA	NA	NA
Dehalococcoides Enumeration/Gram	6×10^3 U	6×10^3 U	3×10^3 J	6×10^3 U	6×10^3 U	6×10^3 U	6×10^3 U	6×10^3 U	6×10^3 U
DNA Concentration in Sample (extractable), ng/g	2668	3480	2537	3179	2490	1975	2660	3976	3124
PCR Amplifiable DNA	ND	ND	Detected	ND	ND	ND	ND	ND	ND
% vcrA***	-	-	0.0005-0.001	-	-	-	-	-	-
Vinyl Chloride Reductase (vcrA) Gene Copies/Gram	-	-	6×10^3	-	-	-	-	-	-
DNA Concentration in Sample (extractable), ng/g	-	-	2537	-	-	-	-	-	-
PCR Amplifiable DNA	-	-	Detected	-	-	-	-	-	-

* Percent *Dehalococcoides* (Dhc) in microbial population. This value is calculated by dividing the number of Dhc 16S ribosomal ribonucleic acid (rRNA) gene copies by the total number of bacteria as estimated by the mass of DNA extracted from the sample. Range represents normal variation in Dhc enumeration and U corresponds to below detection limit for qPCR.

** Based on quantification of Dhc 16S rRNA gene copies. Dhc are generally reported to contain one 16S rRNA gene copy per cell; therefore, this number is often interpreted to represent the number of Dhc cells present in the sample.

*** Percentage of bacteria in the microbial population that harbor the *vcrA* gene. This value is calculated by dividing the measured number of cells haboring the vinyl chloride reductase A (*vcrA*) gene by the total number of bacteria in the sample estimated using the mass of DNA extracted from the sample. Range represents normal variation in enumeration of *vcrA*.

**** Phosphorous (P1) or weak Bray test measures phosphorus which is readily available to the plants, Phosphorus (Bicarb) test measures the amount of readily available phosphorus in slightly basic (pH of 7.0 - 7.2) to highly basic soils (pH >7.3r), Phosphorus (P2) or strong Bray test measures readily available phosphorus plus a part of the reserve phosphorus in soil, Phosphorus (M2) and Phosphorus (M3) use a number of acids to extract the soil phosphorus whereas the Bray test uses weak HCl.

For the 8-pair SVE samples, mean detected TCE concentration was 69 µg/kg for the inside-treatment area and 558 µg/kg for the outside-treatment area. The t-test conducted on the 8-pair samples resulted in p-value of 0.081 that corresponds to a 91.9% confidence in support of the hypothesis that the inside-treatment area TCE concentrations are smaller than the outside-treatment area TCE concentrations. The number of samples was not enough to conduct Mann-Whitney test.

Similar to pre-treatment characterization phase, soil samples were collected and analyzed for moisture content, nutrient concentrations, particle size, and DHC bacteria. Lab analyses showed almost no change in the median moisture content and nutrient concentrations. **Table 21** summarizes the analytical results of soil samples tested during post-treatment characterization phase for grain size distribution, pH, nutrients (NO_3-N, Phosphorus), and DHC bacteria. During the pre-treatment characterization phase DHC was detected in two samples at depth of 40 feet bgs (i.e., IW-3-40 and MW-5-40). During the post-treatment characterization phase, DHC was only detected in IW-3-40.

5.7 BENCH-SCALE TREATABILITY STUDY

In support of the H_2T demonstration in the field, a bench-scale treatability study of reductive dechlorination in unsaturated soil using several gaseous electron donor mixtures was conducted by Dr. Pat Evans' team at CDM Smith Environmental Treatability Laboratory. A summary of the bench-scale treatability study is described in this section. A full description of the treatability study is in Appendix E.

5.7.1 Background and Objectives

The treatability study was conducted parallel to the field demonstration to determine whether reductive dechlorination could occur using site soil and to investigate the effect of bioaugmentation, the impurities in the liquefied petroleum gas (LPG), and moisture content. Hydrogen was mixed with nitrogen and propane in the GEDIT demonstration for three reasons. First, nitrogen is a relatively inexpensive carrier gas that allows greater flow rates to transport the hydrogen. Second, mixing the hydrogen with propane reduces the buoyancy so that the mixture can be transported horizontally rather than rising. Third, propane is metabolized by aerobic bacteria which consume oxygen and which is inhibitory to reductive dechlorination.

LPG is an attractive alternative to propane because of its ready availability and low cost relative to pure propane. LPG typically contains mostly propane and butane but it also contains other compounds such as mercaptans which serve as odorants. LPG was not found to be inhibitory to perchlorate reduction (Evans et al., 2011), but may be inhibitory to reductive dechlorination. It should be noted that that the LPG used for the field demonstration came from a different source than the LPG used for the bench-scale studies. There could be significant variability in the amount of minor constituents in LPG (i.e., differences from different refineries, as well as batch-to-batch differences); and that differences in the levels of minor constituents, such as acetylene, could potentially have an important impact on the degree to which LPG is (or is not) inhibitory to reductive dechlorination.

The treatability study described here addressed whether this inhibition would occur. Finally, soil moisture is an important factor promoting microbial metabolism. Biodegradation of perchlorate in vadose zone soil was determined to be inhibited by low soil moisture contents (Cai et al., 2010). Therefore, it was important to determine whether Site soil moisture contents were capable of supporting reductive dechlorination of TCE.

The objectives of the bench-scale treatability study were to:

- Determine the extent to which reductive dechlorination of TCE occurs under unsaturated conditions in vadose-zone soil from the Site.
- Identify the optimum gaseous electron donor mixture to be used in the demonstration, and investigate performance differences between propane and LPG.
- Evaluate the effects of soil moisture levels, gaseous electron donor mixtures, phosphorus addition, and bioaugmentation on reductive dechlorination of TCE and its daughter products.

5.7.2 Study Design

Complete biological reductive dechlorination of TCE is dependent on the presence and activity of *Dehalococcoides* (DHC) organisms. Because these organisms are not ubiquitous in the environment, bioaugmentation has been shown to promote reductive dechlorination. While questions remain as to how a liquid bioaugmentation culture would be introduced into the vadose zone, the microcosm study evaluated bioaugmention to determine whether reductive dechlorination would occur under conditions where DHC were known to be present. Tests 1 through 11 were not bioaugmented and Tests 12 through 22 were bioaugmented with Shaw SDC-9^{TM} culture. Each of the conditions was run in duplicate, for a total of 44 microcosms.

Soil cores were collected from depths up to 40 feet, shipped to the lab and was processed and tested prior to microcosm setup. Three moisture levels were targeted to evaluate the effect of soil moisture. These conditions were chosen to represent the range of moisture concentrations that may be encountered in the field. The moisture content of 30 percent was selected as highest moisture content in which a homogenized soil/water mixture did not show visible separation of water (i.e., the field capacity). The two other moistures (15 and 19 percent) were selected based on Site data. Two hydrogen concentrations of 1 and 10 percent were evaluated for each moisture level and each bioaugmentation condition. LPG was added at concentrations equal to the hydrogen concentration in Tests representing different electron donor concentrations, moisture contents, and bioaugmentation. All test conditions containing electron donor were amended with 1 percent carbon dioxide as a carbon source for microbial growth. The electron-donor-free control bottles did not receive carbon dioxide.

To evaluate the potential inhibition of LPG, additional tests using pure propane were tested only at the high moisture content. Because LPG includes constituents that could be inhibitory to the reductive dechlorination process, additional microcosms were set up using propane instead of LPG. Only the highest moisture level was used for these conditions, which allowed comparison of LPG and propane under conditions expected to be optimal for reductive dechlorination. After about six weeks of incubation, there were clear differences in TCE degradation between bioaugmented and un-augmented bottles. It was hypothesized that phosphorous nutrient limitation may be inhibiting the un-bioaugmented microcosms. Triethylphosphate (TEP), a gaseous phosphorous nutrient, was added to Test Conditions 1 and 2 on Day 49 to test this hypothesis. Additional hydrogen was added when the hydrogen concentration in a bottle fell below a set threshold (5 percent for the 10 percent hydrogen bottles; 0.5 percent for the 1 percent hydrogen bottles). After each hydrogen addition, the headspace composition was re-tested in the affected bottles. Details of the test design are in Appendix E. The experimental conditions are summarized in this section and shown in **Table 22**.

Table 22: Microcosm study experimental conditions

Condition	Soil moisture	Phosphorus addition (Day 49)	Bio-augmentation	Gas Composition			
				H_2	LPG	Propane	CO_2
1	30%	Y	N	10%	10%	0	1%
2	30%	Y	N	10%	0	10%	1%
3	30%	N	N	1%	1%	0	1%
4	30%	N	N	1%	0	1%	1%
5	30%	N	N	0	0	0	0
6	19%	N	N	10%	10%	0	1%
7	19%	N	N	1%	1%	0	1%
8	19%	N	N	0	0	0	0
9	17%	N	N	10%	10%	0	1%
10	17%	N	N	1%	1%	0	1%
11	17%	N	N	0	0	0	0
12	30%	N	Y	10%	10%	0	1%
13	30%	N	Y	10%	0	10%	1%
14	30%	N	Y	1%	1%	0	1%
15	30%	N	Y	1%	0	1%	1%
16	30%	N	Y	0	0	0	0
17	19%	N	Y	10%	10%	0	1%
18	19%	N	Y	1%	1%	0	1%
19	19%	N	Y	0	0	0	0
20	17%	N	Y	10%	10%	0	1%
21	17%	N	Y	1%	1%	0	1%
22	17%	N	Y	0	0	0	0

5.7.3 Treatability Test Results

Extent of Dechlorination: TCE removals ranged from 35 percent to >99 percent, and a few conditions achieved full dechlorination to ethene. This demonstrates that complete reductive dechlorination was possible in this soil. Data trend plots for the each test condition are presented in Appendix E.

Control bottles with neither gaseous electron donors nor bioaugmentation (conditions 5, 8, and 11) achieved 40% to 60% removal of TCE. Possible mechanisms of TCE removal in these bottles include abiotic attenuation, biological reduction fueled by organic matter already present in the site soil, sorption to the rubber stopper, and removal and dilution of TCE in the headspace during gas sampling. No production of cis-1,2-DCE or VC was observed in these bottles, which suggests that biotic degradation was not a significant factor in the observed TCE removal. Headspace removal during gas sampling was also likely to be insignificant: only about 1% of the headspace was exchanged during each round of sampling, so less than 10 percent of the headspace would have been removed during sampling over the course of the experiment. Therefore, abiotic attenuation and sorption to the stoppers were probably the major sources of TCE removal in the un-bioaugmented controls.

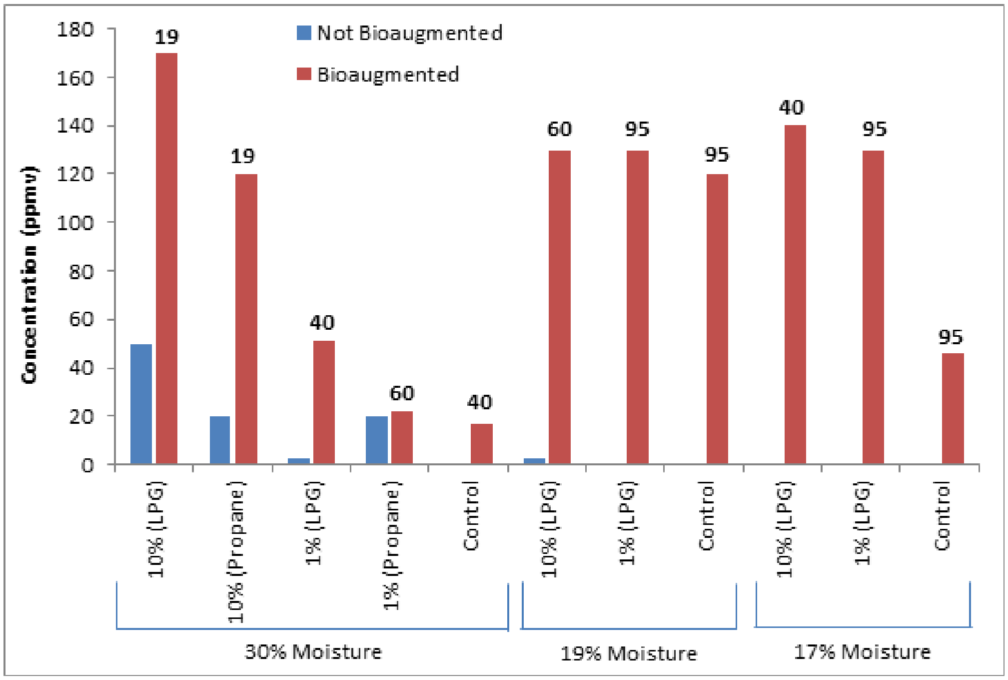


Figure 40: Effect of bioaugmentation on peak cis-1,2-DCE concentrations with varying hydrogen concentrations with LPG or propane and moisture contents. Labels above bars indicate time (in days) to peak concentration.

Effects of Bioaugmentation: TCE removal was consistently higher with bioaugmentation (Test conditions 12 through 22) than without (Test conditions 1 through 11). No un-bioaugmented condition exceeded 70 percent TCE removal, whereas several of the bioaugmented conditions achieved >99 percent removal. Production of cis-1,2-DCE occurred in all of the bioaugmented conditions, indicating that part of the TCE loss was due to biodegradation. In contrast, production of cis-1,2-DCE occurred in less than half of the un-bioaugmented conditions. Furthermore, cis-1,2-DCE production occurred earlier and to a greater extent in the bioaugmented conditions (**Figure 40**). The slight cis-1,2-DCE production seen in a few of the un-bioaugmented conditions suggests that, given enough time, reductive dechlorination of TCE to cis-1,2-DCE can occur in Site soils without bioaugmentation. However, in the time period of the treatability study (i.e., 172 days), the extent of dechlorination in these conditions was small. Detection occurred only on the final sampling event (Day 172) in un-bioaugmented conditions.

Most of the bioaugmented conditions achieved some removal of cis-1,2-DCE, accompanied by production of VC. Full reductive dechlorination to ethene was seen in conditions 12 and 13, which had a high moisture content of 30 percent, a high electron donor concentration of 10 percent, and bioaugmentation. In contrast, conditions without bioaugmentation showed no conversion of cis-1,2-DCE to VC or ethene. Methane production was observed with and without bioaugmentation at the 30 percent moisture content and in the presence of LPG (**Figure 41**). While methane production was greater with bioaugmentation, the observed differences do not explain the relatively poor reductive dechlorination activity without bioaugmentation. In other words, un-bioaugmented microcosms produced 50 percent or more as much methane as bioaugmented microcosms, but were much less efficient in terms of TCE dechlorination to cis-1,2-DCE.

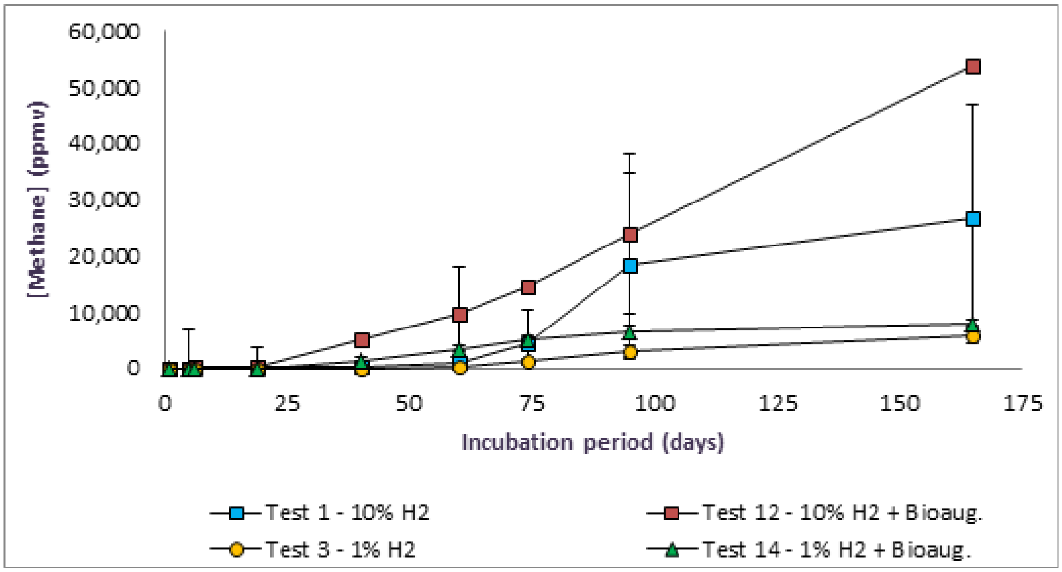


Figure 41: Effect of bioaugmentation methane production in the presence of LPG and at the 30% moisture content.

Effects of Moisture Content: Moisture level and electron donor concentration interacted to produce complex effects. With a high electron donor concentration, increased moisture was beneficial, whereas at a low electron donor concentration, increased moisture was detrimental. **Figure 42** shows TCE concentrations over time in these conditions.

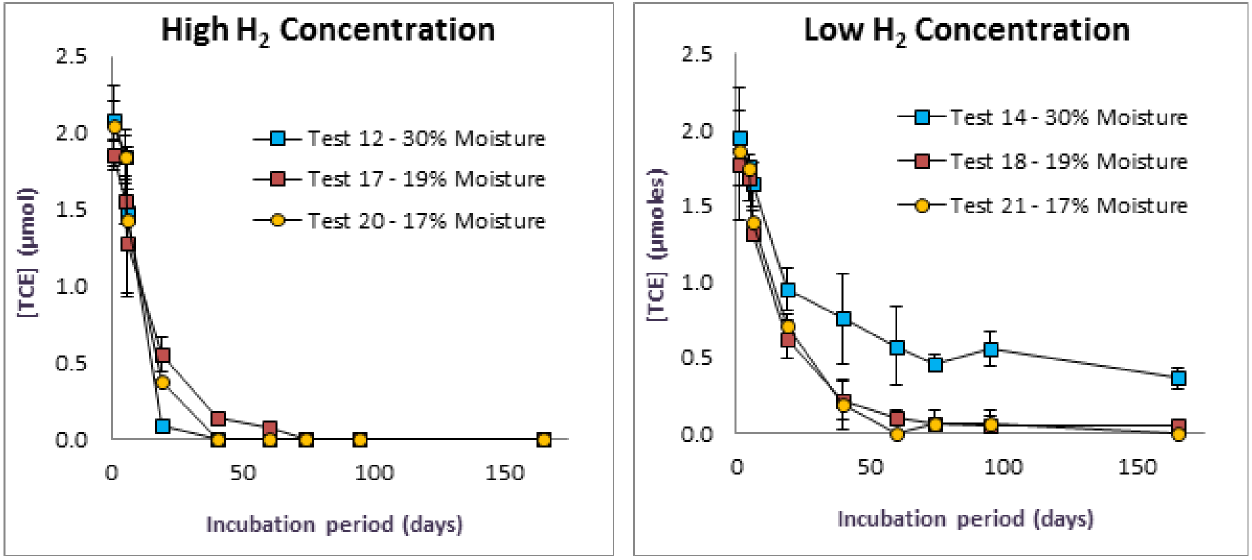


Figure 42: TCE concentrations with high (left) and low (right) hydrogen concentration and LPG for varying moisture contents

When high hydrogen concentrations, bioaugmentation, and LPG were used, TCE removal was not significantly affected by increased moisture levels. Increase in moisture had the opposite effect on TCE removal when the electron donor concentration was low.

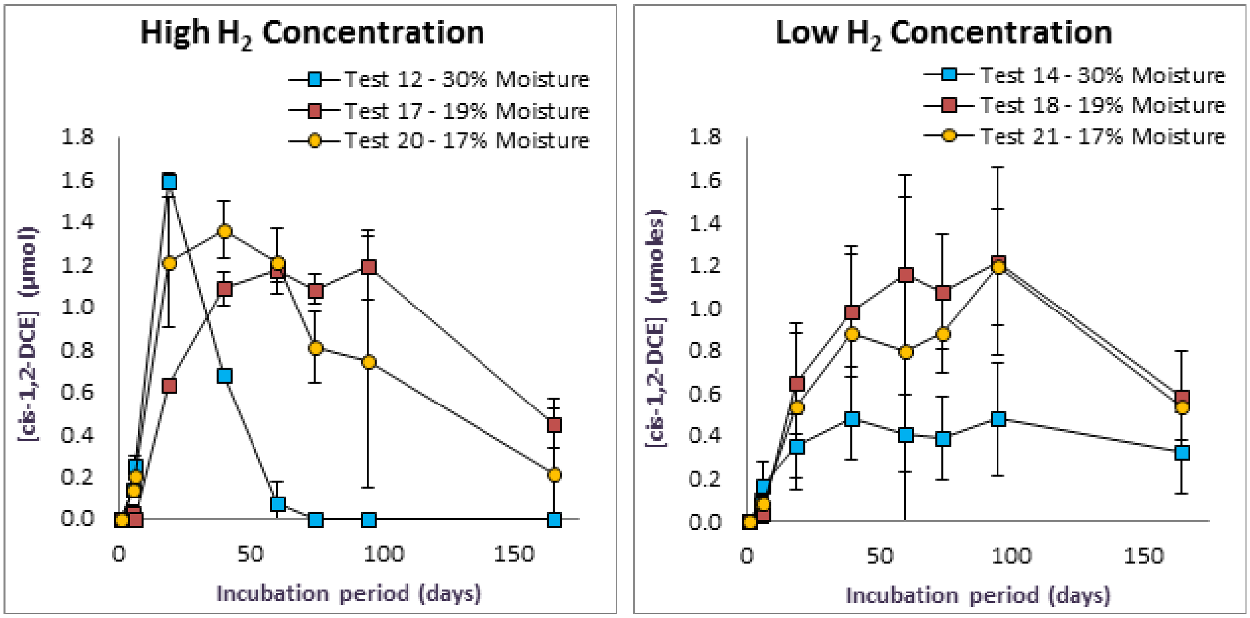


Figure 43: cis-1,2-DCE concentrations with high (left) and low (right) hydrogen concentration and LPG for varying moisture contents

Concentrations of cis-1,2-DCE over time at high and low hydrogen concentrations are shown in **Figure 43**. Moisture level did impact the reductive dechlorination of cis-1,2-DCE and vinyl chloride in the tests with high hydrogen concentration. In the test with 30 percent moisture, near-complete cis-1,2-DCE removal occurred by day 74. cis-1,2-DCE accumulated and was subsequently reductively dechlorinated at slower rates at lower moisture contents. Vinyl chloride was largely removed by the end of the experiment with 30 percent moisture but was either still accumulating or just beginning to be dechlorinated at lower moisture contents. Ethene production was observed only in the test condition with 30 percent moisture. Overall, the high-moisture condition performed better than those with lower moistures. In the tests with low hydrogen concentration, transformation of cis-1,2-DCE was incomplete regardless of moisture level, although some degradation occurred at low moisture levels. Minor vinyl chloride accumulation was observed in all three conditions and no ethene production was observed.

Methane production was generally similar for all three conditions (**Figure 44**) with the possibility of lesser production in Test condition 20 with the lowest moisture content. Methane generation with low hydrogen concentrations were qualitatively and quantitatively different from that observed with high hydrogen concentrations. Methane production under low hydrogen concentrations was significantly lower than under high hydrogen concentrations for all moisture contents. Additionally, methane production was more sensitive to moisture content at lower hydrogen concentrations. These data alone do not explain the incomplete reductive dechlorination of TCE at 30 percent moisture. Competition for hydrogen by methanogens and reductive dechlorinators appears to have been a contributing factor. The hydrogen consumption generally followed a similar pattern as methane production.

Comparison of the time profiles of VOC reductive dechlorination with methane accumulation and hydrogen consumption suggests that hydrogen was initially directed toward reductive dechlorination. After a period of acclimation, hydrogenotrophic methanogenesis accelerated. While reductive dechlorination was incomplete at the lower moisture contents, hydrogen consumption and methanogenic activities were high and not inhibited commensurately by low moisture contents.

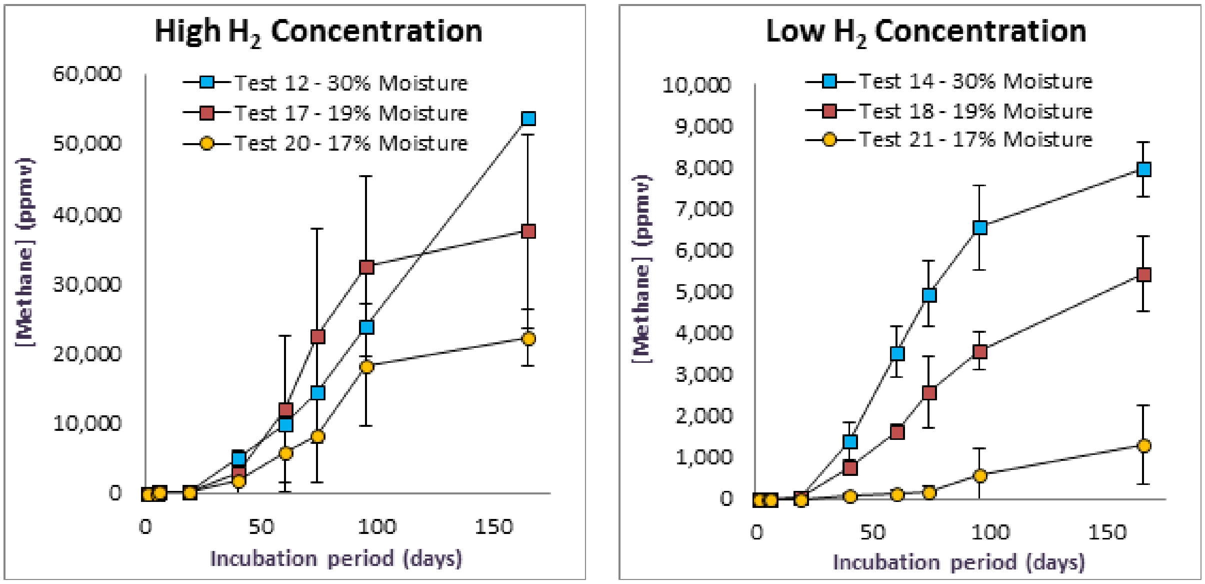


Figure 44: Methane concentrations with high (left) and low (right) hydrogen concentration and LPG for varying moisture contents

Effects of LPG versus Propane: **Figure 45** shows the effect of LPG vs. propane on the reductive dechlorination of TCE. There were no clear differences in reductive dechlorination between conditions with LPG and those with propane. LPG (Test condition 12) and propane (Test condition 13) both allowed full reductive dechlorination to ethene with a high electron donor concentration, 30% moisture, and bioaugmentation (**Figure 45**). If any significant differences were present, LPG appeared to be superior to propane in terms of the rate of reductive dechlorination.

Effects of Phosphorus Addition: On day 49, phosphorus nutrient in the form of triethyl phosphate (TEP) was added to Test conditions 1 and 2. These conditions were chosen because they had a high moisture level and high electron donor concentration, but unlike bioaugmented Test conditions 12 and 13, they had shown little removal of TCE. No immediate effect on TCE removal was observed, although the rate of hydrogen consumption and methane production increased. This suggests that the addition of phosphorus may have stimulated microbial activity, but it is not clear whether it promoted TCE degradation. By the end of the experiment, some TCE removal did occur but was not complete. Whether additional incubation time in the absence of TEP addition would have stimulated complete dechlorination is not known. Nevertheless, TEP addition did not yield results equivalent to the bioaugmented microcosms.

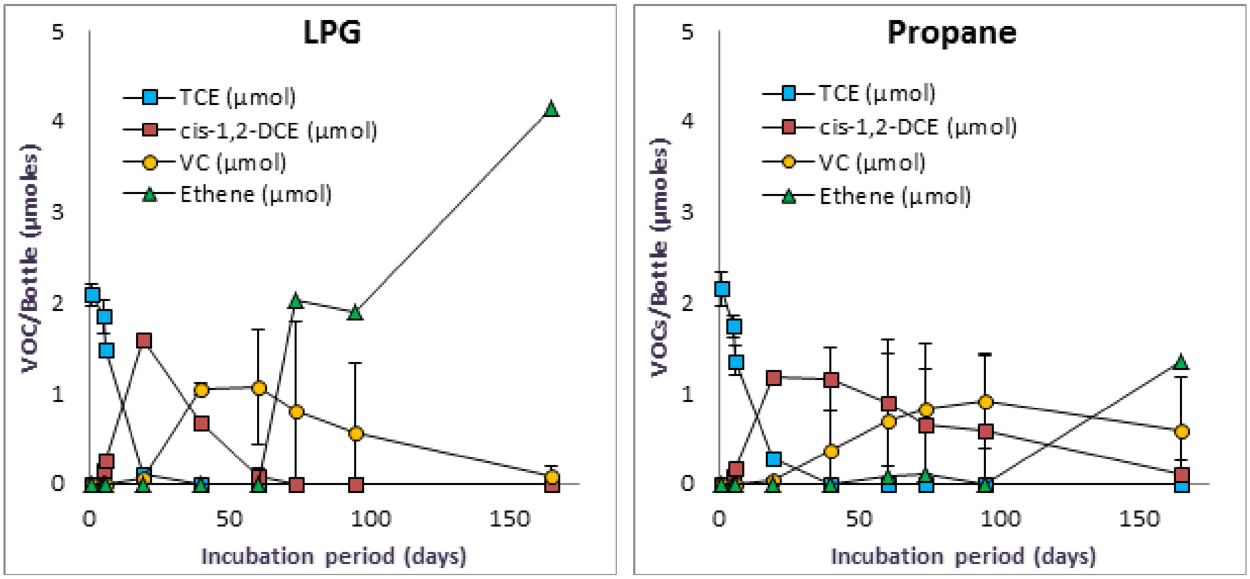


Figure 45: Reductive dechlorination of TCE in the presence of LPG (left) and propane (right), 10% hydrogen, 30% moisture, and bioaugmentation

5.7.4 Treatability Study Conclusions

The treatability study demonstrated that complete reductive dechlorination of TCE and its daughter products could occur in Site soils with the addition of the gaseous electron donor hydrogen. However, several factors influenced the success of electron donor addition. Bioaugmentation with a commercially available culture containing *Dehalococcoides* had the greatest impact. All bioaugmented conditions rapidly achieved at least some transformation of TCE to cis-1,2-DCE, whereas none of the un-bioaugmented conditions did so until the last sampling point of the experiment. Complete dechlorination of TCE to ethene occurred only with bioaugmentation, and when moisture level and electron donor concentration were both high. For fastest bioremediation of Site vadose zone soil using this technology a combination of bioaugmentation, high electron donor dosing, and moisture addition would be required.

However, the fact that some TCE transformation did occur in un-bioaugmented bottles after 100 days of incubation suggests that, given time, dechlorinator activity may increase at the site. Whether additional time would lead to complete reductive dechlorination is not known, but is not considered likely. Addition of the phosphorous nutrient – triethyl phosphate – did not appear to promote reductive dechlorination in un-bioaugmented microcosms, but may have initiated methanogenesis. LPG, which was added along with hydrogen, carbon dioxide, and nitrogen, was not inhibitory to reductive dechlorination when compared to pure propane gas. Because the LPG used in the bench-scale testing was not from the same source as the LPG used during the field demonstration, the lack of inhibition observed during the bench-scale testing does not unequivocally prove that the LPG used in the field was not inhibitory. It is possible that there could be differences in the concentrations of inhibitory minor constituents in LPG, from one refinery to another, and also batch-to-batch differences. However, the observed increases in DCE during the field demonstration serves as one line-of-evidence indicating that the LPG used at the site did not appear to be inhibitory to reductive dechlorination.

A high moisture content (30%) promoted the most complete reductive dechlorination under conditions with high electron donor concentration (10%) and bioaugmentation, interestingly, lower moisture contents (17% to 19%) promoted reductive dechlorination of TCE to cis-1,2-DCE more effectively than a high moisture content (30%) when the electron donor concentration was low (1%). The reason appears to be competition for hydrogen since hydrogenotrophic methanogenesis led to rapid depletion of one percent hydrogen in the high moisture condition. This depletion may have resulted in hydrogen concentrations less than threshold requirements for reductive dechlorination. Thus use of low hydrogen concentrations in a field setting would require continuous injection to prevent depletion.

5.8 SUMMARY

We tested a new Hydrogen-based Treatment technology (H_2T) where gaseous hydrogen and other gases were injected into a fine-grained vadose zone at a former missile silo site in Nebraska. The hydrogen gas was designed to stimulate biodegradation of the chlorinated solvent contaminants that persisted in this zone even after 3 years of soil vapor extraction (SVE). The process can be thought as a type of “Anaerobic Bioventing” for unsaturated zones containing chlorinated solvents.

Over the 6-month test, a total of 830,000 standard cubic feet of gas was injected with the following average composition: 79% nitrogen, 10% hydrogen, 10% propane, and 1% carbon dioxide. The nitrogen and propane were added to help keep the system anaerobic from oxygen diffusing into the test zone. The carbon dioxide was added to ensure a carbon source for the dechlorinating bacteria. Because of inconclusive sampling results during the test, the total gas flow rate and hydrogen composition were doubled for the last month of the injection phase and the total gas flow rate was increased from 2.5 scfm to 5.0 scfm and hydrogen composition was increased from 10% to 20%. An increase in hydrogen and propane concentrations and decrease in oxygen concentrations were observed at the monitoring points after increase in the flow rate and hydrogen composition.

The total estimated TCE mass in the treatment zone (excluding results from MW-9, since this well is located outside the treatment area) dropped from 289 gr during the pre-treatment characterization phase to 127 gr during the post-treatment characterization phase. The total estimated cis-1,2-DCE mass increased from 464 gr during the pre-treatment characterization phase to 573 gr during the post-treatment characterization phase. The estimated mass showed that approximately 56% reduction in TCE mass and approximately 24% increase in DCE mass (sum of cis 1,2- and trans 1,2-DCE) were observed, for a total of 6% reduction in total chlorinated compounds. The molar mass of chlorinated compounds was unchanged (7.1 moles before vs. 7.1 moles after). Therefore while the system was successful at converting TCE, a “cis-DCE stall” condition at the site appeared to be present at the site.

The success criteria of H_2T performance and outcomes are summarized below:

- The target radius of influence (ROI) of 15 feet was achieved. ROI for helium was 15 feet. Low O_2 concentration in MWs up to 40 feet. H_2, and propane detected in MWs up to 40 feet.
- 50% or greater reduction in baseline (no action) mass was not achieved. TCE mass reduced by 56% over six months. (This was TCE remaining in soil after 3 years of SVE operation). Number of soil samples above 57µg/kg standard dropped from 27% to 10%. Total moles of CVOC unchanged due to apparent cis-DCE stall.
- In some cases, cost savings can be achieved compared to SVE or excavation.
- 50% reduction in the carbon footprint compared to SVE with oxidizer or carbon was achieved. H_2T carbon footprint was 8 tons of CO_2 compared to 21 tons for SVE (high end). H_2T CO_2 footprint was 43% of SVE (low end).
- Flammabilities of less than 10% of LEL at surface were achieved. No health and safety incidents occurred. H_2, and propane never detected in ambient air.
- The H_2T system was easy to implement. Lower time requirement for system setup, data collection, etc. compared to SVE. One field technician did the weekly O&M, made the pressure-flow readings and collected the data.

5.8.1 Comparison of Field and Laboratory Test Results

H_2T demonstration at the site and the treatability tests in the laboratory were conducted in parallel. Key points from the field and laboratory tests are summarized below:

- The H_2T process removed half the TCE from the test zone that had been treated with soil vapor extraction for 3 years. This indicates the process may be effective for treating finer-grained units that are difficult to treat with SVE.
- In-test measurements of redox-related parameters (oxygen, methane) indicated that deeply anaerobic conditions were not achieved uniformly through the test zone, a likely contributing factor for the observed cis-DCE stall condition. For example, the average oxygen content in the treatment zone soils during test ranged from 0.1% to 11%.
- Lab microcosm work where the gas mixture was added to soil samples from the site indicated that samples that had been bioaugmented with dechlorinating bacteria performed much better than unamended soils, indicated a dechlorinating bacterial limitation at the site. The team strongly recommends that one should understand the bacterial limitation and issues involved with vadose zone bioaugmentation before attempting this technology.
- Redox-related parameters (oxygen, methane) measured in the field indicated that deeply anaerobic conditions were not achieved uniformly through the test zone, a likely contributing factor for the observed cis-DCE stall condition. The research team concluded that the system’s inability to create deeply anaerobic conditions was likely a major factor in the cis-DCE stall issue. The team recommends that one should understand the issues involved with creating and sustaining deeply reducing conditions before attempting this technology.

- Additional microcosm results indicated that low moisture may have been a contributing factor to this bacterial limitation. Lab microcosm work showed that a high moisture content (30%) promoted the most complete reductive dechlorination under conditions with high electron donor concentration (10%) and bioaugmentation. However, lower moisture contents (17% to 19%) promoted reductive dechlorination of TCE to cis-1,2-DCE more effectively than a high moisture content (30%) when the electron donor concentration was low (1%). The later condition for moisture content and electron donor concentration was similar to the condition observed in the field.
- It is possible to safely injection the hydrogen, nitrogen, propane, carbon dioxide gas mixture in the test zone. The radius of influence from the injection point was approximately 15 feet.
- In-test vapor VOC monitoring data were not very helpful in evaluating the progress of remediation.
- The H_2T system for this test was more successful than the existing SVE system at removing TCE from the fine-grained soils at this test site, but was not successful at removing a significant fraction of the cis-DCE. To help drive a full-scale H_2T drive a treatment zone to deeply anaerobic conditions, some type of barriers over the top and around the sides of the treatment zone (even something as simple as adding water to reduce the gas permeability of the soils) might help break out of a cis-DCE stall condition.

5.8.2 Lessons Learned

A summary of the lessons learned during the H_2T implementation at the demonstration site is below:

- While cis-DCE was observed in the unsaturated zone, it still may be difficult to get to deeply anaerobic conditions. Future applications need to consider how to put in barriers to stop or reduce oxygen inward diffusion around outside of treatment zone, and potential caps or covers for top (we did not have a top diffusion problem at the demonstration site). One potential approach is wetting the soils around the perimeter of the treatment zone with soaker hoses or injection wells. One potential approach is wetting the soils around the perimeter of the treatment zone with soaker hoses and injection wells. It is likely that multi-level injection wells would be required to provide adequate distribution of water, around the perimeter, and across all the desired depth intervals.
- Extensive consideration was given near the last half of this test to see if some type of bioaugmentation could be performed. In the end the difficulties in distributing a liquid containing bacteria throughout this fine-grained unsaturated test zone was considered to be difficult.
- The H_2T process is best suited for fine-grained soils with a reasonable degree of pneumatic interconnectivity. The structure of silty, loess-like soil at the site may have included some micro-fractures, which probably conveyed the majority of the volume of gas around some areas within the treatment zone. It would follow that the postulated, disconnected, zones of low permeability may have retained enough oxygen to inhibit reductive dechlorination within these zones. In a general sense, it is postulated that higher permeability soils (i.e., fine-

grained sands) may allow for more uniform distribution of gasses, and more rapid displacement of oxygen; which could improve the effectiveness of the technology. However, one downside to trying to implement the technology in a higher permeability soils is that there would probably be a higher rate of gas consumption, which would impact costs. The research team concluded that the system's inability to create deeply anaerobic conditions was likely a major factor in the cis-DCE stall issue.

- Both microbial limitations and the inability to sustain highly reducing conditions throughout the treatment zone are important for vadose soils, especially after an SVE system has been in operation, because there are likely to be very low populations of *Dehalococcoides* in aerobic media and even slow oxygen influx from the surface or perimeters could make it difficult to sustain sufficiently reducing conditions. Practitioners considering this technology should select sites with appropriate levels of anaerobic conditions and populations of *Dehalococcoides* in the vadose zone.
- Implementation of H_2T is likely as or more expensive than SVE, but more effective for removing parent compounds. For the hypothetical full scale treatment, H_2T was at least half the cost of excavation.
- Extensive vapor sampling for chlorinated compounds during the test may not be that useful. Sampling for the injection gases and oxygen and methane was useful to the research team conducting this pilot test.
- For full scale systems, use of hydrogen generators has the potential to reduce gas costs by up to 50%. These generators need access to water and electrical power or a fuel such as methane or propane, however.

6.0 PERFORMANCE ASSESSMENT

A summary of the performance objectives for this demonstration, along with an overview of technology performance, was presented in Section 3. This section includes a more detailed assessment of technology performance based on the quantitative data presented in Section 5. Following completion of the sampling and analysis program, the data were reviewed to determine whether the success criteria for each performance objective have been met. The evaluation of each individual performance objective is discussed below.

6.1 ACHIEVEMENT OF A GREATER ROI

Success Criteria Achieved? **YES**

Measurements of different gases at the monitoring points were used for this purpose. Monitoring points were located between 10 to 40 feet from the injection points. Success was defined as an ROI that is 50% greater compared to ROI of liquid addition to the unsaturated zone, estimated to be 5 to 10 feet. The ROI achievement was evaluated in two ways:

(1) Tracer test using helium/nitrogen tracer gas.

Helium gas reached the 10-ft distance monitoring wells at all depths (i.e., shallow, medium, and deep). Tracer gas reached almost all the monitoring wells including the 15-ft distance monitoring wells after Day 4. However, the levels of helium percentage were not high enough at the monitoring points farther than 15 feet from the injection points (i.e., 50% of the helium concentration in the injection gas) to confirm that the ROI extended beyond approximately 15 feet. The tracer test also generated data that demonstrated the presence of preferential pathways.

(2) Evaluating the ROI by looking at the concentrations of oxygen, hydrogen, and propane gases before, during, and after the gas injection phase.

Average oxygen concentrations were reduced from 16.1% to 0.4% in shallow, 16.8% to 5.7% in medium, and 16.3% to 5.7% in deep monitoring points. The low oxygen concentrations in the shallow monitoring points were observed at distances up to 40 feet away from the point of injection, while for the medium and deep monitoring points, oxygen concentrations increased significantly at around 15 feet distance from the point of injection. While anaerobic conditions never reached at the medium and deep monitoring points, low oxygen concentrations were attainable at shallower depths.

Hydrogen was detectable at all depths and distances as far as 40 feet from the injection point exceeding the 15-feet target ROI. Hydrogen concentrations never reached the injected concentration of 10%. The highest hydrogen concentrations were observed at the shallow depths (i.e., 15 ft-bgs) and generally decreased as the depth increased and as the distance from injection point increased.

Propane was more easily distributed than hydrogen both with respect to distance from injection and depth. The detected propane concentration before gas injection (i.e., May 2011) ranged from

<0.02 ppmv to 4.5 ppmv. Measured propane concentrations after gas injection (i.e., December 2011) ranged from 11.5 ppmv to 85,030 ppmv. Propane was easily distributed at significant distances from the point of injection at the 20, 30, and 40-ft bgs depths. For example, propane concentration of 16,397 ppmv was observed at MW-8D which is 40 feet away from the injection point.

6.2 GREATER REDUCTION IN BASELINE MASS

Success Criteria Achieved? **YES FOR TCE, NO FOR DAUGHTER PRODUCTS**

The mass of trichloroethene (TCE) and its daughter products in soil was measured both before and after the demonstration was calculated. This analysis included the change in concentration and mass for 48 sample pairs collected from all of the injection and monitoring well locations during pre- and post-treatment characterization phases. Success was defined as 50% or greater reduction in baseline (no action) mass.

The median TCE concentrations of all 48 samples (i.e., 12 sampling locations and 4 depths) dropped from approximately 8 µg/kg during the pre-treatment characterization phase to 4 µg/kg during the post-treatment characterization phase. The median cis-1,2-DCE concentrations of all 48 samples (i.e., 12 sampling locations and 4 depths) increased from 17 µg/kg during the pre-treatment characterization phase to 40 µg/kg during the post-treatment characterization phase. The median TCE concentration decreased approximately 50% and median cis-1,2-DCE concentration increased approximately 123%.

The number of soil samples with TCE concentrations above 57 µg/kg which is the NDEQ soil remediation goal dropped from 13 samples in pre-treatment to 5 samples in post-treatment. The number of soil samples with cis-1,2-DCE concentrations above 400 µg/kg which is the NDEQ soil remediation goal dropped from 10 samples in pre-treatment to 9 samples in post-treatment.

The total estimated TCE mass in the treatment zone - excluding results from MW-9, since this well is located outside the treatment area - dropped from 289 gr during the pre-treatment characterization phase to 127 gr during the post-treatment characterization phase. The total estimated cis-1,2-DCE mass increased from 464 gr during the pre-treatment characterization phase to 573 gr during the post-treatment characterization phase. The estimated mass showed that approximately 56% reduction in TCE mass and approximately 24% increase in cis-1,2-DCE mass were observed. An increase in the total mass of trans-1,2-DCE was also observed. The total molar mass of chlorinated compounds was unchanged (7.1 moles before vs. 7.1 moles after). Therefore while the system was successful at converting TCE, a “cis-DCE stall” condition at the site appeared to be present at the site.

Several t-test and Mann-Whitney analyses were performed to compare the means of the 48-pair TCE samples from pre- and post-treatment characterization phases. Average TCE concentration dropped from 166 µg/kg during the pre-treatment characterization phase to 74 µg/kg during the post-treatment characterization phase. The t-test conducted on the 48-pair samples resulted in p-value of 0.092 that corresponds to a 90.8% confidence in support of the hypothesis that the post-treatment TCE concentrations are smaller than the pre-treatment TCE concentrations. The Mann-

Whitney analysis also resulted in a similar p-value of 0.104 that corresponds to a 89.6% confidence in support of the hypothesis that post-treatment TCE concentrations are significantly smaller than the pre-treatment TCE concentrations.

Both t-test and Mann-Whitney analyses show that there is approximately 90% confidence that the post-treatment TCE concentrations are significantly less than the pre-treatment TCE concentrations. The data sets are characterized by large variability (e.g., extreme positive outliers) and relatively large number of non-detects, which tends to adversely affects the power of statistical tests to detect differences. Similar analyses were performed for cis-1,2-DCE and the results show that there is greater than a 90% but less than a 95% probability that the post-treatment cis-1,2-DCE soil concentrations are significantly greater than the pre-treatment cis-1,2-DCE soil concentrations.

6.3 COST SAVINGS COMPARED TO CONTINUED SVE OPERATION

Success Criteria Achieved? **SOMETIMES**

The cost of H_2T application compared to SVE and soil excavation was calculated using the following cost drivers: the radius of influence to estimate the number of injection points, capital costs (injection skid; manifold system, wells), and O&M costs (delivered gas, operator cost). . Three scenarios were considered and compared based on data collected during this H_2T demonstration. In each scenario the H_2T system was compared with an alternative SVE system. All three scenarios represent the successful design used in the demonstration and had an ROI of 15 feet and a gas composition based on 20 percent hydrogen.

For all scenarios, the cost of H_2T was greater than SVE system operation. In Scenarios 1 and 2, the cost of H_2T system operation for two years based on the implemented demonstration design conditions was \$39/cy compared to the entire SVE system operation (i.e., \$37/cy) and soil excavation (i.e., \$97/cy). In Scenario 3, the cost of H_2T system operation based on the implemented demonstration design conditions was \$39/cy compared to the continuation of the existing SVE system operation (i.e., \$20/cy). Finally, in Scenario 4, the cost of H_2T system operation by using the existing SVE wells as gas injection wells was \$35/cy compared to the continuation of the existing SVE system operation (i.e., \$20/cy).

It must be noted that the decision to switch to H_2T operation over an SVE system should be made based on the overall performance and not only on the cost assessments. For example, in the demonstration site where an SVE system was operating since 2008, the SVE system was not able to reduce the mass in the vadose zone due to the very low permeability soil (i.e., clayey silt loess material). Small molecules of hydrogen gas, on the other hand, were able to diffuse into the small pores of the low-permeability soil.

6.4 REDUCTION IN CARBON FOOTPRINT COMPARED TO SVE

Success Criteria Achieved? **MOSTLY YES**

The carbon footprint was estimated for two variations of H_2T (i.e., liquid nitrogen/hydrogen cylinder delivery versus on-site nitrogen and hydrogen generation) and compared to two variations of SVE system operation (i.e., continuous versus pulsed operation at 25% time). Success was defined as 50% reduction in the carbon footprint compared to SVE.

Using spreadsheet calculations (see Appendix G), the following values were calculated for the demonstration TCE site operating for a year (i.e., a treatment zone with dimensions of approximately 2,200 ft^2 area and 40 foot thickness). The most sensitive parameters included: 1) use of cylinders, gas in cryo-liquid form; tube trailers, or on-site nitrogen and/or hydrogen generators; 2) amount of electricity used by SVE system blower and gas generators; 3) amount of gas used in the direct hydrogen delivery process; and 4) number of trips required to deliver gas to the site. There were considerable uncertainties in the calculation. At some sites, use of SVE and activated carbon could result in a lower carbon footprint than the direct hydrogen injection process. Results from carbon footprint calculation are summarized in **Table 23**.

Table 23: Results of carbon footprint calculations

Item	**Amount (tons per year)**	**Source of Data**	**Item**	**Amount (tons per year)**	**Source of Data**
High End Carbon Footprint Cases					
SVE + GAC Treatment Continuous Operation			Direct Hydrogen Delivery Process Liquid Nitrogen Delivery		
Electricity for Blower	19.0	SRT[1]	Producing H_2, LPG, and CO_2	5.4	assume 1% efficiency for H_2 consumption
Regenerating GAC	2.1	SRT	Producing N_2	0.6	from energy use calculations
Transporting GAC	0.3	SRT	Transporting gas to site	2.1	estimated trips + SRT
TOTAL	**21.4**		**TOTAL**	**8.1**	
Percent Reduction in carbon footprint compared to SVE+GAC: **62%**					
Low End Cases Carbon Footprint Cases					
SVE + GAC Treatment Pulsed Operation at 25% Time			On-Site Nitrogen and Hydrogen Generation		
Electricity for Blower	5.3	Tier 2 SRT[2]	Producing CO_2	0.6	assume 1% efficiency for H_2 consumption
Regenerating GAC	2.1	SRT	Producing H_2 and N_2 on-site	2.8	from energy use calculations
Transporting GAC	0.3	SRT	Transporting gas to site	1.0	estimated trips + SRT
TOTAL	**7.7**		**TOTAL**	**4.4**	
Percent Reduction in carbon footprint compared to SVE+GAC: **43%**					

[1] SRT Tier 1 typical value assumes system operates 90% of time

[2] Assumes system operates 25% of time

For the high end carbon footprint case, where a constant operation of SVE+GAC was compared with direct liquid nitrogen/hydrogen cylinder delivery, the carbon footprint was 21.4 tons of CO_2 for SVE+GAC versus 8.1 tons of CO_2 for the H_2T system. For the high end case, the carbon footprint of H_2T system operation is approximately 62% less than SVE system operation. For the low end case, where a pulsed operation of SVE+GAC was compared with on-site nitrogen and hydrogen generation, the carbon footprint was 7.7 tons of CO_2 for SVE+GAC versus 4.4 tons of CO_2 for the H_2T system. For the low end case, the carbon footprint of H_2T system operation is approximately 43% less than SVE system operation. Note that the high-end hydrogen case has approximately the same footprint as the low-end SVE case. In the carbon footprint calculations, it was assumed that the generated methane stays in the vadose zone and the amount is negligible compared to other contributors to the carbon footprint. Therefore, methane generation and its potential emission were not included in the carbon footprint calculations.

6.5 SAFETY

Success Criteria Achieved? **YES**

One of the potential risks associated with field implementation of the H_2T system is the use of gases (i.e., H_2 and LPG) that are explosive under certain conditions. Although the concentration of the explosive gases in the gas mixture is 20% by volume, it was expected that the H_2T process was considered safe because the flammable gases disperse quite readily in the atmosphere and no detections of flammable gases above ground were observed. It is also expected that the oxygen levels at the injection points below ground surface are close to zero. Nevertheless, standard engineering practices can be used to provide a safe system. As part of H_2T performance objective the concentrations of H_2 and propane were monitored at the surface to maintain levels below the lower explosive levels (LEL) at the surface. The effectiveness was a function of satisfying all of the compressed gas safety codes (i.e., NFPA50A, NFPA55). As part of H_2T performance objective the lower explosive level (LEL) of H_2 and propane were monitored at the surface to maintain concentrations of the explosive gases below the LEL at the surface.

The objective was considered to be met if flammable gas concentrations of less than 10% of the lower explosive limit (LEL) at surface are achieved. In order to evaluate the safety concerns associated with the technology, flammability relative to explosivity limits were assessed along with H_2 air emissions. Soil gas monitoring included explosivity measurements using an explosivity meter.

No health and safety incidents occurred during the demonstration and flammable gas concentrations above the ground surface were not detectable. It should be noted that hydrogen and propane concentrations exceeded the LELs at some points below ground surface, but there was not enough oxygen available at those points to make the system potentially explosive. While concerns regarding safety of hydrogen and propane injections are reasonable, the results of this demonstration indicate the technology can be implemented safely.

6.6 EASE OF USE

Success Criteria Achieved? **YES**

The effectiveness of the technology is also related to the relatively easy implementation of the H_2T system compared to other technologies such as SVE. It was anticipated that the ease of permitting (no air permits were required) and the ease of operation make the implementation of this technology quick and easy. Success criteria for this performance objective were evaluated qualitatively. It should be noted that a site-specific comparison of H_2T vs. SVE operation should be implemented because the ease of use also depends whether engineering controls for safety is implemented for H_2T or vapor-phase emissions control system is needed for SVE.

Required operator manpower was evaluated for both the existing SVE system and for H_2T system. Feedback from field personnel regarding ease of use of H_2T compared to SVE was also used. The metric for this performance objective was the frequency at which an operator needed to visit the site. The reasons for site visitation during normal operations included gas cylinder change-outs, system leak test, pressure and flow readings, and monitoring. This occurred once per week (i.e., weekly O&M) or every few weeks (i.e., tank re-fill or cylinder replacement), which was considered reasonable.

7.0 COST ASSESSMENT

This section provides an assessment of full-scale H_2T costs and drivers. The H_2T demonstration site (former Atlas Missile site) was used as a basis for developing the cost estimates. Four different scenarios were developed for in situ treatment of TCE in the unsaturated zone at this site. These scenarios were developed to compare actual demonstration design and operating conditions to likely full-scale design and operating conditions.

As part of the demonstration, the cost of implementing the field demonstration program was carefully tracked and this cost data was used to estimate the expected cost of implementing the H_2T system at other sites. In addition, the cost of potential bioaugmentation and barrier measures including capping or wetting the margins to prevent oxygen intrusion were roughly estimated. Bioaugmentation costs were included as a contingency (assuming bioaugmentation can be done effectively at some sites) to achieve complete dechlorination. A cost model was developed for H_2T system. The key elements of the cost models are provided in **Table 24**.

Table 24: Cost model for a H_2T system

Cost Element	Tracked Data
Treatability study	Personnel required and associated labor and materials
Gas injection skid	Capital cost: $ per skid construction
Consumable gases	Unit: $ per cubic foot of treated soil Data requirements: - Volume and $ per cubic foot of consumable gases - Cylinder and tank rental costs - Gas delivery costs
Baseline characterization	• Costs associated with labor and materials were tracked • Standard contaminant & hydrogeology assessment, no cost tracking
Soil sample collection and analysis	• Personnel required and labor costs, material costs, laboratory costs
Data evaluation	• Personnel required and labor costs
Bioaugmentation	• Costs associated with labor and materials were estimated
Injection and monitoring points installation	Unit: $ per injection point, $ per monitoring point or Unit: $ per cubic foot of treated soil Data Requirements: - Recommended installation method - Mobilization cost - Time required - Material
Barrier implementation: capping and/or wetting the margins	• Costs associated with labor and materials were estimated
Waste disposal	Waste soil was disposed on-site. No cost was tracked.
Operation and maintenance costs	No unique requirements, but issues that arose were noted.

7.1 COST MODEL

A cost evaluation assuming full-scale treatment of affected soils at the former Atlas Missile Site was performed. This treatment zone represented approximately 46,000 cubic yards of soil. All costs associated with the field validation/demonstration of the H_2T system were tracked in an Excel spreadsheet. The site-specific conditions must be considered in the design when the cost analysis calculations in this cost model are transferred to other sites. Three scenarios were considered and compared in this cost assessment based on data collected during this H_2T demonstration. In each scenario the H_2T system was compared with an alternative SVE system. All scenarios represent the successful H_2T design used in the demonstration except for the nitrogen and hydrogen generators and have an ROI of 15 feet and a gas composition based on 20 percent hydrogen.

There are 39 SVE wells at the site in the area that TCE soil concentration had initially exceeded the NDEQ soil remediation goal of 57 µg/kg before the start of SVE system operation in 2008 (i.e., approximately 27,500 square feet or 0.6 acre). For the purpose of this study, a cost assessment for a similar SVE system was performed (i.e., number of wells, flow rates, on-site treatment system, treatment area, etc.). **Figure 46** shows the treatment area (i.e., the area within the red line) and the number and location of the existing SVE wells.

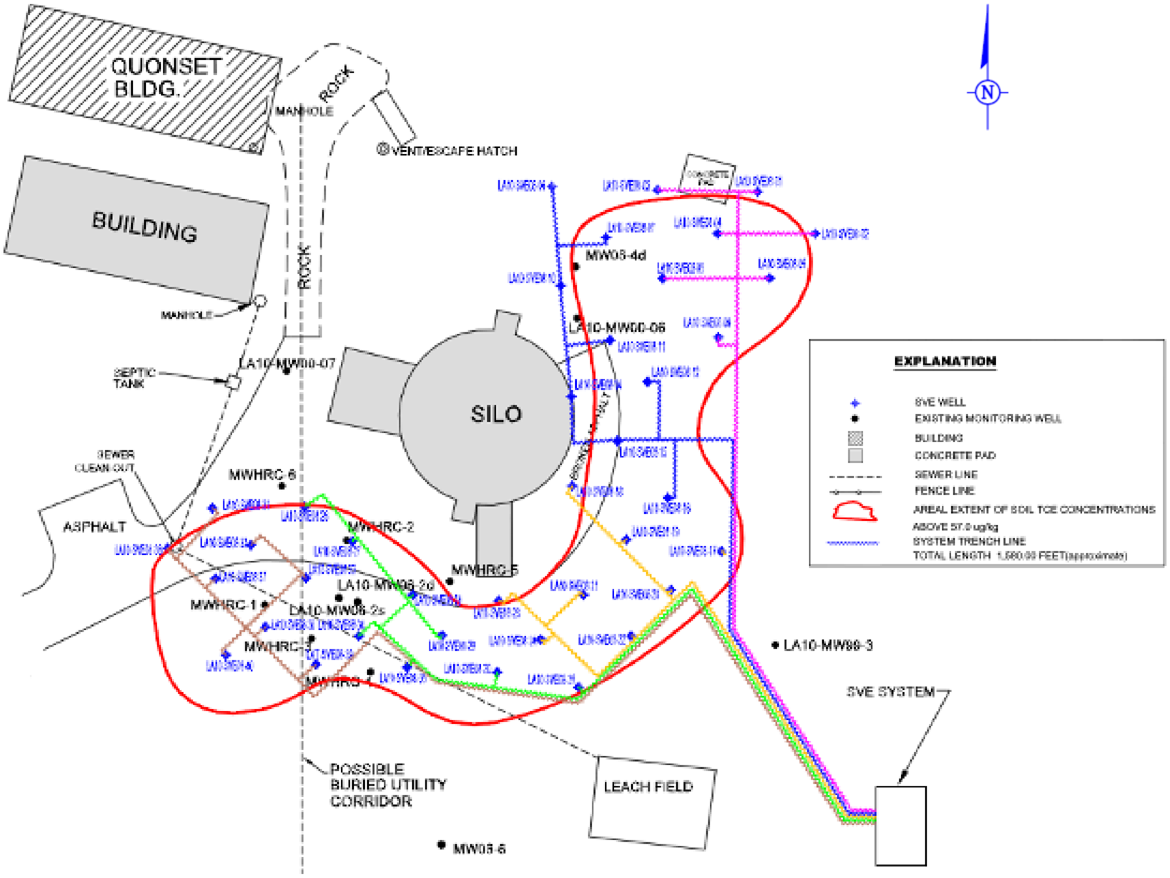


Figure 46: Soil vapor extraction system map (Source: *Kemron, 2009*)

SVE Scenario 1: H_2T vs. New SVE System. This scenario represents the comparison of costs associated with the H_2T system with the costs associated with setting up and operating an entire SVE system including the capital cost of well installation and GAC treatment system or soil excavation. Scenario 1 represents the design used in the demonstration where gas injection wells were installed for the H_2T system and the SVE wells were shut down and were not used as gas injection wells.

Excavation Scenario 2: H_2T vs. Soil Excavation. This scenario represents the comparison of costs associated with the H_2T system with the costs associated with soil excavation. Similar to Scenario 1, Scenario 2 represents the design used in the demonstration where gas injection wells were installed for the H_2T system.

SVE Scenario 3: H_2T with New Gas Injection Wells vs. Continuing Operation of an Existing SVE System. This scenario represents the comparison of costs associated with the H_2T system with the costs associated with continuing an existing SVE system operation. Similar to Scenarios 1 and 2, Scenario 3 represents the design used in the demonstration where gas injection wells were installed for the H_2T system and the SVE wells were shut down and were not used as gas injection wells.

SVE Scenario 4: H_2T with Existing SVE Wells vs. Continuing Operation of an Existing SVE System. In scenario 3, the existing SVE wells were used as the gas injection wells for the H_2T system. Scenario 4 represents the conditions where the screen intervals are not very long and the site managers decide to use the existing SVE wells as H_2T gas injection wells.

7.1.1 Assumptions

The assumptions made during this cost assessment are summarized below:

- Pre- and post-project site characterization activities are similar for the H_2T and SVE systems.
- For scenarios where injection and monitoring well installation is required, one monitoring point will be installed for every five injection points. The designs of injection and monitoring wells were different.
- The total area of TCE contamination at the demonstration site is based on the TCE soil concentrations above 57µg/kg is the same in all depths from 0 to 60 ft bgs and was estimated based on the data presented in the Site Investigation Report (Kemron, 2007).
- ROI was 15 feet for both the SVE and H_2T systems in all scenarios. ROI was approximately 15 feet for the SVE system based on the placement of the existing SVE wells.
- Soil type in the treatment area allows the uniform distribution of both injected gas for H_2T system and extracted air for the SVE system.
- Labor unit costs for site characterization activities, well installation, O&M, and system performance monitoring are similar for the H_2T and SVE systems.
- The whole project will take two years.

- Because of the large injected gas volume, nitrogen and hydrogen gases are produced using generators. Vendor quotes were used for the capital costs and power consumption of the generators.
- Gas unit costs do not change over the course of the project.
- LPG was replaced by hydrogen and the total hydrogen composition in the injected gas mixture is increased to 20% for all flowrates.
- Water barrier wells were installed at the treatment zone perimeter using 74 temporary holes (i.e., assuming 5-foot ROI). It was assumed that water would be injected at an injection rate of 5 gallons per minute (gpm) per well.
- Bioaugmentation was implemented to the entire treatment zone area with 10-foot radius of influence. I was assumed that the bioaugmentation was performed in 88 wells (i.e., assuming 10-foot ROI) at an injection rate of 10 gpm per well was assumed.

The specific elements of the cost model unique to the implementation of the H_2T system are described below.

7.1.2 Cost Elements

No rigorous cost model has been developed for anaerobic bioventing; however, the costs should be similar to aerobic bioventing with the following additional costs: field treatability and tracer tests; gas mixture additions; and additional soil and gas analyses.

Gas Mixture Injection Skid: Application of the H_2T system requires construction of the gas mixture injection skid. The design, labor and material costs associated with construction of the gas mixture injection skid were tracked in the Excel spreadsheet.

Consumable Gases (i.e., H_2, N_2, LPG, and CO_2): Application of the H_2T system requires hydrogen and nitrogen gases as the major components of the gas mixture. These gases will be provided either by a vendor in the form of compressed gas or liquid, or by using generators. For the demonstration, material costs associated with preparation of the gas mixture were tracked in an Excel spreadsheet. For the demonstration the hydrogen gas was provided in cylinders and nitrogen was provided in liquid form in a tube trailers. No vaporizer was needed for nitrogen.

It should be noted that the cost of nitrogen and hydrogen generators should be included in the cost estimate for large scale H_2T system where large amount of nitrogen and hydrogen required. When high volume of nitrogen and hydrogen needed for injection, it is more economical to purchase a generator and produce nitrogen and/or hydrogen on-site than to buy these gases in cylinders, tube trailers or liquid nitrogen tanks. If H_2T is applied at a small site, it is possible that purchasing compressed or liquid nitrogen or hydrogen cylinders is more cost effective. Because the volume of gas needed is site-specific, when estimating H_2T implementation costs at another site, a cost comparison is needed to decide whether a nitrogen or hydrogen generators should be used.

Installation of Injection and Monitoring Points: Application of the H_2T system requires installation of injection and monitoring points, such that the labor and material costs associated with installation of these points was tracked.

Treatability and Tracer Studies: A H_2T treatability study to determine the site-specific requirements for implementation of the technology may be useful at some sites. The field treatability study involves one or both of the following elements: 1) injection of air into a single well at various flow rates to characterize gas permeability and pneumatic radius of influence in the vadose zone, and 2) tracer tests to determine the rate of consumption of oxygen and influence of oxygen diffusion from the surface. During the tracer test, H_2 and helium are injected together and H_2 and O_2 consumption is monitored in comparison with helium as the conservative tracer.

Cost data that was tracked included the following cost parameters: labor, materials, and analytical testing. Labor was tracked according to the type of personnel required to conduct the treatability study (field technician, engineer, program manager, etc.) and their associated labor hours.

Bioaugmentation and Water Barrier Installation: Successful application of the H_2T technology at some or many sites (such as this site) may require bioaugmentation in the vadose zone and/or installation of barriers such as capping or wetting the margins to prevent oxygen intrusion. Costs associated with this step were estimated based on the required labor time and material.

Soil and Soil Vapor Sample Collection and Analysis: Application of the H_2T system requires measurement of CVOC concentrations in soil and soil vapor, oxygen levels throughout the study area (zone of influence), and soil moisture in different soil layers (Alternatively, soil moisture can be estimated based on field observations and knowledge of local climate.). For the demonstration, costs associated with collection and analysis of soil and soil vapor samples were tracked.

Data Evaluation: Application of the H_2T system requires review of the soil boring logs, CVOC soil and soil vapor concentrations and other site data to evaluate the performance of the H_2T system at the site. Costs associated with this step were estimated based on the field demonstration as well as experience with application of other bioventing systems at other sites.

Operation and Maintenance (O&M): Application of the H_2T system requires operation and maintenance (O&M) that includes delivered gas and operator costs. These labor and material costs were tracked as part of the demonstration.

7.2 COST ANALYSIS

This section provides a cost comparison of each of the scenarios. The cost inputs for this estimate were based on demonstration data, vendor quotes, or the Remedial Action Cost Engineering and Requirements (RACER) software (RACER, Version 10.4). Drillers and certified analytical laboratories that were part of the H_2T demonstration were used to estimate drilling and analytical costs. The cost breakdown for each scenario is presented in **Table 25**.

Table 25: Project implementation costs at former Atlas Missile Site for different designs

		SCENARIO 1		SCENARIO 2		SCENARIO 3		SCENARIO 4	
		H_2T	SVE	H_2T	EXCAVATION	H_2T	SVE	H_2T	SVE
COST ELEMENT	**DATA TRACKED**	**(entire system)**	**(entire system)**	**(entire system)**	**(entire system)**	**(entire system)**	**(existing system)**	**(use SVE wells)**	**(existing system)**
TASK 1. Treatability Study and Site Characterization (i.e., Soil concentration, permeability test, microcosm study, qPCR testing, etc.)									
Project management	Labor (Sr. Technical), 50 hrs	$7,500	$7,500	$7,500	$7,500	$7,500	$0	$7,500	$0
Travel to the site	Airfare, per diem, etc.	$10,000	$10,000	$10,000	$10,000	$10,000	$0	$10,000	$0
Drilling	Drilling subcontractor	$25,000	$25,000	$25,000	$25,000	$25,000	$0	$25,000	$0
Soil sample collection and shipping	Labor time and material	$6,000	$6,000	$6,000	$6,000	$6,000	$0	$6,000	$0
Analytical laboratory	Lab fee	$10,000	$10,000	$10,000	$10,000	$10,000	$0	$10,000	$0
Waste disposal	Permitting, labor and material	$6,000	$6,000	$6,000	$0	$6,000	$0	$6,000	$0
Microcosm study	Laboratory fees	$40,000	$0	$40,000	$0	$40,000	$0	$40,000	$0
Data review and analysis	Sr. Technical, 50 hrs	$7,500	$7,500	$7,500	$7,500	$7,500	$0	$7,500	$0
Miscellaneous costs	-	$10,000	$10,000	$10,000	$10,000	$10,000	$0	$10,000	$0
Task 1 Total		**$122,000**	**$82,000**	**$122,000**	**$76,000**	**$122,000**	**$0**	**$122,000**	**$0**
TASK 2. Engineering Design, Construction (i.e., Gas Injection Skid, SVE System, Gas Distribution System, etc.)									
Project management	Labor (Sr. Technical), 80 hrs	$12,000	$12,000	$12,000	$6,000	$12,000	$6,000	$12,000	$6,000
Travel to the site	Airfare, per diem, etc.	$10,000	$10,000	$10,000	$0	$10,000	$0	$10,000	$0
System Design	Sr. Technical / Subcontractor	$40,000	$65,000	$40,000	$0	$40,000	$0	$40,000	$0
System Construction	Subcontractor	$80,000	$300,000	$80,000	$0	$80,000	$0	$80,000	$0
Shipping	Shipping to the site	$2,000	$2,000	$2,000	$0	$2,000	$0	$2,000	$0
Bioaugmentation	Labor time and material	$310,000	$0	$310,000	$0	$310,000	$0	$310,000	$0
Barrier implementation: capping and/or w etting the margins	Labor time and material	$120,000	$0	$120,000	$0	$120,000	$0	$120,000	$0
Miscellaneous costs	-	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
TASK 2 Total		**$584,000**	**$399,000**	**$584,000**	**$16,000**	**$584,000**	**$16,000**	**$584,000**	**$16,000**
TASK 3. Installation									
Project management	Labor (Sr. Technical), 40 hrs	$6,000	$12,000	$6,000	$0	$6,000	$12,000	$6,000	$12,000
Travel to the site	Airfare, per diem, etc.	$20,000	$20,000	$20,000	$0	$20,000	$20,000	$20,000	$20,000
Drilling	Drilling subcontractor	$125,000	$125,000	$125,000	$0	$125,000	$0	$0	$0
System Installation (e.g., piping, trenching, etc.)	Labor time and material	$45,000	$65,000	$45,000	$0	$45,000	$0	$30,000	$0
Leak test, Tracer test	Labor time and material	$5,000	$5,000	$5,000	$0	$5,000	$0	$5,000	$0
Miscellaneous costs	-	$25,000	$25,000	$25,000	$0	$25,000	$25,000	$25,000	$25,000
TASK 3 Total		**$226,000**	**$252,000**	**$226,000**	**$0**	**$226,000**	**$57,000**	**$86,000**	**$57,000**
TASK 4. System Operation (i.e., O&M, Monitoring, etc.)									
Project management	Labor (Sr. Technical), 200 hrs	$30,000	$30,000	$30,000	$20,000	$30,000	$30,000	$30,000	$30,000
Travel to the site	Airfare, per diem, etc.	$35,000	$35,000	$35,000	$35,000	$35,000	$35,000	$35,000	$35,000
Sample collection and shipping	Labor time and material	$60,000	$50,000	$60,000	$30,000	$60,000	$50,000	$60,000	$50,000
Analytical laboratory	Lab fee	$80,000	$50,000	$80,000	$50,000	$80,000	$50,000	$80,000	$50,000
Gas	Material and delivery	$476,000	$0	$476,000	$0	$476,000	$0	$476,000	$0
Electricity	Pow er to run SVE system	$0	$70,000	$0	$0	$0	$70,000	$0	$70,000
On-site vapor treatment system	Material and maintenance	$0	$150,000	$0	$0	$0	$150,000	$0	$150,000
Weekly O&M	Technician, 800 hrs	$65,000	$65,000	$65,000	$8,000	$65,000	$65,000	$65,000	$65,000
Vapor monitoring (field)	Labor time and material	$45,000	$25,000	$45,000	$25,000	$45,000	$25,000	$45,000	$25,000
Soil excavation	Labor time and material	$0	$0	$0	$870,000	$0	$0	$0	$0
Off-site transportation and w aste disposal	Labor time and material	$0	$0	$0	$2,500,000	$0	$0	$0	$0
Miscellaneous costs	-	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000
TASK 4 Total		**$821,000**	**$505,000**	**$821,000**	**$3,568,000**	**$821,000**	**$505,000**	**$821,000**	**$505,000**
TASK 5. Post-Remediation Site Characterization									
Project management	Labor (Sr. Technical), 50 hrs	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
Travel to the site	Airfare, per diem, etc.	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Drilling	Drilling subcontractor	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000
Soil sample collection and shipping	Labor time and material	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000
Waste disposal	Permitting, labor and material	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000
Analytical laboratory	Laboratory fees	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
Data review and analysis	Labor (Sr. Technical), 50 hrs	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
Miscellaneous costs	-	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000
Task 5 Total		**$112,000**	**$112,000**	**$112,000**	**$112,000**	**$112,000**	**$112,000**	**$112,000**	**$112,000**
TASK 6. Final Report and Demobilization									
Prepare Draft Technical Report	Labor (Sr. Technical), 200 hrs	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000
Review Draft Technical Report	Labor (Sr. Technical), 50 hrs	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
Prepare Final Technical Report	Labor (Sr. Technical), 150 hrs	$22,500	$22,500	$22,500	$22,500	$22,500	$22,500	$22,500	$22,500
Prinicipal Oversight/Review	Labor (Sr. Technical), 40 hrs	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
Demobilization	-	$35,000	$35,000	$35,000	$35,000	$35,000	$35,000	$35,000	$35,000
Task 6 Total		**$110,000**	**$110,000**	**$110,000**	**$110,000**	**$110,000**	**$110,000**	**$110,000**	**$110,000**
CONTINGENCY	15%	$296,250	$219,000	$296,250	$582,300	$296,250	$120,000	$275,250	$120,000
TOTAL COST		$2,271,250	$1,679,000	$2,271,250	$4,464,300	$2,271,250	$920,000	$2,110,250	$920,000
COST PER CUBIC YARD	Total volume = 46,000 cy	$49	$37	$49	$97	$49	$20	$46	$20

The cost model was provided to estimate the H_2T implementation cost for the following cases:

1) H_2T as a replacement for traditional soil treatment technologies (e.g., SVE, excavation, or liquid-based biodegradation) at sites where no treatment has yet occurred (Scenarios 1 and 2); and
2) H_2T as a cheaper polishing step to replace expensive SVE systems that are no longer removing large amounts of contaminant mass (Scenarios 3 and 4).

All performance data was normalized to the volume of bulk treated soil for evaluating the cost benefit. Cost calculations were performed so that the cost of the H_2T technology can be compared to the competing technology, SVE or excavation. Four scenarios were considered and compared in this cost assessment based on data collected during this H_2T demonstration. The cost assessment was performed for the implementation and/or continuation of a system similar to the existing SVE system at the site.

In Scenarios 1 and 2, the cost of H_2T system operation for two years based on the implemented demonstration design conditions was \$49/cy compared to the entire SVE system operation (i.e., \$37/cy) and soil excavation (i.e., \$97/cy). In Scenario 3, the cost of H_2T system operation based on the implemented demonstration design conditions was \$49/cy compared to the continuation of the existing SVE system operation (i.e., \$20/cy). Finally, in Scenario 4, the cost of H_2T system operation by using the existing SVE wells as gas injection wells was \$46/cy compared to the continuation of the existing SVE system operation (i.e., \$20/cy).

For all the cost analysis scenarios, the cost of using gas generators was used. Because of the high volume of nitrogen and hydrogen needed for injection, it is more economical to purchase a generator and produce nitrogen and/or hydrogen on-site than to buy these gases in tube trailers, liquid nitrogen tanks or pressurized cylinders. Approximately 42% of the total cost of the H_2T system is the cost of gas if the gas is purchased and delivered to the site as liquid nitrogen and compressed hydrogen cylinders. When nitrogen and hydrogen generators are used, only 22% of the total cost of the H_2T system is the cost of gas and the unit cost of H_2T is reduced by approximately 31%, from \$71/cy to \$49/cy.

For all scenarios, the cost of H_2T was greater than SVE system operation. However, it is expected that for cases where larger contaminated areas are being treated for longer treatment periods, the H_2T system is more economical than SVE or excavation. It must be noted that the decision to switch to H_2T operation over an SVE system should be made based on the overall performance and not only on the cost assessments. For example, in the demonstration site where an SVE system was operating since 2008, the SVE system was not able to reduce the mass in the vadose zone due to the very low permeability soil (i.e., clayey silt loess material), likely due to preferential removal from a high-permeability layer at the bottom of the treatment interval. Small molecules of hydrogen gas, on the other hand, were able to diffuse into the small pores of the low-permeability soil.

When comparing each task across the different scenarios, the costs of the treatability study, gas permeability test, engineering design, and project management are similar under different scenarios. For the excavation it was assumed that 40% of the excavated soil would be re-packed in-place and only 60% of the contaminated excavated soil will be transported off-site and disposed as waste.

For this demonstration, propane was cheaper than hydrogen and therefore was used as 10% of the gas mixture to deplete oxygen. However in large-scale projects where a hydrogen generator will be used, it is more economical to eliminate propane gas and inject 20% hydrogen gas instead.

It should be noted that for the demonstration site where bulk nitrogen and hydrogen gases where purchased and delivered to the site, the gas cost was approximately \$3 per cubic yard per month at the original flowrate, and approximately \$7 per cubic yard per month for the last month after doubling the flowrate and hydrogen gas composition.

7.3 COST DRIVERS

The total costs of implementing H_2T are mainly driven by gas-related costs as presented in **Table 25**. Sensitivity analyses were performed to evaluate the effects of gas flowrate and ROI on the unit cost of H_2T implementation.

7.3.1 Sensitivity to Gas Flowrate

As mentioned in the Cost Analysis section, for higher gas flowrates where large volumes of nitrogen and hydrogen needed for injection, it is more economical to purchase nitrogen and hydrogen generators and generate these gases on-site than to buy these gases in tube trailers, liquid nitrogen tanks or pressurized cylinders. In this section, the cost calculations are performed based on gas costs using nitrogen and hydrogen generators. It was also assumed that the ROI is 15 feet for all different gas flowrates. All of the cost calculations are for a two-year H_2T system operation.

Gas-related costs included gas generators, compressed gases (i.e., CO_2 and helium), and electricity consumption. The purpose of using LPG during the demonstration was to reduce the gas cost since LPG is a cheaper gas compared to hydrogen gas when hydrogen is provided in compressed cylinders. Since hydrogen generator was used for the cost calculations in this section, LPG was replaced by hydrogen and the total hydrogen composition in the injected gas mixture was increased to 20% for all flowrates. Therefore, LPG cost is excluded from the cost analysis.

It should be noted that the total cost of the H_2T system could be decreased if the oxygen infiltration from above, bottom and/or sides is prevented or reduced. The oxygen infiltration from above could be prevented or reduced if a surface cover (i.e., plastic or concrete) is used in the treatment area. It is, however, more difficult to prevent or reduce the oxygen infiltration from the sides or bottom. Two possible ways to reduce lateral oxygen infiltration from sides are to use a closed loop of gas injection wells and/or to use water barriers on the perimeter of the treatment zone. **Figure 47** shows the effect of total gas flowrate on the unit cost of H_2T. Site-specific pilot studies must be conducted to determine the optimum gas flowrate required to keep the treatment zone anaerobic.

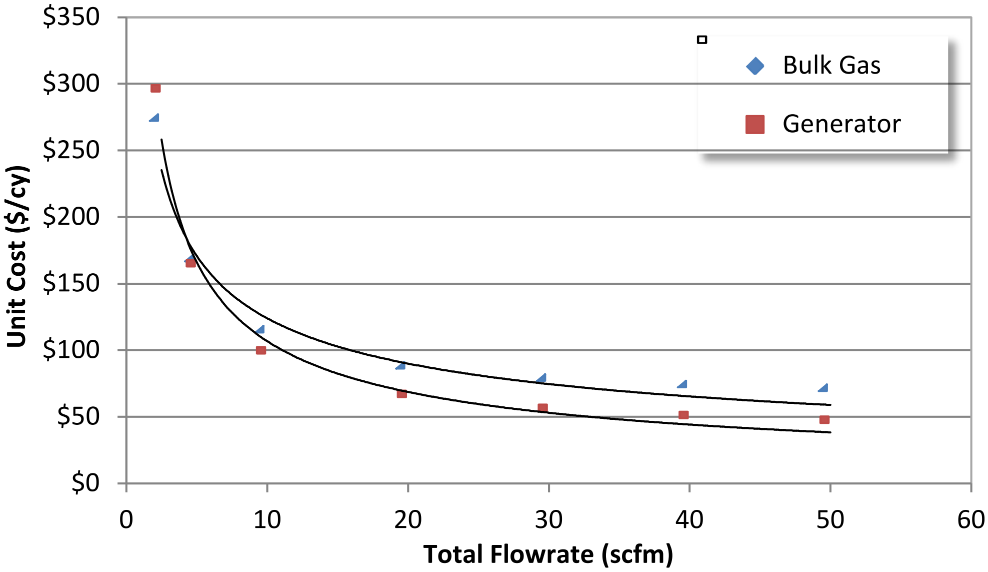


Figure 47: Sensitivity of H_2T costs to total gas flowrate

At a gas injection flowrate of approximately 5 scfm the gas cost using bulk gas versus an on-site generator was similar. For total gas flowrates higher than 5 scfm the use of nitrogen and hydrogen generators are more economical. These cost calculations are for a two-year H_2T system operation. If the H_2T system operation is longer than two years, the cost savings by using gas generators will be increased.

7.3.2 Sensitivity to Radius of Influence (ROI)

ROI can affect both the number of injection wells and the total gas flowrate. A main advantage of using H_2T over SVE is that the small hydrogen molecules diffuse into the low-permeability soil (i.e., silt and clay) more easily, thereby increasing the radius of influence. This makes the H_2T technology a good alternative to the SVE system when SVE operation is not effective in low-permeability soils.

The ROI is related to several factors including soil lithology and heterogeneity, gas flow rate and composition, well design, and superposition. In this demonstration three injection locations and three depths at each location were used. In large scale H_2T implementation where multiple injection wells are installed in a grid pattern, the ROI is expected to increase compare to this demonstration and lesser gas is expected to be used as a result of superposition. Site-specific pilot studies and tracer tests should be conducted to determine the ROI required to keep the treatment zone anaerobic.

Figure 48 shows the effect of ROI on the unit cost of H_2T. Sensitivity analysis was performed for ROI values from 5 to 25 feet in a treatment area of 27,500 ft^2. The number of injection wells was increased dramatically from 15 to 350 when the ROI is decreased from 25 feet to 5 feet. By increasing the ROI from 10 feet to 15 feet, the total cost of H_2T operation is reduced by approximately 23% (i.e., $64/cy to $49/cy), while increasing the ROI from 15 ft to 20 feet, the total cost of H_2T operation is reduced by approximately 10% (i.e., $49/cy to $44/cy). It was assumed that the total number of pore volumes injected within two years of H_2T operation was similar for all the ROI values and therefore, the gas cost for all different ROI values were the same. The analysis shows that the effect of ROI on the total H_2T cost is significant and an accurate estimate of site ROI is needed.

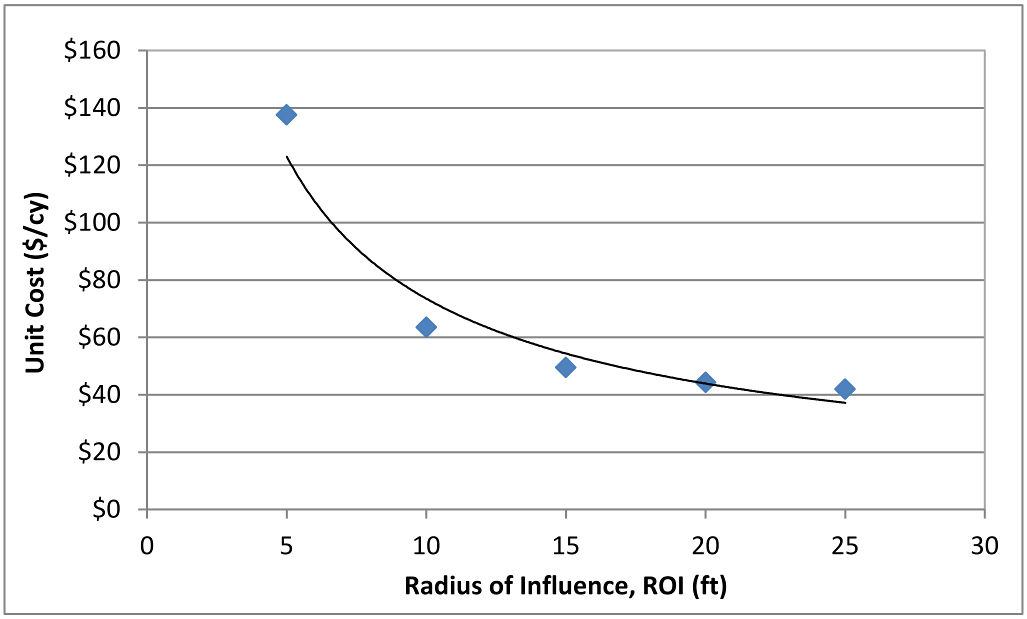


Figure 48: Sensitivity of H_2T costs to radius of influence (ROI)

8.0 IMPLEMENTATION ISSUES

8.1 REGULATIONS AND PERMITS

The primary application for H_2T is anticipated to be treatment of contaminants such as TCE in unsaturated soil for the purpose of groundwater protection. A site-specific feasibility study should be conducted to evaluate H_2T compared to other alternatives such as excavation, soil vapor extraction, and thermal treatment. Specific permits for H_2T may be required by local codes and will include drilling, well installation permits and hazardous materials storage permits. Other permits may be necessary and will be dependent on local codes.

8.2 END-USER CONCERNS

A summary of H_2T-specific implementation issues are:

- One of the main safety concerns associated with H_2T application is the flammability of hydrogen and LPG and the potential production of methane gas. Flammable gases were not detected above the ground surface. Thus, release of flammable gas to the atmosphere was not a safety issue. It was shown in this demonstration that the safety concerns could be addressed easily by following the safety codes (e.g., NFPA50A, NFPA55, etc.), placing flammable gas/no smoking placards, monitor gas concentrations and compare them to the lower explosive levels (LELs) at the surface soil and ambient air.
- Soil permeability and heterogeneity, soil moisture, etc. can greatly affect the performance of H_2T system. Computer modeling as well as pilot tests can be conducted to improve the design basis. These can generate data related to soil gas permeability, radius of influence, hydrogen utilization rates, and oxygen infiltration, all of which are valuable for deciding whether or not H_2T should be applied at a site. For example, for this demonstration, preliminary diffusion modeling conducted by Dr. Brian Looney, indicated significant oxygen diffusion from the sides, and that likely was one of the reasons that deep anaerobic conditions were not achieved in the middle or deep monitoring intervals.
- A suitable population of dechlorinating organisms *(Dehalococcoides)* (DHC*)* is needed to ensure complete conversion of PCE or TCE to non-toxic products (e.g., ethane). Quantitative polymerase chain reaction (qPCR) testing is recommended to quantify and characterize DHC bacteria at a site where H_2T application is considered. qPCR testing can be done with either groundwater or soil samples.
- Liquid nitrogen was supplied in a commercially available trailer during this demonstration project. Approximately 20-30% of the liquid nitrogen was wasted due to ventilation to the atmosphere. The lost volume of nitrogen from tube trailers should be considered when the decision for using tube trailers versus nitrogen generator is being made.
- Hydrogen was supplied in cylinders and LPG was supplied in a tank during this demonstration project. Using both hydrogen and LPG at the site increases safety concerns, and relevant safety codes must be followed for the distance between LPG tank and the hydrogen cylinders (i.e., 30 feet for this demonstration). For large-scale projects where an on-site hydrogen generator is used, it is more economical to replace LPG by hydrogen gas.

- If generators are to be used at a site, whether the generators are powered by fuel or electricity, the safety concerns must be addressed with regard to the placement of the generators and their proximity to the treatment area.

8.3 PROCUREMENT

As mentioned before, gas supply and drilling costs are the main cost drivers for the H_2T system operation. The gas injection and monitoring wells could be installed using direct-push method that is typical of many environmental remediation projects. Several gas vendors can supply the required gases if gases are supplied as compressed gas (i.e., H_2 or CO_2) or in liquid form (i.e., N_2 or LPG). There are several manufacturers where nitrogen and hydrogen gas generators can be purchased for a variety of flowrates and purities. H_2T skid required for gas mixing and distribution is not off-the-shelf and will require engineering design and custom fabrication. However, the skid may be re-used for similar projects.

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APPENDICES

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix A: Points of Contact

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Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix B: Soil Vapor Sampling Programs (July and August 2010)

SOIL VAPOR SAMPLING PROGRAMS
JULY/AUGUST 2010

Project Title: Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project Number: ER-1027

September 2010

1.0 SAMPLE COLLECTION

During the site selection process, to further evaluate the site, the project team decided to conduct soil vapor monitoring and sampling program at Atlas Missile Site in Former Lincoln AFB in York, Nebraska. The program objective was to collect additional data (e.g., oxygen in soil vapor) and supplement existing COC data (e.g., TCE, DCE, and VC). The data collection program consisted of turning off the SVE system for approximately 10 days prior to the first sampling event and collecting soil vapor samples from all of the existing soil vapor extraction (SVE) wells at both sites. First soil vapor sampling event was conducted in July 27, 2010 approximately 10 days after turning off the SVE system. Second soil vapor sampling event was conducted in August 30-31, 2010 approximately 45 days after the SVE system shut down.

Soil vapor monitoring and sampling programs were conducted on July 27 and August 30, 2010. Prior to sampling, approximately two well casing volume of air (e.g., approximately 2 cubic feet) was purged from the casing using a vacuum pump to ensure that the soil gas sample is representative of vapors associated with the soils in the vadose and are not being influenced by stagnant air in the casing. Soil vapor monitoring consisted of recording oxygen, carbon dioxide, methane, and LEL readings on-site using a GEM2000 landfill gas monitor. Soil vapor sampling consisted of the collection of approximately 700 mL soil vapor samples in 1 liter Tedlar bags for off-site analysis. Off-site analysis included VOC analysis using HAPSITE ER portable GC. Samples were collected from all 39 SVE wells.

2.0 SAMPLE ANALYSIS USING THE HAPSITE ER

Samples were analyzed using a portable Gas Chromatograph/Mass Spectrometer HAPSITE ER Chemical Identification System. The HAPSITE ER has the capability to identify VOCs and SVOCs in the ppb to ppm range. Samples were analyzed for concentrations of six VOCs, including PCE, TCE, Carbon Tetrachloride, 1,2-DCA, 1,2-Cis-DCE, 1,2-Trans-DCE, 1,2-DCE, and 1,1-DCE. Specific analytes of interest for this project include TCE, 1,2-Cis-DCE, and 1,2-Trans DCE. The analytical method was calibrated to provide accurate concentration readings plus or minus 30% for concentrations ranging from 1 ppb to 1 ppm. When samples were analyzed with concentrations that exceeded this range, the HAPSITE ER produced a measurement that was an underestimate of the true concentration. Consequently, samples with concentrations exceeding 1 ppm were diluted in fresh tedlar bags, and re-analyzed to obtain accurate concentrations, which were then multiplied by the dilution factor.

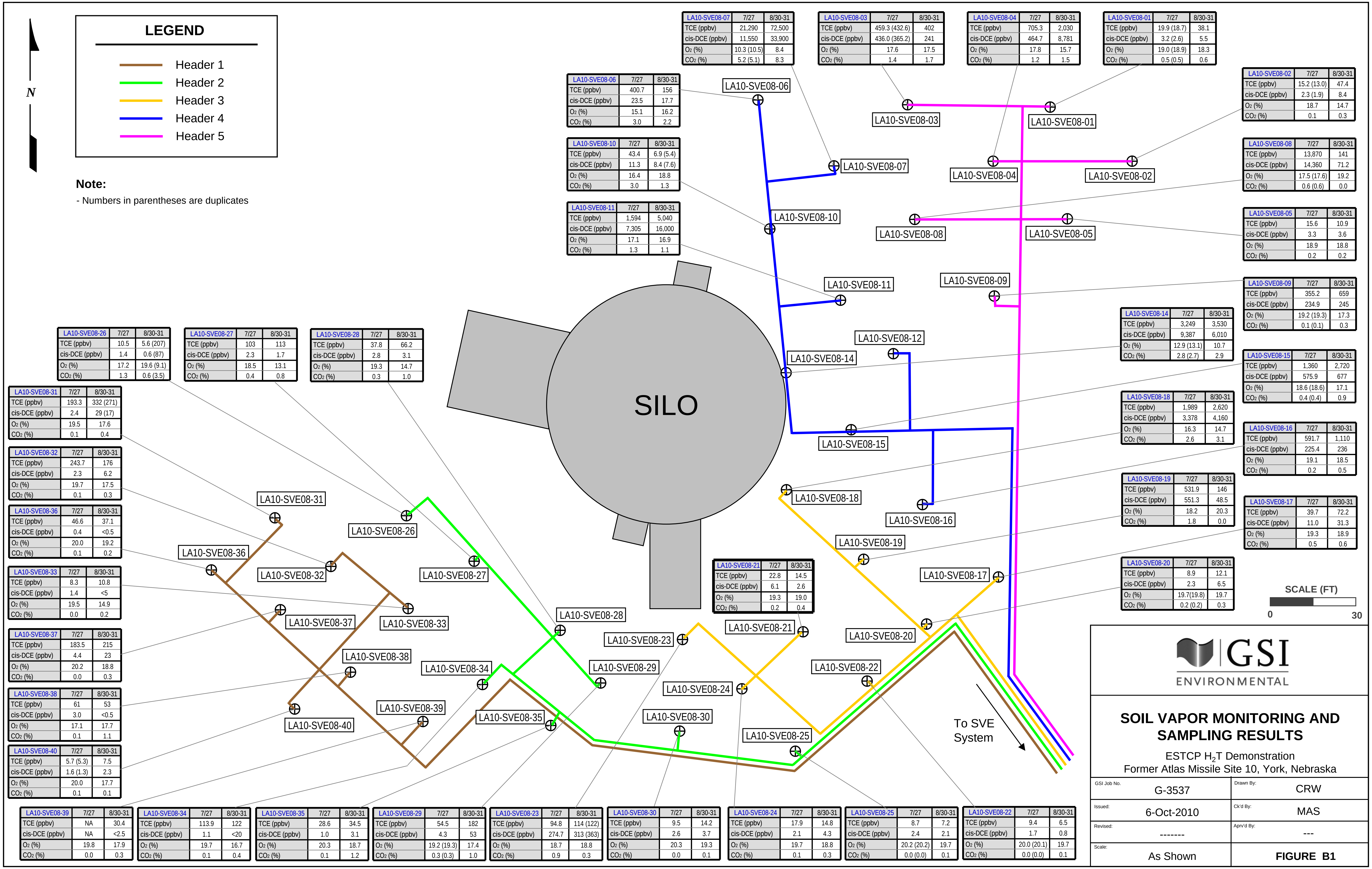
Calibration checks were performed at the beginning and end of each sampling day by analyzing tedlar bags containing a standard mix of known concentration. During the two days of sampling, it was apparent that measurements were consistently biased low by 30%. Consequently, we estimate that the errors associated with sample concentrations for this particular sampling event was plus 30% and minus 10%.

3.0 RESULTS

The locations of the SVE wells and their associated COC concentrations in soil vapor during July 2010 sampling program are shown in Figure B1. Table B1 and B3 summarizes the analytical data for the samples collected during July and August 2010 sampling programs, respectively. Table B2 and B4 summarizes the results of the soil vapor monitoring for O_2, CO_2, and CH_4 during July and August 2010 sampling programs, respectively.

The highest soil vapor TCE concentrations were found at the east-northeast side of the silo with maximum TCE concentration at SVE well LA10-SVE08-07 (21,290 ppbv), and maximum cis-1,2-DCE concentration at SVE well LA10-SVE08-08 (14,360 ppbv) during July sampling program. Maximum TCE concentration was observed at SVE well LA10-SVE08-07 (72,500 ppbv), and maximum cis-1,2-DCE concentration at SVE well LA10-SVE08-07 (33,900 ppbv) during July sampling program.

Analytical data for the samples collected during August 2010 sampling program generally showed significant rebound for TCE and cis-1,2-DCE. SVE well LA10-SVE08-08 showed a significant drop in both TCE and cis-1,2-DCE concentrations. Since all the wells around this well had increase in TCE and cis-1,2-DCE concentrations, we think there has been some sampling error for the sample collected from SVE well LA10-SVE08-08. As expected, higher cis-1,2-DCE concentrations were observed in the same area where oxygen levels were relatively low (e.g., 10-15%). Based on the TCE and cis-1,2-DCE concentrations and lower oxygen levels at York site in the SVE wells on the northeastern side of the Silo (e.g., LA10-SVE08-07, LA10-SVE08-08, LA10-SVE08-11, LA10-SVE08-14, and LA10-SVE08-18), the area east-northeast of the Silo was decided as the location to apply H_2T.



LEGEND

- Header 1
- Header 2
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- Header 4
- Header 5

Note:

- Numbers in parentheses are duplicates

LA10-SVE08-07	7/27	8/30-31
TCE (ppbv)	21,290	72,500
cis-DCE (ppbv)	11,550	33,900
O_2 (%)	10.3 (10.5)	8.4
CO_2 (%)	5.2 (5.1)	8.3

LA10-SVE08-03	7/27	8/30-31
TCE (ppbv)	459.3 (432.6)	402
cis-DCE (ppbv)	436.0 (365.2)	241
O_2 (%)	17.6	17.5
CO_2 (%)	1.4	1.7

LA10-SVE08-04	7/27	8/30-31
TCE (ppbv)	705.3	2,030
cis-DCE (ppbv)	464.7	8,781
O_2 (%)	17.8	15.7
CO_2 (%)	1.2	1.5

LA10-SVE08-01	7/27	8/30-31
TCE (ppbv)	19.9 (18.7)	38.1
cis-DCE (ppbv)	3.2 (2.6)	5.5
O_2 (%)	19.0 (18.9)	18.3
CO_2 (%)	0.5 (0.5)	0.6

LA10-SVE08-06	7/27	8/30-31
TCE (ppbv)	400.7	156
cis-DCE (ppbv)	23.5	17.7
O_2 (%)	15.1	16.2
CO_2 (%)	3.0	2.2

LA10-SVE08-10	7/27	8/30-31
TCE (ppbv)	43.4	6.9 (5.4)
cis-DCE (ppbv)	11.3	8.4 (7.6)
O_2 (%)	16.4	18.8
CO_2 (%)	3.0	1.3

LA10-SVE08-11	7/27	8/30-31
TCE (ppbv)	1,594	5,040
cis-DCE (ppbv)	7,305	16,000
O_2 (%)	17.1	16.9
CO_2 (%)	1.3	1.1

LA10-SVE08-02	7/27	8/30-31
TCE (ppbv)	15.2 (13.0)	47.4
cis-DCE (ppbv)	2.3 (1.9)	8.4
O_2 (%)	18.7	14.7
CO_2 (%)	0.1	0.3

LA10-SVE08-08	7/27	8/30-31
TCE (ppbv)	13,870	141
cis-DCE (ppbv)	14,360	71.2
O_2 (%)	17.5 (17.6)	19.2
CO_2 (%)	0.6 (0.6)	0.0

LA10-SVE08-05	7/27	8/30-31
TCE (ppbv)	15.6	10.9
cis-DCE (ppbv)	3.3	3.6
O_2 (%)	18.9	18.8
CO_2 (%)	0.2	0.2

LA10-SVE08-09	7/27	8/30-31
TCE (ppbv)	355.2	659
cis-DCE (ppbv)	234.9	245
O_2 (%)	19.2 (19.3)	17.3
CO_2 (%)	0.1 (0.1)	0.3

LA10-SVE08-14	7/27	8/30-31
TCE (ppbv)	3,249	3,530
cis-DCE (ppbv)	9,387	6,010
O_2 (%)	12.9 (13.1)	10.7
CO_2 (%)	2.8 (2.7)	2.9

LA10-SVE08-15	7/27	8/30-31
TCE (ppbv)	1,360	2,720
cis-DCE (ppbv)	575.9	677
O_2 (%)	18.6 (18.6)	17.1
CO_2 (%)	0.4 (0.4)	0.9

LA10-SVE08-18	7/27	8/30-31
TCE (ppbv)	1,989	2,620
cis-DCE (ppbv)	3,378	4,160
O_2 (%)	16.3	14.7
CO_2 (%)	2.6	3.1

LA10-SVE08-16	7/27	8/30-31
TCE (ppbv)	591.7	1,110
cis-DCE (ppbv)	225.4	236
O_2 (%)	19.1	18.5
CO_2 (%)	0.2	0.5

LA10-SVE08-19	7/27	8/30-31
TCE (ppbv)	531.9	146
cis-DCE (ppbv)	551.3	48.5
O_2 (%)	18.2	20.3
CO_2 (%)	1.8	0.0

LA10-SVE08-17	7/27	8/30-31
TCE (ppbv)	39.7	72.2
cis-DCE (ppbv)	11.0	31.3
O_2 (%)	19.3	18.9
CO_2 (%)	0.5	0.6

LA10-SVE08-20	7/27	8/30-31
TCE (ppbv)	8.9	12.1
cis-DCE (ppbv)	2.3	6.5
O_2 (%)	19.7(19.8)	19.7
CO_2 (%)	0.2 (0.2)	0.3

LA10-SVE08-21	7/27	8/30-31
TCE (ppbv)	22.8	14.5
cis-DCE (ppbv)	6.1	2.6
O_2 (%)	19.3	19.0
CO_2 (%)	0.2	0.4

LA10-SVE08-26	7/27	8/30-31
TCE (ppbv)	10.5	5.6 (207)
cis-DCE (ppbv)	1.4	0.6 (87)
O_2 (%)	17.2	19.6 (9.1)
CO_2 (%)	1.3	0.6 (3.5)

LA10-SVE08-27	7/27	8/30-31
TCE (ppbv)	103	113
cis-DCE (ppbv)	2.3	1.7
O_2 (%)	18.5	13.1
CO_2 (%)	0.4	0.8

LA10-SVE08-28	7/27	8/30-31
TCE (ppbv)	37.8	66.2
cis-DCE (ppbv)	2.8	3.1
O_2 (%)	19.3	14.7
CO_2 (%)	0.3	1.0

LA10-SVE08-31	7/27	8/30-31
TCE (ppbv)	193.3	332 (271)
cis-DCE (ppbv)	2.4	29 (17)
O_2 (%)	19.5	17.6
CO_2 (%)	0.1	0.4

LA10-SVE08-32	7/27	8/30-31
TCE (ppbv)	243.7	176
cis-DCE (ppbv)	2.3	6.2
O_2 (%)	19.7	17.5
CO_2 (%)	0.1	0.3

LA10-SVE08-36	7/27	8/30-31
TCE (ppbv)	46.6	37.1
cis-DCE (ppbv)	0.4	<0.5
O_2 (%)	20.0	19.2
CO_2 (%)	0.1	0.2

LA10-SVE08-33	7/27	8/30-31
TCE (ppbv)	8.3	10.8
cis-DCE (ppbv)	1.4	<5
O_2 (%)	19.5	14.9
CO_2 (%)	0.0	0.2

LA10-SVE08-37	7/27	8/30-31
TCE (ppbv)	183.5	215
cis-DCE (ppbv)	4.4	23
O_2 (%)	20.2	18.8
CO_2 (%)	0.0	0.3

LA10-SVE08-38	7/27	8/30-31
TCE (ppbv)	61	53
cis-DCE (ppbv)	3.0	<0.5
O_2 (%)	17.1	17.7
CO_2 (%)	0.1	1.1

LA10-SVE08-40	7/27	8/30-31
TCE (ppbv)	5.7 (5.3)	7.5
cis-DCE (ppbv)	1.6 (1.3)	2.3
O_2 (%)	20.0	17.7
CO_2 (%)	0.1	0.1

LA10-SVE08-39	7/27	8/30-31
TCE (ppbv)	NA	30.4
cis-DCE (ppbv)	NA	<2.5
O_2 (%)	19.8	17.9
CO_2 (%)	0.0	0.3

LA10-SVE08-34	7/27	8/30-31
TCE (ppbv)	113.9	122
cis-DCE (ppbv)	1.1	<20
O_2 (%)	19.7	16.7
CO_2 (%)	0.1	0.4

LA10-SVE08-35	7/27	8/30-31
TCE (ppbv)	28.6	34.5
cis-DCE (ppbv)	1.0	3.1
O_2 (%)	20.3	18.7
CO_2 (%)	0.1	1.2

LA10-SVE08-29	7/27	8/30-31
TCE (ppbv)	54.5	182
cis-DCE (ppbv)	4.3	53
O_2 (%)	19.2 (19.3)	17.4
CO_2 (%)	0.3 (0.3)	1.0

LA10-SVE08-23	7/27	8/30-31
TCE (ppbv)	94.8	114 (122)
cis-DCE (ppbv)	274.7	313 (363)
O_2 (%)	18.7	18.8
CO_2 (%)	0.9	0.3

LA10-SVE08-30	7/27	8/30-31
TCE (ppbv)	9.5	14.2
cis-DCE (ppbv)	2.6	3.7
O_2 (%)	20.3	19.3
CO_2 (%)	0.0	0.1

LA10-SVE08-24	7/27	8/30-31
TCE (ppbv)	17.9	14.8
cis-DCE (ppbv)	2.1	4.3
O_2 (%)	19.7	18.8
CO_2 (%)	0.1	0.3

LA10-SVE08-25	7/27	8/30-31
TCE (ppbv)	8.7	7.2
cis-DCE (ppbv)	2.4	2.1
O_2 (%)	20.2 (20.2)	19.7
CO_2 (%)	0.0 (0.0)	0.1

LA10-SVE08-22	7/27	8/30-31
TCE (ppbv)	9.4	6.5
cis-DCE (ppbv)	1.7	0.8
O_2 (%)	20.0 (20.1)	19.7
CO_2 (%)	0.0 (0.0)	0.1

GSI ENVIRONMENTAL

SOIL VAPOR MONITORING AND SAMPLING RESULTS

ESTCP H_2T Demonstration
Former Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537	Drawn By: CRW
Issued: 6-Oct-2010	Ck'd By: MAS
Revised: -------	Apv'd By: ---
Scale: As Shown	FIGURE B1

Table B1
SOIL VAPOR SAMPLING RESULTS USING HAPSITE ER - H1774
July 27, 2010

Atlas Missile Site 10
Former Lincoln AFB, York, Nebraska

Sample	tblHapsiteLogFileMethod	Dilution	Units	VC	1,1-DCE	1,2-trans-DCE	1,1-DCA	1,2-cis-DCE	1,2-DCA	CTCl	TCE	PCE
LA10-SVE08-01	SIM_1PPM_Hill_VI_List		PPBV	39.5	0.6	2.7	0.8	3.2	ND	ND	19.9	0.2
LA10-SVE08-01	SIM_100PPB_Hill_VI_List		PPBV	ND	0.2	0.2	0.1	2.6	ND	0.0	18.7	0.1
LA10-SVE08-02	SIM_1PPM_Hill_VI_List		PPBV	ND	0.5	2.0	0.4	2.3	ND	ND	15.2	0.2
LA10-SVE08-02	SIM_100PPB_Hill_VI_List		PPBV	0.3	0.1	0.1	0.1	1.9	0.1	0.1	13.0	0.1
LA10-SVE08-03	SIM_1PPM_Hill_VI_List	10X	PPBV	ND	62.8	39.7	14.1	436.0	ND	ND	459.3	1.4
LA10-SVE08-03	SIM_1PPM_Hill_VI_List		PPBV	ND	2.2	28.7	90.0	365.2	2.8	ND	432.6	ND
LA10-SVE08-04	SIM_1PPM_Hill_VI_List		PPBV	ND	26.2	16.5	4.9	464.7	ND	ND	705.3	ND
LA10-SVE08-05	SIM_1PPM_Hill_VI_List		PPBV	46.1	0.9	2.8	0.8	3.3	ND	ND	15.6	ND
LA10-SVE08-06	SIM_1PPM_Hill_VI_List		PPBV	ND	2.9	8.0	50.2	23.5	22.3	8.9	400.7	0.2
LA10-SVE08-07	SIM_1PPM_Hill_VI_List	100X	PPBV	ND	1240.0	782.9	225.9	11550.0	115.6	ND	21290.0	42.2
LA10-SVE08-08	SIM_1PPM_Hill_VI_List	100X	PPBV	ND	556.8	351.6	81.6	14360.0	91.0	ND	13870.0	26.9
LA10-SVE08-09	SIM_1PPM_Hill_VI_List		PPBV	43.1	0.8	10.9	57.4	234.9	2.7	ND	355.2	0.1
LA10-SVE08-10	SIM_100PPB_Hill_VI_List		PPBV	0.7	0.5	0.4	0.1	11.3	0.1	ND	43.4	0.1
LA10-SVE08-11	SIM_1PPM_Hill_VI_List	100X	PPBV	ND	489.8	309.4	1748.0	7305.0	ND	ND	1594.0	20.1
LA10-SVE08-12	SIM_1PPM_Hill_VI_List	10X	PPBV	ND	12.5	56.8	451.6	1357.0	ND	ND	1259.0	1.6
LA10-SVE08-14	SIM_1PPM_Hill_VI_List	10X	PPBV	ND	2022.0	1277.0	366.6	9387.0	22.1	ND	3249.0	2.4
LA10-SVE08-15	SIM_1PPM_Hill_VI_List	10X	PPBV	ND	101.2	63.9	71.9	575.9	ND	ND	1360.0	1.3
LA10-SVE08-16	SIM_1PPM_Hill_VI_List		PPBV	ND	0.8	14.0	53.9	225.4	4.3	ND	591.7	ND
LA10-SVE08-17	SIM_100PPB_Hill_VI_List		PPBV	1.1	0.3	1.1	0.3	11.0	0.1	0.1	39.7	0.1
LA10-SVE08-18	SIM_1PPM_Hill_VI_List	10X	PPBV	ND	663.8	419.2	822.4	3378.0	ND	ND	1989.0	1.2
LA10-SVE08-19	SIM_100PPB_Hill_VI_List		PPBV	25.8	35.0	342.4	233.2	551.3	ND	0.0	531.9	0.1
LA10-SVE08-20	SIM_1PPM_Hill_VI_List		PPBV	ND	3.0	1.9	0.5	2.3	ND	ND	8.9	ND
LA10-SVE08-21	SIM_100PPB_Hill_VI_List		PPBV	1.0	0.7	0.6	0.2	6.1	0.1	0.1	22.8	0.1
LA10-SVE08-22	SIM_1PPM_Hill_VI_List		PPBV	ND	0.3	0.2	0.0	1.7	0.1	0.1	9.4	0.1
LA10-SVE08-23	SIM_1PPM_Hill_VI_List		PPBV	ND	50.8	32.1	67.0	274.7	1.0	ND	94.8	0.1
LA10-SVE08-24	SIM_100PPB_Hill_VI_List		PPBV	ND	0.3	0.2	0.1	2.1	0.2	0.1	17.9	0.1
LA10-SVE08-25	SIM_1PPM_Hill_VI_List		PPBV	43.3	1.1	2.1	0.6	2.4	ND	ND	8.7	ND
LA10-SVE08-26	SIM_1PPM_Hill_VI_List		PPBV	ND	1.8	1.2	0.4	1.4	ND	ND	10.5	0.1
LA10-SVE08-27	SIM_1PPM_Hill_VI_List		PPBV	ND	3.1	0.8	6.3	2.3	ND	ND	103.0	ND
LA10-SVE08-28	SIM_100PPB_Hill_VI_List		PPBV	ND	0.5	0.4	0.7	2.8	0.1	0.1	37.8	0.1
LA10-SVE08-29	SIM_100PPB_Hill_VI_List		PPBV	ND	0.2	0.6	3.8	4.3	8.3	0.0	54.5	0.1
LA10-SVE08-30	SIM_1PPM_Hill_VI_List		PPBV	60.2	0.9	2.2	0.7	2.6	ND	ND	9.5	0.1
LA10-SVE08-31	SIM_1PPM_Hill_VI_List		PPBV	63.9	1.1	2.0	0.6	2.4	ND	ND	193.3	ND
LA10-SVE08-32	SIM_1PPM_Hill_VI_List		PPBV	ND	0.5	0.3	1.9	2.3	1.4	ND	243.7	ND
LA10-SVE08-33	SIM_1PPM_Hill_VI_List		PPBV	ND	1.9	1.2	ND	1.4	ND	ND	8.3	ND
LA10-SVE08-34	SIM_1PPM_Hill_VI_List		PPBV	ND	0.8	0.9	ND	1.1	ND	ND	113.9	ND
LA10-SVE08-35	SIM_100PPB_Hill_VI_List		PPBV	1.0	0.2	0.2	0.1	1.0	0.1	0.1	28.6	0.1
LA10-SVE08-36	SIM_100PPB_Hill_VI_List		PPBV	0.4	0.3	0.2	0.1	0.4	0.2	0.1	46.6	0.1
LA10-SVE08-37	SIM_1PPM_Hill_VI_List		PPBV	ND	0.7	0.4	1.0	4.4	1.3	ND	183.5	ND
LA10-SVE08-38	SIM_1PPM_Hill_VI_List		PPBV	39.2	0.9	0.6	0.7	3.0	ND	ND	61.0	ND
LA10-SVE08-40	SIM_1PPM_Hill_VI_List		PPBV	ND	0.9	1.4	0.5	1.6	ND	0.4	5.7	ND
LA10-SVE08-40	SIM_100PPB_Hill_VI_List		PPBV	ND	0.1	0.2	0.1	1.3	ND	0.1	5.3	0.1

Note:

1) Two calibration curves were generated one up to 100ppbv and one up to 1ppmv.
2) Samples from LA10-SVE08-01 and LA10-SVE08-40 were tested with both calibration curves to test the accuracy of both calibration curves.
3) Sample from LA10-SVE08-03 was tested with and without dilution to test the error in the dilution.
4) Sample from LA10-SVE08-19 was tested with the 100ppbv calibration curve and the result for TCE was above 100ppbv, but there was not any more vapor sample to be tested with
5) Air and N2 blank samples and calibration checkes were tested often during the analysis.
6) ND = Not Detected. Detection limits were 0.5 ppbv for all the chemicals tested here.
7) Samples that exceeded 1.0 ppm were diluted 10X or 100X

Table B2
SOIL VAPOR MONITORING RESULTS USING GEM 2000 Landfill Gas Monitor CH4/CO2/O2
July 27, 2010

Atlas Missile Site 10
Former Lincoln AFB, York, Nebraska

Date/Time	Well ID	CH4 %	CO2 %	O2 %	Balance %	%LEL %	Baro. Press. inches Hg	Rel. Pressure inches H2O
7/27/2010 7:44	LA10-SVE08-01	0	0.5	19	80.5	0	28.24	27.98
7/27/2010 7:45	Field Blank	0	0	20.7	79.3	0	28.24	0.95
7/27/2010 7:46	LA10-SVE08-01_R	0	0.5	18.9	80.6	0	28.24	23.6
7/27/2010 7:56	LA10-SVE08-02	0	0.1	18.7	81.2	0	28.2	149.48
7/27/2010 8:06	LA10-SVE08-04	0	1.2	17.8	81	0	28.2	35.88
7/27/2010 8:21	LA10-SVE08-05	0	0.2	18.9	80.9	0	28.21	49.32
7/27/2010 8:22	Field Blank	0	0	19.6	80.4	0	28.21	0.55
7/27/2010 8:23	Field Blank	0	0	20.6	79.4	0	28.21	0.74
7/27/2010 8:29	LA10-SVE08-03	0	1.4	17.6	81	0	28.21	36.91
7/27/2010 8:36	LA10-SVE08-07	0	5.2	10.3	84.5	0	28.21	18.73
7/27/2010 8:37	LA10-SVE08-07_R	0	5.1	10.5	84.4	0	28.21	16.73
7/27/2010 8:43	LA10-SVE08-06	0	3	15.1	81.9	0	28.21	28.46
7/27/2010 8:52	LA10-SVE08-08	0.1	0.6	17.5	81.8	2	28.21	33.62
7/27/2010 8:53	LA10-SVE08-08_R	0.1	0.6	17.6	81.7	2	28.21	12.65
7/27/2010 8:54	Field Blank	0	0	20.7	79.3	0	28.21	0.92
7/27/2010 9:03	A10-SVE08-10	0.1	3	16.4	80.5	2	28.21	29.89
7/27/2010 9:10	A10-SVE08-11	0.1	1.3	17.1	81.5	2	28.21	30.95
7/27/2010 9:11	Field Blank	0	0	20.6	79.4	0	28.21	0.98
7/27/2010 9:18	A10-SVE08-12	0.1	0.6	18.4	80.9	2	28.21	25.1
7/27/2010 9:19	A10-SVE08-12_R	0.1	0.6	18.4	80.9	2	28.21	23.35
7/27/2010 9:26	A10-SVE08-09	0.2	0.1	19.2	80.5	4	28.21	43.64
7/27/2010 9:28	A10-SVE08-09_R	0.2	0.1	19.3	80.4	4	28.21	42.67
7/27/2010 9:29	Field Blank	0	0	20.7	79.3	0	28.21	0.56
7/27/2010 9:36	A10-SVE08-15	0.1	0.4	18.6	80.9	2	28.21	36.98
7/27/2010 9:37	A10-SVE08-15_R	0.1	0.4	18.6	80.9	2	28.21	20.35
7/27/2010 9:48	A10-SVE08-14	0.2	2.8	12.9	84.1	4	28.2	35.73
7/27/2010 9:49	A10-SVE08-14_R	0.2	2.7	13.1	84	4	28.2	22.63
7/27/2010 9:50	Field Blank	0	0	20.6	79.4	0	28.2	0.84
7/27/2010 9:55	A10-SVE08-16	0.2	0.2	19.1	80.5	4	28.2	50.64
7/27/2010 11:16	A10-SVE08-17	0.1	0.5	19.3	80.1	2	28.19	29.4
7/27/2010 11:24	A10-SVE08-20	0.1	0.2	19.7	80	2	28.18	33.82
7/27/2010 11:25	A10-SVE08-20_R	0.1	0.2	19.8	79.9	2	28.18	20.08
7/27/2010 11:31	A10-SVE08-19	0.1	1.8	18.2	79.9	2	28.19	23.82
7/27/2010 11:39	A10-SVE08-18	0.1	2.6	16.3	81	2	28.19	23.4
7/27/2010 11:40	Field Blank	0	0	20.8	79.2	0	28.19	0.64
7/27/2010 11:49	A10-SVE08-21	0.1	0.2	19.3	80.4	2	28.19	34.8
7/27/2010 11:55	A10-SVE08-22	0.2	0	20	79.8	4	28.19	50.94
7/27/2010 11:56	A10-SVE08-22_R	0.2	0	20.1	79.7	4	28.19	22.89
7/27/2010 12:05	Field Blank	0	0	20.7	79.3	0	28.19	0.95
7/27/2010 12:10	A10-SVE08-24	0.2	0.1	19.7	80	4	28.19	28.26
7/27/2010 12:11	A10-SVE08-24_R	0.2	0.1	19.7	80	4	28.19	28.41
7/27/2010 12:12	Field Blank	0	0	20.6	79.4	0	28.19	1.01
7/27/2010 12:19	A10-SVE08-25	0.2	0	20.2	79.6	4	28.19	41.04
7/27/2010 12:20	A10-SVE08-25_R	0.2	0	20.2	79.6	4	28.19	27.58
7/27/2010 12:26	A10-SVE08-29	0.2	0.3	19.2	80.3	4	28.19	40.69
7/27/2010 12:27	A10-SVE08-29_R	0.2	0.3	19.3	80.2	4	28.19	26.89
7/27/2010 12:28	A10-SVE08-30	0.2	0	20.3	79.5	4	28.19	0.85
7/27/2010 12:33	A10-SVE08-23	0.2	0.9	18.7	80.2	4	28.19	27.09
7/27/2010 12:34	Field Blank	0	0	20.5	79.5	0	28.19	0.98
7/27/2010 12:40	A10-SVE08-28	0.2	0.3	19.3	80.2	4	28.19	34.64
7/27/2010 12:46	A10-SVE08-35	0.2	0.1	20.3	79.4	4	28.19	36.35
7/27/2010 12:53	A10-SVE08-34	0.2	0.1	19.7	80	4	28.18	36.85
7/27/2010 12:54	A10-SVE08-34_R	0.2	0.1	19.7	80	4	28.18	40.95
7/27/2010 12:55	Field Blank	0.1	0	20.4	79.5	2	28.18	0.91
7/27/2010 12:56	Field Blank	0.1	0	20.6	79.3	2	28.18	0.91
7/27/2010 12:57	Field Blank	0	0	20.7	79.3	0	28.18	0.92
7/27/2010 12:58	Field Blank	0	0	20.7	79.3	0	28.18	0.92
7/27/2010 13:04	A10-SVE08-39	0.3	0	19.8	79.9	6	28.18	34.82
7/27/2010 13:10	A10-SVE08-38	0.3	0.1	17.1	82.5	6	28.18	37.69
7/27/2010 13:17	A10-SVE08-37	0.3	0	20.2	79.5	6	28.18	33.34
7/27/2010 13:44	A10-SVE08-40	0.3	0.1	20	79.6	6	28.18	36.83
7/27/2010 13:51	A10-SVE08-32	0.3	0.1	19.7	79.9	6	28.17	33.75
7/27/2010 13:56	A10-SVE08-33	0.3	0	19.5	80.2	6	28.17	42.7
7/27/2010 13:57	Field Blank	0.1	0	20.7	79	2	28.17	0.99
7/27/2010 13:58	Field Blank	0.1	0	20.8	78.9	2	28.17	1
7/27/2010 13:59	Field Blank	0	0	20.7	79	6	28.17	1
7/27/2010 14:03	A10-SVE08-27	0.3	0.4	18.5	80.8	6	28.17	25.54
7/27/2010 14:09	A10-SVE08-26	0.3	1.3	17.2	81.2	6	28.17	29.92
7/27/2010 14:10	Field Blank	0.3	0	20.6	79.1	6	28.17	1.02
7/27/2010 14:17	A10-SVE08-31	0.3	0.1	19.5	80.1	6	28.16	30.61
7/27/2010 14:23	A10-SVE08-36	0.3	0.1	20	79.6	6	28.16	37.62

Note:
Balance = 100 - CH4 - CO2 - O2

Table B3
SOIL VAPOR SAMPLING RESULTS USING HAPSITE ER - H1774
August 30-31, 2010

Atlas Missile Site 10
Former Lincoln AFB, York, Nebraska

Sample	Date Cellected	Dilution Factor	Rep. Limit	Units	VC	1,2-trans-DCE	1,2-cis-DCE	TCE
LA10-SVE08-01	8/31/2010 11:39	1X	0.5	PPBV	ND	ND	5.5	38.1
LA10-SVE08-02	8/31/2010 11:56	1X	0.5	PPBV	ND	ND	8.4	47.4
LA10-SVE08-03	8/31/2010 12:13	80X	40	PPBV	ND	ND	241	402
LA10-SVE08-04	8/31/2010 11:48	250X	125	PPBV	ND	ND	878	2030
LA10-SVE08-05	8/31/2010 12:05	1X	0.5	PPBV	ND	ND	3.59	10.9
LA10-SVE08-06	8/31/2010 12:50	16X	8	PPBV	ND	ND	17.7	156
LA10-SVE08-07	8/31/2010 13:35	32000X	16000	PPBV	ND	ND	33900	72500
LA10-SVE08-08	8/31/2010 13:24	40X	20	PPBV	ND	ND	71.2	141
LA10-SVE08-09	8/31/2010 12:23	160X	80	PPBV	ND	ND	245	659
LA10-SVE08-10	8/31/2010 12:59	1X	0.5	PPBV	ND	ND	8.45	6.88
LA10-SVE08-10 (Dup.)	8/31/2010 12:59	1X	0.5	PPBV	ND	ND	7.6	5.4
LA10-SVE08-11	8/31/2010 12:40	1600X	800	PPBV	ND	ND	16000	5040
LA10-SVE08-12	8/31/2010 12:31	500X	250	PPBV	ND	ND	2840	2580
LA10-SVE08-14	8/31/2010 13:15	1000X	500	PPBV	ND	757	6010	3530
LA10-SVE08-15	8/31/2010 10:25	320X	160	PPBV	ND	ND	677	2720
LA10-SVE08-16	8/31/2010 10:16	160X	80	PPBV	ND	ND	236	1110
LA10-SVE08-17	8/31/2010 10:52	1X	0.5	PPBV	ND	ND	31.3	72.2
LA10-SVE08-18	8/31/2010 10:37	640X	320	PPBV	ND	460	4160	2620
LA10-SVE08-19	8/31/2010 10:07	80X	40	PPBV	ND	ND	48.5	146
LA10-SVE08-20	8/31/2010 9:59	1X	0.5	PPBV	ND	ND	6.5	12.1
LA10-SVE08-21	8/31/2010 9:42	1X	0.5	PPBV	ND	ND	2.6	14.5
LA10-SVE08-22	8/31/2010 9:50	1X	0.5	PPBV	ND	ND	0.8	6.5
LA10-SVE08-23	8/30/2010 17:30	1X	0.5	PPBV	ND	ND	312.8	114.0
LA10-SVE08-23 (Dup.)	8/31/2010 9:20	1X	0.5	PPBV	ND	ND	363.1	121.9
LA10-SVE08-24	8/31/2010 9:26	1X	0.5	PPBV	ND	ND	4.3	14.8
LA10-SVE08-25	8/31/2010 9:34	1X	0.5	PPBV	ND	ND	2.1	7.2
LA10-SVE08-26	8/30/2010 17:15	1X	0.5	PPBV	ND	ND	87	207
LA10-SVE08-26 (re-do)	8/31/2010 8:30	1X	0.5	PPBV	ND	ND	0.565	5.58
LA10-SVE08-27	8/30/2010 17:20	2X	1	PPBV	ND	ND	1.68	113.0
LA10-SVE08-28	8/31/2010 9:15	1X	0.5	PPBV	ND	ND	3.1	66.2
LA10-SVE08-29	8/31/2010 9:00	1X	0.5	PPBV	ND	ND	53	182
LA10-SVE08-30	8/31/2010 9:10	1X	0.5	PPBV	ND	ND	3.7	14.2
LA10-SVE08-31	8/30/2010 16:30	1X	0.5	PPBV	ND	ND	29	332
LA10-SVE08-31 (Dup.)	8/30/2010 16:30	1X	0.5	PPBV	ND	ND	17	271
LA10-SVE08-32	8/30/2010 17:10	1X	0.5	PPBV	ND	ND	6.2	176
LA10-SVE08-33	8/30/2010 0:00	10X	5	PPBV	ND	ND	ND	10.8
LA10-SVE08-34	8/31/2010 8:40	40X	20	PPBV	ND	ND	ND	122
LA10-SVE08-35	8/31/2010 8:50	1X	0.5	PPBV	ND	ND	3.1	34.5
LA10-SVE08-36	8/30/2010 16:45	1X	0.5	PPBV	ND	ND	ND	37.1
LA10-SVE08-37	8/30/2010 16:50	1X	0.5	PPBV	ND	ND	23.0	215
LA10-SVE08-38	8/30/2010 17:50	1X	0.5	PPBV	ND	ND	ND	53
LA10-SVE08-39	8/30/2010 18:00	5X	2.5	PPBV	ND	ND	ND	30.4
LA10-SVE08-40	8/30/2010 17:40	1X	0.5	PPBV	ND	ND	2.3	7.5
Blank - Up Wind	8/31/2010 13:10	1X	0.5	PPBV	ND	ND	ND	ND
Blank - Down Wind	8/31/2010 13:11	1X	0.5	PPBV	ND	ND	ND	ND

Note:

ND = Not Detected

Table B4
SOIL VAPOR MONITORING RESULTS USING GEM 2000 Landfill Gas Monitor CH4/CO2/O2
August 30-31, 2010

Atlas Missile Site 10
Former Lincoln AFB, York, Nebraska

Date/Time	**Well ID**	**CH4** %	**CO2** %	**O2** %	**Balance** %	**%LEL** %	**Vac. Pres.** inch-Hg
8/30/2010 16:30	LA10-SVE08-31	0.2	0.4	17.6	81.8	4	5
8/30/2010 16:45	LA10-SVE08-36	0.2	0.2	19.2	80.4	4	5
8/30/2010 16:50	LA10-SVE08-37	0.2	0.3	18.8	80.7	4	
8/30/2010 17:00	LA10-SVE08-32	0.2	0.3	17.5	82.0	4	5
8/30/2010 17:10	LA10-SVE08-26	0.2	3.5	9.1	87.2	4	13
8/30/2010 17:20	LA10-SVE08-27	0.2	0.8	13.1	85.9	4	5
8/30/2010 17:30	LA10-SVE08-33	0.2	0.2	14.9	84.7	4	
8/30/2010 17:40	LA10-SVE08-40	0.2	0.1	17.7	82	4	
8/30/2010 17:50	LA10-SVE08-38	0.2	1.1	17.7	81	4	
8/30/2010 18:00	LA10-SVE08-39	0.2	0.3	17.9	81.6	4	
8/30/2010 21:46	Blank	0.0	0.0	20.9	79.1	0	
8/31/2010 8:30	LA10-SVE08-26	0.0	0.6	19.6	79.8	0	6
8/31/2010 8:40	LA10-SVE08-34	0.0	0.4	16.7	82.9	0	4
8/31/2010 8:50	LA10-SVE08-35	0.0	1.2	18.7	80.1	0	4
8/31/2010 9:00	LA10-SVE08-29	0.0	1.0	17.4	81.6	0	4
8/31/2010 9:10	LA10-SVE08-30	0.0	0.1	19.3	80.6	0	4
8/31/2010 9:15	LA10-SVE08-28	0.0	1.0	14.7	84.3	0	5
8/31/2010 9:20	LA10-SVE08-23	0.0	0.3	18.8	80.9	0	5
8/31/2010 9:26	LA10-SVE08-24	0.1	0.3	18.8	80.8	2	3.5
8/31/2010 9:34	LA10-SVE08-25	0.1	0.1	19.7	80.1	2	3.5
8/31/2010 9:42	LA10-SVE08-21	0.1	0.4	19.0	80.5	2	4
8/31/2010 9:50	LA10-SVE08-22	0.1	0.1	19.7	80.1	2	4
8/31/2010 9:59	LA10-SVE08-20	0.1	0.3	19.7	79.9	2	5
8/31/2010 10:07	LA10-SVE08-19	0.1	0.0	20.3	79.6	2	5
8/31/2010 10:16	LA10-SVE08-16	0.1	0.5	18.5	80.9	2	4.5
8/31/2010 10:25	LA10-SVE08-15	0.1	0.9	17.1	81.9	2	5
8/31/2010 10:37	LA10-SVE08-18	0.1	3.1	14.7	82.1	2	7
8/31/2010 10:52	LA10-SVE08-17	0.1	0.6	18.9	80.4	2	4.5
8/31/2010 11:39	LA10-SVE08-01	0.1	0.6	18.3	81	2	5
8/31/2010 11:48	LA10-SVE08-04	0.1	1.5	15.7	82.7	2	3
8/31/2010 11:56	LA10-SVE08-02	0.1	0.3	14.7	84.9	2	3
8/31/2010 12:05	LA10-SVE08-05	0.1	0.2	18.8	80.9	2	3.5
8/31/2010 12:13	LA10-SVE08-03	0.1	1.7	17.5	80.7	2	5.5
8/31/2010 12:23	LA10-SVE08-09	0.2	0.3	17.3	82.2	4	5
8/31/2010 12:31	LA10-SVE08-12	0.2	1.0	17.1	81.7	4	7
8/31/2010 12:40	LA10-SVE08-11	0.2	1.1	16.9	81.8	4	7
8/31/2010 12:50	LA10-SVE08-06	0.2	2.2	16.2	81.4	4	5
8/31/2010 12:59	LA10-SVE08-10	0.2	1.3	18.8	79.7	4	5
8/31/2010 13:15	LA10-SVE08-14	0.2	2.9	10.7	86.2	4	5
8/31/2010 13:24	LA10-SVE08-08	0.2	0.0	19.2	80.6	4	12.5
8/31/2010 13:35	LA10-SVE08-07	0.2	8.3	8.4	83.1	4	15
8/31/2010 13:35	Ambient Air	0.2	0.0	19.3	80.5	4	

Note:
Balance = 100 - CH4 - CO2 - O2

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix C: Figures and Tables from Previous Site Reports

Figure C1

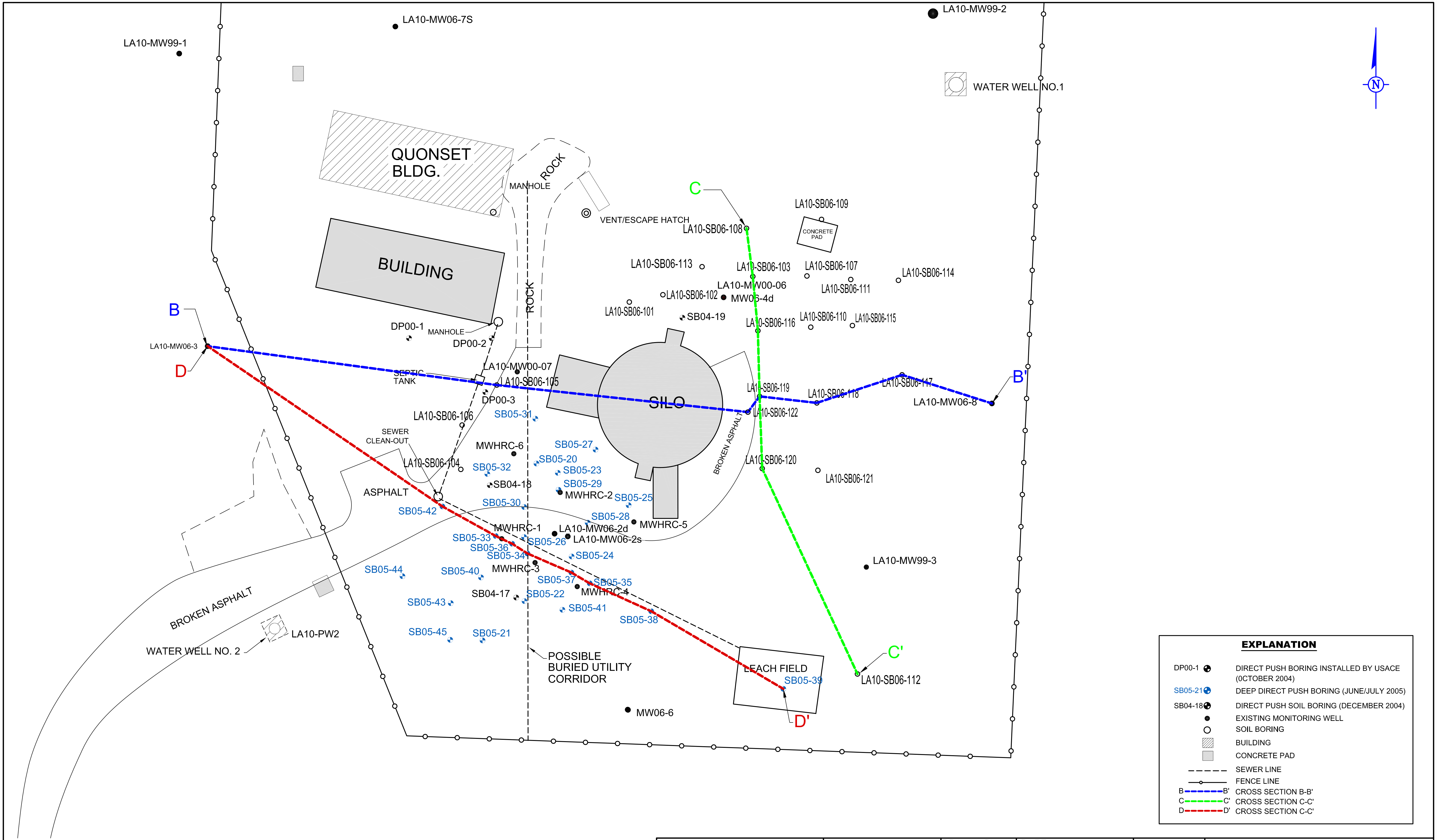
Geological Cross Sections

Figure 5: Site Cross Section Location Map
Figure 6: Geological Cross Section B-B'
Figure 7: Geological Cross Section C-C'

Source:

Kemron, 2007, Soil vapor extraction pilot test report, former Lincoln Air Force Base, Atlas Missile Site 10, York, Nebraska, prepared for U.S. Army corps of Engineers, November 2007

M:\SE-ATLANTA PROJECTS\0 SE50\0 SE 5002 YORK Atlas\MAPS 11-07\ LITHOLOGIC CR. SECT. MAP. FIGs 5, 6, 7.dwg 11/28/2007 kgrigoryan CH



NOTES:

1. BASE MAP DEVELOPED FROM FIGURE 4-1 OF US ARMY CORPS OF ENGINEERS "SUPPLEMENTAL REMEDIAL INVESTIGATION/ FEASIBILITY STUDY AND HRC PILOT STUDY" DATED SEPTEMBER 2003.
2. ALL BORING LOCATIONS AND UNDERGROUND UTILITIES ARE APPROXIMATE.

KEMRON
ENVIRONMENTAL SERVICES

0 25 50
SCALE 1"=50'

DRAWN BY: KG
DATE 29 NOVEMBER 2006
REVIEWED:
PROJECT NO. SE5002-001-005
APPROVED:
DWG. FILE NO. SOIL CRS. SECT.

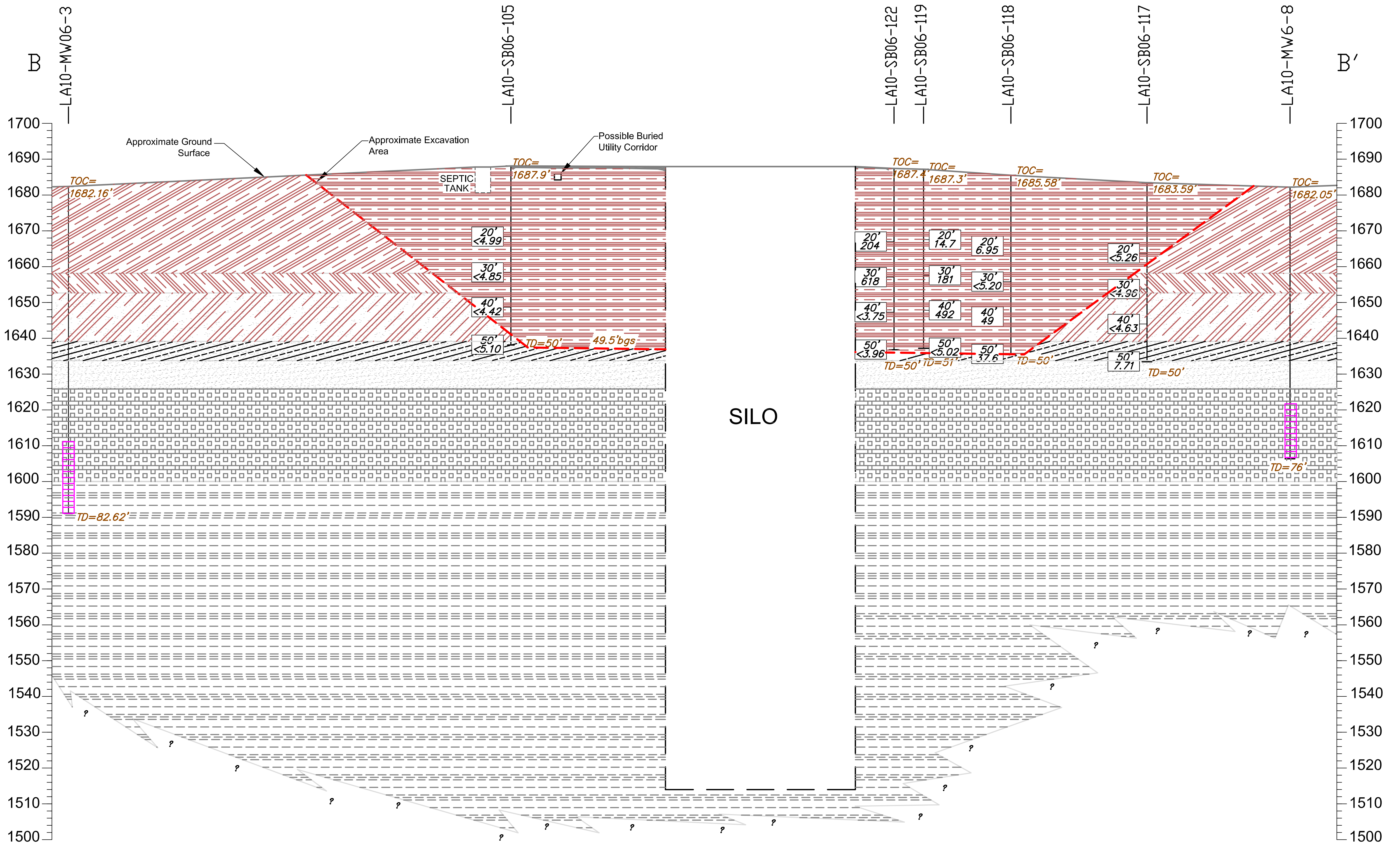
FIGURE 5

SITE CROSS SECTION LOCATION MAP

Atlas Missile SITE 10,
Former Lincoln Air Force Base
York, Nebraska

CROSS SECTION B-B'

WEST TO EAST



LEGEND

WELL SCREEN LOCATION

30' 173 — DEPTH IN ft, TCE DATA IN ug/L

LA10-MW06-1 — MONITORING WELL LOCATION, 2006

LA10-GB06-203 — GEOPROBE SAMPLING LOCATION, 2006

Vertical 1"=30'

VE=0.75

Horizontal 1"=40'

LITHOLOGIC PATTERNS

▨	CLAYEY SILT
▤	NATIVE MATERIAL BACKFILL-CONSISTING OF SILTY CLAY & CLAYEY SILT W/FINE SANDS
▨	SILTY CLAY
▨	CLAYEY SILT W/FINE SANDS
▨	SILTY FINE SANDS
☐	FINE SANDS
▦	MEDIUM TO COARSE FLUVIAL SANDS (GRAND ISLAND FORMATION)
▤	HIGH PLASTIC FINE SANDY CLAY/ GLACIAL TILL (KANSIAN TILL)

KEMRON ENVIRONMENTAL SERVICES	DRAWN BY: KG	DATE 30 NOVEMBER 2006	FIGURE 6
	REVIEWED:	PROJECT NO. SE5002-001-005	
	APPROVED:	DWG. FILE NO. CRS. SECT. B-B'	

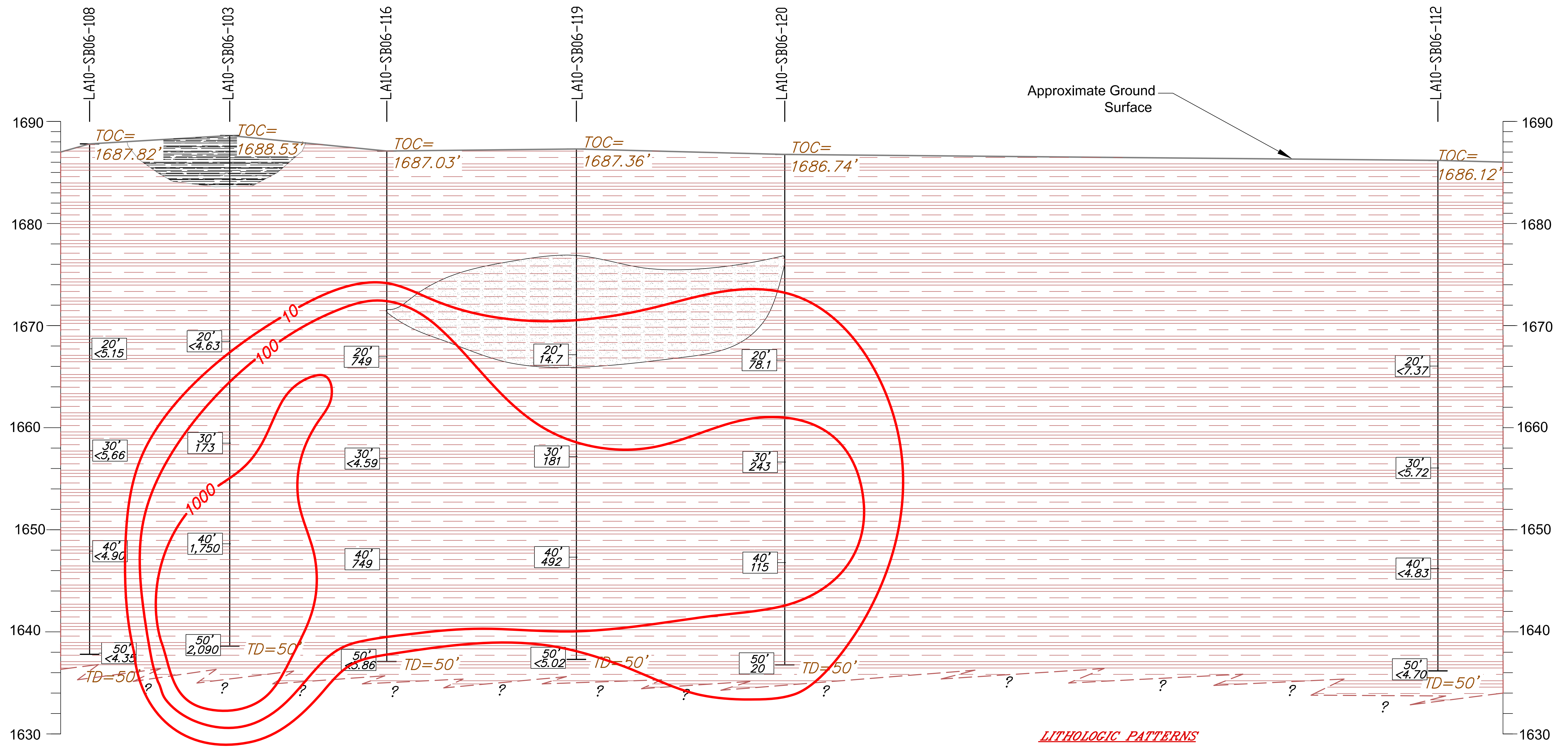
GEOLOGIC CROSS SECTION B-B'

Atlas Missile SITE 10,
Former Lincoln Air Force Base
York, Nebraska

M:\SE-ATLANTA PROJECTS\0 SE50\0 SE 5002 YORK Atlas\MAPS 11-07\ LITHOLOGIC CR. SECT. MAP. FIGs 5, 6, 7.dwg 11/28/2007 kgrigoryan CH

CROSS SECTION C-C'

NORTH TO SOUTH



LITHOLOGIC PATTERNS

▤	FILL MATERIAL-SAND
▤	CLAYEY SILTS & SILTY CLAYS
▤	SILTY CLAY WITH SAND

LEGEND

30' 173	DEPTH IN ft TCE DATA IN ug/L
LA10-MW06-1	MONITORING WELL LOCATION, 2006
LA10-GB06-203	GEOPROBE SAMPLING LOCATION, 2006
10	TRICHLOROETHENE ISOCONCENTRATION

Vertical 1"=10'

VE=2

Horizontal 1"=20'

KEMRON ENVIRONMENTAL SERVICES	DRAWN BY: KG	DATE 7 DECEMBER 2006	FIGURE 7	GEOLOGIC CROSS SECTION C-C' TCE ISOCONCENTRATION MAP Atlas Missile SITE 10, Former Lincoln Air Force Base York, Nebraska
	REVIEWED:	PROJECT NO. SE5002-001-005		
	APPROVED:	DWG. FILE NO. CRS. SECT. C-C'		

M:\SE-ATLANTA PROJECTS\0 SE50\0 SE 5002 YORK Atlas\MAPS 11-07\ LITHOLOGIC CR. SECT. MAP. FIGs 5, 6, 7.dwg 11/28/2007 kgrigoryan CH

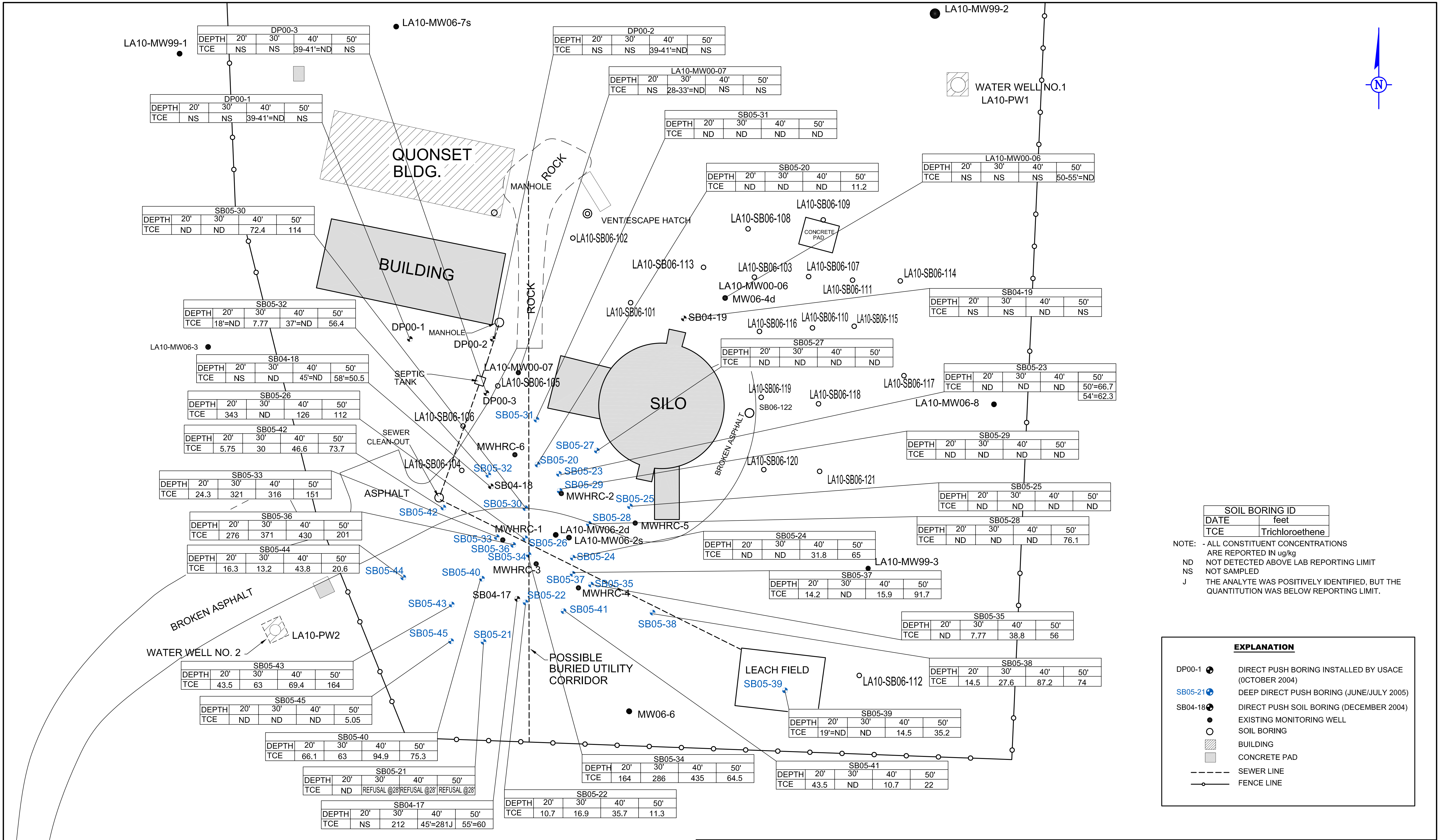
Figure C2

Soil TCE Concentration Map, 1999-2006

Figure 2A: Site Soil Investigation, 1999-2005
Figure 2B: Site Soil Investigation, 2006

Source:

Kemron, 2007, Soil vapor extraction pilot test report, former Lincoln Air Force Base, Atlas Missile Site 10, York, Nebraska, prepared for U.S. Army corps of Engineers, November 2007



DP00-3

DEPTH	20'	30'	40'	50'
TCE	NS	NS	39-41'=ND	NS

DP00-2

DEPTH	20'	30'	40'	50'
TCE	NS	NS	39-41'=ND	NS

LA10-MW00-07

DEPTH	20'	30'	40'	50'
TCE	NS	28-33'=ND	NS	NS

DP00-1

DEPTH	20'	30'	40'	50'
TCE	NS	NS	39-41'=ND	NS

SB05-31

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	ND

SB05-20

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	11.2

LA10-MW00-06

DEPTH	20'	30'	40'	50'
TCE	NS	NS	NS	50-55'=ND

SB05-30

DEPTH	20'	30'	40'	50'
TCE	ND	ND	72.4	114

SB04-19

DEPTH	20'	30'	40'	50'
TCE	NS	NS	ND	NS

SB05-32

DEPTH	20'	30'	40'	50'
TCE	18'=ND	7.77	37'=ND	56.4

SB04-18

DEPTH	20'	30'	40'	50'
TCE	NS	ND	45'=ND	58'=50.5

SB05-27

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	ND

SB05-23

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	50'=66.7 54'=62.3

SB05-26

DEPTH	20'	30'	40'	50'
TCE	343	ND	126	112

SB05-42

DEPTH	20'	30'	40'	50'
TCE	5.75	30	46.6	73.7

SB05-29

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	ND

SB05-33

DEPTH	20'	30'	40'	50'
TCE	24.3	321	316	151

SB05-25

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	ND

SB05-36

DEPTH	20'	30'	40'	50'
TCE	276	371	430	201

SB05-28

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	76.1

SB05-24

DEPTH	20'	30'	40'	50'
TCE	ND	ND	31.8	65

SB05-44

DEPTH	20'	30'	40'	50'
TCE	16.3	13.2	43.8	20.6

SB05-37

DEPTH	20'	30'	40'	50'
TCE	14.2	ND	15.9	91.7

SB05-35

DEPTH	20'	30'	40'	50'
TCE	ND	7.77	38.8	56

SB05-43

DEPTH	20'	30'	40'	50'
TCE	43.5	63	69.4	164

SB05-38

DEPTH	20'	30'	40'	50'
TCE	14.5	27.6	87.2	74

SB05-45

DEPTH	20'	30'	40'	50'
TCE	ND	ND	ND	5.05

SB05-39

DEPTH	20'	30'	40'	50'
TCE	19'=ND	ND	14.5	35.2

SB05-40

DEPTH	20'	30'	40'	50'
TCE	66.1	63	94.9	75.3

SB05-34

DEPTH	20'	30'	40'	50'
TCE	164	286	435	64.5

SB05-41

DEPTH	20'	30'	40'	50'
TCE	43.5	ND	10.7	22

SB05-21

DEPTH	20'	30'	40'	50'
TCE	ND	REFUSAL @28'	REFUSAL @28'	REFUSAL @28'

SB05-22

DEPTH	20'	30'	40'	50'
TCE	10.7	16.9	35.7	11.3

SB04-17

DEPTH	20'	30'	40'	50'
TCE	NS	212	45'=281J	55'=60

SOIL BORING ID

DATE	feet
TCE	Trichloroethene

NOTE: - ALL CONSTITUENT CONCENTRATIONS ARE REPORTED IN ug/kg

ND	NOT DETECTED ABOVE LAB REPORTING LIMIT
NS	NOT SAMPLED
J	THE ANALYTE WAS POSITIVELY IDENTIFIED, BUT THE QUANTITUTION WAS BELOW REPORTING LIMIT.

EXPLANATION

DP00-1 ◒	DIRECT PUSH BORING INSTALLED BY USACE (0CTOBER 2004)
SB05-21 ◒	DEEP DIRECT PUSH BORING (JUNE/JULY 2005)
SB04-18 ◒	DIRECT PUSH SOIL BORING (DECEMBER 2004)
●	EXISTING MONITORING WELL
○	SOIL BORING
▨	BUILDING
▢	CONCRETE PAD
– – – – –	SEWER LINE
—o——	FENCE LINE

NOTES:

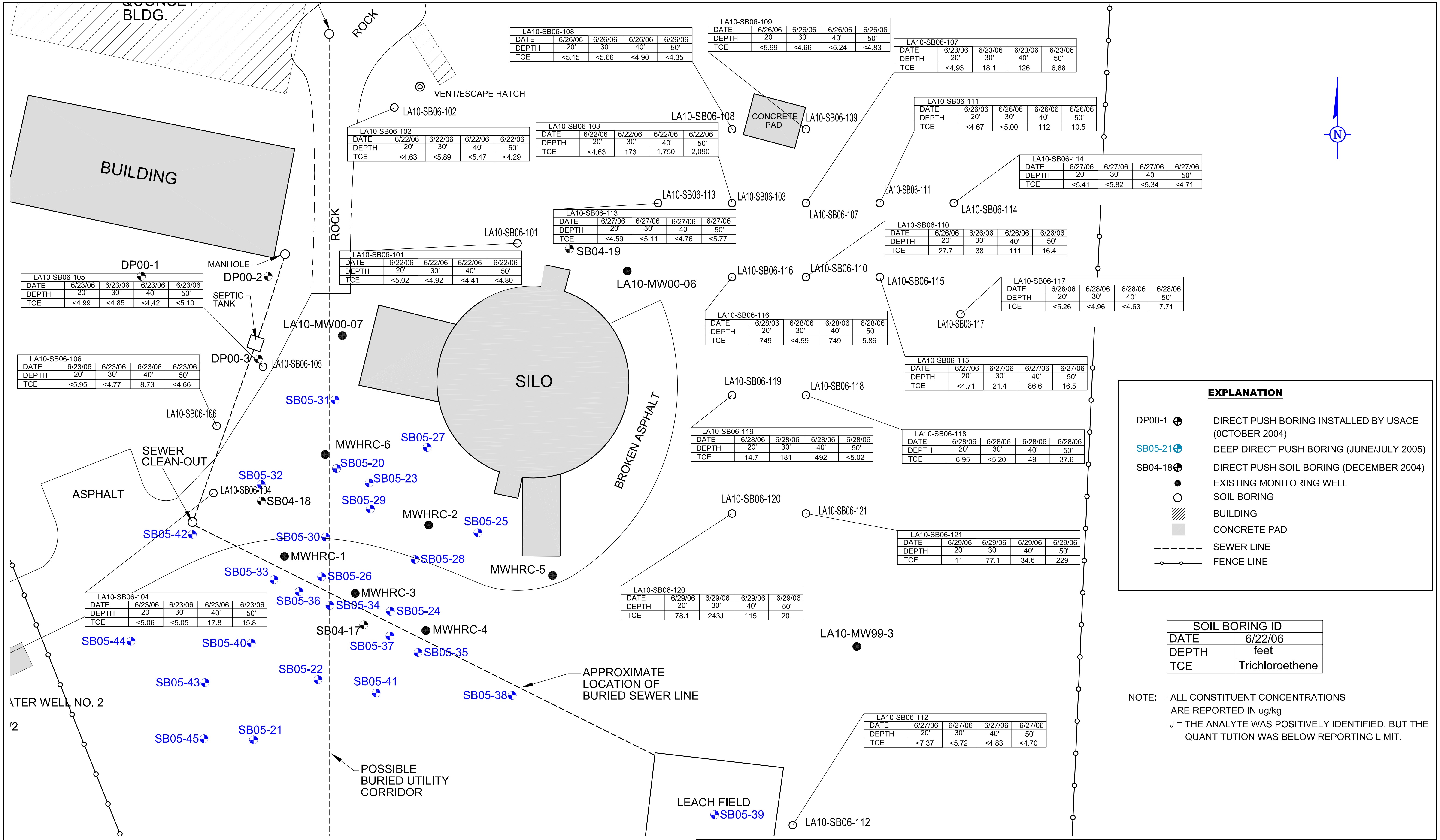
1. BASE MAP DEVELOPED FROM FIGURE 4-1 OF US ARMY CORPS OF ENGINEERS "SUPPLEMENTAL REMEDIAL INVESTIGATION/ FEASIBILITY STUDY AND HRC PILOT STUDY" DATED SEPTEMBER 2003.
2. ALL BORING LOCATIONS AND UNDERGROUND UTILITIES ARE APPROXIMATE.

KEMRON
ENVIRONMENTAL SERVICES

DRAWN BY: KG	DATE 20 DECEMBER 2006	FIGURE 2A
REVIEWED:	PROJECT NO. SE5002-001-005	
APPROVED:	DWG. FILE NO. S.SOIL.INVS. 99-05	

SITE SOIL INVESTIGATION,
1999-2005

Atlas Missile SITE 10,
Former Lincoln Air Force Base
York, Nebraska



LA10-SB06-101				
DATE	6/22/06	6/22/06	6/22/06	6/22/06
DEPTH	20'	30'	40'	50'
TCE	<5.02	<4.92	<4.41	<4.80

LA10-SB06-102				
DATE	6/22/06	6/22/06	6/22/06	6/22/06
DEPTH	20'	30'	40'	50'
TCE	<4.63	<5.89	<5.47	<4.29

LA10-SB06-103				
DATE	6/22/06	6/22/06	6/22/06	6/22/06
DEPTH	20'	30'	40'	50'
TCE	<4.63	173	1,750	2,090

LA10-SB06-104				
DATE	6/23/06	6/23/06	6/23/06	6/23/06
DEPTH	20'	30'	40'	50'
TCE	<5.06	<5.05	17.8	15.8

LA10-SB06-105				
DATE	6/23/06	6/23/06	6/23/06	6/23/06
DEPTH	20'	30'	40'	50'
TCE	<4.99	<4.85	<4.42	<5.10

LA10-SB06-106				
DATE	6/23/06	6/23/06	6/23/06	6/23/06
DEPTH	20'	30'	40'	50'
TCE	<5.95	<4.77	8.73	<4.66

LA10-SB06-107				
DATE	6/23/06	6/23/06	6/23/06	6/23/06
DEPTH	20'	30'	40'	50'
TCE	<4.93	18.1	126	6.88

LA10-SB06-108				
DATE	6/26/06	6/26/06	6/26/06	6/26/06
DEPTH	20'	30'	40'	50'
TCE	<5.15	<5.66	<4.90	<4.35

LA10-SB06-109				
DATE	6/26/06	6/26/06	6/26/06	6/26/06
DEPTH	20'	30'	40'	50'
TCE	<5.99	<4.66	<5.24	<4.83

LA10-SB06-110				
DATE	6/26/06	6/26/06	6/26/06	6/26/06
DEPTH	20'	30'	40'	50'
TCE	27.7	38	111	16.4

LA10-SB06-111				
DATE	6/26/06	6/26/06	6/26/06	6/26/06
DEPTH	20'	30'	40'	50'
TCE	<4.67	<5.00	112	10.5

LA10-SB06-112				
DATE	6/27/06	6/27/06	6/27/06	6/27/06
DEPTH	20'	30'	40'	50'
TCE	<7.37	<5.72	<4.83	<4.70

LA10-SB06-113				
DATE	6/27/06	6/27/06	6/27/06	6/27/06
DEPTH	20'	30'	40'	50'
TCE	<4.59	<5.11	<4.76	<5.77

LA10-SB06-114				
DATE	6/27/06	6/27/06	6/27/06	6/27/06
DEPTH	20'	30'	40'	50'
TCE	<5.41	<5.82	<5.34	<4.71

LA10-SB06-115				
DATE	6/27/06	6/27/06	6/27/06	6/27/06
DEPTH	20'	30'	40'	50'
TCE	<4.71	21.4	86.6	16.5

LA10-SB06-116				
DATE	6/28/06	6/28/06	6/28/06	6/28/06
DEPTH	20'	30'	40'	50'
TCE	749	<4.59	749	5.86

LA10-SB06-117				
DATE	6/28/06	6/28/06	6/28/06	6/28/06
DEPTH	20'	30'	40'	50'
TCE	<5.26	<4.96	<4.63	7.71

LA10-SB06-118				
DATE	6/28/06	6/28/06	6/28/06	6/28/06
DEPTH	20'	30'	40'	50'
TCE	6.95	<5.20	49	37.6

LA10-SB06-119				
DATE	6/28/06	6/28/06	6/28/06	6/28/06
DEPTH	20'	30'	40'	50'
TCE	14.7	181	492	<5.02

LA10-SB06-120				
DATE	6/29/06	6/29/06	6/29/06	6/29/06
DEPTH	20'	30'	40'	50'
TCE	78.1	243J	115	20

LA10-SB06-121				
DATE	6/29/06	6/29/06	6/29/06	6/29/06
DEPTH	20'	30'	40'	50'
TCE	11	77.1	34.6	229

EXPLANATION

DP00-1 ⊕	DIRECT PUSH BORING INSTALLED BY USACE (0CTOBER 2004)
SB05-21 ⊕	DEEP DIRECT PUSH BORING (JUNE/JULY 2005)
SB04-18 ⊕	DIRECT PUSH SOIL BORING (DECEMBER 2004)
●	EXISTING MONITORING WELL
○	SOIL BORING
▨	BUILDING
▩	CONCRETE PAD
– – – –	SEWER LINE
–o–o–	FENCE LINE

SOIL BORING ID	
DATE	6/22/06
DEPTH	feet
TCE	Trichloroethene

NOTE:
- ALL CONSTITUENT CONCENTRATIONS ARE REPORTED IN ug/kg
- J = THE ANALYTE WAS POSITIVELY IDENTIFIED, BUT THE QUANTITUTION WAS BELOW REPORTING LIMIT.

NOTES:
1. BASE MAP DEVELOPED FROM FIGURE 4-1 OF US ARMY CORPS OF ENGINEERS "SUPPLEMENTAL REMEDIAL INVESTIGATION/ FEASIBILITY STUDY AND HRC PILOT STUDY" DATED SEPTEMBER 2003.
2. ALL BORING LOCATIONS AND UNDERGROUND UTILITIES ARE APPROXIMATE.

M:\SE-ATLANTA PROJECTS\0 SE50\0 SE 5002 YORK Atlas\MAPS 11-07\ SITE SOIL INVESTIGATION 2006. FIG 2B.dwg 11/28/2007 kgrigoryan CH

KEMRON
ENVIRONMENTAL SERVICES

0 15 30
SCALE 1"=30'

DRAWN BY: KG	DATE 20 DECEMBER 2006
REVIEWED:	PROJECT NO. SE5002-001-005
APPROVED:	DWG. FILE NO. S.SOIL INVEST. 06

FIGURE 2B

SITE SOIL INVESTIGATION 2006

Atlas Missile SITE 10,
Former Lincoln Air Force Base
York, Nebraska

Table C1

Soil Analytical Data, 2004-2006

Table 2: Soil Analytical Data, Laboratory Results, 2004-2006

Source:

Kemron, 2007, Soil vapor extraction pilot test report, former Lincoln Air Force Base, Atlas Missile Site 10, York, Nebraska, prepared for U.S. Army corps of Engineers, November 2007

Soil Analytical Data, Laboratory Results, 2004-2006
Former Lincoln Air Force Base
Atlas Missile Site 10
York, York County, Nebraska

Table 2: Soil Analytical Data, Laboratory Results, 2004-2006
SW5260B (TCL-Volatile Organics)

Boring Location	**Depth (feet) (ft bgs)**	**Date**	**Trichloroethene** (µg/Kg)	**cis-1,2-Dichloroethene** (µg/Kg)	**trans- 1,2-Dichloroethene** (µg/Kg)	**Acetone ug/g** (µg/Kg)	**Trichlorofluoromethane** (µg/Kg)	**Toluene** (µg/Kg)
LA10-SB04-16	30	12/7/2004	<3.88	<3.88	DNA	DNA	DNA	DNA
LA10-SB04-17	30	12/8/2004	212	20.0	DNA	DNA	DNA	DNA
	45	12/8/2004	281 J	16.1	DNA	DNA	DNA	DNA
	55	12/8/2004	60.0	<4.50	DNA	DNA	DNA	DNA
LA10-SB04-18	30	12/9/2004	<6.74	<6.74	DNA	DNA	DNA	DNA
	45	12/9/2004	<5.55	<5.55	DNA	DNA	DNA	DNA
	58	12/9/2004	50.5	<4.48	DNA	DNA	DNA	DNA
LA10-SB04-19	30	12/9/2004	<4.25	<4.25	DNA	DNA	DNA	DNA
	45	12/9/2004	<4.80	<4.80	DNA	DNA	DNA	DNA
LA10-SB05-20	20	6/27/2005	<3.99	<3.99	DNA	DNA	DNA	DNA
	30	6/27/2005	<3.73	<3.73	DNA	DNA	DNA	DNA
	40	6/7/2005	<3.70	<3.70	DNA	DNA	DNA	DNA
	50	6/27/2005	11.2	<4.34	DNA	DNA	DNA	DNA
LA10-SB05-21	20	6/27/2005	<4.19	<4.19	DNA	DNA	DNA	DNA
LA10-SB05-22	20	6/27/2005	10.7	<5.34	DNA	DNA	DNA	DNA
	30	6/27/2005	16.9	<3.91	DNA	DNA	DNA	DNA
	40	6/28/2005	35.7	<4.30	DNA	DNA	DNA	DNA
	50	6/28/2005	11.3	<5.03	DNA	DNA	DNA	DNA
LA10-SB05-23	20	6/28/2005	<4.03	<4.03	DNA	DNA	DNA	DNA
	30	6/28/2005	<3.96	<3.96	DNA	DNA	DNA	DNA
	40	6/28/2005	<7.40	<7.40	DNA	DNA	DNA	DNA
	50	6/28/2005	66.7	<4.31	DNA	DNA	DNA	DNA
	54	6/28/2005	62.3	<4.01	DNA	DNA	DNA	DNA
LA10-SB05-24	20	6/28/2005	<6.02	<6.02	DNA	DNA	DNA	DNA
	30	6/28/2005	<4.63	<4.63	DNA	DNA	DNA	DNA
	40	6/28/2005	31.8	<5.26	DNA	DNA	DNA	DNA
	50	6/28/2005	65	<5.39	DNA	DNA	DNA	DNA
LA10-SB05-25	20	6/28/2005	<4.30	<4.30	DNA	DNA	DNA	DNA
	30	6/28/2005	<4.67	<4.67	DNA	DNA	DNA	DNA
	40	6/28/2005	<9.14	<9.14	DNA	DNA	DNA	DNA
	50	6/29/2005	<4.11	<4.11	DNA	DNA	DNA	DNA
LA10-SB05-26	20	6/28/2005	343	5.16	DNA	DNA	DNA	DNA
	30	6/28/2005	<3.64	<3.64	DNA	DNA	DNA	DNA
	40	6/28/2005	126	<6.91	DNA	DNA	DNA	DNA
	50	6/29/2005	112	<5.51	DNA	DNA	DNA	DNA
LA10-SB05-27	20	6/29/2005	<5.08	<5.08	DNA	DNA	DNA	DNA
	30	6/29/2005	<5.03	<5.03	DNA	DNA	DNA	DNA
	40	6/29/2005	<5.01	<5.01	DNA	DNA	DNA	DNA
	50	6/29/2005	<5.28	<5.28	DNA	DNA	DNA	DNA
LA10-SB05-28	20	6/29/2005	<4.76	<4.76	DNA	DNA	DNA	DNA
	30	6/29/2005	<4.35	<4.35	DNA	DNA	DNA	DNA
	40	6/29/2005	<5.86	<5.86	DNA	DNA	DNA	DNA
	50	6/29/2005	76.1	<4.77	DNA	DNA	DNA	DNA
LA10-SB05-29	20	6/30/2005	<4.48	<4.48	DNA	DNA	DNA	DNA
	30	6/30/2005	<5.04	<5.04	DNA	DNA	DNA	DNA
	40	6/30/2005	<5.07	<5.07	DNA	DNA	DNA	DNA
	50	6/30/2005	<5.79	<5.79	DNA	DNA	DNA	DNA
LA10-SB05-30	20	6/30/2005	<4.89	<4.89	DNA	DNA	DNA	DNA
	30	6/30/2005	<6.10	<6.10	DNA	DNA	DNA	DNA
	40	6/30/2005	72.4	<4.85	DNA	DNA	DNA	DNA
	50	6/30/2005	114	<4.98	DNA	DNA	DNA	DNA
LA10-SB05-31	20	6/30/2005	<5.20	<5.20	DNA	DNA	DNA	DNA
	30	6/30/2005	<5.63	<5.63	DNA	DNA	DNA	DNA
	40	6/30/2005	<4.95	<4.95	DNA	DNA	DNA	DNA
	50	6/30/2005	<6.25	<6.25	DNA	DNA	DNA	DNA
LA10-SB05-32	18	6/29/2005	<5.15	<5.15	DNA	DNA	DNA	DNA
	30	6/30/2005	<4.48	<4.48	DNA	DNA	DNA	DNA
	37	6/30/2005	<5.05	<5.05	DNA	DNA	DNA	DNA
	40	6/30/2005	57.0	<5.32	DNA	DNA	DNA	DNA
	50	6/30/2005	56.4	<6.28	DNA	DNA	DNA	DNA
LA10-SB05-33	20	6/30/2005	24.3	<6.24	DNA	DNA	DNA	DNA
	30	6/30/2005	321	60.2	DNA	DNA	DNA	DNA
	40	6/30/2005	316	39.5	DNA	DNA	DNA	DNA
	50	6/30/2005	151	16.5	DNA	DNA	DNA	DNA
LA10-SB05-34	20	7/1/2005	164	13.4	DNA	DNA	DNA	DNA
	30	7/1/2005	286	43.4	DNA	DNA	DNA	DNA
	40	7/1/2005	435	26.7	DNA	DNA	DNA	DNA
	50	7/1/2005	64.5	5.96	DNA	DNA	DNA	DNA
LA10-SB05-35	20	7/1/2005	<3.82	<3.82	DNA	DNA	DNA	DNA
	30	7/1/2005	7.77	<4.30	DNA	DNA	DNA	DNA
	40	7/1/2005	38.8	<4.87	DNA	DNA	DNA	DNA
	50	7/1/2005	56	<4.11	DNA	DNA	DNA	DNA
LA10-SB05-36	20	7/6/2005	276	24.2	DNA	DNA	DNA	DNA
	30	7/6/2005	377	65.2	DNA	DNA	DNA	DNA
	40	7/6/2005	430	41.1	DNA	DNA	DNA	DNA
	50	7/6/2005	201	21.8	DNA	DNA	DNA	DNA

Soil Analytical Data, Laboratory Results, 2004-2006
Former Lincoln Air Force Base
Atlas Missile Site 10
York, York County, Nebraska

Table 2: Soil Analytical Data, Laboratory Results, 2004-2006
SW5260B (TCL-Volatile Organics)

Boring Location	**Depth (feet) (ft bgs)**	**Date**	**Trichloroethene** (µg/Kg)	**cis-1,2-Dichloroethene** (µg/Kg)	**trans- 1,2-Dichloroethene** (µg/Kg)	**Acetone ug/g** (µg/Kg)	**Trichlorofluoromethane** (µg/Kg)	**Toluene** (µg/Kg)
LA10-SB05-37	20	7/6/2005	14.2	<5.49	DNA	DNA	DNA	DNA
	30	7/6/2005	<5.55	<5.55	DNA	DNA	DNA	DNA
	40	7/6/2005	15.9	<5.38	DNA	DNA	DNA	DNA
	50	7/6/2005	91.7	<5.07	DNA	DNA	DNA	DNA
LA10-SB05-38	20	7/5/2005	14.5	<5.43	DNA	DNA	DNA	DNA
	30	7/5/2005	27.6	<5.03	DNA	DNA	DNA	DNA
	40	7/5/2005	87.2	<5.79	DNA	DNA	DNA	DNA
	50	7/5/2005	74.0	<5.25	DNA	DNA	DNA	DNA
LA10-SB05-39	19	7/5/2005	<5.94	<5.94	DNA	DNA	DNA	DNA
	30	7/5/2005	<4.58	<4.58	DNA	DNA	DNA	DNA
	40	7/5/2005	14.5	<5.78	DNA	DNA	DNA	DNA
	50	7/5/2005	35.2	<5.66	DNA	DNA	DNA	DNA
LA10-SB05-40	20	7/6/2005	66.1	12.10	DNA	DNA	DNA	DNA
	30	7/6/2005	63.0	12.00	DNA	DNA	DNA	DNA
	40	7/6/2005	94.9	12.70	DNA	DNA	DNA	DNA
	50	7/6/2005	75.3	8.79	DNA	DNA	DNA	DNA
LA10-SB05-41	20	7/6/2005	<5.26	<5.26	DNA	DNA	DNA	DNA
	30	7/6/2005	<5.71	<5.71	DNA	DNA	DNA	DNA
	40	7/6/2005	10.7	<4.79	DNA	DNA	DNA	DNA
	50	7/6/2005	22.0	<5.12	DNA	DNA	DNA	DNA
LA10-SB05-42	20	7/6/2005	5.75	<2.24	DNA	DNA	DNA	DNA
	30	7/6/2005	30.0	<5.67	DNA	DNA	DNA	DNA
	40	7/6/2005	46.6	<5.84	DNA	DNA	DNA	DNA
	50	7/6/2005	73.7	<5.41	DNA	DNA	DNA	DNA
LA10-SB05-43	20	7/7/2005	43.4	<6.12	DNA	DNA	DNA	DNA
	30	7/7/2005	63.0	<5.10	DNA	DNA	DNA	DNA
	40	7/7/2005	69.4	<5.14	DNA	DNA	DNA	DNA
	50	7/7/2005	164	<5.34	DNA	DNA	DNA	DNA
LA10-SB05-44	20	7/7/2005	16.3	<4.76	DNA	DNA	DNA	DNA
	30	7/7/2005	13.2	<4.35	DNA	DNA	DNA	DNA
	40	7/7/2005	43.8	<5.35	DNA	DNA	DNA	DNA
	50	7/7/2005	20.6	<3.82	DNA	DNA	DNA	DNA
LA10-SB05-45	20	7/8/2005	<5.34	<5.34	DNA	DNA	DNA	DNA
	30	7/8/2005	<4.46	<4.46	DNA	DNA	DNA	DNA
	40	7/8/2005	<4.52	<4.52	DNA	DNA	DNA	DNA
	50	7/8/2005	5.05	<4.55	DNA	DNA	DNA	DNA
LA10-SB06-101	20	6/22/2006	<5.02	<5.02	<5.02	<10.0	<10.0	<5.02
	30	6/22/2006	<4.92	<4.92	<4.92	<9.83	<9.83	5.1
	40	6/22/2006	<4.41	<4.41	<4.41	<8.82	<8.81	<4.41
	50	6/22/2006	<4.80	<4.80	<4.80	16.0	<9.60	<4.80
LA10-SB06-102	20	6/22/2006	<4.63	<4.63	<4.63	<9.26	<9.26	<4.63
	30	6/22/2006	<5.89	<5.89	<5.89	20.5	<11.8	<5.89
	40	6/22/2006	<5.47	<5.47	<5.47	54.5	<10.9	<5.47
	50	6/22/2006	<4.29	<4.29	<4.29	<8.58	<8.58	<4.29
LA10-SB06-103	20	6/22/2006	<4.63	<4.63	<4.63	<9.27	<9.27	<4.63
	30	6/22/2006	173	89.3	4.49	<8.82	<8.82	<4.41
	40	6/22/2006	1750	910	13.7	<9.96	<9.96	<4.98
	50	6/22/2006	2090	530	15.6	<10.4	<10.4	<5.19
LA10-SB06-104	20	6/23/2006	<5.06	<5.06	<5.06	<10.1	<10.1	<5.06
	30	6/23/2006	<5.05	<5.05	<5.05	<10.1	<10.1	<5.05
	40	6/23/2006	17.8	<5.68	<5.68	<11.4	<11.4	<5.68
	50	6/23/2006	15.8	<4.89	<4.89	<9.79	<9.79	<4.89
LA10-SB06-105	20	6/23/2006	<4.99	<4.99	<4.99	<9.98	<9.98	<4.99
	30	6/23/2006	<4.85	<4.85	<4.85	30	<9.70	6.59
	40	6/23/2006	<4.42	<4.42	<4.42	32	<8.84	<4.42
	50	6/23/2006	<5.10	<5.10	<5.10	14.4	<10.2	<5.10
LA10-SB06-106	20	6/23/2006	<5.95	<5.95	<5.95	<11.9	<11.9	<5.95
	30	6/23/2006	<4.77	<4.77	<4.77	27.8	<9.54	<4.77
	40	6/23/2006	8.73	<6.15	<6.15	<12.3	<12.3	<6.15
	50	6/23/2006	<4.66	<4.66	<4.66	<9.32	<9.32	<4.66
LA10-SB06-107	20	6/23/2006	<4.93	<4.93	<4.93	19.6	<9.87	<4.93
	30	6/23/2006	18.1	110	7.36	<9.43	<9.43	<4.72
	40	6/23/2006	126	206	10.2	<10.8	<10.8	<5.40
	50	6/23/2006	6.88	<4.45	<4.45	<8.89	<8.89	<4.45
LA10-SB06-108	20	6/26/2006	<5.15	<5.15	<5.15	17.8	<10.3	<5.15
	30	6/26/2006	<5.66	<5.66	<5.66	193	<11.3	<5.66
	40	6/26/2006	<4.90	<4.90	<4.90	<9.80	<9.80	<4.90
	50	6/26/2006	<4.35	<4.35	<4.35	16.9	<8.69	<4.35
LA10-SB06-109	20	6/26/2006	<5.99	<5.99	<5.99	25.7	<12.0	<5.99
	30	6/26/2006	<4.66	<4.66	<4.66	<9.32	<9.32	<4.66
	40	6/26/2006	<5.24	<5.24	<5.24	<10.5	<10.5	<5.24
	50	6/26/2006	<4.83	<4.83	<4.83	<9.65	<9.65	<4.83
LA10-SB06-110	20	6/26/2006	27.7	273J	12.1	<10.5	<10.5	<5.26
	30	6/26/2006	38	198	<5.01	<10.0	<10.0	<5.01
	40	6/26/2006	111	107	<5.68	<11.4	<11.4	<5.68
	50	6/26/2006	16.4	17.6	<4.95	<9.91	<9.91	<4.95

Soil Analytical Data, Laboratory Results, 2004-2006
Former Lincoln Air Force Base
Atlas Missile Site 10
York, York County, Nebraska

Table 2: Soil Analytical Data, Laboratory Results, 2004-2006
SW5260B (TCL-Volatile Organics)

Boring Location	**Depth (feet) (ft bgs)**	**Date**	**Trichloroethene** (µg/Kg)	**cis-1,2-Dichloroethene** (µg/Kg)	**trans- 1,2-Dichloroethene** (µg/Kg)	**Acetone ug/g** (µg/Kg)	**Trichlorofluoromethane** (µg/Kg)	**Toluene** (µg/Kg)
LA10-SB06-111	20	6/26/2006	<4.67	<4.67	<4.67	<9.33	<9..33	<4.67
	30	6/26/2006	<5.00	<5.00	<5.00	<10.0	<10.0	<5.00
	40	6/26/2006	112	73.2	<4.97	<9.94	<9.94	<4.97
	50	6/26/2006	10.5	16.6	<5.61	<11.2	<11.2	<5.61
LA10-SB06-112	20	6/27/2006	<7.37	<7.37	<7.37	<14.7	<14.7	<7.37
	30	6/27/2006	<5.72	<5.72	<5.72	<11.4	<11.4	<5.72
	40	6/27/2006	<4.83	<4.83	<4.83	<9.67	<9.67	<4.83
	50	6/27/2006	<4.70	<4.70	<4.70	<9.40	<9.40	<4.70
LA10-SB06-113	20	6/27/2006	<4.59	<4.59	<4.59	<9.17	<9.17	<4.59
	30	6/27/2006	<5.11	<5.11	<5.11	<10.2	<10.2	<5.11
	40	6/27/2006	<4.76	<4.76	<4.76	<9.53	<9.53	<4.76
	50	6/27/2006	<5.77	<5.77	<5.77	13.1	<11.5	<5.77
LA10-SB06-114	20	6/27/2006	<5.41	<5.41	<5.41	<10.8	<10.8	<5.41
	30	6/27/2006	<5.82	<5.82	<5.82	<11.6	<11.6	<5.82
	40	6/27/2006	<5.34	<5.34	<5.34	<10.7	<10.7	<5.34
	50	6/27/2006	<4.71	<4.71	<4.71	<9.42	<9.42	<4.71
LA10-SB06-115	20	6/27/2006	<4.71	<4.71	<4.71	51.8	<9.42	<4.71
	30	6/27/2006	21.4	19.4	<5.61	<11.2	<11.2	<5.61
	40	6/27/2006	86.6	45.8	<4.84	<9.68	<9.68	<4.84
	50	6/27/2006	16.5	6.91	<5.38	<10.8	<10.8	<5.38
LA10-SB06-116	20	6/28/2006	749	1560	98.3	<9.71	<9.71	<4.85
	30	6/28/2006	<4.59	730	13	18.3	<9.18	<4.59
	40	6/28/2006	749	261J	5.9	<8.99	<8.99	<4.50
	50	6/28/2006	5.86	<4.22	<4.22	<8.44	12.6	<4.22
LA10-SB06-117	20	6/28/2006	<5.26	<5.26	<5.26	<10.5	<10.5	<5.26
	30	6/28/2006	<4.96	4.96	28.2	28.2	<9.92	<4.96
	40	6/28/2006	<4.63	<4.63	15.3	15.3	<9.25	<4.63
	50	6/28/2006	7.71	<4.52	<4.52	<9.04	<9.04	<4.52
LA10-SB06-118	20	6/28/2006	6.95	14.6	<5.62	<11.2	<11.2	<5.62
	30	6/28/2006	<5.20	46.7	<5.20	<10.4	<10.4	<5.20
	40	6/28/2006	49	46.6	<4.97	<9.94	<9.94	<4.97
	50	6/28/2006	37.6	<5.38	<5.38	<10.8	<10.8	<5.38
LA10-SB06-119	20	6/28/2006	14.7	77.4	<4.87	<9.74	<9.74	<4.87
	30	6/28/2006	181	55.1	<5.41	<10.8	<10.8	<5.41
	40	6/28/2006	492	69.1	<5.93	<11.9	<11.9	<5.93
	50	6/28/2006	<5.02	7.36	<5.02	<10.0	<10.0	<5.02
LA10-SB06-120	20	6/29/2006	78.1	72.6	6.59	<9.31	<9.31	<4.65
	30	6/29/2006	243J	83.4	5.04	<9.29	<9.29	<4.64
	40	6/29/2006	115	242.7	<4.69	<9.37	<9.37	<4.69
	50	6/29/2006	20	6.91	<4.84	<9.67	<9.67	<4.84
LA10-SB06-121	20	6/29/2006	11	32.1	<4.90	<9.80	<9.80	<4.90
	30	6/29/2006	77.1	33.2	<4.87	<9.74	<9.74	<4.87
	40	6/29/2006	34.6	<4.82	<4.82	<9.64	<9.64	<4.82
	50	6/29/2006	229	<4.71	<4.71	<9.41	<9.41	<4.71
LA10-SB06-122	20	9/12/2006	204	84.0	<4.26	<8.52	<8.52	<4.26
	30	9/12/2006	618	118	<4.63	11.1	<9.26	<4.63
	40	9/12/2006	<3.75	<3.75	<3.75	8.75	<7.51	<3.75
	50	9/12/2006	<3.96	<3.96	<3.96	8.87	<7.93	<3.96
LA10-MW06-6	20	9/10/2006	<4.38	<4.38	<4.38	<8.76	<8.76	<4.38
	30	9/10/2006	<3.96	<3.96	<3.96	<7.91	<7.91	<3.96
	40	9/10/2006	18.1	<4.13	<4.13	<8.25	<8.25	<4.13
	50	9/10/2006	6.38	<4.11	<4.11	8.67	<8.21	<4.11
LA10-MW06-7S	20	9/8/2006	<4.73	<4.73	<4.73	<9.45	<9.45	<4.73
	30	9/8/2006	<3.88	<3.88	<3.88	<7.76	<7.76	<3.88
	40	9/8/2006	<3.77	<3.77	<3.77	<7.53	<7.53	<3.77
	50	9/8/2006	4.27	<3.72	<3.72	<7.43	<7.43	<3.72
LA10-MW06-8	20	9/9/2006	4.67	<4.61	<4.61	<9.21	<9.21	<4.61
	30	9/9/2006	7.81	<4.12	<4.12	<8.23	<8.23	<4.12
	40	9/9/2006	18.2	<3.75	<3.75	<7.51	<7.51	<3.75
	50	9/9/2006	7.1	<3.83	<3.83	<7.66	<7.66	<3.83
Soil Drum Composite		10/26/2006	<50	<50	<50	NA	NA	NA

Notes:
e=estimated value above calibration range
J= the analyte was positively identified, but the quantitation was below the reporting limit.
NA= Not Analyzed
DNA = Data Not Available

Table C2

SVE Well Construction Details

Table 1: SVE Well Construction Data

Source:

Kemron, 2009, Soil vapor extraction operations and maintenance (O&M) manual, former Lincoln Air Force Base, Atlas Missile Site 10, York, Nebraska, prepared for U.S. Army corps of Engineers, March 2009

Former Lincol
Atlas Missile Site 10
York, York County, Nebraska
SE 5002.200.001

TABLE 1: SVE WELL CONSTRUCTION DATA

Well ID	Date Completed	Latitude (N)	Longitude (W)	Ground Surface Elevation (ft MSL)	TOC Elevation (ft MSL)	Total Depth (ft bgs)	Screened Interval (ft bgs)	Elevation Top Screen (ft MSL)	Elevation Bottom Screen (ft MSL)
LA10-SVE08-1	7/10/2008	40º 53' 43.98405"	97º 41' 08.08858"	1685.563	1685.097	50	15 - 50	1670.563	1635.563
LA10-SVE08-2	7/11/2008	40º 53' 43.80935"	97º 41' 07.79161"	1683.409	1683.093	50	15 - 50	1668.409	1633.409
LA10-SVE08-3	7/10/2008	40º 53' 44.00111"	97º 41' 08.61339"	1687.659	1687.238	50	15 - 50	1672.659	1637.659
LA10-SVE08-4	7/10/2008	40º 53' 43.82373"	97º 41' 08.30560"	1686.468	1685.884	50	15 - 50	1671.468	1636.468
LA10-SVE08-5	7/11/2008	40º 53' 43.63904"	97º 41' 08.03810"	1684.676	1684.373	50	15 - 50	1669.676	1634.676
LA10-SVE08-6	7/10/2008	40º 53' 44.02834"	97º 41' 09.16902"	1687.909	1687.28	50	15 - 50	1672.909	1637.909
LA10-SVE08-7	7/10/2008	40º 53' 43.81969"	97º 41' 08.88939"	1687.801	1687.368	50	15 - 50	1672.801	1637.801
LA10-SVE08-8	7/10/2008	40º 53' 43.64893"	97º 41' 08.59955"	1686.609	1686.247	50	15 - 50	1671.609	1636.609
LA10-SVE08-9	7/11/2008	40º 53' 43.40892"	97º 41' 08.31356"	1685.884	1685.513	50	15 - 50	1670.884	1635.884
LA10-SVE08-10	7/10/2008	40º 53' 43.62907"	97º 41' 09.13625"	1688.093	1687.684	50	15 - 50	1673.093	1638.093
LA10-SVE08-11	7/10/2008	40º 53' 43.40970"	97º 41' 08.88390"	1687.238	1686.788	50	15 - 50	1672.238	1637.238
LA10-SVE08-12	7/22/2008	40º 53' 43.23759"	97º 41' 08.69365"	1687.938	1686.468	50	15 - 50	1672.938	1637.938
LA10-SVE08-14	7/10/2008	40º 53' 43.18762"	97º 41' 09.09779"	1688.288	1687.759	50	15 - 50	1673.288	1638.288
LA10-SVE08-15	7/10/2008	40º 53' 43.00515"	97º 41' 08.85709"	1687.426	1686.926	50	15 - 50	1672.426	1637.426
LA10-SVE08-16	7/10/2008	40º 53' 42.77316"	97º 41' 08.60179"	1686.388	1685.993	50	15 - 50	1671.388	1636.388
LA10-SVE08-17	7/11/2008	40º 53' 42.55317"	97º 41' 08.32960"	1684.609	1684.263	50	15 - 50	1669.609	1634.609
LA10-SVE08-18	7/22/2008	40º 53' 42.83145"	97º 41' 09.10445"	1687.888	1687.472	50	15 - 50	1672.888	1637.888
LA10-SVE08-19	7/10/2008	40º 53' 42.61277"	97º 41' 08.82500"	1686.738	1686.155	50	15 - 50	1671.738	1636.738
LA10-SVE08-20	7/11/2008	40º 53' 42.40781"	97º 41' 08.59887"	1686.263	1685.855	50	15 - 50	1671.263	1636.263
LA10-SVE08-21	7/9/2008	40º 53' 42.39603"	97º 41' 09.05940"	1687.147	1686.738	50	15 - 50	1672.147	1637.147
LA10-SVE08-22	7/9/2008	40º 53' 42.22504"	97º 41' 08.81433"	1686.451	1685.997	50	15 - 50	1671.451	1636.451
LA10-SVE08-23	7/15/2008	40º 53' 42.38054"	97º 41' 09.50638"	1688.181	1687.518	50	15 - 50	1673.181	1638.181
LA10-SVE08-24	7/9/2008	40º 53' 42.22394"	97º 41' 09.29129"	1687.218	1686.648	50	15 - 50	1672.218	1637.218
LA10-SVE08-25	7/11/2008	40º 53' 42.02880"	97º 41' 09.09862"	1686.014	1685.685	50	15 - 50	1671.014	1636.014
LA10-SVE08-26	7/11/2008	40º 53' 42.77629"	97º 41' 10.51223"	1688.335	1687.993	50	15 - 50	1673.335	1638.335
LA10-SVE08-27	7/11/2008	40º 53' 42.63454"	97º 41' 10.26700"	1688.535	1688.089	50	15 - 50	1673.535	1638.535
LA10-SVE08-28	7/15/2008	40º 53' 42.41494"	97º 41' 09.95468"	1688.11	1687.618	50	15 - 50	1673.11	1638.11
LA10-SVE08-29	7/8/2008	40º 53' 42.24684"	97º 41' 09.77026"	1687.014	1686.289	50	15 - 50	1672.014	1637.014
LA10-SVE08-30	7/9/2008	40º 53' 42.09638"	97º 41' 09.52475"	1685.914	1685.552	50	15 - 50	1670.914	1635.914
LA10-SVE08-31	7/11/2008	40º 53' 42.79985"	97º 41' 10.99549"	1688.189	1687.639	50	15 - 50	1673.189	1638.189

Former Lincol
Atlas Missile Site 10
York, York County, Nebraska
SE 5002.200.001

TABLE 1: SVE WELL CONSTRUCTION DATA

Well ID	Date Completed	Latitude (N)	Longitude (W)	Ground Surface Elevation (ft MSL)	TOC Elevation (ft MSL)	Total Depth (ft bgs)	Screened Interval (ft bgs)	Elevation Top Screen (ft MSL)	Elevation Bottom Screen (ft MSL)
LA10-SVE08-32	7/12/2008	40º 53' 42.62979"	97º 41' 10.79798"	1688.56	1688.048	50	15 - 50	1673.56	1638.56
LA10-SVE08-33	7/11/2008	40º 53' 42.49245"	97º 41' 10.51580"	1688.277	1687.743	50	15 - 50	1673.277	1638.277
LA10-SVE08-34	7/8/2008	40º 53' 42.25653"	97º 41' 10.24499"	1687.077	1686.489	50	15 - 50	1672.077	1637.077
LA10-SVE08-35	7/9/2008	40º 53' 42.12517"	97º 41' 09.99735"	1686.348	1685.685	50	15 - 50	1671.348	1636.348
LA10-SVE08-36	7/12/2008	40º 53' 42.62816"	97º 41' 11.23862"	1688.139	1687.431	50	15 - 50	1673.139	1638.139
LA10-SVE08-37	7/16/2008	40º 53' 42.49943"	97º 41' 10.98786"	1688.014	1687.598	50	15 - 50	1673.014	1638.014
LA10-SVE08-38	7/8/2008	40º 53' 42.30330"	97º 41' 10.73397"	1686.393	1685.852	50	15 - 50	1671.393	1636.393
LA10-SVE08-39	7/8/2008	40º 53' 42.14795"	97º 41' 10.47542"	1686.085	1685.452	50	15 - 50	1671.085	1636.085
LA10-SVE08-40	7/11/2008	40º 53' 42.19500"	97º 41' 10.94646"	1685.885	1685.289	50	15 - 50	1670.885	1635.885

Figure C3

Soil Boring Logs and SVE Well Construction

Drilling Logs: LA10-SVE08-01 to LA10-SVE08-40

Source:

Kemron, 2009, Soil vapor extraction operations and maintenance (O&M) manual, former Lincoln Air Force Base, Atlas Missile Site 10, York, Nebraska, prepared for U.S. Army corps of Engineers, March 2009

Borehole Number: LA10-SVE08-01

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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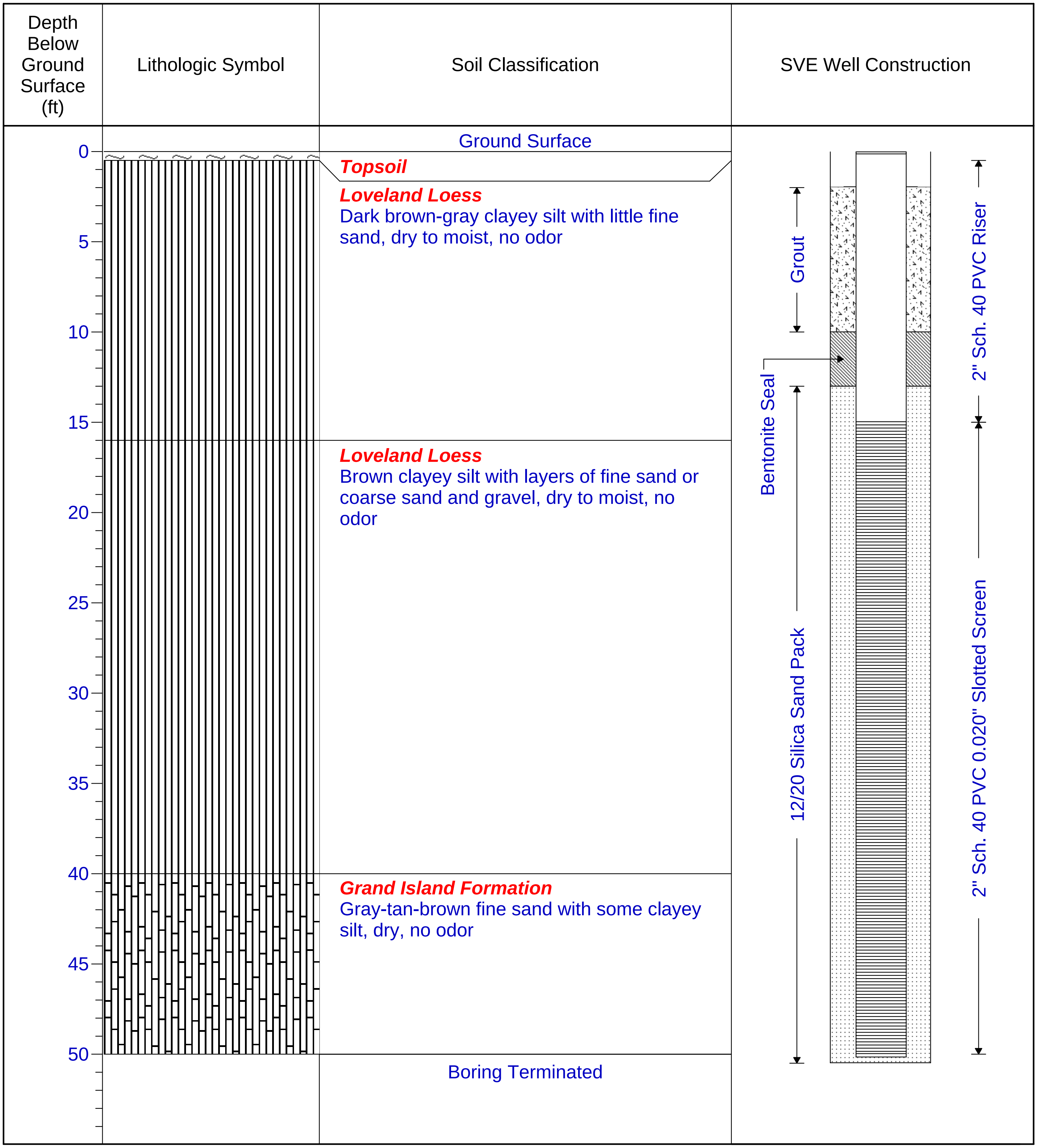

Ground Surface

Topsoil

Loveland Loess
Dark brown-gray clayey silt with little fine sand, dry to moist, no odor

Loveland Loess
Brown clayey silt with layers of fine sand or coarse sand and gravel, dry to moist, no odor

Grand Island Formation
Gray-tan-brown fine sand with some clayey silt, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-02

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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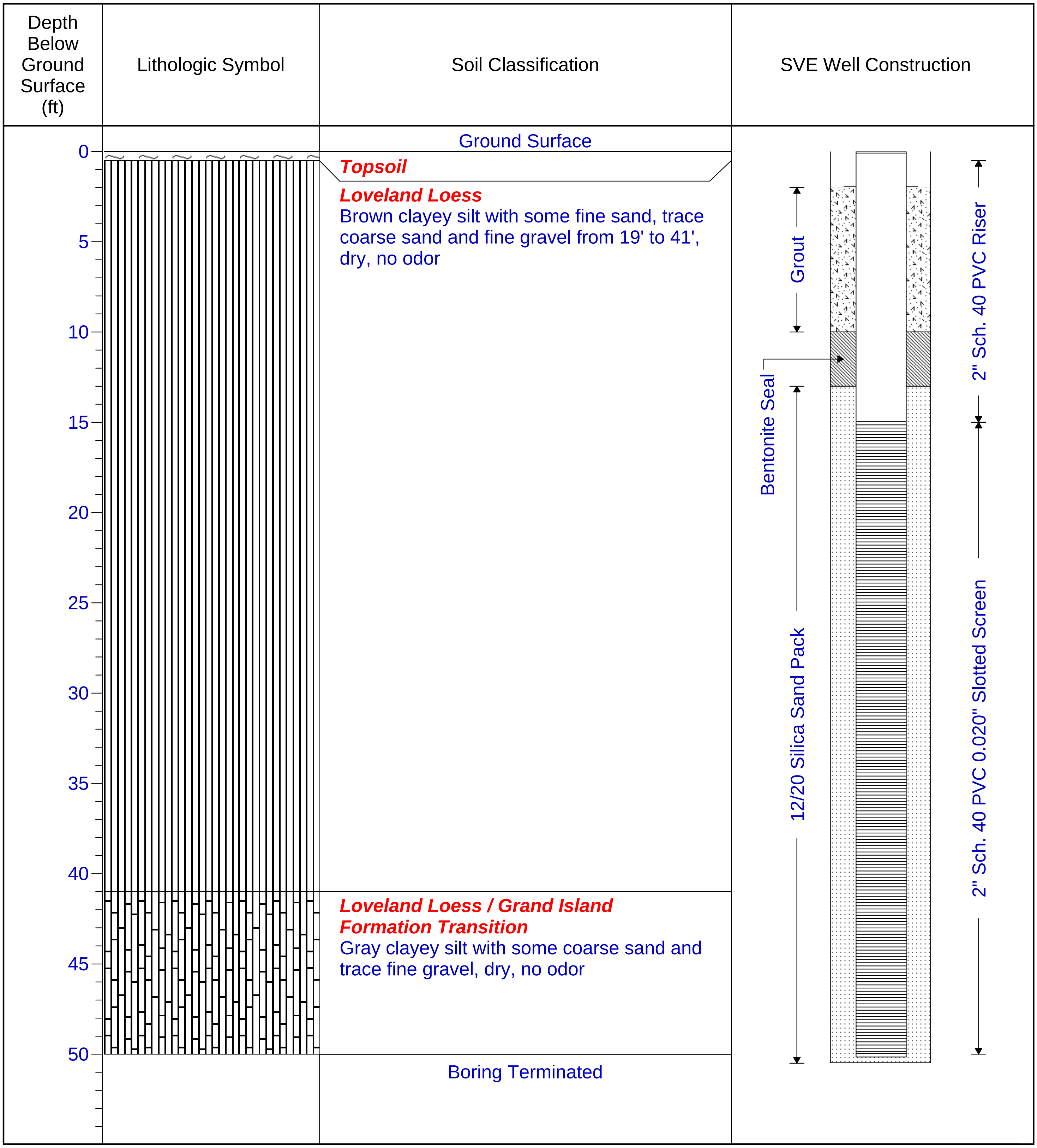

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with some fine sand, trace coarse sand and fine gravel from 19' to 41', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and trace fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-03

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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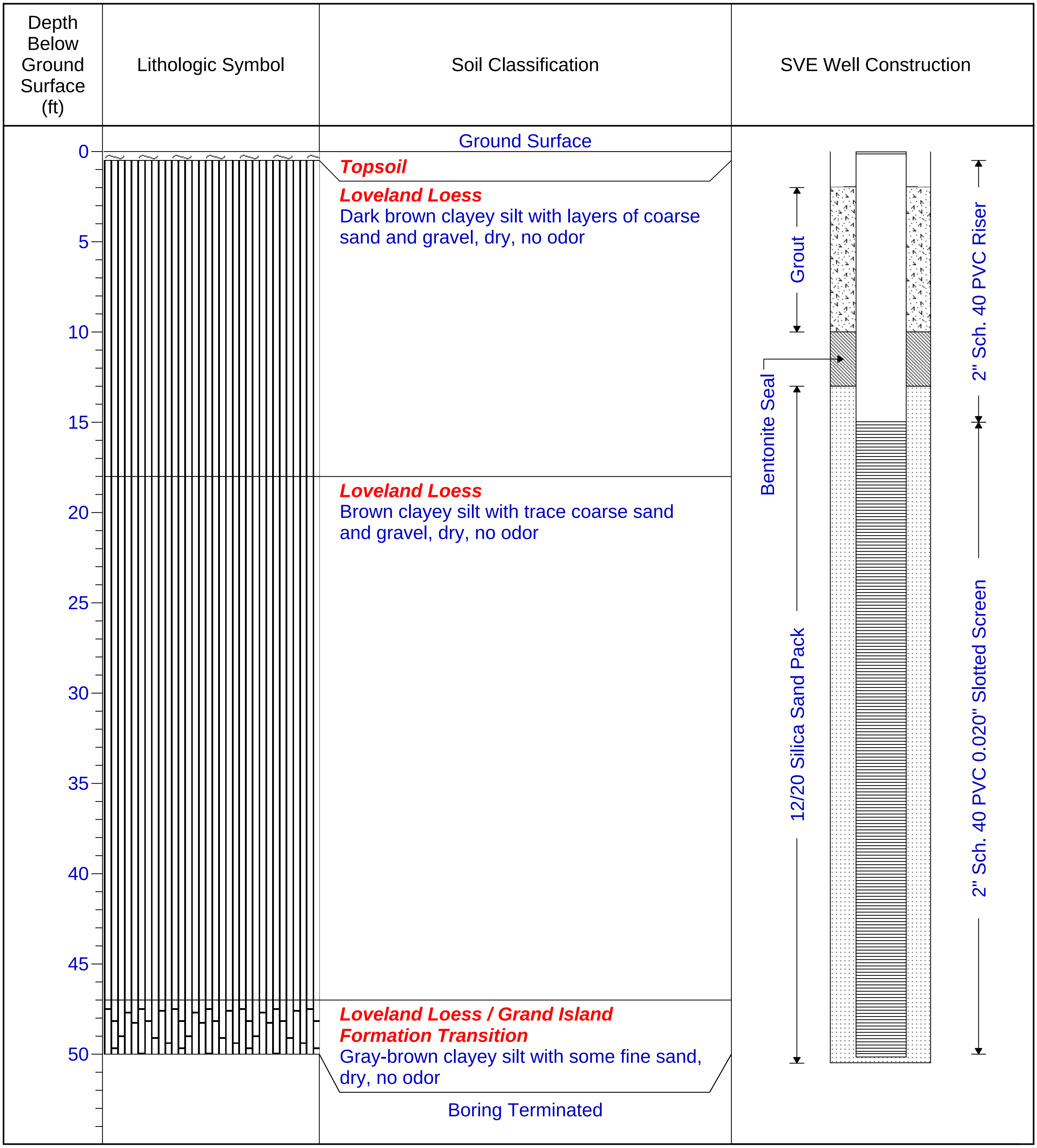

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with layers of coarse sand and gravel, dry, no odor

Loveland Loess
Brown clayey silt with trace coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-04

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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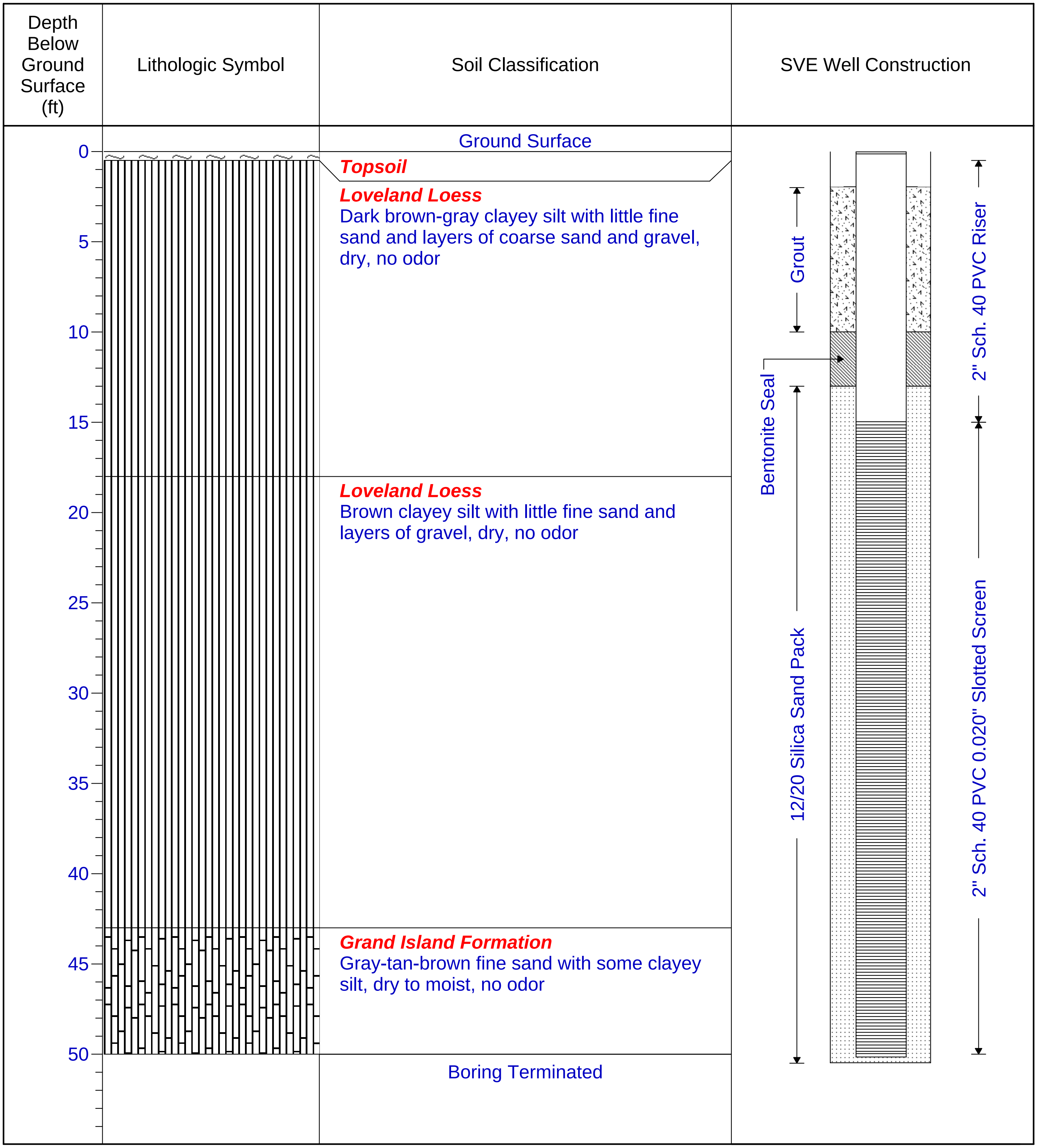

Ground Surface

Topsoil

Loveland Loess
Dark brown-gray clayey silt with little fine sand and layers of coarse sand and gravel, dry, no odor

Loveland Loess
Brown clayey silt with little fine sand and layers of gravel, dry, no odor

Grand Island Formation
Gray-tan-brown fine sand with some clayey silt, dry to moist, no odor

Boring Terminated

Borehole Number: LA10-SVE08-05

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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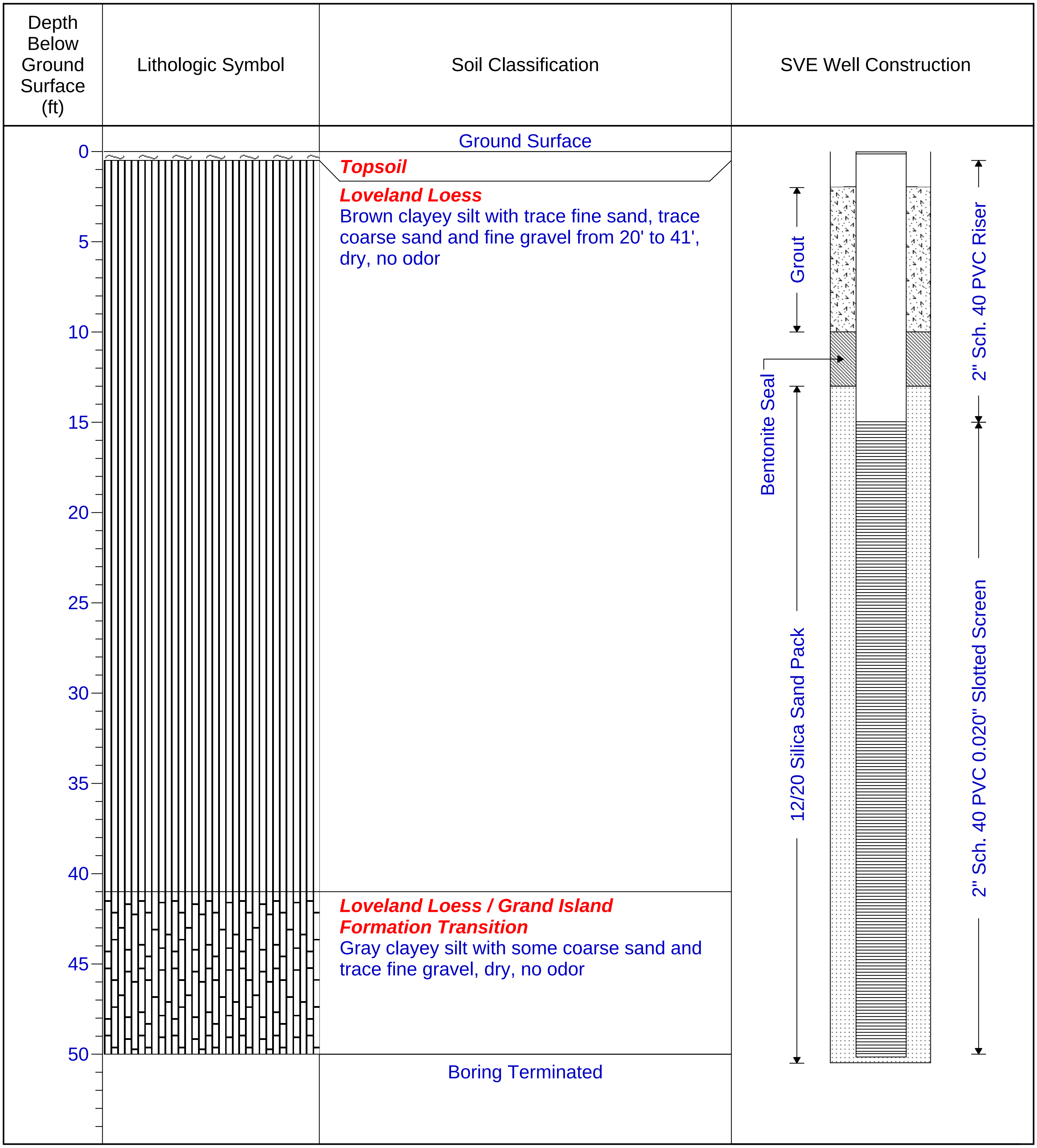

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 20' to 41', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and trace fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-06

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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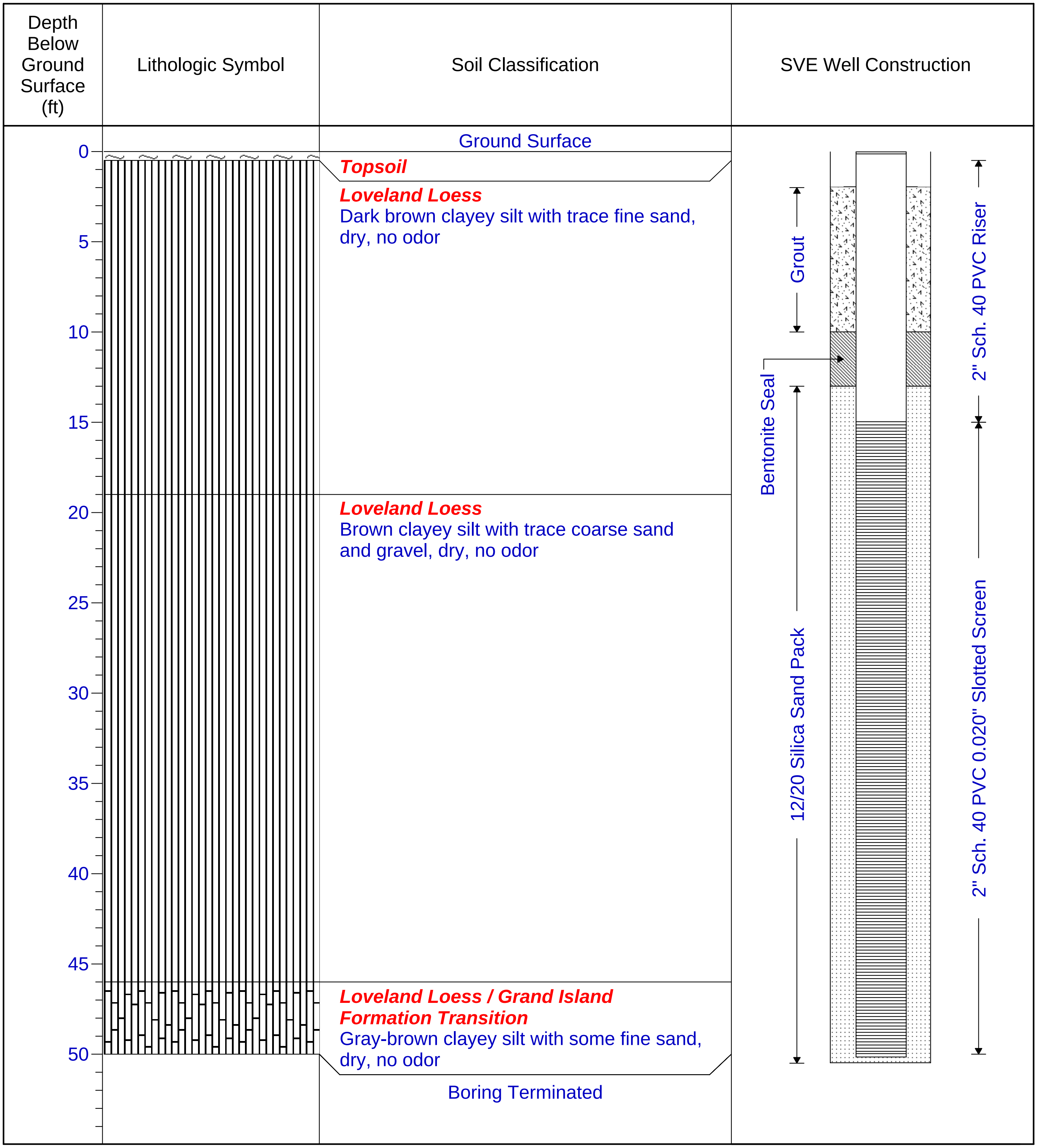

Topsoil

Loveland Loess
Dark brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand, dry, no odor

Borehole Number: LA10-SVE08-07

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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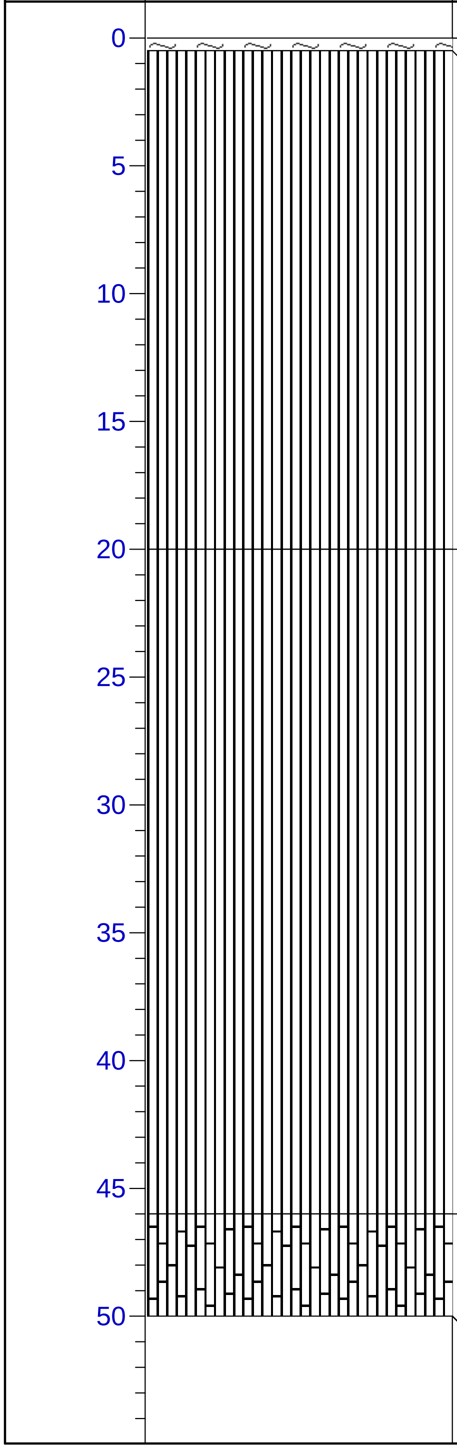
Depth Below Ground Surface (ft)	Lithologic Symbol	Soil Classification	SVE Well Construction



Ground Surface

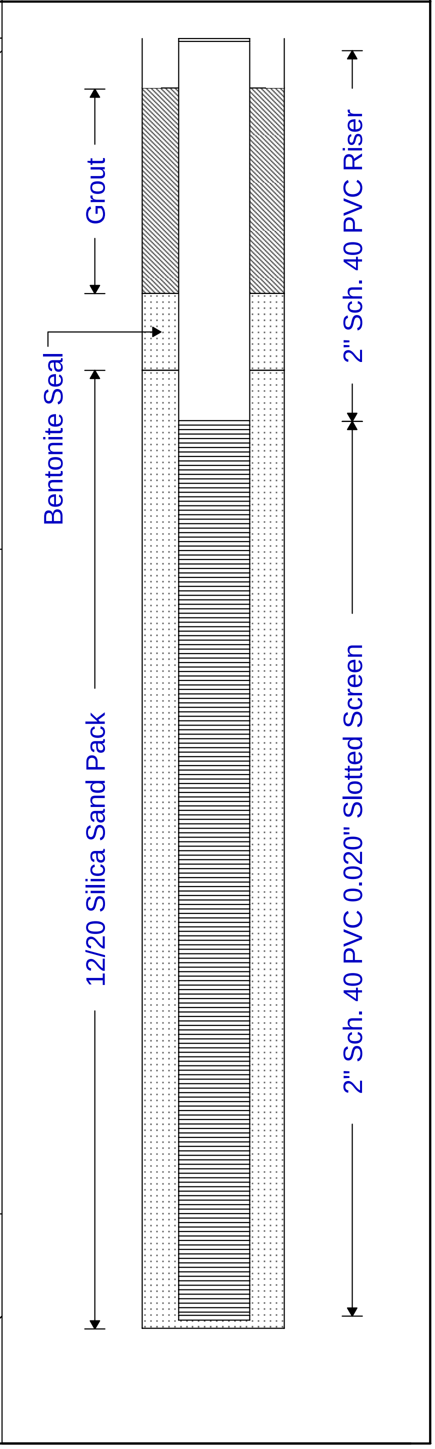
Topsoil

Loveland Loess
Dark brown-gray clayey silt with layers of fine to coarse sand and gravel, dry, no odor

Loveland Loess
Brown clayey silt with layers of fine or coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand, dry, no odor

Boring Terminated



Borehole Number: LA10-SVE08-08

Project No: SE5002-200	***Geologist:*** Keith Rice
Project: Atlas Missile Site 10	***Drilled By:*** Peterson Drilling, Inc.
Client: USACE Omaha	***Drill Method:*** Hollow Stem Auger
Drill Date: 07/10/2008	***Bore Hole Diameter:*** 6.25"
Site Location: York, NE	***Sampling Method:*** N/A

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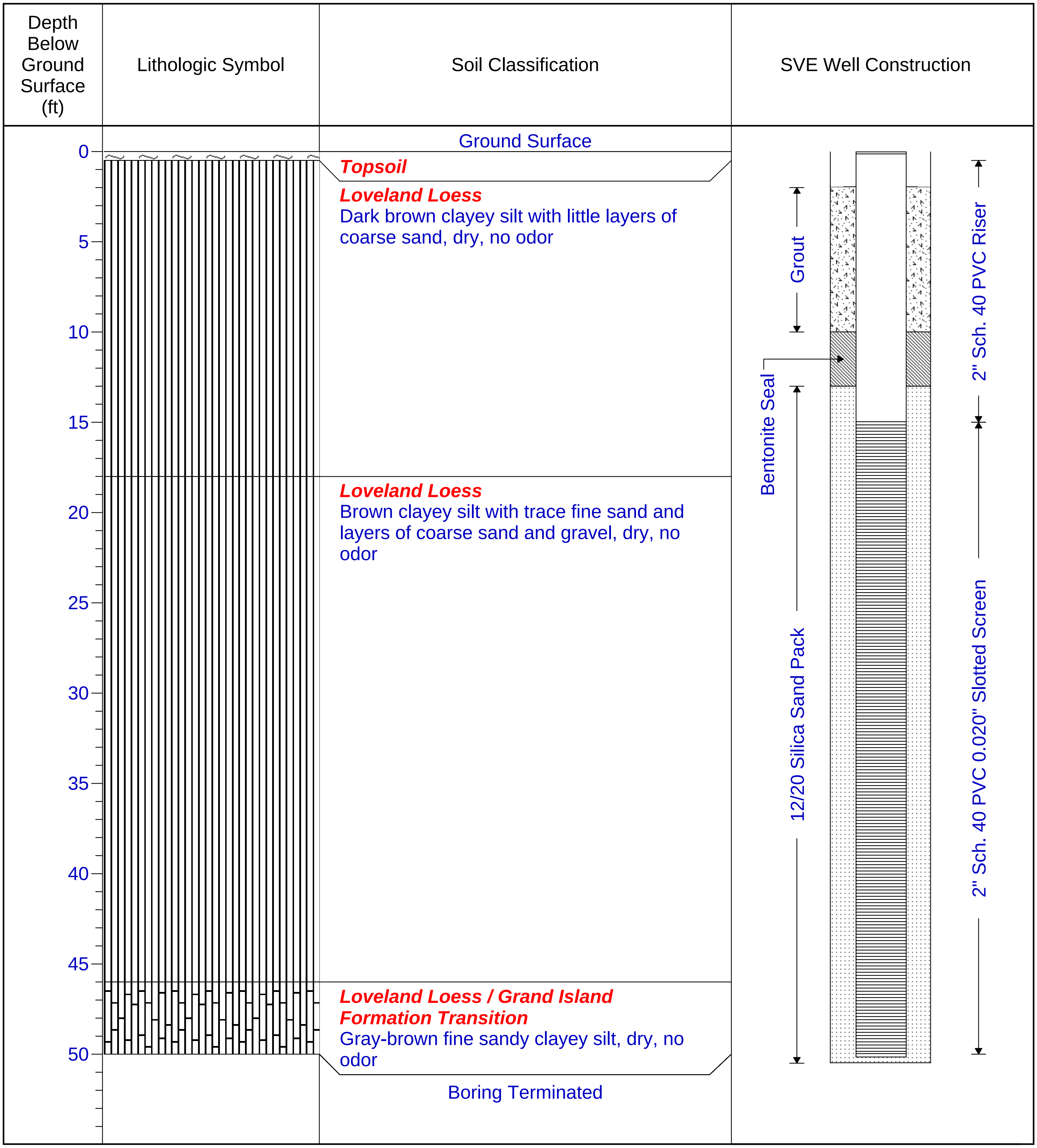

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with little layers of coarse sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine sand and layers of coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown fine sandy clayey silt, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-09

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE
Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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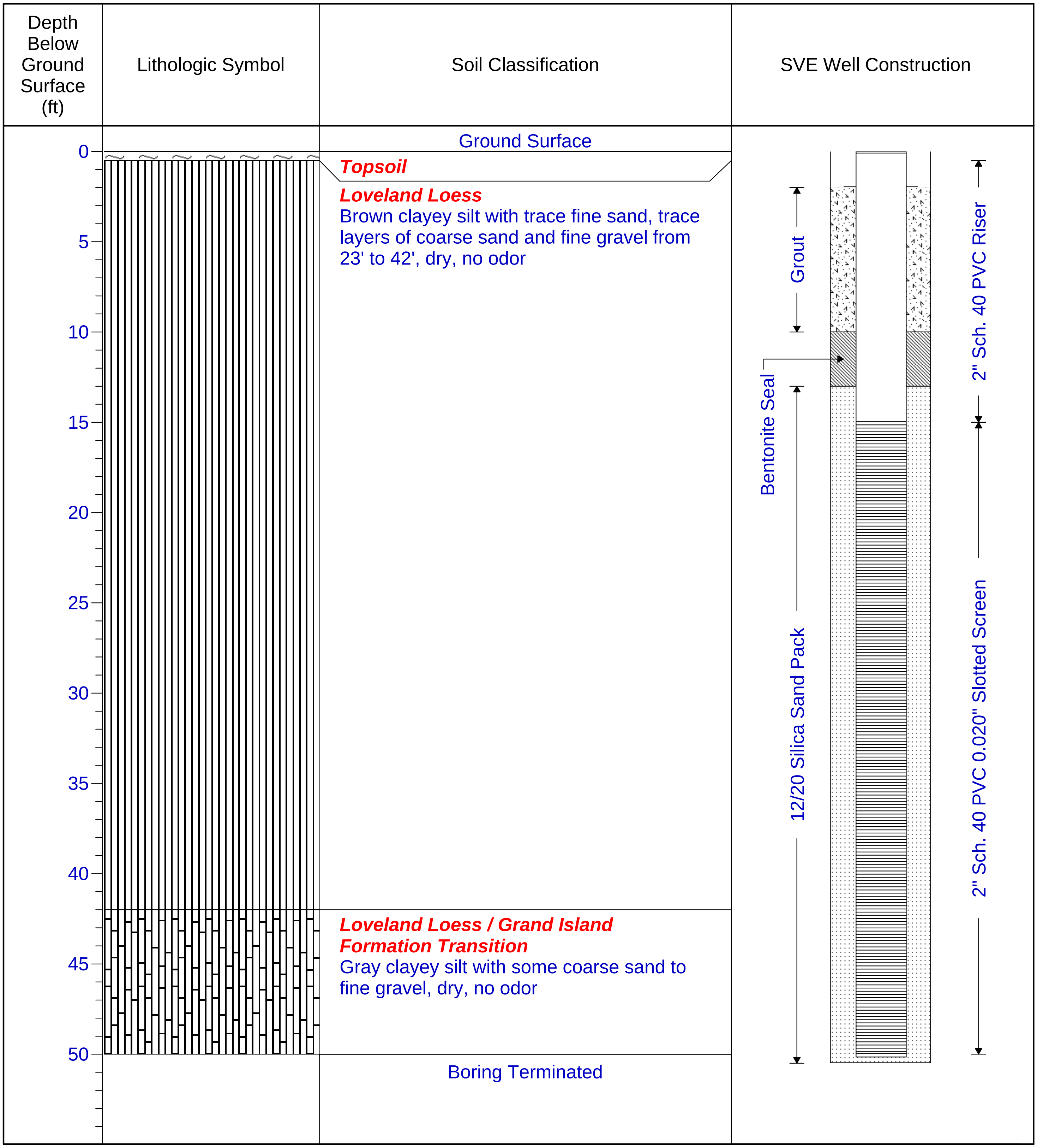

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace layers of coarse sand and fine gravel from 23' to 42', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand to fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-10

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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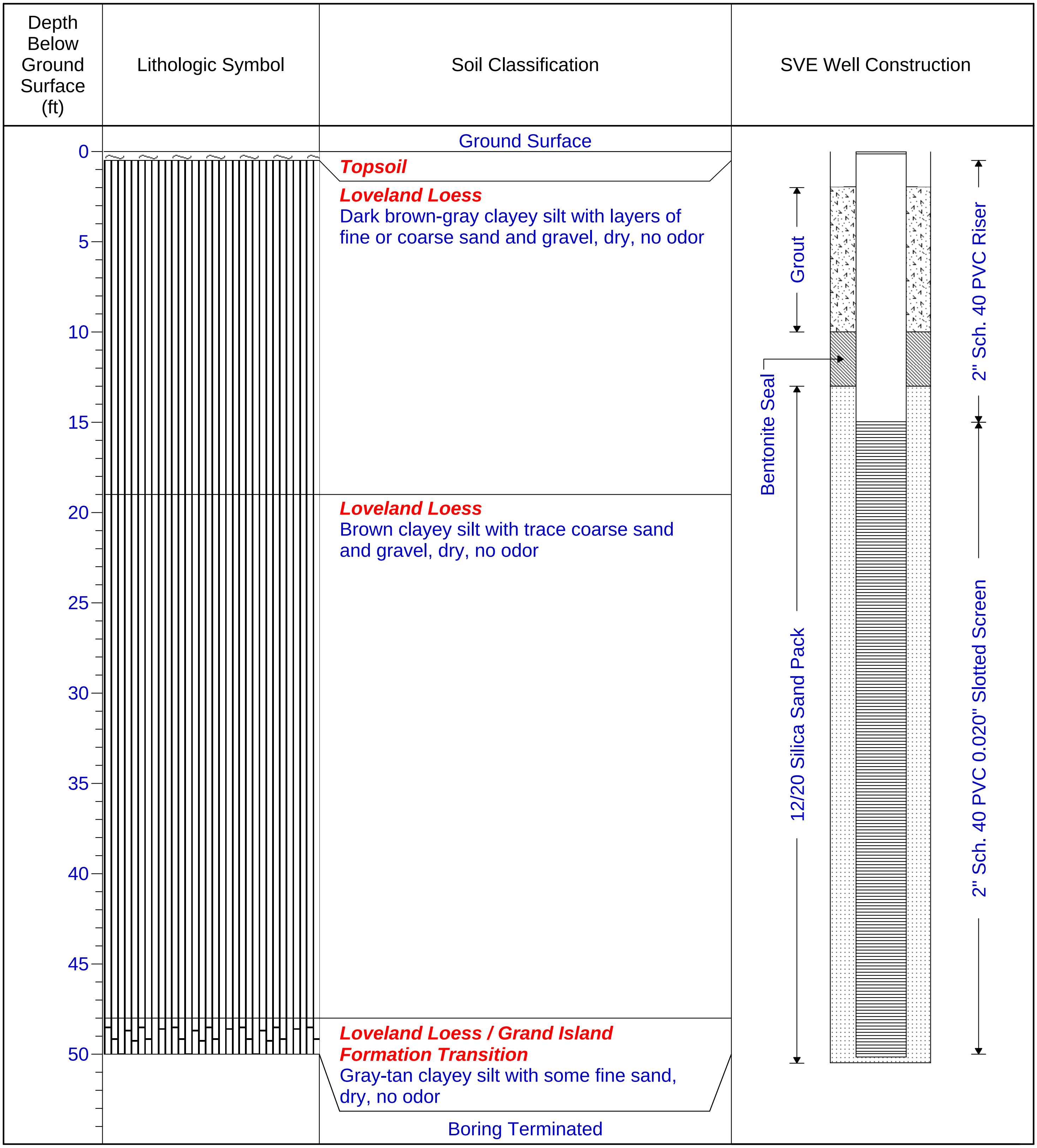

Ground Surface

Topsoil

Loveland Loess
Dark brown-gray clayey silt with layers of fine or coarse sand and gravel, dry, no odor

Loveland Loess
Brown clayey silt with trace coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-tan clayey silt with some fine sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-11

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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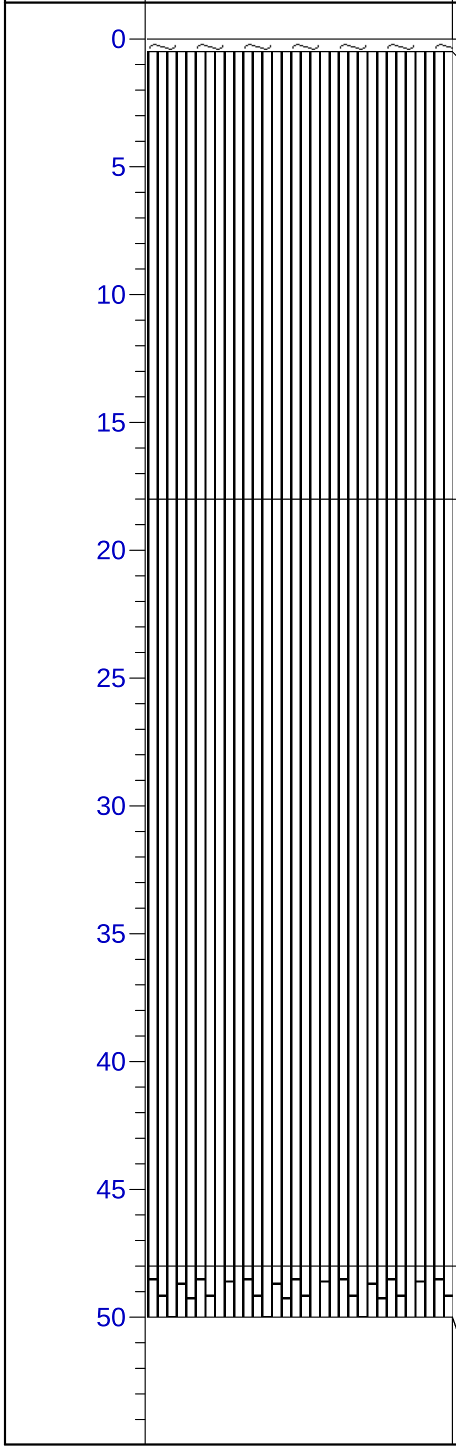
Depth Below Ground Surface (ft)	Lithologic Symbol	Soil Classification	SVE Well Construction



Ground Surface

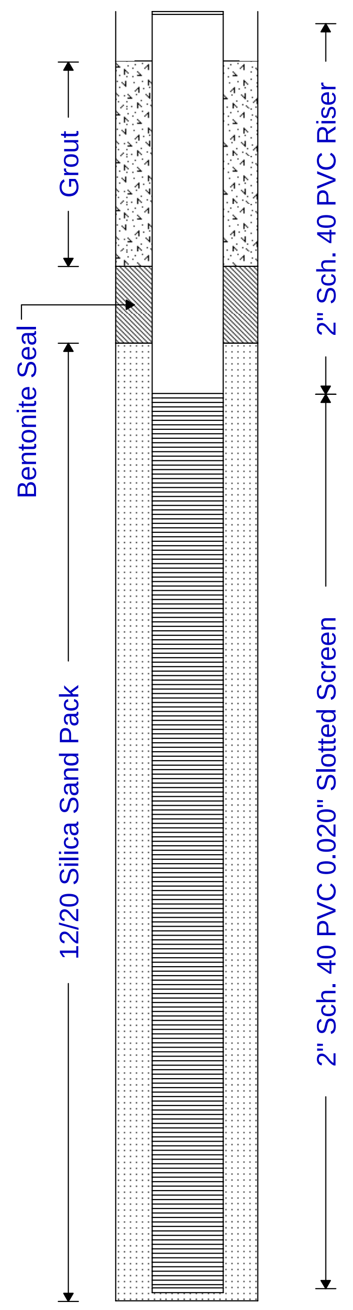
Topsoil

Loveland Loess
Dark brown clayey silt with trace layers of coarse sand and gravel, dry, no odor

Loveland Loess
Brown clayey silt with trace fine/coarse sand layers, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-tan clayey silt with some fine sand, dry, no odor

Boring Terminated



Borehole Number: LA10-SVE08-12

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/22/2008
Site Location: York, NE

Geologist: Wesley Bowen
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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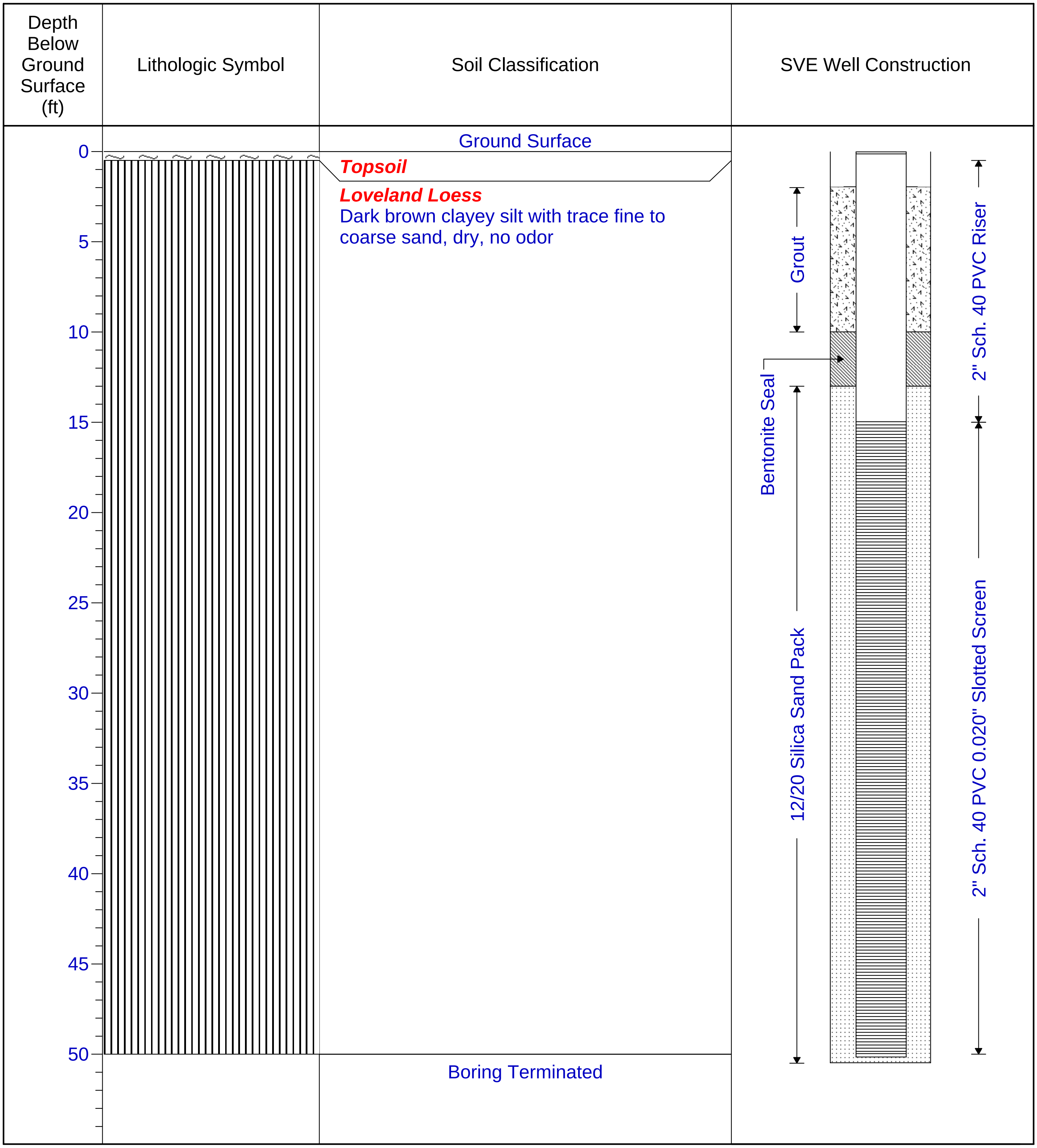
Depth Below Ground Surface (ft)
Lithologic Symbol
Soil Classification
SVE Well Construction

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with trace fine to coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-14

Project No: SE5002-200	**Geologist:** Keith Rice
Project: Atlas Missile Site 10	**Drilled By:** Peterson Drilling, Inc.
Client: USACE Omaha	**Drill Method:** Hollow Stem Auger
Drill Date: 07/10/2008	**Bore Hole Diameter:** 6.25"
Site Location: York, NE	**Sampling Method:** N/A

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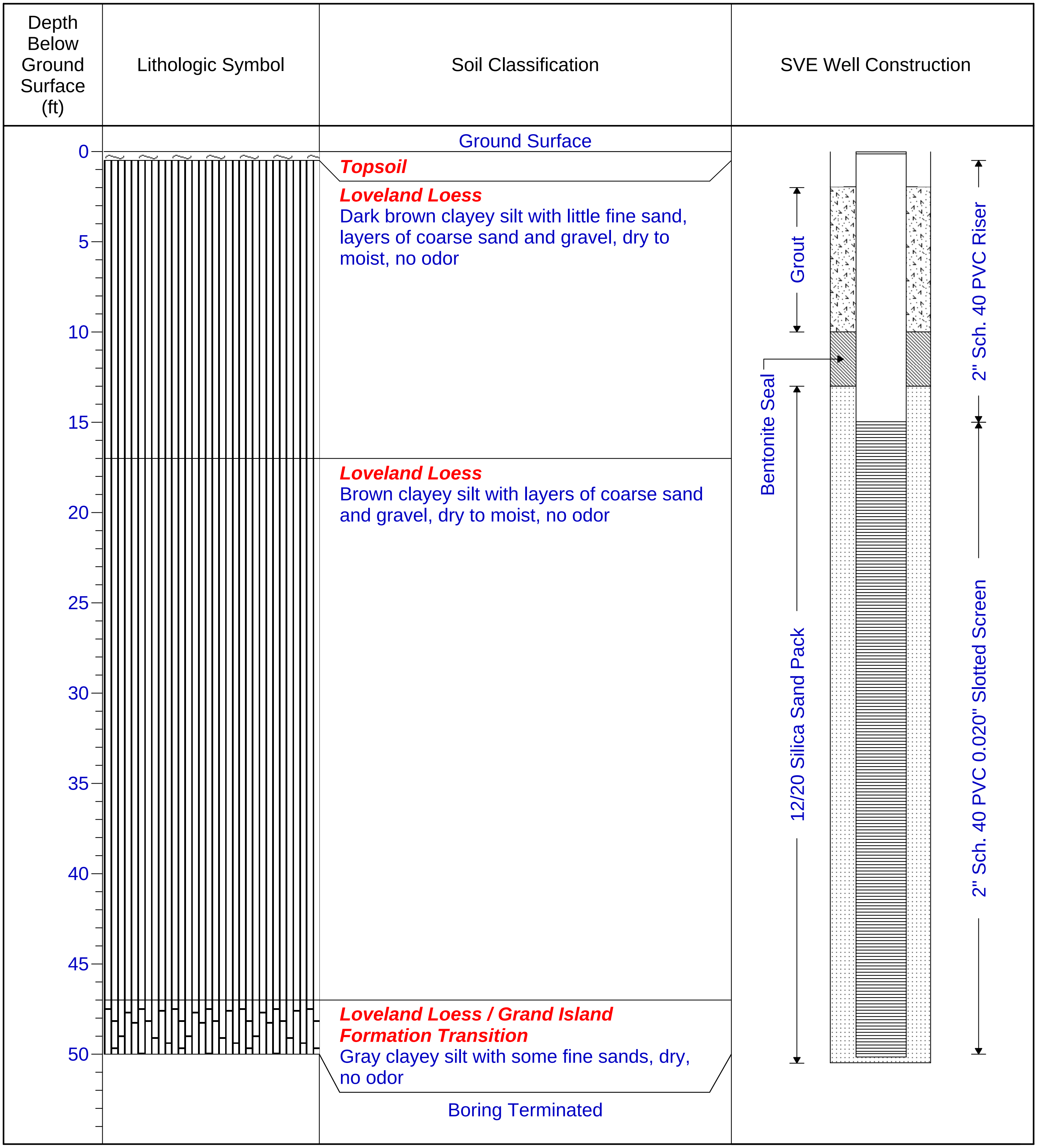

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with little fine sand, layers of coarse sand and gravel, dry to moist, no odor

Loveland Loess
Brown clayey silt with layers of coarse sand and gravel, dry to moist, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some fine sands, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-15

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE
Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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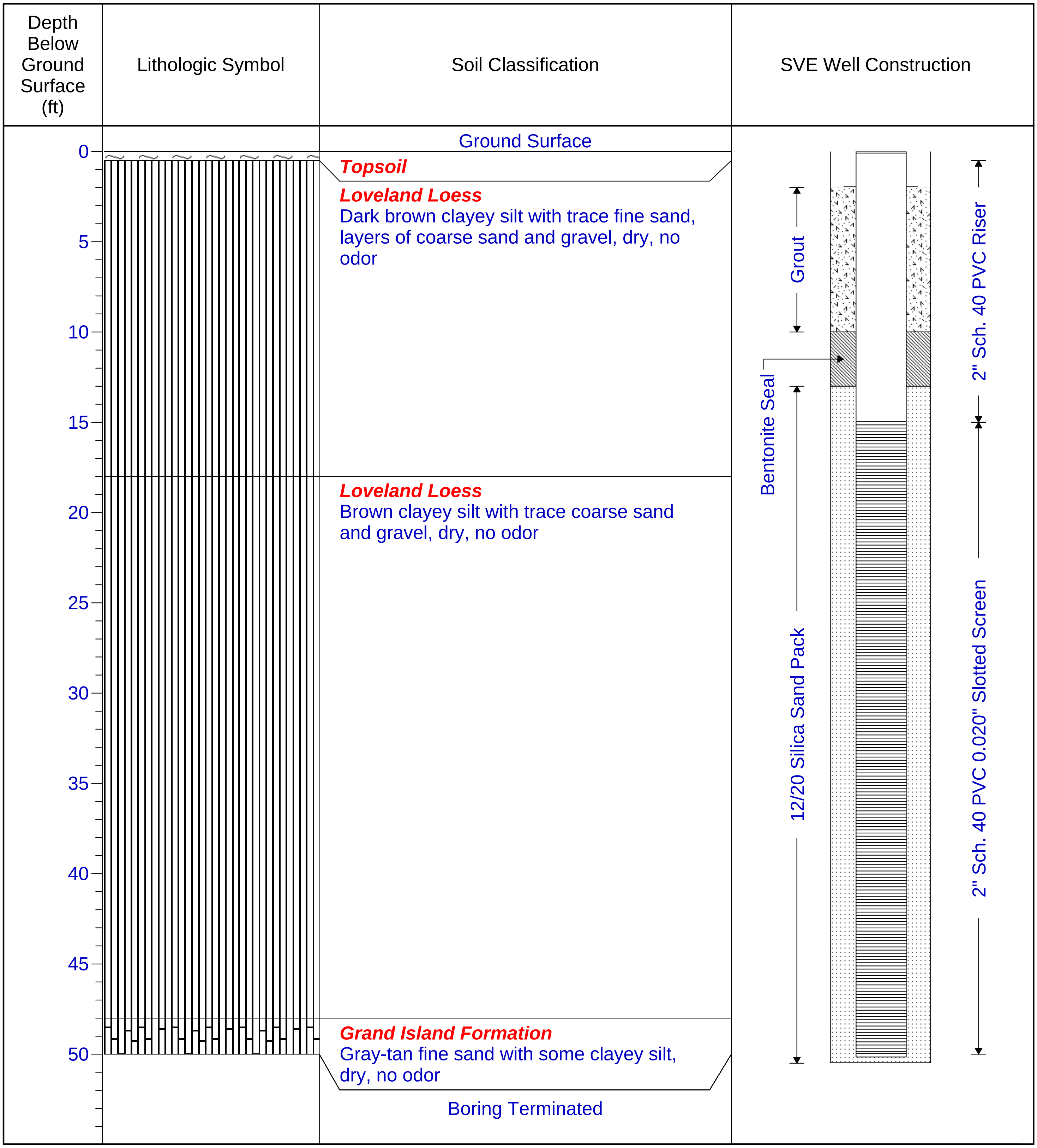

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with trace fine sand, layers of coarse sand and gravel, dry, no odor

Loveland Loess
Brown clayey silt with trace coarse sand and gravel, dry, no odor

Grand Island Formation
Gray-tan fine sand with some clayey silt, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-16

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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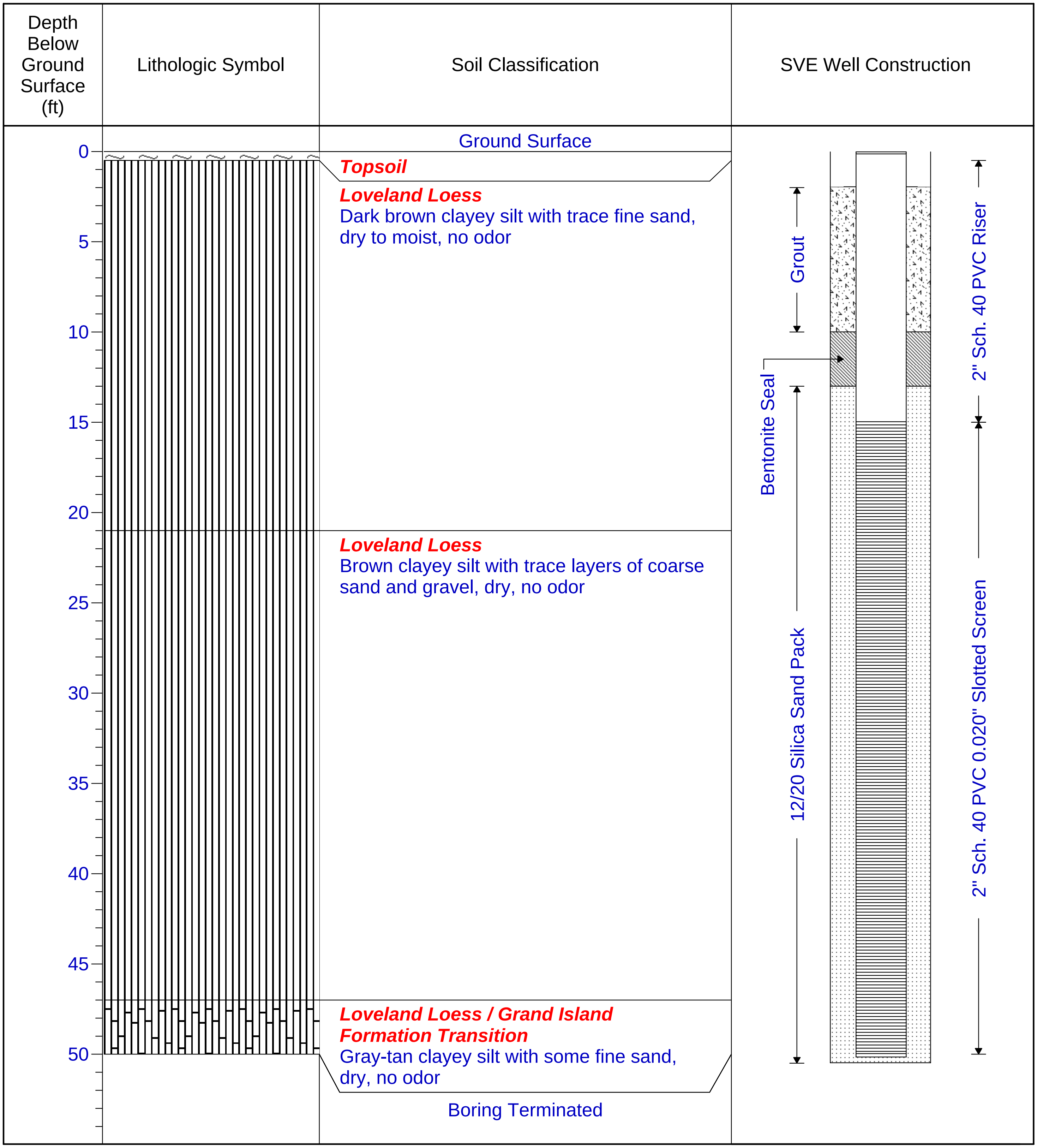

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with trace fine sand, dry to moist, no odor

Loveland Loess
Brown clayey silt with trace layers of coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-tan clayey silt with some fine sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-17

Project No: SE5002-200	***Geologist:*** Keith Rice
Project: Atlas Missile Site 10	***Drilled By:*** Peterson Drilling, Inc.
Client: USACE Omaha	***Drill Method:*** Hollow Stem Auger
Drill Date: 07/11/2008	***Bore Hole Diameter:*** 6.25"
Site Location: York, NE	***Sampling Method:*** N/A

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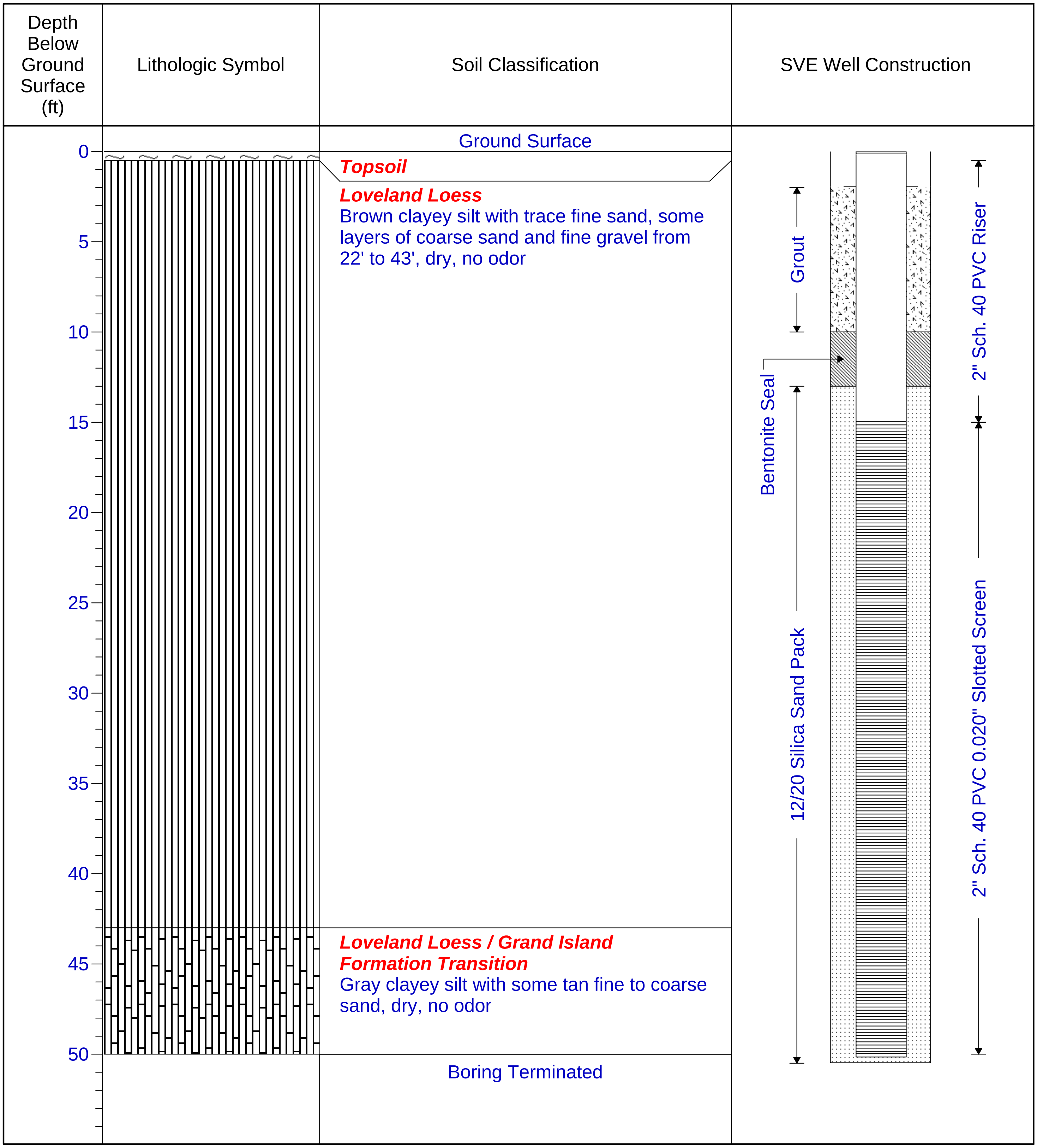

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, some layers of coarse sand and fine gravel from 22' to 43', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some tan fine to coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-18

Project No: SE5002-200	**Geologist:** Wesley Bowen
Project: Atlas Missile Site 10	**Drilled By:** Peterson Drilling, Inc.
Client: USACE Omaha	**Drill Method:** Hollow Stem Auger
Drill Date: 07/22/2008	**Bore Hole Diameter:** 6.25"
Site Location: York, NE	**Sampling Method:** N/A

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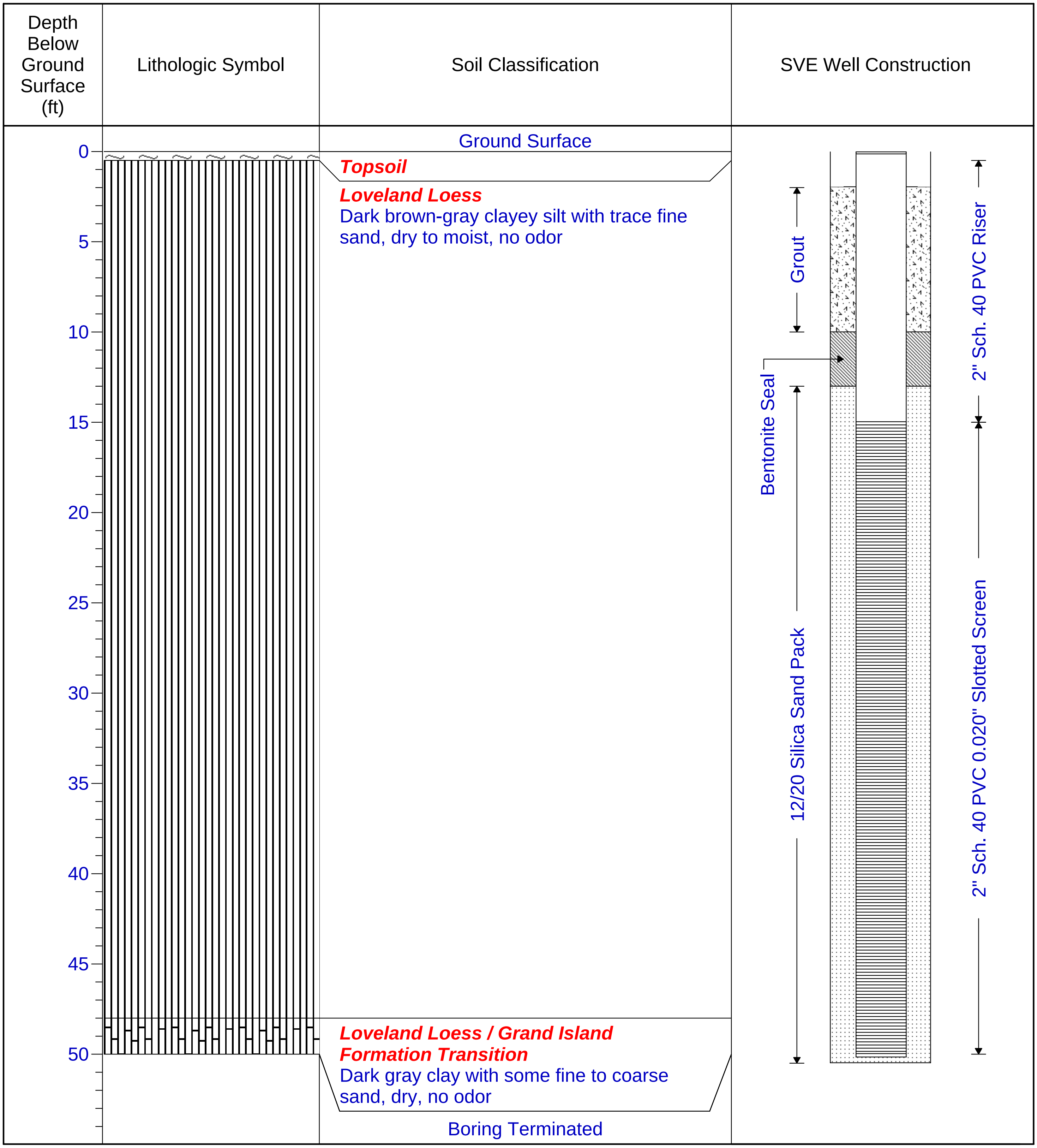

Ground Surface

Topsoil

Loveland Loess
Dark brown-gray clayey silt with trace fine sand, dry to moist, no odor

Loveland Loess / Grand Island Formation Transition
Dark gray clay with some fine to coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-19

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/10/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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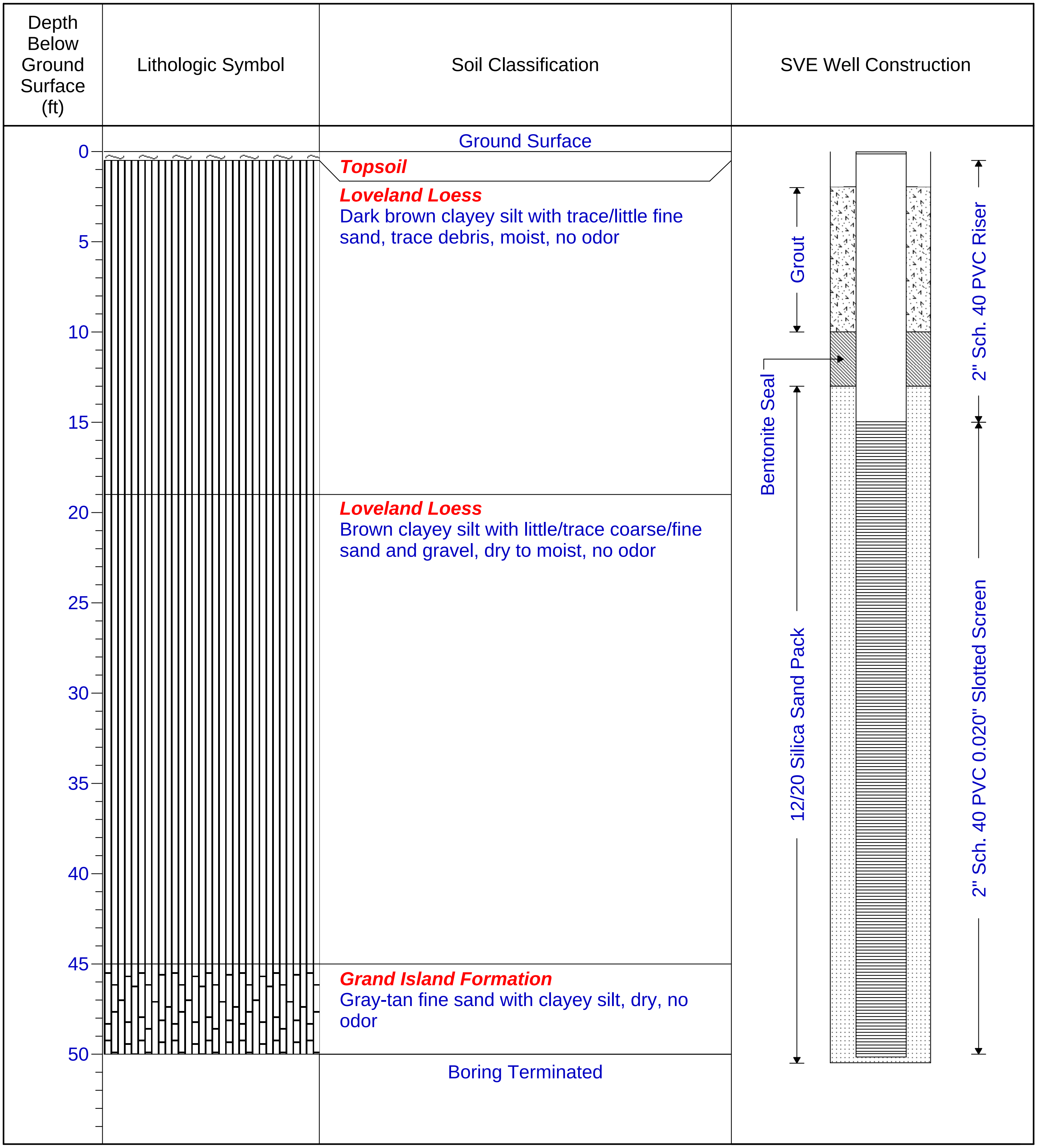

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with trace/little fine sand, trace debris, moist, no odor

Loveland Loess
Brown clayey silt with little/trace coarse/fine sand and gravel, dry to moist, no odor

Grand Island Formation
Gray-tan fine sand with clayey silt, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-20

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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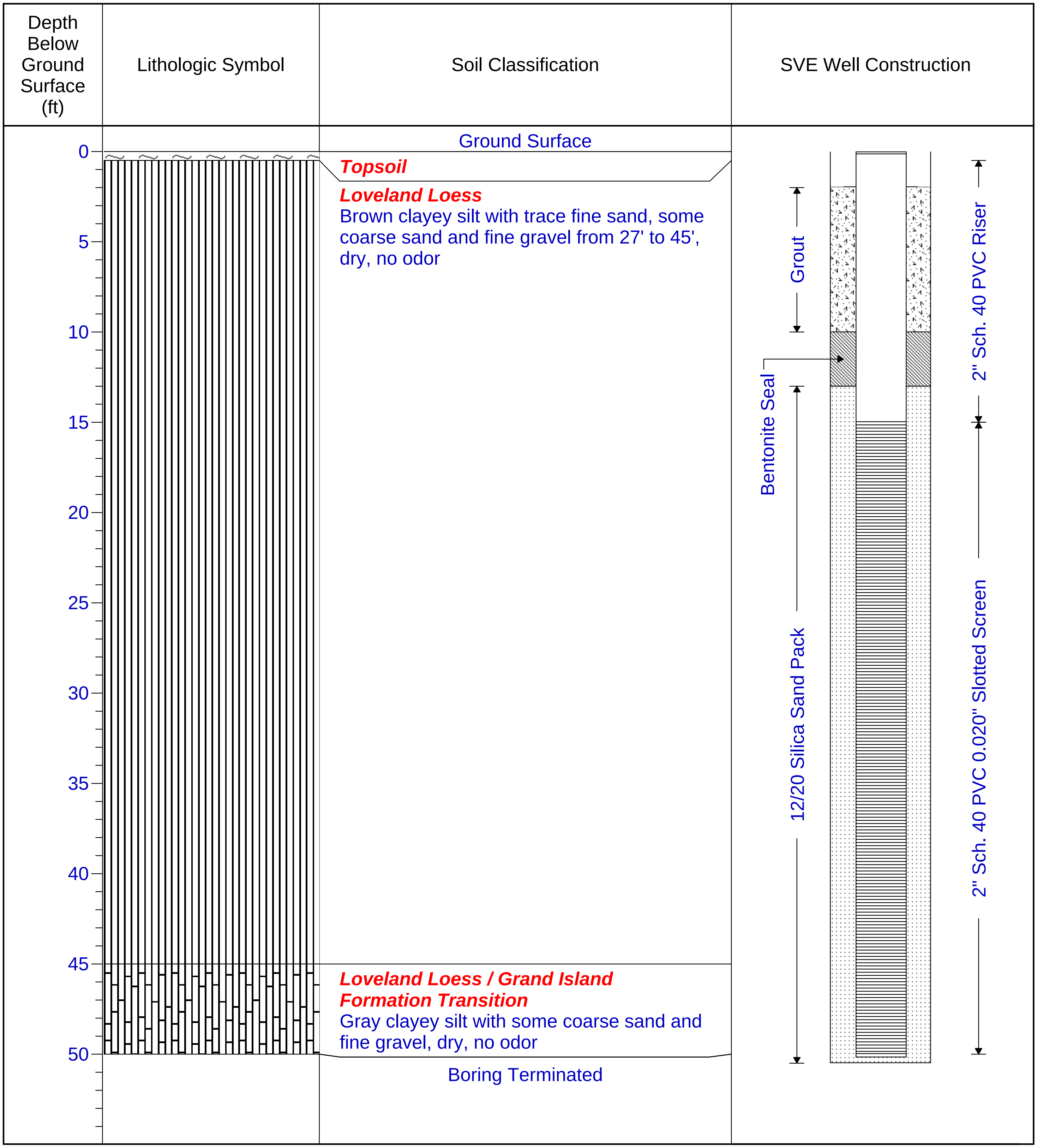

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, some coarse sand and fine gravel from 27' to 45', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-21

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/09/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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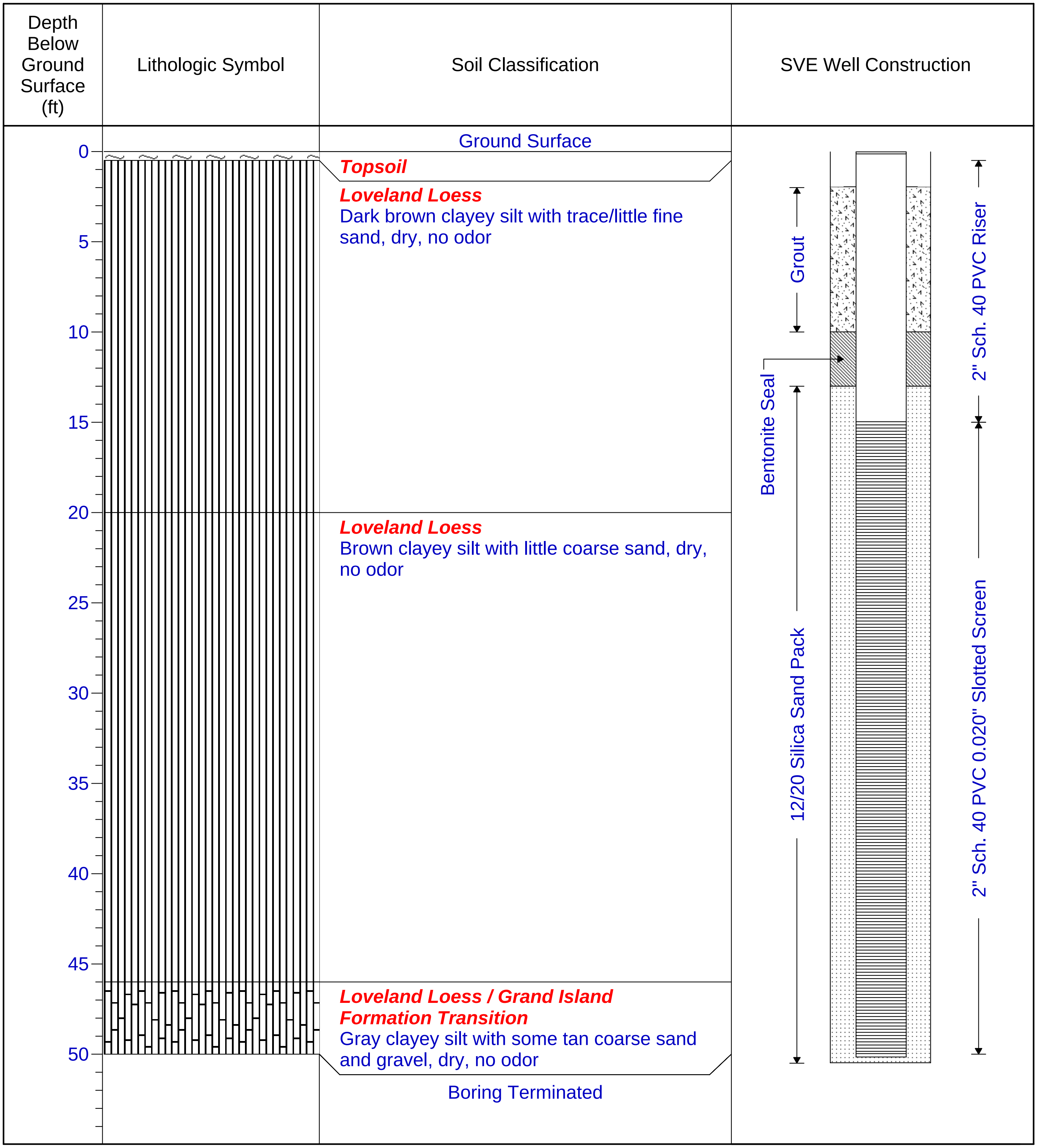

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with trace/little fine sand, dry, no odor

Loveland Loess
Brown clayey silt with little coarse sand, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some tan coarse sand and gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-22

Project No: SE5002-200	**Geologist:** Keith Rice
Project: Atlas Missile Site 10	**Drilled By:** Peterson Drilling, Inc.
Client: USACE Omaha	**Drill Method:** Hollow Stem Auger
Drill Date: 07/09/2008	**Bore Hole Diameter:** 6.25"
Site Location: York, NE	**Sampling Method:** N/A

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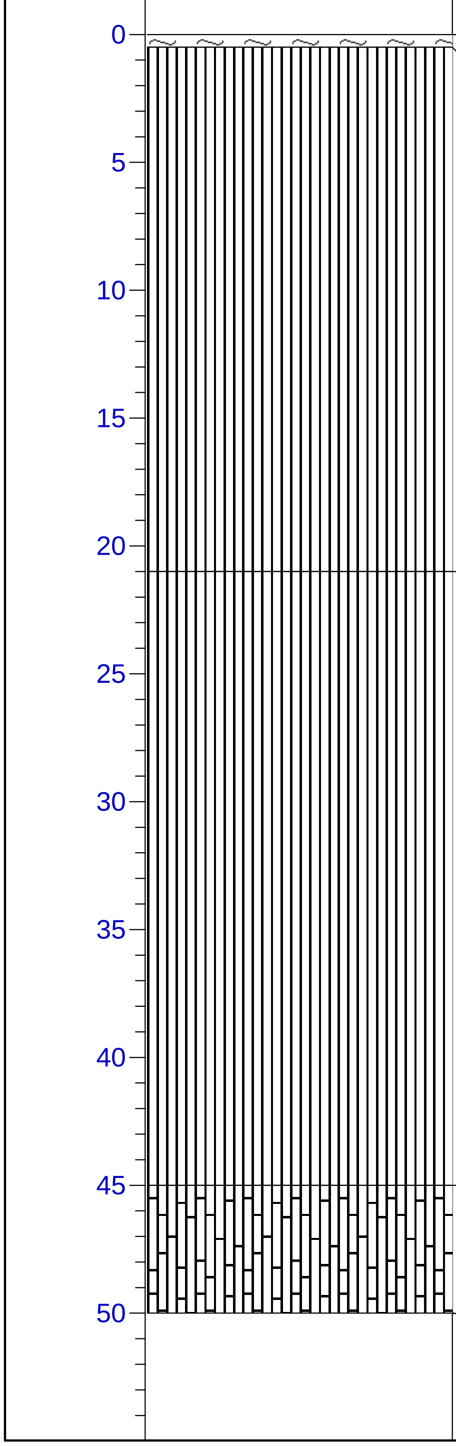
Depth Below Ground Surface (ft)	Lithologic Symbol	Soil Classification	SVE Well Construction



Ground Surface

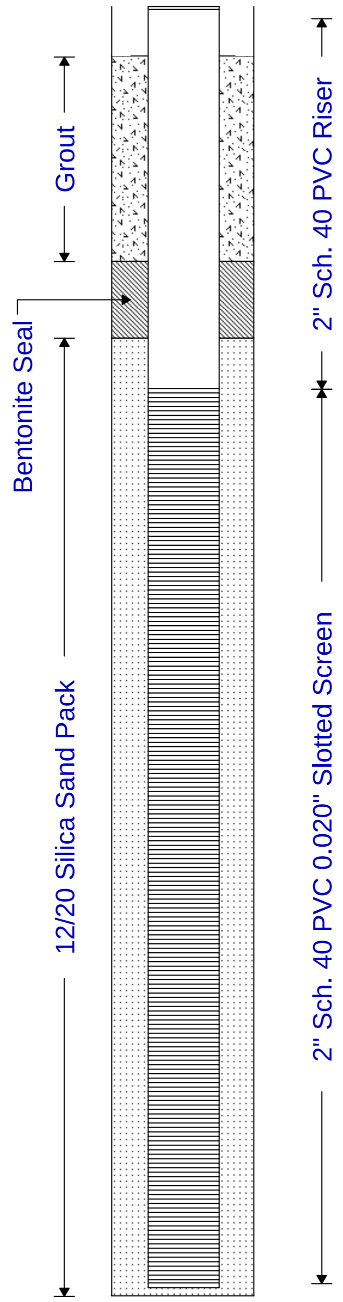
Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine sand, little coarse sand and fine gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with tan coarse sand, dry, no odor

Boring Terminated



Borehole Number: LA10-SVE08-23

Project No: SE5002-200	***Geologist:*** Keith Rice
Project: Atlas Missile Site 10	***Drilled By:*** Peterson Drilling, Inc.
Client: USACE Omaha	***Drill Method:*** Hollow Stem Auger
Drill Date: 07/15/2008	***Bore Hole Diameter:*** 6.25"
Site Location: York, NE	***Sampling Method:*** N/A

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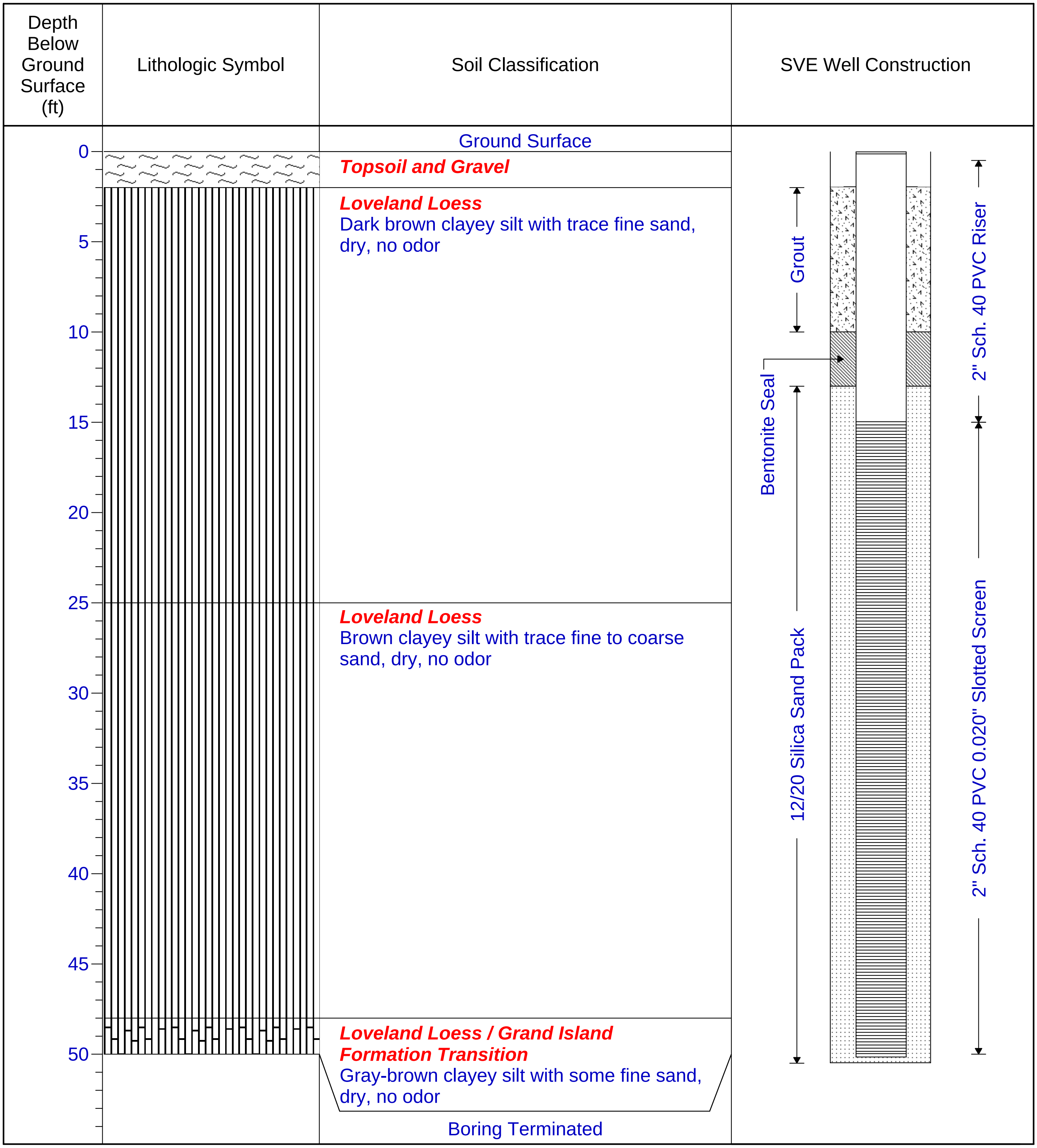

Ground Surface

Topsoil and Gravel

Loveland Loess
Dark brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine to coarse sand, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-24

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/09/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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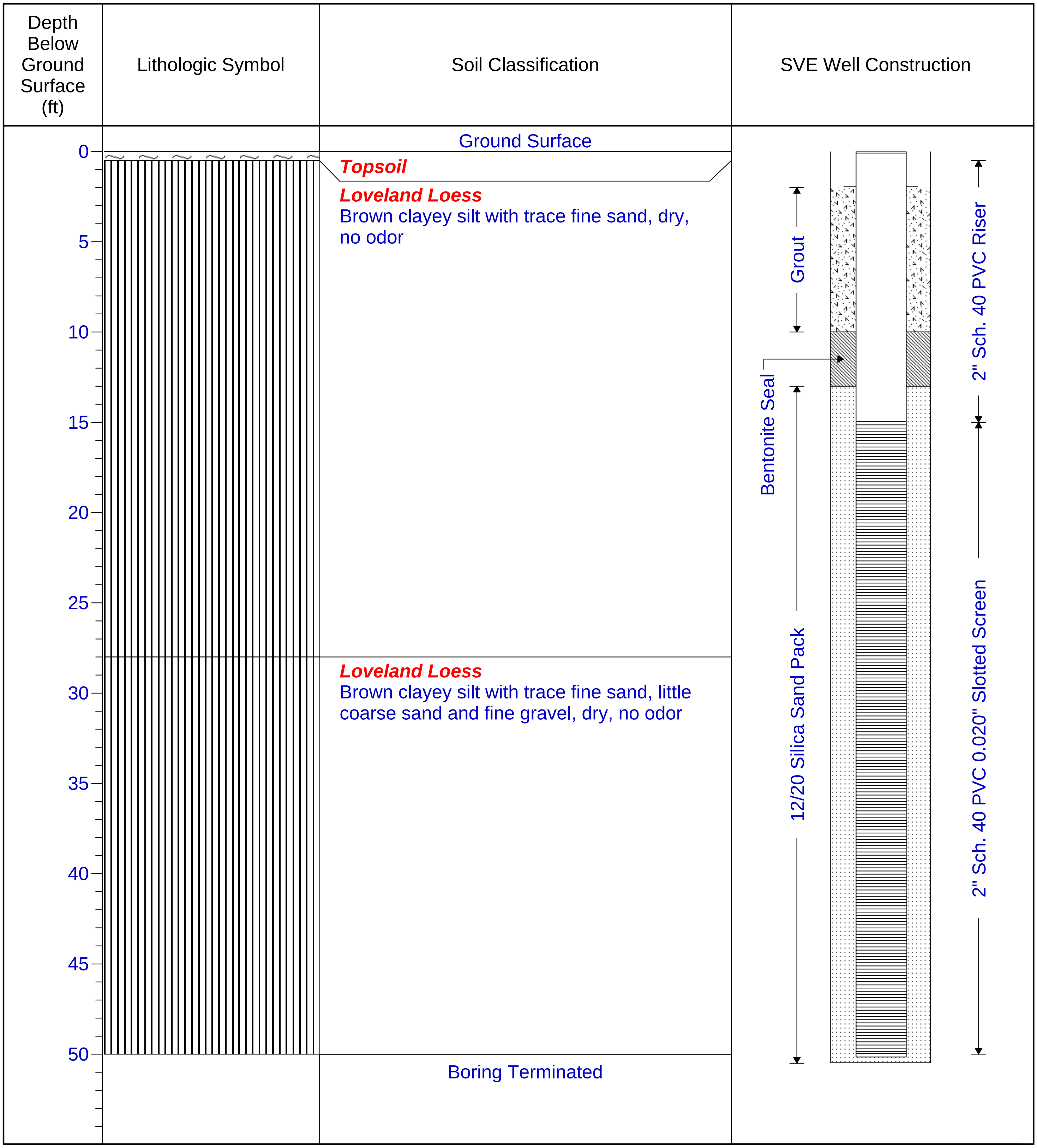

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine sand, little coarse sand and fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-25

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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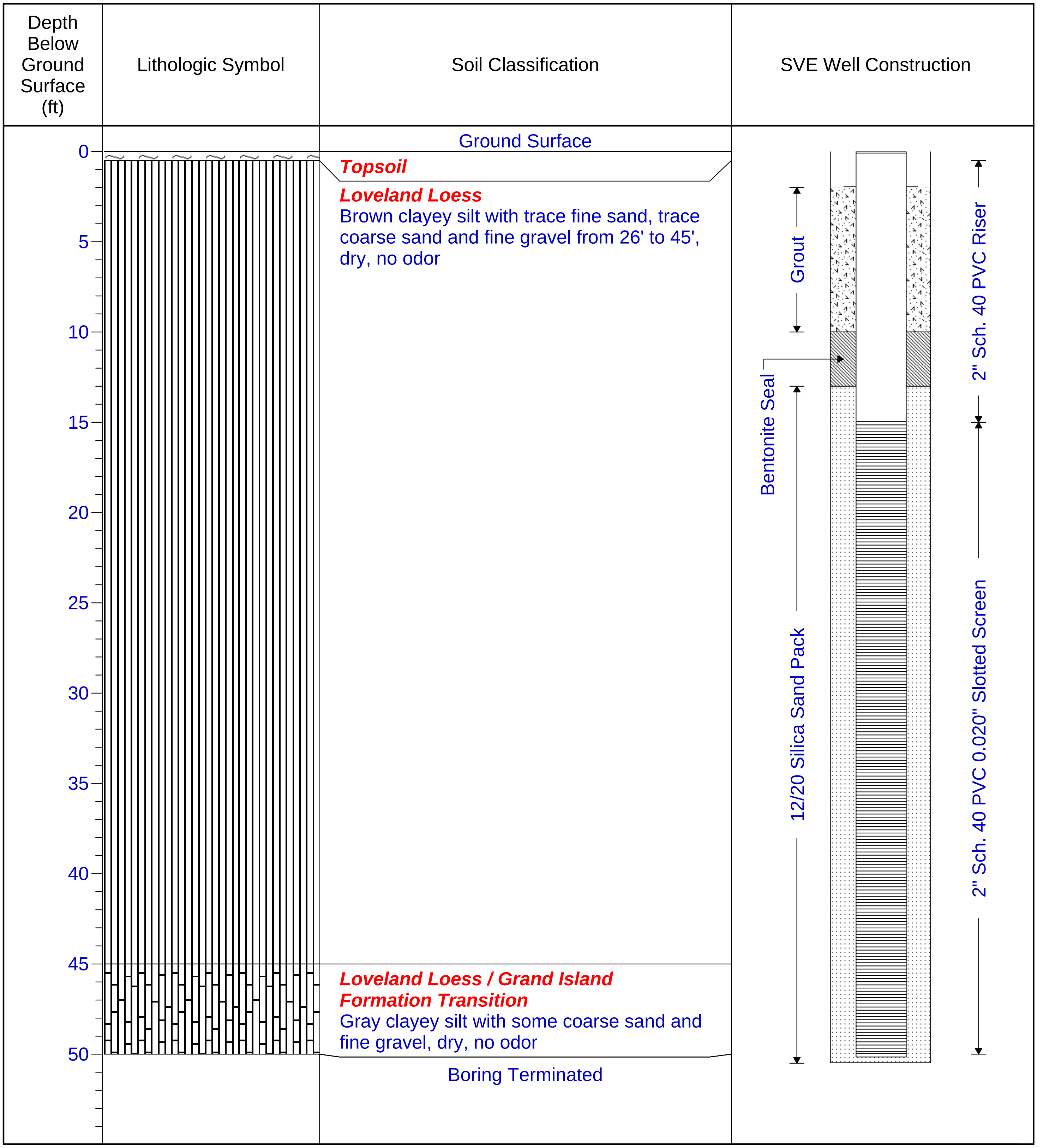

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 26' to 45', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and fine gravel, dry, no odor

Borehole Number: LA10-SVE08-26

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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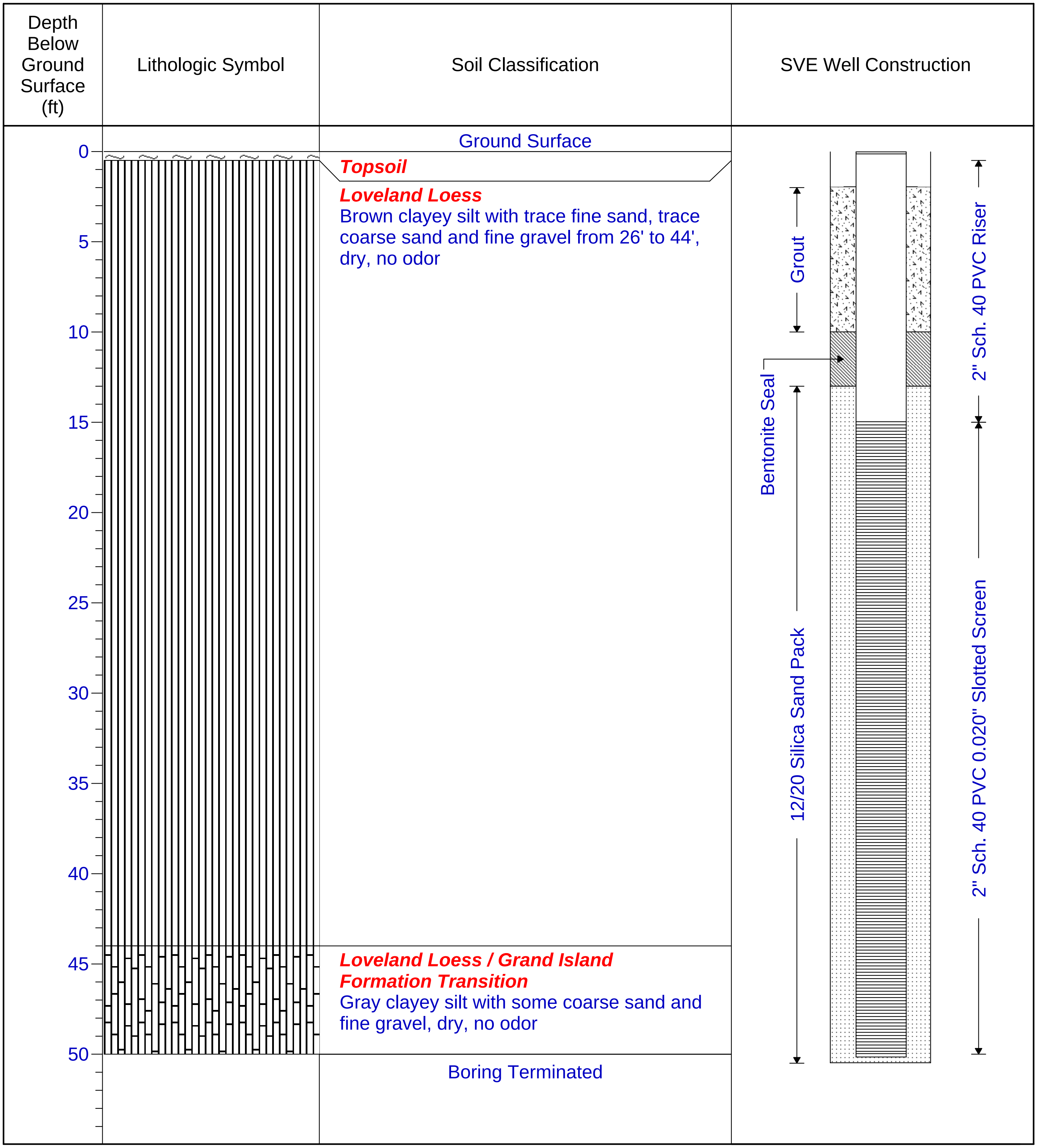

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 26' to 44', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-27

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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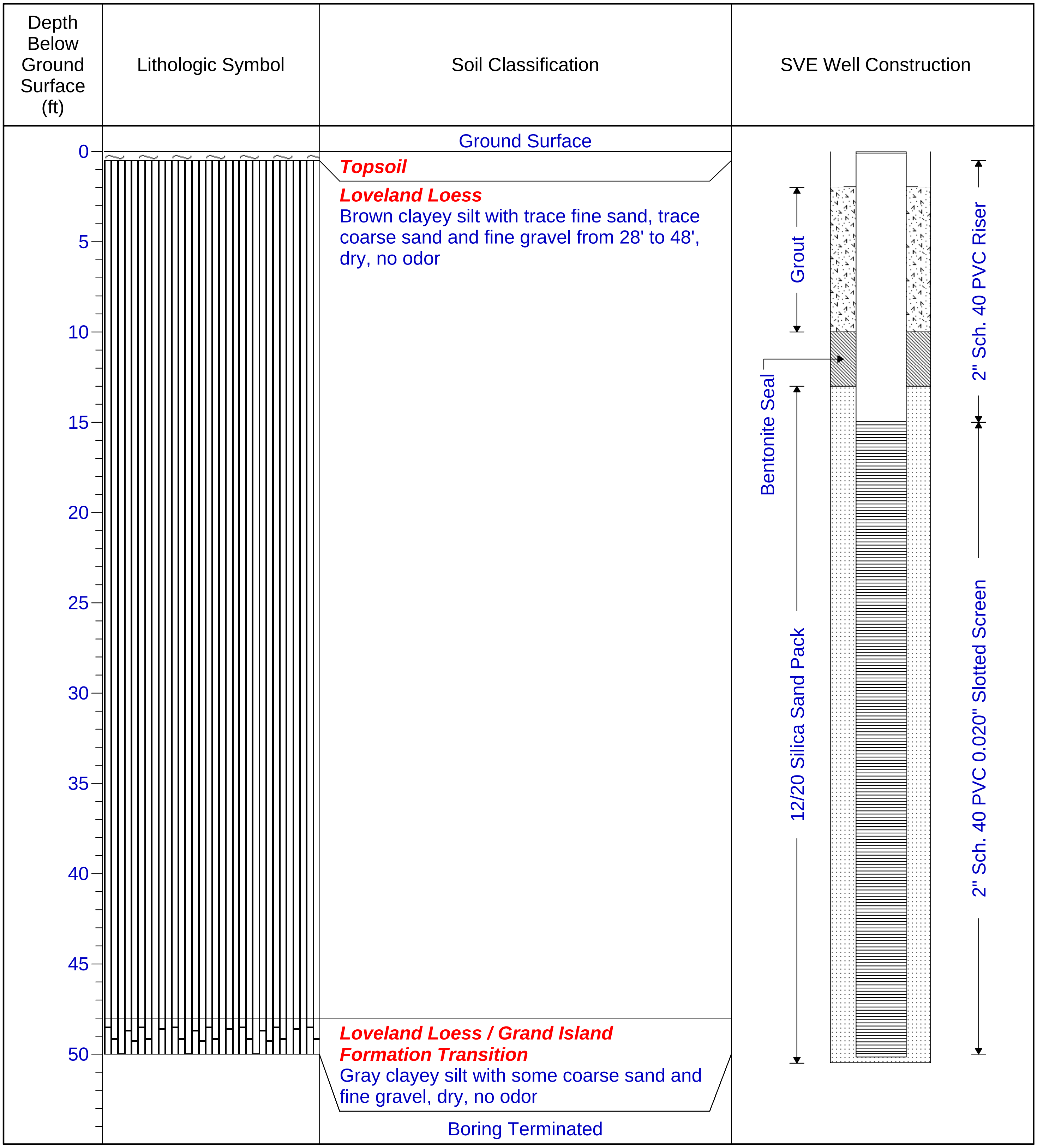

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 28' to 48', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-28

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/15/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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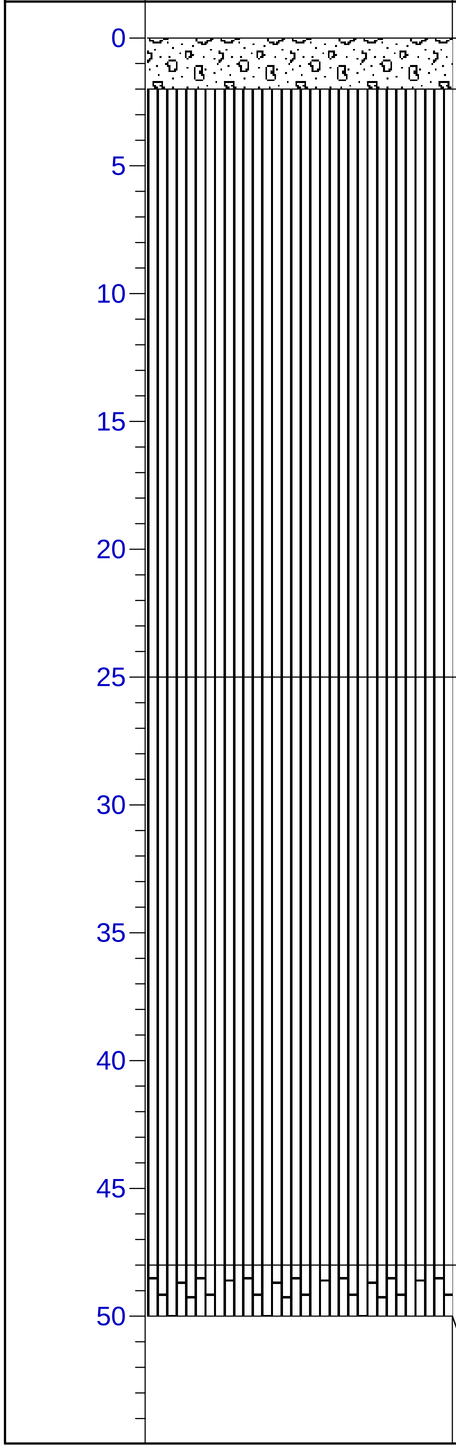
Depth Below Ground Surface (ft)	Lithologic Symbol	Soil Classification	SVE Well Construction



Ground Surface

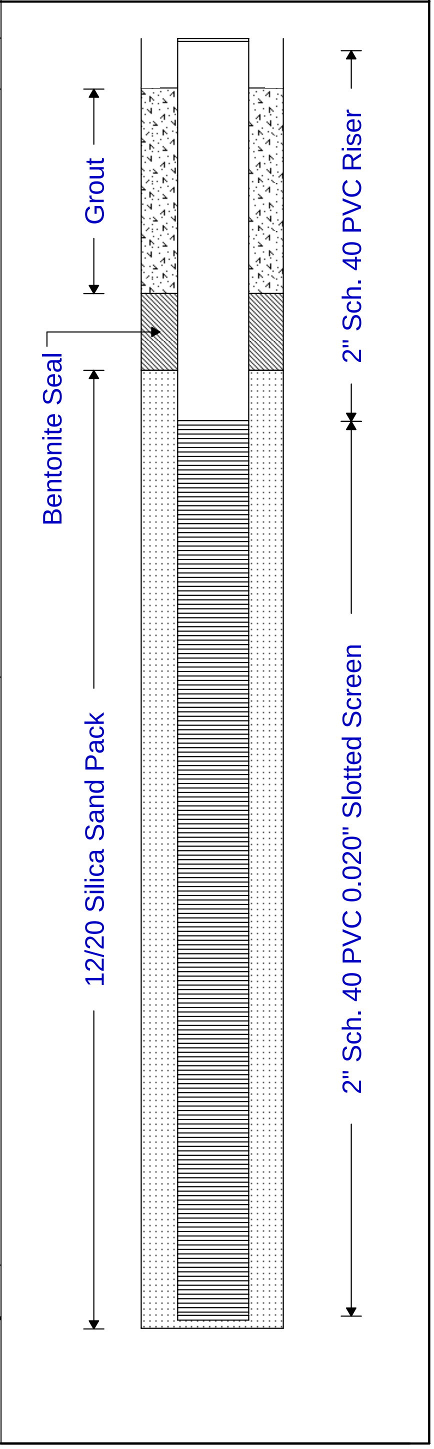
Gravel

Loveland Loess
Dark brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine to coarse sand, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand, dry, no odor

Boring Terminated



Borehole Number: LA10-SVE08-29

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/08/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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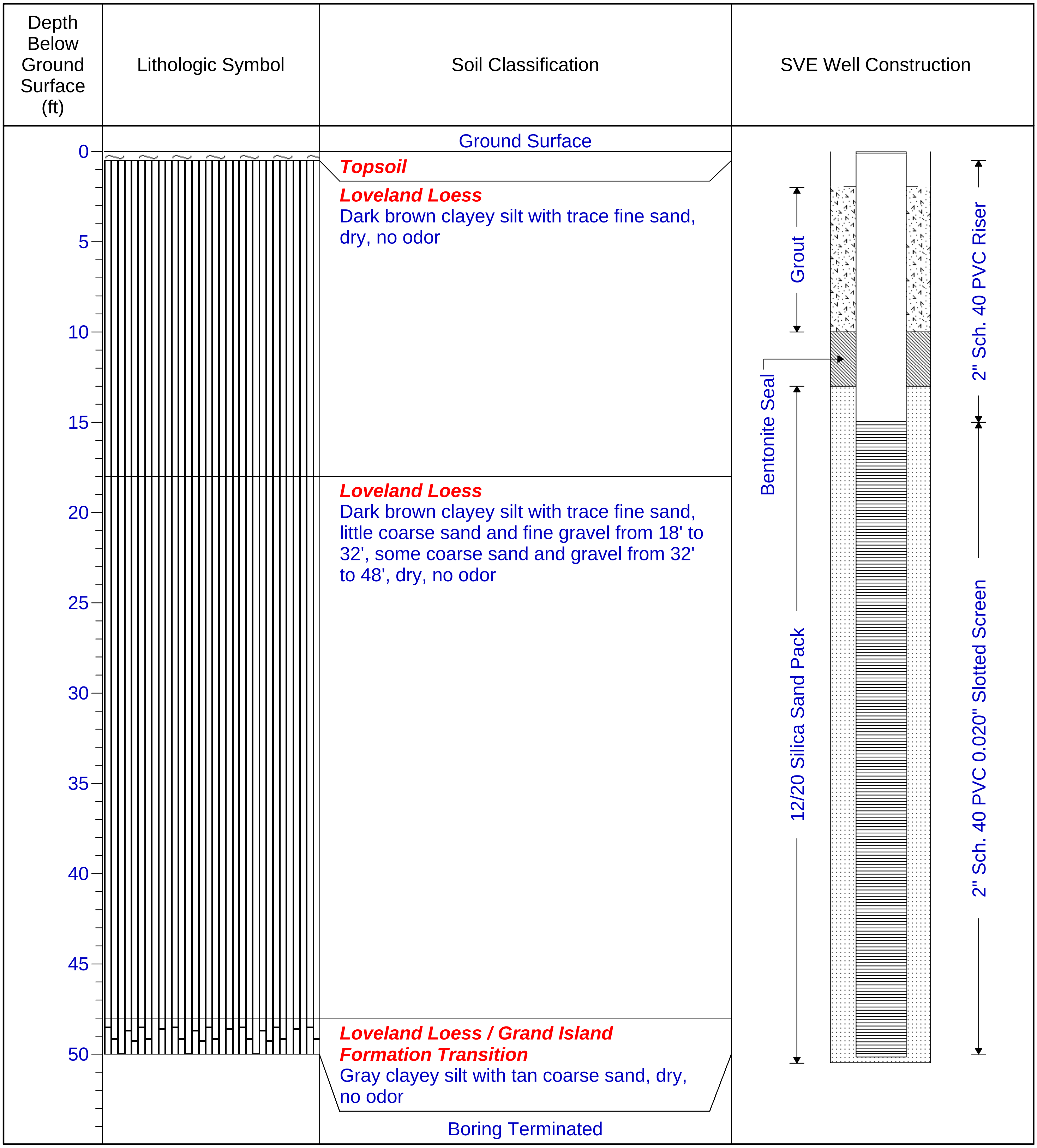

Ground Surface

Topsoil

Loveland Loess
Dark brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Dark brown clayey silt with trace fine sand, little coarse sand and fine gravel from 18' to 32', some coarse sand and gravel from 32' to 48', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with tan coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-30

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/09/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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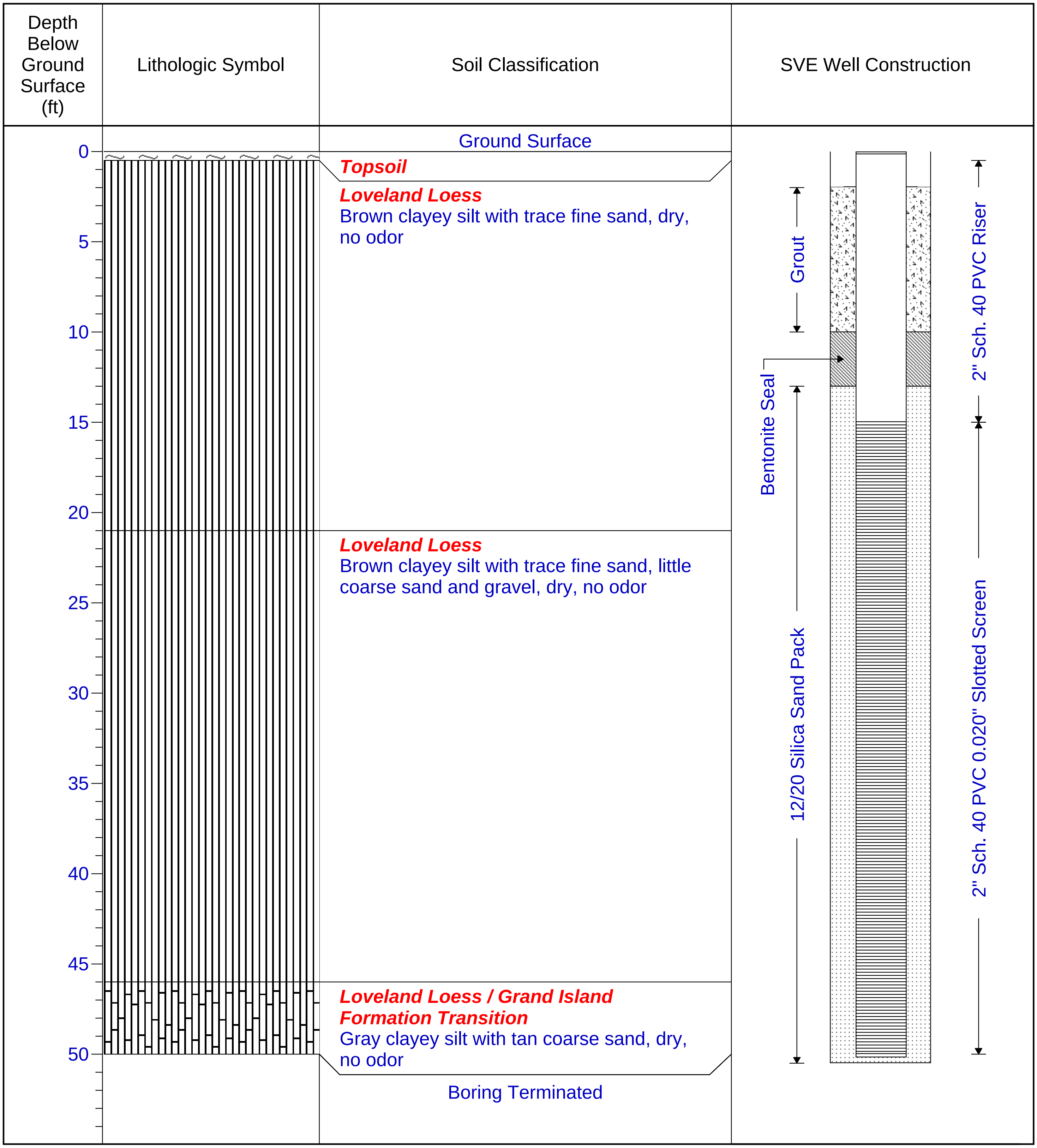

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine sand, little coarse sand and gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with tan coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-31

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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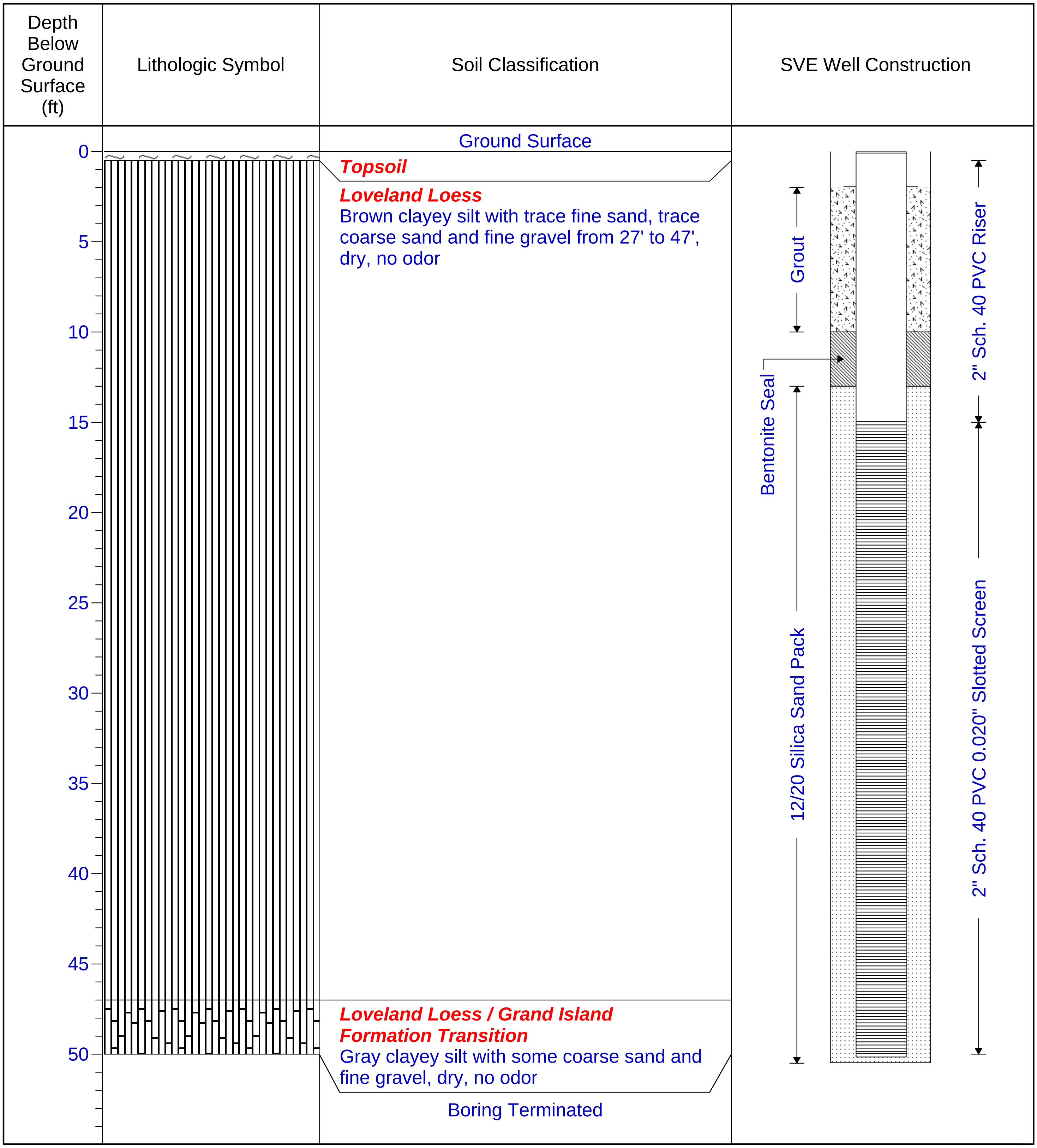

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 27' to 47', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and fine gravel, dry, no odor

Borehole Number: LA10-SVE08-32

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/12/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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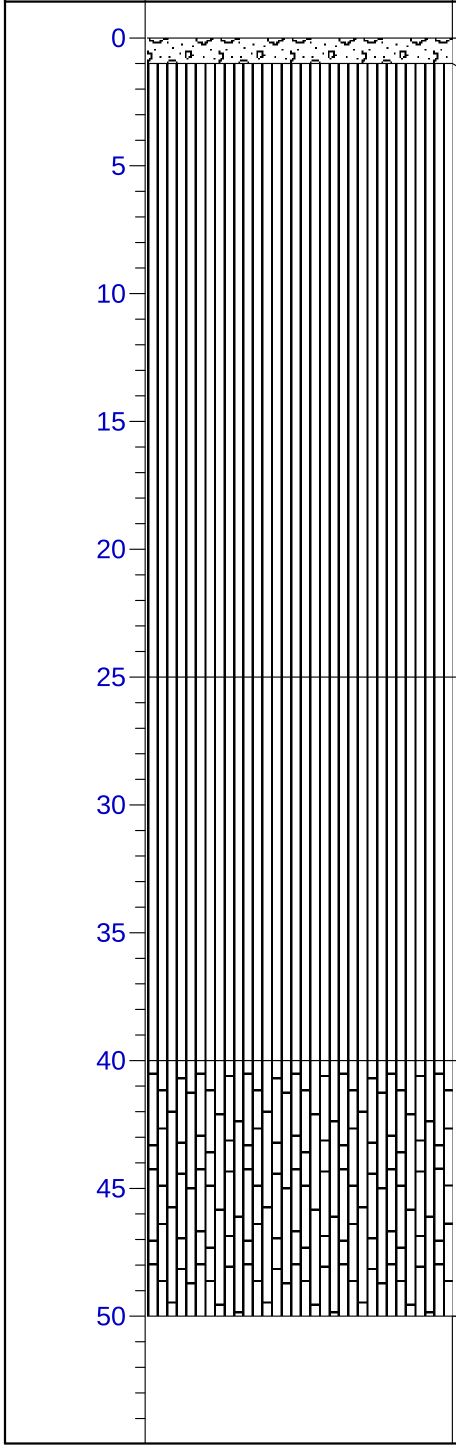
Depth Below Ground Surface (ft) | Lithologic Symbol | Soil Classification | SVE Well Construction



Ground Surface

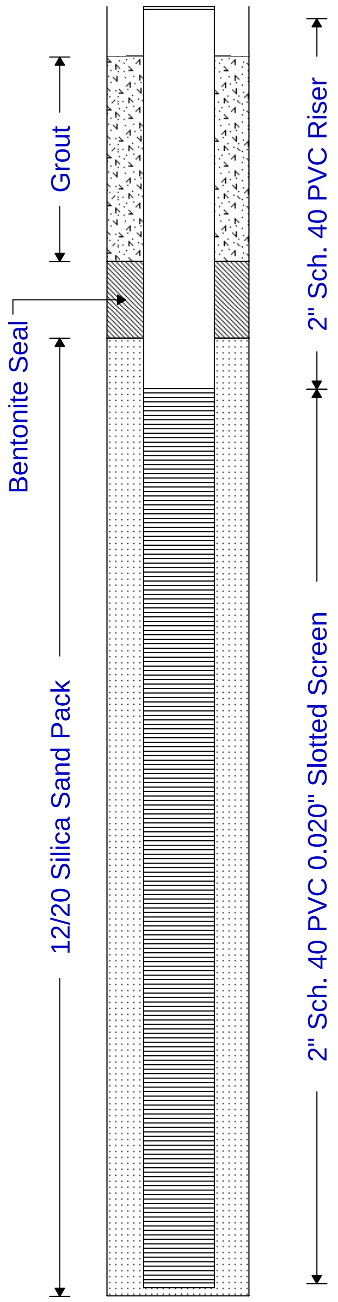
Gravel

Loveland Loess
Dark brown clayey silt with little to trace coarse sand and gravel, moist (due to overnight rain), no odor

Loveland Loess
Brown clayey silt with trace fine to coarse sand, dry, no odor

Loveland Loess / Grand Island Formation Transition
Brown clayey silt with increasing amounts of fine sand with depth, dry, no odor

Boring Terminated



Borehole Number: LA10-SVE08-33

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/11/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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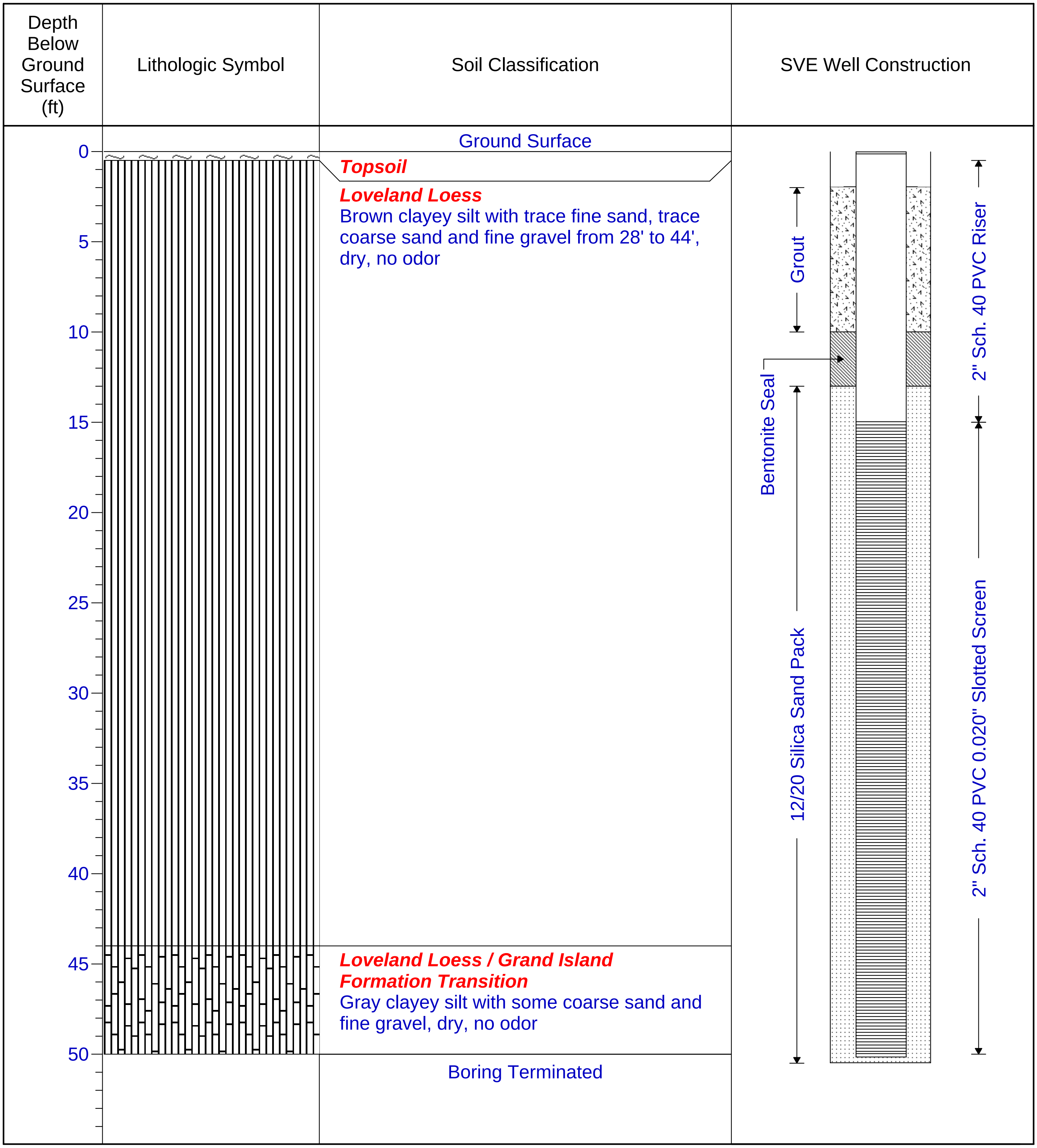

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 28' to 44', dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with some coarse sand and fine gravel, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-34

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/08/2008
Site Location: York, NE
Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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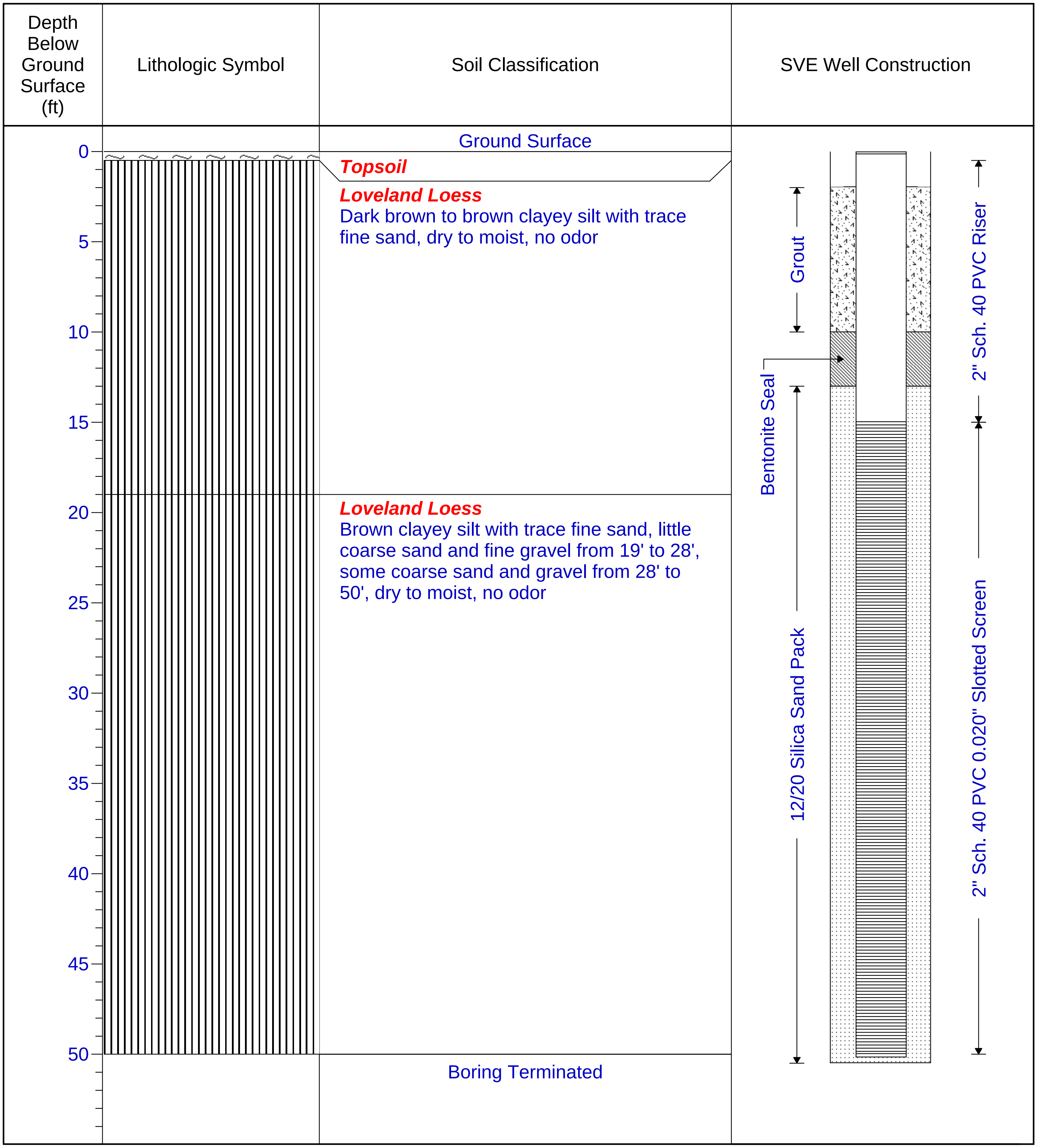

Ground Surface

Topsoil

Loveland Loess
Dark brown to brown clayey silt with trace fine sand, dry to moist, no odor

Loveland Loess
Brown clayey silt with trace fine sand, little coarse sand and fine gravel from 19' to 28', some coarse sand and gravel from 28' to 50', dry to moist, no odor

Boring Terminated

Borehole Number: LA10-SVE08-35

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/09/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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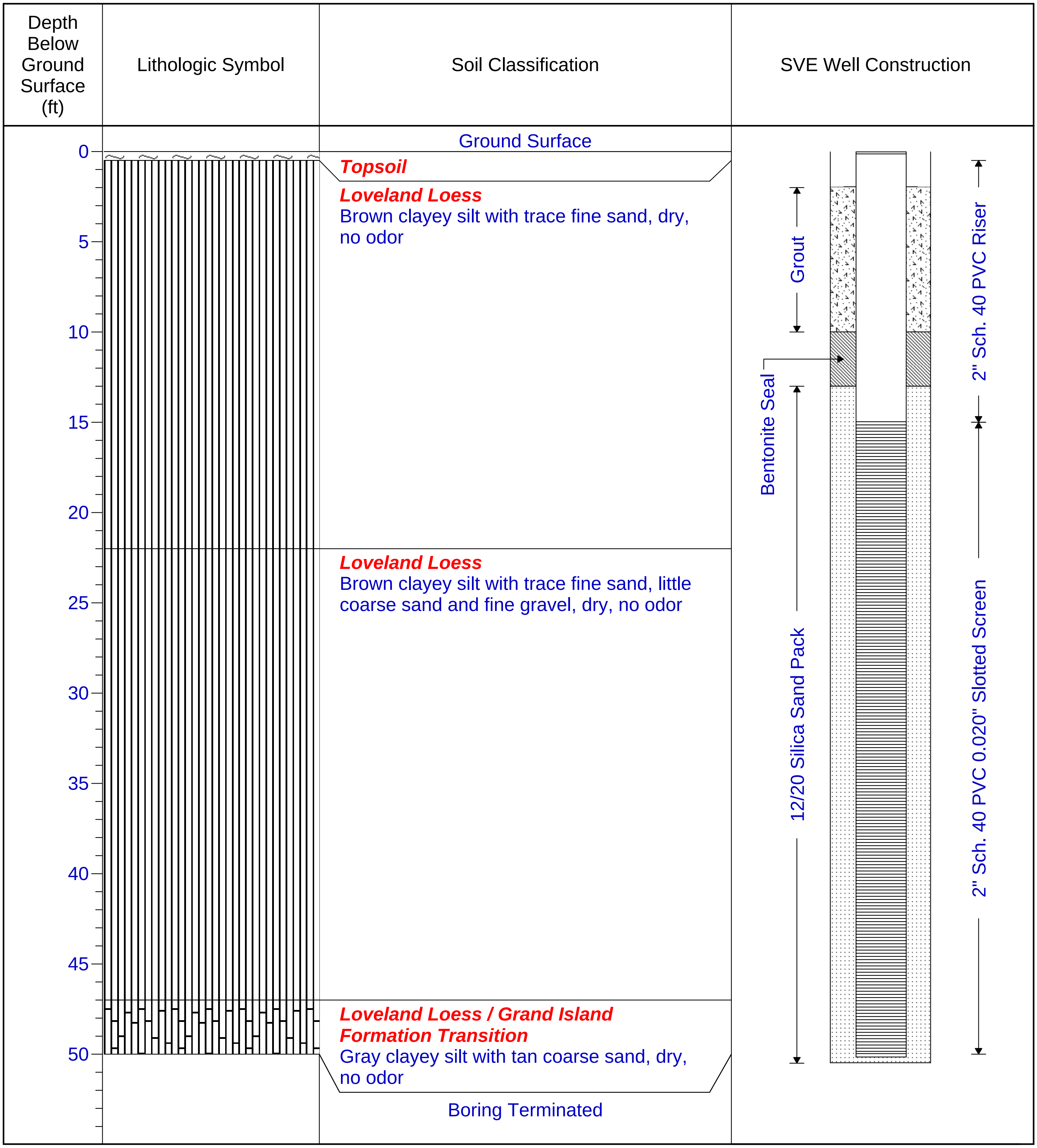

Ground Surface

Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine sand, little coarse sand and fine gravel, dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with tan coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-36

Project No: SE5002-200	**Geologist:** Keith Rice
Project: Atlas Missile Site 10	**Drilled By:** Peterson Drilling, Inc.
Client: USACE Omaha	**Drill Method:** Hollow Stem Auger
Drill Date: 07/12/2008	**Bore Hole Diameter:** 6.25"
Site Location: York, NE	**Sampling Method:** N/A

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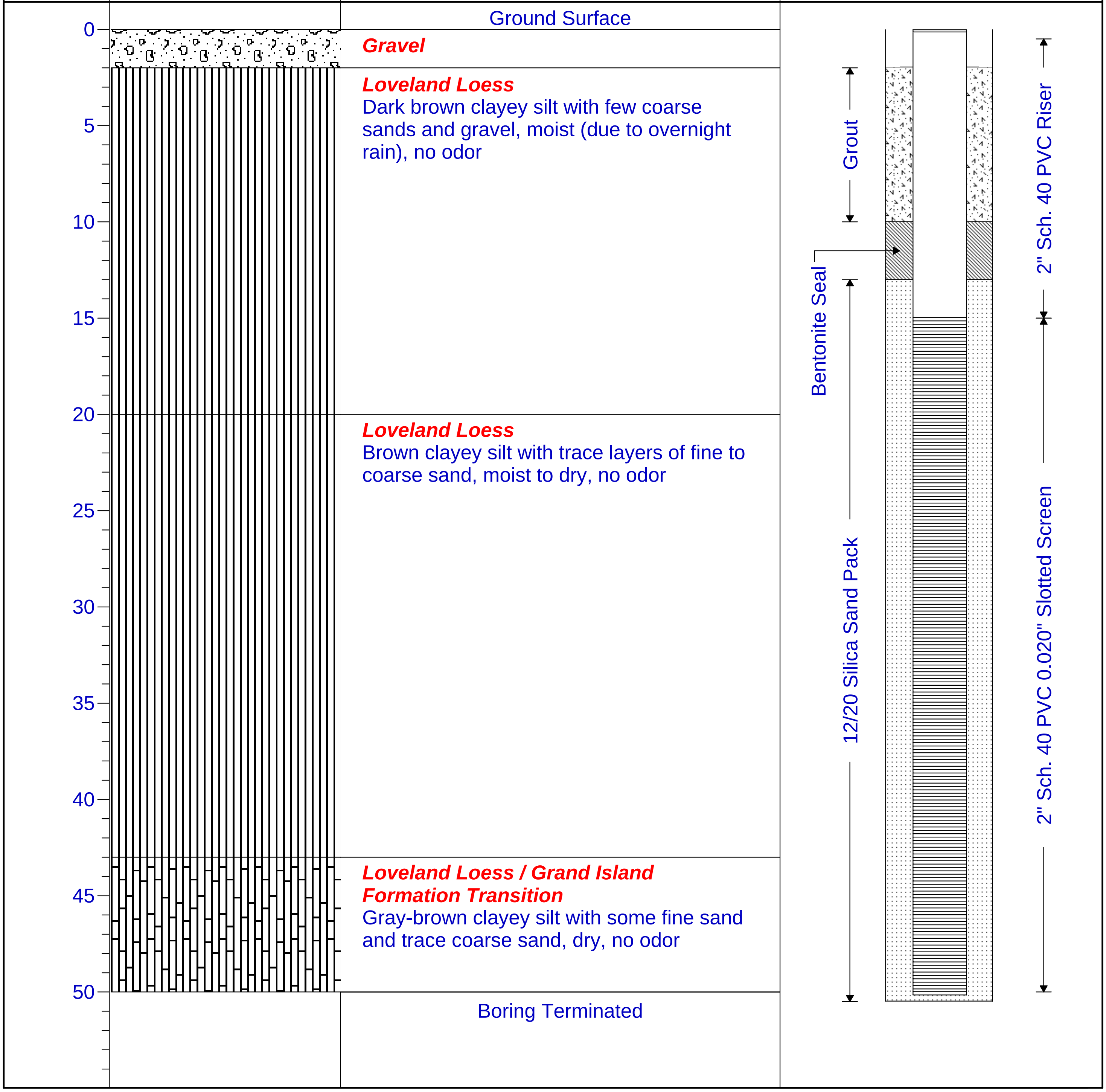
Depth Below Ground Surface (ft)	Lithologic Symbol	Soil Classification	SVE Well Construction



Ground Surface

Gravel

Loveland Loess
Dark brown clayey silt with few coarse sands and gravel, moist (due to overnight rain), no odor

Loveland Loess
Brown clayey silt with trace layers of fine to coarse sand, moist to dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand and trace coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-37

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/16/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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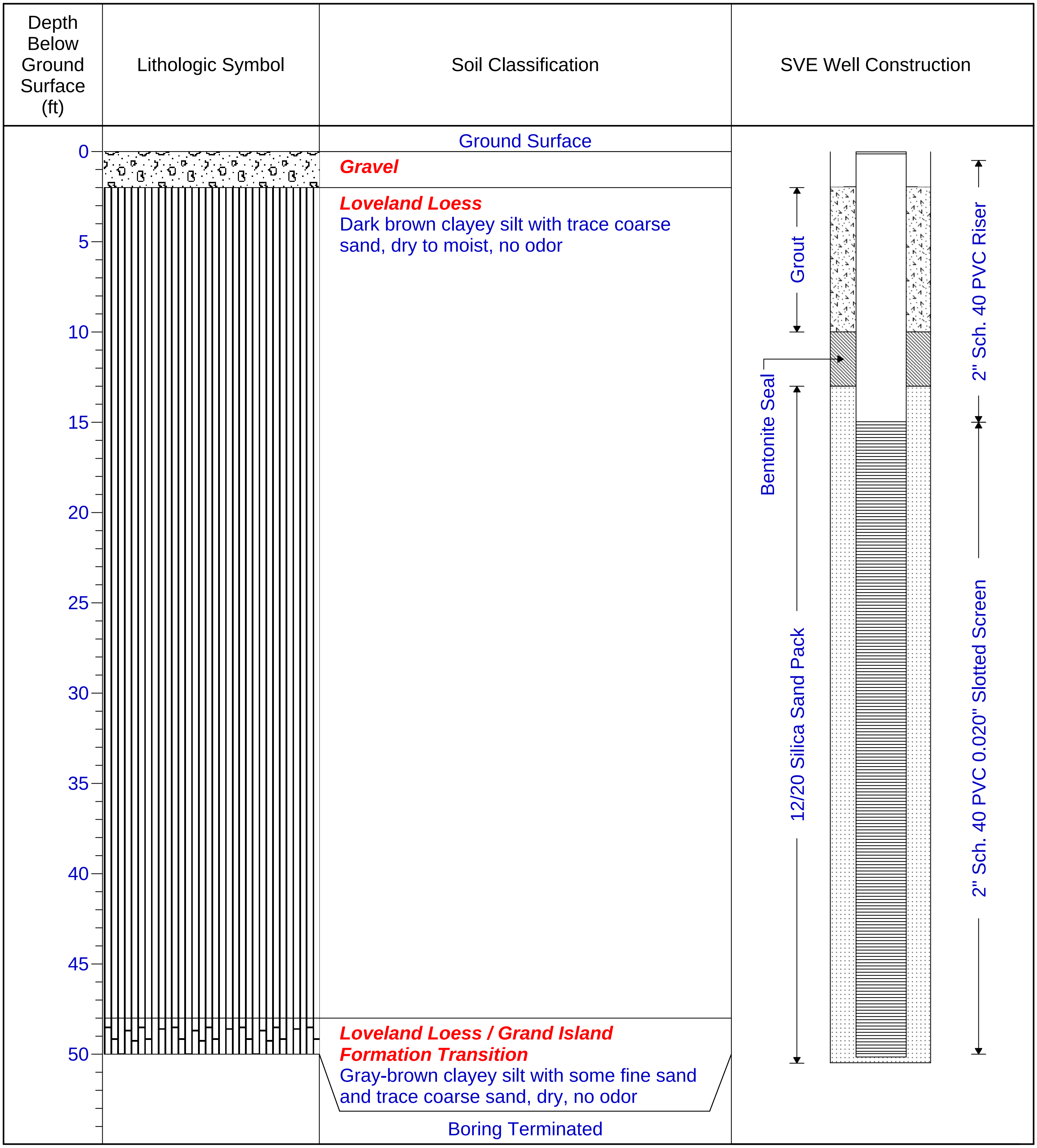

Ground Surface

Gravel

Loveland Loess
Dark brown clayey silt with trace coarse sand, dry to moist, no odor

Loveland Loess / Grand Island Formation Transition
Gray-brown clayey silt with some fine sand and trace coarse sand, dry, no odor

Boring Terminated

Borehole Number: LA10-SVE08-38

Project No: SE5002-200
Project: Atlas Missile Site 10
Client: USACE Omaha
Drill Date: 07/08/2008
Site Location: York, NE

Geologist: Keith Rice
Drilled By: Peterson Drilling, Inc.
Drill Method: Hollow Stem Auger
Bore Hole Diameter: 6.25"
Sampling Method: N/A

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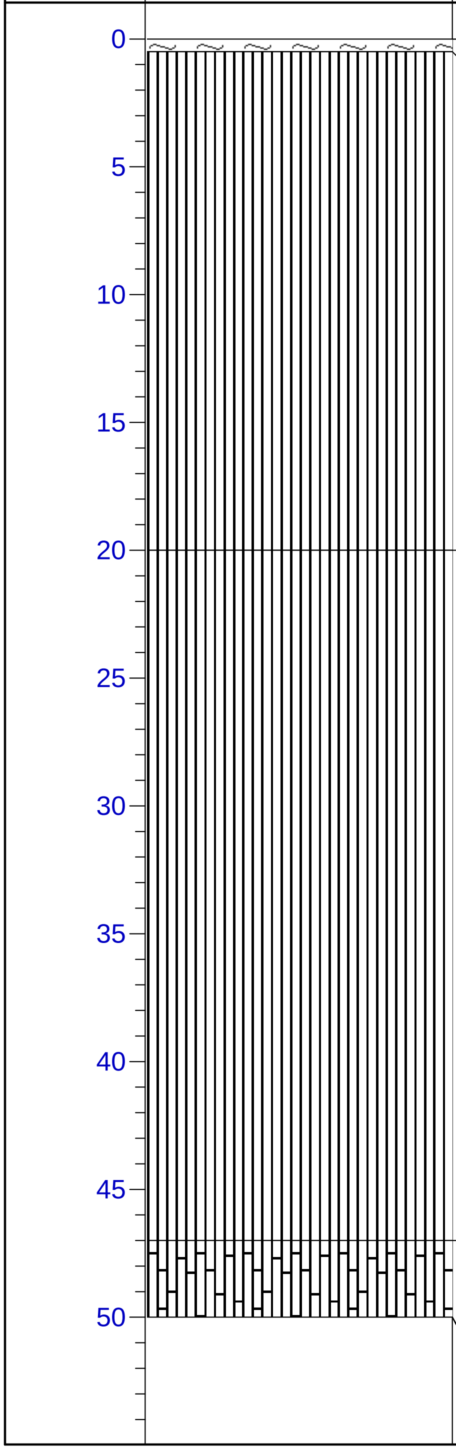
Depth Below Ground Surface (ft)	Lithologic Symbol	Soil Classification	SVE Well Construction



Ground Surface

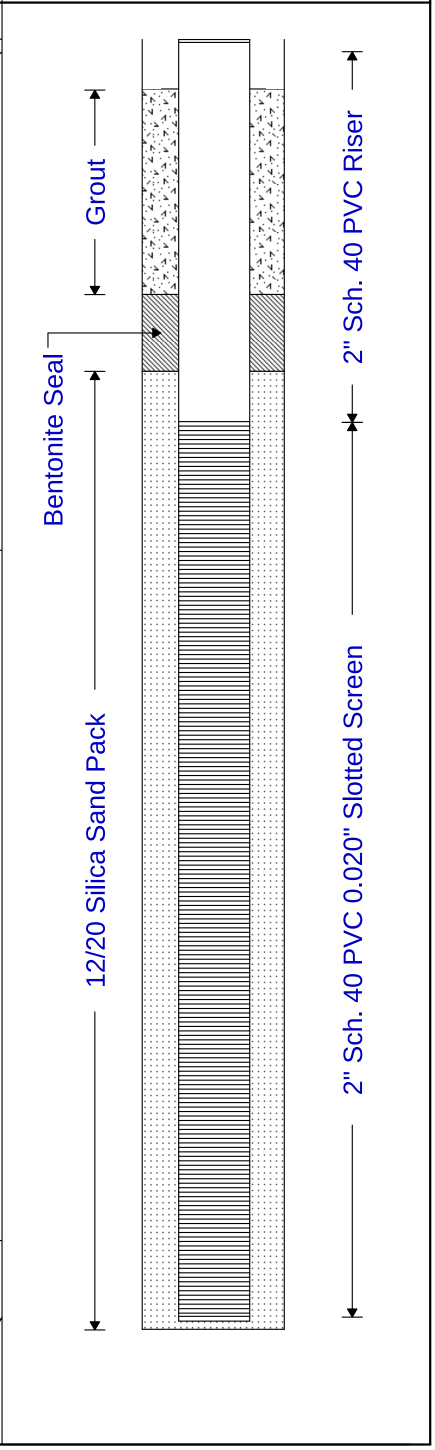
Topsoil

Loveland Loess
Dark brown to brown clayey silt with trace fine sands, dry to moist, no odor

Loveland Loess
Brown clayey silt with some coase sand and gravel from 20' to 25', little fine/coarse sand and gravel from 25' to 47', moist to dry, no odor

Loveland Loess / Grand Island Formation Transition
Gray clayey silt with tan coarse sand, dry, no odor

Boring Terminated



Borehole Number: LA10-SVE08-39

Project No: SE5002-200	***Geologist:*** Keith Rice
Project: Atlas Missile Site 10	***Drilled By:*** Peterson Drilling, Inc.
Client: USACE Omaha	***Drill Method:*** Hollow Stem Auger
Drill Date: 07/08/2008	***Bore Hole Diameter:*** 6.25"
Site Location: York, NE	***Sampling Method:*** N/A

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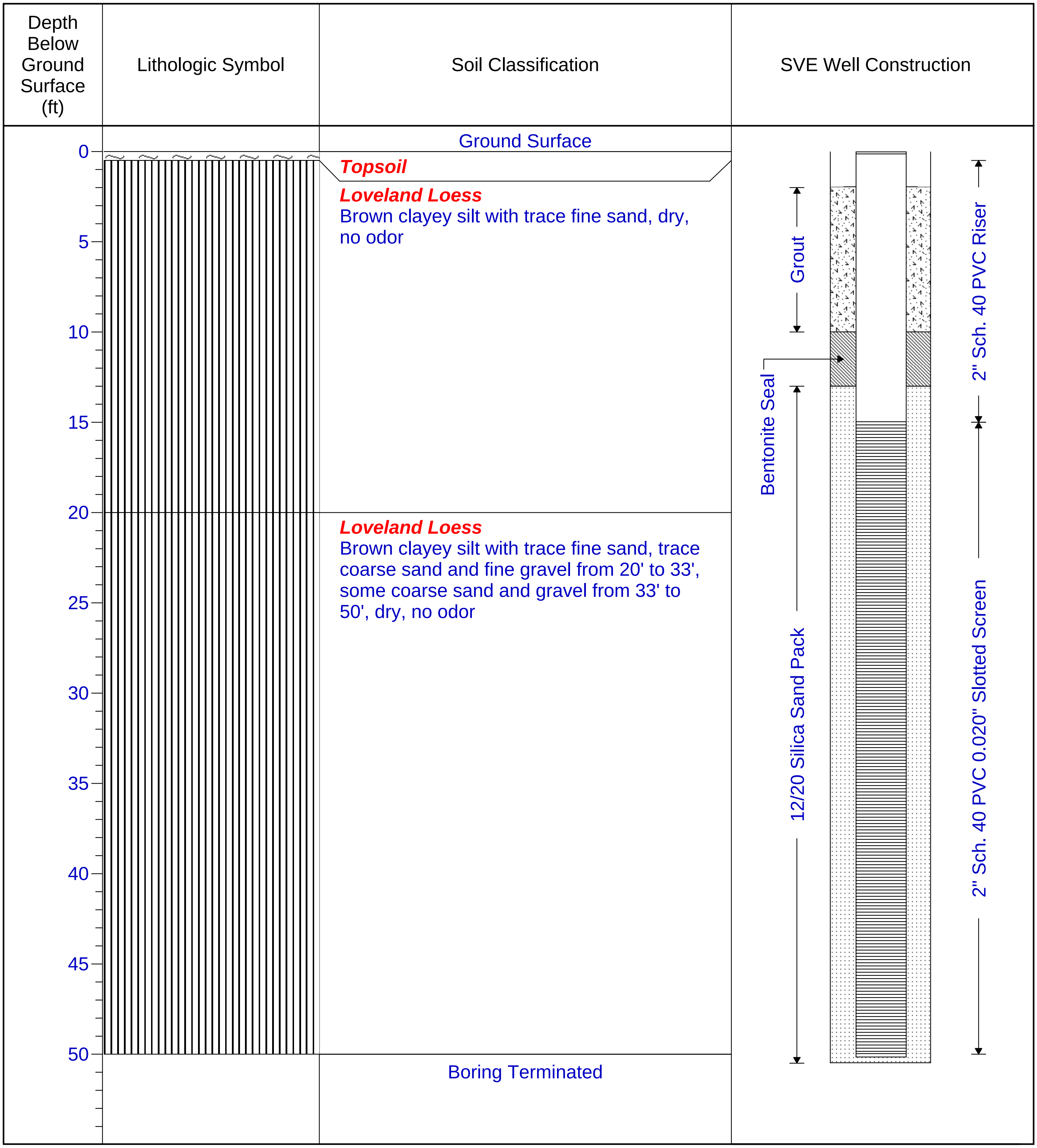


Topsoil

Loveland Loess
Brown clayey silt with trace fine sand, dry, no odor

Loveland Loess
Brown clayey silt with trace fine sand, trace coarse sand and fine gravel from 20' to 33', some coarse sand and gravel from 33' to 50', dry, no odor

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix D: Boring Logs and Well Construction Details

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 1.25 ft, Some Rocks, dry

Olive gray clayey SILT (ML), low plasticity, no hydrocarbon odor, low moisture content

- color change to dark gray below 3 ft, stiff, dry to low moisture content, shell and rock fragments throughout

Dark gray silty CLAY-clayey SILT (CL-ML), dry to low moisture content, no hydrocarbon odor, very stiff, low plasticity, lots of rock fragments throughout, some black iron staining

- less stiff below 8 ft

- color change to dark brown below 9 ft

Brownish-olive clayey SILT (ML), moderate stiffness, black iron staining, low plasticity, dry to low moisture content

- color change to olive gray below 14 ft, dry to low moisture content, no hydrocarbon odor, moderate stiffness, low plasticity, lots of rock fragments and nodules throughout

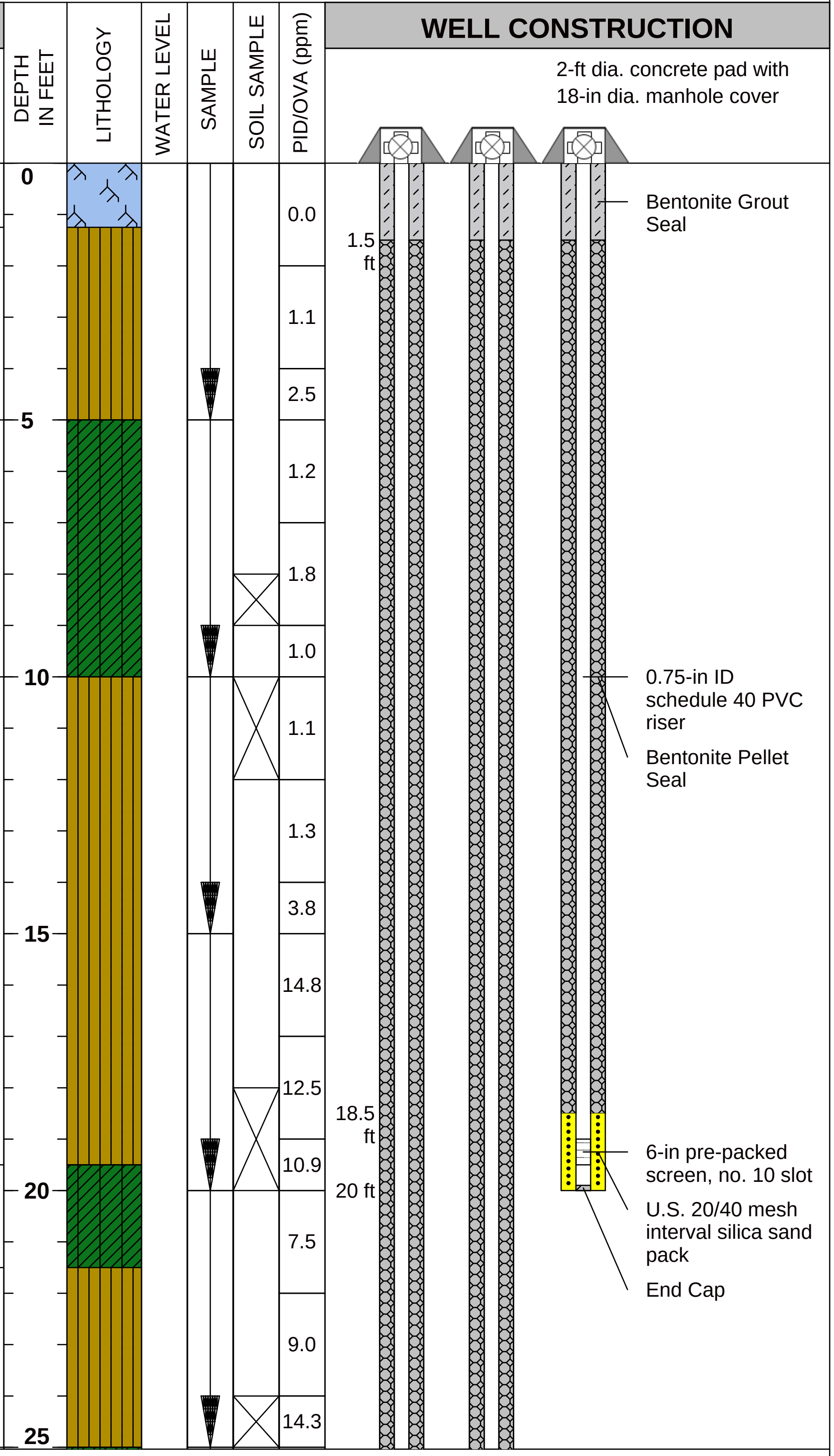
- increased moisture content below 17 ft

- color change to brown below 18 ft

Dark gray silty CLAY-clayey SILT (CL-ML), low to moderate moisture content, no hydrocarbon odor, moderate stiffness, low plasticity

Brown clayey SILT (ML), with red-black iron-oxide staining, low to moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

- increased moisture below 22.5 ft, some very fine sand, black iron staining



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
IW-1S, IW-1M, IW-1D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.1

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

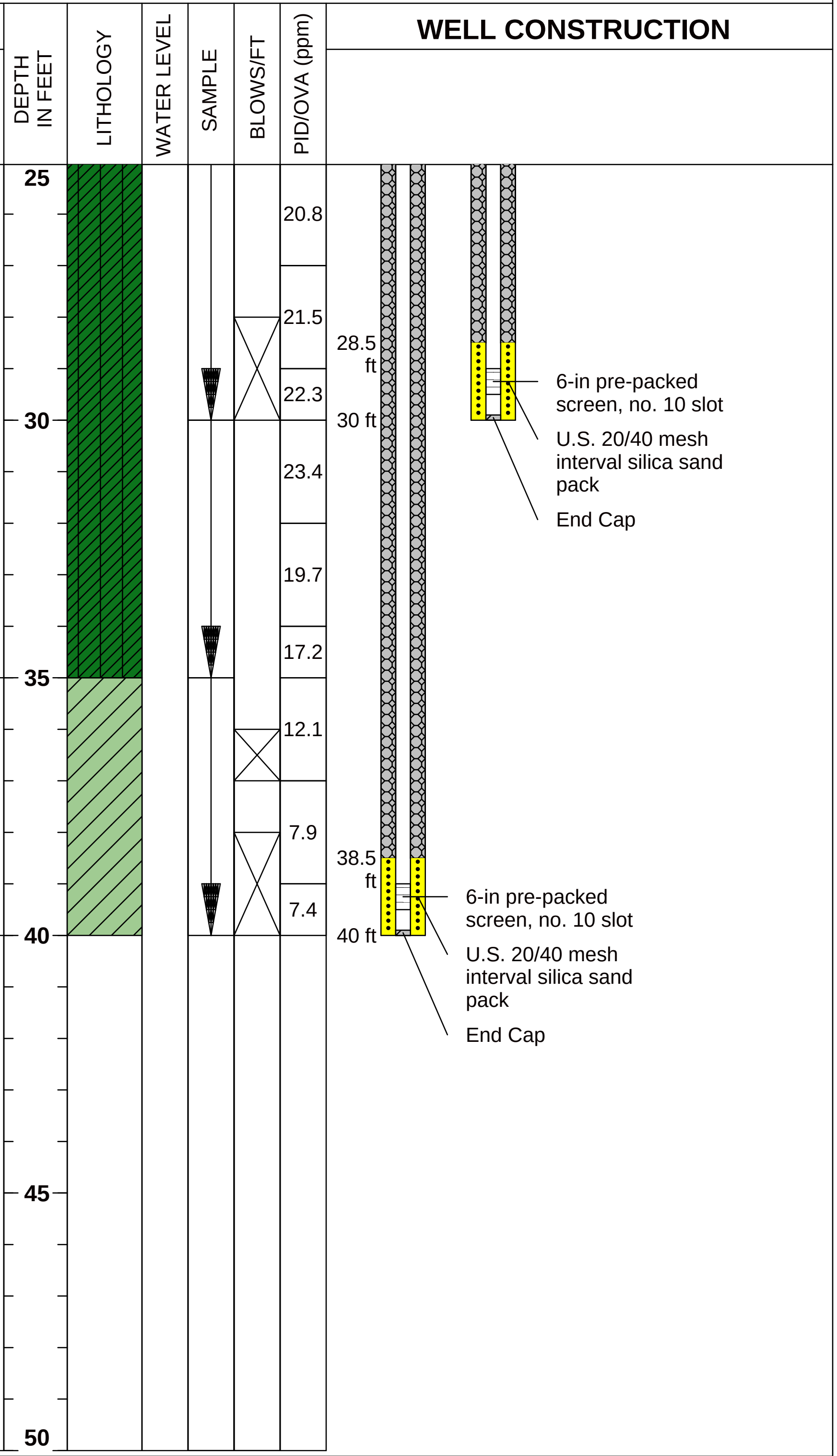
Brown silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, moderate stiffness, low plasticity

- stiff below 32 ft

- less stiff below 33 ft, increased moisture content, black iron staining

Brown silty CLAY (CL), very stiff, no hydrocarbon odor, low to moderate plasticity, black iron staining throughout, low moisture content

Total Depth = 40 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
IW-1S, IW-1M, IW-1D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.1

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 1.5 ft, grass, dry

Light brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 3 ft, rock fragments

- very stiff below 5 ft

- color change to dark brown below 7.5 ft

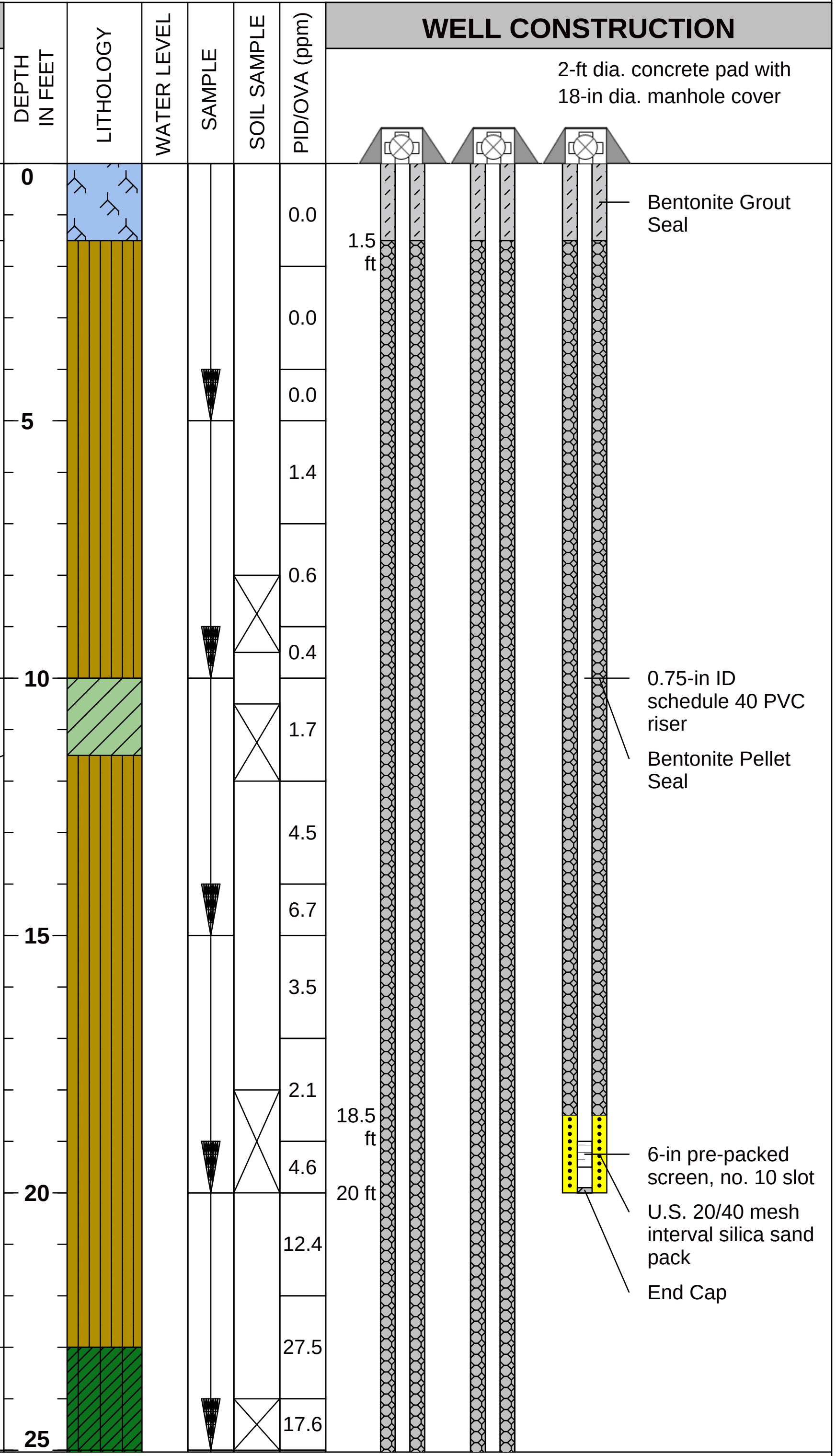
Dark gray silty CLAY (CL), very stiff, no hydrocarbon odor, slight plasticity, black iron staining, low moisture content, small pockets of very fine sand throughout

Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor

- color change to olive gray below 14.5 ft, moderate stiffness, rock fragments

- increased stiffness below 19 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
IW-2S, IW-2M, IW-2D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.2

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Light brown clayey SILT (ML), some rock fragments, moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

- moist to wet from 28 to 30 ft

- very stiff below 30.5 ft, red-black iron-oxide staining

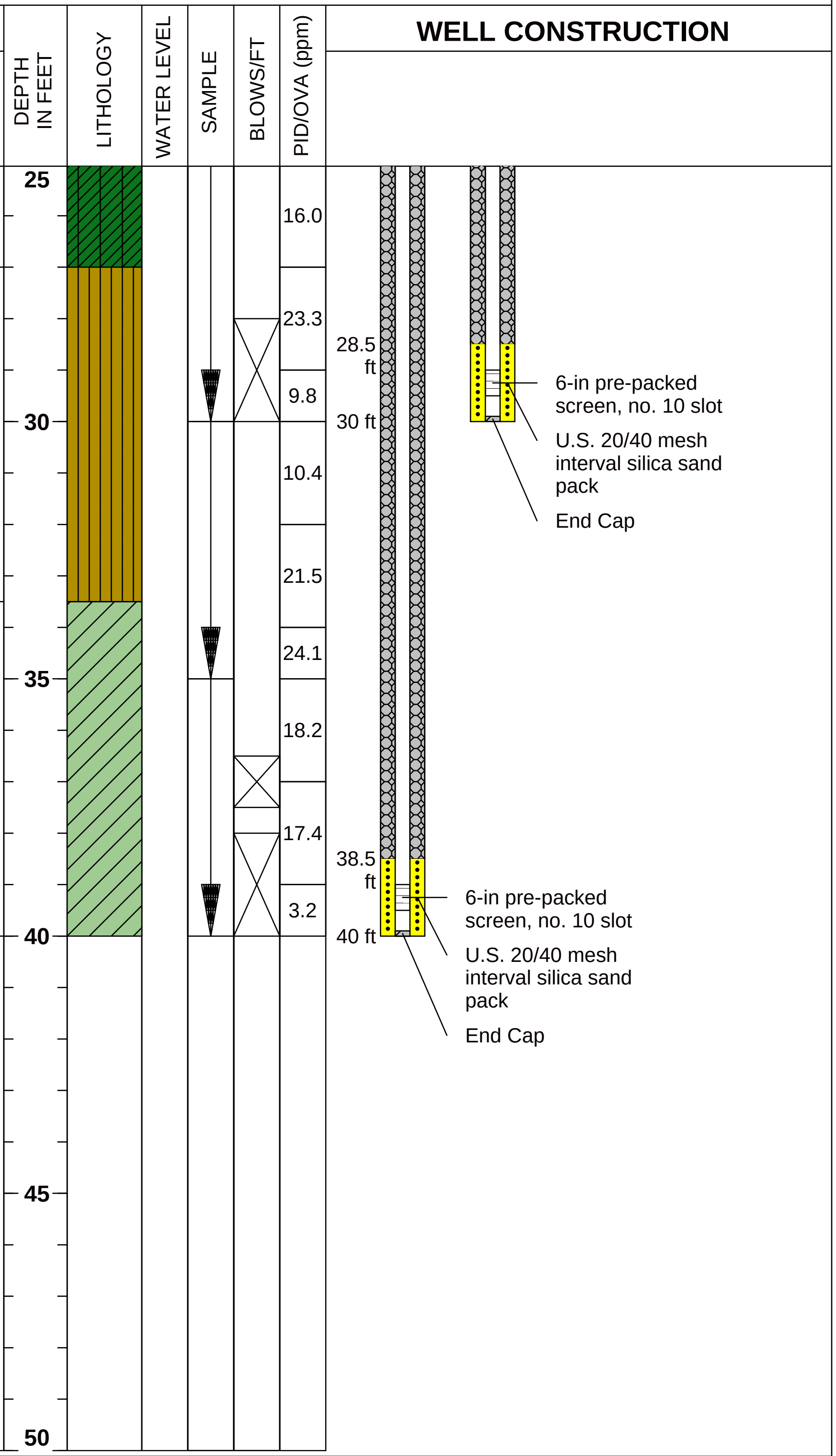
- less stiff below 32 ft, increased moisture content, black iron staining

Brown silty CLAY (CL), very stiff, no hydrocarbon odor, moderate plasticity, black iron staining, moderate moisture content

- very moist below 37 ft

Total Depth = 40 ft

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
IW-2S, IW-2M, IW-2D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.2

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 0.75 ft, dry to low moisture content

Light brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 3 ft

- very stiff below 5.5 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), very stiff, no hydrocarbon odor, slight plasticity, black iron staining, low moisture content, small pockets of very fine sand throughout

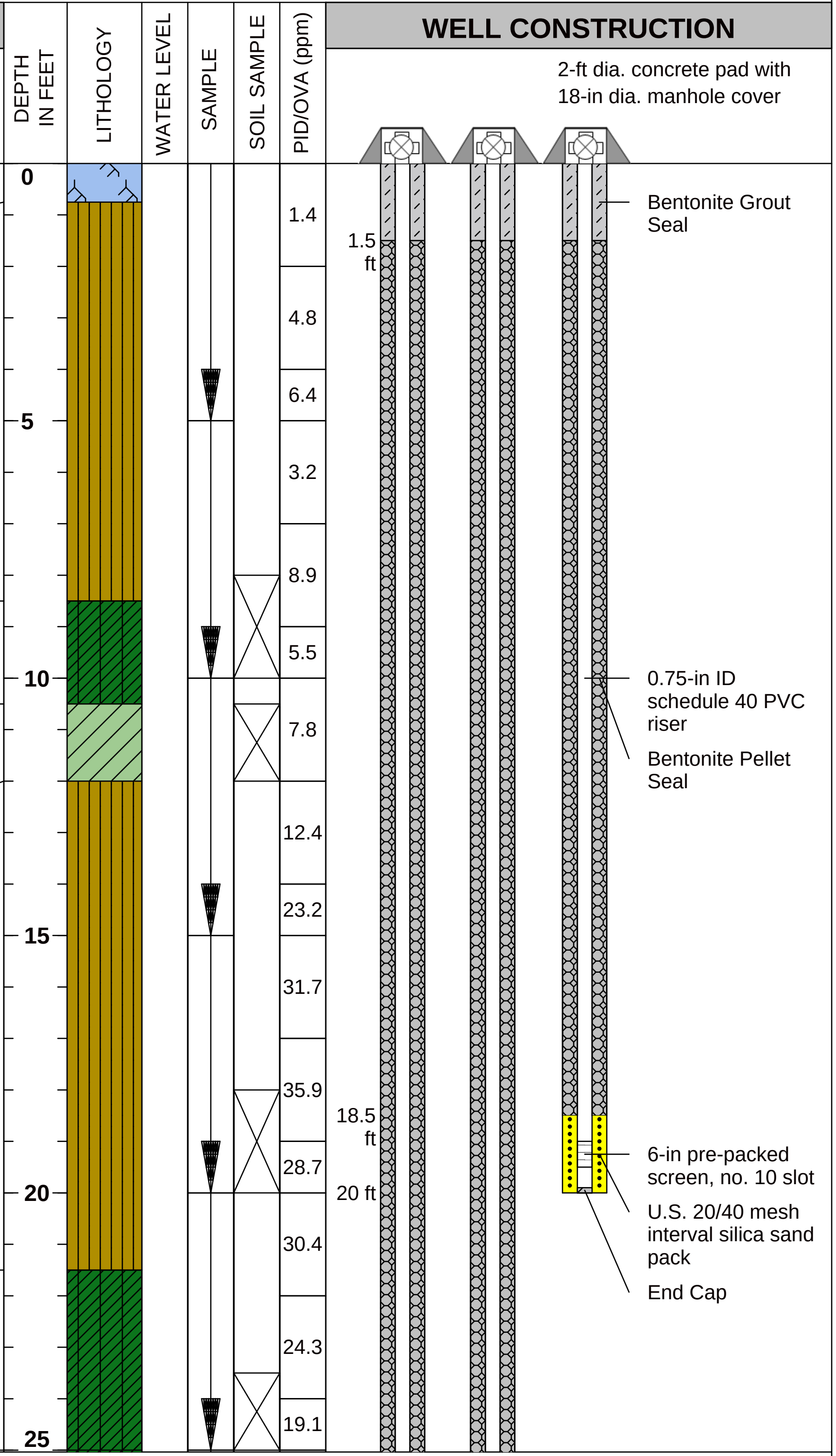
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor

- color change to olive gray below 16 ft, moderate stiffness, rock fragments

- increased stiffness below 18.5 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

WELL CONSTRUCTION



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GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
IW-3S, IW-3M, IW-3D

ESTCP H2T Vadose Demonstration
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Figure A.3

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Light brown clayey SILT (ML), some rock fragments, moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

- moist to wet below 29 ft

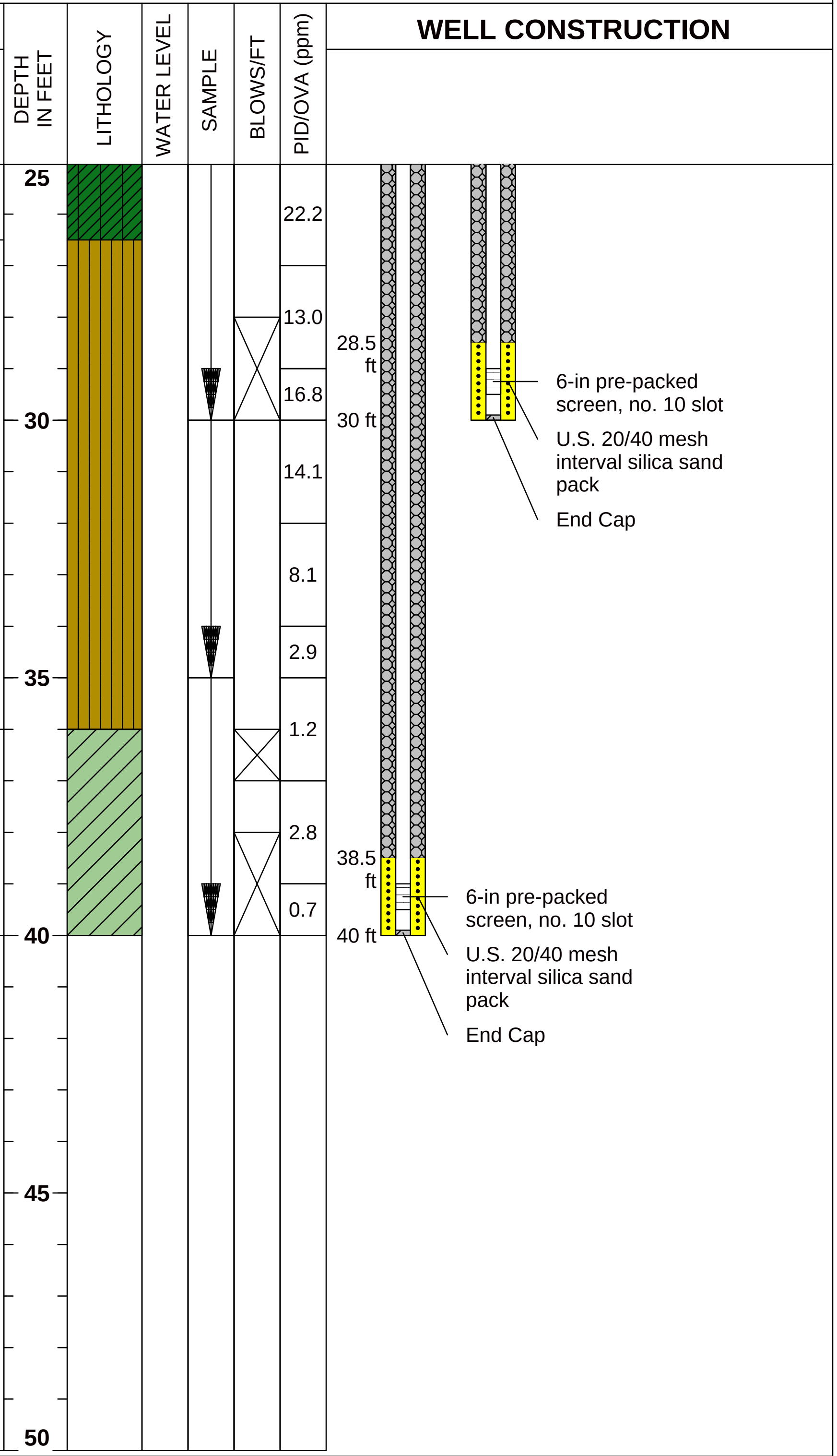
- very stiff below 32 ft, red-black iron-oxide staining

- less stiff below 34 ft, increased moisture content, black iron staining

Brown silty CLAY (CL), very stiff, no hydrocarbon odor, moderate plasticity, black iron staining, moderate moisture content

- very moist below 38.5 ft

Total Depth = 40 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
IW-3S, IW-3M, IW-3D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.3

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 9 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 1 ft, dry

Dark brown clayey sandy SILT (ML), thin layers of very fine to medium sand, low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 3.5 ft

Olive gray silty CLAY-clayey SILT (CL-ML), low to moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, black iron staining, dry, small pockets of very fine sand throughout

Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor, layers of fine to medium size sand throughout

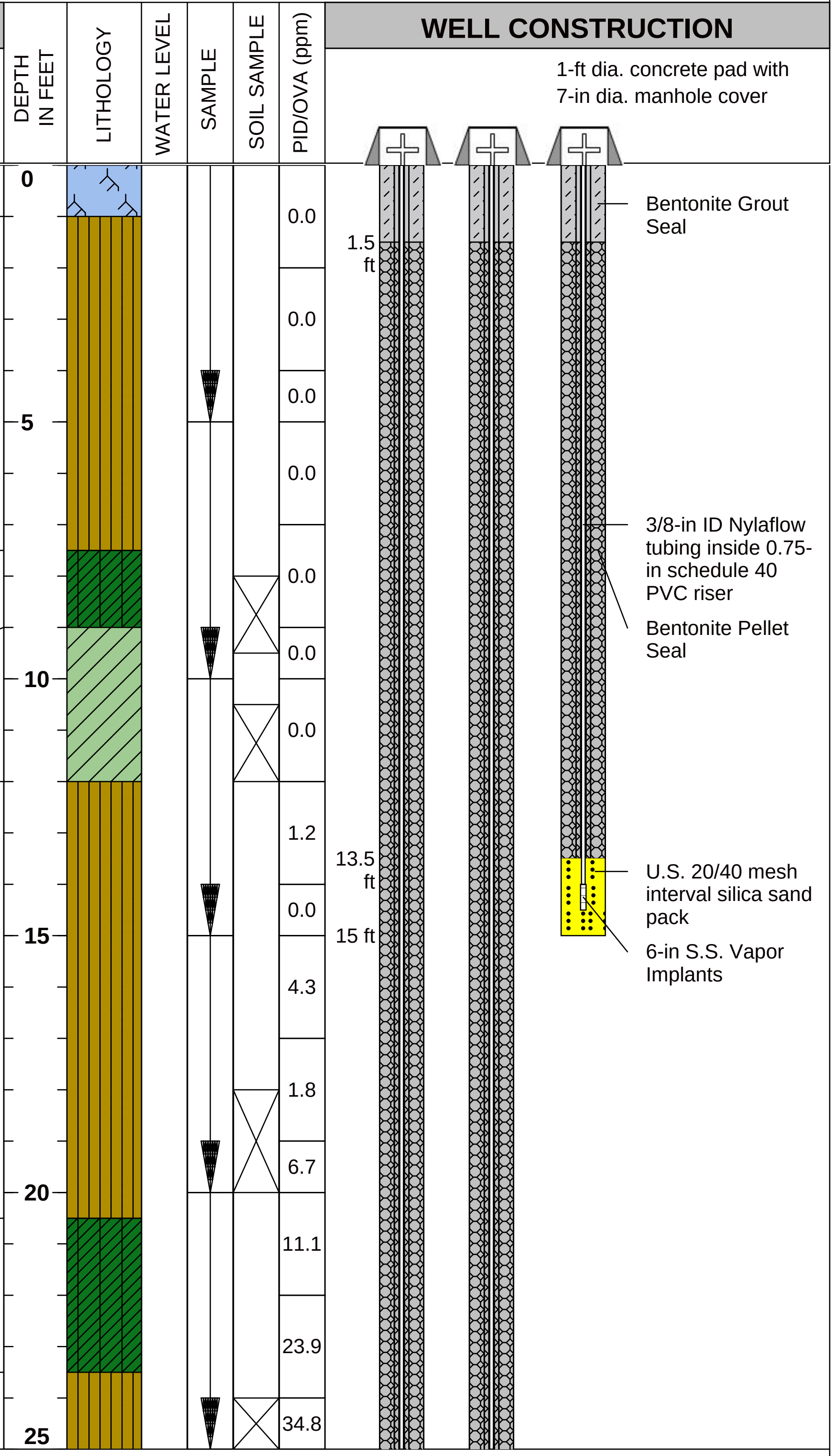
- color change to olive gray below 15 ft, moderate stiffness

- increased stiffness below 18 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Brown clayey SILT (ML), low moisture content, stiff, low plasticity, no hydrocarbon odor

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-1S, MW-1M, MW-1D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.4

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 9 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Brown clayey SILT (ML), low moisture content, stiff, low plasticity, no hydrocarbon odor

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Light brown clayey SILT (ML), some rock fragments, moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

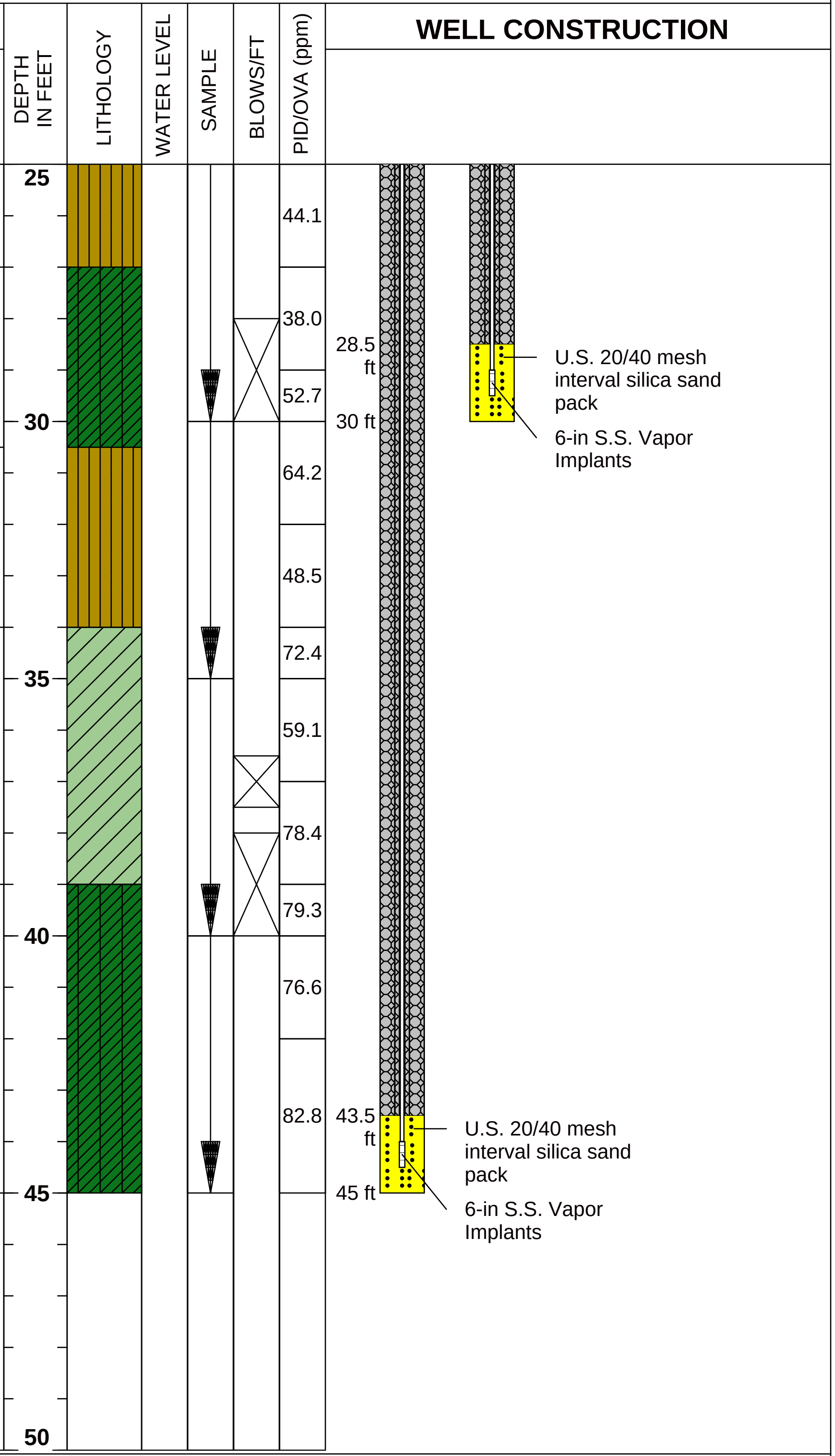
- very stiff below 32 ft, black iron-oxide staining

Brown silty CLAY (CL), very stiff, no hydrocarbon odor, low plasticity, black iron staining, moderate moisture content

- very moist below 37 ft

Brown silty CLAY-clayey SILT (CL-ML), moderate to high moisture content, no hydrocarbon odor, stiff, low plasticity

Total Depth = 45 ft



ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-1S, MW-1M, MW-1D

ESTCP H2T Vadose Demonstration
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Figure A.4

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 0.75 ft, lots of rocks, grass, dry

Dark brown clayey sandy SILT (ML), some very fine sand, low plasticity, no hydrocarbon odor, low moisture content, stiff

- color change to olive gray below 4 ft

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, black iron-oxide staining, low moisture content, thin layers of very fine sand throughout

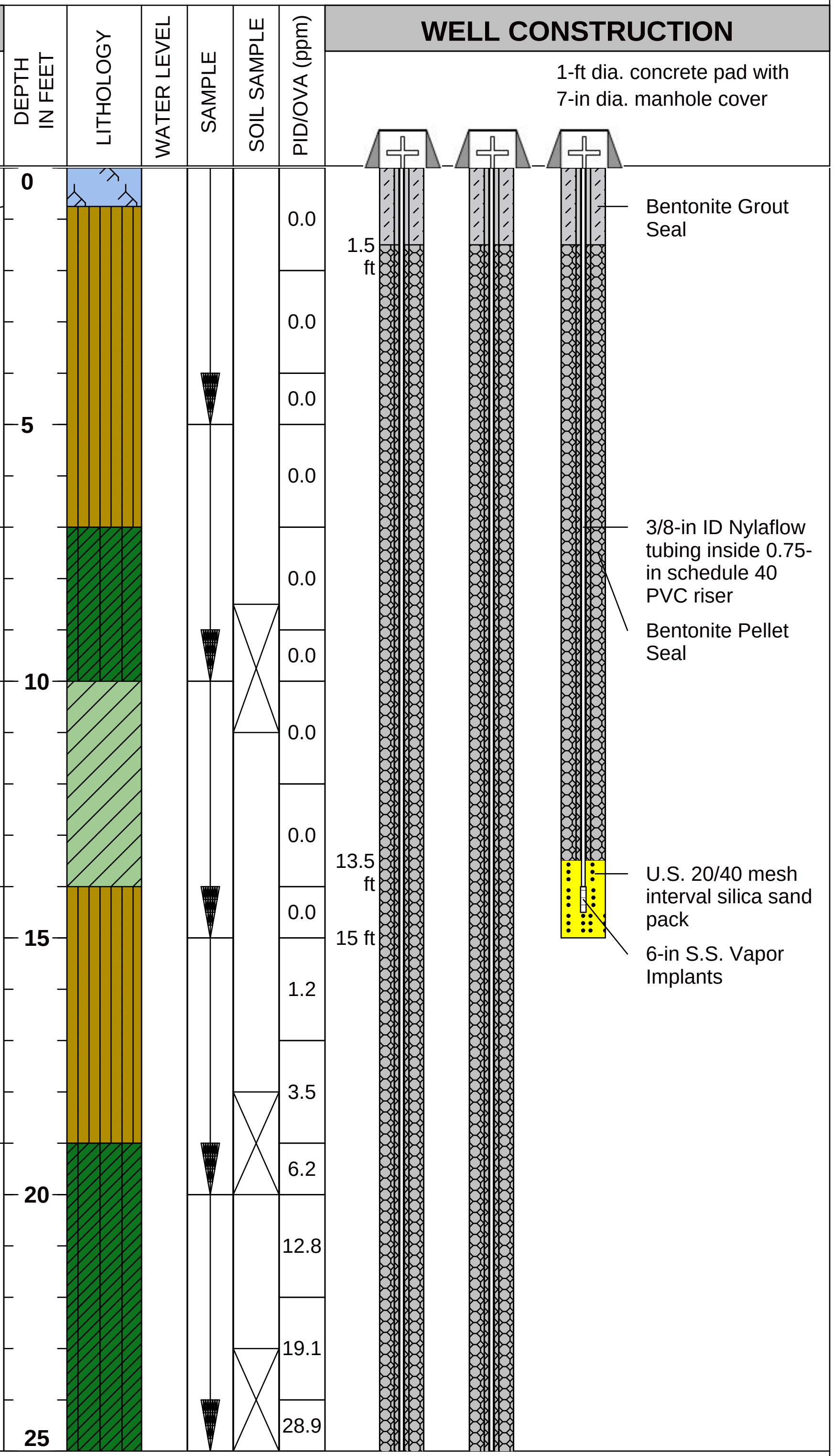
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor, layers of fine to medium size sand throughout

- color change to olive gray below 15 ft, moderate stiffness

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, moderate stiffness, low plasticity

- very stiff below 22 ft

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-2S, MW-2M, MW-2D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.5

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Brown clayey SILT (ML), low moisture content, stiff, low plasticity, no hydrocarbon odor

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Brown clayey SILT (ML), moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

- very stiff below 32 ft, black iron-oxide staining

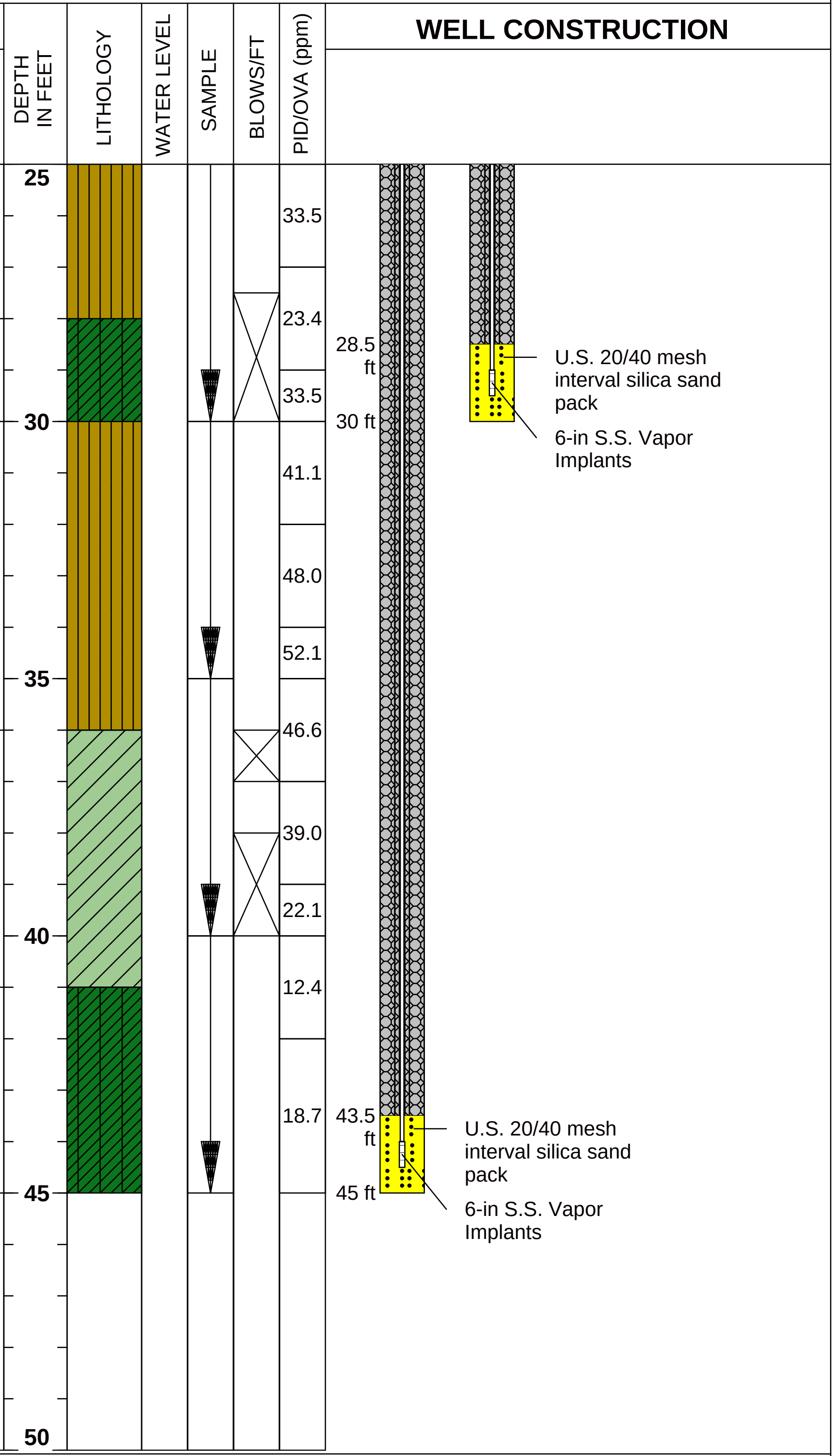
Brown silty CLAY (CL), very stiff, no hydrocarbon odor, low plasticity, black iron-oxide staining, moderate moisture content

- very moist below 38 ft

Brown silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Total Depth = 45 ft

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-2S, MW-2M, MW-2D

ESTCP H2T Vadose Demonstration
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Figure A.5

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 1 ft, some rocks, dry

Brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- very stiff below 4 ft

- color change to dark brown below 7 ft

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

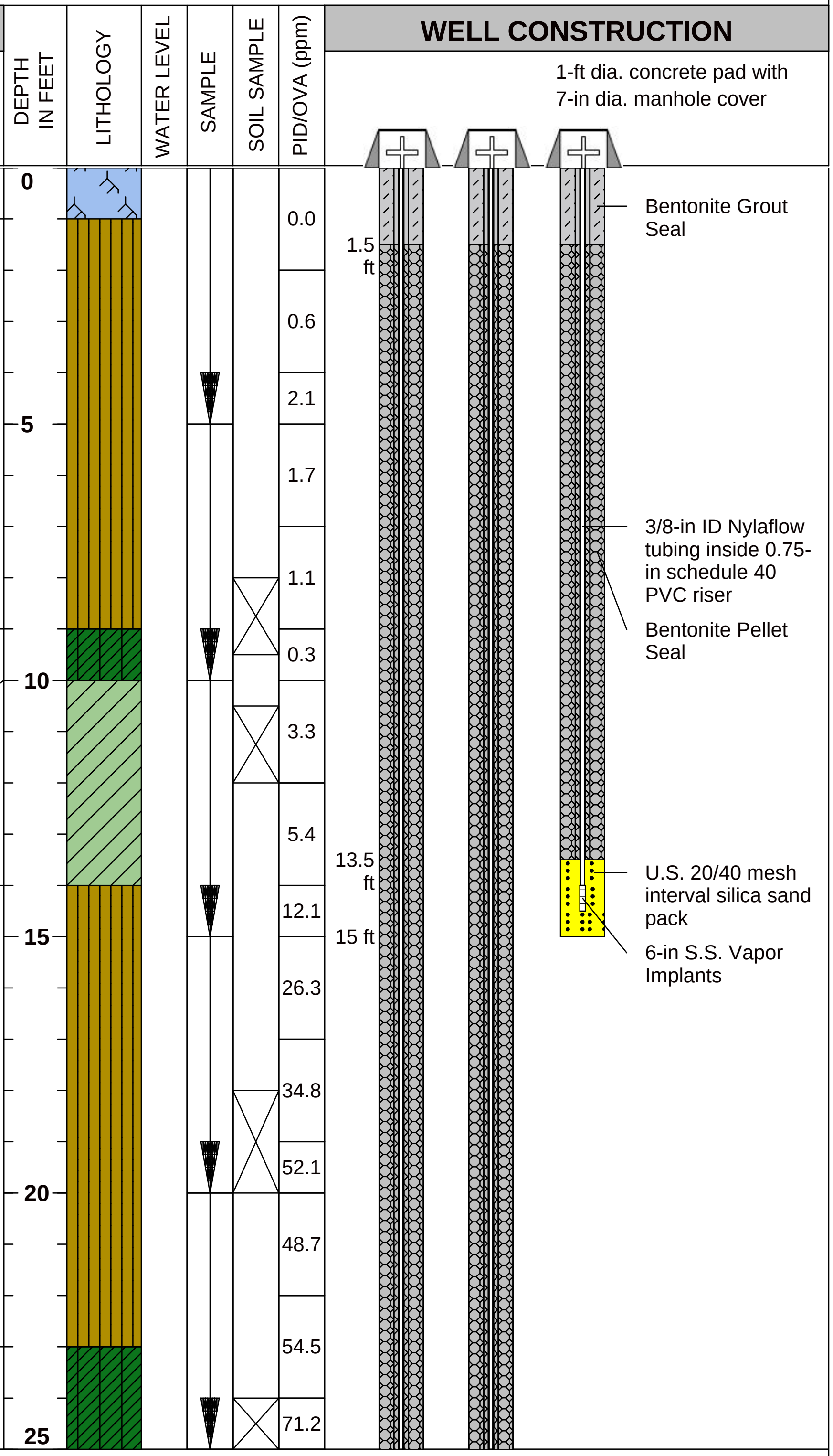
Dark gray silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, low moisture content, thin layers of very fine sand throughout

Brown clayey SILT (ML), black iron-oxide staining, low moisture content, stiff, low plasticity, no hydrocarbon odor

- color change to olive gray below 16 ft, moderate stiffness, rock fragments

- increased stiffness below 19 ft

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-3S, MW-3M, MW-3D

ESTCP H2T Vadose Demonstration
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Figure A.6

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

Light brown clayey SILT (ML), some rock fragments, moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

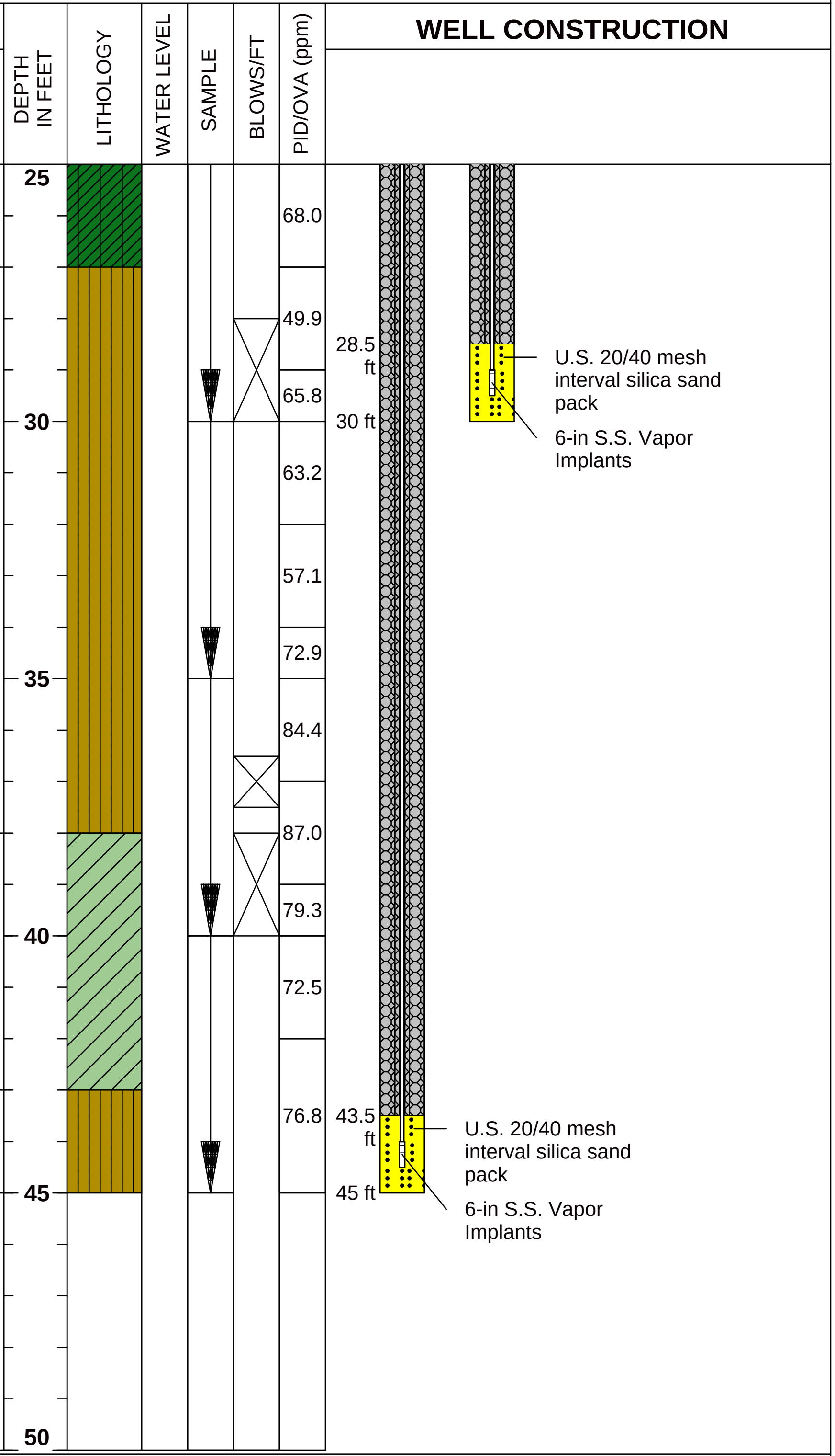
- moist to wet below 30 ft

- less stiff below 34 ft, increased moisture content, black iron-oxide staining

Brown silty CLAY (CL), stiff, no hydrocarbon odor, moderate plasticity, black iron-oxide staining, moderate moisture content

Brown clayey SILT (ML), moderate to high moisture content, stiff, low plasticity, no hydrocarbon odor

Total Depth = 45 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-3S, MW-3M, MW-3D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Issued: 8 June 2011
Figure A.6

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 1 ft, some rocks, dry

Brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to dark gray below 4 ft

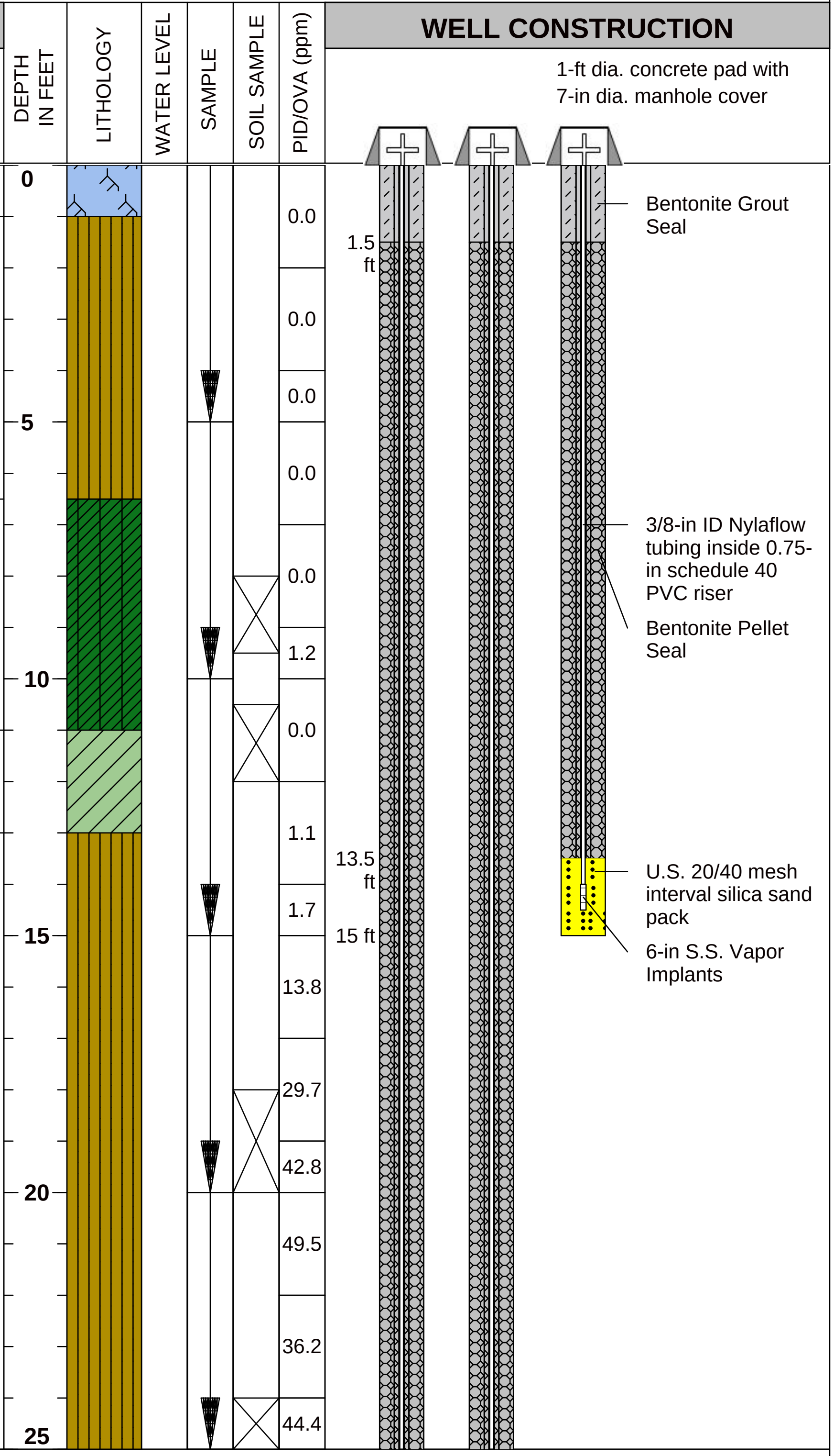
Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, low moisture content

Brown clayey SILT (ML), black iron-oxide staining, low moisture content, stiff, low plasticity, no hydrocarbon odor

- color change to olive gray below 17 ft, moderate stiffness, rock fragments

- increased moisture content below 21 ft



LOG & RECORD OF WELL CONSTRUCTION
MW-4S, MW-4M, MW-4D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Issued: 8 June 2011

Figure A.7

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

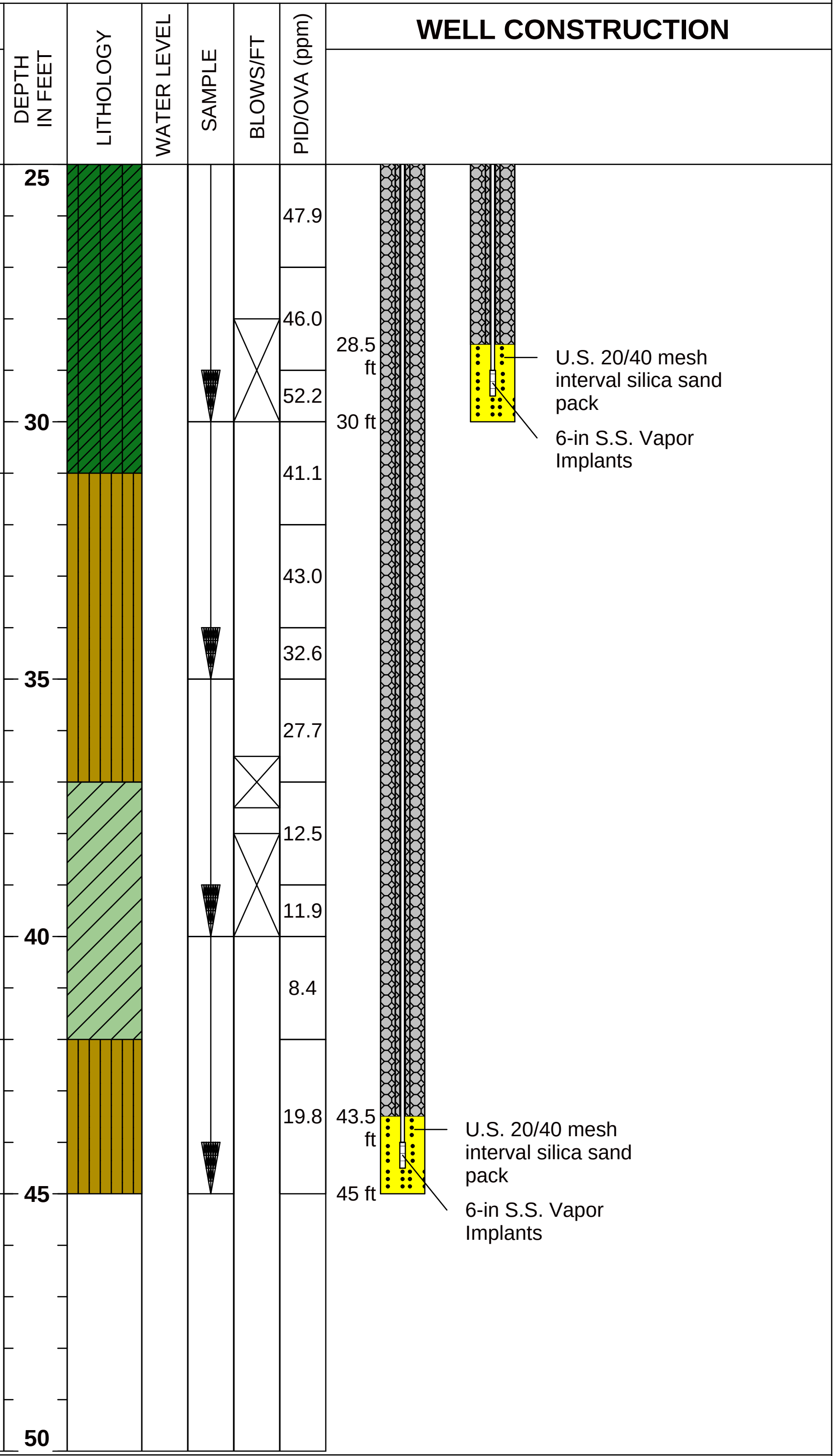
Light brown clayey SILT (ML), some rock fragments, moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

- increased moisture content below 33.5 ft

Brown silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, moderate moisture content

Brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

Total Depth = 45 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-4S, MW-4M, MW-4D

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Figure A.7

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Top soil from 0 to 0.75 ft, low moisture content

Light brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 2 ft

- very stiff below 6 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), very stiff, no hydrocarbon odor, slight plasticity, low moisture content, some very fine sand

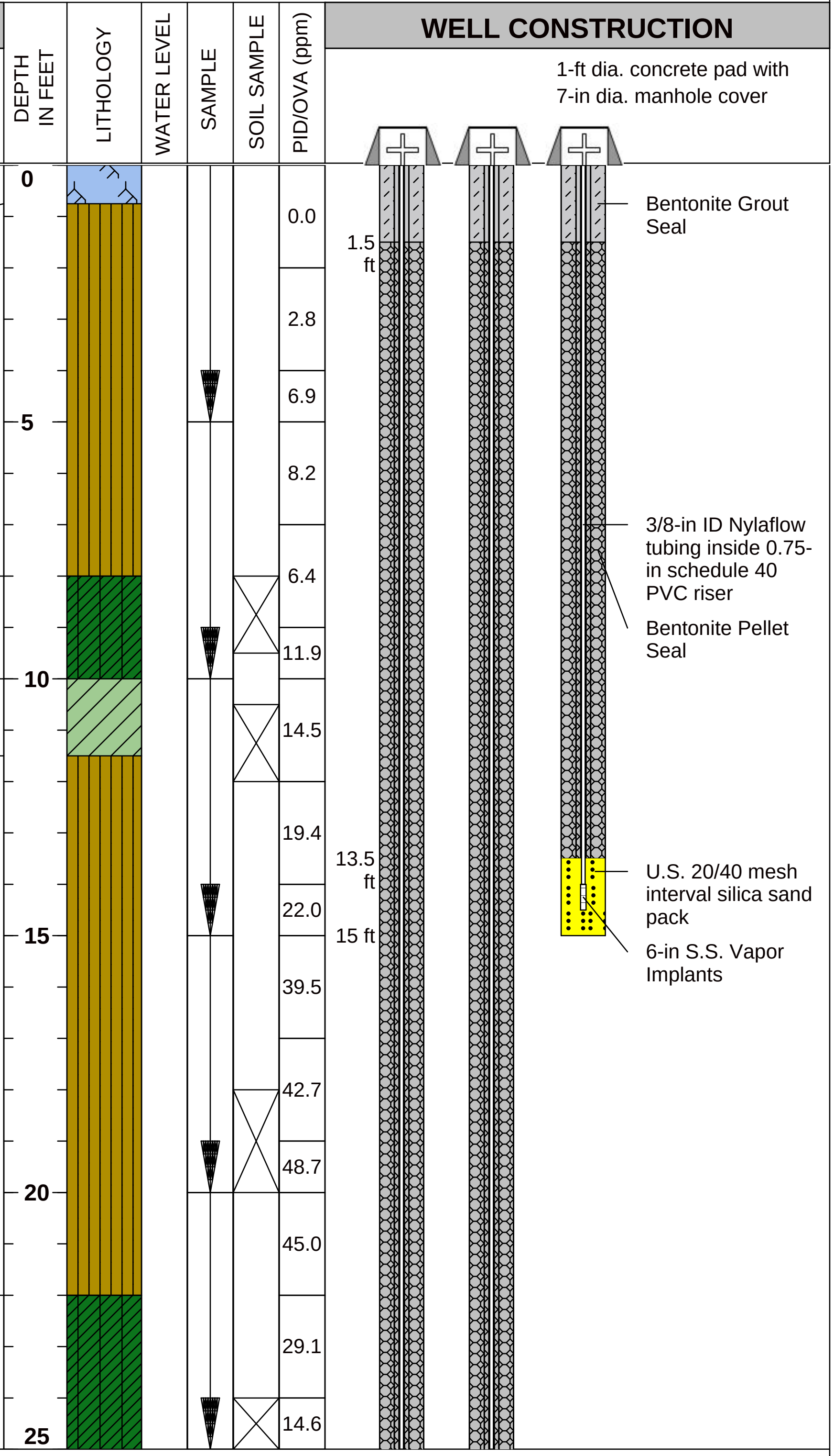
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor, layers of fine to moderate size sand throughout

- color change to olive gray below 15 ft, moderate stiffness, rock fragments

- increased stiffness below 19 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-5S, MW-5M, MW-5D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.8

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Light brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

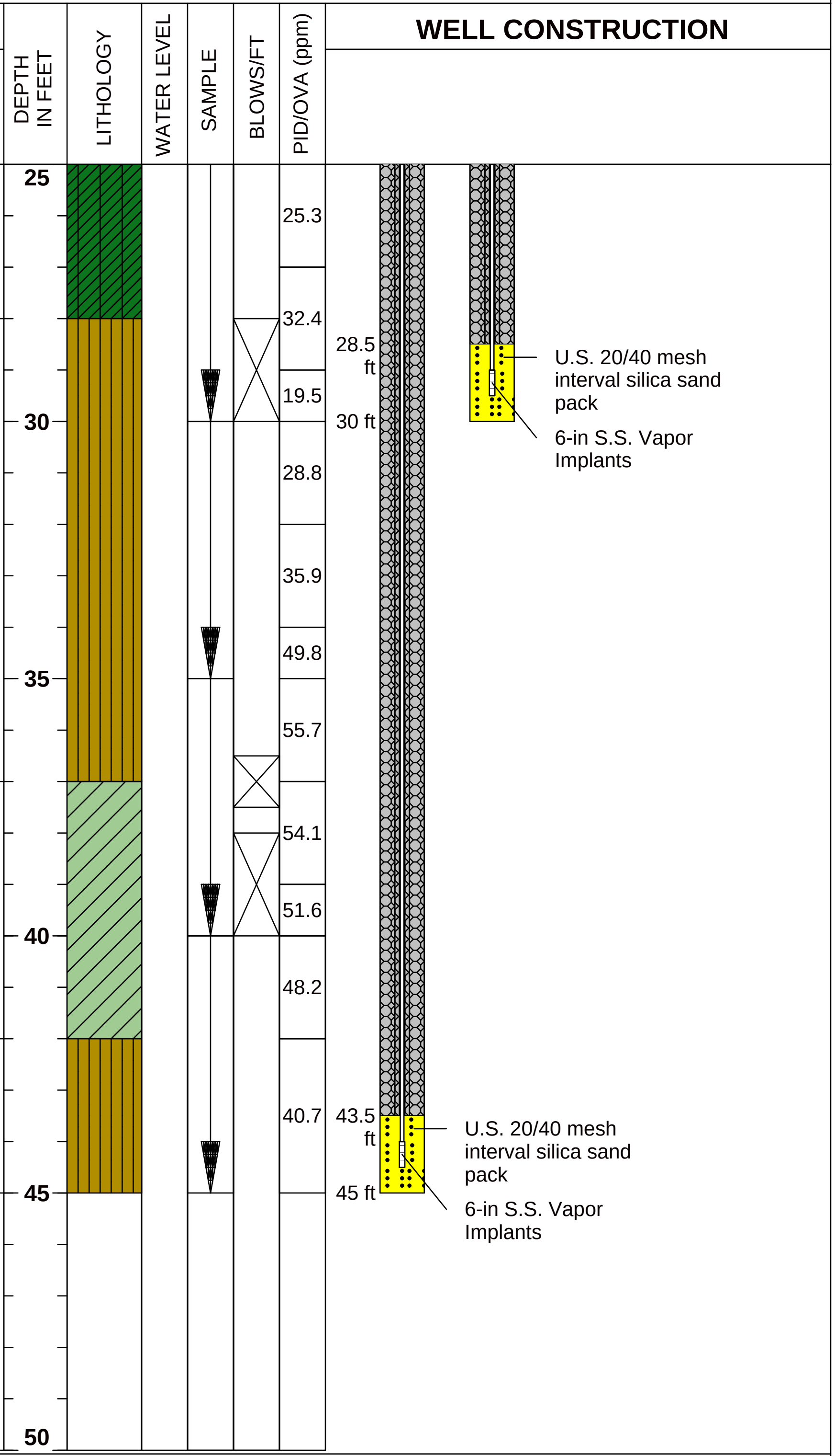
- very stiff below 31 ft

- less stiff below 34 ft, increased moisture content

Brown silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, moderate moisture content

Brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

Total Depth = 45 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-5S, MW-5M, MW-5D

ESTCP H2T Vadose Demonstration
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Figure A.8

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Top soil from 0 to 0.75 ft, low moisture content

Light brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 2 ft

- very stiff below 6 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), very stiff, no hydrocarbon odor, slight plasticity, low moisture content, some very fine sand

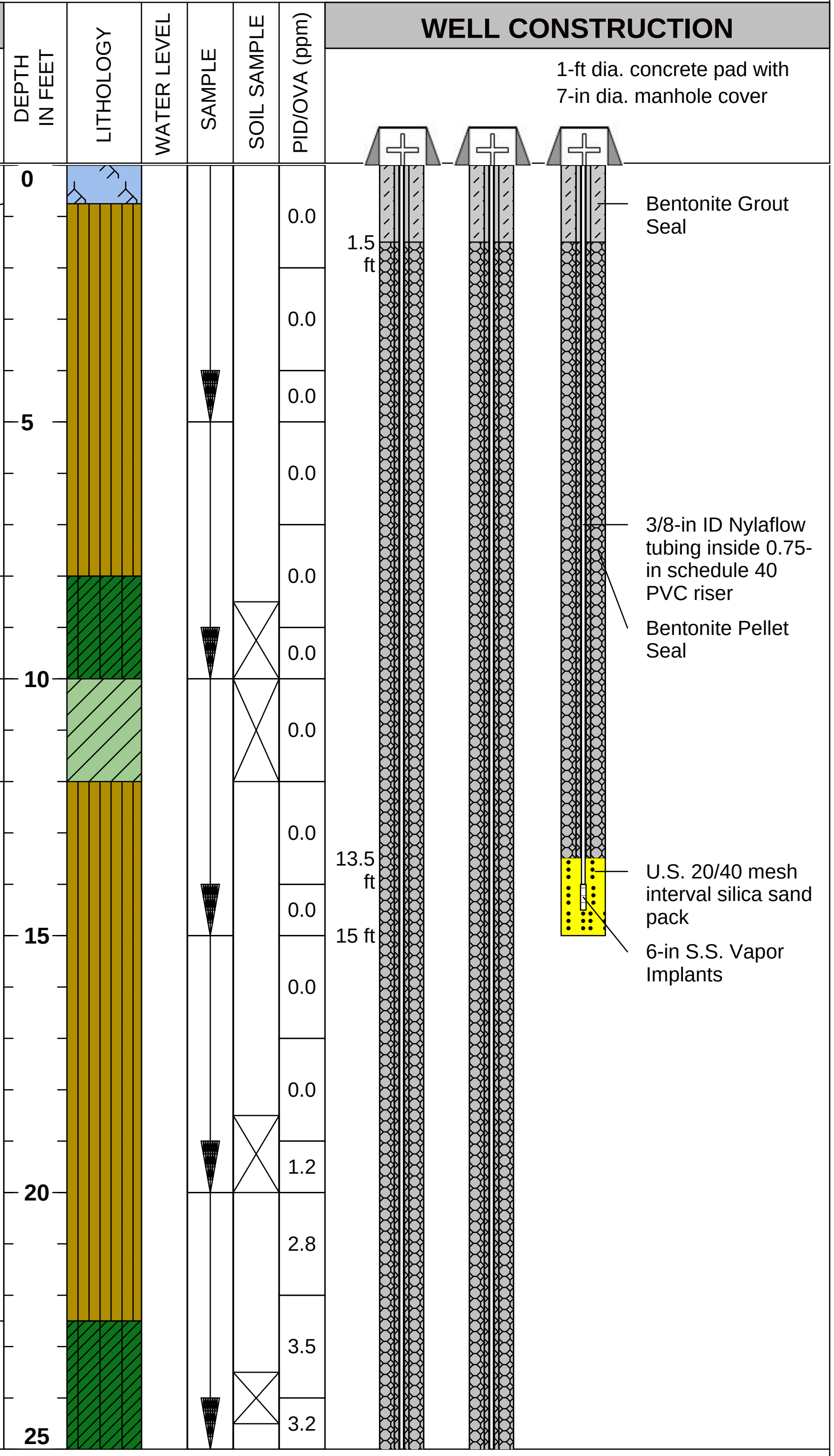
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor, layers of fine to moderate size sand throughout

- color change to olive gray below 16 ft, stiff

- increased stiffness below 20 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION MW-6S, MW-6M, MW-6D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

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Figure A.9

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Brown clayey SILT (ML), low to moderate moisture content, stiff, low plasticity, no hydrocarbon odor

- less stiff below 33 ft, increased moisture content

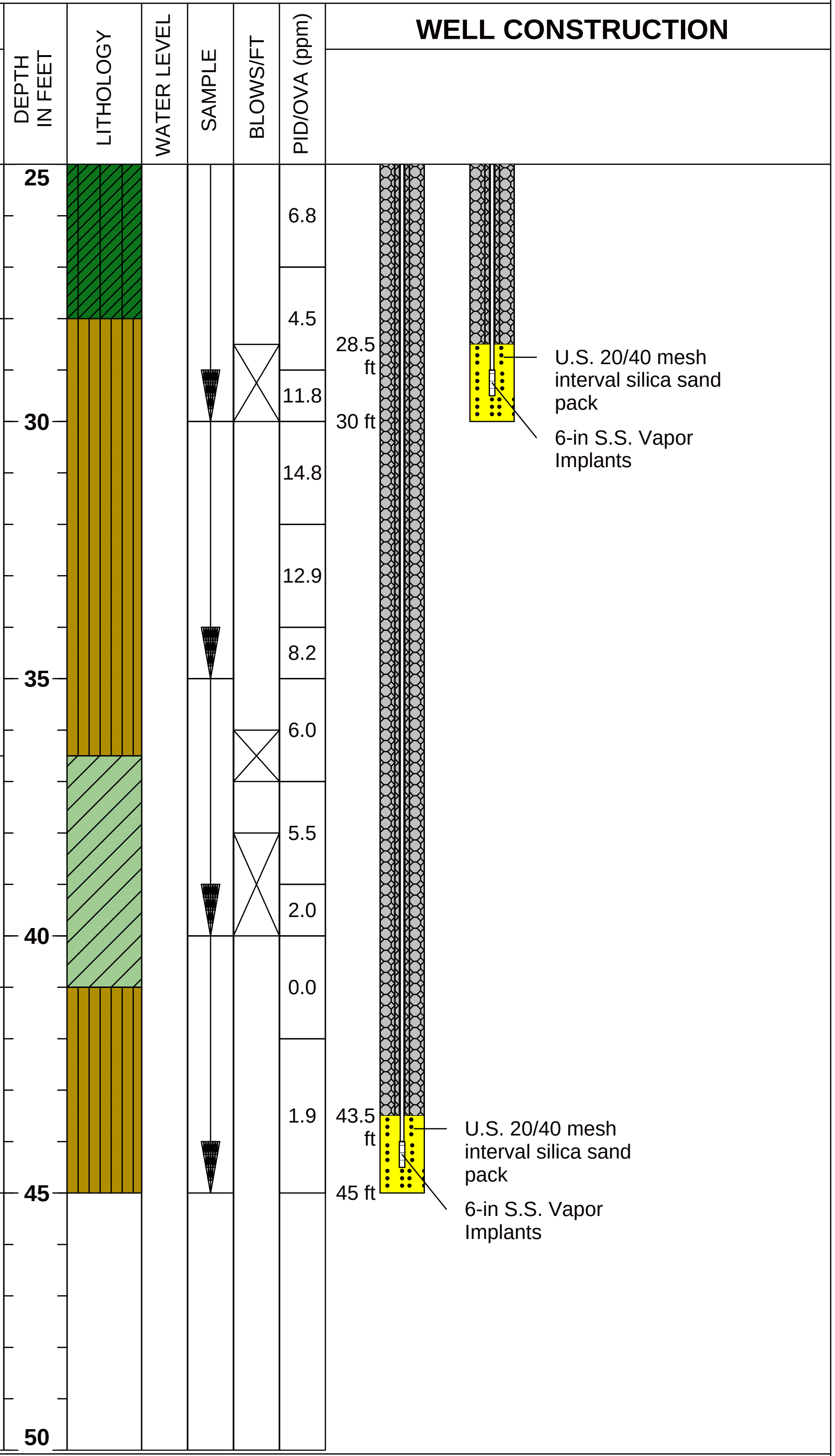
Brown silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, low moisture content

- increased moisture content below 39 ft

Brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

- layers of fine to medium size sand below 43.5 ft

Total Depth = 45 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-6S, MW-6M, MW-6D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537
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Issued: 8 June 2011

Figure A.9

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Top soil from 0 to 1 ft, low moisture content

Light brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 3 ft

- very stiff below 5.5 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), very stiff, no hydrocarbon odor, slight plasticity, low moisture content, some very fine sand

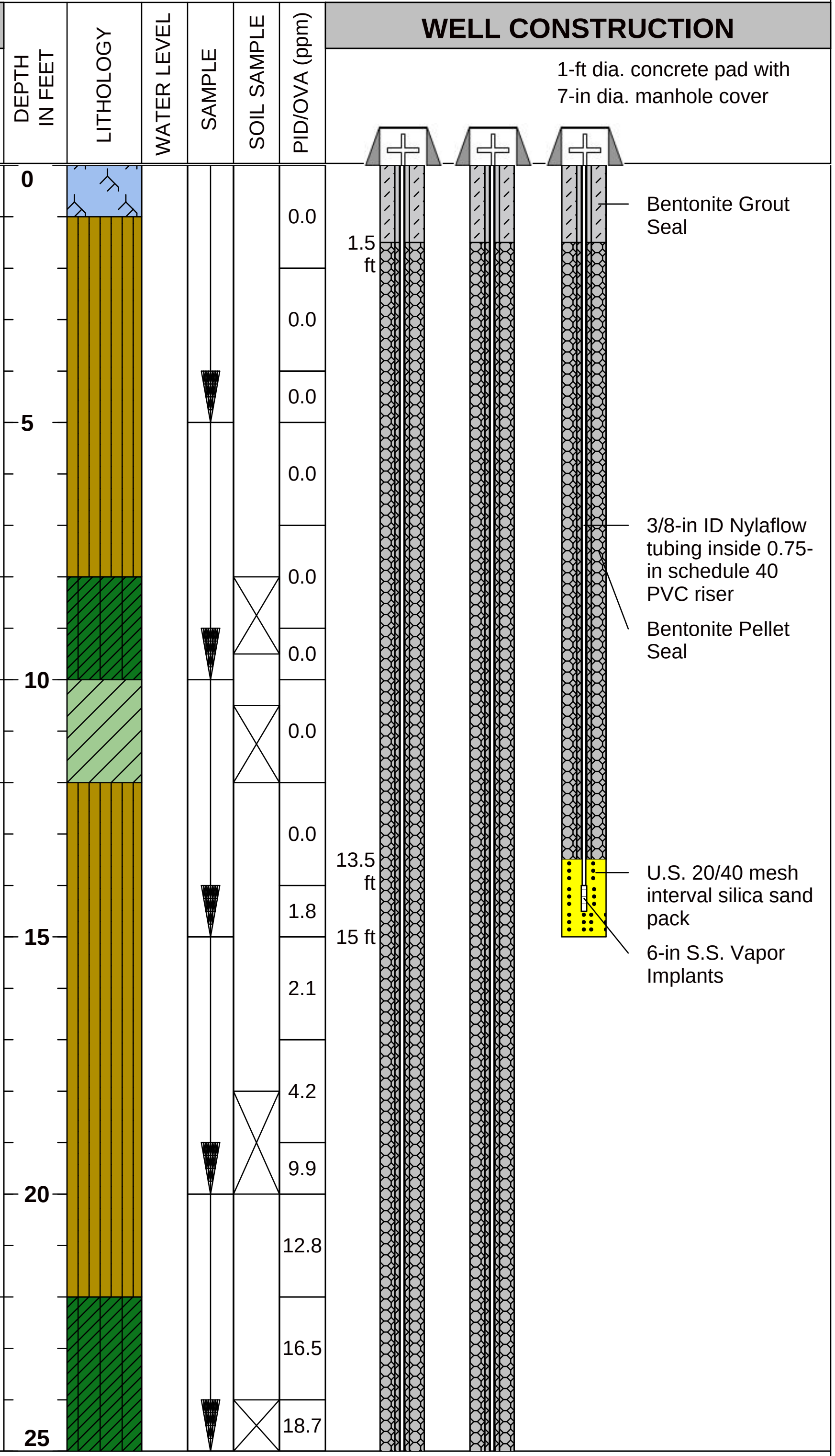
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor, layers of fine to moderate size sand throughout

- color change to olive gray below 16 ft, stiff

- increased stiffness below 20 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION MW-7S, MW-7M, MW-7D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537
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Issued: 8 June 2011

Figure A.10

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Brown clayey SILT (ML), low to moderate moisture content, stiff, low plasticity, no hydrocarbon odor

- less stiff below 33 ft, increased moisture content

Brown silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, low moisture content

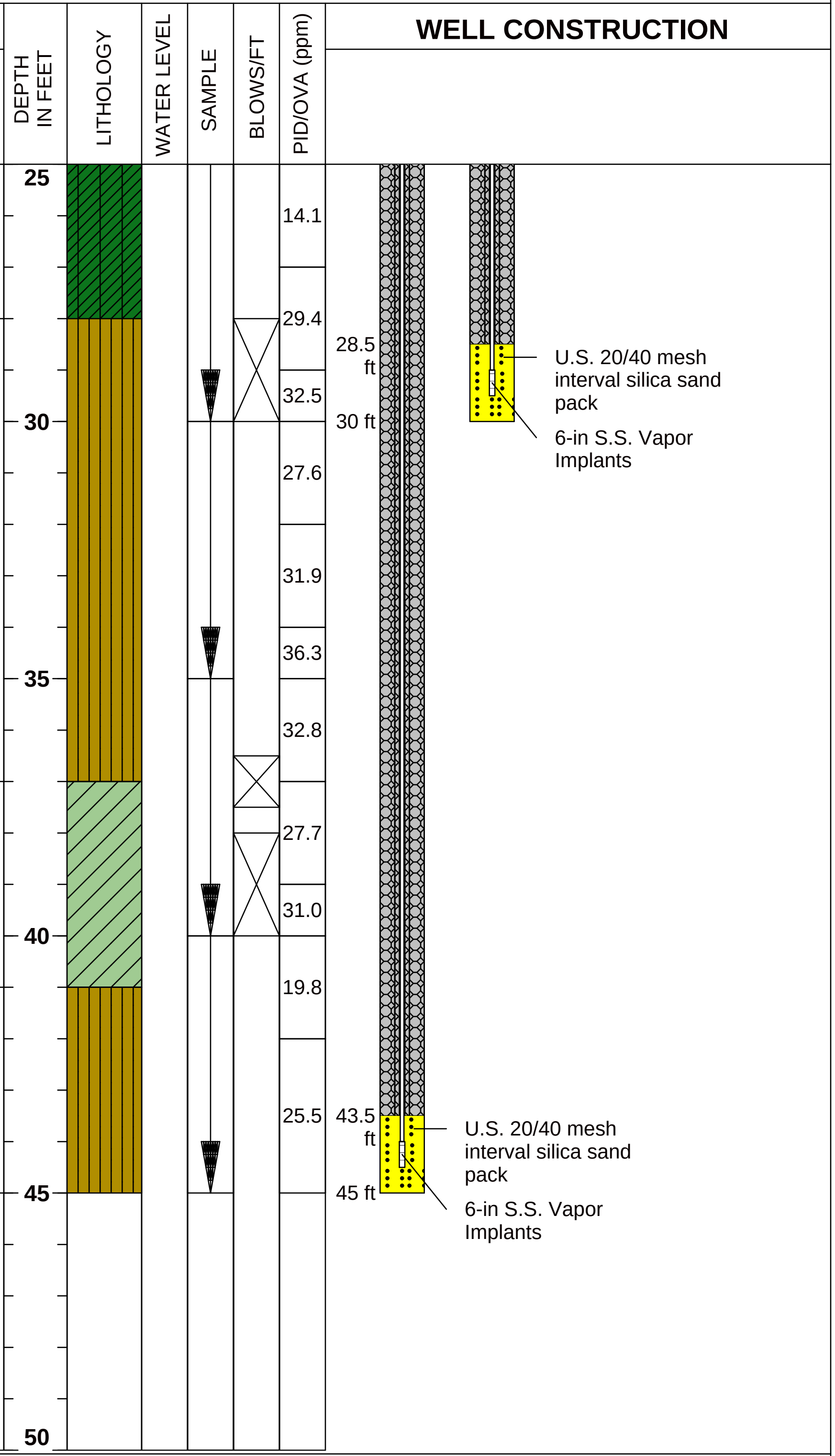
- increased moisture content below 38.5 ft

Brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

- some very fine to fine sand below 43 ft

Total Depth = 45 ft

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-7S, MW-7M, MW-7D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537
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Issued: 8 June 2011
Figure A.10

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Top soil from 0 to 0.75 ft, low moisture content

Brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to olive gray below 3 ft

- very stiff below 5.5 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

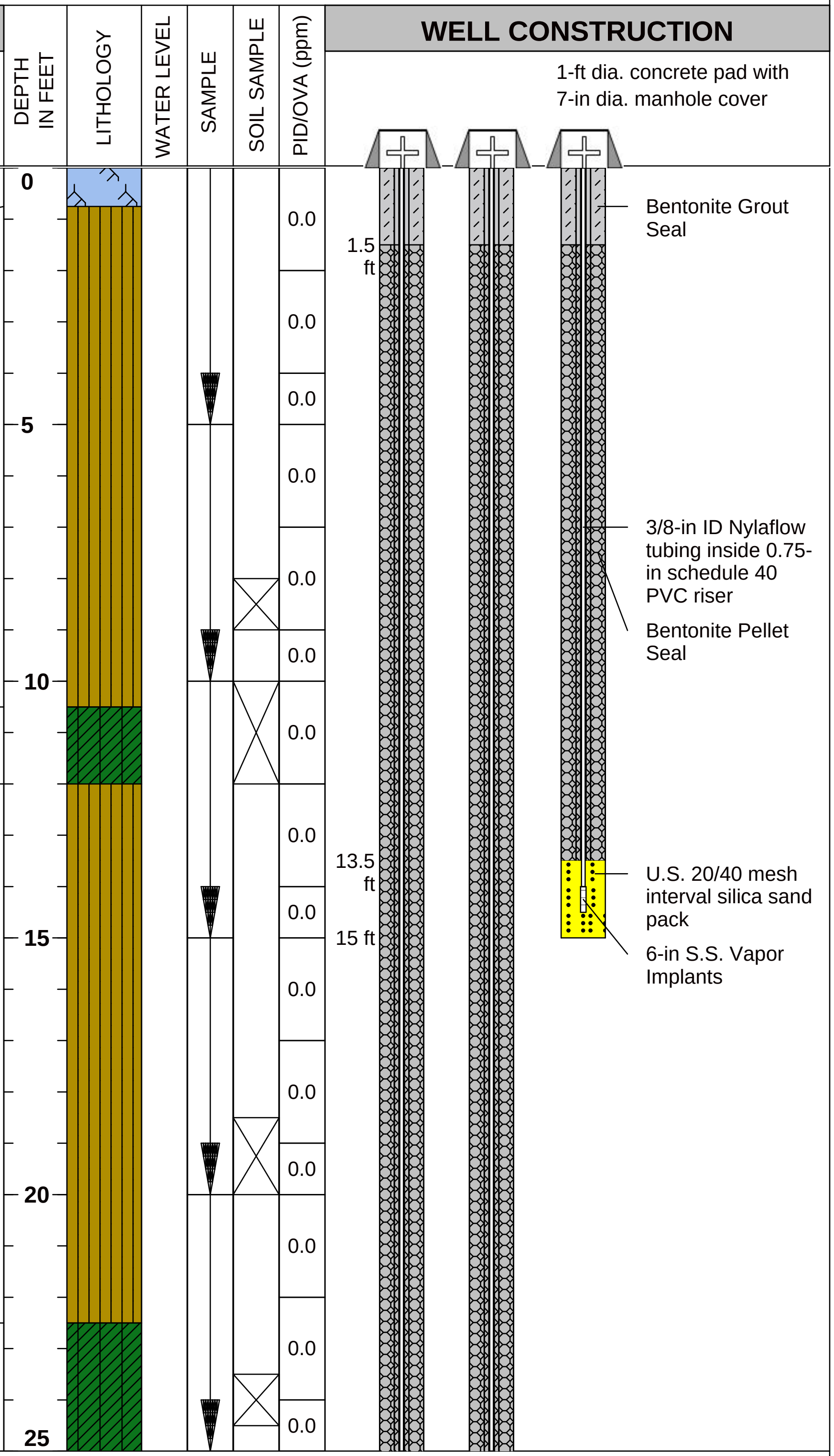
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, very stiff, low plasticity, no hydrocarbon odor, layers of fine to moderate size sand throughout

- color change to olive gray below 15 ft

- increased stiffness below 20 ft

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

WELL CONSTRUCTION



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-8S, MW-8M, MW-8D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537
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Issued: 8 June 2011

Figure A.11

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), moderate moisture content, no hydrocarbon odor, stiff, low plasticity

Brown clayey SILT (ML), low to moderate moisture content, stiff, low plasticity, no hydrocarbon odor

- less stiff below 33 ft, increased moisture content

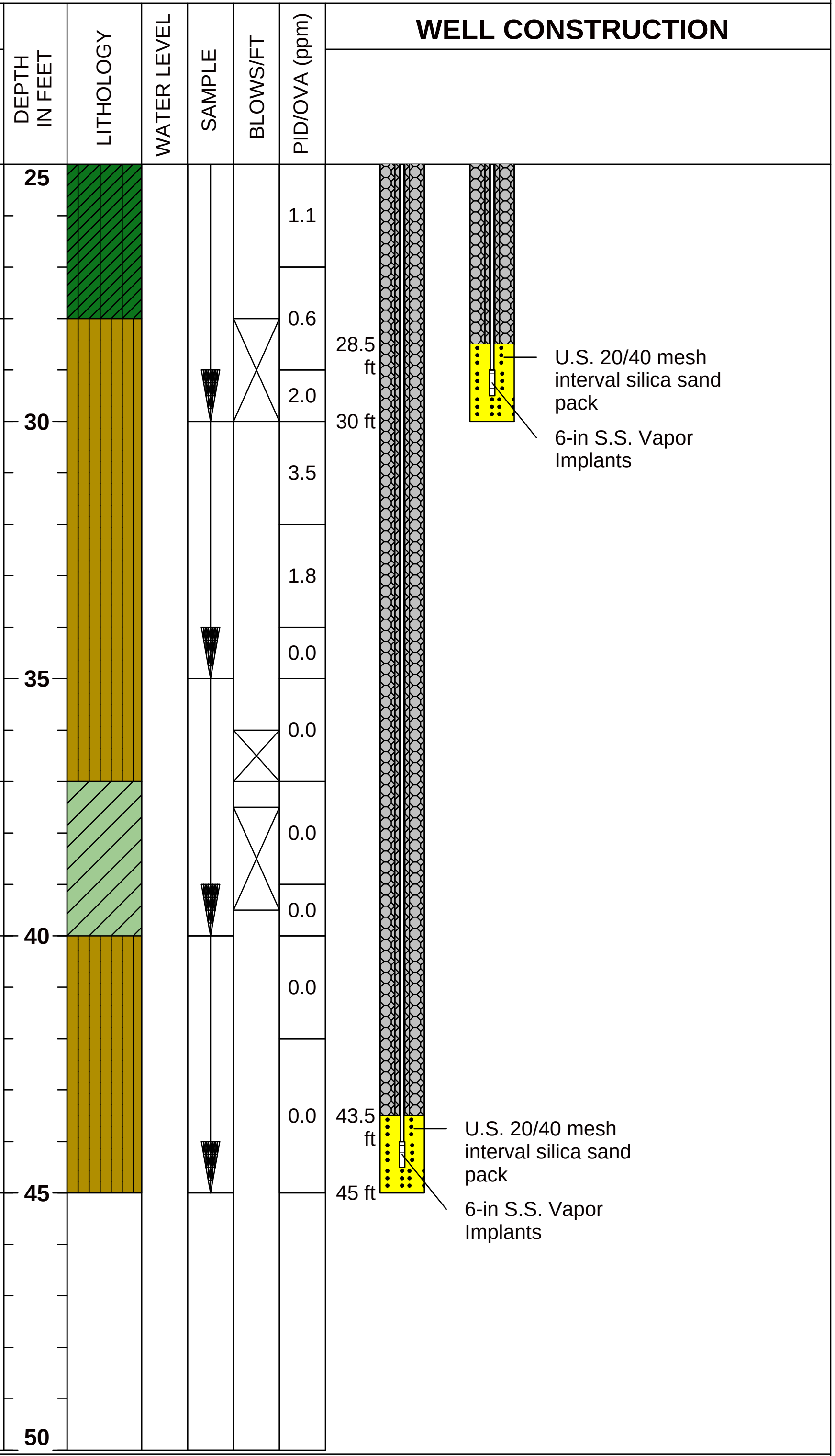
Brown silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, low moisture content

Brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

- very stiff below 42 ft

Total Depth = 45 ft

WELL CONSTRUCTION



LOG & RECORD OF WELL CONSTRUCTION
MW-8S, MW-8M, MW-8D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537
Page 2 of 2
Issued: 8 June 2011

Figure A.11

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

GROUND SURFACE

Topsoil from 0 to 1 ft, some rocks, dry

Brown clayey sandy SILT (ML), low plasticity, no hydrocarbon odor, dry, stiff

- color change to dark gray below 4 ft

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

Dark gray silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, low moisture content

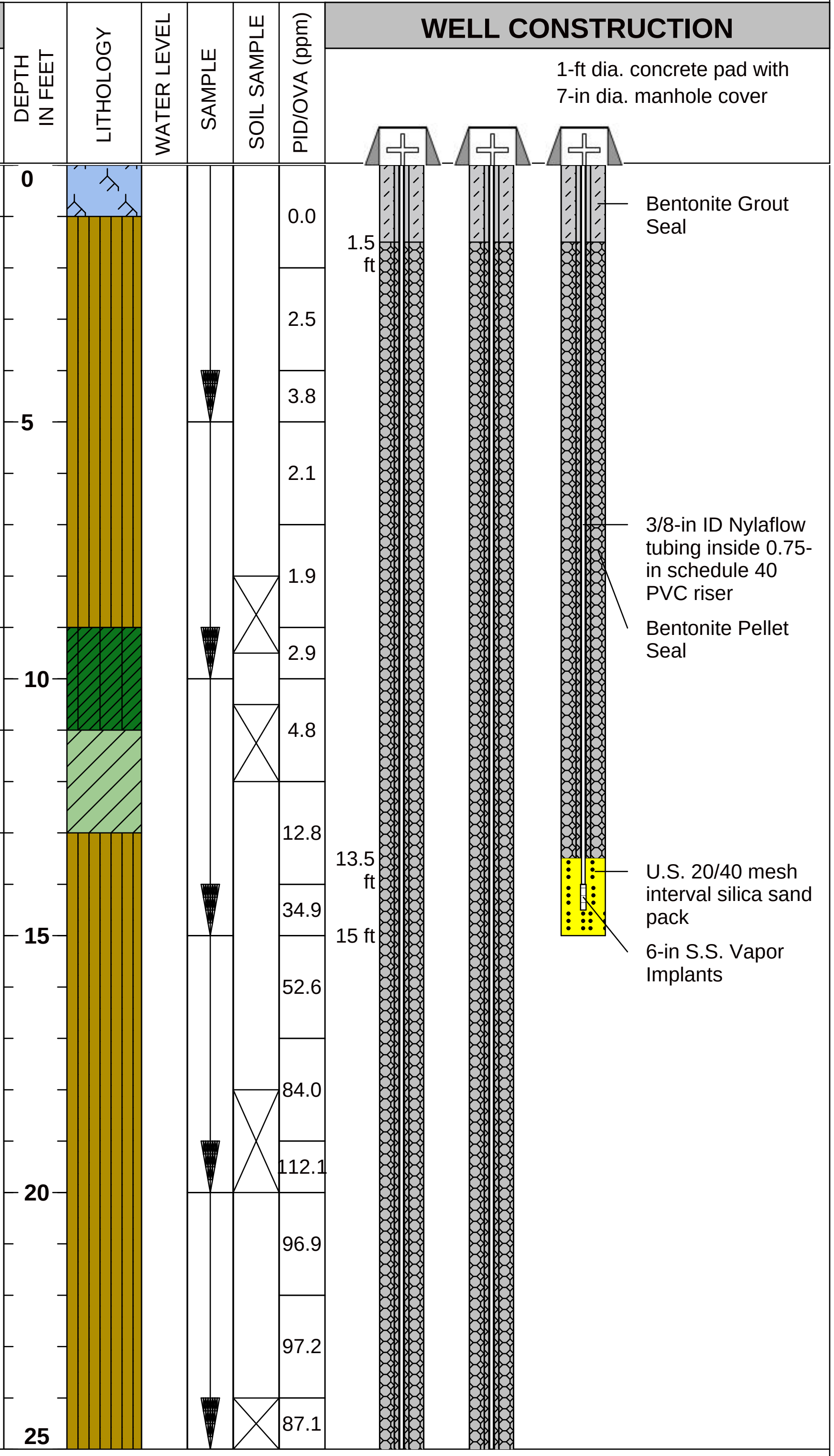
Brown clayey SILT (ML), black iron-oxide staining, low moisture content, stiff, low plasticity, no hydrocarbon odor

- color change to olive gray below 17 ft, moderate stiffness, rock fragments

- increased moisture content below 21 ft

PID/OVA (ppm)
0.0
2.5
3.8
2.1
1.9
2.9
4.8
12.8
34.9
52.6
84.0
112.1
96.9
97.2
87.1

WELL CONSTRUCTION



LOG & RECORD OF WELL CONSTRUCTION
MW-9S, MW-9M, MW-9D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI ENVIRONMENTAL

GSI Job No. G-3537
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Issued: 8 June 2011

Figure A.12

GEOLOGIST: Ahmad Seyedabbasi
DRILLER: John Wilkinson, Saberprobe
DRILLING METHOD: Direct Push
HOLE DIAMETER: 2.25 inches

COMPLETION DATE: 10 May 2011
GROUND SURFACE ELEV.: Not Measured
TOP OF CASING ELEV.: Not Measured
STATE PLANE COORDINATES: Not Measured

SOIL DESCRIPTION

Olive gray silty CLAY-clayey SILT (CL-ML), low moisture content, no hydrocarbon odor, stiff, low plasticity

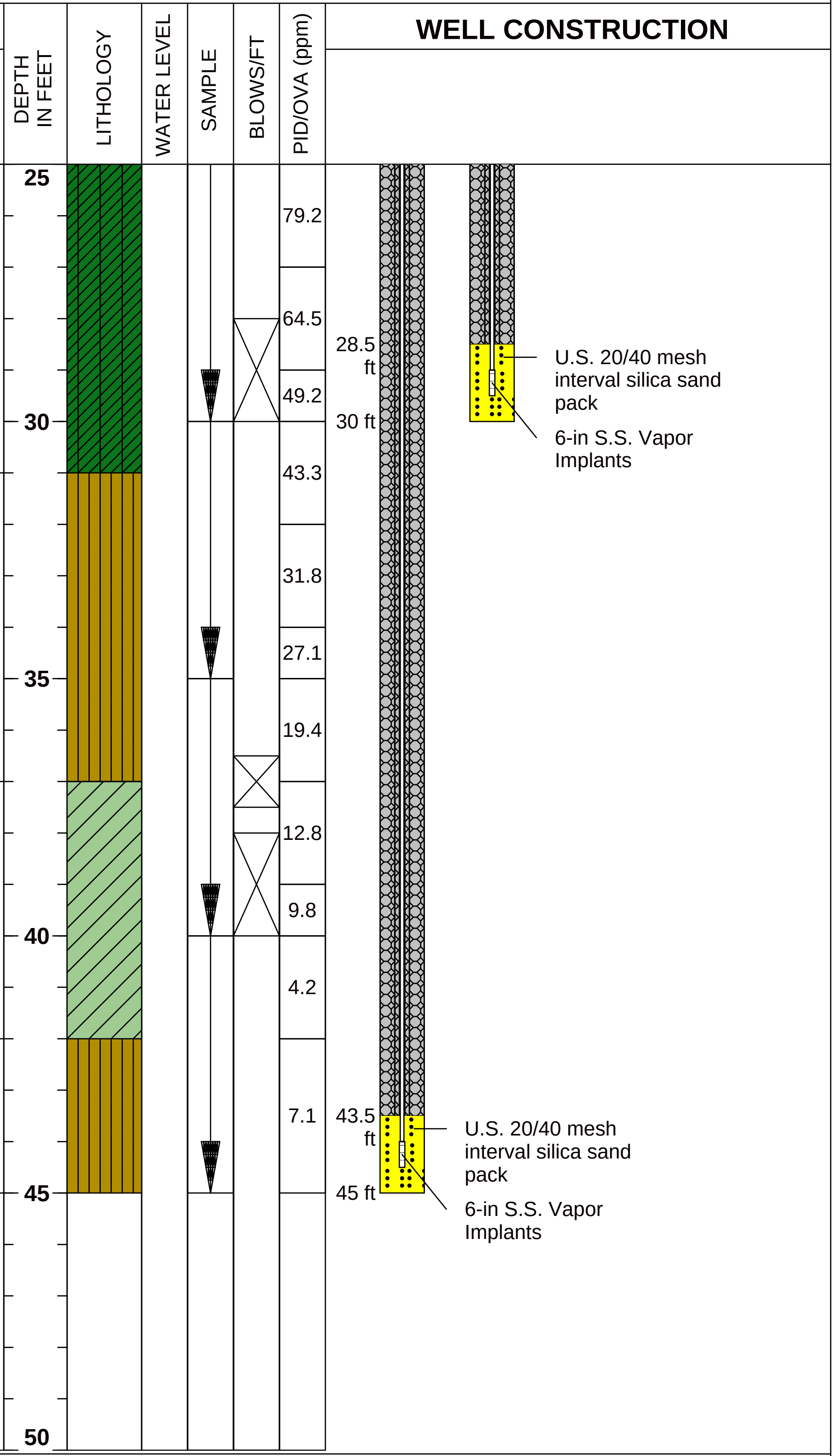
Light brown clayey SILT (ML), some rock fragments, moderate moisture content, moderate stiffness, low plasticity, no hydrocarbon odor

- increased moisture content below 33.5 ft

Brown silty CLAY (CL), stiff, no hydrocarbon odor, low plasticity, moderate moisture content

Brown clayey SILT (ML), moderate moisture content, stiff, low plasticity, no hydrocarbon odor

Total Depth = 45 ft



GSI ENVIRONMENTAL

LOG & RECORD OF WELL CONSTRUCTION
MW-9S, MW-9M, MW-9D

ESTCP H2T Vadose Demonstration
Atlas Missile Site 10, York, Nebraska

GSI Job No. G-3537
Page 2 of 2
Issued: 8 June 2011

Figure A.12

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones
Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix E: Bench-Scale Treatability Study Report

DRAFT Treatability Report

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery:

Project Number: ER-201027

June 27, 2012

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List of Acronyms

Atm	Atmospheres (pressure)
C	Celsius
CH_4	Methane
cis-1,2-DCE	Cis-1,2-dichloroethene
CO_2	Carbon Dioxide
DHC	*Dehalococcoides*
ESTCP	Environmental Security Technology Certification Program
FID	Flame Ionization Detector
g	Gram
GC	Gas Chromatography
GEDIT	Gaseous electron donor injection technology
H_2	Hydrogen
H2T	Hydrogen injection technology
kg	Kilogram
L	Liter
LPG	Liquefied Petroleum Gas
µmol	Micromole
mg	Milligram
mL	Milliliter
N_2	Nitrogen
ppmv	Parts per million by volume
SVE	Soil Vapor Extraction
TCD	Thermal Conductivity Detector
TCE	Trichloroethene
TEP	Triethyl Phosphate
VC	Vinyl Chloride
VOCs	Volatile Organic Compounds

1.0 INTRODUCTION

In support of ESTCP Project ER-201027, *Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery*, a bench-scale treatability study of reductive dechlorination in unsaturated soil using several gaseous electron donor mixtures was conducted in accordance with the January 12, 2011 memorandum from the project team to ESTCP. This report presents the objectives, materials and methods, results, conclusions, and recommendations for the treatability study.

1.1 Background

The York Atlas 10 Site in Nebraska (Site) has a chlorinated solvent source in the vadose zone, dominated by trichloroethene (TCE) and some cis-1,2-dichloroethene (cis-1,2-DCE). Soil-vapor extraction (SVE) has been used at the site. While SVE has substantially reduced TCE concentrations, residual contamination exists. A field demonstration of hydrogen injection technology (H2T) was conducted to reductively dechlorinate TCE *in situ*.

Biological reductive dechlorination of TCE requires the presence electron donors, anaerobic conditions, and the presence of *Dehaloccoccoides ethenogenes* (DHC). This process has been demonstrated in groundwater in both laboratory and field conditions. It is now a common and accepted process for site cleanup. On the other hand, little, if any, demonstration of this technology in unsaturated vadose zone soils has been conducted. *In situ* bioremediation of perchlorate and nitrate in vadose zone soil has been demonstrated previously using an analogous process called gaseous electron donor injection technology or GEDIT (Evans 2007; Evans and Trute 2006; Nzengung et al. 2009; Evans et al. 2011; Cai et al. 2010)

The microbes responsible for reductive dechlorination of TCE, cis-1,2-DCE, and VC require electron donors for their metabolism. In groundwater systems, commonly-used donors include compounds such as vegetable oil, molasses, whey, glycerin, ethanol, or lactic acid/lactate salt. In the vadose zone, these compounds are not readily distributed. Hydrogen is another electron donor that is capable of promoting complete reductive dechlorination of TCE to ethene by DHC and can be delivered in the vadose zone. However, use of hydrogen to promote complete reductive dechlorination of TCE in vadose zone soil has not been demonstrated. The treatability study described in this report was conducted parallel to the field demonstration to determine whether reductive dechlorination could occur using site soil.

Other questions were also addressed in the treatability study. Hydrogen was mixed with nitrogen and propane in the GEDIT demonstration for three reasons. First, nitrogen is a relatively inexpensive carrier gas that allows greater flow rates to transport the hydrogen. Second, mixing the hydrogen with propane reduces the buoyancy so that the mixture can be transported horizontally rather than rising. Third, propane is metabolized by aerobic bacteria which consume oxygen and which is inhibitory to reductive dechlorination. Liquefied petroleum gas (LPG) is an attractive alternative to propane because of its ready availability and low cost relative to pure propane. LPG typically contains mostly propane and butane but it also contains other compounds such mercaptans which serve as odorants. LPG was not found to be inhibitory to perchlorate reduction (Evans et al. 2011), but may be inhibitory to reductive dechlorination. The treatability study described here addressed whether this inhibition would occur.

Finally, soil moisture is an important factor promoting microbial metabolism. Biodegradation of perchlorate in vadose zone soil was determined to be inhibited by low soil moisture contents (Cai et al. 2010). Therefore, it was important to determine whether Site soil moisture contents were capable of supporting reductive dechlorination of TCE.

1.2 Objectives

The objectives of this study were to:

- Determine the extent to which reductive dechlorination of TCE occurs under unsaturated conditions in vadose-zone soil from the Site.
- Identify the optimum gaseous electron donor mixture to be used in the demonstration, and investigate performance differences between propane and LPG.
- Evaluate the effects of soil moisture levels, gaseous electron donor mixtures, phosphorus addition, and bioaugmentation on reductive dechlorination of TCE and its daughter products.

2.0 MATERIALS & METHODS

2.1 Study Design

This study used microcosms to examine the effectiveness of various electron donor mixtures, electron donor concentrations, soil moisture contents, bioaugmentation, and nutrient supplementation as shown in **Table 2-1**.

Complete biological reductive dechlorination of TCE is dependent on the presence and activity of DHC. Because these organisms are not ubiquitous in the environment and bioaugmentation has been shown to promote reductive dechlorination. While questions remain as to how a liquid bioaugmentation culture would be introduced into the vadose zone, this study evaluated bioaugmention to determine whether reductive dechlorination would occur under conditions where DHC were known to be present. Tests 1 through 11 were not bioaugmented and Tests 12 through 22 were bioaugmented with Shaw SDC-9^{TM} culture.

To evaluate the effect of soil moisture, this study targeted three moisture levels. These conditions were chosen to represent the range of moisture concentrations that may be encountered in the field. The moisture content of 30 percent was selected as highest moisture content in which a homogenized soil/water mixture did not show visible separation of water (i.e., the field capacity). The two other moistures (15 and 19 percent) were selected based as Site data. Tests 1 through 5 and 12 through 16 contained 30 percent moisture. Tests 6 through 8 and 17 through 19 contained 19 percent moisture. Tests 9 through 11 and 20 through 22 contained 17 percent moisture.

The rate of microbial activity can be limited by the electron donor concentration. However, injection of higher hydrogen concentrations may be costly. Therefore, two different concentrations of hydrogen were evaluated. For each moisture level and each bioaugmentation condition, hydrogen concentrations of 1 and 10 percent were tested. For example, in the un-bioaugmented, 30 percent moisture condition (i.e., Tests 1 through 5), Tests 1 and 2 evaluated 10 percent hydrogen, Tests 3 and 4 evaluated 1 percent hydrogen, and Test 5 was a control with 0 percent hydrogen.

LPG was added at concentrations equal to the hydrogen concentration in Tests representing different electron donor concentrations, moisture contents, and bioaugmentation. To evaluate the potential inhibition of LPG, additional tests using pure propane were tested only at the high moisture content. For example, Tests 1 and 2 contained equal concentrations of LPG and propane, respectively, to allow comparison.

Because LPG includes constituents that could be inhibitory to the reductive dechlorination process, additional microcosms were set up using propane instead of LPG. Only the highest moisture level was used for these conditions, which allowed comparison of LPG and propane under conditions expected to be optimal for reductive dechlorination.

All test conditions containing electron donor were amended with 1 percent carbon dioxide as a carbon source for microbial growth. The electron-donor-free control bottles did not receive carbon dioxide.

After about six weeks of incubation, there were clear differences in TCE degradation between bioaugmented and un-augmented bottles. We hypothesized that phosphorous nutrient limitation may be inhibiting the un-bioaugmented microcosms. Triethylphosphate (TEP), a gaseous phosphorous nutrient, was added to Test Conditions 1 and 2 on Day 49 to test this hypothesis.

Table 2-1: Experimental Conditions

Condition	Soil moisture	Phosphorus addition (Day 49)	Bio-augmentation	Gas Composition			
				H_2	LPG	Propane	CO_2
1	30%	Y	N	10%	10%	0	1%
2	30%	Y	N	10%	0	10%	1%
3	30%	N	N	1%	1%	0	1%
4	30%	N	N	1%	0	1%	1%
5	30%	N	N	0	0	0	0
6	19%	N	N	10%	10%	0	1%
7	19%	N	N	1%	1%	0	1%
8	19%	N	N	0	0	0	0
9	17%	N	N	10%	10%	0	1%
10	17%	N	N	1%	1%	0	1%
11	17%	N	N	0	0	0	0
12	30%	N	Y	10%	10%	0	1%
13	30%	N	Y	10%	0	10%	1%
14	30%	N	Y	1%	1%	0	1%
15	30%	N	Y	1%	0	1%	1%
16	30%	N	Y	0	0	0	0
17	19%	N	Y	10%	10%	0	1%
18	19%	N	Y	1%	1%	0	1%
19	19%	N	Y	0	0	0	0
20	17%	N	Y	10%	10%	0	1%
21	17%	N	Y	1%	1%	0	1%
22	17%	N	Y	0	0	0	0

2.2 Soil Collection and Processing

Soil cores were collected from depths up to 40 feet on 8/24/11 and shipped overnight on ice to the CDM Smith Environmental Treatability Laboratory in Bellevue, Washington. Approximately 5 kilograms (kg) of Site soil were received at the lab on 8/25/11. Because the microorganisms responsible for reductive dechlorination of TCE are highly sensitive to oxygen, exposure to air was minimized during soil collection, shipping, and handling. Once received in the lab, the soil cores were placed in a nitrogen-purged anaerobic chamber (Plas Labs Inc., Lansing, MI) with an oxygen concentration of <1% as measured using a GasAlertMicro 5 gas detector (BW Technologies, Lincolnshire, IL). Prior to microcosm setup, the soil was processed and tested as summarized in **Table 2-2.** All handling of soils used for the microcosms occurred in the anaerobic chamber, while soils used for moisture tests and the field-capacity test were removed from the anaerobic chamber for testing.

Table 2-2: Soil Processing

Date	Event	Description
8/25/11	Soil Receipt	Soil cores were received at the lab. Cores were passed into anaerobic chamber, opened, and each core homogenized.
8/25/11-8/26/11	Soil moisture test	Moisture was tested by mass-loss on drying at 104 °C using soil from core 36 to 37 feet.
8/25/11-8/26/11	Field capacity test	Water-holding capacity of soil was tested using soil from core 36 to 37 feet. Water was added to samples of soil achieve mixtures of approximately 20%, 25%, 30%, 35%, and 40% moisture (wet weight.); mixtures were observed for soil-water separation. Actual moisture content of mixtures was tested by drying at 104 °C.
8/26/11	Homogenization	Soil from all cores was thoroughly blended and clumps were broken apart until the mixture was a granular texture.
8/28/11-8/31/11	Partial Drying	Portions of the homogenized soil were partially dried at room temperature in the anaerobic chamber to generate soil with targeted low moisture contents. Subsamples of the dried soils were tested for moisture by mass-loss on drying at 104 °C.

2.3 Microcosm Setup

Microcosms were set up on 9/1/11 in 240-milliliter (mL) serum bottles (BellCo Glass, Vineland, NJ). The setup was conducted in the nitrogen-purged anaerobic chamber in order to minimize oxygen exposure. Each of the conditions shown in **Table 2-1** was run in duplicate, for a total of 44 microcosms. For microcosms with 30 percent and 19 percent moisture, the soil was dried to 18% moisture and then adjusted to the desired moisture level. Soil dried to 15 percent moisture was used for the 17 percent moisture condition. The soil moisture was adjusted via the addition of deionized water and, in the case of the bioaugmented conditions, 0.2 mL/bottle of a culture of *Dehalococcoides* (SDC-9^{TM}, from The Shaw Group, Lawrenceville, NJ). Each bottle contained 20.5 ± 0.4 g (wet weight) of soil. The 19 percent and 17 percent moisture soils had a malleable consistency, so pieces of soil were shaped to fit through the neck of the serum bottle and added to the bottle until the approximate desired soil mass was reached. The soil was then tamped into a thin layer on the bottom of the bottle, as shown in **Figure 2-1**, and the final soil mass was measured. The soil at 30 percent moisture was too loose to for this method, so it was emplaced into the serum bottles using a pastry bag. These bottles were manually agitated to settle the soil into an even layer in the bottom of the bottle, shown in **Figure 2-2**. Immediately after soil addition and tamping or settling, each bottle was sealed with a thick butyl rubber stopper held in place with an aluminum crimp. Once sealed, the bottles were removed from the anaerobic chamber for the remainder of the experiment.

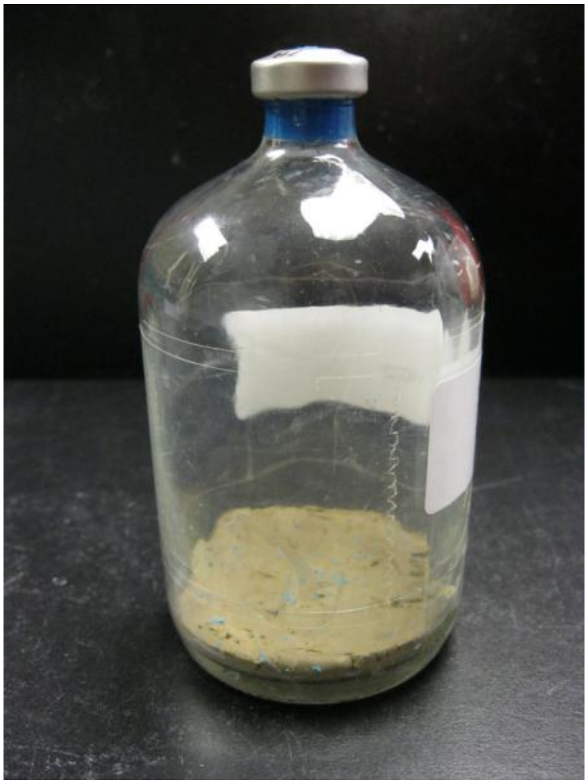


Figure 2-1: Microcosm Bottle with Soil at 19 Percent Moisture

Figure 2-2: Microcosm Bottle with Soil at 30 Percent Moisture

The extensive soil manipulations prior to and during microcosm setup promoted the volatilization of VOCs from the soil. The sealed bottles were therefore spiked with TCE (Sigma-Aldrich, St. Louis, MO) in order to ensure a starting vapor-phase concentration of >100 parts per million by volume (ppmv). Additions were made through the stoppers via gas-tight needle and syringe (Hamilton Co., Reno, NV). The microcosms were allowed to equilibrate for 5 days after spiking with TCE before addition of hydrogen, propane, LPG, and carbon dioxide.

A volume (41.1 mL) of gas was removed from all the bottles prior to gas addition to prevent over-pressurization. All withdrawals and injections were made using gas-tight syringes and needles (Hamilton Co., Reno, NV). Injected gas volumes are shown in **Table 2-3**. High-purity nitrogen and ultra-high purity hydrogen were supplied by Airgas USA, LLC (Long Beach, CA), 98% propane was supplied by Sigma-Aldrich (St. Louis, MO), 99.8% carbon dioxide was supplied by Supelco Analytical (Bellefonte, PA), and LPG was supplied by Benzomatic (Columbus, OH).

Table 2-3: Initial Gas Concentration Adjustments

Test	**Gas Volume Removed (mL at 20°C and 1 atm)**	**Gas Injected (mL at 20°C and 1 atm)**				
		N_2	H_2	LPG	Propane	CO_2
1	41.1	0	23.0	23.0	0	2.3
2	41.1	0	23.0	0	23.0	2.3
3	41.1	41.4	2.3	2.3	0	2.3
4	41.1	41.4	2.3	0	2.3	2.3
5	41.1	48.3	0	0	0	0
6	41.1	0	23.0	23.0	0	2.3
7	41.1	41.4	2.3	2.3	0	2.3
8	41.1	48.3	0	0	0	0
9	41.1	0	23.0	23.0	0	2.3
10	41.1	41.4	2.3	2.3	0	2.3
11	41.1	48.3	0	0	0	0
12	41.1	0	23.0	23.0	0	2.3
13	41.1	0	23.0	0	23.0	2.3
14	41.1	41.4	2.3	2.3	0	2.3
15	41.1	41.4	2.3	0	2.3	2.3
16	41.1	48.3	0	0	0	0
17	41.1	0	23.0	23.0	0	2.3
18	41.1	41.4	2.3	2.3	0	2.3
19	41.1	48.3	0	0	0	0
20	41.1	0	23.0	23.0	0	2.3
21	41.1	41.4	2.3	2.3	0	2.3
22	41.1	48.3	0	0	0	0

Note: These adjustments were made on 9/7/2011, six days after microcosm setup.

2.4 Microcosm Maintenance, Sampling, and Analysis

The microcosm bottles were incubated in the dark at room temperature for the duration of the experiment. The electron donors were added on day 6 of the experiment; this was done to allow the TCE addition to equilibrate between the soil and headspace. On day 49, TEP (Sigma-Aldrich, St. Louis, MO) was added to Test conditions 1 and 2 at an amount of 0.62 mg/bottle or a concentration of 30 mg/kg of TEP (wet weight basis).

The headspace composition was analyzed for volatile organic compounds (VOCs) and electron donors at several points throughout the experiment. All headspace analyses were conducted on an HP 5890 gas chromatograph equipped with a thermal conductivity detector (TCD), flame ionization detector (FID), and an HP 7694 autosampler. Headspace samples (1 mL volume) were taken using a gastight syringe and injected into 10-mL headspace vials (Thermo Scientific, Waltham, MA). An equal volume of high-purity nitrogen was injected into the microcosm bottles immediately prior to sampling to offset the volume removed by sampling and to maintain a slight positive pressure. Separation and analysis of hydrogen and carbon dioxide was conducted using an Agilent GS-Gaspro column and TCD. Need GC conditions. Methane, ethane, ethene, acetylene, propane, TCE, cis-1,2-dichloroethene, and vinyl chloride separation and analysis was conducted using a Restek ShinCarbon ST column and FID.

Additional hydrogen was added when the hydrogen concentration in a bottle fell below a set threshold (5 percent for the 10 percent hydrogen bottles; 0.5 percent for the 1 percent hydrogen bottles). After each hydrogen addition, the headspace composition was re-tested in the affected bottles. The dates of microcosm set-up, phosphorus addition, headspace sampling, and hydrogen additions are shown in **Table 2-4**.

Table 2-4: Headspace Sampling, Analysis, Hydrogen Addition, and TEP Addition Events

Date	Elapsed Time from Bottle Setup (days)	Event	Bottles (Both A and B replicates of each condition, except for individual conditions as noted)
9/1/2011	0	Bottle Setup and TCE Addition	All
9/2/2011	1	FID analysis	All
9/6/2011	5	FID analysis	All
9/7/2011	6	H_2, CO_2, and LPG addition	See Table 2-1
9/8/2011	7	TCD analysis	All
9/20/2011	19	FID analysis	All
9/21/2011	20	TCD analysis	All
9/23/2011	22	H_2 Addition; TCD re-analysis	3, 4, 7, 10, 14, 15, 18, 21A
10/11/2011	40	FID analysis	All
10/12/2011	41	TCD analysis	All
10/13/2011	42	H_2 Addition; TCD re-analysis	12, 13, 14, 15
10/20/2011	49	TEP Addition	1, 2
10/31/2011	60	FID analysis	All
11/2/2011	62	TCD analysis	All
11/3/2011	63	H_2 Addition; TCD re-analysis	3, 4, 13A, 14, 15, 17A, 18A, 21B
11/14/2011	74	FID analysis	All
11/15/2011	75	TCD analysis	All
11/18/2011	78	H_2 Addition; TCD re-analysis	1, 2, 3, 4, 12, 13, 14, 15, 17, 18B, 20A
12/5/2011	95	FID analysis	All
12/6/2011	96	TCD analysis	All
12/8/2011	98	H_2 Addition; TCD re-analysis	1, 2, 3, 4, 7, 13A, 15, 17A, 18, 20B
2/13/2012	165	FID analysis	All
2/20/2012	172	TCD analysis	All

3.0 RESULTS

3.1 Extent of Dechlorination

TCE removals ranged from 35 percent to >99 percent, and a few conditions achieved full dechlorination to to ethene. This demonstrates that complete reductive dechlorination was possible in this soil. **Table 3-1** summarizes the VOC transformations in each condition, and the following sections discuss the effects of each of the treatment variables in more detail. Data trend plots for the each test condition are presented in the Appendix.

Control bottles with neither gaseous electron donors nor bioaugmentation (conditions 5, 8, and 11) achieved 40% to 60% removal of TCE. Possible mechanisms of TCE removal in these bottles include abiotic attenuation, biological reduction fueled by organic matter already present in the site soil, sorption to the rubber stopper, and removal and dilution of TCE in the headspace during gas sampling. No production of cis-1,2-DCE or VC was observed in these bottles, which suggests that biotic degradation was not a significant factor in the observed TCE removal. Headspace removal during gas sampling was also likely to be insignificant: only about 1% of the headspace was exchanged during each round of sampling, so less than 10 percent of the headspace would have been removed during sampling over the course of the experiment. Therefore, abiotic attenuation and sorption to the stoppers were probably the major sources of TCE removal in the un-bioaugmented controls.

Table 3-1: VOC Transformation Summary

Test	Soil moisture	Phosphorus addition	Bio-augmentation	Gas Composition				TCE removal [1]	cis-1,2-DCE production	cis-1,2-DCE trans-formation [2]	VC production	VC trans-formation [2]	Ethene Production
		(Day 49)		H_2	LPG	Propane	CO_2						
1	30%	Y	N	10%	10%	0	1%	69%	√				
2	30%	Y	N	10%	0	10%	1%	48%	√				
3	30%	N	N	1%	1%	0	1%	48%	√				
4	30%	N	N	1%	0	1%	1%	57%	√				
5	30%	N	N	0	0	0	0	38%					
6	19%	N	N	10%	10%	0	1%	35%	√				
7	19%	N	N	1%	1%	0	1%	39%					
8	19%	N	N	0	0	0	0	56%					
9	17%	N	N	10%	10%	0	1%	57%					
10	17%	N	N	1%	1%	0	1%	44%					
11	17%	N	N	0	0	0	0	46%					
12	30%	N	Y	10%	10%	0	1%	>99%	√	√	√	√	√
13	30%	N	Y	10%	0	10%	1%	>99%	√	√	√	√	√
14	30%	N	Y	1%	1%	0	1%	78%	√	partial	slight		
15	30%	N	Y	1%	0	1%	1%	79%	√				
16	30%	N	Y	0	0	0	0	71%	√				
17	19%	N	Y	10%	10%	0	1%	>99%	√	partial	√		
18	19%	N	Y	1%	1%	0	1%	96%	√	partial			
19	19%	N	Y	0	0	0	0	89%	√	partial			
20	17%	N	Y	10%	10%	0	1%	>99%	√	partial	√		
21	17%	N	Y	1%	1%	0	1%	>99%	√	partial	√		
22	17%	N	Y	0	0	0	0	80%	√	slight			

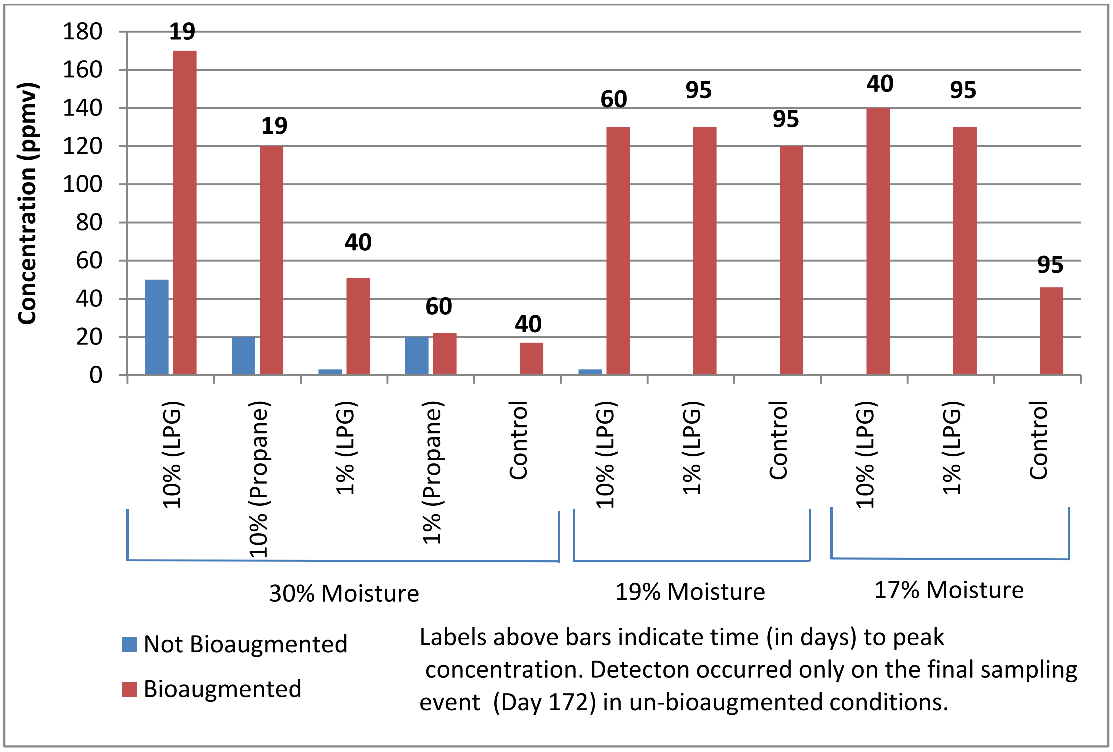
Notes:

1. Calculated as the percent reduction in TCE concentration from T=6 days (immediately after electron-donor addition) to T=165 days, averaged for the replicate bottles in each condition.
2. Transformation of cis-1,2 -DCE and VC was defined as an increase in the concentration of the compound (production) followed by a decrease.

3.2 Effects of Bioaugmentation

As shown in **Table 3-1**, TCE removal was consistently higher with bioaugmentation (Test conditions 12 through 22) than without (Test conditions 1 through 11). No un-bioaugmented condition exceeded 70 percent TCE removal, whereas several of the bioaugmented conditions achieved >99 percent removal.

Production of cis-1,2-DCE occurred in all of the bioaugmented conditions, indicating that part of the TCE loss was due to biodegradation. In contrast, production of cis-1,2-DCE occurred in less than half of the un-bioaugmented conditions. Furthermore, cis-1,2-DCE production occurred earlier and to a greater extent in the bioaugmented conditions (**Figure 3-1**). The slight cis-1,2-DCE production seen in a few of the un-bioaugmented conditions suggests that, given enough time, reductive dechlorination of TCE to cis-1,2-DCE can occur in Site soils without bioaugmentation. However, in the time period of this test, the extent of dechlorination in these conditions was small.



Labels above bars indicate time (in days) to peak concentration. Detecton occurred only on the final sampling event (Day 172) in un-bioaugmented conditions.

Figure 3-1: Effect of Bioaugmentation on Peak cis-1,2-DCE Concentrations with Varying Hydrogen Concentrations with LPG or Propane and Moisture Contents.

Most of the bioaugmented conditions achieved some removal of cis-1,2-DCE, accompanied by production of VC. Full reductive dechlorination to ethene was seen in conditions 12 and 13, which had a high moisture content of 30 percent, a high electron donor concentration of 10 percent, and bioaugmentation. In contrast, conditions without bioaugmentation showed no conversion of cis-1,2-DCE to VC or ethene.

Methane production was observed with and without bioaugmentation at the 30 percent moisture content and in the presence of LPG (**Figure 3-2**). While methane production was greater with bioaugmentation, the observed differences do not explain the relatively poor reductive dechlorination activity without bioaugmentation. In other words, un-bioaugmented microcosms produced 50 percent or more as methane as bioaugmented microcosms, but were much less efficient in terms of TCE dechlorination to cis-1,2-DCE.

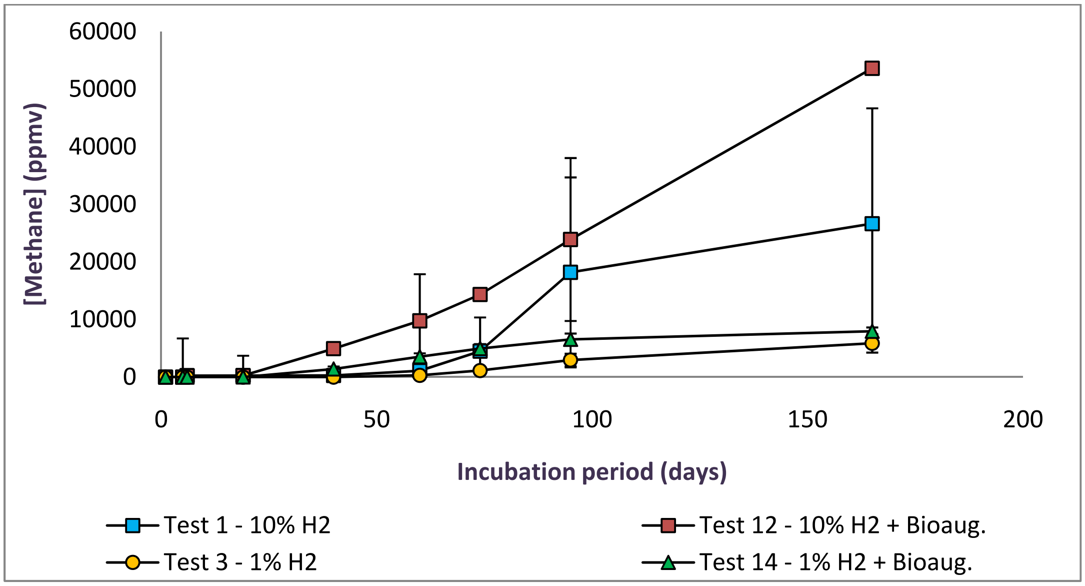


Figure 3-2: Effect of Bioaugmentation Methane Production in the Presence of LPG and at the 30 Percent Moisture Content.

3.3 Effects of Moisture Level and Electron Donor Concentration

Because complete TCE removal and further reductive dechlorination occurred only with bioaugmentation, this section focuses on the bioaugmented conditions. Moisture level and electron donor concentration interacted to produce complex effects. With a high electron donor concentration, increased moisture was beneficial, whereas at a low electron donor concentration, increased moisture was detrimental.

3.3.1 Moisture Effects with High Electron Donor Concentration

When high hydrogen concentrations, bioaugmentation, and LPG were used (Test conditions 12, 17, and 20), TCE removal was not significantly affected by increased moisture levels. **Figure 3-3** shows TCE concentrations over time in these conditions. It can be seen that they achieved complete TCE removal, at similar rates, regardless of moisture content. Moisture level did impact the reductive dechlorination of cis-1,2-DCE and VC. Concentrations of cis-1,2-DCE and VC over time in these conditions are shown in **Figures 3-4** and **3-5**. In Test condition 12 with 30 percent moisture, near-complete cis-1,2-DCE removal occurred by day 74. Cis-1,2-DCE accumulated and was subsequently reductively dechlorinated at slower rates at lower moisture contents in Test conditions 17 and 20. VC was largely removed by the end of the experiment with 30 percent moisture (Test condition 12) but was either still accumulating or just beginning to be dechlorinated at lower moisture contents (**Figure 3-5**). Ethene production was observed only in Test condition 12 with 30 percent moisture (**Figure 3-6**). Overall, the high-moisture condition performed better than those with lower moistures.

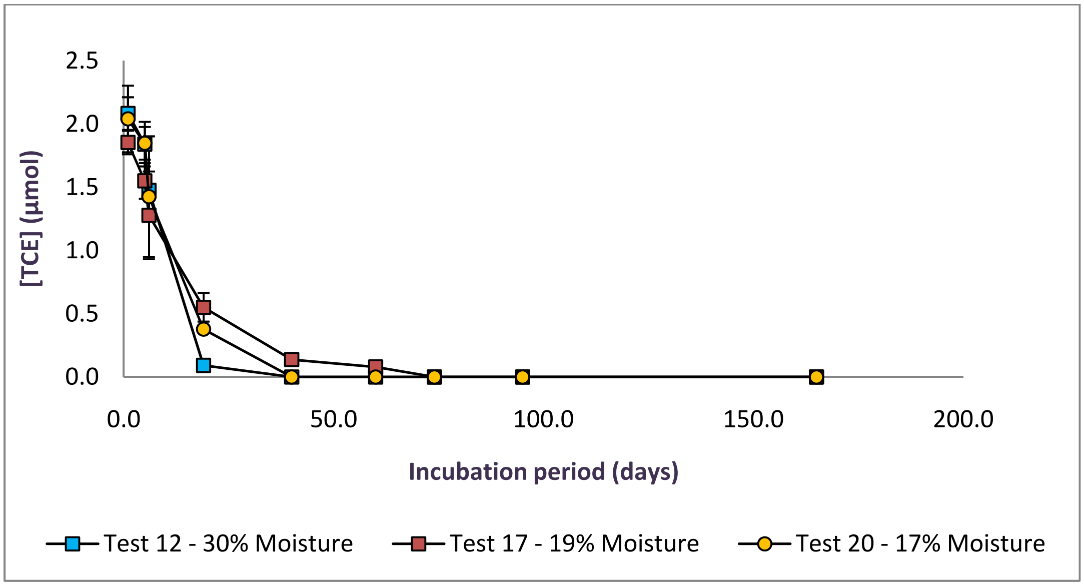


Figure 3-3: TCE Concentrations with High Hydrogen Concentration and LPG for Varying Moisture Contents.

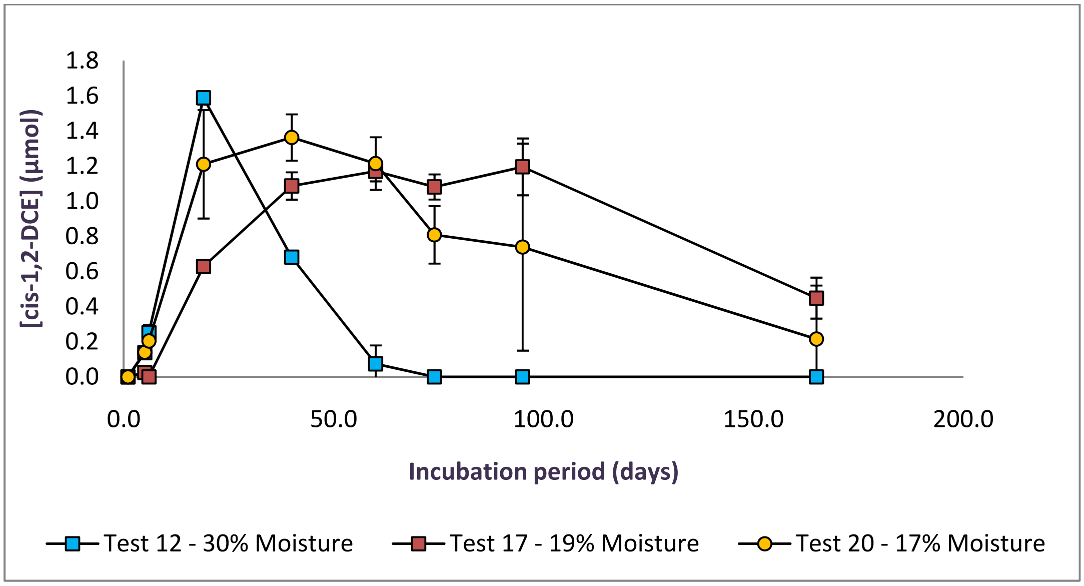


Figure 3-4: Cis-1,2-DCE Concentrations with High Hydrogen Concentration and LPG for Varying Moisture Contents.

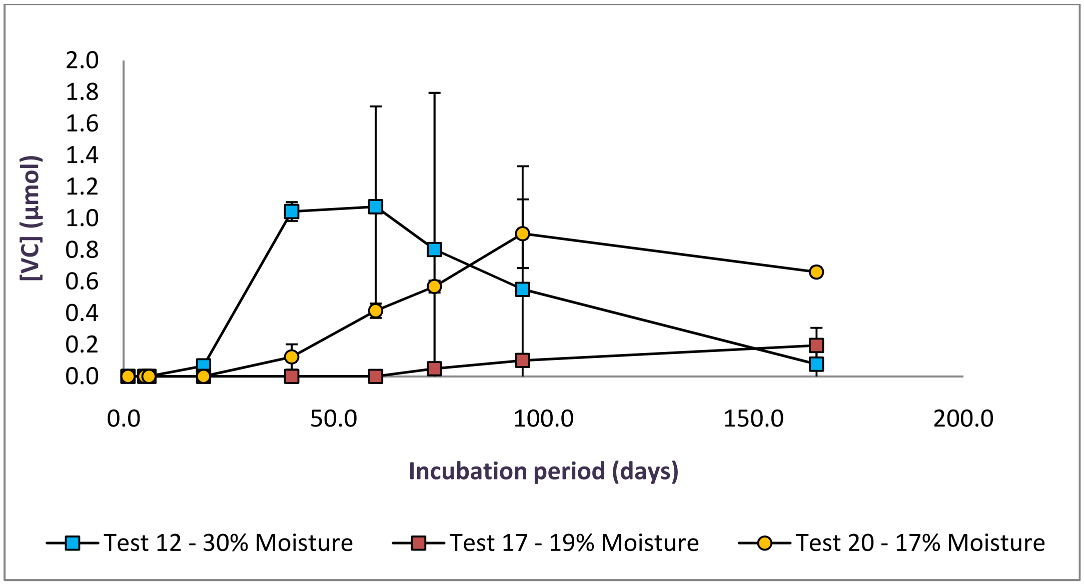


Figure 3-5: VC Concentrations with High Hydrogen Concentration and LPG for Varying Moisture Contents.

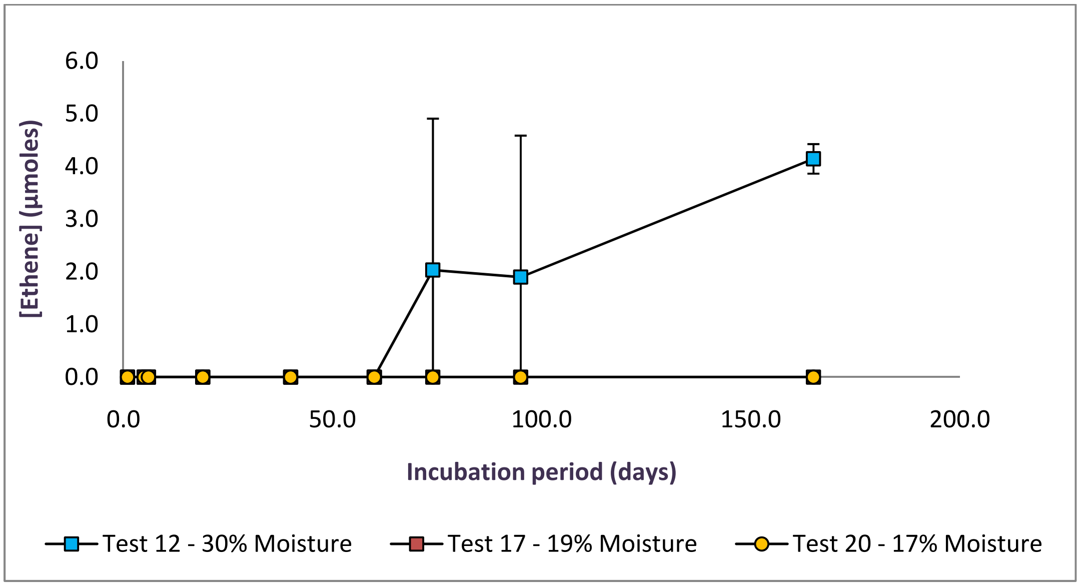


Figure 3-6: Ethene Concentrations with High Hydrogen Concentration and LPG for Varying Moisture Contents.

Methane production was generally similar for all three conditions (**Figure 3-7**) with the possibility of lesser production in Test condition 20 with the lowest moisture content. The hydrogen consumption generally increased with increasing moisture contents (**Figure 3-8**). Comparison of the time profiles of VOC reductive dechlorination with methane accumulation and hydrogen consumption suggests that hydrogen was initially directed toward reductive dechlorination. After a period of acclimation, hydrogenotrophic methanogenesis accelerated.

While reductive dechlorination was incomplete at the lower moisture contents, hydrogen consumption and methanogenesis activities were high and not inhibited commensurately by low moisture contents.

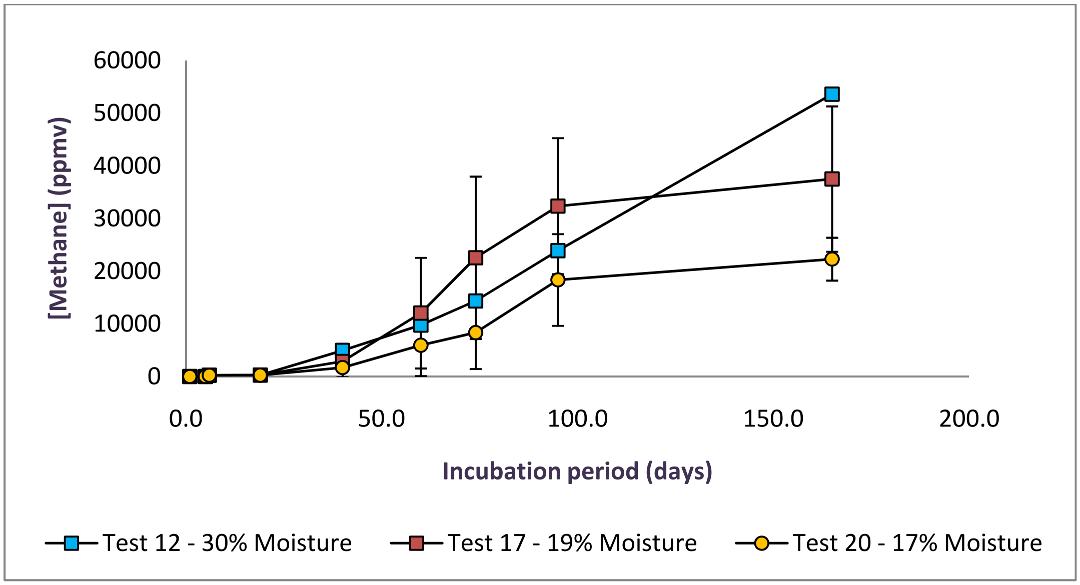


Figure 3-7: Methane Concentrations with High Hydrogen Concentration and LPG for Varying Moisture Contents.

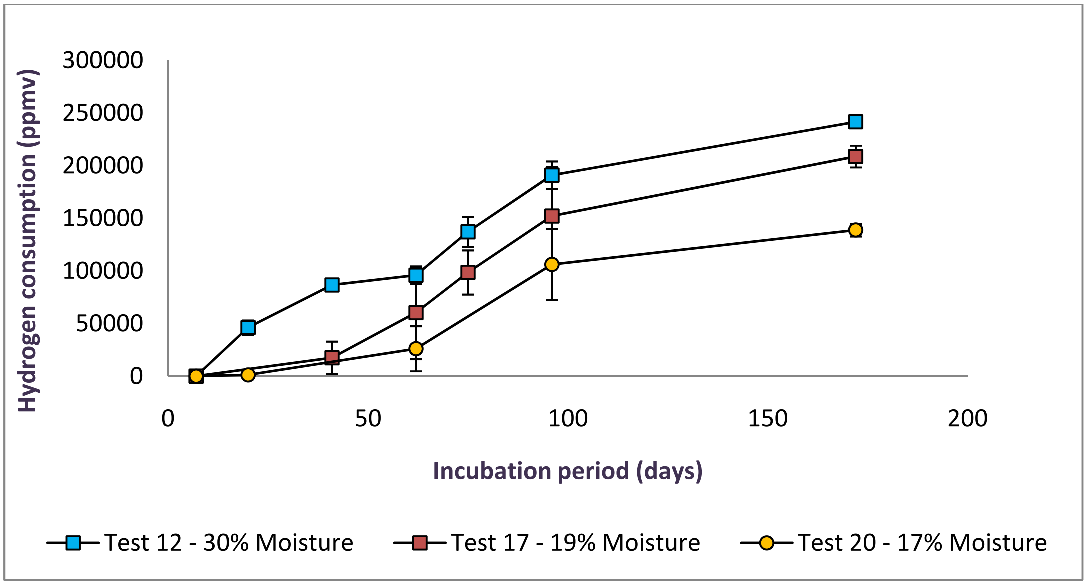


Figure 3-8: Hydrogen Consumption Concentrations with High Hydrogen Concentration and LPG for Varying Moisture Contents.

3.3.2 Moisture Effects with Low Electron Donor Concentration

Although an increase in moisture improved dechlorination when the electron donor concentration was high, it had the opposite effect on TCE removal when the electron donor concentration was low (Test conditions 14, 18, and 21). The TCE concentrations over time for these conditions are shown in **Figure 3-9**. In Test conditions 18 and 21 (moisture of 19% and 17%, respectively), TCE was largely removed by day 60, with a concomitant production of cis-1,2-DCE (**Figure 3-10**). In Test condition 14 with 30% moisture, the TCE was not fully removed and less cis-1,2-DCE production occurred. Transformation of cis-1,2-DCE was incomplete regardless of moisture level, although some degradation occurred at low moisture levels. Minor VC accumulation was observed in all three conditions and no ethene production was observed.

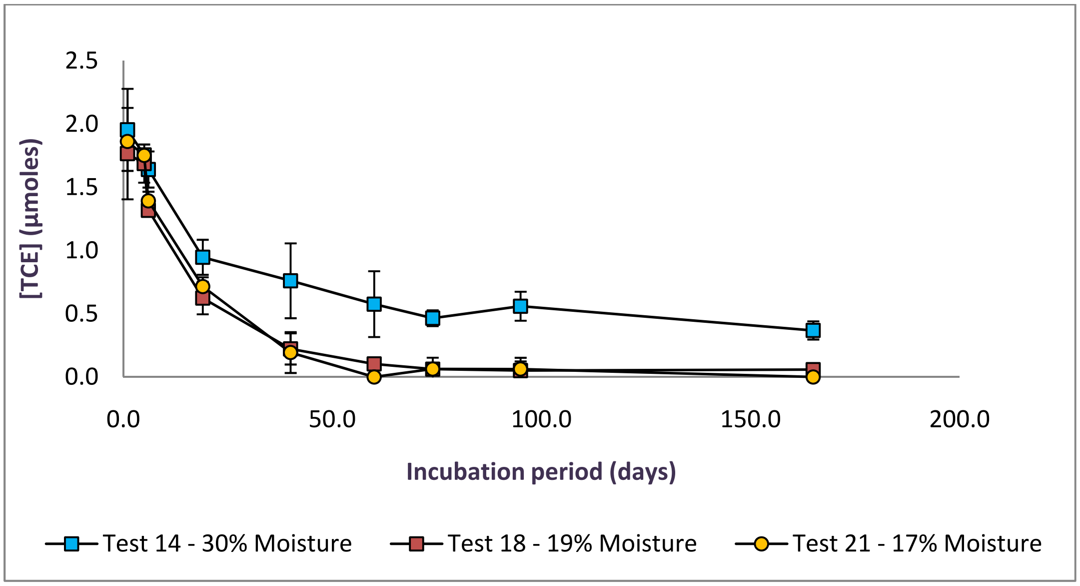


Figure 3-9: TCE Concentrations with Low Hydrogen Concentration and LPG for Varying Moisture Contents.

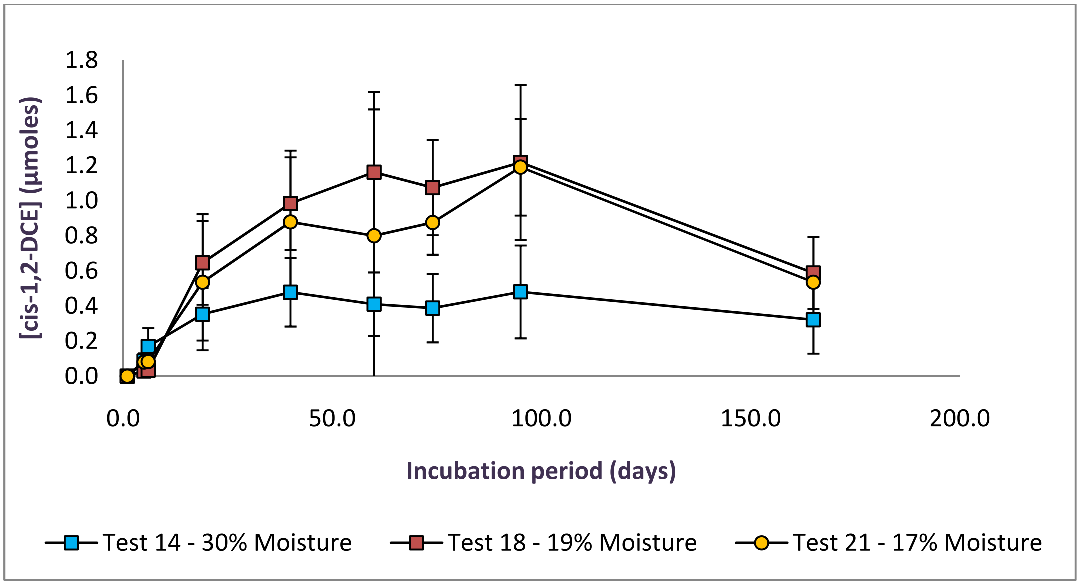


Figure 3-10: Cis-1,2-DCE Concentrations with Low Hydrogen Concentration and LPG for Varying Moisture Contents.

Methane generation (**Figure 3-11**) and hydrogen consumption (**Figure 3-12**) with low hydrogen concentrations were qualitatively and quantitatively different from that observed with high hydrogen concentrations (**Figures 3-7** and **3-8**). Methane production and hydrogen consumption under low hydrogen concentrations were significantly lower than under high hydrogen concentrations for all moisture contents. Additionally, methane production and hydrogen consumption were more sensitive to moisture content at lower hydrogen concentrations. These data alone do not explain the incomplete reductive dechlorination of TCE at 30 percent moisture. Competition for hydrogen by methanogens and reductive dechlorinators appears to have been a contributing factor. **Figure 3-13** demonstrates that hydrogen was frequently depleted in the high moisture and low hydrogen concentration condition. Such was not the case in the high moisture and high hydrogen concentration condition. At lower moisture contents, low hydrogen concentration test conditions were either depleted of hydrogen much less frequently or not at all. These data suggest that Test condition 14 with 30 percent moisture and low hydrogen did not promote complete reductive dechlorination of TCE because: 1) high moisture promoted a rapid rate of methanogenesis, 2) this rapid rate in combination with the low hydrogen concentration (i.e., 1 percent) led to frequent hydrogen depletion, and 3) hydrogen concentrations may have been less than necessary thresholds most of the time for reductive dechlorination. The results of these tests suggest that the methanogens were more active at high moisture levels and were able to out-compete the reductive dechlorinators for the limited hydrogen. Methanogen activity was lower at lower moisture levels and more hydrogen was available for use by the reductive dechlorinators. However, despite the successful removal of TCE under conditions of low moisture and low hydrogen, much cis-1,2-DCE remained at the end of the experiment.

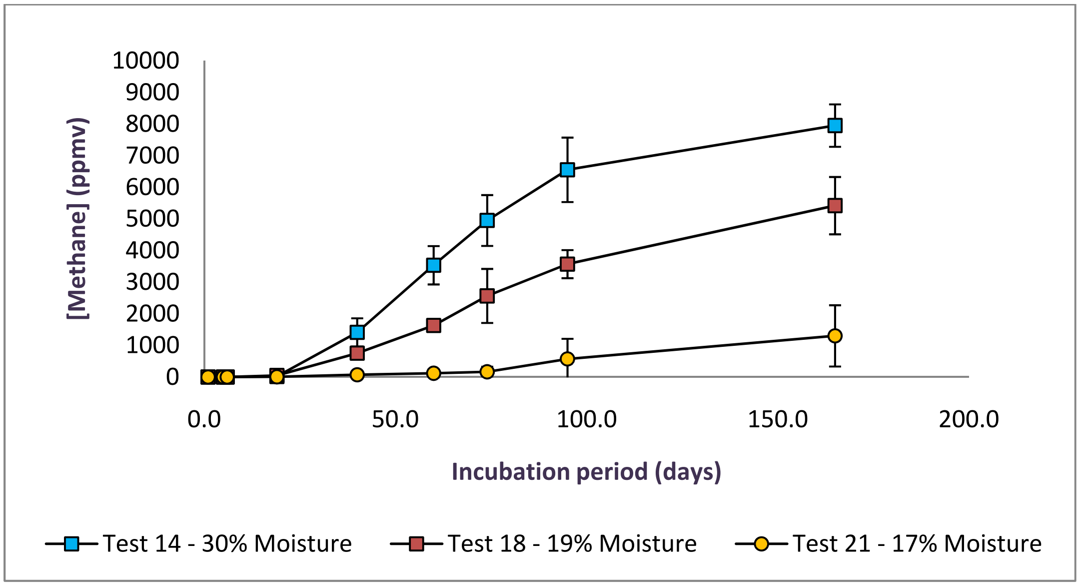


Figure 3-11: Methane Concentrations with Low Hydrogen Concentration and LPG for Varying Moisture Contents.

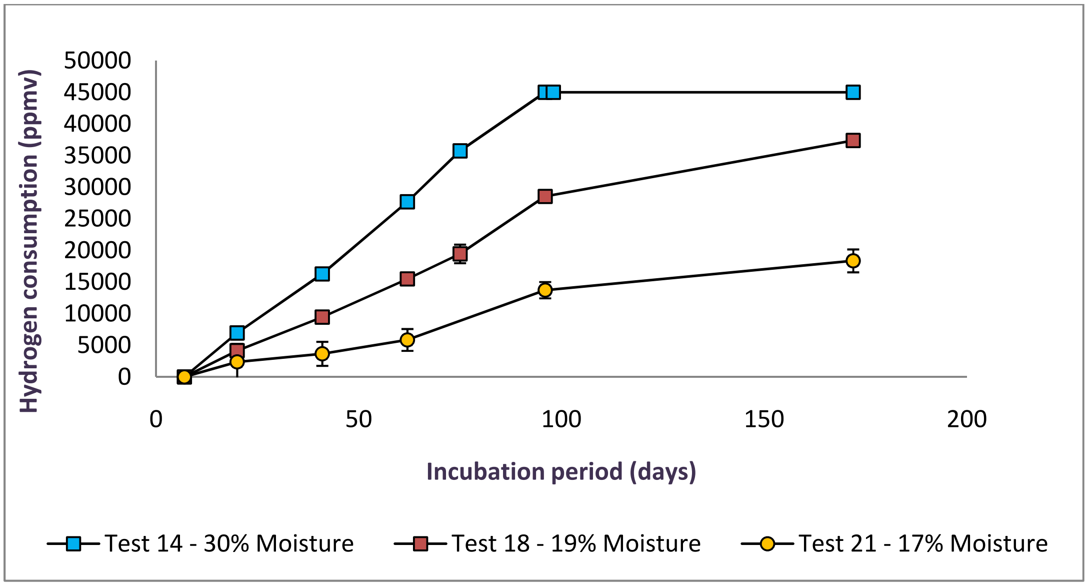


Figure 3-12: Hydrogen Consumption with Low Hydrogen Concentration and LPG for Varying Moisture Contents.

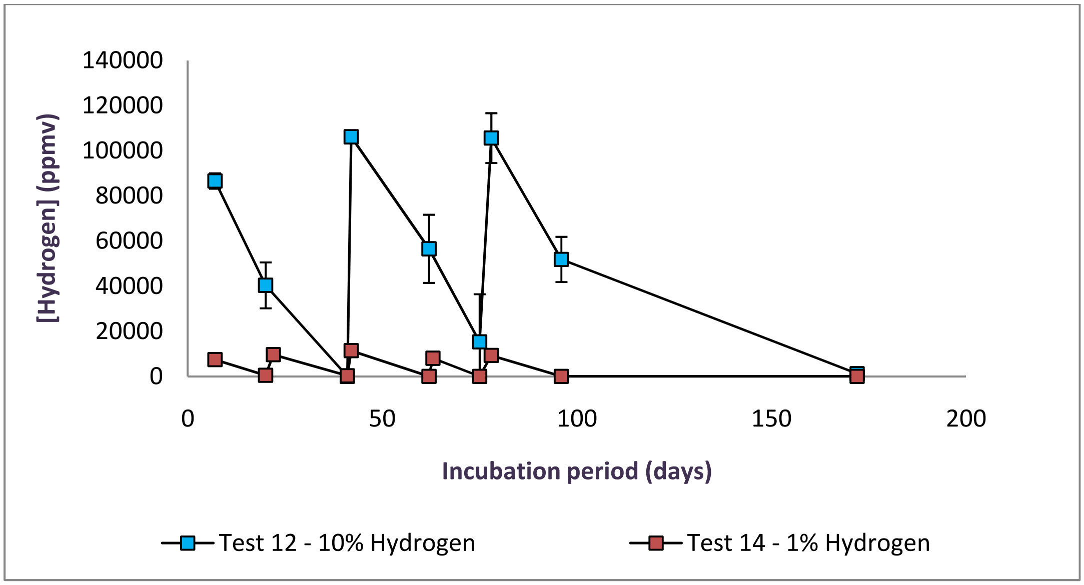


Figure 3-13: Hydrogen Concentrations under Conditions of 30 Percent Moisture and the Presence of LPG.

3.4 Effects of LPG vs. Propane

As can be seen in the **Table 3-1** and **Figure 3-1** above, there were no clear differences in reductive dechlorination between conditions with LPG and those with propane. LPG (Test condition 12) and propane (Test condition 13) both allowed full reductive dechlorination to ethene with a high electron donor concentration, 30 percent moisture, and bioaugmentation (**Figures 3-14** and **3-15**). If any significant differences were present, LPG appeared to be superior to propane in terms of the rate of reductive dechlorination.

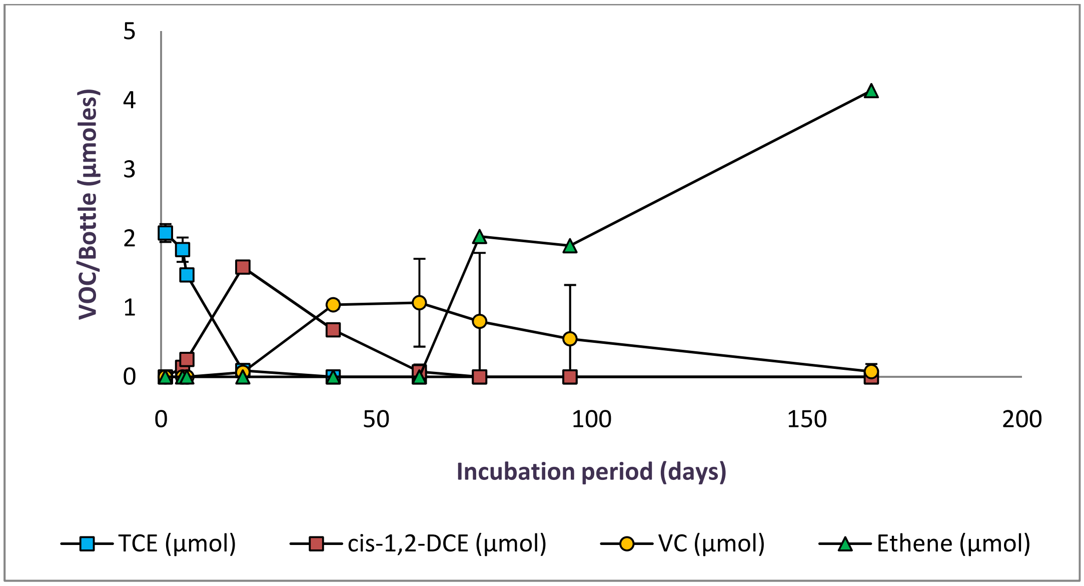


Figure 3-14: Reductive Dechlorination of TCE in the Presence of LPG, 10 Percent Hydrogen, 30 Percent Moisture, and Bioaugmentation (Test Condition 12).

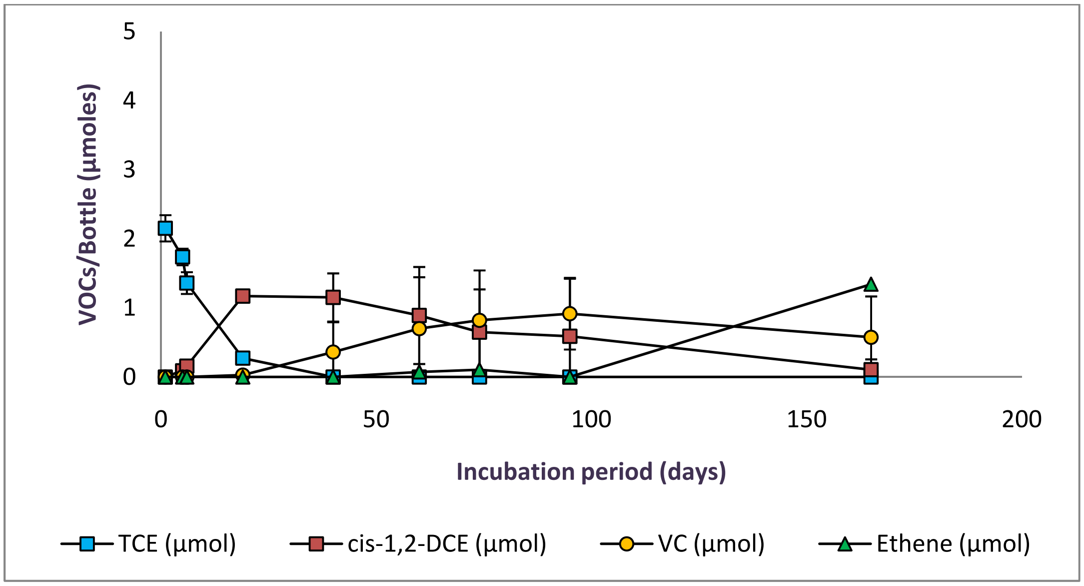


Figure 3-15: Reductive Dechlorination of TCE in the Presence of Propane, 10 Percent Hydrogen, 30 Percent Moisture, and Bioaugmentation (Test Condition 13).

3.5 Effects of Phosphorus Addition

On day 49, phosphorus nutrient in the form of triethyl phosphate was added to Test conditions 1 and 2. These conditions were chosen because they had a high moisture level and high electron donor concentration, but unlike bioaugmented Test conditions 12 and 13, they had shown little removal of TCE. No immediate effect on TCE removal was observed, although the rate of hydrogen consumption increased, as shown in Figures 3-16 and 3-17. Whether additional incubation time in the absence of TEP addition would have stimulated hydrogen consumption is not known. By the end of the experiment, some TCE removal did occur but was not complete. This suggests that the addition of phosphorus may have stimulated microbial activity, but it is not clear whether it promoted TCE degradation. Nevertheless, TEP addition did not yield results equivalent to the bioaugmented microcosms.

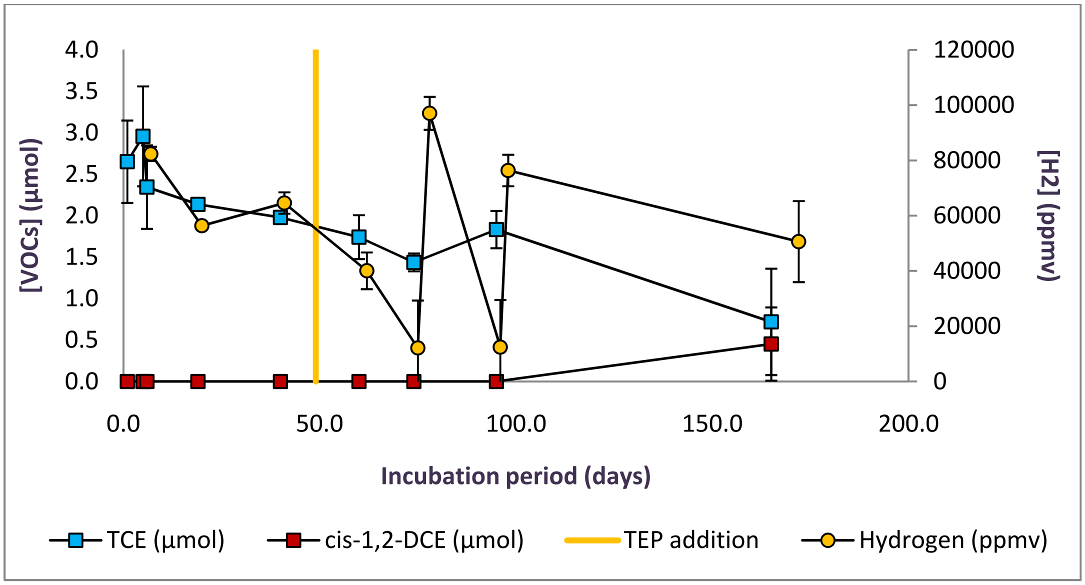


Figure 3-16: Effect of TEP Addition on Reductive Dechlorination and Hydrogen Consumption with High Hydrogen, LPG, 30 Percent Moisture, and no Bioaugmentation.

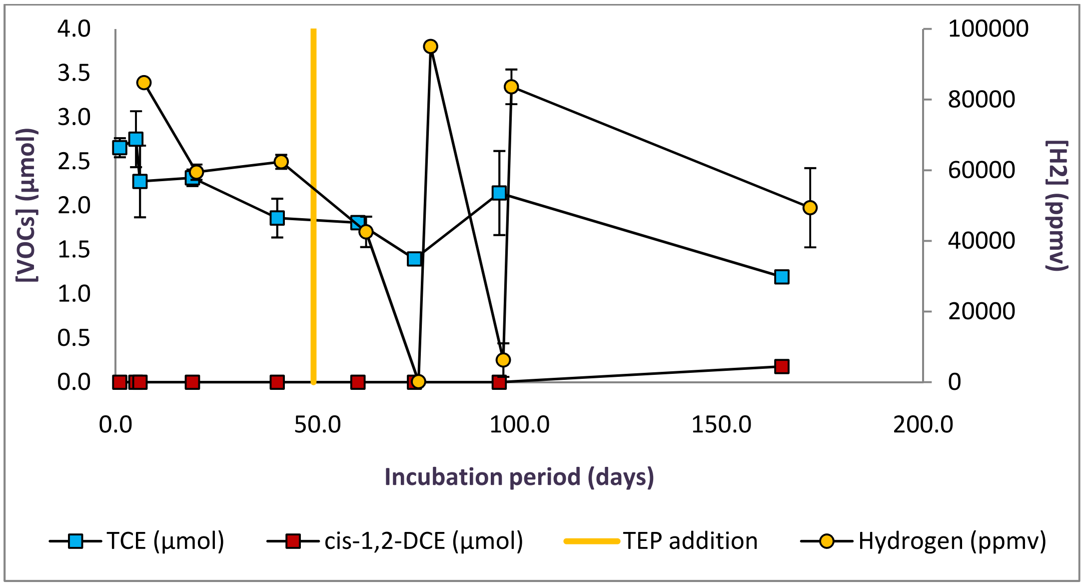


Figure 3-17: Effect of TEP Addition on Reductive Dechlorination and Hydrogen Consumption with High Hydrogen, Propane, 30 Percent Moisture, and no Bioaugmentation.

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated that complete reductive dechlorination of TCE and its daughter products can occur in Site soils with the addition of the gaseous electron donor hydrogen. However, several factors influenced the success of electron donor addition. Bioaugmentation with a commercially available culture containing *Dehalococcoides* had the greatest impact. All bioaugmented conditions rapidly achieved at least some transformation of TCE to cis-1,2-DCE, whereas none of the un-bioaugmented conditions did so until the last sampling point of the experiment. Complete dechlorination of TCE to ethene occurred only with bioaugmentation, and when moisture level and electron donor concentration were both high. For fastest bioremediation of Site vadose zone soil using this technology a combination of bioaugmentation, high electron donor dosing, and moisture addition would be required.

However, the fact that some TCE transformation did occur in un-bioaugmented bottles after 100 days of incubation suggests that, given time, dechlorinator activity may increase at the site. Whether additional time would lead to complete reductive dechlorination is not known, but is not considered likely. Addition of the phosphorous nutrient – triethyl phosphate – did not appear to promote reductive dechlorination in un-bioaugmented microcosms, but may have initiated methanogenesis. LPG, which was added along with hydrogen, carbon dioxide, and nitrogen, was not inhibitory to reductive dechlorination when compared to pure propane gas.

A high moisture content (30 percent) promoted the most complete reductive dechlorination under conditions with high electron donor concentration (10 percent) and bioaugmentation, Interestingly, lower moisture contents (17 to 19 percent) promoted reductive dechlorination of TCE to cis-1,2-DCE more effectively than a high moisture content (30 percent) when the electron donor concentration was low (1 percent). The reason appears to be competition for hydrogen since hydrogenotrophic methanogenesis led to rapid depletion of one percent hydrogen in the high moisture condition. This depletion may have resulted in hydrogen concentrations less than threshold requirements for reductive dechlorination. Thus use of low hydrogen concentrations in a field setting would require continuous injection to prevent depletion.

5.0 REFERENCES

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Appendix: Graphs of VOC and Electron Donor Concentrations for all Test Conditions

On the following graphs, pale green line indicates date of phosphorus addition; yellow lines indicate dates of hydrogen re-spiking.

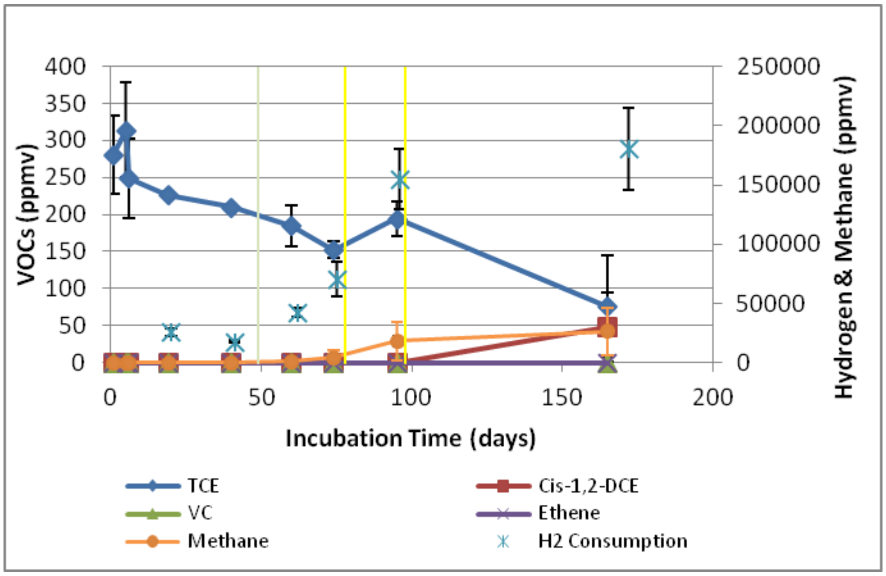


Figure C-1: Condition 1. 10% H2, 10% LPG, 1% CO2, 30% Moisture, No Bioaugmentation

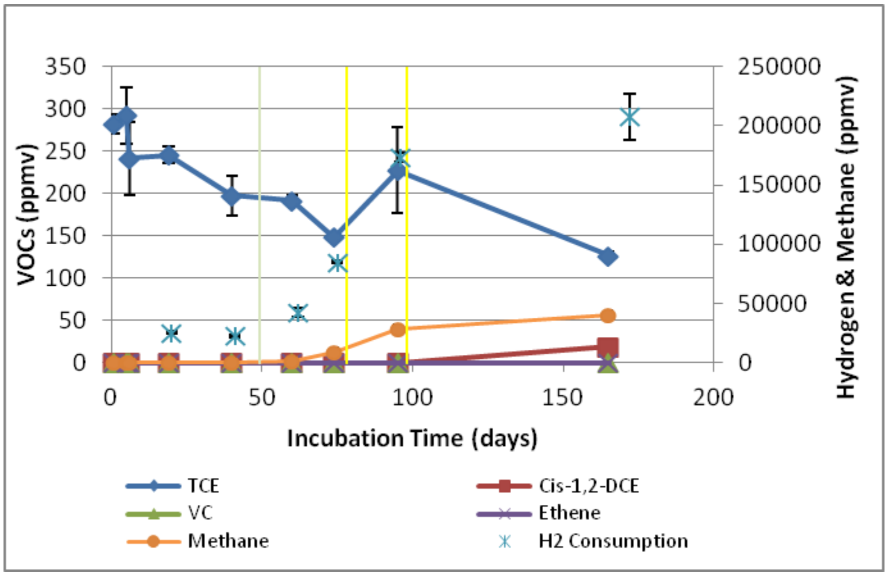


Figure C-2: Condition 2. 10% H2, 10% Propane, 1% CO2, 30% Moisture, No Bioaugmentation

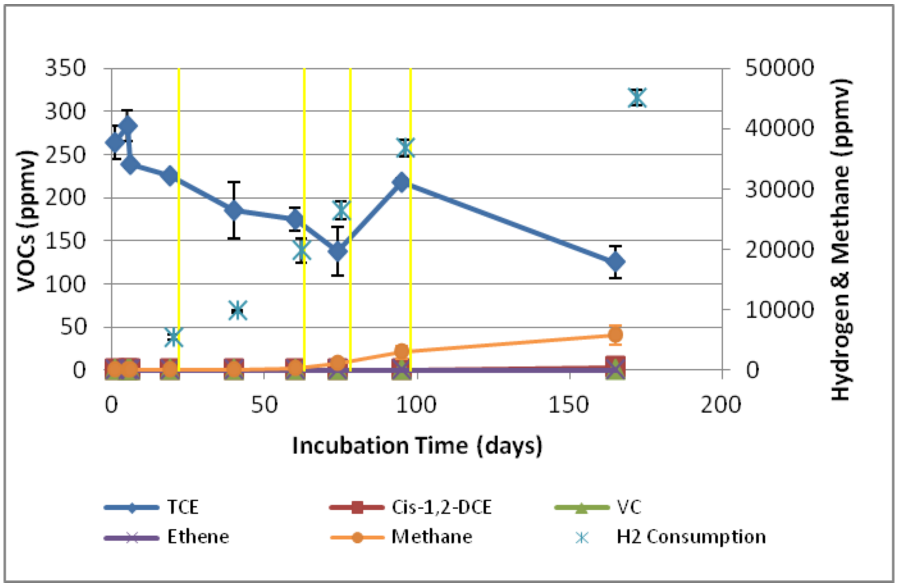


Figure C-3: Condition 3. 1% H2, 1% LPG, 1% CO2, 30% Moisture, No Bioaugmentation

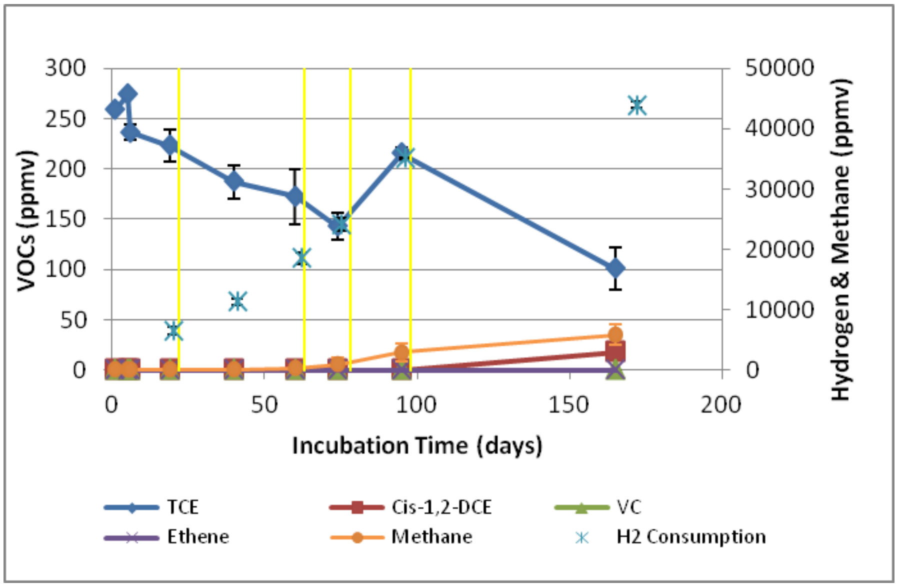


Figure C-4: Condition 4. 1% H2, 1% Propane, 1% CO2, 30% Moisture, No Bioaugmentation

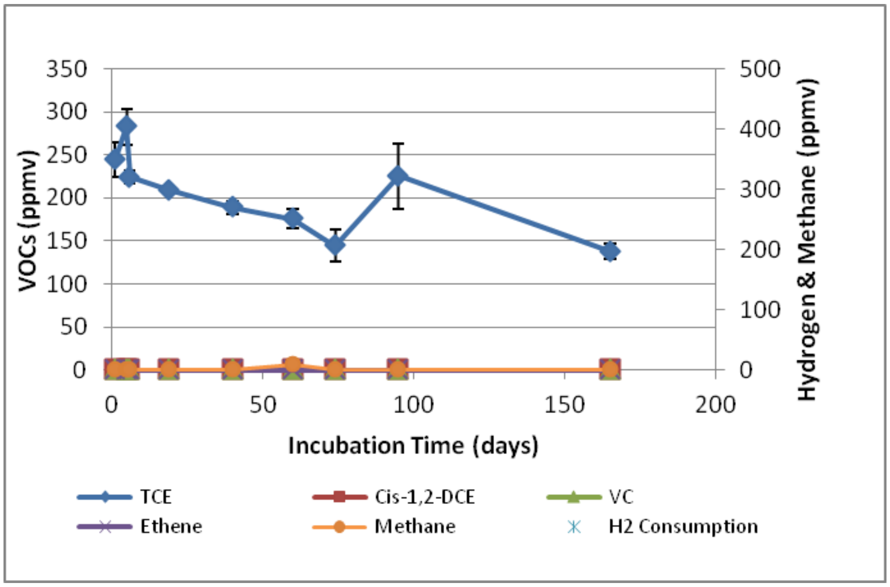


Figure C-5: Condition 5. Control, 30% Moisture, No Bioaugmentation

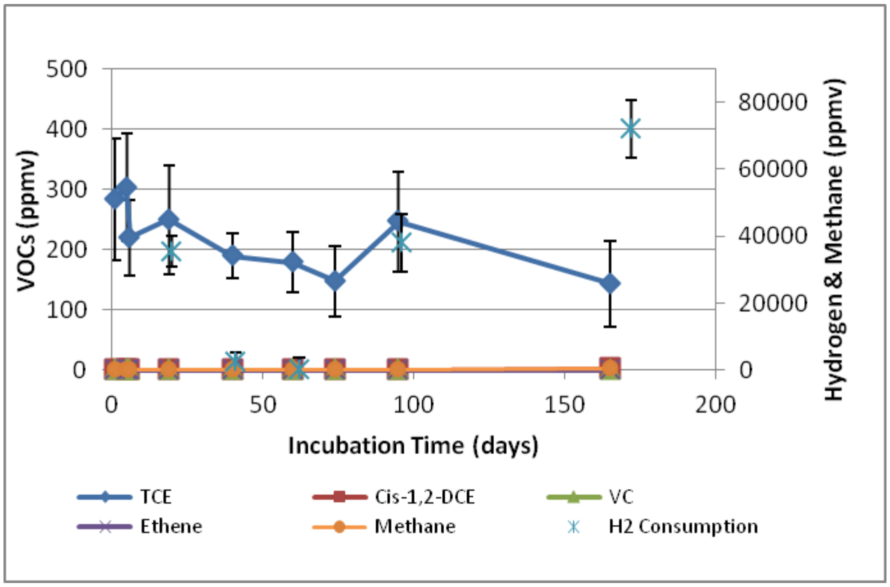


Figure C-6: Condition 6. 10% H2, 10% LPG, 1% CO2, 19% Moisture, No Bioaugmentation

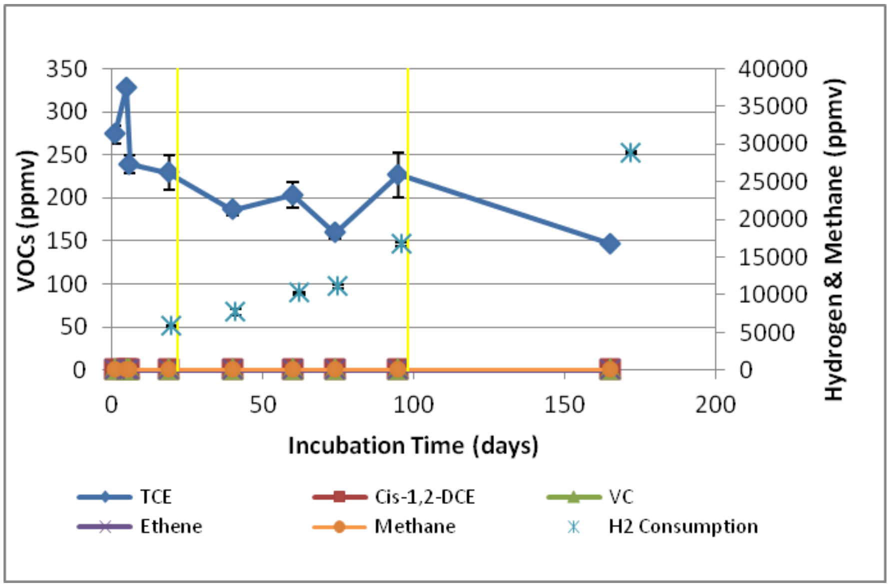


Figure C-7: Condition 7. 1% H2, 1% LPG, 1% CO2, 19% Moisture, No Bioaugmentation

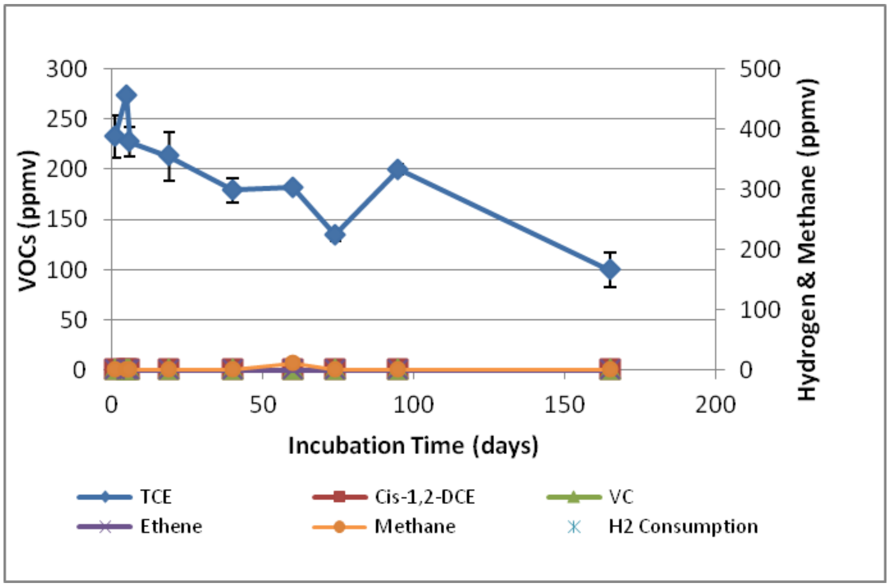


Figure C-8: Condition 8. Control, 19% Moisture, No Bioaugmentation

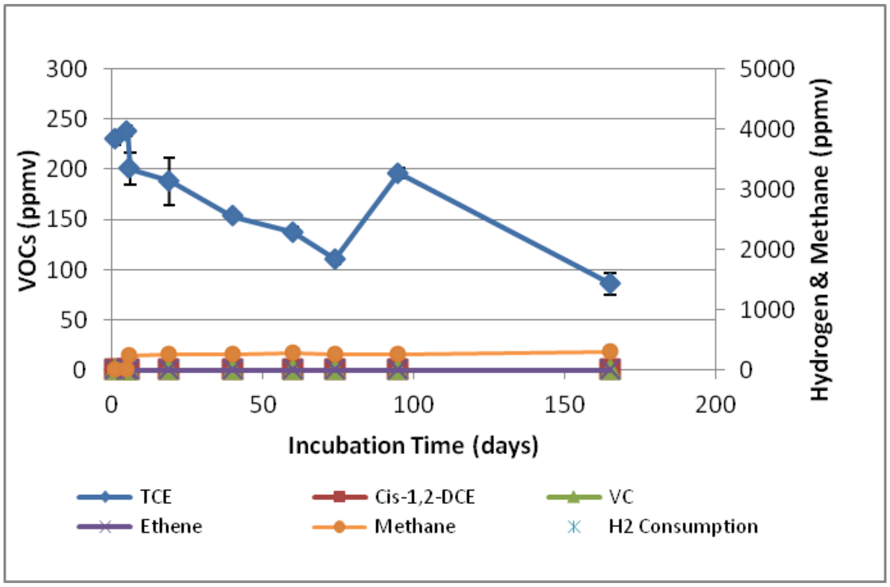


Figure C-9: Condition 9. 10% H2, 10% LPG, 1% CO2, 17% Moisture, No Bioaugmentation

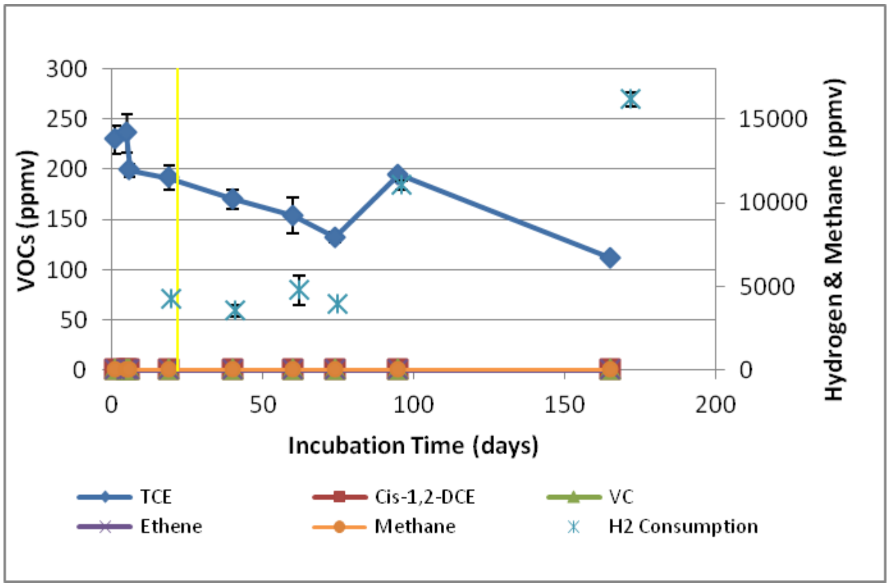


Figure C-10: Condition 10. 1% H2, 1% LPG, 1% CO2, 17% Moisture, No Bioaugmentation

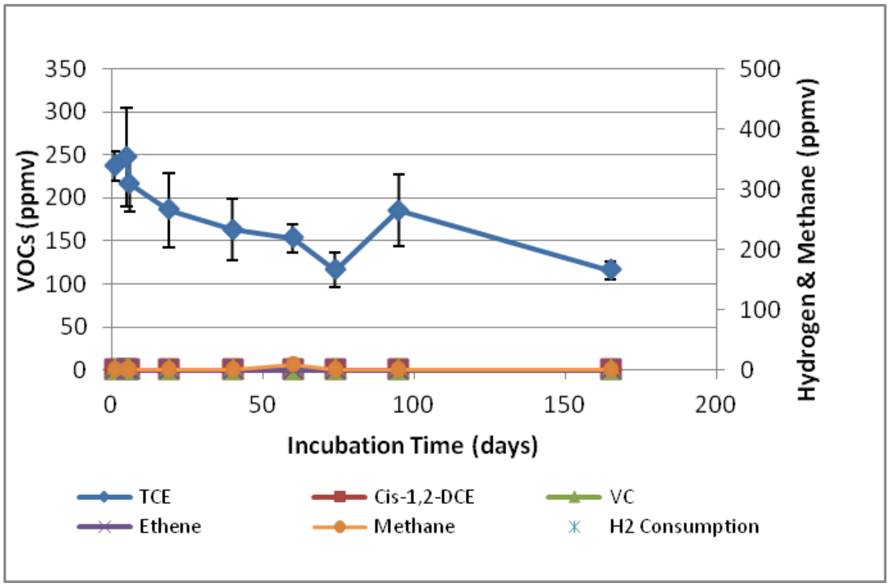


Figure C-11: Condition 11. Control, 17% Moisture, No Bioaugmentation

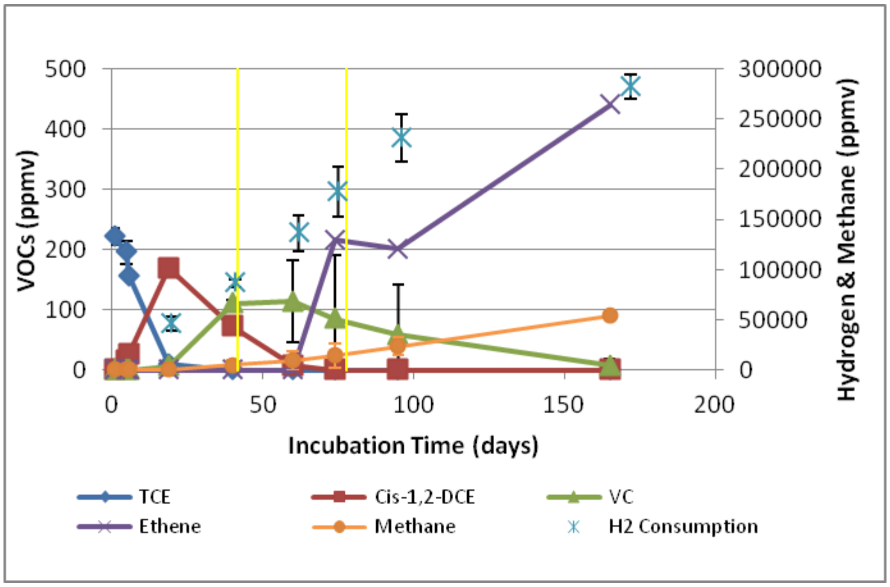


Figure C-12: Condition 12. 10% H2, 10% LPG, 1% CO2, 30% Moisture, Bioaugmented

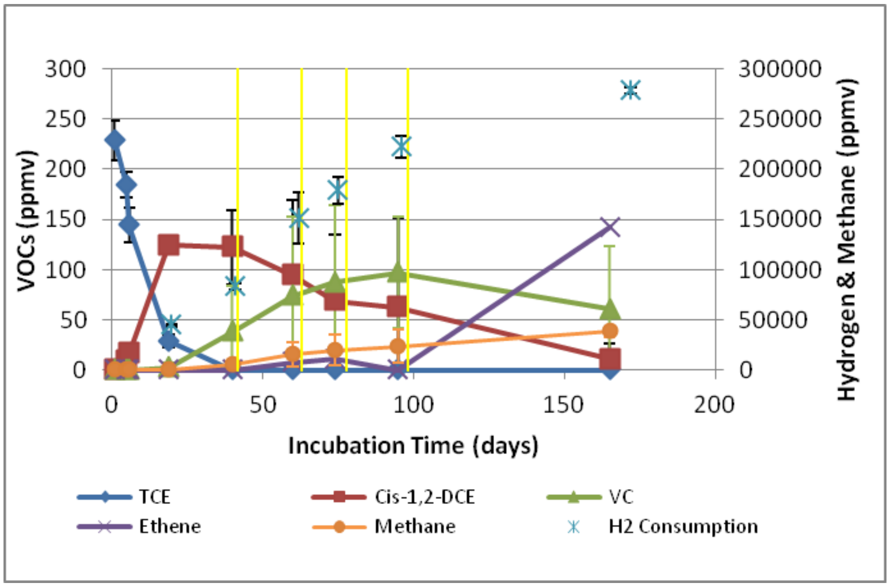


Figure C-13: Condition 13. 10% H2, 10% Propane, 1% CO2, 30% Moisture, Bioaugmented

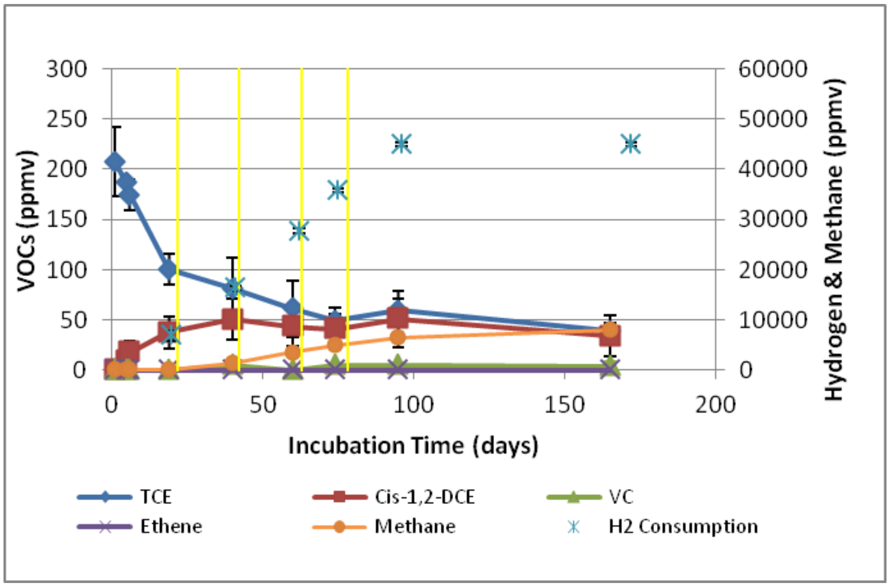


Figure C-14: Condition 14. 1% H2, 1% LPG, 1% CO2, 30% Moisture, Bioaugmented

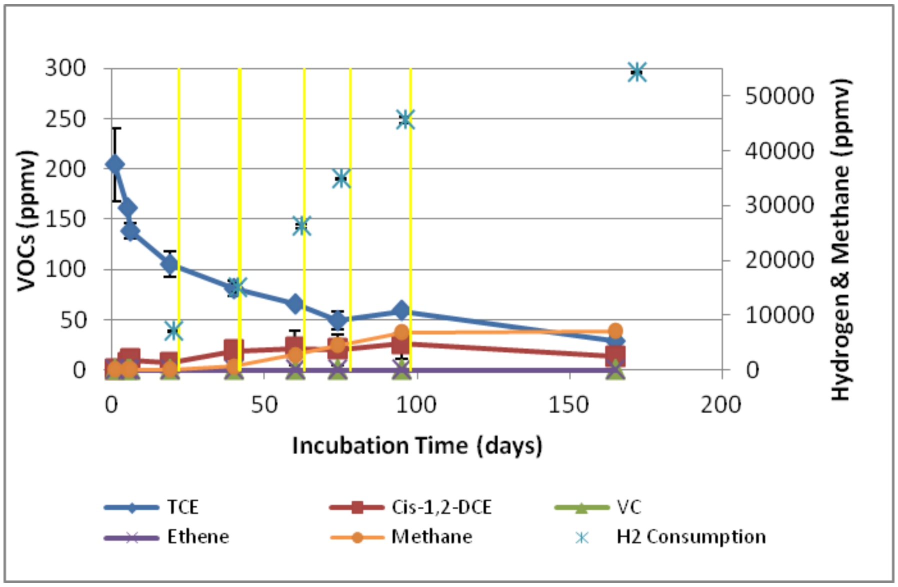


Figure C-15: Condition 15. 1% H2, 1% Propane, 1% CO2, 30% Moisture, Bioaugmented

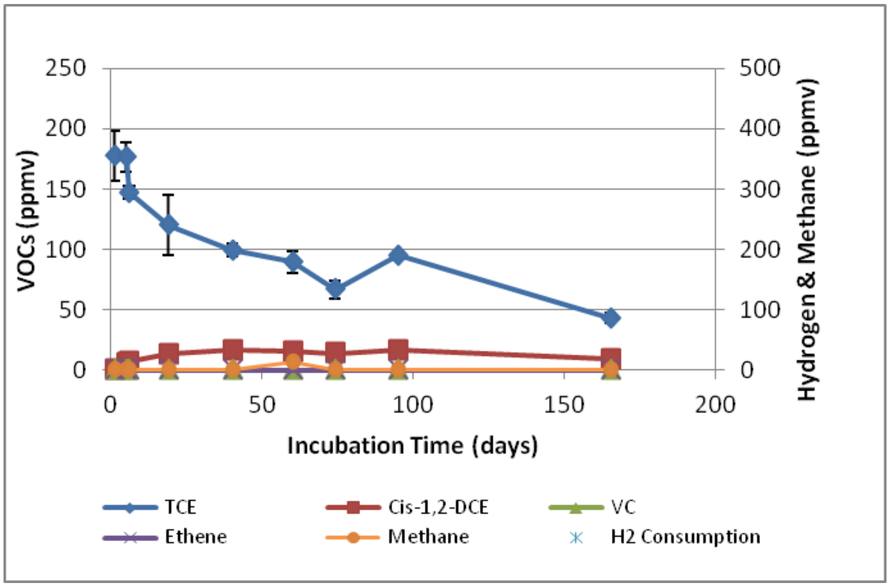


Figure C-16: Condition 16. Control, 30% Moisture, Bioaugmented

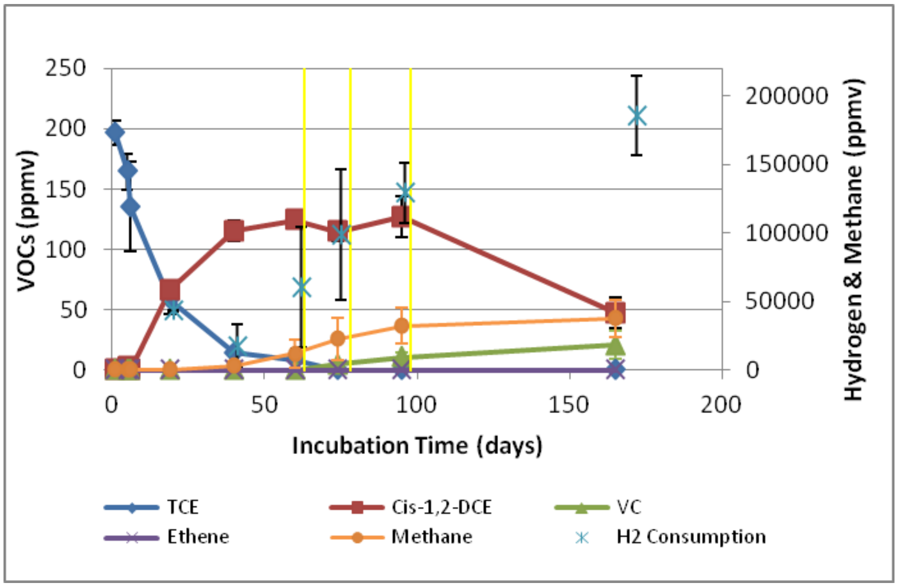


Figure C-17: Condition 17. 10% H2, 10% LPG, 1% CO2, 19% Moisture, Bioaugmented

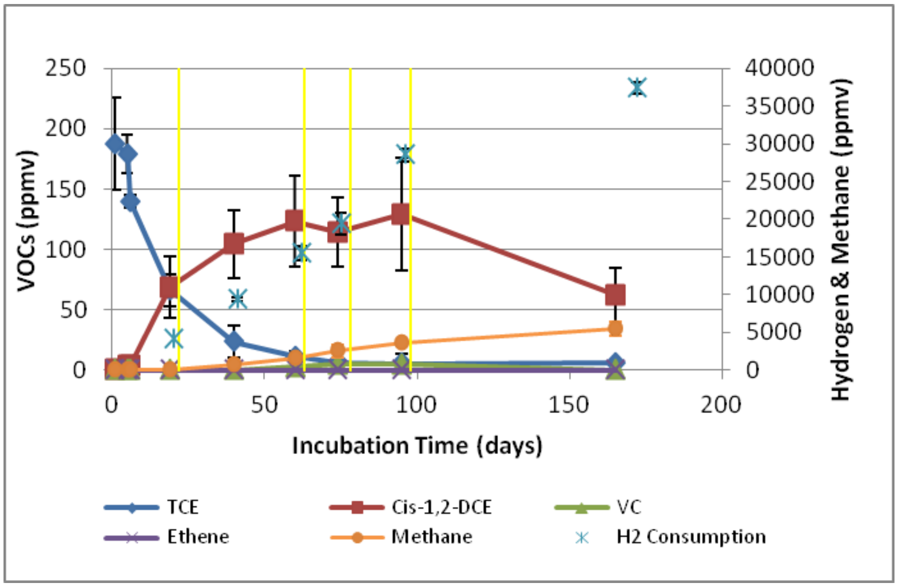


Figure C-18: Condition 18. 1% H2, 1% LPG, 1% CO2, 19% Moisture, Bioaugmented

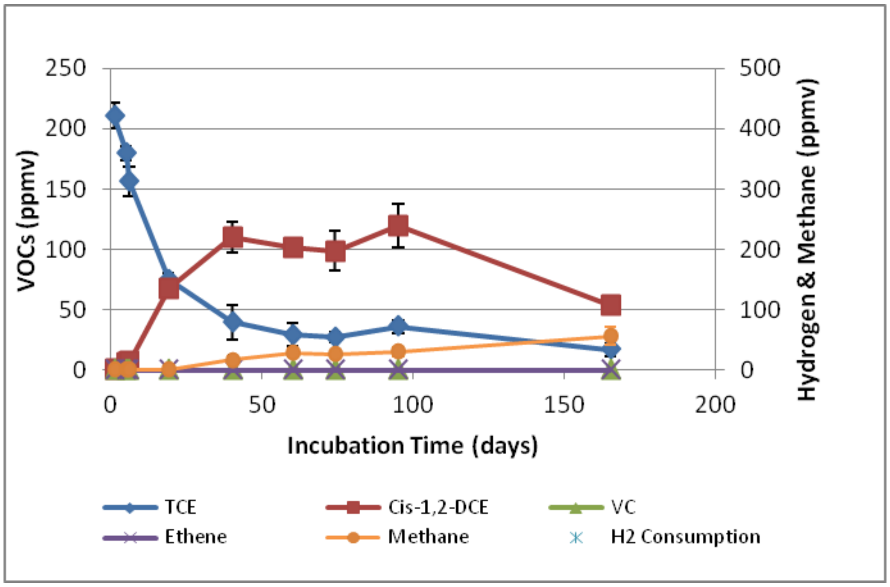


Figure C-19: Condition 19. Control, 19% Moisture, Bioaugmented

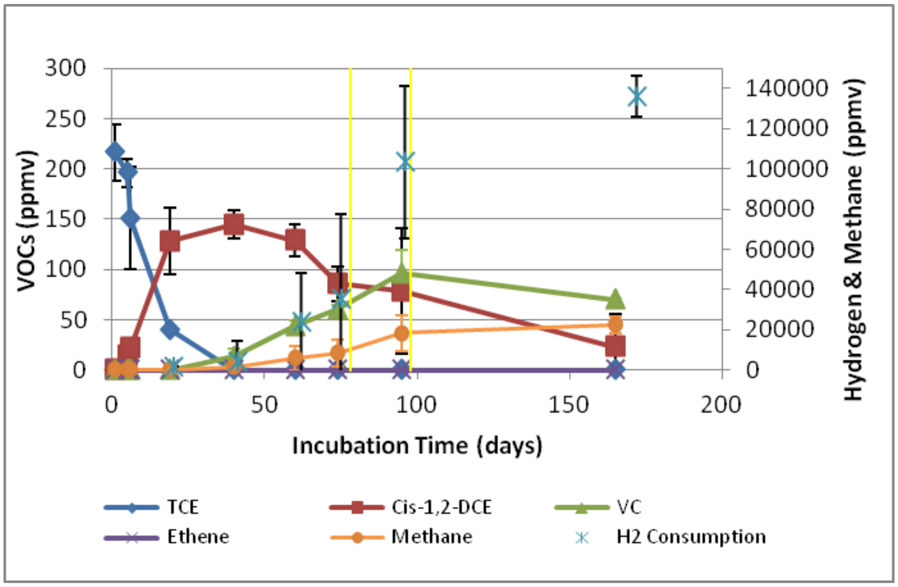


Figure C-20: Condition 20. 10% H2, 10% LPG, 1% CO2, 17% Moisture, Bioaugmented

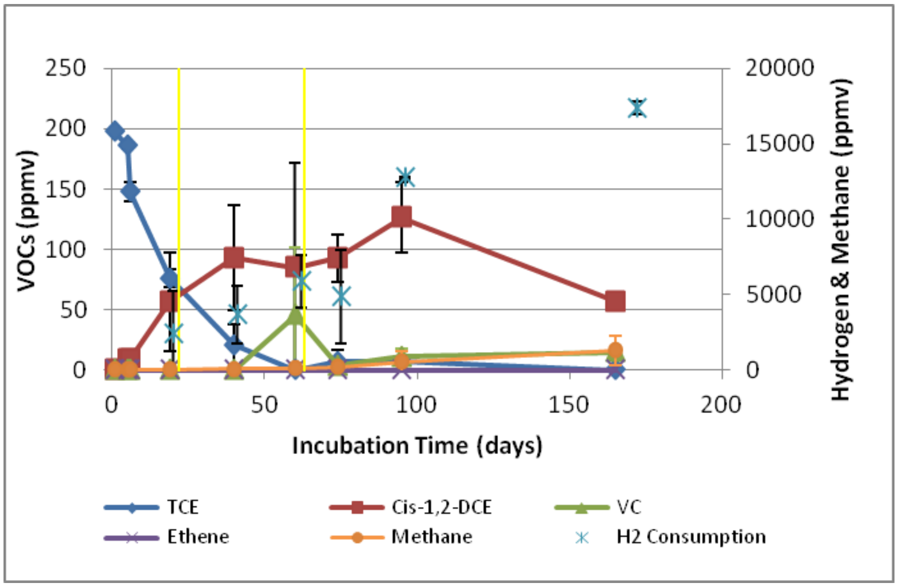


Figure C-21: Condition 21. 1% H2, 1% LPG, 1% CO2, 17% Moisture, Bioaugmented

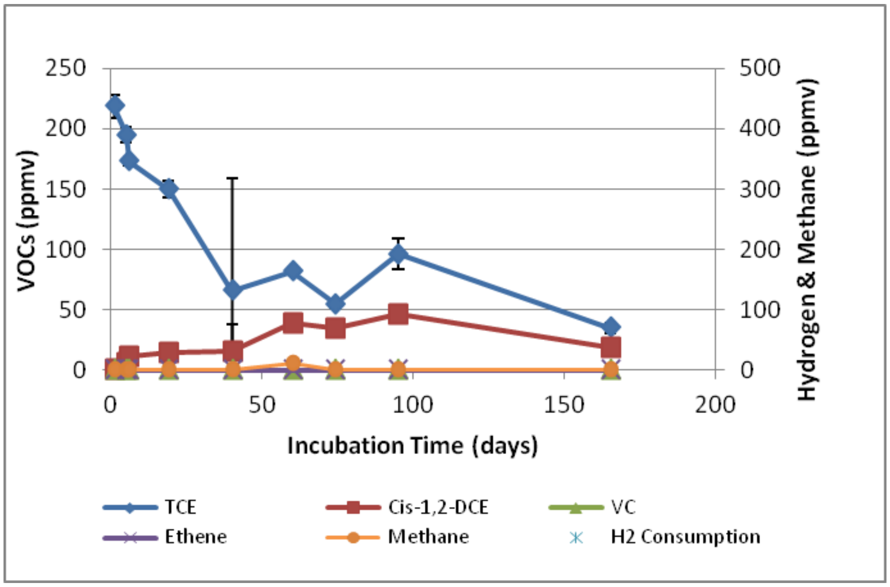


Figure C-22: Condition 22. Control, 17% Moisture, Bioaugmented

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix F: Weekly Operation & Maintenance (O&M) Checklist

Table F1
Rotameter Readings (SCFM) from Gas Mixing Section and Gas Injection Section of the Injection Skid
H2T Implementation, Former Atlas Missile Site, York NE

			Gas Mixing Section				Gas Injection Section								
			N2	LPG	H2	CO2	IW-1S	IW-1M	IW-1D	IW-2S	IW-2M	IW-2D	IW-3S	IW-3M	IW-3D
			Target value (scfm)				Target value (scfm)								
Week #	**Date**	**Temp. (oF)**	**2.0**	**0.25**	**0.25**	**0.025**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**
1	14-Jun-11	65-75	2.0	0.25	0.25	0.025	0.20	0.08	0.10	0.20	0.28	0.16	0.38	0.20	0.34
2	21-Jun-11	66	2.0	0.22	0.25	0.025	0.24	0.08	0.08	0.24	0.25	0.19	0.25	0.36	0.25
3	28-Jun-11	75	2.1	0.22	0.24	0.023	0.21	0.08	0.10	0.23	0.25	0.15	0.26	0.26	0.27
4	5-Jul-11	80	2.1	0.25	0.23	0.025	0.21	0.13	0.08	0.25	0.27	0.13	0.29	0.27	0.27
5	12-Jul-11	73	2.1	0.26	0.25	0.030	0.32	0.14	0.05	0.29	0.23	0.13	0.26	0.22	0.26
6	21-Jul-11	86-95	2.0	0.25	0.25	0.025	0.30	0.12	0.04	0.33	0.20	0.10	0.28	0.18	0.25
7	26-Jul-11	93-98	2.0	0.25	0.25	0.025	0.28	0.14	0.04	0.26	0.21	0.10	0.29	0.19	0.26
8	2-Aug-11	83-92	2.0	0.25	0.25	0.025	0.28	0.14	0.05	0.30	0.20	0.10	0.28	0.18	0.26
9	9-Aug-11	81-84	2.0	0.25	0.25	0.025	0.28	0.14	0.05	0.26	0.20	0.10	0.28	0.18	0.27
10	16-Aug-11	77	2.2	0.24	0.25	0.025	0.28	0.18	0.05	0.36	0.21	0.12	0.32	0.19	0.28
11	23-Aug-11	96	2.0	0.25	0.25	0.025	0.29	0.18	0.05	0.26	0.22	0.11	0.26	0.20	0.28
12	30-Aug-11	84	2.0	0.25	0.25	0.025	0.26	0.17	0.05	0.28	0.20	0.11	0.28	0.19	0.28
13	6-Sep-11	73	1.8	0.25	0.25	0.026	0.26	0.16	0.05	0.26	0.17	0.11	0.26	0.17	0.26
14	13-Sep-11	71	2.0	0.25	0.25	0.025	0.28	0.18	0.05	0.28	0.19	0.11	0.29	0.19	0.28
15	21-Sep-11	68	2.0	0.25	0.25	0.024	0.28	0.19	0.05	0.28	0.19	0.11	0.29	0.20	0.29
16	27-Sep-11	78	2.0	0.25	0.25	0.026	0.28	0.19	0.05	0.28	0.18	0.11	0.28	0.20	0.28
17	4-Oct-11	70	2.0	0.25	0.25	0.024	0.27	0.19	0.05	0.27	0.19	0.11	0.27	0.20	0.28
18	10-Oct-11	71	2.0	0.25	0.25	0.020	0.24	0.10	0.05	0.16	0.10	0.06	0.22	0.10	0.15
19	20-Oct-11	58	2.0	0.25	0.25	0.019	0.29	0.12	0.05	0.19	0.11	0.06	0.27	0.13	0.18
20	25-Oct-11	61	1.5	0.15	0.15	0.024	0.28	0.12	0.05	0.19	0.12	0.08	0.28	0.12	0.19
21	31-Oct-11	59	1.8	0.26	0.25	0.022	0.25	0.17	0.05	0.35	0.16	0.12	0.25	0.17	0.26
22	8-Nov-11	46	2.0	0.24	0.24	0.025	0.27	0.21	0.05	0.24	0.19	0.12	0.29	0.22	0.30
23	11-Nov-11	51	2.0	0.26	0.26	0.025	0.26	0.22	0.05	0.28	0.18	0.11	0.26	0.24	0.28
24	22-Nov-11	54	3.5	0.5	0	0.05	0.44	0.44	0.11	0.46	0.25	0.16	0.46	0.5	0.38
25	29-Nov-11	47	3.5	0.49	0.5	0.054	0.44	0.53	0.1	0.46	0.28	0.18	0.47	0.57	0.41
26	6-Dec-11	10	3.5	0.35	0.5	0.045	0.4	0.55	0.1	0.42	0.27	0.17	0.43	0.54	0.39
27	14-Dec-11	39	1.0	0.1	0.1	0.01	0.05	0.14	0.02	0.1	0.06	0.04	0.12	0.14	0.13
28	20-Dec-11	30	1.0	0.1	0.1	0.01	0.03	0.14	0.02	0.08	0.09	0.06	0.1	0.13	0.14
29	28-Dec-11	42	1.0	0.1	0.1	0.01	0.04	0.15	0.02	0.09	0.1	0.09	0.1	0.13	0.14
30	5-Jan-12	61	2.5	-	-	-	-	-	-	-	-	-	-	-	-
31	10-Jan-12	54	2.5	-	-	-	-	-	-	-	-	-	-	-	-

Table F2
Pressure Readings (PSIG) from Gas Mixing Section and Gas Injection Section of the Injection Skid
H2T Implementation, Former Atlas Missile Site, York NE

				Gas Mixing Section				Gas Injection Section								
Week #	Date	Temp. (oK)	Bleed Line	N2	LPG	H2	CO2	IW-1S	IW-1M	IW-1D	IW-2S	IW-2M	IW-2D	IW-3S	IW-3M	IW-3D
1	14-Jun-11	294	16.5	40	30	17	15	15	11.75	15	14	11.5	15	5.25	15.5	10.75
2	21-Jun-11	292	13.5	30	19	15	22	13	11.75	13.5	9.5	9.75	13	7	12.5	8.5
3	28-Jun-11	297	11.25	30	20	15	20	11.5	11.75	11.75	10.25	8.75	11.25	6.5	9	8.5
4	5-Jul-11	300	14.75	30	30	27	20	9.75	12.75	13	8.75	12	12.75	6.25	12.5	11.25
5	12-Jul-11	296	13.5	35	35	30	35	8	14	14	7.25	13	13.75	6	13.5	13
6	21-Jul-11	306	12.25	38	35	27	20	6	12.25	13	7	12	12.5	6.25	12.5	12
7	26-Jul-11	308	12.75	37	35	30	21	5.25	13	13.5	6.25	12.5	13	6.25	13	12.5
8	2-Aug-11	304	12.25	37	35	30	21	5	12.75	12.75	6.25	12	12.5	5.75	12.25	12.25
9	9-Aug-11	301	12.5	35	34	30	21	5	12.75	13	6	12	12.75	5.5	12.5	12
10	16-Aug-11	298	12.75	37	33	30	21	5	13	13.25	5.25	12.5	13	5.25	13	12.5
11	23-Aug-11	309	12.5	37	34	30	21	5	12.25	13	5	12.25	13	5	12.75	12.25
12	30-Aug-11	302	12.25	37	33	30	21	5	12.75	12.75	5	12	12.75	5.25	12.5	12
13	6-Sep-11	296	11.5	39	27	30	21	4.75	11.75	11.75	5	11.25	11.75	5	12	11.25
14	13-Sep-11	295	12	39	32	30	21	4.75	12.25	12.5	5	11.75	12.25	5	12.25	11.5
15	21-Sep-11	293	12	39	32	30	21	5	12	12.5	5	11.75	12	4.5	12	11.5
16	27-Sep-11	299	12.5	39	35	30	20	4.75	11.75	12.25	5	11.5	12	4.25	12	11
17	4-Oct-11	294	11	39	32	30	20	5	12	12.25	5.25	11.5	12	4.25	12	11.25
18	10-Oct-11	295	12	30	33	30	21	5.25	9.25	9.25	5	8.75	9.25	4.75	9.5	9
19	20-Oct-11	287	11.5	37	35	30	21	5.5	10	10	6	9.5	10	5.25	10.25	9.75
20	25-Oct-11	289	5	34	35	35	20	5.5	6	5.75	5.75	6	5.25	5.25	6	5.25
21	31-Oct-11	288	6.5	30	35	30	21	3.75	6.75	6.75	4.75	6.25	6	4.5	7	6
22	8-Nov-11	281	7.25	30	35	30	21	4.75	7.5	7.75	4.25	7	7.5	5	7.25	6.75
23	11-Nov-11	284	7	30	35	30	21	5	7	7.5	4.75	6.75	7.25	5	7	6.25
24	22-Nov-11	285	8	50	50	0	45	6.25	6.25	8.5	5	7.25	8	6	6	7
25	29-Nov-11	281	8.5	47	49	40	44	6.5	6	9	5.5	7.5	8.5	6.25	5.5	7
26	6-Dec-11	261	8.5	49	31	40	40	7	5.75	9	6	7.5	8.5	6.75	5.5	7.5
27	14-Dec-11	277	3	50	40	40	40	3.25	3.25	3.25	2.75	3	3	3	3.25	3.25
28	20-Dec-11	272	3.5	50	40	40	40	4	3.5	3.5	3	3.25	3.5	3.75	3.75	3.75
29	28-Dec-11	279	4	50	40	40	40	4.25	4	4.25	3.5	3.5	4	4	4.25	4
30	5-Jan-12	289	7	45	-	-	-	-	-	-	-	-	-	-	-	-
31	10-Jan-12	285	7	45	-	-	-	-	-	-	-	-	-	-	-	-

Table F3
Mixing and Injection Flowrates (SCFM) Corrected for Pressure and Temperature
H2T Implementation, Former Atlas Missile Site, York NE

				Gas Mixing Section				Gas Injection Section								
				N2	LPG	H2	CO2	IW-1S	IW-1M	IW-1D	IW-2S	IW-2M	IW-2D	IW-3S	IW-3M	IW-3D
				Target value (scfm)				Target value (scfm)								
Week #	**Date**	**Time (days)**	**Temp. (oF)**	**2.0**	**0.25**	**0.25**	**0.025**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**	**0.28**
1	14-Jun-11	0	65-75	2.10	0.26	0.26	0.03	0.39	0.14	0.20	0.38	0.48	0.31	0.50	0.40	0.57
2	21-Jun-11	7	66	1.91	0.21	0.24	0.02	0.44	0.14	0.15	0.39	0.41	0.35	0.36	0.65	0.39
3	28-Jun-11	14	75	1.82	0.19	0.21	0.02	0.36	0.14	0.17	0.38	0.38	0.25	0.36	0.40	0.41
4	5-Jul-11	21	80	2.04	0.24	0.22	0.02	0.33	0.23	0.14	0.38	0.47	0.23	0.39	0.48	0.45
5	12-Jul-11	28	73	1.98	0.25	0.24	0.03	0.48	0.26	0.09	0.42	0.42	0.24	0.35	0.41	0.47
6	21-Jul-11	37	86-95	1.75	0.22	0.22	0.02	0.40	0.21	0.07	0.46	0.34	0.17	0.37	0.31	0.42
7	26-Jul-11	42	93-98	1.76	0.22	0.22	0.02	0.35	0.24	0.07	0.34	0.36	0.17	0.38	0.33	0.45
8	2-Aug-11	49	83-92	1.76	0.22	0.22	0.02	0.35	0.25	0.09	0.40	0.34	0.17	0.37	0.31	0.45
9	9-Aug-11	56	81-84	1.79	0.22	0.22	0.02	0.36	0.25	0.09	0.35	0.34	0.18	0.37	0.32	0.47
10	16-Aug-11	63	77	2.01	0.22	0.23	0.02	0.36	0.33	0.09	0.47	0.37	0.22	0.42	0.34	0.50
11	23-Aug-11	70	96	1.75	0.22	0.22	0.02	0.36	0.31	0.09	0.32	0.37	0.19	0.32	0.35	0.48
12	30-Aug-11	77	84	1.77	0.22	0.22	0.02	0.33	0.30	0.09	0.36	0.34	0.19	0.36	0.33	0.48
13	6-Sep-11	84	73	1.58	0.22	0.22	0.02	0.33	0.28	0.09	0.34	0.29	0.19	0.34	0.30	0.44
14	13-Sep-11	91	71	1.79	0.22	0.22	0.02	0.36	0.32	0.09	0.36	0.33	0.20	0.38	0.34	0.48
15	21-Sep-11	99	68	1.80	0.23	0.23	0.02	0.37	0.34	0.09	0.37	0.33	0.19	0.37	0.35	0.50
16	27-Sep-11	105	78	1.80	0.23	0.23	0.02	0.35	0.33	0.09	0.36	0.31	0.19	0.35	0.35	0.47
17	4-Oct-11	112	70	1.73	0.22	0.22	0.02	0.35	0.34	0.09	0.36	0.33	0.19	0.34	0.35	0.48
18	10-Oct-11	118	71	1.79	0.22	0.22	0.02	0.32	0.16	0.08	0.21	0.15	0.09	0.28	0.16	0.23
19	20-Oct-11	128	58	1.81	0.23	0.23	0.02	0.40	0.20	0.08	0.27	0.18	0.10	0.36	0.22	0.30
20	25-Oct-11	133	61	1.01	0.10	0.10	0.02	0.38	0.17	0.07	0.26	0.17	0.11	0.38	0.17	0.25
21	31-Oct-11	139	59	1.31	0.19	0.18	0.02	0.31	0.25	0.07	0.46	0.23	0.17	0.32	0.25	0.36
22	8-Nov-11	147	46	1.55	0.19	0.19	0.02	0.36	0.32	0.08	0.31	0.29	0.18	0.40	0.33	0.45
23	11-Nov-11	150	51	1.52	0.20	0.20	0.02	0.35	0.33	0.08	0.37	0.26	0.17	0.35	0.36	0.40
24	22-Nov-11	161	54	2.76	0.39	0.00	0.04	0.63	0.63	0.17	0.62	0.37	0.25	0.65	0.71	0.56
25	29-Nov-11	168	47	2.86	0.40	0.41	0.04	0.64	0.76	0.16	0.64	0.43	0.29	0.68	0.80	0.61
26	6-Dec-11	175	10	3.08	0.31	0.44	0.04	0.65	0.84	0.18	0.65	0.45	0.29	0.69	0.81	0.65
27	14-Dec-11	183	39	0.63	0.06	0.06	0.01	0.06	0.18	0.03	0.12	0.07	0.05	0.15	0.18	0.16
28	20-Dec-11	189	30	0.66	0.07	0.07	0.01	0.04	0.18	0.03	0.10	0.12	0.08	0.13	0.17	0.18
29	28-Dec-11	197	42	0.66	0.07	0.07	0.01	0.05	0.20	0.03	0.11	0.13	0.12	0.13	0.17	0.18
30	5-Jan-12	205	61	1.86	0.00	0.00	0.00	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
31	10-Jan-12	210	54	1.88	0.00	0.00	0.00	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21

	T (oF)	P (psig)
Gas Mixture Section Rotameters were calibrated at:	70	15
Gas Injection Section Rotameters were calibrated at:	55	0

Table F4
Injected Volumes (CF) in each Zone (Shallow, Medium, and Deep)
H2T Implementation, Former Atlas Missile Site, York NE

Week #	Date	Total flowrate injected scfm	Total Volume injected cf	Total Cum. Gas Volume cf	Shallow flowrate injected scfm	Medium flowrate injected scfm	Deep flowrate injected scfm	Shallow Volume injected cf	Medium Volume injected cf	Deep Volume injected cf	Shallow Cum. Gas Volume cf	Medium Cum. Gas Volume cf	Deep Cum. Gas Volume cf
1	14-Jun-11	3.38	-	0	1.27	1.02	1.08	-	-	-	0	0	0
2	21-Jun-11	3.28	33,555	33,555	1.19	1.20	0.89	12,419	11,210	9,926	12,419	11,210	9,926
3	28-Jun-11	2.86	30,943	64,498	1.10	0.93	0.84	11,531	10,716	8,696	23,950	21,926	18,622
4	5-Jul-11	3.11	30,110	94,608	1.11	1.18	0.83	11,111	10,592	8,407	35,061	32,518	27,029
5	12-Jul-11	3.15	31,570	126,178	1.25	1.09	0.81	11,880	11,422	8,269	46,941	43,940	35,297
6	21-Jul-11	2.75	38,236	164,414	1.22	0.86	0.67	16,030	12,622	9,585	62,971	56,561	44,882
7	26-Jul-11	2.71	19,645	184,060	1.08	0.94	0.69	8,291	6,458	4,897	71,262	63,019	49,779
8	2-Aug-11	2.73	27,402	211,462	1.12	0.90	0.71	11,090	9,246	7,066	82,351	72,266	56,845
9	9-Aug-11	2.71	27,417	238,879	1.07	0.91	0.73	11,040	9,108	7,270	93,391	81,373	64,115
10	16-Aug-11	3.09	29,239	268,118	1.24	1.04	0.80	11,662	9,830	7,747	105,053	91,203	71,862
11	23-Aug-11	2.79	29,616	297,734	1.01	1.03	0.75	11,341	10,414	7,860	116,394	101,618	79,722
12	30-Aug-11	2.79	28,080	325,813	1.04	0.98	0.76	10,333	10,092	7,655	126,727	111,709	87,377
13	6-Sep-11	2.59	27,115	352,928	1.01	0.87	0.72	10,334	9,292	7,489	137,061	121,001	94,866
14	13-Sep-11	2.86	27,481	380,410	1.10	0.99	0.77	10,613	9,354	7,514	147,675	130,355	102,380
15	21-Sep-11	2.92	33,257	413,667	1.10	1.02	0.79	12,681	11,599	8,977	160,355	141,954	111,357
16	27-Sep-11	2.79	24,641	438,308	1.06	0.98	0.75	9,334	8,668	6,639	169,690	150,622	117,996
17	4-Oct-11	2.83	28,302	466,610	1.05	1.02	0.76	10,610	10,077	7,616	180,300	160,699	125,612
18	10-Oct-11	1.69	19,498	486,109	0.81	0.47	0.41	8,001	6,436	5,062	188,300	167,134	130,674
19	20-Oct-11	2.11	27,322	513,431	1.03	0.60	0.48	13,195	7,720	6,406	201,495	174,855	137,081
20	25-Oct-11	1.95	14,605	528,036	1.02	0.50	0.43	7,357	3,963	3,285	208,853	178,818	140,365
21	31-Oct-11	2.42	18,874	546,910	1.09	0.72	0.60	9,124	5,281	4,468	217,977	184,099	144,833
22	8-Nov-11	2.72	29,630	576,540	1.07	0.94	0.71	12,493	9,585	7,552	230,470	193,684	152,385
23	11-Nov-11	2.67	11,649	588,189	1.08	0.95	0.64	4,644	4,086	2,919	235,114	197,770	155,305
24	22-Nov-11	4.59	57,459	645,647	1.89	1.71	0.98	23,528	21,042	12,889	258,641	218,813	168,193
25	29-Nov-11	5.02	48,403	694,051	1.97	1.98	1.07	19,465	18,603	10,335	278,106	237,416	178,529
26	6-Dec-11	5.20	51,484	745,534	1.98	2.10	1.12	19,907	20,572	11,004	298,014	257,988	189,533
27	14-Dec-11	1.00	35,702	781,237	0.33	0.43	0.24	13,349	14,550	7,804	311,362	272,537	197,337
28	20-Dec-11	1.03	8,779	790,015	0.27	0.47	0.29	2,626	3,873	2,279	313,989	276,411	199,616
29	28-Dec-11	1.12	12,386	802,401	0.30	0.49	0.33	3,289	5,552	3,545	317,278	281,963	203,161
30	5-Jan-12	1.89	17,332	819,734	0.63	0.63	0.63	5,344	6,478	5,510	322,621	288,441	208,671
31	10-Jan-12	1.89	13,608	833,342	0.63	0.63	0.63	4,536	4,536	4,536	327,157	292,977	213,207

Sample Filled Checklist

Week 6

TABLE 1
WEEKLY CHECKLIST FOR O&M OF H_2T REMEDIATION SYSTEM

start end

Date: 7-22-11

Ambient temperature: 86° 95°

Personnel: Franklin Doerrmann / EA

General Weather Condition: Sunny, Hot

Task	Possible Range	Target Value/Range	Meet Target Value?	Measured Value	Measured Value after Adjustment	Notes / Comments
General						
1. Send copy of weekly checklist for previous week to GSI						
2. Are all the gas connections exterior to skid and above-ground piping in tact?	[✓ Yes]-No	Yes	[✓ Yes]-No			If no, shutdown and repair
3. Any sign of vandelism?	Yes-[✓ No]	No	[✓ Yes]-No			
4. Did Praxair change or refill any of the gases in the previous week?						If yes, report the # of cylinders replaced or the new liquid N_2 or Propane levels
- Nitrogen (Tank)	Yes-[✓ No]	--	--			
- Propane (Tank)	Yes-[✓ No]	--	--			
- Hydrogen (Cylinder)	Yes-[✓ No]	--	--			
- CO2 (Cylinder)	[✓ Yes]-No	--	--			2 cylinders right bank
- Helium (Cylinder)	Yes-No	--	--			
5. Leak test the connections on the gas supply tanks using soapy water						If yes, shutdown, repair, and note location of the leak
- Nitrogen leak?	Yes-[✓ No]	No	Yes-No			
- Propane leak?	Yes-[✓ No]	No	Yes-No			
- Hydrogen leak?	Yes-[✓ No]	No	Yes-No			
- CO2 leak?	Yes-[✓ No]	No	Yes-No			
- Helium leak?	Yes-No	No	Yes-No			
6. Leak test the connections on the skid using soapy water. Any leaks?	Yes-[✓ No]	No	[✓ Yes]-No			If yes, shutdown and repair
7. Leak test the connections on the injection wellheads using soapy water						If yes, shutdown and repair
- Hose to wellhead connection, leak?	Yes-[✓ No]	No	[✓ Yes]-No			
- Wellhead to well casing connection, leak?	Yes-[✓ No]	No	[✓ Yes]-No			
8. Inspect rotameters for unusual noises or vibrations. Any noted?	Yes-[✓ No]	No	[✓ Yes]-No			If yes, troubleshoot problem and repair
9. Inspect pressure gauges for unusual noises or vibrations. Any noted?	Yes-[✓ No]	No	[✓ Yes]-No			If yes, troubleshoot problem and repair

TABLE 1
WEEKLY CHECKLIST FOR O&M OF H_2T REMEDIATION SYSTEM

Date: ______________ Ambient temperature: ______________

Personnel: ______________ General Weather Condition: ______________

Task	Possible Range	Target Value/Range	Meet Target Value?	Measured Value	Measured Value after Adjustment	Notes / Comments
Gas Supply Tanks						
10. Nitrogen bulk tank trailer (inches of water column)	0-30 in-H_2O	>10 in-H_2O	[✓ Yes]-No	19.5	19.5	Report to Praxair for refill at 10 in-H_2O
11. Nitrogen bulk tank trailer (PSI) - Tank Pressure	0-150 psi	--	[✓ Yes]-No	245	245	
12. Nitrogen bulk tank trailer (PSI) - Tank Pressure at the Regulator - Right gauge	0-150 psi	--	[✓ Yes]-No	250	250	
13. Nitrogen bulk tank trailer (PSI) - Outlet Pressure at the Regulator - Left gauge	0-50 psi	See note	--	38	38	Adjust so that pressure at (30) is at target value
14. Hydrogen (PSI) - Right Bank	0-2500 psi	> 300 psi	Yes-[✓ No]	250	250	Switch to the full side if empty; Report to Praxair for replacement
15. Hydrogen (PSI) - Left Bank	0-2500 psi	> 300 psi	[✓ Yes]-No	2100	2100	Switch to the full side if empty; Report to Praxair for replacement
16. Hydrogen (PSI) - Outlet Pressure at the Regulator	0-50 psi	See note	--	27	27	Adjust so that pressure at (30) is at target value
17. Propane (tank %)	0-80%	> 20%	Yes-No	62	62	Report to Praxair for refill at 20%
18. Propane (PSI) - Tank Pressure at the Regulator - Right gauge	0-2500 psi	> 300 psi	Yes-No	100	100	
19. Propane (PSI) - Outlet Pressure at the Regulator - Left gauge	0-50 psi	See note	--	35	35	Adjust so that pressure at (30) is at target value
20. CO2 (PSI) - Right Bank	0-2500 psi	> 300 psi	Yes-No	1950	2000+	Switch to the full side if empty; Report to Praxair for replacement
21. CO2 (PSI) - Left Bank	0-2500 psi	> 300 psi	Yes-No	1150	1200	Switch to the full side if empty; Report to Praxair for replacement
22. CO2 (PSI) - Outlet Pressure at the Regulator	0-50 psi	15 psi	Yes-No	20	20	Adjust so that pressure at (30) is at target value
23. Helium (PSI) - Tank Pressure at the Regulator -Right gauge	0-2500 psi	> 300 psi	Yes-No	N/A	N/A	Report to Praxair for replacement
24. Helium (PSI) - Outlet Pressure at the Regulator - Left gauge	0-50 psi	15 psi	Yes-No	N/A	N/A	Adjust if outside target value

TABLE 1
WEEKLY CHECKLIST FOR O&M OF H_2T REMEDIATION SYSTEM

Date: ____________________ Ambient temperature: ____________________

Personnel: ____________________ General Weather Condition: ____________________

Task	Possible Range	Target Value/Range	Meet Target Value?	Measured Value	Measured Value after Adjustment	Notes / Comments
Injection Skid						
Gas Mixing Section						
25. Flow rate at Nitrogen Rotameter (scfm)	1.0-10 scfm	2.0 scfm	[✓ Yes]-No	2.0	2.0	Adjust if outside target value
25. Flow rate at Propane Rotameter (scfm)	0.13-1.3 scfm	0.25 scfm	[✓ Yes]-No	0.2	0.2	Adjust if outside target value
26. Flow rate at Hydrogen Rotameter (scfm) - LOW FLOW	0.2-2.0 scfm	0.25 scfm	[✓ Yes]-No	0.2	0.2	Adjust if outside target value
27. Flow rate at Hydrogen Rotameter (scfm) - HIGH FLOW	0.71-7.1 scfm	-- scfm	Yes-No	N/A	N/A	Adjust if outside target value. Not to be used unless instructed by GSI
28. Flow rate at CO2 Rotameter (scfm)	0.011-0.11 scfm	0.025 scfm	[✓ Yes]-No	0.025	0.025	Adjust if outside target value
29. Flow rate at Helium Rotameter (scfm)	0.88-8.7 scfm	1.0 scfm	Yes-No	N/A	N/A	Adjust if outside target value
30. Bleed Line (Manual Relief Valve) Pressure Gauge (PSI) - Left side	0-50 psig	15 psig	Yes-[✓ No]	7.25	8.0	Adjust (13, 16, 19, and 22) to reach to target value if outside target value
Gas Injection Section						
IW-1S						
31. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes-[✓ No]	7.75	8.25	Adjust if outside target value
32. Flow rate at IW-1S Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes-[✓ No]	0.3	0.28	Adjust if outside target value; Leave at max flowrate if below target
33. Pressure after the rotameter (psi)	0-50 psig	< 20 psi	--	4	3.25	Adjust if outside target value
IW-1M						
34. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes-[✓ No]	8.25	8.75	Adjust if outside target value
35. Flow rate at IW-1M Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes-[✓ No]	0.12	0.14	Adjust if outside target value; Leave at max flowrate if below target
36. Pressure after the rotameter (psi)	0-50 psig	< 30 psi	--	7.75	8.0	Adjust if outside target value

TABLE 1
WEEKLY CHECKLIST FOR O&M OF H_2T REMEDIATION SYSTEM

Date: ______________________

Personnel: ______________________

Ambient temperature: ______________________

General Weather Condition: ______________________

Task	Possible Range	Target Value/Range	Meet Target Value?	Measured Value	Measured Value after Adjustment	Notes / Comments
IW-1D						
37. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes [✓ No]	8.0	8.5	Adjust if outside target value
38. Flow rate at IW-1D Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes [✓ No]	0.04	0.05	Adjust if outside target value; Leave at max flowrate if below target
39. Pressure after the rotameter (psi)	0-50 psig	< 40 psi	--	8.0	8.25	Adjust if outside target value
IW-2S						
40. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes [✓ No]	8.0	8.5	Adjust if outside target value
41. Flow rate at IW-2S Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes [✓ No]	0.33	0.28	Adjust if outside target value; Leave at max flowrate if below target
42. Pressure after the rotameter (psi)	0-50 psig	< 20 psi	--	5	4	Adjust if outside target value
IW-2M						
43. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes [✓ No]	8.25	9	Adjust if outside target value
44. Flow rate at IW-2M Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes [✓ No]	0.2	0.21	Adjust if outside target value; Leave at max flowrate if below target
45. Pressure after the rotameter (psi)	0-50 psig	< 30 psi	--	7	7.25	Adjust if outside target value
IW-2D						
46. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes [✓ No]	7.75	8.25	Adjust if outside target value
47. Flow rate at IW-2D Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes [✓ No]	0.10	0.10	Adjust if outside target value; Leave at max flowrate if below target
48. Pressure after the rotameter (psi)	0-50 psig	< 40 psi	--	7.5	8	Adjust if outside target value
IW-3S						
49. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes [✓ No]	7.5	8.0	Adjust if outside target value
50. Flow rate at IW-3S Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	[✓ Yes] No	0.28	0.28	Adjust if outside target value; Leave at max flowrate if below target
51. Pressure after the rotameter (psi)	0-50 psig	< 20 psi	--	5.25	5.5	Adjust if outside target value

TABLE 1
WEEKLY CHECKLIST FOR O&M OF H_2T REMEDIATION SYSTEM

Date: ______________________ Ambient temperature: ______________________

Personnel: ______________________ General Weather Condition: ______________________

Task	Possible Range	Target Value/Range	Meet Target Value?	Measured Value	Measured Value after Adjustment	Notes / Comments
IW-3M						
52. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes-[✓ No]	8.0	8.5	Adjust if outside target value
53. Flow rate at IW-3M Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes-[✓ No]	0.18	0.19	Adjust if outside target value; Leave at max flowrate if below target
54. Pressure after the rotameter (psi)	0-50 psig	< 30 psi	--	7.5	8	Adjust if outside target value
IW-3D						
55. Pressure before the rotameter (psi)	0-50 psig	15 psi	Yes-[✓ No]	7.75	8	Adjust if outside target value
56. Flow rate at IW-3D Rotameter (scfm)	0.15-1.5 scfm	0.28 scfm	Yes-[✓ No]	0.25	0.27	Adjust if outside target value; Leave at max flowrate if below target
57. Pressure after the rotameter (psi)	0-50 psig	< 40 psi	--	7	7.5	Adjust if outside target value
Injection Wells						
58. Pressure at IW-1S Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
59. Pressure at IW-1M Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
60. Pressure at IW-1D Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
61. Pressure at IW-2S Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
62. Pressure at IW-2M Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
63. Pressure at IW-2D Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
64. Pressure at IW-3S Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair
65. Pressure at IW-3M Wellhead (psi)	0 - > 5 psi	> 0 psi	Yes-[✓ No]	0	Bay Gauge	If no, troubleshoot problem, provide any possible explanation, repair
66. Pressure at IW-3D Wellhead (psi)	0 - > 5 psi	> 0 psi	[✓ Yes]-No	75	75	If no, troubleshoot problem, provide any possible explanation, repair

TABLE 1
WEEKLY CHECKLIST FOR O&M OF H_2T REMEDIATION SYSTEM

Date: ______________________

Ambient temperature: ______________________

Personnel: ______________________

General Weather Condition: ______________________

Task	Possible Range	Target Value/Range	Meet Target Value?	Measured Value	Measured Value after Adjustment	Notes / Comments
Weekly O&M Evaluation Results						
67. Is there any leak or damage in the system?	Yes-[✓ No]	No	[✓ Yes]-No			If yes, shutdown and repair
68. Are all the regulators adjusted to the target value/range?	[✓ Yes]-No	Yes	[✓ Yes]-No			If no, adjust if outside target value
69. Are all the rotameters adjusted to the target value/range?	Yes-[✓ No]	Yes	Yes-[✓ No]	See Below		If no, adjust if outside target value
70. Is hydrogen valve on the skid set to the "LOW FLOW" rotameter?	Yes-No	Yes	Yes-No			If no, switch the hydrogen valve to operate the "LOW FLOW" side

NOTES:
Describe any problems, unusual noises, vibrations, wear, or damage, etc.
Describe any corrective actions taken or planned.

All rotameters except 1S, 2S, 3S are at top of adjustment - No adjustment left

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix G: Carbon Footprint Calculations

CARBON FOOTPRINT CALCULATION: H_2 INJECTION VS. SVE
High End Cases

H_2 System for one year

Carbon footprint from gas manufacture			
Volume of soil	84,823	ft3	
Volume of soil	2,401,920	liters	
Porosity	0.25		
Pore volume	21,206	scf	
Assume 1 pore per week	1	PVs per week	
Volume per year	1,102,699	scf per year	
Carbon footprint for H_2 generation			
% H_2	10%		
total volume H_2 per year	110,270	scf per year	
total volume per year	3,122,496	liters per year	
moles of H_2	128,648	moles per year	
mass of H_2	257	kg H_2	
moles CH_4	0.25	moles CH_4 per mole H_2 generated	
moles of CH_4	32,162	moles CH_4	
	32,162	moles CO_2	
	1,415	kg CO_2	
	1.6	tons CO_2	
Carbon footprint of N_2 (assume liq N_2)			
% N_2	79%		
total volume N_2 per year	871,132	scf of N_2	
	24,667,718	liters of N_2	
	1,016,321	moles N_2 per yr	
	28,457	kg per year	
	0.0183	kg CO_2 per kg N_2	(http://en.allexperts.com/q/Environmental-Science-1471/2008/10/carbon-footprint-manufacturing-liquid.htm)
	521	kg CO_2	
	0.6	tons CO_2	
Carbon footprint of LPG			
% LPG	10%		
total volume LPG per year	110,270	scf of LPG	
	3,122,496	liters of LPG	
	128,648	moles LPG per yr	
	3,602	kg per year	
	0.8	kg CO_2 per kg LPG	(http://www.epa.gov/greenpower/pubs/calcmeth.htm)
	2,943	kg CO_2	
	3.2	tons CO_2	
Carbon footprint of CO_2			
% CO_2	1%		
total volume CO_2 per year	11,027	scf of CO_2	
	312,250	liters of CO_2	
	12,865	moles CO_2 per yr	
	566	kg per year	
	0.6	tons CO_2	
Carbon footprint from transport of gas to site			
assume 100 miles	800	miles per year	Assume 4 trips for CO_2 and H_2, and 4 trips LOX truck
assume 5 mpg (SRT)	160	gallons	
	25.8	lbs CO_2 per gallon	
	4,128	lbs CO_2	
	1,876	kg CO_2	
	2.1	tons CO_2	
TOTAL	**7.3**	mtons CO_2	
TOTAL	**8.1**	tons CO_2	
Amount of TCE Converted to Ethane			
H_2 available	320	kg H_2	
Conversion at 100%	22	kg TCE per kg H_2	
Assumed efficiency	1%	efficiency percentage	
Amount of TCE converted	70.4	kg TCE	

GAC Calculation

GAC System for one year (Constant Operation)			
Volume of soil	84,823	ft3	
Volume of soil	2,401,920	liters	
Density of soil	1.6	kg/L	
Mass of soil	3,843,072	kg	
Mass TCE removed, treated	70.4	kg	(assume same removal as H_2 process running at 1% efficiency)
FROM SRT:			
Regeneration	1.9	metric tons	(from SRT: 10 kg GAC per kg TCE; 2.7 kg CO_2 per kg GAC)
	2.1	tons per year	
Electricity (5 hp blower)	**19.0**	tons per year (from SRT)	
Carbon footprint from transport of GAC to and from site			
assume 100 miles 1 trips per year	100	miles per year	
assume 5 mpg (SRT)	20	gallons	
	25.8	lbs CO_2 per gallon	
	516	lbs CO_2	
	235	kg CO_2	
	0.23	metric tons	
	0.3	tons per year	
TOTAL	**19.4**	mtons CO_2	
TOTAL	**21.4**	tons CO_2	

CARBON FOOTPRINT CALCULATION: H2 INJECTION VS. SVE

Low End Cases

H2 System for one year

Carbon footprint from gas manufacture			
Volume of soil	84,823	ft3	
Volume of soil	2,401,920	liters	
Porosity	0.25		
Pore volume	21,206	scf	
Assume 1 pore per week	1	PVs per week	
Volume per year	1,102,699	scf per year	
Carbon footprint for H2 (H2 generator)			
% H2	20%		
total volume H2 per year	220,540	scf per year	
Power consumption	350	watt	Power consumption for on-site H2 Generator
	8,760	hours per year	
	3,066	kWh	
	1.34	lbs CO2 per kWh	
	1,867	kg CO2	
	2.1	tons CO2	
Carbon footprint of N2 (PSA N2 Generator)			
Power consumption	120	watt	Power consumption for on-site N2 Generator
	8,760	hours per year	
	1,051	kWh	
	1.34	lbs CO2 per kWh	
	640	kg CO2	
	0.7	tons CO2	
Carbon footprint of CO2			
% CO2	1%		
total volume CO2 per year	11,027	scf of CO2	
	312,250	liters of CO2	
	12,865	moles CO2 per yr	
	566	kg per year	
	0.6	tons CO2	
Carbon footprint from transport of gas to site			
assume 100 miles	400	miles per year	Assume 4 trips for CO2
assume 5 mpg (SRT)	80	gallons	
	25.8	lbs CO2 per gallon	
	2,064	lbs CO2	
	938	kg CO2	
	1.0	tons CO2	
TOTAL	**4.0**	mtons CO2	
TOTAL	**4.4**	tons CO2	
Amount of TCE Converted to Ethane			
H2 available	320	kg H2	
Conversion at 100%	22	kg TCE per kg H2	
Assumed efficiency	1%	efficiency percentage	
Amount of TCE converted	70.4	kg TCE	

SVE System with GAC for one year

GAC System for one year (Pulsed Operation)			
Volume of soil	84,823	ft3	
Volume of soil	2,401,920	liters	
Density of soil	1.6	kg/L	
Mass of soil	3,843,072	kg	
Mass TCE removed, treated	70.4	kg	(assume same removal as H2 process running at 1% efficiency)
FROM SRT:			
Regeneration	1.9	metric tons	(from SRT: 10 kg GAC per kg TCE; 2.7 kg CO2 per kg GAC)
	2.1	tons per year	
Electricity (5 hp blower)	**5.3**	tons per year (from SRT)	
Carbon footprint from transport of GAC to and from site			
assume 100 miles 1 trips per year	100	miles per year	
assume 5 mpg (SRT)	20	gallons	
	25.8	lbs CO2 per gallon	
	516	lbs CO2	
	235	kg CO2	
	0.23	metric tons	
	0.3	tons per year	
TOTAL	**6.9**	mtons CO2	
TOTAL	**7.7**	tons CO2	

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix H: Quality Assurance Project Plan

QUALITY ASSURANCE PROJECT PLAN

ENHANCED ATTENUATION OF UNSATURATED CHLORINATED SOLVENT SOURCE ZONES USING DIRECT HYDROGEN DELIVERY

ESTCP Project ER-1027

TABLE OF CONTENTS

LIST OF ACRONYMNS

TABLES

LIST OF ACRONYMNS

ASTM	American Society of Testing Materials
bgs	Below ground surface
CCC	Calibration Check Compound
CMS	Corrective Measures Study
COC	Chemical of Concern
DO	Dissolved Oxygen
DQCR	Daily Quality Control Report
DQO	Data Quality Objective
FCR	Field Change Request ft Feet
GC/MS	Gas Chromatograph/Mass Spectrometer
HASP	Health and Safety Plan
HPLC	High Performance Liquid Chromatography
IDL	Instrument Detection Limit lb Pounds
LCS	Laboratory Control Sample
LIMS	Laboratory Information Management System
LTO	Laboratory Task Order mg Milligram
MDL	Method Detection Limit
mL	Milliliter
MS	Matrix Spike
MSD	Matrix Spike Duplicate
MQL	Method Quantitation Limit
ng	Nanogram
NIST	National Institute of Standards and Testing
OVA	Organic Vapor Analyzer
PE	Performance Evaluation
PCMT	Potential Corrective Measure Technology
PR/VSI	Preliminary Review/Visual Site Inspection
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RF	Response Factor
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
RWBS	Reagent Water Blank Spike
SOP	Standard Operating Procedure
SPCC	System Performance Check Compound
TCL	Target Compound List
µg	Microgram
µL	Microliter
USEPA	United States Environmental Protection Agency
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound
VTSR	Validated Time of Sample Receipt

1.0 PROJECT DESCRIPTION

1.1 Project Overview

This Quality Assurance Project Plan (QAPP) has been prepared for the Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery investigation to be conducted by GSI Environmental, Inc. (GSI). The Demonstration Plan that accompanies this QAPP describes the project background and investigation objectives, including the site description and history, the project objectives, the injection and sampling program design and rationale, and the project schedule.

This QAPP describes data quality objectives (DQOs) as well as the field and laboratory procedures to be implemented in order to fulfill the project objectives. This QAPP was prepared in general accordance with applicable U.S. Environmental Protection Agency (EPA) guidance.

1.2 Objective of the QAPP

The general objective of quality assurance is to collect defensible environmental data of known quality that is adequate for the intended use of the data. To accomplish this objective, data quality objectives (DQOs) have been developed for the H_2 Injection Study. DQOs are qualitative and quantitative statements which clarify the study objectives, define the most appropriate types of data to collect, determine the most appropriate conditions from which to collect data, and specify acceptable decisions regarding the data's usage (USEPA 1994a). The DQO planning process is a tool to determine which type, quality, and quantity of data will be sufficient to support the overall project objectives.

2.0 PROJECT ORGANIZATION AND RESPONSIBILITY

2.1 Project Organizational Chart

GSI has overall responsibility for implementation of the Demonstration Plan. PTS Geolabs, Inc. (PTS), in Houston, Texas will analyze soil cores for physical properties, TestAmerica Laboratories, Inc., in Houston, Texas will analyze soil samples for COCs, and SPL will analyze air samples for COCs. Responsibilities for project management, quality assurance, laboratory, and field personnel are defined below.

2.2 Management Responsibilities

GSI Principal Investigator: The GSI Principal Investigator (PI) will be responsible for implementing the project. The primary function of the PI will be to ensure that technical, financial, and scheduling objectives are achieved. The PI, supported by the GSI Project Manager and other GSI personnel will:

- Define project objectives and develop a detailed demonstration plan schedule;
- Establish project policy and procedures to address the specific needs of the project;
- Acquire and apply resources as needed to ensure performance within budget and schedule constraints;
- Orient field personnel and support staff to the project's special considerations;
- Review the work performed on each task to ensure quality, responsiveness, and timeliness;
- Review and analyze work performed relative to planned requirements and authorizations;
- Approve reports and deliverables before submittal to ESTCP;
- Retain ultimate responsibility for preparation and quality of interim and final reports; and
- Represent the project team at meetings.

GSI Health and Safety Officer: The GSI Health and Safety Officer will be responsible for overall health and safety practices associated with the field work. Specific functions and duties will include the following tasks:

- Establish the requirements of the project Health and Safety Plan (HASP);
- Arrange or conduct audits of field activities to ensure that proper health and safety procedures are being used;
- Communicate with the PI, GSI Technical Staff, and GSI Field Technical Staff concerning project issues related to health and safety.

GSI QA Manager: The GSI QA Manager will report directly to the PI and will be responsible for reviewing QA documentation to evaluate compliance with sampling and analytical procedures.

GSI Technical Staff: The GSI Technical Staff will assist the PI in field activities such as collecting soil samples and soil cores, performing field analyses, and recording field measurements and office activities such as data review and report development. GSI Technical Staff will be familiar with relevant project reports and plans including the Demonstration Plan, the QAPP, and the Health and Safety Plan.

Laboratory Project Manager: The Project Manager will report to the PI. The Project Manager will be responsible for ensuring laboratory resources are available as needed for the project and will provide oversight of final laboratory reports.

Laboratory QA Manager: The QA Manager will have overall responsibility for data generated in the laboratory. The QA Manager will be independent of the laboratory production responsibilities, but will communicate data issues through the Project Manager. In addition, the QA Manager will

- Monitor the day-to-day quality of the laboratory data.
- Maintain and review all quality control data.
- Conduct internal performance and system audits to ensure compliance with laboratory protocols.
- Review and maintain updated Standard Operating Procedures (SOPs).
- Prepare Performance Evaluation reports and corrective action reports.

Laboratory Technical Staff: The Technical Staff will be responsible for sample analysis and identification of necessary corrective actions. Staff members will report directly to the Project Manager.

3.0 QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT DATA

In order to provide technically sound and defensible results, data quality objectives (DQOs) have been developed for the laboratory analysis of VOC concentrations and soil core properties during the study. DQOs have been developed with a consideration of the level of detail available in the reference method to be used for analysis. Consequently, detailed DQOs have been developed for data produced during analysis of VOC concentrations in accordance with USEPA SW-846 methods, and a limited set of DQOs has been developed for data produced during analysis of soil core properties properties by API or ASTM methods.

For the analysis of VOC concentrations by USEPA SW-846 and TO-15 methods, quantifiable

DQOs have been developed for accuracy, precision, and completeness. Acceptable levels of non-quantifiable data quality parameters (i.e., representativeness and completeness) will be assured through the proper implementation of field and laboratory SOPs.

For the analysis of VOC concentrations in vapor associated with the field portable GC instrument, project DQO’s have been established that are appropriate for demonstrating acceptable instrument performance.

Definitions, development, and interpretation of DQO parameters and detection limits are presented below.

3.1 Precision

3.1.1 Definition

Precision is a measure of the degree to which two or more measurements are in agreement as a result of repeated application of a process under specific conditions. The overall precision and reproducibility of a measurement system is affected by variations introduced by sampling and analysis.

3.1.2 Field Precision Objectives

Field precision will be assessed by collecting and analyzing field duplicates at a minimum rate of 1 duplicate per 20 analytical samples. The field precision objective for laboratory analysis of VOCs is ±30% relative percent difference (RPD) between field duplicates. No other analyses will have field precision objectives.

3.1.3 Laboratory Precision Objectives

Laboratory precision objectives for laboratory QC samples are listed in **Table 2.1**. Precision objectives for analysis of VOCs are listed in **Table 2.2**. In accordance with method requirements, laboratory precision will be assessed by analysis of various duplicates sets (e.g., laboratory duplicates, reagent water blank spike duplicates, matrix spike duplicates).

3.2 Accuracy

3.2.1 Definition

Accuracy is the degree of agreement between an observed value (or an average of several values) and an accepted reference value. Deviations from standard values result from cumulative inconsistencies in the measurement system. Potential sources of variance include (but are not limited to) sample collection, preservation, and handling procedures; matrix effects, and analytical procedures.

3.2.2 Field Accuracy Objectives

Accuracy in the field will be assessed through the use of trip blanks and through the adherence to all sample handling, preservation, and holding times. One trip blank will be submitted for laboratory analysis each day that samples are submitted for analysis of VOC concentration (see **Table 2.4**). Accuracy objectives for field samples will be met if concentrations of VOCs are below project quantitation limits in the trip blank.

Assessment of field accuracy for VOC analysis by the portable GC will be determined by the periodic analysis of control samples and blank samples (ambient air).

3.2.3 Laboratory Accuracy Objectives

In accordance with method requirements, laboratory accuracy will be assessed by the analysis of various spike samples (e.g., spikes, matrix spikes, control standards, interference check samples, standard reference samples, and surrogates). Where required by the method, an LCS will consist of a standard purchased from a source other than that for the calibration standards. The use of an LCS will be based on the availability of a USEPA, National Institute of Standards and Testing (NIST), or commercially certified LCS. Accuracy objectives for laboratory samples will be met if percent recoveries fall within the limits shown on **Tables 2.2** and **2.3**.

3.3 Completeness

3.3.1 Definition

Completeness is expressed as the percentage of valid data points obtained from a measurement system or method.

3.3.2 Field Completeness Objectives

Field completeness will be assessed for target parameters by comparing the number of valid field samples to the total number of field samples collected. The validity of field samples will be assessed by comparison of documented field practices to requirements of this QAPP and the accompanying Demonstration Plan. The completeness objective for field samples will be at least 90%.

3.3.3 Laboratory Completeness Objectives

The results of a laboratory analysis will be considered valid if predetermined data quality objective standards are met or exceeded for precision and accuracy. Completeness requirements for other analytical parameters will be based on available QC data provided in accordance with applicable API and ASTM methods. Laboratory completeness will be assessed for VOCs by comparing the number of valid measurements to the total number of measurements. Completeness for laboratory samples will be at least 95%.

3.4 Representativeness

3.4.1 Definition

Representativeness is a qualitative parameter that expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. As such, representativeness describes whether samples collected, or the aliquots selected by the laboratory for analysis, are sufficient in number, type, location, frequency, and size to be characteristic of the substance analyzed.

3.4.2 Measures to Ensure Representativeness of Field Data

Field representativeness will be satisfied by following the sample collection procedures specified in the QAPP. In addition, collection of duplicate samples will provide a measure of the variability of analyte present in a particular sample volume.

3.4.3 Measures to Ensure Representativeness of Laboratory Data

Representativeness in the laboratory will be ensured by using the proper analytical procedures, meeting sample holding times, and analyzing and assessing field duplicates.

3.5 Comparability

3.5.1 Definition

Comparability is an expression of the confidence with which one data set can be compared with another.

3.5.2 Measures to Ensure Comparability of Field Data

Comparability of field data will be assured by adhering to standard sampling procedures described in the QAPP, using traceable calibration standards; using standard measurement and reporting units; and using the pre-determined acceptance criteria for precision and accuracy presented in this QAPP.

3.5.3 Measures to Ensure Comparability of Laboratory Data

Comparability of laboratory data will be assured by adhering to standard analytical procedures described in this QAPP, using traceable calibration standards; using standard measurement and reporting units; and using pre-determined acceptance criteria for precision and accuracy.

3.6 Level of Quality Control Effort

3.6.1 Level of Field Quality Control Effort

Requirements for collection of field quality control samples are provided on **Table 2.4**. Field precision will be assessed by collecting and analyzing field duplicate samples. For soil samples, matrix effects on the sample analysis will be assessed through the collection and analysis of matrix spikes and duplicates. Additional sample volumes will be collected in order to prepare MS/MSD sets for soil samples.

Sampling accuracy will be assessed by collecting and analyzing field duplicates. Results from the analysis of trip blanks will be used to assess the potential for sample contamination during sample shipment, handling, and storage.

3.6.2 Level of Laboratory Quality Control Effort

Requirements for laboratory QC samples are provided on **Table 2.1**. Results from method blank samples for all constituents analyzed will be reviewed to assess potential sources of contamination associated with laboratory procedures. Laboratory method blanks will be prepared and analyzed at a frequency of 1 per sample batch (i.e., each group of samples prepared and analyzed as a group, not to exceed 20 samples).

Results for MS/MSD pairs will be reviewed to evaluate the effect of the sample matrix on the sample preparation and measurement methodology. MS/MSD sets will be analyzed at a frequency of 1 per sample batch (i.e., each group of samples prepared and analyzed as a group, not to exceed 20 samples). Recovery and relative percent difference targets for MS/MSD sets are listed on **Table 2.2**.

Accuracy for the analysis of volatile organic compounds will be assessed by evaluating the recoveries of surrogate compounds spiked into all samples. Laboratory control limits for surrogates are provided on **Table 2.3** of this QAPP.

4.0 SAMPLING PROCEDURES

Field sampling procedures employed during the H_2 Injection demonstration study will be consistent throughout the project, thus providing data representative of site conditions, comparability with analytical considerations, practicality, and simplicity. Procedures for installation of soil borings and all aspects of collection, preservation, and transport of soil core samples are provided in the Demonstration Plan or this QAPP.

Method specified sample containers, preservatives, and holding times are summarized for air and soil samples on **Table 3**.

4.1 Soil Sampling Procedures

Soil Sample Collection

Samples will be collected using standard sample tooling for the drilling methods selected. Continuous cores will be collected from boreholes in the targeted intervals, and samples will be collected by first removing the outer layer of each core to obtain undisturbed fresh soil.

Sampling Equipment

Dedicated equipment will be used to collect samples from soil cores. This includes metal trowels and knives. Encore samplers will not be used as part of this study.

Soil Sample Handling

Samples will be transferred immediately to appropriate method-specific sampling containers (glass with screw-top caps). Labels for all samples will identify the sampling location and time, and shipments will be prepared in a manner consistent with method and laboratory protocols (e.g., proper containers and preservatives, cooled to 4ºC to minimize volatilization and other losses).

4.2 Vapor Sampling Procedures

Purging prior to sampling

The test points designated for soil gas sampling will be fitted with a sealing device to prevent atmospheric air from entering the well casing. Prior to sampling, a predetermined volume of air will be purged from the casing to ensure that the soil gas sample is representative of vapors associated with the soils in the vadose and are not being influenced by stagnant air in the casing. Depending on the porosity of the vadose soils, a vacuum may be created in the casing during the purging process. Care should be taken to purge slowly enough that the seal on the casing remains intact and atmospheric air is not allowed into the casing.

Field GC sample collection

As part of the field sampling program, a field portable GC instrument (Photovac Voyager or HAPSITE ER) will be used to measure VOC concentrations in the soil gas points. Soil vapor samples will be drawn using a vacuum pump and transferred to a 1 L tedlar bag until a sufficient sample volume has been collected. A 50 uL gas tight syringe will be used, if needed, to transfer the vapor sample from the tedlar bag to the sample port on the portable GC instrument.

5.0 CUSTODY PROCEDURES

In order to generate defensible analytical data, sample custody procedures will be implemented for handling environmental samples and associated records during sample collection, shipment, transfer, and storage. These procedures will support the authenticity of sampling data by tracing samples from the time of collection, through analysis, data generation, and report preparation.

A sample is considered to be within custody if the item is i) in one's physical possession; or ii) in one's view after being in one's physical possession; or iii) in a locked receptacle after being in one's physical possession; or iv) in a designated secure area. Procedures described below address custody during field sample collection, laboratory analysis, and file storage.

When completing written records to document sample custody, errors will be corrected by drawing a single line through the error, re-entering the correct information, and initialing and dating the correction.

5.1 Field Custody Procedures

Sample containers provided by the laboratory for this project will be shipped by common carrier or other suitable method in sealed coolers to a location designated by the PI. The laboratory will include a shipping form/laboratory chain-of-custody listing containers shipped and the purpose of each container. Containers will be considered in the custody of the laboratory until received by GSI or a designated representative. Upon receipt, the shipment will be checked to verify that all containers are intact. The containers will be maintained in the custody of the receiver in a clean, secure area until used for sample collection.

Procedures described below address custody during field sample collection, laboratory analysis, and file storage for the data collected in the study

- Field sampling personnel will be personally responsible for the care and custody of the samples until transferred or properly dispatched.
- Sample bags, bottles and vessels will be labeled with sample numbers and locations at the time of sample collection.
- Sample labels will be completed with permanent ink.

After collection, field sampling personnel will maintain sample custody in accordance with the following procedure:

1. The sample label affixed to the container will be inspected to confirm that all of the required information has been provided.

2. If appropriate, the sample container will be sealed in a zip-lock plastic bag, wrapped in bubble pack, and packed in a wet-ice or dry-ice cooler in a manner to minimize shifting or movement.

3. For each set of samples sent to the laboratory, a triplicate chain-of-custody form will be completed. Information on the chain-of-custody form and the sample container labels will be checked against the field logbook entries and the samples will be recounted. The information contained on the chain-of-custody form will include the following:

- Site name and address or location;
- Project number;

- Date of sample collection;
- Name of sampler responsible for sample submittal;
- Identification of samples that accompany the form including
- Field ID number,
- Number of samples,
- Date/time collected,
- Sample container type, volume, preservative,
- Parameters/methods of interest,
- Data level requirement (e.g., Level II),
- Comments about sample conditions;
- Signature of person relinquishing custody and signature of person accepting custody, plus date and time; and
- Identification of common carrier.

4. If a commercial courier service (e.g., Federal Express) transports the samples to the laboratory, the chain-of-custody form will be signed by a member of the field team, and a copy retained by the field team. The remaining two copies of the form will be sealed in a zip-type plastic bag and placed in the cooler with the samples. The cooler will be sealed with packaging tape and two custody seals signed and dated by a member of the field team. Custody seals will be placed on the exterior of the cooler over the lid and sides. Package routing documentation maintained by the courier service will serve as chain-of-custody documentation during shipment, because commercial couriers do not sign chain-of-custody forms.

5. If samples are picked up by a laboratory representative, a member of the field team will sign the chain-of-custody record indicating that the samples have been transferred to the lab courier. The lab courier will also sign the form, indicating that the samples have been transferred to his or her custody. One copy of the chain-of-custody form will be retained by the field team and the remaining two copies will be sealed in a zip-type plastic bag and placed in the cooler chest with the samples.

5.2 Laboratory Custody Procedures

For the H_2 Injection study, normal laboratory custody procedures will be implemented. Samples received and logged into the laboratory will remain in the custody of the laboratory personnel at the laboratory until disposal.

5.2.1 Sample Receipt and Inspection

Upon arrival at the laboratory, samples will immediately be taken to the sample receiving area and logged into the laboratory sample registry in which the date and time of sample receipt will be recorded. The shipping container will be opened immediately and the temperature of the shipping container measured and documented on the appropriate laboratory form.

Shipping containers having custody seals will be inspected for integrity upon arrival at the laboratory. The appropriate space on the chain-of-custody (i.e., "custody intact") will be checked "Y" for yes or "N" for no. If tampering of the custody seal is apparent, the sample custodian will immediately contact the Laboratory Project Manager who will be responsible to notify the GSI Project Manager.

Information on the chain-of-custody form will be checked against the sample labels and then signed by the sample custodian. The sample custodian will also inspect sample containers for leakage. A multi-phase sample which has leaked will not be acceptable for analysis, because the sample integrity has been altered. Samples in plastic containers appearing to bulge or evolve gas will be treated with caution, because toxic fumes or material of an explosive nature may be present. Discrepancies between information on sample labels and information provided on the chain-of-custody form or broken/altered samples will be resolved with the Laboratory Project Manager before the sample is assigned for analysis.

If a custody problem occurs, the sample custodian will immediately notify the Laboratory Project Manager. The Laboratory Project Manager will resolve the custody problem as soon as practical and notify the GSI Project Manager, if necessary. After notification, an initialed note will be made on the custody form which states who was notified, reason for notification, and resolution, if applicable.

5.2.2 Internal Tracking and Numbering

The sample custodian or designee will have responsibility for maintaining sample receipt logbooks, assigning a project log number to the samples, signing the chain-of-custody form, reporting inconsistencies to the Laboratory Project Manager, and distributing samples to the laboratory sections in accordance with applicable analytical procedures. The laboratory section sample custodian is responsible for ensuring that samples are placed in storage, for monitoring conditions in sample storage areas, and maintaining records for chain-of-custody within the laboratory. The Project Manager or designee is responsible for initiating paperwork for report files and analytical worksheets and logging samples into the Laboratory Information Management System (LIMS), if applicable.

Each sample will be assigned a unique laboratory sample number at the time of log-in to facilitate tracking of samples, extracts, and digests during analysis. The laboratory sample number will be recorded on the chain-of-custody form and Sample Registry, and logged into the computerized LIMS, if applicable. Any accompanying paper work will be placed in a project file until the order is completed. The laboratory project identification number will be recorded on all containers submitted in the project shipment.

After initiating a new log-in number, the Project Manager or designee will enter electronically or otherwise record relevant sample information, as follows:

- Laboratory sample number
- Client project identification
- Date received/date due
- Matrix/sample identification
- Date and time of sample collection
- Storage location/container size/container type/preservative
- Analyses required
- Problems/special instructions

After assignment of the project identification number, samples will be labeled to identify the project number and sample designation. The samples will then be dispersed to the appropriate sample storage area. As required, sample storage temperature logs will be maintained for storage refrigerators or freezers to assure maintenance of proper sample temperature throughout the analyses.

5.2.3 Internal Laboratory Custody Transfers

An internal laboratory chain-of-custody record is not required when samples are transferred to different areas of the laboratory.

5.2.4 Laboratory Storage Areas

As required, samples and extracts will be stored in uniquely identified refrigerated storage units located in secure areas of the laboratory. Samples are logged into the various department storage areas prior to preparation, analysis, or disposal. Samples to be analyzed for volatile organic compounds (VOCs) will be segregated from other samples. Samples will be stored separately from standards.

On a daily basis, the sample custodian or appropriate designee will measure and record the temperature of each refrigerator or freezer used for sample storage. Temperature records will be reviewed on a monthly basis to note any trends or inconsistencies. For samples to be analyzed for VOCs and SVOCs, the acceptable range for sample storage is 4±2°C. The sample custodian will notify the Laboratory Project Manager of any refrigerator temperature problem which cannot be corrected by simple thermostat adjustment. A list of emergency repair numbers will be attached to the exterior of each refrigeration unit.

5.2.5 Requirements for Sample Disposal

Unless requested otherwise, digests and extracts, these will be disposed of as soon as holding times have expired or 30 days after results are reported to GSI.

If analyses performed on composite aqueous samples meet public sewer system discharge criteria, the composite samples will be neutralized, if necessary, and discharged into the public sewer system. Tests performed on the composite samples must demonstrate that the levels of contaminants present do not exceed hazardous characteristics.

5.2.6 Inter-Laboratory Custody Transfers

Under normal circumstances, samples will be analyzed by portable GC, SPL in Houston, Texas, TestAmerica in Houston, Texas, or PTS Geolabs in Houston, Texas. In the event of a natural disaster (e.g., a hurricane), samples to be analyzed by one laboratory may be sent to another in-network laboratory for analyses. When samples are transferred to another laboratory in the network, a chain-of-custody form will be initiated at shipping time by the sample custodian. A completed and signed fax of the Interdivisional Shipping Log will be sent to the receiving division custody department. This inter-laboratory chain-of-custody form will be sent with the samples and upon arrival at the division laboratory, laboratory custody procedures described above will be followed.

5.2.7 Data Archiving, Storage and Final Evidence File

Laboratory records will be maintained in a secure area with other associated project records. Hard copies of final reports, chain-of-custody forms, and any ancillary documentation pertinent to the project will be stored in a secured storage area. Analytical data stored in a LIMS will be maintained under a high level of data security by the use of passwords and file access/lock codes. At the end of a project, all custody forms will be returned to the laboratory project manager. Copies of custody information will be retained in the reporting laboratories' client files. Hard copies of reports, chain-of-custody forms and sample registries will be kept by the laboratory for a period of three years. Raw data and bench data files will be kept by the laboratory for a period of three years.

5.3 Final Evidence Files

A project file will be developed for the study data including the following items: reports, field notes, laboratory reports, signed chain-of-custody forms, sampling procedures, and any other pertinent documents, including, but not limited to the following items:

- Standard operating procedures
- Field notes and field logbooks
- Laboratory reports and data deliverables
- Signed chain-of-custody documentation (tags, air bills, signed forms)
- Photographs

These items will be stored in a cabinet at the GSI office and access limited to concerned project personnel. The project file will be maintained at this location until the conclusion of the project. The GSI Project Manager will serve as the file custodian for the study.

6.0 CALIBRATION PROCEDURES AND FREQUENCY

This section describes the calibration procedures and the frequency at which these procedures will be performed for both field and laboratory instruments.

6.1 Field Instrument Calibration

The field instruments to be used for this project will be a pH, temperature, and specific conductivity meter, a field-portable helium meter, and a field-portable gas chromatograph. These instruments will be maintained and calibrated with sufficient frequency and in such a manner that accuracy and reproducibility of results will be consistent with the manufacturer's specifications.

Equipment will be examined prior to conducting field activities to verify proper operating condition. This will include review of the appropriate SOP and equipment maintenance schedule to ensure that required maintenance is completed. Field notes from previous sampling trips will be reviewed for notation of prior equipment problems, and to ensure that necessary repairs to have been completed.

Calibrations will be documented in the field logbook and will include the date/time of calibration, name of person performing the calibration, reference standards used, temperature at which readings were taken, and the readings. Multiple readings on the one sample or standard, as well as readings on replicate samples, will likewise be documented. Internally calibrated field instruments failing to meet calibration/check-out criteria will be returned to the manufacturer for service and an alternate instrument will be used. The accuracy and traceability of reference standards used for field instrument calibration will be documented by recording the manufacturer's name and the standard lot number in the instrument calibration log book.

The field GC instrument will be calibrated using a 3 or 5 point calibration prior to deployment in the field. A standard mixture of target compounds at an appropriate concentration will be analyzed at the beginning of each day to update compound retention times and detector response factors in the calibration file. A calibration verification standard will be analyzed at least once per day to verify that the calibration is still valid.

6.2 Laboratory Instrumentation Calibration

The laboratory will employ specific procedures for the operation and calibration of analytical instruments in order to facilitate optimum instrument performance, thereby generating data of acceptable accuracy and precision. Prior to initiating sample analysis, laboratory instruments will demonstrate acceptable performance with respect to applicable standards from the manufacturer or selected reference methods (i.e., USEPA, API, or ASTM).

6.2.1 Storage of Standards

As soon as practical after receipt, standards will be transferred to a designated storage area in the laboratory. Volatile standards will be stored in a freezer; semi-volatile standards at room temperature; and other commercially purchased stock standards at 4°C, in a freezer, or at room temperature, as appropriate. Organic standards will be stored separately from samples. Certification sheets will be kept on file within each lab division and stored for future reference.

6.2.2 Traceability of Standards

Standards used for calibration of instrumentation used in analyzing samples for the H_2 Injection study will be NIST traceable, EPA A2LA certified, or obtained from another appropriate source. Records will be maintained to verify the traceability of all standards used and will include pertinent information such as the date, analyst, compound, purity, dilution volume, etc., as appropriate.

6.2.3 Instrument Calibration

Instrument calibration protocols will meet or exceed the requirements specified in the EPA, API, or ASTM reference method employed for sample analysis. Initial instrument calibration curves will be generated, verified, and routinely monitored during instrumental analyses, as required by specific SOPs. Records of calibration, repairs, or replacement will be maintained by the designated laboratory personnel performing quality control activities and filed at the location where the work is performed.

7.0 ANALYTICAL PROCEDURES

7.1 Field Analytical and Measurement Procedures

Field-Portable Gas Chromatograph

Samples collected for the analysis by the field-portable GC will be drawn using a vacuum pump and then transferred to a 1 L tedlar bag until a sufficient sample volume has been collected. A sample will be drawn from the tedlar bag with a gas tight 50 uL syringe for injection into the field GC, if needed.

7.2 Laboratory Analytical and Measurement Procedures

7.2.1 List of Project Target Compounds and Laboratory Detection Limits

7.2.1.1 VOCs in Soil

TestAmerica in Houston will analyze soil samples obtained from monitoring locations installed during the study for target constituents (VOCs, organic carbon) in accordance with USEPA SW-846 methods and other applicable methods. Analytical procedures and project-specific laboratory reporting limits for target constituents in water are provided on Table 1.3. Laboratory reporting limits for SW-846 methods have been experimentally determined in accordance with

FR vol. 49, no. 209, page 198-199.
Detection limits for the study will be laboratory Reporting Limits (RLs) corresponding to three to five times the method detection limit (MDL). The laboratory will report COC concentrations at or below the RLs described in this QAPP, unless the specified detection limits are not obtainable by the laboratory due to high parameter concentrations requiring sample dilution or matrix interferences. The laboratory will report COC concentrations less than the RL but greater than the MDL as estimated and will flag such results as estimated values in accordance with the laboratory data reduction procedures specified in Section 9 of this QAPP.

TestAmerica has previously conducted a baseline detection limit study for all methods per USEPA CLP guidelines, and records of the study are maintained at the laboratory. Results of the study are periodically updated and/or revised when changes in instrumentation or methods occur within the laboratory. This study is intended to establish, in accordance with accepted regulatory procedures, the baseline (lowest possible) method detection limits (MDLs) and instrument detection limits (IDLs) obtainable by the laboratory. TestAmerica maintains on file the results of the most recent detection limit study for project specific COCs.

7.2.1.2 VOCs in air

Portable GC will be used to analyze air samples obtained from monitoring locations installed during the study for VOCs in accordance with USEPA SW-846 methods. Analytical procedures and project-specific laboratory reporting limits for organic compounds in air, as analyzed by USEPA SW-846 methods, are provided on Table 1.2. Laboratory reporting limits for SW-846 methods have been experimentally determined in accordance with EPA method TO-15.

For circumstances when the vapor samples will be sent to the laboratory, SPL in Houston, Texas will analyze the vapor samples. Detection limits for the study will be laboratory Reporting Limits (RLs) corresponding to three to five times the method detection limit (MDL). The laboratory will report COC concentrations at or below the RLs described in this QAPP, unless the specified detection limits are not obtainable by the laboratory due to high parameter concentrations requiring sample dilution or matrix interferences. The laboratory will report COC concentrations less than the RL but greater than the MDL as estimated and will flag such results as estimated values in accordance with the laboratory data reduction procedures specified in Section 9 of this QAPP.

SPL has previously conducted a baseline detection limit study for all methods per USEPA CLP guidelines, and records of the study are maintained at the laboratory. Results of the study are periodically updated and/or revised when changes in instrumentation or methods occur within the laboratory. This study is intended to establish, in accordance with accepted regulatory procedures, the baseline (lowest possible) method detection limits (MDLs) and instrument detection limits (IDLs) obtainable by the laboratory. Columbia Analytical Services maintains on file the results of the most recent detection limit study for project specific COCs.

7.2.1.3 Soil Physical Properties

PTS in Houston, Texas, will analyze core samples and soil samples for physical properties in accordance with laboratory SOPs prepared and reviewed for consistency with API and ASTM reference methods. Laboratory reporting limits for physical properties (see Table 1.3) have been experimentally determined in accordance with the applicable API or ASTM reference method and corresponding laboratory SOP.

7.2.2 List of Associated QC Samples

As summarized on Table 2.1, each laboratory SOP includes a QC section addressing minimum QC requirements for the analysis of specific analyte groups.

8.0 INTERNAL QUALITY CONTROL CHECKS

8.1 Field QC Checks

Field QC samples will be collected and analyzed in order to i) evaluate field precision and accuracy, and ii) facilitate validation of sample results. Field sampling precision and accuracy will be assessed through the collection and laboratory analysis of field replicates and field blanks. Samples will be collected per applicable procedures provided in the Field Sampling Plan.

Data from field QC samples will be examined to determine if any problems are evident for specific media or with laboratory procedures. The Contractor QA Manager will advise the Contractor Project Manager of the problems encountered so that the appropriate corrective action can be taken. Procedures for communicating corrective actions are described in Section 13 of this QAPP.

8.1.1 Blank Samples

8.1.1.1 Equipment Rinsate Blanks

Dedicated disposable sampling equipment will be used in this study, no equipment rinsate blanks are required.

8.1.1.2 GC Instrument Blank Verification

A sample of ambient air will be analyzed by the field GC instrument on a periodic basis, typically every 10 samples, to serve as a blank verification.

8.1.2 QC Check Samples

The precision of field sample collection techniques will be evaluated by collecting and analyzing field duplicates. Duplicate samples will be defined as those samples collected simultaneously from the same source under identical conditions into separate but identical containers, and preserved, stored, transported and analyzed in the same manner. Thus, to prepare a duplicate, an aliquot will be collected from a sample source and divided equally into two separate but identical sample containers. Each duplicate will be identically preserved, stored, transported and analyzed. Field duplicates will be given a different identification number to disguise the source of the sample from the laboratory. Field replicates will be analyzed by the same laboratory analyzing investigative samples.

During the course of the study, duplicates will be collected at a frequency of one duplicate for every 10 samples (10%) for each matrix. Field duplicates will be analyzed for VOCs only.

8.1.3 Field Instrument QC Check Samples

A standard mixtures of chlorinated VOCs will be analyzed at least once per day (in addition to the initial calibration verification) to confirm acceptable operation of the field GC instrument.

8.2 Laboratory QC Checks

8.2.1 Analysis of Soil and Vapor for COCs

TestAmerica and SPL will implement a QA/QC program to ensure the reliability and validity of analyses performed in the laboratory. Analytical procedures will be documented in writing as SOPs, each including a section addressing minimum QC requirements for the procedure. Internal quality control checks differ slightly for individual procedures, but in general QC requirements will include the following:

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

QC sample results will be properly recorded and included in the analytical data package. The data package will contain sufficient QC information to allow reconstruction and evaluation of the laboratory QC process by an independent data reviewer.

Data generated in the laboratory will be properly recorded and compiled into a deliverable package containing sufficient QC information for comparison to relevant criteria. Samples analyzed in non-conformance with the QC criteria will be re-analyzed by the laboratory if sufficient volume is available. The sample volumes listed on Table 3 generally provide sufficient volumes and/or weights of sample for re-analysis, if required.

Laboratory Internal Quality Control Program: Data quality objectives for internal laboratory control checks will be consistent with USEPA precision and accuracy criteria specified for selected analytical methods. The laboratory will continue to demonstrate an ability to produce acceptable results using the methods selected through the generation of acceptable QC data. Analytical data will be evaluated by the laboratory prior to submittal based on internal reviews of the QC data. Analytical quality control checks will be performed in the laboratory. These procedures will be based upon USEPA reference methods and generally accepted standards of good laboratory practice. Key components of the laboratory Analytical Quality Control Program include the following quality control practices and considerations:

- Designation of a Laboratory QA Manager to implement the laboratory QA/QC program;
- Adherence to specified laboratory sample acceptance procedures to maintain proper handling, processing, and storage of submitted samples;
- Use of the computerized laboratory data management system to record, document, and assimilate pertinent technical and administrative data;
- Use of USEPA reference methods and recommended instrumentation;
- Adherence to mandatory procedures for operation, calibration, and maintenance of laboratory and field instrumentation;
- Use of proper laboratory measuring equipment, glassware, water, chemical reagents, industrial gases;
- Constant surveillance and documentation of acceptable analytical method accuracy and precision through initial analytical method performance evaluations;
- Use of continuous surrogate spike recovery evaluations, where appropriate, to maintain

acceptable method performance;

- Use of systematic method blank evaluations to identify analytical system interferences and background contamination levels;
- Adherence to proper laboratory documentation measures to maintain the complete integrity and legal validity of all laboratory analyses;
- Use of voluntary intra-laboratory performance evaluations to internally assess and evaluate analytical performance; and
- Participation in laboratory certifications, audits, and approval programs.

Analytical Data Quality: The principle criteria for validating data quality will be the continuous monitoring of acceptable analytical accuracy, precision, and overall method performance, through systematic analyses of quality control samples. The laboratory will conduct both initial and continuous analytical method performance evaluations to ensure that all generated analytical data meet applicable QC and method performance criteria. Each analytical method commonly used in the laboratory will utilize specific quality control procedures to continually monitor acceptable analytical method accuracy and precision. These specific quality control procedures are detailed in the analytical methods SOPs based upon USEPA reference methods. QC criteria for internal standards for analysis of VOCs are provided on Table 4.

8.2.2 Analysis of Soil Properties

PTS will implement a QA/QC program to ensure the reliability and validity of analyses performed in the laboratory. Analytical procedures will be documented in writing as SOPs, including minimum requirements for internal QC checks if any are specified by the corresponding API or ASTM reference method. QC sample results will be properly recorded and included in the analytical data package. The data package will contain sufficient QC information to allow reconstruction and evaluation of the laboratory QC process by an independent data reviewer.

Data generated in the laboratory will be properly recorded and compiled into a deliverables package containing sufficient QC information for comparison to relevant criteria. Samples analyzed in non-conformance with the QC criteria will be re-analyzed by the laboratory if sufficient volume is available.

Data quality objectives for internal laboratory control checks will be consistent with API and ASTM precision and accuracy criteria specified for selected analytical methods. The laboratory will continue to demonstrate an ability to produce acceptable results using the methods selected through the generation of acceptable QC data. Analytical data will be evaluated by the laboratory prior to submittal based on internal reviews of the QC data. Analytical quality control checks will be performed in the laboratory be based upon API and ASTM reference methods and generally accepted standards of good laboratory practice. Key components of the laboratory Analytical Quality Control Program include the following quality control practices and considerations:

- Designation of a Laboratory QA Manager to implement the laboratory QA/QC program;
- Adherence to specified laboratory sample acceptance procedures to maintain proper handling, processing, and storage of submitted samples;
- Use of the computerized laboratory data management system to record, document, and assimilate pertinent technical and administrative data;
- Use of API and ASTM analytical methods and instrumentation;
- Adherence to mandatory procedures for operation, calibration, and maintenance of instrumentation;

- Use of proper laboratory measuring equipment, glassware, water, chemical reagents, industrial gases;
- Constant surveillance and documentation of acceptable analytical method accuracy and precision through initial analytical method performance evaluations;
- Adherence to proper laboratory documentation measures to maintain the complete integrity and legal validity of all laboratory analyses;

9.0 DATA REDUCTION, VALIDATION, AND REPORTING

Data generated during field and laboratory analyses will be reduced and validated prior to reporting. No data shall be disseminated by the field crew or the laboratories until subjected to the reduction and validation procedures described below. For both field and laboratory data recording and reduction, errors will be corrected by drawing a single line through the error, re-entering the correct information, and initialing and dating the correction.

9.1 Data Reduction

9.1.1 Field Data Reduction Procedures

Field measurements will be taken directly from field instruments which are direct reading instruments requiring no data reduction; therefore, data from these instruments will be written into field log books immediately after measurements are taken. Field measurements associated with the field GC instrument will be logged by the instrument and then transferred to a computer at the end of each day. In order to convert raw data from instrument reading to reportable results, raw data will be reduced to reportable values by instrument hardware and software or by other manual procedures suggested in the applicable reference method. Data reduction procedures for the analysis of samples using the field GC instrument will follow the guidelines identified in Section 9.1.2 for laboratory data reduction procedures.

9.1.2 Laboratory Data Reduction Procedures

In order to convert raw data from instrument reading to reportable results, raw data will be reduced to reportable values by instrument hardware and software or by other manual procedures suggested in the applicable reference method. Reduction of laboratory measurements and laboratory reporting of analytical parameters will be conducted in accordance with the procedures specified for each USEPA, API, or ASTM analytical method. Data reduction and recordkeeping activities of the primary analyst will be as follows:

- ***General Data Reduction:*** All methods employed for analysis of samples collected during the study will involve certain data reduction procedures following established laboratory QA/AC protocol. The analyst will record and maintain accurate laboratory records and computer files to include sample identification, weights or volumes, dilution factors, analysis date and method, and analyst initials. Proper instrument and method calibrations will be performed and verified. The analyst will confirm results of the analytical sequence or batch, including QA/QC verification. After converting raw data to final form by following proper procedures for calculations, rounding, and significant figures, sample results will be manually transcribed or automatically transferred from the instrument report to the results data sheet. Internal chain-of-custody records will be maintained as described in Section 5 of this QAPP. The laboratory will flag analytical results in order to note the conditions listed below:

  - U = Analyte was analyzed for but not detected.
  - J = Results are estimated owing to mass spectral data indicating the presence of a compound

meeting applicable identification criteria, but quantitated at less than the MQL and greater than the MDL.

- B = Analyte detected in corresponding method or laboratory blank.
- X = Results are flagged for a reason other than specified above as noted by the laboratory.

- ***Sample Preparation:*** Preparation analysts will record accurate data used in final calculations. Such data will be maintained in extraction and digest logbooks, bench sheets, and chemist's notebooks containing sample weights or volume, final extract volumes, surrogate and spike amounts, and standard reference numbers.

- ***Soil Properties Analyses:*** Duties of the soil properties analyst will include recording results from direct-reading or automated instruments onto a data sheet. The analyst will be responsible for transcribing, as necessary, results for selected soil properties parameters to spreadsheets for data reduction. Final results will be recorded on a data sheet and then entered into the Laboratory Information Management System (LIMS), as applicable.

- ***Instrument Analyses:*** Instrument analysts will verify calculations, analyte identifications, related QA/QC calculations, and sample results. Calculations will include surrogate spike recoveries, laboratory control sample (LCS) recoveries results of sample duplicates and matrix spikes, and results for method and matrix-specific blanks. Lab results will be recorded by the analyst on a data sheet and the associated QA/QC data sheet. Computer or integrator reduction will be employed for the analysis of volatile and semi-volatile organics by GS/MS. Instrumentation will generate a quantitation report and sample results will be calculated by computer integration, spreadsheet, or manual calculation. Positive sample results will be transcribed by the analyst to the sample results sheet and QC data entered into a QA/QC summary spreadsheet.

- ***Record Keeping:*** Bench sheets for sample extraction, digestion, and soil properties will be maintained in bound notebooks. Chromatographic documentation and data record will include sample preparation logs, extraction logs, bench sheets, instrument logs, instrument tune reports, quantitation reports, and instrument printouts. Run logs will be maintained for instrument analyses to document injection of each standard, quality control sample, and client sample. Equipment maintenance logs will be employed to document maintenance activities as discussed in Section 11 of this QAPP. Completion of chain-of-custody forms is discussed in Section 5 of this QAPP. Unused areas of the daily bench sheets and instrument logs will be crossed out, initialed and dated by the corresponding analyst or technician.

9.2 Data Validation

Data validation procedures will be performed for both field and laboratory operations as described below.

9.2.1 Procedures Used to Validate Field Data

The field data package, including field records and measurements acquired by the sampling team personnel, will be reviewed by the GSI QA Manager, as follows:

- Sampling records and chain-of-custody forms will be reviewed to verify that samples, field duplicates, and trip blanks were collected at the frequency specified in the QAPP and were properly prepared, preserved, and submitted to the laboratory.
- Instrument field records will be reviewed for documentation of proper calibration and maintenance.

- Chain-of-custody forms will be reviewed for proper completion, signatures of field personnel and the laboratory sample custodian, and dates.

9.2.2 Procedures Used to Validate Laboratory Data

Data production will begin with the generation of data results by the analyst and continue through a multi-level review and validation process. Each step in the review process will be performed to assure the integrity and validity of the data generated by the laboratories. Data will be sequentially passed on to the peer review analyst of the staff chemist, the department supervisor, and finally the data entry personnel. The laboratory report will be reviewed by the Laboratory QA Manager assigned to the project and then will be certified by the laboratory manager or designee. Each step in the review process will be performed to assure the integrity and validity of the date generated by the laboratories, as follows:

Quality control data (e.g., laboratory duplicates, surrogates, matrix spikes, and matrix spike duplicates) will be compared to method acceptance criteria. Data considered to be acceptable will be entered into the laboratory computer system. Data summaries will be sent to the Laboratory QA Manager for review. If approved, data will be logged into the project database. Unacceptable data will be appropriately qualified in the project report. Case narratives will be prepared to include information concerning data falling outside acceptance limits, and any other anomalous conditions encountered during sample analysis. Data will be issued after approval by the Laboratory QA Manager.

9.3 Data Reporting

9.3.1 Field Data Reporting

Field data reporting comprises a tabulation of the results of measurements made in the field either by direct recording into field notes or by data logging capabilities of the instrument.

Data associated with the field GC instrument will be reported using vendor supplied software to produce tabulated final data in an electronic format.

9.3.2 Laboratory Data Reporting

9.3.2.1 Soil and Vapor Analysis

A LIMS will be utilized for generation of laboratory data reports. After data have been entered and verified as described in Section 9.2 above, a draft report will be generated for review by the Laboratory QA Manager. Laboratory data reports will consist of sample results plus the QA/QC data specified below. The following are general requirements for each sample analyzed by the laboratory:

- The results of each analysis;
- The list of the COCs;
- The method of analysis and the detection limit for each analyte;
- Dates of sample collection, receipt, preparation, and analysis;
- Copy of the chain-of-custody forms signed by the sample custodian;
- A narrative summarizing any QA/QC non-conformances and the corrective action taken; and
- A list relating laboratory ID to sample ID.

The list below describes the information to be provided for analysis of VOCs by GC/MS, as applicable:

- Evaluation of holding time, sample preservation, and percent solids;
- Dilutions;
- Results of bromofluorobenzene or decafluorotriphenylphosphine GC/MS tuning;
- Results of initial and continuing calibration;
- Results of blank analyses;
- Results of surrogates spikes, the expected value, control limits, and percent recovery;
- Results of matrix spike/matrix spike duplicate, control limits, expected value, RPD, and percent recovery;
- Results for laboratory control samples, expected value, control limits, and percent recovery;
- Results of internal standards;
- Compound identification, quantification, and detection limits; and
- Results of laboratory duplicates.

The laboratory will keep on file, for a period of three years, the following information:

- Sequential measurements readout records,
- Digestion logs,
- Percent solids raw data,
- Raw data calculation worksheets,
- GC/MS tuning and mass calculations sheets,
- Sample chromatograms,
- Mass spectra data for each sample, and
- Any other data that is associated with the samples analyzed.

After the Laboratory QA Manager has determined that the report summaries and case narratives meet project requirements, data will be compiled into a report for submittal to the GSI project manager.

9.3.2.2 Soil Physical Properties

After data have been entered and verified as described in Section 9.2 above, a draft report will be generated for review by the Laboratory QA Manager. Laboratory data reports will consist of sample results plus the QA/QC specified in the laboratory SOP and API or ASTM reference method.

9.4 Third-Party Data Validation

Analytical data will be validated internally by GSI and will not be submitted to a third party for independent validation. Minimum requirements will be as follows:

- Chain-of-custody documentation associated with samples.
- A cover sheet listing samples included in the sample data group and a cross-reference between field and laboratory sample numbers.
- A case narrative describing any analytical problems encountered during analysis of the sample data group.
- Tables summarizing analytical results with reporting limits, identification, and quantification of each parameter.
- Analytical results of quality control samples (i.e., field and laboratory blanks, initial and continuing calibration verifications, spikes, duplicates, surrogates, laboratory control samples, ICP interference check samples, chromatograms, and mass spectral data).

10.0 PERFORMANCE AND SYSTEM AUDITS

Performance and system audits will be conducted to verify that sampling and analysis are performed in accordance with applicable SOPs specified for field and laboratory activities. The audits of field and laboratory activities include two independent components: internal and external audits.

10.1 Field Performance and System Audits

10.1.1 Internal Field Audits

10.1.1.1 Internal Field Audit Responsibilities

Internal audits of field activities, including sampling and field measurements, will be conducted by the GSI Project Manager or a designated alternate. Additional team members may also be present during various phases of the audits. These audits will be conducted to evaluate performance, verify that procedures are followed, and correct deficiencies in the execution of field procedures.

10.1.1.2 Internal Field Audit Frequency

An internal field audit will be conducted at least once at the beginning of the site sample collection activities to verify that established procedures are being followed.

10.1.1.3 Internal Field Audit Procedures

To verify compliance with established procedures and implementation of appropriate QA procedures, internal audits will involve the review and examination of the following: i) field measurement and sampling records, ii) instrument operation and calibration records, iii) sample collection documentation, iv) sample handling and packaging procedures, and v) chain-of-custody procedures. Results of field performance audits will be documented on a field audit checklist. If the first audit reveals significant deficiencies, one or more follow-up audits will be conducted to verify that QA procedures are maintained throughout the project.

10.1.2 External Field Audits

External field audits will not be conducted during this study.

10.2 Laboratory Performance and System Audits

10.2.1 Internal Laboratory Audits

10.2.1.1 Internal Laboratory Audit Responsibilities

Internal system and performance audits at each laboratory will be the responsibility of the respective Laboratory QA Managers.

10.2.1.2 Internal Laboratory Audit Frequency

The frequency of the internal laboratory system audit will be the responsibility of the respective Laboratory QA Managers.

10.2.1.3 Internal Laboratory Audit Procedures

Performance and systems audits for sampling and analysis operations will include on-site review of laboratory quality assurance systems and on-site review of equipment for calibration and measurement techniques.

10.2.2 External Laboratory Audits

External laboratory audits will not be conducted as part of the study.

11.0 PREVENTIVE MAINTENANCE

11.1 Field Instrument Preventive Maintenance

Field instruments are to be checked and calibrated prior to beginning the field program and daily before use to verify that instruments are in good working order. Routine preventive maintenance procedures for field instruments are specified in the relevant operation manuals.

11.2 Laboratory Instrument Routine Maintenance Activities

As part of the laboratory QA/QC program, a routine preventive maintenance program will be conducted by the laboratories to minimize the occurrence of instrument failure or other system malfunction. The laboratory workload will be scheduled to accommodate planned downtime required to complete routine maintenance procedures. Trained operators will complete routine maintenance procedures (e.g., changing oven fans, replacing electronic control boards, changing vacuum pump oil, cleaning, etc.) for GC/MS instruments. An inventory of spare parts will be maintained to facilitate timely repair of instruments and minimize downtime.

When routine maintenance procedures do not correct a problem with instrumentation, outside repair services will be available on a next day basis. The laboratory will not maintain test equipment to be used in the maintenance of instrumentation; rather, service representatives will bring the necessary test equipment for the service call.

Records of preventive maintenance activities for each piece of equipment will be maintained in Calibration and Maintenance log books assigned to that instrument. Preventive maintenance performed during the project will be noted in the field logbook and the instrument Calibration and Maintenance log book.

11.3 Inspection/Acceptance Requirements for Supplies and Consumables

Supplies and spare parts will be maintained for both field and laboratory instruments to assure timely completion of sample screening and analysis. For field work, critical spare parts such as batteries will be kept on-site to reduce downtime. Backup instruments and equipment will be available on-site or within 1 day shipment to avoid delays in the field schedule. An inventory of spare parts will also be kept on hand in order to complete the routine maintenance tasks described in Section 11.2.

12.0 PROCEDURES TO ASSESS DATA QUALITY OBJECTIVES

12.1 Accuracy Assessment

In order to evaluate the accuracy of laboratory results, LCSs and MS/MSDs will be prepared at the frequency shown on Table 2.4 by spiking with VOCs prior to analysis. For the LCS, the ratio between the measured concentration and the known concentration in the spiked sample converted to a percentage is equal to the percent recovery. For MS/MSDs, the difference between the measured concentration in the spike and the concentration in the native sample is divided by the known spike concentration to obtain the percent recovery, as follows:

$$\%R = \frac{\text{Measured Concentration in Spike Sample - Concentration in Native Sample}}{\text{Known Spike Concentration}} \times 100$$

Daily tabulations for each commonly analyzed organic compound will be maintained on instrument-specific, matrix-specific, and analyte-specific bases. Control charts of results obtained from LCS will be maintained for selected organic analytes to track the accuracy of laboratory data.

12.2 Precision Assessment

Spiked samples will be prepared by selecting a sample at random from each sample shipment received at the laboratory, dividing the sample into equal aliquots, and then spiking each of the aliquots with a known amount of analyte. The duplicate samples will then be included in the analytical sample set. The splitting of the sample allows the analyst to determine the precision of the preparation and analytical techniques associated with the duplicate sample. The RPD between the spike and duplicate spike (or between MS and MSD) will be calculated as follows:

$$RPD = \frac{\text{Concentration in Spike 1 - Concentration in Spike 2}}{0.5(\text{Concentration in Spike 1} + \text{Concentration in Spike 2})} \times 100$$

12.3 Completeness Assessment

Completeness is the ratio of the number of valid sample results to the total number of samples analyzed with a specific matrix and/or analysis. After analytical testing, the percent completeness will be calculated as follows

$$\text{Completeness} = \frac{(\text{number of valid measurements})}{(\text{number of measurements planned})} \times 100$$

13.0 CORRECTIVE ACTION

Corrective action will be taken to identify, recommend, approve, and implement measures to remedy unacceptable procedures or out-of-control performances potentially affecting data quality. Corrective actions may be required for i) non-conformance with procedures specified by the QAPP, ii) malfunction of sampling or analytical equipment, or iii) changes in sampling network or frequency. Non-conformances include those instances of conducting activities outside the requirements of the QAPP (i.e., missing holding times or detecting blank contamination). Analytical and equipment problems may occur during sampling, sample handling, sample preparation, or laboratory analysis. Modifications in the sampling network may result from inaccessible locations or from inadvertent omissions in sample collection.

Any non-conformance to quality control procedures specified in the QAPP will be identified, reported, and corrected. If the non-conformance is identified during sample collection or analysis, corrective action will be implemented immediately by the field technician or laboratory analyst. If the non-conformance is identified during an internal/external audit or third-party data validation, corrective action will be implemented after notification of the GSI Project Manager, and/or the Laboratory Project Manager.

Any corrective actions taken during the course of the study will be documented in the final project report described in Section 14 of this QAPP.

13.1 Field Corrective Action

13.1.1 Corrective Action for Procedural Non-Conformances

The GSI Field Operations Manager and Field Technical Staff will be responsible for reporting suspected technical or QA non-conformances or deficiencies to the GSI Project Manager. The GSI Project Manager will be responsible for ensuring that any necessary corrective actions are implemented. If appropriate, the GSI Project Manager will suspend additional work depending on the nature of the non-conforming activity until the corrective action is completed. The GSI Project Manager will ensure that corrective action for the non-conformance is completed by evaluating and controlling additional work on non-conforming items, determining appropriate action, and communicating with concerned persons via telephone, e-mail, or other medium.

13.1.2 Corrective Action for Changes in Sampling Network

The GSI Field Operations Manager and Field Technical Staff will communicate work plan modifications to project management for review and approval prior to implementation of significant modifications to the QAPP. In order to avoid unnecessary project delays, minor field adjustments (e.g., moving a sampling location less than 25 ft to avoid an obstruction) will be made at the discretion of the GSI Field Operations Manager and implemented without prior approval from project management, provided other health and safety considerations have been addressed (e.g., utility clearance). Such modifications will be recorded in the field logbook and brought to the prompt attention of project management. The GSI Project Manager will then review the modification to ensure that the modification does not compromise project quality assurance objectives. GSI Field Technical Staff will not initiate work program modifications without prior communication with the GSI Field Operations Manager.

Significant plan modifications will be implemented only after obtaining the approval of the GSI Project Manager. Program changes will be documented and copies of the affected document will be distributed to recipients via e-mail or other medium. The GSI Project Manager will be responsible for the controlling, tracking, and implementation of the identified changes. A discussion of field program modifications will be included in the final project report.

If the proposed modification has the potential to adversely impact attainment of project QA objectives, the GSI Project Manager will be notified while the sampling crew is still in the field. Such a situation would result if i) a sampling location were to be eliminated; ii) a sampling location were to be moved a significant distance from its designated location owing to access limitations or obstructions; or iii) sampling frequency were to be decreased. Possible corrective actions could include i) re-mobilization to collect additional samples, or ii) evaluation to determine if data already collected were sufficient to satisfy QA objectives.

If the GSI Project Manager determines that the modification will not adversely impact the achievement of project QA objectives, no further action will be taken and a summary of the findings will be included in the final project report. If the modification has the potential to adversely impact the achievement of project QA objectives, additional locations will be sampled or additional samples will be collected and the findings documented in the final project report.

13.1.3 Field Corrective Action Reports

In cases in which corrective actions of field procedures are required, a description of the nature of the problem, an evaluation of the cause, if known, and the action taken will be prepared by the GSI Field Operations Manager or QA Manager for inclusion in the final project report. Deficiencies identified during the data validation and assessment process will also be included in the final project report.

13.2 Laboratory Corrective Action

Data packages prepared by the laboratory will include a discussion of the QC problems encountered and corrective actions taken. If an out-of-control event or potential out-of-control event is noted in the laboratory, an investigation and corrective action will be taken appropriate to the analysis and the event. Laboratory corrective action may be required if any of the following occur:

- QC data are outside the warning or acceptable windows for precision and accuracy,
- Blanks contain target analytes above acceptable levels,
- Undesirable trends are detected in spike recoveries or RPDs between duplicates,
- Unusual changes in detection limits are noted,
- Deficiencies are detected by the QA Department during internal or external audits or from the results of performance evaluation samples, or
- Inquiries concerning data quality are received.

The Laboratory QA Manager will be responsible for implementing laboratory corrective action. Individual analysts will be responsible for assessing the results from sample analysis. Results not meeting applicable criteria will be reported to a supervisor who will recommend a corrective action to be implemented by the section manager, the QC chemist and the QA/QC Supervisor. The Laboratory QA Manager will be responsible for ensuring that corrective actions are taken, as appropriate, in the following situations:

- ***Out-of-Control Criteria:*** An out-of-control situation will exist when a blank, calibration standard, laboratory control sample, sample replicate, or spike recovery analysis fails to meet applicable quality control criteria. Corrective action procedures are often handled at the bench level by the analyst who reviews the preparation for possible errors, checks the instrument calibration, spike and calibration mixes, and instrument sensitivity. If the out-of-control situation cannot be remedied by the analyst, an investigation to determine the cause of the problem will be undertaken by the analyst and department supervisor, and a Quality Assurance Action Report will be initiated. Analyses completed during the out-of-control situation will be repeated after the out-of-control situation has been corrected. If the problem persists or cannot be identified, the matter will be referred to the laboratory supervisor, manager and/or QA Department for further investigation. After resolution, the corrective action procedure will be documented and filed with the QA Department.

- ***Warning Criteria:*** Corrective measures will be implemented when one of the following two conditions occurs: i) quality assurance data for blanks, laboratory control samples, sample replicates, or matrix spikes exceed two standard deviations of applicable limits or ii) a trend or shift is observed for the reference standard. Provided other criteria are within applicable limits, samples need not be re-analyzed. A Quality Assurance Corrective Action Report will be initiated by the analyst and the Laboratory Supervisor, and corrective action will be implemented prior to analyzing additional samples. If the situation occurs with the next sample batch, an out-of-control situation exists, and steps outlined above are taken. If matrix interference is indicated by out-of-control replicate analyses or matrix spike recovery data, re-analysis of a sample batch is necessary only when other QC data do not meet applicable specifications.

- ***Performance Audit:*** If the laboratory fails to meet applicable requirements reviewed during a performance of systems audit, corrective action will be taken. The QA/QC coordinator will notify the Laboratory Project Manager and the USEPA QA Manager in the event of a corrective action taken in response to an audit. Applicable federal and state guidelines and requirements regarding response to audit findings are observed by laboratory.

13.3 Corrective Action during Data Validation and Data Assessment

The GSI QA Manager will review analytical reports generated by each laboratory prior to data use and filing. Upon receiving data validation or data assessment results, the GSI QA Manager will identify the need for corrective action and notify concerned persons by an appropriate medium. Specified corrective action will be developed to assure meeting required QA objectives. The GSI Project Manager and the Laboratory Project Managers will be responsible for implementing corrective actions in the field and laboratory, respectively. Corrective action required may include re-sampling, collecting additional samples, or re-measurement of field parameters. The laboratory may be required to repair or re-calibrate instrumentation, re-inject or re-analyze samples, or provide additional raw data. Proposed and implemented corrective actions will be documented in the final project.

14.0 QUALITY ASSURANCE REPORTS TO MANAGEMENT

The final report for the study will be the responsibility of the GSI Project Manager. The final report will contain a section identified as the Project QA Report that addresses data quality, including the accuracy, precision, and completeness of the data, results of any performance or system audits, and any corrective action needed or taken during the project.

14.1 Contents of Project QA Report

The QA report will contain i) results of field and laboratory audits conducted during the time period covered by the report, ii) an assessment of QA results with respect to data quality objectives, iii) a summary of corrective actions that may have been implemented, and iv) results of any corrective action activities. If applicable, references to QAPP modifications will be highlighted.

14.2 Frequency of QA Reports

The Project QA Report will be prepared on a one-time basis and submitted in conjunction with the final report for the study.

15.0 REFERENCES

USEPA, 1994a. *Guidance for the Data Quality Objectives Process*, U. S. Environmental Protection Agency.

USEPA, 1994b. *National Functional Guidelines for Organic Data Review*, U.S. Environmental Protection Agency, December 1994.

USEPA, 1998. *Region 5 RCRA QAPP Instructions,* U. S. Environmental Protection Agency. Revision: April1998.

TABLE 1.1
ANALYTICAL PARAMETERS FOR SOIL AND VAPOR SAMPLES

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Analysis	**Laboratory**	**Analytical Method**
Organic		
Volatile Organic Compounds	TestAmerica Portable GC/SPL	SW846- 8260B (soil) GC/TO-15 (vapor)
Total Organic Carbon	TestAmerica	USDA 90.3 - Walkley-Black (soil)
Chemical Properties		
pH	TestAmerica	EPA 150.1
Physical Properties		
Intrinsic Permeability	PTS Geolabs	API RP 40 / ASTM D2434
Porosity, total and air-filled	PTS Geolabs	API RP 40
Dry Bulk Density	PTS Geolabs	API RP 40/ASTM D4564/ASTM D2937
Volumetric Moisture Content	PTS Geolabs	ASTM DD216/ASTM D4959/ ASTM D4643

TABLE 1.2
ANALYTICAL PARAMETERS AND DATA QUALITY OBJECTIVES FOR VOC ANALYSIS OF VAPOR: TO-15

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Analyte	CAS Number	Analytical Method		MRL		MDL		Investigation DQO (Note 2)
		Prep.	Det.	ug/m^3	ppbv	ug/m^3	ppbv	ug/m^3
Volatile Organics by TO-1								
1,1,1-Trichloroethane	71-55-6	NA	TO-15	1.30	0.23	0.5	0.092	5.00E+00
1,1,2,2-Tetrachloroethane	79-34-5	NA	TO-15	1.30	0.18	0.5	0.073	5.00E+00
1,1,2-Trichloroethane	79-00-5	NA	TO-15	1.30	0.23	0.5	0.092	5.00E+00
1,1-Dichloroethane	75-34-3	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
1,1-Dichloroethene	75-35-4	NA	TO-15	1.30	0.33	0.5	0.13	5.00E+00
1,2,4-Trichlorobenzene	120-82-1	NA	TO-15	1.30	0.17	0.5	0.067	5.00E+00
1,2,4-Trimethylbenzene	95-63-6	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
1,2-Dibromo-3-chloropropane	96-12-8	NA	TO-15	1.30	0.13	0.5	0.052	5.00E+00
1,2-Dibromoethane	106-93-4	NA	TO-15	1.30	0.16	0.5	0.065	5.00E+00
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	76-14-2	NA	TO-15	1.30	0.18	0.5	0.072	5.00E+00
1,2-Dichlorobenzene	95-50-1	NA	TO-15	1.30	0.21	0.5	0.083	5.00E+00
1,2-Dichloroethane	107-06-2	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
1,2-Dichloropropane	78-87-5	NA	TO-15	1.30	0.28	0.5	0.11	5.00E+00
1,3,5-Trimethylbenzene	108-67-8	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
1,3-Butadiene	106-99-0	NA	TO-15	1.30	0.58	0.5	0.23	5.00E+00
1,3-Dichlorobenzene	541-73-1	NA	TO-15	1.30	0.21	0.5	0.083	5.00E+00
1,4-Dichlorobenzene	106-46-7	NA	TO-15	1.30	0.21	0.5	0.083	5.00E+00
1,4-Dioxane	123-91-1	NA	TO-15	1.30	0.35	0.5	0.14	5.00E+00
2-Butanone (MEK)	78-93-3	NA	TO-15	1.30	0.43	0.5	0.17	5.00E+00
2-Hexanone	591-78-6	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
2-Propanol (Isopropyl Alcohol)	67-63-0	NA	TO-15	2.50	1.03	0.5	0.2	5.00E+00
3-Chloro-1-propene (Allyl Chloride)	107-05-1	NA	TO-15	1.30	0.40	0.5	0.16	5.00E+00
4-Ethyltoluene	622-96-8	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
4-Methyl-2-pentanone	108-10-1	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
Acetone	67-64-1	NA	TO-15	13	5.3	5	2.1	1.50E+01
Acetonitrile	75-05-8	NA	TO-15	1.30	0.75	0.5	0.3	5.00E+00
Acrolein	107-02-8	NA	TO-15	1.30	0.55	0.5	0.22	5.00E+00
Acrylonitrile	107-13-1	NA	TO-15	1.30	0.58	0.5	0.23	5.00E+00
alpha-Pinene	80-56-8	NA	TO-15	1.30	0.23	0.5	0.09	5.00E+00
Benzene	71-43-2	NA	TO-15	1.30	0.40	0.5	0.16	5.00E+00
Benzyl Chloride	100-44-7	NA	TO-15	1.30	0.24	0.5	0.097	5.00E+00
Bromodichloromethane	75-27-4	NA	TO-15	1.30	0.19	0.5	0.075	5.00E+00
Bromoform	75-25-2	NA	TO-15	1.30	0.12	0.5	0.048	5.00E+00
Bromomethane	74-83-9	NA	TO-15	1.30	0.33	0.5	0.13	5.00E+00
Carbon Disulfide	75-15-0	NA	TO-15	1.30	0.40	0.5	0.16	5.00E+00
Carbon Tetrachloride	56-23-5	NA	TO-15	1.30	0.20	0.5	0.08	5.00E+00
Chlorobenzene	108-90-7	NA	TO-15	1.30	0.28	0.5	0.11	5.00E+00
Chloroethane	75-00-3	NA	TO-15	1.30	0.48	0.5	0.19	5.00E+00
Chloroform	67-66-3	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
Chloromethane	74-87-3	NA	TO-15	1.30	0.60	0.5	0.24	5.00E+00
cis-1,2-Dichloroethene	156-59-2	NA	TO-15	1.30	0.33	0.5	0.13	5.00E+00
cis-1,3-Dichloropropene	10061-01-5	NA	TO-15	1.30	0.28	0.5	0.11	5.00E+00
Cumene	98-82-8	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
Cyclohexane	110-82-7	NA	TO-15	2.50	0.73	0.5	0.15	5.00E+00
Dibromochloromethane	124-48-1	NA	TO-15	1.30	0.15	0.5	0.059	5.00E+00
Dichlorodifluoromethane (CFC 12)	75-71-8	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
d-Limonene	5989-27-5	NA	TO-15	1.30	0.23	0.5	0.09	5.00E+00
Ethanol	64-17-5	NA	TO-15	13	6.8	5	2.7	1.50E+01
Ethyl Acetate	141-78-6	NA	TO-15	2.50	0.70	0.5	0.14	5.00E+00
Ethylbenzene	100-41-4	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
Hexachlorobutadiene	87-68-3	NA	TO-15	1.30	0.12	0.5	0.047	5.00E+00
m,p-Xylenes	179601-23-1	NA	TO-15	2.50	0.58	1	0.23	5.00E+00
Methyl Methacrylate	80-62-6	NA	TO-15	2.50	0.60	0.5	0.12	5.00E+00
Methyl tert-Butyl Ether	1634-04-4	NA	TO-15	1.30	0.35	0.5	0.14	5.00E+00
Methylene Chloride	75-09-2	NA	TO-15	1.30	0.35	0.5	0.14	5.00E+00
Naphthalene	91-20-3	NA	TO-15	1.30	0.24	0.5	0.095	5.00E+00
n-Butyl Acetate	123-86-4	NA	TO-15	1.30	0.28	0.5	0.11	5.00E+00
n-Heptane	142-82-5	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
n-Hexane	110-54-3	NA	TO-15	1.30	0.35	0.5	0.14	5.00E+00
n-Nonane	111-84-2	NA	TO-15	1.30	0.24	0.5	0.095	5.00E+00
n-Octane	111-65-9	NA	TO-15	1.30	0.28	0.5	0.11	5.00E+00
n-Propylbenzene	103-65-1	NA	TO-15	1.30	0.25	0.5	0.1	5.00E+00
o-Xylene	95-47-6	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
Propene	115-07-1	NA	TO-15	1.30	0.73	0.5	0.29	5.00E+00
Styrene	100-42-5	NA	TO-15	1.30	0.30	0.5	0.12	5.00E+00
Tetrachloroethene	127-18-4	NA	TO-15	1.30	0.19	0.5	0.074	5.00E+00
Tetrahydrofuran (THF	109-99-9	NA	TO-15	1.30	0.43	0.5	0.17	5.00E+00
Toluene	108-88-3	NA	TO-15	1.30	0.33	0.5	0.13	5.00E+00
trans-1,2-Dichloroethene	156-60-5	NA	TO-15	1.30	0.33	0.5	0.13	5.00E+00
trans-1,3-Dichloropropene	10061-02-6	NA	TO-15	1.30	0.28	0.5	0.11	5.00E+00
Trichloroethene	79-01-6	NA	TO-15	1.30	0.23	0.5	0.093	5.00E+00
Trichlorofluoromethane	75-69-4	NA	TO-15	1.30	0.22	0.5	0.089	5.00E+00
Trichlorotrifluoroethane	76-13-1	NA	TO-15	1.30	0.16	0.5	0.065	5.00E+00
Vinyl Acetate	108-05-4	NA	TO-15	13	3.5	5	1.4	1.50E+01
Vinyl Chloride	75-01-4	NA	TO-15	1.30	0.50	0.5	0.2	5.00E+00

Notes:

1. Method Reporting Limits (MRLs) assume a 400mL sample volume (from a 1 L summa containing 400mL of soil gas and 600mL inert gas)
   Method Detection Limits (MDLs) based on MDL study conducted using 6L summa canister samples.
2. Actual reporting limits will be higher depending on the canister pressurization dilution factor and/or sample matrix effects, typically a factor of 1.5-2.0.
3. MRLs and MDLs shown are based on data provided by Columbia Analytical Services.
4. Laboratory MDLs are continuously being evaluated and may differ slightly from these values.
5. Prep. = Digestion or extraction method. Det. = Determinative method for quantitation.

TABLE 1.3
ANALYTICAL PARAMETERS AND DATA QUALITY OBJECTIVES FOR VOC ANALYSIS OF VAPOR: TO-15 SIM

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Analyte	CAS Number	Analytical Method		MRL		Investigation DQO (Note 2)
		Prep.	Det.	ug/m^3	ppbv	
Volatile Organics by TO-15 SIM						
1,1,1-Trichloroethane	71-55-6	NA	TO-15 SIM	0.025	0.0046	2.50E-02
1,1,2,2-Tetrachloroethane	79-34-5	NA	TO-15 SIM	0.025	0.0036	2.50E-02
1,1,2-Trichloroethane	79-00-5	NA	TO-15 SIM	0.10	0.018	1.00E-01
1,1-Dichloroethane	75-34-3	NA	TO-15 SIM	0.025	0.0062	2.50E-02
1,1-Dichloroethene	75-35-4	NA	TO-15 SIM	0.025	0.0063	2.50E-02
1,2,4-Trichlorobenzene	120-82-1	NA	TO-15 SIM	0.025	0.0034	2.50E-02
1,2-Dibromoethane	106-93-4	NA	TO-15 SIM	0.025	0.0033	2.50E-02
1,2-Dichlorobenzene	95-50-1	NA	TO-15 SIM	0.025	0.0042	2.50E-02
1,2-Dichloroethane	107-06-2	NA	TO-15 SIM	0.025	0.0062	2.50E-02
1,2-Dichloropropane	78-87-5	NA	TO-15 SIM	0.025	0.0054	2.50E-02
1,3-Dichlorobenzene	541-73-1	NA	TO-15 SIM	0.025	0.0042	2.50E-02
1,4-Dichlorobenzene	106-46-7	NA	TO-15 SIM	0.025	0.0042	2.50E-02
Benzene	71-43-2	NA	TO-15 SIM	0.10	0.031	1.00E-01
Carbon Tetrachloride	56-23-5	NA	TO-15 SIM	0.025	0.0040	2.50E-02
Chlorobenzene	108-90-7	NA	TO-15 SIM	0.10	0.022	1.00E-01
Chloroethane	75-00-3	NA	TO-15 SIM	0.025	0.0095	2.50E-02
Chloroform	67-66-3	NA	TO-15 SIM	0.10	0.020	1.00E-01
Chloromethane	74-87-3	NA	TO-15 SIM	0.025	0.012	2.50E-02
cis-1,2-Dichloroethene	156-59-2	NA	TO-15 SIM	0.025	0.0063	2.50E-02
cis-1,3-Dichloropropene	10061-01-5	NA	TO-15 SIM	0.025	0.0055	2.50E-02
Dichlorodifluoromethane (CFC 12	75-71-8	NA	TO-15 SIM	0.025	0.0051	2.50E-02
Ethylbenzene	100-41-4	NA	TO-15 SIM	0.10	0.023	1.00E-01
m,p-Xylenes	179601-23-1	NA	TO-15 SIM	0.10	0.023	1.00E-01
Methylene Chloride	75-09-2	NA	TO-15 SIM	0.10	0.029	1.00E-01
Naphthalene	91-20-3	NA	TO-15 SIM	0.10	0.019	1.00E-01
o-Xylene	95-47-6	NA	TO-15 SIM	0.10	0.0023	1.00E-01
Tetrachloroethene	127-18-4	NA	TO-15 SIM	0.025	0.0037	2.50E-02
Toluene	108-88-3	NA	TO-15 SIM	0.025	0.0066	2.50E-02
trans-1,2-Dichloroethene	156-60-5	NA	TO-15 SIM	0.025	0.0063	2.50E-02
Trichloroethene	79-01-6	NA	TO-15 SIM	0.025	0.0047	2.50E-02
Trichlorotrifluoroethane	76-13-1	NA	TO-15 SIM	0.025	0.0033	2.50E-02
Vinyl Chloride	75-01-4	NA	TO-15 SIM	0.025	0.0098	2.50E-02

Notes:

1. Method Reporting Limits (MRLs) assume a 1 L sample volume (from 6 L canister).
2. Actual reporting limits will be higher depending on the canister pressurization dilution factor and/or sample matrix effects, typically a factor of 1.5-2.0.
3. Method reporting limits (MDLs) and Method Detection limits (MDLs) shown are based on data provided by Columbia Analytical Services.
4. Laboratory MDLs are continuously being evaluated and may differ slightly from these values.
5. Prep. = Digestion or extraction method. Det. = Determinative method for quantitation.

TABLE 1.3
ANALYTICAL PARAMETERS AND DATA QUALITY OBJECTIVES FOR TARGET ANALYTES IN S

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

		Analytical Method				Investigation DQO
	CAS			MDL	MQL	
Analyte	Number	Prep.	Det.	mg/kg	mg/kg	mg/L
Volatile Organics						
1,1,1-Trichloroethane	71-55-6	5030B	8260B	0.00074	0.005	0.005
1,1,2,2-Tetrachloroethane	79-34-5	5030B	8260B	0.00087	0.005	0.005
1,1,2-Trichloroethane	79-00-5	5030B	8260B	0.00073	0.005	0.005
1,1-Dichloroethane	75-34-3	5030B	8260B	0.00087	0.005	0.005
1,1-Dichloroethene	75-35-4	5030B	8260B	0.00122	0.005	0.005
1,2-Dichloroethane	107-06-2	5030B	8260B	0.0009	0.005	0.005
1,2-Dichloroethene (total	540-59-0	5030B	8260B	0.0019	0.01	0.01
1,2-Dichloropropane	78-87-5	5030B	8260B	0.00071	0.005	0.005
2-Hexanone	591-78-6	5030B	8260B	0.00101	0.01	0.01
4-Methyl-2-pentanone (MIBK	108-10-1	5030B	8260B	0.00147	0.01	0.01
Acetone	67-64-1	5030B	8260B	0.00166	0.01	0.01
Benzene	71-43-2	5030B	8260B	0.00063	0.005	0.005
Bromodichloromethane	75-27-4	5030B	8260B	0.00066	0.005	0.005
Bromoform	75-25-2	5030B	8260B	0.00137	0.005	0.005
Bromomethane	74-83-9	5030B	8260B	0.00083	0.01	0.01
Carbon Disulfide	75-15-0	5030B	8260B	0.00055	0.01	0.01
Carbon Tetrachloride	56-23-5	5030B	8260B	0.00113	0.005	0.005
Chlorobenzene	108-90-7	5030B	8260B	0.00096	0.005	0.005
Chloroethane	75-00-3	5030B	8260B	0.0014	0.01	0.01
Chloroform	67-66-3	5030B	8260B	0.00066	0.005	0.005
Chloromethane	74-87-3	5030B	8260B	0.00166	0.01	0.01
cis-1,2-Dichloroethene	156-59-2	5030B	8260B	0.00083	0.005	0.005
cis-1,3-Dichloropropene	10061-01-5	5030B	8260B	0.00054	0.005	0.005
Dibromochloromethane	124-48-1	5030B	8260B	0.00094	0.005	0.005
Ethylbenzene	100-41-4	5030B	8260B	0.00102	0.005	0.005
Methyl Ethyl Ketone (2-Butanone	78-93-3	5030B	8260B	0.0019	0.01	0.01
Methylene Chloride	75-09-2	5030B	8260B	0.00219	0.01	0.01
Styrene	100-42-5	5030B	8260B	0.00071	0.005	0.005
Tetrachloroethene	127-18-4	5030B	8260B	0.00071	0.005	0.005
Toluene	108-88-3	5030B	8260B	0.00138	0.005	0.005
trans-1,2-Dichloroethene	156-60-5	5030B	8260B	0.00114	0.005	0.005
trans-1,3-Dichloropropene	10061-02-6	5030B	8260B	0.00058	0.005	0.005
Trichloroethene	79-01-6	5030B	8260B	0.0014	0.005	0.005
Vinyl Chloride	75-01-4	5030B	8260B	0.0009	0.01	0.01
Xylenes (total)	1330-20-7	5030B	8260B	0.00113	0.005	0.005
Total Organic Carbon						
TOC		Walkley-Black		0.03%	0.10%	0.10%

Notes:
1. Investigation DQOs correspond to the reporting limit (RL) for each analyte.
2. Method detection limits (MDLs) and reporting limits (RLs) shown are based on data provided by TestAmerica, Houston.
   Analytical methods are referenced from "Test Methods for Evaluating Solid Wastes, SW-846, Update III, 3rd edition," December 1996.
3. Applicable results will be reported as estimated value between method detection limit (MDL) and the method quantitation limit (MQL).
4. Laboratory MDLs are continuously being evaluated and may differ slightly from these values.
5. Prep. = Digestion or extraction method.
   Det. = Determinative method for quantitation.

— = No value specified.
NA = Not applicable to this constituent.

TABLE 2.1
PRECISION AND ACCURACY OBJECTIVES FOR LABORATORY SAMPLE

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Parameter	EPA Reference Method	QC Sample Type	Frequency	Data Quality Objectives					
				Precision (% RPD)			Accuracy		
				Air	Soil	Soil Core	Air	Soil	Soil Core
1. Volatile Organics	Soil: 8260B	Method Blank	1 per 20 samples	NA	NA	NA	Target Analytes <RL	Target Analytes <RL	NA
		Laboratory Spike and Duplicate	1 per 20 samples	See Table 2.2	See Table 2.2	NA	See Table 2.2	See Table 2.2	NA
		Matrix Spike and Duplicate	1 per 20 samples	See Table 2.2	See Table 2.2	NA	See Table 2.2	See Table 2.2	NA
	Air: GC/TO-15	Blank	1 per 10 samples	NA	NA	NA	NA	NA	NA
		Control Standard	1 per day	NA	NA	NA	70-130%	NA	NA
		Duplicate Sample	1 per 10 samples	<30	NA	NA	NA	NA	NA
2. pH	EPA 150.1	Lab Control Standard	NA	NA	NA	NA	NA	NA	NA
3. Intrinsic Permeability	API RP 40 / ASTM D2434	Lab Control Standard	NA	NA	NA	NA	NA	NA	NA
4. Porosity	API RP 40	Lab Control Standard	NA	NA	NA	NA	NA	NA	+0.02% Pore Volume
5. Bulk Density	API RP 40/ASTM D4564 ASTM D2937	Lab Control Standard	NA	NA	NA	NA	NA	NA	+0.5 of 1 Porosity %
6. Volumetric Moisture Content	API RP 40/ASTM D4564 ASTM D2937	Lab Control Standard	NA	NA	NA	NA	NA	NA	NA
7. Total Organic Carbon	ASTM DD216/ASTM D4959	Method Blank	NA	NA	NA	NA	NA	NA	+3.0% Method Response Factor
	ASTM D4643	Lab Control Standard	NA	NA	NA	+30% Initial Value	NA	NA	+30% Certified Value

Notes:
1. Precision objectives represent relative percent difference (% RPD) between duplicates
2. Samples, standards, and quality control (QC) samples analyzed for volatile organics will be spiked with surrogates (see Table 2.3
3. NA = Precision/accuracy data quality objective not applicable to this QC sample
   RL = Reporting limit.
   RPD = Relative percent difference
   %R = Percent Recovery

TABLE 2.2
PRECISION AND ACCURACY OBJECTIVES FOR CONSTITUENTS IN SOIL

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Analyte	CAS Number	Analytical Method Prep.	Analytical Method Det	Accuracy (%Rec)	Precision (% RPD)
Volatile Organics					
Acetone	67-64-1	5030B	8260B	44-136	30
Benzene (MS)	71-43-2	5030B	8260B	66-128	30
Bromodichloromethane	75-27-4	5030B	8260B	68-121	30
Bromoform	75-25-2	5030B	8260B	50-130	30
Bromomethane	74-83-9	5030B	8260B	28-164	30
Carbon disulfide	75-15-0	5030B	8260B	53-176	30
Carbon tetrachloride (MS)	56-23-5	5030B	8260B	63-132	30
Chlorobenzene (MS)	108-90-7	5030B	8260B	67-126	30
Chloroethane	75-00-3	5030B	8260B	30-136	30
Chloroform	67-66-3	5030B	8260B	67-126	30
Chloromethane	74-87-3	5030B	8260B	21-153	30
Dibromochloromethane	124-48-1	5030B	8260B	63-125	30
Dichloroethane, 1,1-	75-34-3	5030B	8260B	64-130	30
Dichloroethane, 1,2-	107-06-2	5030B	8260B	61-135	30
Dichloroethene, 1,1- (MS)	75-35-4	5030B	8260B	40-157	30
Dichloroethene, cis-1,2-	156-59-2	5030B	8260B	62-130	30
Dichloroethene, trans-1,2-	156-60-6	5030B	8260B	65-130	30
Dichloropropane, 1,2-	78-87-5	5030B	8260B	71-122	30
Dichloropropene, cis-1,3-	10061-01-5	5030B	8260B	66-129	30
Dichloropropene, trans-1,3-	10061-02-6	5030B	8260B	66-134	30
Ethylbenzene	100-41-4	5030B	8260B	64-127	30
Hexanone, 2-	591-78-6	5030B	8260B	52-142	30
Methyl ethyl ketone (MEK, 2-Butanone)	78-93-3	5030B	8260B	42-186	30
Methyl-2-pentanone, 4- (MIBK)	108-10-1	5030B	8260B	52-146	30
Methylene chloride	75-09-2	5030B	8260B	48-144	30
Styrene	100-42-5	5030B	8260B	63-128	30
Tetrachloroethane, 1,1,2,2-	79-34-5	5030B	8260B	59-134	30
Tetrachloroethene	127-18-4	5030B	8260B	69-125	30
Toluene (MS)	108-88-3	5030B	8260B	69-125	30
Trichloroethane, 1,1,1-	71-55-6	5030B	8260B	70-127	30
Trichloroethane, 1,1,2-	79-00-5	5030B	8260B	67-124	30
Trichloroethene (MS)	79-01-6	5030B	8260B	70-136	30
Vinyl chloride	75-01-4	5030B	8260B	28-159	30
Xylenes (total)	1330-20-7	5030B	8260B	65-129	30
Total Organic Carbon					
TOC		Walkley-Black		80-120	30

Notes:
1. Laboratory control limits based upon data provided by TestAmerica.
2. %Rec = Percent recovery. %RPD = Relative percent difference.

TABLE 2.3
LABORATORY CONTROL LIMITS FOR SURROGATES IN ANALYTICAL CONSTITUENTS

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Analyte	EPA SW-846 Reference Method	Laboratory Control Limits for Percent Recovery	
		Air (%)	Soil (%)
Volatile Organics			
4-Bromofluorobenzene	8260B	80-120	57-140
Dibromofluoromethane	8260B	80-120	68-130
Toluene-d8	8260B	80-120	50-130
1,2-Dichloromethane-d4	8260B	80-120	61-130

Notes:
1. Control limits based upon historical data provided by TestAmerica and EPA published values.
2. Laboratory procedures will be conducted in accordance with the EPA reference methods shown above.

TABLE 2.4
REQUIREMENTS FOR FIELD QUALITY ASSURANCE SAMPLES

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

QA Sample Type	Matrix	Laboratory Analytes	Preparation/Collection Method	Frequency	Data Quality Objectives
Field Duplicates	*Air*	Volatile Organics	Collect an additional air sample	1 per 10 samples	±30% RPD between duplicates
	Soil	Volatile Organics	Collect 1 additional set of method-specific containers		
Duplicates	*Air*	Volatile Organics	NA	NA	NA
Background	*Air*	Volatile Organics	Collect ambient air sample	1 per sampling location	Concentrations <RL

Notes:
1. RL = Reporting limit. NA = Not applicable.

TABLE 3
SAMPLE CONTAINER, PRESERVATION, AND HOLDING TIME REQUIREMENTS

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

				I
Parameter Group	**Reference Method**	**Sample Container and Preservative**	**Sample Storage**	**Extrac Derivat**
Volatile Organics				
Soil	8260	2-oz glass jar with teflon lined lid	4±2° C	N
Air	GC/TO-15	Gas tight 1 L Tedlar bag	NA	
Chemical Properties (Soils)				
pH	EPA 150.1	2" X 6" tube per sample, chill	4±2° C	N
Physical Properties (Soils)				
Intrinsic Permeability	API RP 40 / ASTM D2434	2" X 6" tube per sample, chill	4±2° C	N
Porosity, total and air-filled	API RP 40	2" X 6" tube per sample, chill	4±2° C	N
Dry Bulk Density	API RP 40/ASTM D4564/ASTM D2937	2" X 6" tube per sample, chill	4±2° C	N
Volumetric Moisture Content	ASTM DD216/ASTM D4959/ ASTM D4643	100 grams, chill	4±2° C	N
Fraction Organic Carbon	Walkley-Black, EPA 9060	100 grams, 4° required	4±2° C	N

Notes:
1. Laboratory procedures will be conducted in accordance with the reference methods specified above.
NA = Not applicable to this analysis or matrix.

TABLE 4
LABORATORY CONTROL LIMITS FOR INTERNAL STANDARDS
VOLATILE ORGANICS

QAPP for Demonstration Plan for Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

Parameter	EPA SW-846 Reference Method	Laboratory Control Limits Relative to Calibration Standard	
		Peak Area Counts	Retention Time
Volatile Organics			
1,4-Difluorobenzene	8260B	NA	+/- 0.5 minutes
Chlorobenzene-d5	8260B	NA	+/- 0.5 minutes
1,4-Dichlorobenzene-d4	8260B	NA	+/- 0.5 minutes
Pentafluorobenzene	8260B	NA	+/- 0.5 minutes

Notes:
1. Control limits based upon data provided by TestAmerica and EPA published limits
2. Laboratory procedures will be conducted in accordance with the EPA reference methods shown above.

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-0707

Appendix I: GSI Health and Safety Plan (HASP)

GSI ENVIRONMENTAL INC.

PROJECT HEALTH AND SAFETY PLAN for

ESTCP H_2 Injection Demonstration Project

Atlas Missile Site 10, Former Lincoln AFB
York, NE

GSI Job No.	G-3537	Revision No.:	1
Plan Prepared By:	Ahmad Seyedabbasi	Date:	September 2010
Plan Reviewed By:			
Plan Approved:		Date:	

ACKNOWLEDGEMENT

I, the undersigned, have been provided with a copy of this Site-Specific Project Health and Safety Plan. I have read the Plan, have attended a project safety orientation session conducted by GSI Environmental Inc. (GSI), and have had the opportunity to ask questions about health and safety issues relating to this project. I understand that it is my responsibility to abide by this Plan, and that physical injury, damage and other harm to myself or others could result from my failure to do so.

Name & Company (please print)	Social Security No.	Signature	Date

PROJECT HEALTH AND SAFETY PLAN

1.0 SCOPE AND APPLICATION

This Project Health and Safety Plan has been prepared in accordance with 29 CFR §1910.120, and is a site-specific supplement to the GSI company Health and Safety Plan (GSI HASP), which specifies GSI's general health and safety policies and procedures. This site-specific plan is to be provided to all site workers under the direction of GSI for their review. In addition, this plan, the GSI HASP, and applicable client safety guidelines will remain on-site at all times during the project, and will be available to all project personnel upon request from the GSI Site Safety Officer (SSO) or other designated representative.

This plan specifies health and safety protocol to be followed during implementation of the project work scope by all site personnel under the direction of GSI, including employees and subcontractors. In the event of conflicting standards between this plan or the GSI HASP and client health and safety requirements, the more protective standard shall apply. All personnel are required to comply with this plan and to indicate their agreement to do so by signing the cover page.

2.0 PROJECT DESCRIPTION

2.1 General Information

Client/Site Steward	Omaha District, USACE (ESTCP is funding agency)
Project Name and General Description	ESTCP Hydrogen Injection in Vadose Zone Demonstration
Project Location (Physical Address)	Former Atlas "F" Missile Site 10, Site ID: 551-10 Former Lincoln AFB, York NE Lat: 40°53'43.02"N, Long: 97°41'7.96"W
Detailed Location Information	Former Atlas "F" Missile Site 10 is located at Former Lincoln AFB in southeastern Nebraska. The nearest town to the site is York (Nebraksa). Site 10 is the former Atlas "F" missile facility operated by the Former Lincoln AFB from 1960 to 1964. Site 10 was deactivated and conveyed to a private individual in 1965. The major structure at the site is the underground missile silo, which is 174 ft in depth and 52 ft in diameter.
Start Date/Duration/ Other Schedule Info.	

2.2 Site Description:

Former Atlas “F” Missile Site 10 is located at Former Lincoln AFB in southeastern Nebraska. The nearest town to the site is York (Nebraksa). Site 10 is the former Atlas “F” missile facility operated by the Former Lincoln AFB from 1960 to 1964. Site 10 was deactivated and conveyed to a private individual in 1965. The major structure at the site is the underground missile silo, which is 174 ft in depth and 52 ft in diameter.

Historic operations at the former missile silo have resulted in trichloroethene (TCE) concentrations in soil and groundwater which exceed Nebraska Department of Environmental Quality regulatory standards for chlorinated volatile organic compounds (CVOCs). The primary constituents of concern are chlorinated solvents, including TCE, cis-1,2-DCE, and VC. These constituents are present in soil, generally range ND-2.0 mg/Kg for TCE and ND-1.6 mg/Kg for cis-1,2-DCE.

2.3 Project Tasks:

3.0 EMERGENCY RESPONSE PROCEDURES

Report all accidents immediately to: Ahmad Seyedabbasi or Robert Lee, (713) 522-6300 or (713) 775-7325, who will subsequently ensure proper client notification.

Describe plant siren/ alarm signals, if applicable, and response

Emergency procedures to be reviewed with Air Force personnel prior to beginning work.

Location of emergency assembly area(s)

To be discussed with Air Force personnel.

Describe other applicable emergency response measures to be taken

All emergency response measures will be consistent with existing protocol for site.

Location and phone number of nearest hospital with emergency room (see attached map)

York General Hospital, York, NE 68467; (402) 362-6671.

4.0 PROJECT ORGANIZATION, PERSONNEL, & TRAINING REQUIREMENTS

4.1 Key Personnel

Position	Name	Phone (Cell Phone)
GSI Project Team Leader (PTL)	Ahmad Seyedabbasi	(713) 775-7325
GSI Safety Administrator	Bob Lee	(713) 775-7330

4.2 Training Requirements – Check all that apply and list any additional

	OSHA 40-hr HAZWOPER	√	
	Contractor Safety Council (CSC) -Basic +		
	Site-Specific (on-site)		
	Unit specific		

4.3 Requirements for Respirator Use

Will respirator use potentially be required? ______Yes __X__No

If yes, GSI Respiratory Protection Plan, found in Section 6.0 of the GSI HASP, is applicable. Affected personnel must have physician's written opinion certifying fitness to use respirator based on pulmonary function test and other considerations, be trained in proper respirator use, and have quantitative fit test.

4.4 Personnel Documents

List documentation of training or medical fitness project personnel will be required to provide.

All personnel are to maintain training and medical records at their respective offices and provide to GSI on request.

5.0 POTENTIAL HAZARDS & HAZARD CONTROL MEASURES

5.1 General Site Access Control

Specify site control measures as necessary to prevent unauthorized persons from entering work area (e.g., fencing, barricades, tape, signs, etc.)

NA

5.2 Project Personnel Access Control

Specify sign-in and sign out procedures for project personnel, and means of notifying site manager if unable to be on-site.

NA

5.3 Underground Utilities Clearance

NA

5.4 General Work Hazards and Avoidance

General work hazards include slip, trip, and fall hazards, head or foot injuries from falling or dropped objects, strains from over-exertion or incorrect lifting, electrical shocks, etc. These hazards can be controlled by good housekeeping measures and safe work practices, as outlined below (see also GSI HASP).

Housekeeping Measures:

- Clearing of excess brush or high vegetation from the work area is not required at this location. Clearing of any kind requires pre-approval.
- The job site must be kept clean and free of trash and debris. All material used during the project should be recycled to the extent possible. Trash will be placed in bags or other suitable containers when generated. Disposable PPE must be disposed in designated containers upon removal.
- Materials such as lumber, well screen and riser pipe, filter pack sand, cement, etc. will be neatly stored in a designated area.
- Tools and equipment must be returned to the tool box or designated area when no longer in use.

General Safe Work Practices:

- Use buddy system.
- Stay alert at all time to activities in your surroundings. Watch for on-coming vehicles, other workers, and overhead hazards.
- Work at a deliberate pace; do not rush a job.
- Avoid heavy lifting and lift with knees bent.
- Use tools only for their intended use, and make sure tools are in good condition. Inspect power tool and extension cords prior to use.
- Maintain safe distance between drillrig mast or other overhead equipment and overhead lines.
- Avoid unauthorized entry to restricted areas including confined space areas.
- Do not operate plant process equipment; do not open or close valves
- Proper PPE (specified below) must be worn at all times. PPE must be inspected regularly and properly maintained.
- Remove gloves and wash hands before handling food or tobacco products.

5.5 Fire and Explosion Hazards and Mitigation

- All drilling or excavation locations must be properly cleared for the presence of underground utilities prior to drilling or digging.
- Gasoline and other fuels must be stored in steel safety cans with mesh flame arresters and spring-mounted relief vent mechanisms. Flammable and combustible materials including paints and solvents must be properly stored away from sources of ignition.
- Suitable secondary containment should be present when using all equipment (i.e., drill rigs, direct push rigs, generators, gas cans)
- Fire extinguishers must be present on all vehicles and drilling and excavation equipment, and in all areas where spark producing equipment is in use.

Other Measures (check as applicable)
X___ Smoking permitted only in designated areas, or

____ Matches and lighters not permitted onsite
____ Hot-work permits must be obtained for spark-producing equipment in designated areas.

5.6 Heat and Cold Exposure-Related Disorders

The major varieties of heat-related disorders, their related symptoms and appropriate treatment are listed below in order of increasing severity.

Condition & Related Symptoms	Heat Stress	Heat Exhaustion or Heat Syncope	Heat Stroke
Cramping	May be present	May be present	Absent
Mental State	Faint, dizzy, fatigue	May be disoriented	Stupor or coma
Skin & Complexion	Cool, moist, flush; rash may be present.	Cool, pale, moist	Red, hot, dry
Temperature	Normal	Normal to low	Very high (>105° F)
Pulse	Rapid (>110 beat /min)	Rapid, weak	Rapid, bounding
Blood Pressure	May be low	May be low	May be high in early stages
Treatment	Give water & electrolytes, loosen or remove clothing, move to shade	Give water & electrolytes, loosen or remove clothing, move to shade	Provide rapid cooling by immersion; cover in wet cloth and transport to emergency room

Prevention Measures: All heat disorders are caused by loss of fluids and the body's inability to cool itself. Heat stress can be prevented by the following measures:

- Pre-hydrate before going into the field: water or water-electrolyte drinks are preferable to caffeinated beverages or soft drinks. Refrain from alcohol the night before field work.
- Drink frequently while in the field. Numerous small drinks at a tepid temperature are better than rapid, large volume intakes of iced drinks.
- Rest at least a few minutes every hour or two.
- Observe co-workers for signs of heat stress.

Due to the location and the March start date, heat-related disorders are not anticipated. Cold exposure-related disorders are a higher concern. Cold injuries (including frostbite and hypothermia) and impaired ability to work are two dangers caused by extremely cold conditions. Warning signals include reduced coordination, drowsiness, impaired judgment, fatigue, and numbing of toes and fingers. Cold exposure can be prevented by appropriate clothing for cold weather work, providing for warm shelter at the work site, and monitoring each worker's physical condition.

Other adverse weather conditions (e.g., hurricane or tropical storm, thunderstorms) may necessitate work stoppage. Criteria for evaluating these conditions are included in the site-wide Health and Safety Plan. This includes sustained winds and/or rain for the work anticipated as part of the current project. For thunderstorms, weather reports for the area will be used to monitor risk of electrical activity and/or heavy rain. When a thunderstorm watches or warning is issued, a 30-minute stand down period will be enacted to provide sufficient time for the storm to pass. The length of this period will be extended as needed if further activity (thunder or lightening) occurs.

5.7 Heavy Equipment Operations

Drilling and other equipment must be in good condition. Particular attention should be paid to the condition of cables and hoisting equipment. The equipment must be equipped with a back-up beeper. Barricades or caution tape should be used as needed to exclude unauthorized personnel from the work area.

During drilling, the drill rig should be positioned to allow for adequate work room and the area kept free of trip and slip hazards. Care must be taken to avoid the catching of loose clothing in moving parts, and to keep hands free of pinch points. Proper PPE including hard hat, safety glasses, gloves, hearing protection, and safety shoes must be worn.

5.8 Confined Space and Excavation Safety

All personnel must obey all posted restrictions on entry to confined spaces. Excavations deeper than 4 ft should not be entered for any purpose unless 1) the excavation walls are properly shored or are sloped at a 1:1 slope, or less steep, and there is no danger of collapse or engulfment; 2) a suitable means of egress such as ramp, stairs or ladder is located so as to require no more than 25 ft of lateral travel to reach it; and 3) testing demonstrates a hazardous atmosphere is not present. Note that there are no entries to confined space or excavations anticipated as part of this project.

5.9 Potential Chemical Exposure Hazards

The following summarizes primary constituents of concern, relevant exposure levels, and the maximum expected concentrations in soil and/or groundwater, to the extent known. Material Safety Data Sheets (MSDS) are provided as an attachment to this document.

Constituents of Concern (COCs)	**Exposure Limits[1]**			**Max. Expected Concentration or Free-Phase (FP)**		**Health Hazard Target Organ Route of Entry[2]**
Chemical Name/ CAS No.	**PEL / TLV (ppm)**	**STEL (ppm)**	**IDLH (ppm)**	**Soil mg/kg**	**Water mg/L**	**Ca = carcinogen** **Abs = skin absorption** **Con = skin or eye contact** **Inh = inhalation** **Ing = ingestion**
Trichloroethene 79-01-6	10 ppm	25 ppm	1000 ppm	< 1 mg/kg	NA	Inh, Ing, Con
cis-1,2-Dichloroethene 156-59-2	200 ppm	NA	1000 ppm	< 100 mg/kg	NA	Inh, Ing, Con
trans-1,2-Dichloroethene/ 156-60-5	200	NA	1000	ND	0.05	Ca, Inh, Abs, Ing, Con
Vinyl Chloride/ 75-01-4	1	C 5	ND	ND	0.44	Ca, Inh, Con

[1] Unless otherwise noted, Permissible Exposure Limits (PEL) and Threshold Limit Values (TLVs) are permissible time-weighted average exposure limits (ppm in air) which must not be exceeded for an 8-hour work-day/40-hour work week. If multiple published values are available, then the listed value represents the lowest of all published values. Short-Term Exposure Limits (STELs) must not be exceeded over a 15-minute period. IDLH –Immediately Dangerous to Life or Health must no be exceeded at any time. NPV = No published value. ND = Not determined

[2] See also NIOSH Pocket Guide to Chemical Hazards.

To minimize potential chemical exposure, the following measures will be taken:

- MSDS must be provided for any chemical brought on-site for project use.
- Workers should remain upwind of contaminated materials to the extent practical.

- PPE specified below will be worn to prevent skin or eye contact with constituents.
- Air quality monitoring will be conducted and respiratory protective equipment used as needed, as described below.
- Eating, drinking, smoking, gum chewing and oral tobacco use are not permitted in areas where chemical exposure could occur.
- Workers must remove gloves in the work area and drink from a water source outside the immediate work zone.
- PPE must be removed and hands thoroughly washed prior to breaking for meals.
- Minimize the formation of dust during drilling and sampling activities, and avoid inhalation of dust particles.

5.10 Other Potential Hazards

Site is located in an open area where ground may be soft and muddy due to recent thawing. All personnel should modify PPE for muddy conditions as appropriate (e.g., rubber boots).

6.0 AIR QUALITY MONITORING

6.1 Air Monitoring Instrument

______ OVA 128 Calibrated to methane standard

______ Drager Tube (specify compound & use)______________________________

______ Personnel Badges (specify compound & use)________________________

______ Lower Explosive Level (LEL) __________________________________

__X__ Other (Specify) Photoionization Detector__________________________

6.2 Monitoring Frequency and Location

Specify where will monitoring be performed (e.g., Worker's breathing zone, site perimeter, contaminant source area, or other area) and Monitoring Frequency (e.g., Continuous, Periodic {hourly, etc.}, on detection of noticeable odor)

Continuous monitoring will be performed in the work-breathing zone during soil vapor sampling activities.

7.0 PERSONAL PROTECTIVE EQUIPMENT (PPE)

7.1 Level D PPE

A minimum of Level D PPE is required for all site personnel at all times, upgraded as necessary depending on task and conditions. Basic Level D PPE shall include the following elements:

1) Hard Hat (w/ mono goggles);
2) Safety Glasses (w/side shields);
3) Safety Shoes (w/steel toes);

4) Body Covering (long pants, shirt w/ sleeves, collar). Basic Level D equipment will be supplemented as follows:

SUPPLEMENTAL LEVEL D PPE

	Item	When/Where to be Used
	Flame Retardant Clothing FRC	
	Hearing Protection	
X	Work gloves	While handling equipment
X	Latex or vinyl surgical gloves	While handling samples or sample equip.
	Neoprene or Nitrile gloves	
	Tyvek Coveralls	
	Polycoat Tyvek Coveralls	
	Chemical-resistant boots	
	Face Shield	

7.2 Level C PPE

Specify action level conditions for Level C PPE (use of Air-Purifying Respirator)

No Level C work will be performed on this project due to expectation of trace VOC levels in soils and groundwater.

Specify equipment and limitations.

Half-face Respirator up to ____ ppm, TOV or _____ ppm (compound) by Draeger

Full Face Respirator up to ____ ppm, TOV or _____ ppm (compound) by Draeger

Specify Cartridge Type____________________________________

Specify action level conditions for Level B (Supplied Air) if applicable, or suspension of work.

No Level B work will be performed on this project.

7.3 Level B PPE

Specify Level B Equipment (pressure demand, continuous flow, etc.).

No Level B work will be performed on this project.

Specify Level B Procedures (personnel, air supply monitoring, etc.).

N/A

Specify conditions for project shut-down.

N/A

8.0 DECONTAMINATION PROTOCOL

Specify procedures for personnel decontamination and management of disposable PPE.

Wash hands thoroughly before leaving the site or eating. PPE will be disposed in trash bags for disposal at designated location, specifically a field dumpster located on site.

Specify procedures for response to non-emergency chemical release.

Contain spills to the extent possible and treated as liquid waste.

9.0 ADDITIONAL INFORMATION

Provide any additional information, procedures, or instructions as needed.

MSDS forms are provided as attachments to this document. Also included as attachments are a map with the location of the closest medical facility, as well as example forms for documenting the site safety meeting and daily activity.

DIRECTIONS TO HOSPITAL

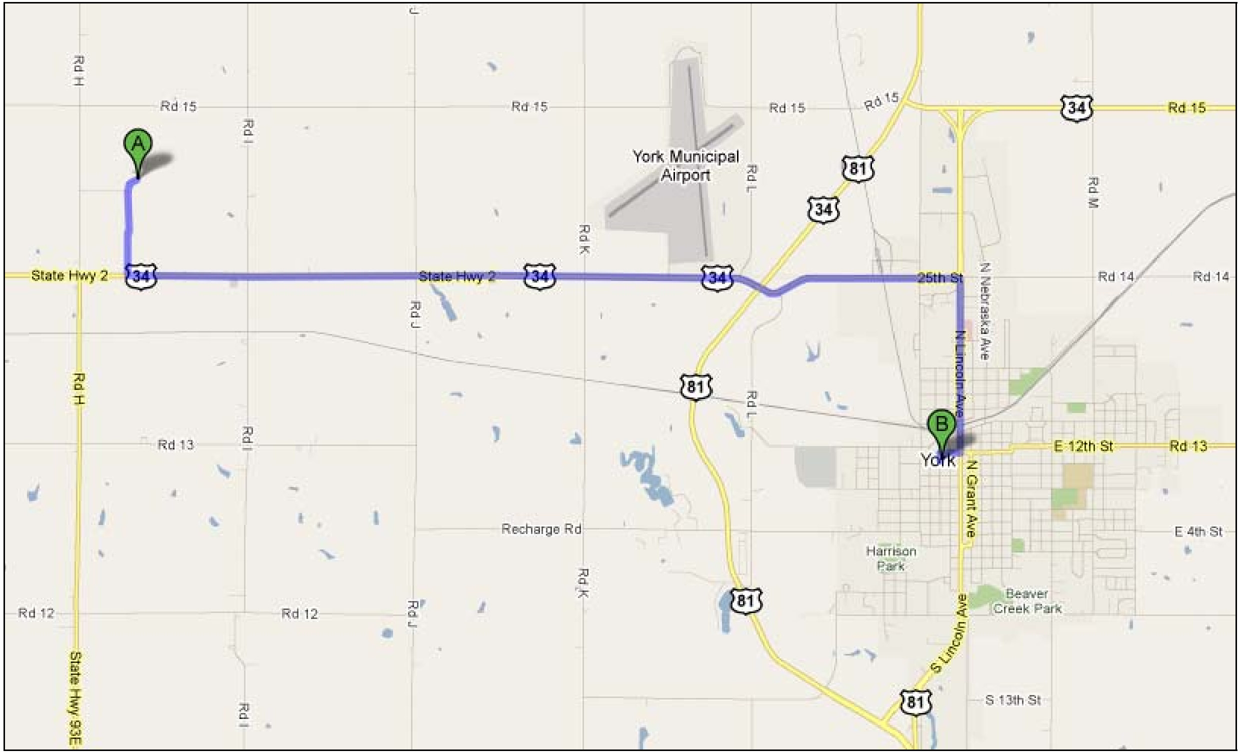
A: **Atlas Missile Site 10, Former Lincoln AFB, York NE**

B: **York General Hospital, York, NE 68467**

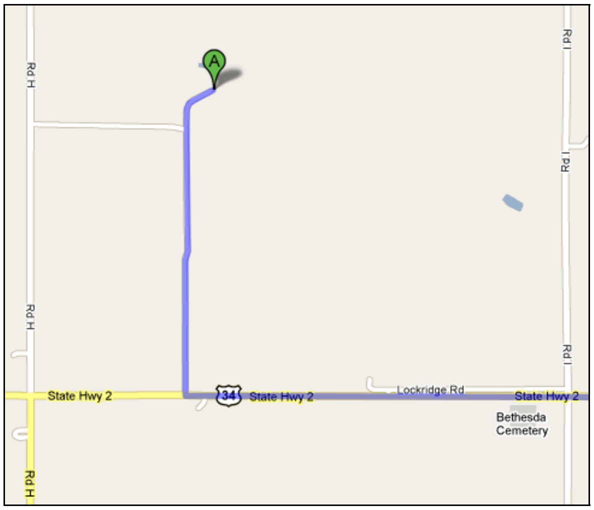
Route: **6.8 mi, 12 min**

A:	Atlas Missile Site 10, Former Lincoln AFB, York NE	
1.	Head southwest toward US-34 W/State Hwy 2	0.6 mi
2.	Turn left at US-34 E/State Hwy 2 (Continue to follow US-34 E)	4.7 mi
2.	Continue onto 25th St	0.2 mi
3.	Turn right at N Lincoln Ave	1.0 mi
4.	Turn right at W 11th St	0.1 mi
5.	Take the 2nd left onto N Beaver Ave	230 ft
B:	York General Hospital, York, NE	

Route: 6.8 mi, 12 min



A: Atlas Missile Site 10, York NE B: York General Hospital, York, NE 68467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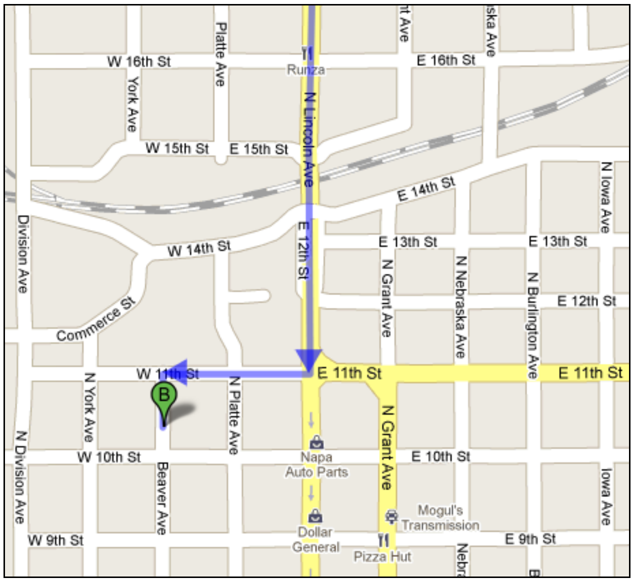
Bethesda Cemetery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N Platte Ave
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Beaver Ave
Napa Auto Parts
E 10th St
Mogul's Transmission
Iowa Ave
W 9th St
Dollar General
Pizza Hut
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SITE SAFETY MEETING

Project/Location: ____________________________
____
Site Safety Officer:____________________________

GSI Job No.__
Page 1 of 1
Date: ______

Meeting Conducted By:_________________
Meeting Attended By:

Name Company Signature

1) ____________________________

2) ____________________________

3) ____________________________

4) ____________________________

5) ____________________________

6) ____________________________

Additional Personnel (See Next Page)

Tasks to be Performed

____

Potential Hazards and Hazard Avoidance Measures

Mechanical Hazards: ____________________________

____

Heat stress: ____________________________

____

Chemical exposure: ____________________________

____

Biological hazards: ____________________________

Other: ____________________________

____

GSI
ENVIRONMENTAL

DAILY SITE SAFETY RECORD

Project/Location: ____________________________ GSI Job No.________
____ Page 1 of __________
Site Safety Officer:___________________________ Date:______________

Field Personnel

Name	Company	Time Onsite-Offsite	Time Onsite-Offsite
1)			
2)			
3)			
4)			
5)			
6)			

Additional Personnel (Attach additional sheets as needed.)

Work Item/Personal Protective Equipment Level

Task: ____

Personnel: ____________________________ PPE: ____________________

Task: ____

Personnel: ____________________________ PPE: ____________________

Air Quality Monitoring: ______ See Record (next page) Not Required

Safety Awareness Issues Discussed: ______________________________

____

____

ACCIDENTS/INJURIES/INCIDENTS

(Description of Incident, Actions Taken. Attach additional sheets as needed)

____

____

____

DAILY SITE SAFETY RECORD

GSI Job No.________
Page 2 of _________
Date _____________

Air Quality Monitoring:

______Foxboro OVA 128
Calibration Check:
(95 ppm Methane Gas)

______Other (Specify) __________________
10 X Scale Reading (ppm)______________
100 X Scale Reading (ppm)______________

Time	Activity	Sample Point	Reading* (ppm)

* Reading above background, sustained for 1 minute period.

Action Level __ ppm Action Level Exceeded? ______________________

Action Taken____

Remarks____

____

____

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix J: Gas Injection Skid Operation & Maintenance Manual

Operation & Maintenance Manual

NES PROJECT NUMBER: 11-116, May 2011
PROJECT NAME: H2T Injection Equipment
GSI Project No. G3537
Former Atlas Missile Site - York, Nebraska

Prepared for:

GSI Environmental Inc.
2211 Norfolk, Suite 1000
Houston, TX 77098-4054

Sales: (508)226-1100 Option 2
Technical Support: (508)226-1100 Option 3

NES Project: 11-116
GSI 3537 – H2T Injection Equipment
Former Atlas Missile Site – York, NE

Operation & Maintenance Manual

Section 5 – Injection Manifold Components

BV-1101 to 1901 ½” Ball Valves - Nibco Model NIBTFPA600-12 Specifications

FM-1102 to 1902 Brooks Flowmeter Summary

FM-1101 to 1902 Flowmeters – Brooks Model 1355E Specifications

Brooks Model 1350e & 1355e Operating Instructions

PI-1101 to 1901 Pressure Gauges Concoa Model 550-0201 Specifications

PI-1102 to 1902 Pressure Gauges Concoa Model 550-0201 Specifications

Section 6 – Well Head Connections

BV-1101 to 1902 ½” Ball Valves - Nibco Model NIBTFPA600-12 Specifications

PI-1103 to 1903 Pressure Gauges Dwyer Model LPG2-D9942N Specifications

2 Ear SS Hose Clamps – Grainger / Oetiker Model 4E602 Specifications

Pincer for Hose Clamps – Grainger / Oetiker Model 4E607 Specifications

Section 1 – Equipment Summary & Warranty

Major Component Summary Table

NES Warranty

WARRANTY

All products not manufactured by RapidTech LLC d/b/a National Environmental Systems, carry the original manufacturer's warranty. Copies are available on request.

RapidTech LLC d/b/a National Environmental Systems, warrants its packaged and manufactured equipment against any defect in material or workmanship, under normal use and storage for a period of twelve (12) months from date of manufacture and invoice, regardless of system start-up date. In the event that products are found to be defective within the warranty period, RapidTech LLC d/b/a National Environmental Systems, sole obligation and remedy shall be the furnishing of replacements for any defective parts, and such replacement parts shall be furnished but not installed by RapidTech LLC d/b/a National Environmental Systems RAPIDTECH LLC D/B/A NATIONAL ENVIRONMENTAL SYSTEMS, WILL NOT BE LIABLE FOR SPECIAL OR CONSEQUENTIAL DAMAGES IN ANY CLAIM SUIT OR PROCEEDINGS ARISING UNDER WARRANTY, NOR WILL RAPIDTECH LLC D/B/A NATIONAL ENVIRONMENTAL SYSTEMS, ACCEPT ANY LIABILITY FOR CLAIMS FOR LABOR, LOSS OR PROFIT, REPAIRS OR OTHER EXPENSES INCIDENTAL TO REPLACEMENT.

The warranty requires that the purchaser complete all operations and maintenance as detailed in each section of the Operation & Maintenance Manual supplied with the purchased system. In addition installation must comply with nationally recognized electrical and mechanical standards as well as best engineering practices in effect at the time of purchase.

The product warranty expressed above is our only warranty and may not be verbally changed or modified by any representative of RapidTech LLC d/b/a National Environmental Systems All freight costs incurred in shipping parts to or from RapidTech LLC d/b/a National Environmental Systems, or to the manufacturer if necessary are at the expense of the customer.

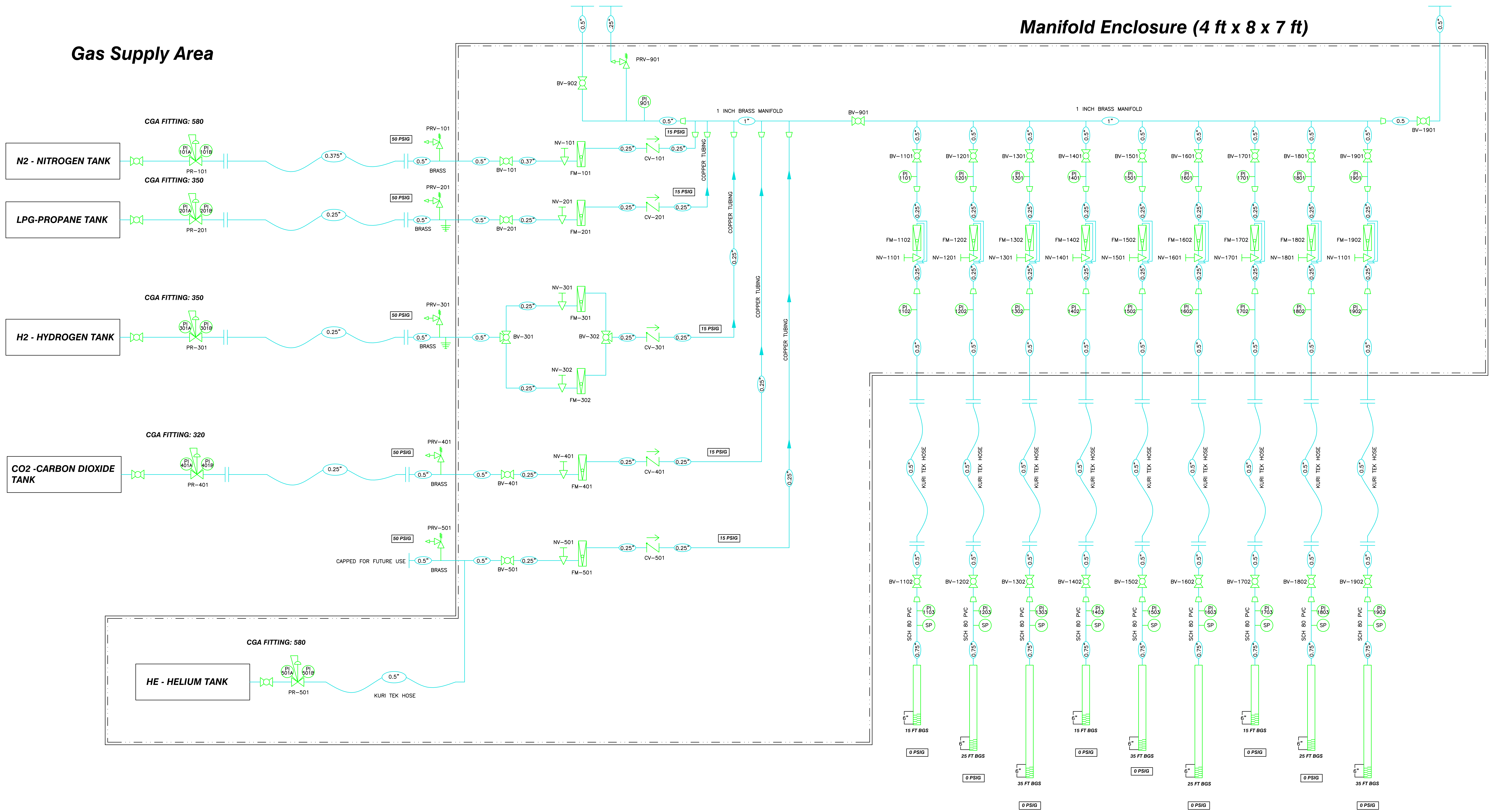
RapidTech LLC dba National Environmental Systems, will invoice the cost of any replacement parts. These parts will be credited upon certification the original part was defective and the defective part was returned within one week of notifying RapidTech LLC d/b/a National Environmental Systems, of the malfunction. If the part is found to have been misused no credit will be issued. In order for RapidTech LLC d/b/a National Environmental Systems, to ship a replacement part on account, all outstanding invoices must be current.

RapidTech LLC d/b/a National Environmental Systems, expressly disclaims any warranties, expressed or implied, including any warranty of merchantability or fit for particular purpose or any warranty arising from a course of dealing or usage of trade. Except to the extent required by applicable law. RapidTech LLC d/b/a National Environmental Systems, shall not be liable, in tort, contract or otherwise, for any loss or damage, whether direct, consequential or incidental, of any person or entity arising in connections with the equipment.

Section 2 – Mechanical Drawing

H2T Injection System Process & Instrumentation Diagram

H2T Injection System Skid Layout Drawing



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NATIONAL ENVIRONMENTAL SYSTEMS
84 Dunham Street – Attleboro, Massachusetts
508–266–1100 (Phone) / 508–266–1180 (Fax)

TITLE
H2T INJECTION SYSTEM
PROCESS & INSTRUMENTATION DIAGRAM (P&ID)

REV.	DESCRIPTION	DATE	APPR.
A	AS BUILT	5/16/11	RXB

REVISIONS

DRWN BY CJJ DATE 03–18–11
CHK BY DATE
APPR BY DATE

GSI G3537 H2T Injection System
Former Atlas Missile Site – York, NE
JOB NO. 11–116

SCALE	SIZE	DWG NO.	SHEET	REV
N/A	D	11–116–P1	1 OF 2	A

Tag No	MODEL	MANUFACTURER	SPEC
FM-101	1358F1B2FC3D1A	BROOKS INSTRUMENT	CALIBRATED FOR NITROGEN GAS / 1 - 10 SCFM RANGE / 50 PSIG INLET PRESSURE / 15 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / 316 SS FLOAT MATERIAL / VITON O-RING & PACKING / BRASS NEEDLE VALVE / 0.375 INCH BACK MOUNT CONNECTIONS
FM-201	1355EH2CCLN1A	BROOKS INSTRUMENT	CALIBRATED FOR PROPANE GAS / 0.13 - 1.3 SCFM RANGE / 50 PSIG INLET PRESSURE / 15 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / SAPHIRE FLOAT MATERIAL / VITON O-RING & PACKING / BRASS NEEDLE VALVE / 0.25 INCH BACK MOUNT CONNECTIONS
FM-301	1355EG2CCLN1A	BROOKS INSTRUMENT	CALIBRATED FOR HYDROGEN GAS / 0.2 - 2.0 SCFM RANGE / 50 PSIG INLET PRESSURE / 15 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / SAPHIRE FLOAT MATERIAL / VITON O-RING & PACKING / BRASS NEEDLE VALVE / 0.25 INCH BACK MOUNT CONNECTIONS
FM-302	1350EP2BCLN1A	BROOKS INSTRUMENT	CALIBRATED FOR HYDROGEN GAS / 0.71 - 7.1 SCFM RANGE / 50 PSIG INLET PRESSURE / 15 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / 316 SS FLOAT MATERIAL / VITON O-RING & PACKING / BRASS NEEDLE VALVE / 0.25 INCH BACK MOUNT CONNECTIONS
FM-401	1355EA2EALM1A	BROOKS INSTRUMENT	CALIBRATED FOR CARBON DIOXIDE GAS / 0.011-0.11 SCFM RANGE / 50 PSIG INLET PRESSURE / 15 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / SAPHIRE FLOAT MATERIAL / BUNA O-RING & PACKING / BRASS NEEDLE VALVE / 0.25 INCH BACK MOUNT CONNECTIONS
FM-501	1350EP2ECLN1A	BROOKS INSTRUMENT	CALIBRATED FOR HELIUM GAS / 0.88 - 8.7 SCFM RANGE / 50 PSIG INLET PRESSURE / 15 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / TANTALUM FLOAT MATERIAL / VITON O-RING & PACKING / BRASS NEEDLE VALVE / 0.255 INCH BACK MOUNT CONNECTIONS
FM-1101 / FM-1901	1355EH2BCLN1A	BROOKS INSTRUMENT	CALIBRATED FOR AIR / 0.15 - 1.5 SCFM RANGE / 15 PSIG INLET PRESSURE / 0 PSIG OUTLET PRESSURE / 70 F OPERATING TEMPERATURE / 316 SS FLOAT MATERIAL / VITON O-RING & PACKING / BRASS NEEDLE VALVE / 0.25 INCH BACK MOUNT CONNECTIONS
PI-901	550-0201	CONCOA	30" - 0 - 30 PSI RANGE / 2 INCH DIAL / 0.25 INCH BOTTOM PROCESS CONNECTION / BRASS WETTED MATERIALS / STEEL CASE
PI-1101 / PI-1901	550-0201	CONCOA	30" - 0 - 30 PSI RANGE / 2 INCH DIAL / 0.25 INCH BOTTOM PROCESS CONNECTION / BRASS WETTED MATERIALS / STEEL CASE
PI-1102 / PI-1902	550-0201	CONCOA	30" - 0 - 30 PSI RANGE / 2 INCH DIAL / 0.25 INCH BOTTOM PROCESS CONNECTION / BRASS WETTED MATERIALS / STEEL CASE
PI-1103 / PI-1903	LPG2-D9942N	DWYER INSTRUMENTS	0 - 5 PSIG / 2.5 INCH DIAL / 0.25 INCH BACK PROCESS CONNECTION / BRASS WETTED MATERIALS / STEEL CASE

Tag No	MODEL	MANUFACTURER	SPEC
PR-101	412 3341 580	CONCOA	BRASS BODY & BONNET CONSTRUCTION / PTFE SEAT MATERIAL / 316L DIAPHRAGM / PTFE INTERNAL SEAL / 3000 PSIG MAXIMUM INLET PRESSURE / -40 TO 140 F TEMPERATURE LIMITS / 2 INCH GAUGES / 0.1 VC / CGA FITTING 580 - NIROGEN
PR-102	412 3341 350	CONCOA	BRASS BODY & BONNET CONSTRUCTION / PTFE SEAT MATERIAL / 316L DIAPHRAGM / PTFE INTERNAL SEAL / 3000 PSIG MAXIMUM INLET PRESSURE / -40 TO 140 F TEMPERATURE LIMITS / 2 INCH GAUGES / 0.1 VC / CGA FITTING 350 - PROPANE
PR-103	412 3341 350	CONCOA	BRASS BODY & BONNET CONSTRUCTION / PTFE SEAT MATERIAL / 316L DIAPHRAGM / PTFE INTERNAL SEAL / 3000 PSIG MAXIMUM INLET PRESSURE / -40 TO 140 F TEMPERATURE LIMITS / 2 INCH GAUGES / 0.1 VC / CGA FITTING 350 - H2
PR-104	412 3341 320	CONCOA	BRASS BODY & BONNET CONSTRUCTION / PTFE SEAT MATERIAL / 316L DIAPHRAGM / PTFE INTERNAL SEAL / 3000 PSIG MAXIMUM INLET PRESSURE / -40 TO 140 F TEMPERATURE LIMITS / 2 INCH GAUGES / 0.1 VC / CGA FITTING 320 - CO2
PR-105	412 3341 580	CONCOA	BRASS BODY & BONNET CONSTRUCTION / PTFE SEAT MATERIAL / 316L DIAPHRAGM / PTFE INTERNAL SEAL / 3000 PSIG MAXIMUM INLET PRESSURE / -40 TO 140 F TEMPERATURE LIMITS / 2 INCH GAUGES / 0.1 VC / CGA FITTING 580 - HELIUM
PRV-101 / PRV-105, PRV-109	VR744MF2BV	PARKER	304 & 302 STAINLESS STEEL CONSTRUCTION / 20 - 100 PSIG ADJUSTABLE RANGE / PRE-SET AT 75 PSIG / 0.25 INCH PROCESS CONNECTIONS / CV - 0.37
CV-101 / CV-105	532-3922	CONCOA	BRASS CONSTRUCTION WITH VITON SEALS, 304 STAINLESS STEEL POPPET & 302 STAINLESS STEEL SPRING / 0.25 INCH PROCESS CONNECTIONS / 300 PSIG MAXIMUM WORKING PRESSURE / CRACKING PRESSURE OF 1 PSIG
BV-101, BV-102, BV-104 & BV-105	NIBTFPA600-12	NIBCO	BRASS CONSTRUCTION / PTFE SEAT / 600 PSIG WOG / 0.5 INCH NPT PROCESS CONNECTIONS
BV-301 & BV-302	7060301	CONBRACO / APOLLO	BRONZE CONSTRUCTION / RPTFE SEAT, STEM BEARING / 400 PSIG WOG / 0.5 INCH NPT PROCESS CONNECTIONS
BV-901	NIBTFPA600-1	NIBCO	BRASS CONSTRUCTION / PTFE SEAT / 600 PSIG WOG / 1.0 INCH NPT PROCESS CONNECTIONS
BV-1102 / BV-1902	NIBTFPA600-12	NIBCO	BRASS CONSTRUCTION / PTFE SEAT / 600 PSIG WOG / 0.5 INCH NPT PROCESS CONNECTIONS
SP	46-931	APPROVED VENDOR	FNPT x MNPT CONNECTION / MAX. PRESSURE 450 PSI WOG / REDUCED PORT/ FORGED BRASS CONSTRUCTION / PTFE SEATS / CHROME PLATED BRASS BALL / BRASS BLOWOUT PROOF STEM

REV.	DESCRIPTION	DATE	APPR.
A	AS BUILT	5/16/11	RXB

REVISIONS

DRWN BY CJJ DATE 03-18-11
CHK BY DATE
APPR BY DATE

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TITLE
H2T INJECTION SYSTEM
PROCESS & INSTRUMENTATION DIAGRAM (P&ID)

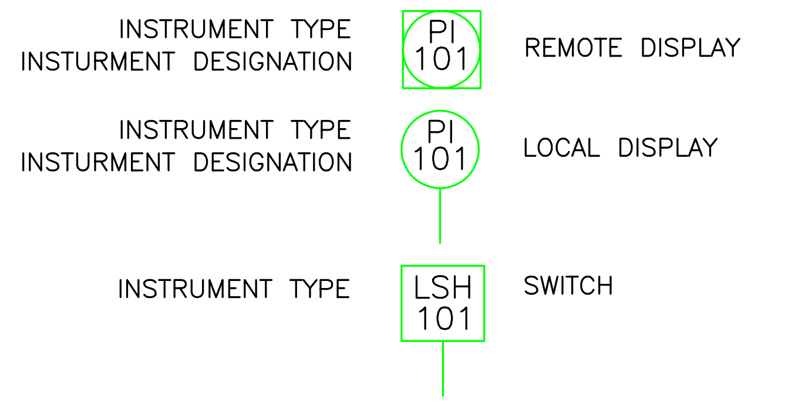
GSI G3537 H2T Injection System
Former Atlas Missile Site - York, NE
JOB NO. 11-116

SCALE N/A
SIZE B
DWG NO. 11-116-P1
SHEET 2 OF 2
REV A

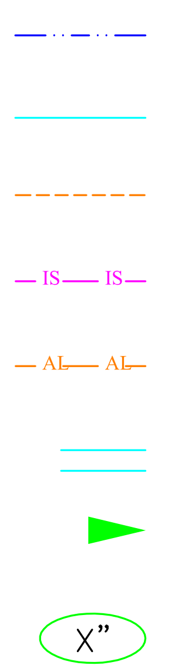
INSTRUMENTATION ABBREVIATIONS

CC	CYCLE COUNTER
CF	COALESCING FILTER
DPT	DIFFERENTIAL PRESSURE TRANSMITTER
FE	FLOW ELEMENT
FI	FLOW INDICATOR
FIT	FLOW INDICATING TRANSMITTER
FM	FLOW METER
PF	PARTICULATE FILTER
PI	PRESSURE INDICATOR
PS	PRESSURE SWITCH
SP	SAMPLE PORT
SV	SOLENOID VALVE
TI	TEMPERATURE INDICATOR
VI	VACUUM INDICATOR
DPG	DIFFERENTIAL PRESSURE GAUGE
FS	FLOW SWITCH OR SENSOR??
VSH	VACUUM SWITCH HIGH
VSL	VACUUM SWITCH LOW
PSH	PRESSURE SWITCH HIGH
PSL	PRESSURE SWITCH LOW
TSH	TEMPERATURE SWITCH HIGH
TSL	TEMPERATURE SWITCH LOW
LSHH	LEVEL SWITCH HIGH HIGH
LSH	LEVEL SWITCH HIGH
LSL	LEVEL SWITCH LOW
LSLL	LEVEL SWITCH LOW LOW
PS	PRESSURE SWITCH
TIT	TEMPERATURE INDICATING TRANSMITTER
TE	TEMPERATURE ELEMENT
HOL	HIGH OIL LEVEL
LOL	LOW OIL LEVEL

INSTRUMENTATION LABELING

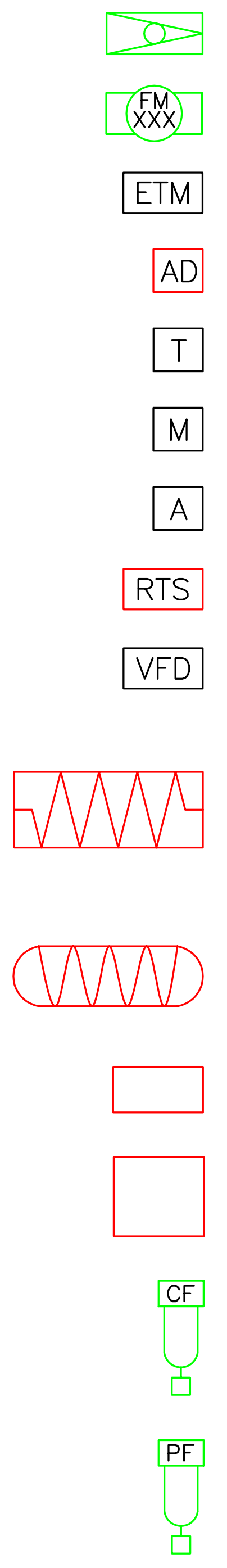


PIPE DESIGNATION



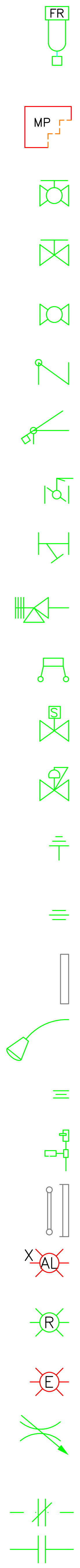
AIR LINE
WATER LINE
CONTROL LINE
INTRINSICALLY SAFE LINE
ANALOG LINE
BREAK
FLOW DIRECTION
PIPE SIZE

SYMBOLS



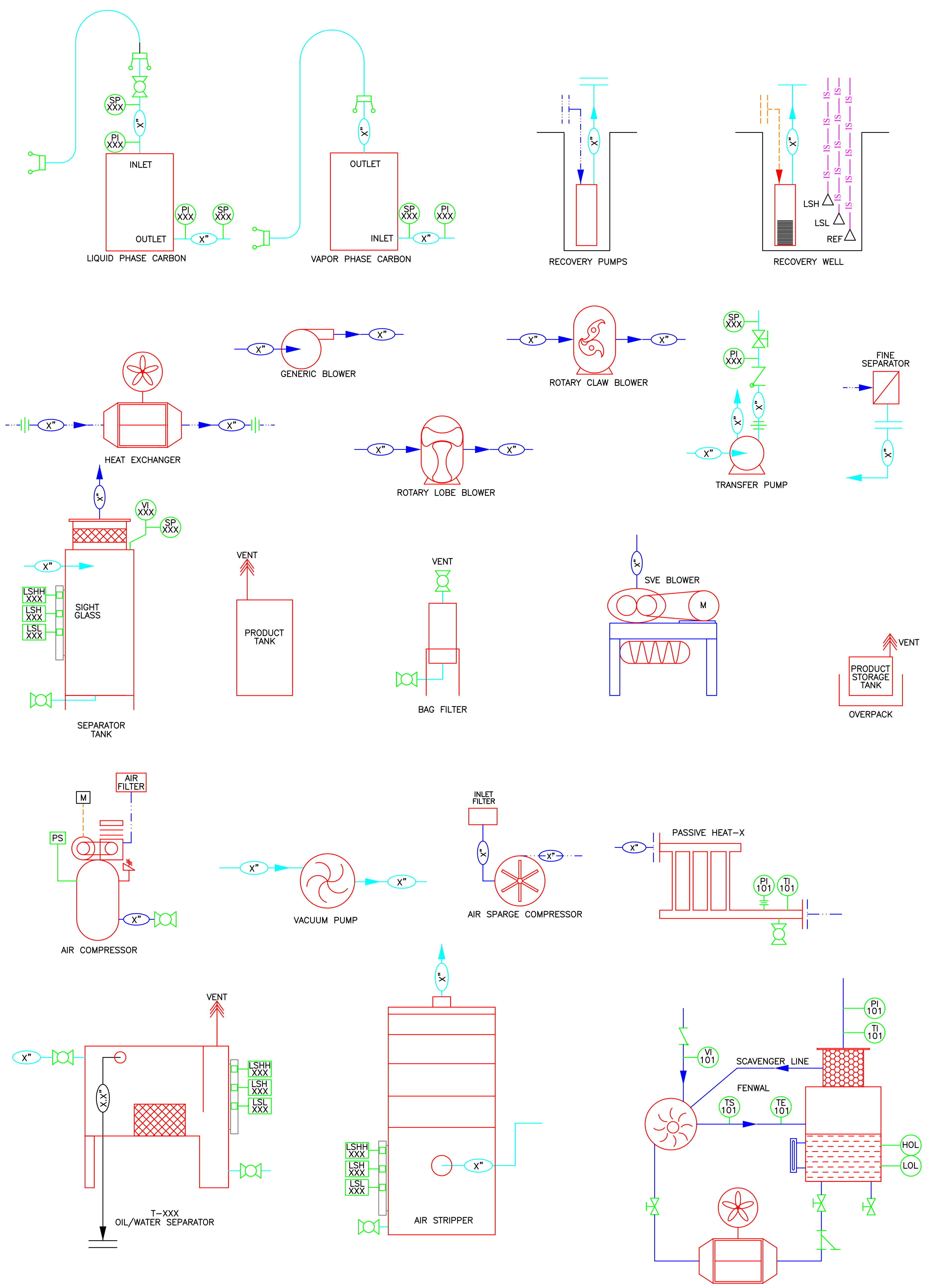
ROTAMETER
FLOW METER
ELAPSED TIME METER
AUTO DIALER
TIMER
MOTOR
AMP METER
REMOTE TELEMETRY SYSTEM
VARIABLE FREQUENCY DRIVE
STATIC MIXER
DISCHARGE SILENCER
DILUTION AIR FILTER
INLET/INLINE FILTER
COALESCING FILTER
PARTICULATE FILTER

SYMBOLS CONTINUED



FILTER REGULATOR
METERING PUMP
GLOBE VALVE
GATE VALVE
BALL VALVE/DRAIN VALVE
CHECK VALVE
RAIN CAP
BUTTERFLY VALVE
WYE STRAINER
RELIEF VALVE
CAMLOCK
SOLENOID VALVE
PRESSURE REGULATOR
SIPHON BREAK
UNION
CLEAR PVC
MECHANICAL FLOAT
PULSE-DAMPING SNUBBER
PITOT TUBE
SIGHT GLASS
ALARM LIGHT
RUN LIGHT
E-STOP
NEEDLE VALVE
FLANGED CONNECTION
REQUIRED FIELD CONNECTION

SYMBOLS CONTINUED



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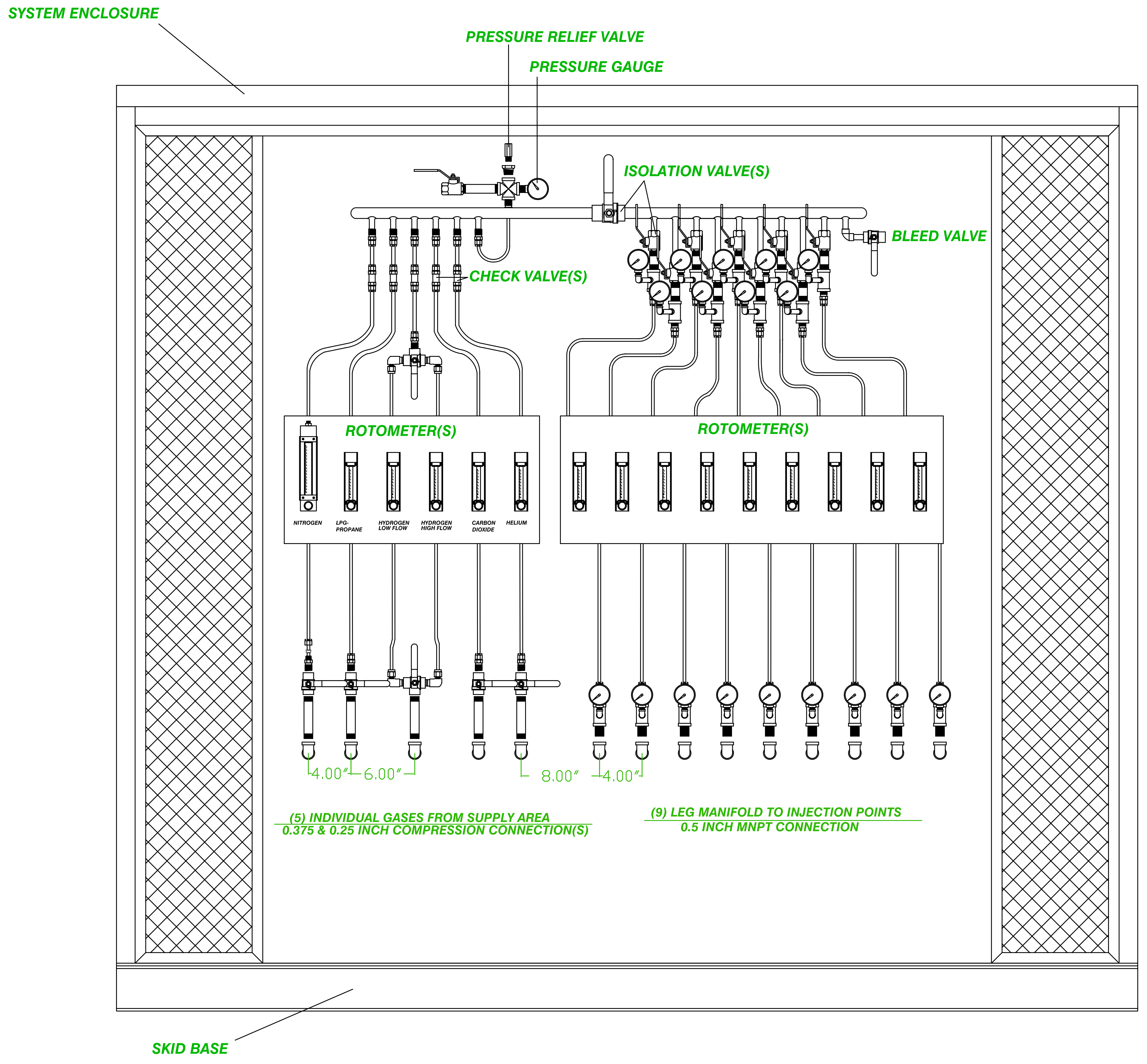
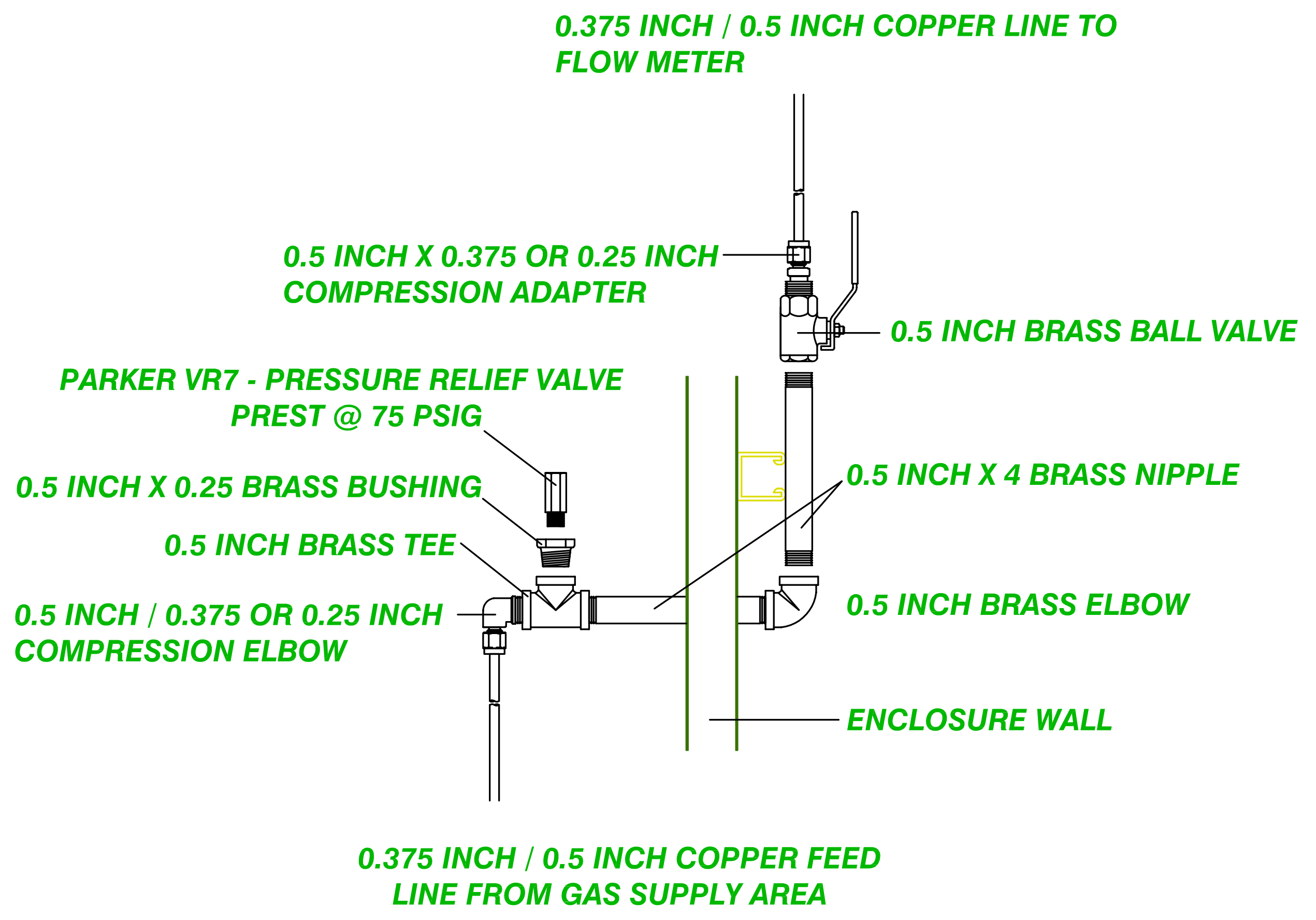
TITLE
PROCESS AND INSTRUMENTATION DIAGRAM
LEGEND

SCALE	SIZE	DWG NO.	SHEET	REV
N/A	D		1 OF 1	A



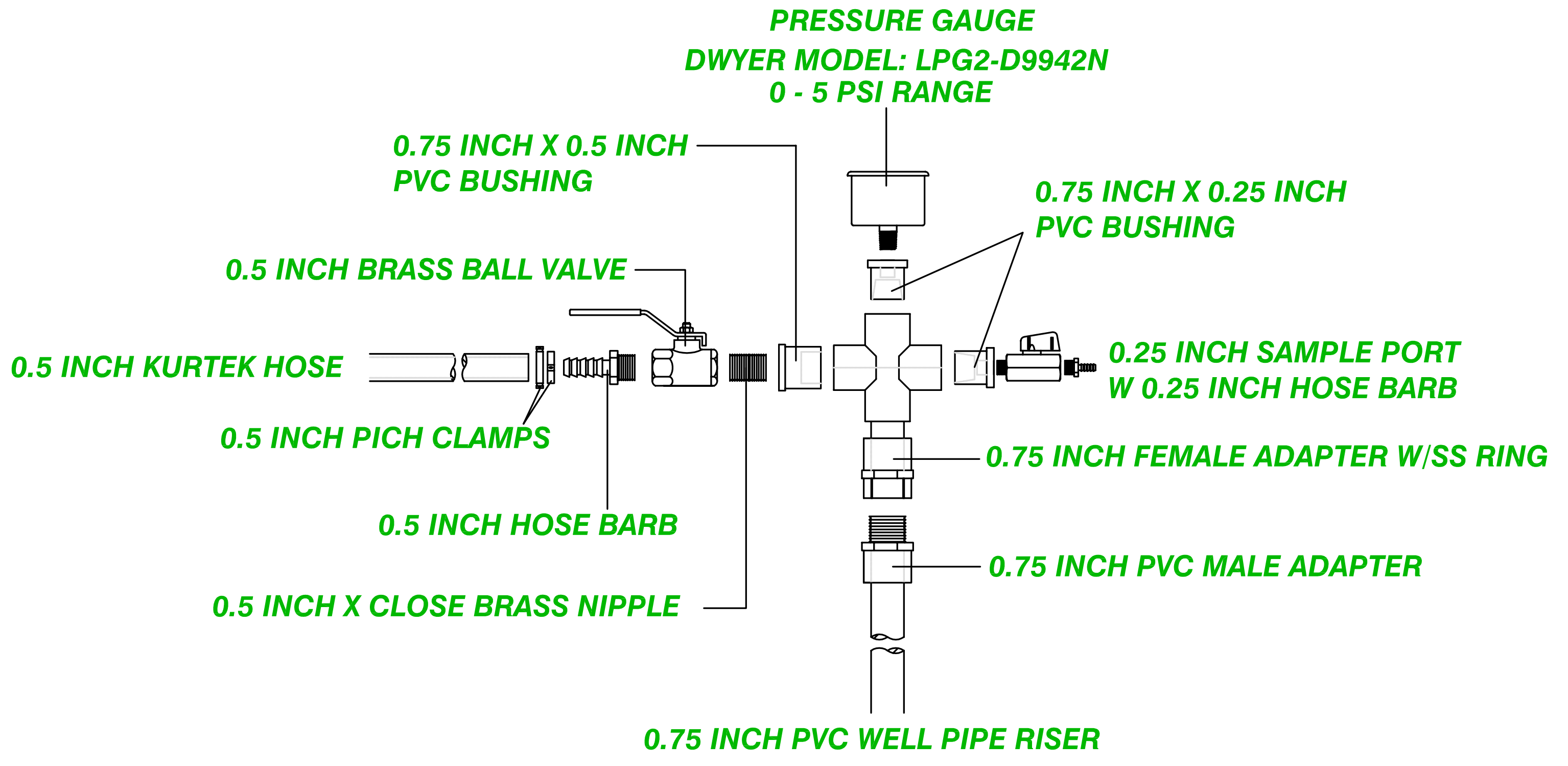
H2 INJECT - SYSTEM LAYOUT

FRONT ELEVATION



REMOTE GAS SUPPLY CONNECTION TYPICAL OF 4

PENATRATIONS 24 INCHES OFF GRADE



WELL FITTING DETAIL - TYPICAL OF 9

ASSEMBLIES ARE SHIPPED LOOSE FOR FIELD INSTALLATION BY OTHERS

REV.	DESCRIPTION	DATE	APPR.
A	AS BUILT	5–18–11	RXB

REVISIONS

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DRWN BY CJJ
DATE 03–30–11
CHK BY
DATE
APPR BY
DATE

TITLE
PRELIMINARY LAYOUT
8 FT X 4 FT ENCLOSURE

GSI G3537 – H2T INJECTION SYSTEM
FORMER MISSLE SILO – YORK, NEBRASKA

JOB NO. 11–116

SCALE	SIZE	DWG NO.	SHEET	REV
N/A	D	11–116–L1	1 OF 1	A

Section 3 – Compressed Gas Regulators & Pressure Relief Valves

Certification of Conformance

N_2

CONCOA Order Number: 3049973

This certifies that the item listed below conforms to all the specifications as set forth in the applicable CONCOA test procedure.

CONCOA Part Number: 4123341-84-580

CONCOA Serial Number: 1140HT5A

Declaration of Conformance - Pressure Equipment Directive
Sound Engineering Practice

CONCOA's pressure regulators, including the item listed above, have internal pressure containment volumes of approximately 0.05 liters. Article 3, Section 3 of the Pressure Equipment Directive 97/23/EC covers pressure equipment and/or assemblies with internal pressure containment volumes of less than 1 liter. Under this article, the product is not to be CE-marked, unless it is also covered by other applicable directives, but must be manufactured in accordance with sound engineering practice.

By virtue of its many years of experience in the design and manufacture of gas equipment and its ISO9001 certification, CONCOA declares that the pressure equipment listed above has been manufactured in compliance with EC directive 97/23/EC and is in compliance with the applicable sections of the regulation.

TESTED BY:
Tester: #10

Date: 04/28/11

CONTROLS CORPORATION OF AMERICA
1501 Harpers Road - Virginia Beach, VA 23454 - Phone (757) 422-8330
Fax (757) 422-3125 - http://www.concoa.com

Certification of Conformance

CO_2

CONCOA Order Number: 3049972

This certifies that the item listed below conforms to all the specifications as set forth in the applicable CONCOA test procedure.

CONCOA Part Number: 4123341-84-320

CONCOA Serial Number: 1140HT58

Declaration of Conformance - Pressure Equipment Directive
Sound Engineering Practice

CONCOA's pressure regulators, including the item listed above, have internal pressure containment volumes of approximately 0.05 liters. Article 3, Section 3 of the Pressure Equipment Directive 97/23/EC covers pressure equipment and/or assemblies with internal pressure containment volumes of less than 1 liter. Under this article, the product is not to be CE-marked, unless it is also covered by other applicable directives, but must be manufactured in accordance with sound engineering practice.

By virtue of its many years of experience in the design and manufacture of gas equipment and its ISO9001 certification, CONCOA declares that the pressure equipment listed above has been manufactured in compliance with EC directive 97/23/EC and is in compliance with the applicable sections of the regulation.

TESTED BY:

Tester: #10

Date: 04/28/11

CONTROLS CORPORATION OF AMERICA
1501 Harpers Road - Virginia Beach, VA 23454 - Phone (757) 422-8330
Fax (757) 422-3125 - http://www.concoa.com

Certification of Conformance

Propane

CONCOA Order Number: 3049974

This certifies that the item listed below conforms to all the specifications as set forth in the applicable CONCOA test procedure.

CONCOA Part Number: 4123341-84-350

CONCOA Serial Number: 1140HT5B

Declaration of Conformance - Pressure Equipment Directive
Sound Engineering Practice

CONCOA's pressure regulators, including the item listed above, have internal pressure containment volumes of approximately 0.05 liters. Article 3, Section 3 of the Pressure Equipment Directive 97/23/EC covers pressure equipment and/or assemblies with internal pressure containment volumes of less than 1 liter. Under this article, the product is not to be CE-marked, unless it is also covered by other applicable directives, but must be manufactured in accordance with sound engineering practice.

By virtue of its many years of experience in the design and manufacture of gas equipment and its ISO9001 certification, CONCOA declares that the pressure equipment listed above has been manufactured in compliance with EC directive 97/23/EC and is in compliance with the applicable sections of the regulation.

TESTED BY:
Tester: #10

Date: 04/28/11

CONTROLS CORPORATION OF AMERICA
1501 Harpers Road - Virginia Beach, VA 23454 - Phone (757) 422-8330
Fax (757) 422-3125 - http://www.concoa.com

Certification of Conformance

CONCOA Order Number: 3049974

This certifies that the item listed below conforms to all the specifications as set forth in the applicable CONCOA test procedure.

CONCOA Part Number: 4123341-84-350

CONCOA Serial Number: 1140HT5C

Declaration of Conformance - Pressure Equipment Directive Sound Engineering Practice

CONCOA's pressure regulators, including the item listed above, have internal pressure containment volumes of approximately 0.05 liters. Article 3, Section 3 of the Pressure Equipment Directive 97/23/EC covers pressure equipment and/or assemblies with internal pressure containment volumes of less than 1 liter. Under this article, the product is not to be CE-marked, unless it is also covered by other applicable directives, but must be manufactured in accordance with sound engineering practice.

By virtue of its many years of experience in the design and manufacture of gas equipment and its ISO9001 certification, CONCOA declares that the pressure equipment listed above has been manufactured in compliance with EC directive 97/23/EC and is in compliance with the applicable sections of the regulation.

TESTED BY:
Tester: #10

Date: 04/28/11

CONTROLS CORPORATION OF AMERICA
1501 Harpers Road - Virginia Beach, VA 23454 - Phone (757) 422-8330
Fax (757) 422-3125 - http://www.concoa.com

Certification of Conformance

He

CONCOA Order Number: 3049973

This certifies that the item listed below conforms to all the specifications as set forth in the applicable CONCOA test procedure.

CONCOA Part Number: 4123341-84-580

CONCOA Serial Number: 1140HT59

Declaration of Conformance - Pressure Equipment Directive Sound Engineering Practice

CONCOA's pressure regulators, including the item listed above, have internal pressure containment volumes of approximately 0.05 liters. Article 3, Section 3 of the Pressure Equipment Directive 97/23/EC covers pressure equipment and/or assemblies with internal pressure containment volumes of less than 1 liter. Under this article, the product is not to be CE-marked, unless it is also covered by other applicable directives, but must be manufactured in accordance with sound engineering practice.

By virtue of its many years of experience in the design and manufacture of gas equipment and its ISO9001 certification, CONCOA declares that the pressure equipment listed above has been manufactured in compliance with EC directive 97/23/EC and is in compliance with the applicable sections of the regulation.

TESTED BY:
#10

Tester: ______________________ Date: 04/28/11

CONTROLS CORPORATION OF AMERICA
1501 Harpers Road - Virginia Beach, VA 23454 - Phone (757) 422-8330
Fax (757) 422-3125 - http://www.concoa.com

412 Series Regulator

Dual Stage

Brass Barstock Body

Six-Port Configuration

316L Stainless Steel Diaphragm

The 412 Series regulators are intended for primary pressure control of non-corrosive, high purity or liquefied gases for applications requiring constant pressure control and delivery regardless of supply pressure variations.


412-1331 shown

Features

- Brass barstock body
  Smooth surface finish
- Front panel-mountable
  Easy installation
- 10 micron filtration in both stages
  Fail-safe seat performance
- Pressure ranges 0-15 to 0-250 PSIG
  Broad range of applications

Typical Applications

- EPA Protocol gases
- Gas and liquid chromatography
- High purity carrier gases
- Zero, span, and calibration gases
- High purity chamber pressurization

400 Series Advantage

- Metal-to-metal diaphragm seal
  No possibility of gas contamination
- Capsule® seat
  Increased serviceability and life
- 316L stainless steel diaphragm
  No inboard diffusion
- Orientable captured vent capable
  Safety in any installation
- Low wetted surface area
  Minimal purge requirements
- Field-adjustable pressure limit
  Safeguard downstream equipment
- Pipe away relief valve
  Safely vents exhaust gases

Materials

Body
Brass barstock

Bonnet
Brass barstock

Seat
PTFE
PCTFE with 4500 PSIG inlet option

Filter
10 micron sintered bronze

Diaphragm
316L stainless steel

Internal Seals
PTFE

Specifications

Maximum Inlet Pressure
3000 PSIG (210 BAR)
4500 PSIG (310 BAR) optional

Temperature Range
-40°F to 140°F (-40°C to 60°C)

Gauges
2” diameter brass

Ports
¼” FPT

Helium Leak Integrity
1 x 10^{-9} scc/sec

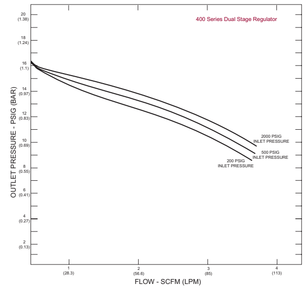
Cv
0.1

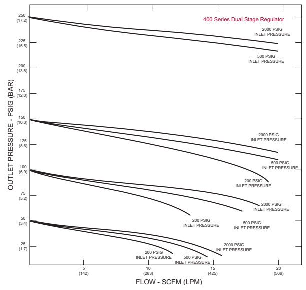
Weight (412-2331-580)
5.3 lbs. (2.40 kg)

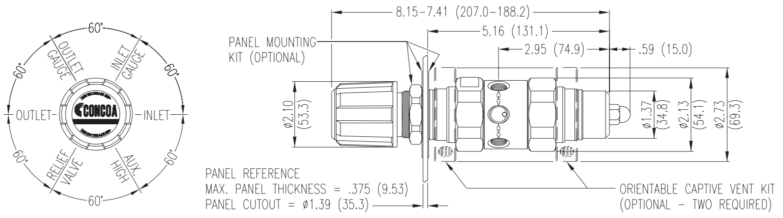
400 Series Regulators

CONCOA
PRECISION GAS CONTROLS

Technical Information







Ordering Information

412	A		B	C	D	-Inlet	Options
Series 412	Outlet Pressure	Outlet Gauge	Inlet Gauge	Outlet Assemblies	Assembly/ Gauges	Inlet Connections	Installed Options
	1: 0-15	30”-0-30 PSIG	0: None	0: ¼” FPT Port	0: Bare Body	000: ¼” FPT	A: Protocol Alarm Station (110V)
	2: 0-50	30”-0-100 PSIG	3: 0-4000 PSIG	1: ¼” MPT	1: Standard Assembly (PSIG/kPa Gauges)	TF2: ⅛” Tube	B: Protocol Alarm Station (220V)
	3: 0-100	30”-0-200 PSIG	5: 0-1000 PSIG	2: ¼” Tube Fitting	2: Standard Assembly (BAR/PSIG Gauges)	TF4: ¼” Tube	C: Protocol Switchover Station
	4: 0-250	0-400 PSIG	6: 0-300 PSIG	3: Diaphragm Valve ¼” Tube Fitting	4: Cleanroom Assembly (PSIG/kPa Gauges)	TF6: ⅜” Tube	D: Deep Purge*
	7: 0-150	30”-0-200 PSIG	7: 0-400 PSIG	4: Diaphragm Valve ¼” MPT	5: Cleanroom Assembly (BAR/PSIG Gauges)	M06: 6mm Tube	G: Protocol Switchover Station with Alarm (110V)
			8: 0-6000 PSIG*	5: Needle Valve ¼” MPT			H: Protocol Switchover Station with Alarm (220V)
				6: ⅛” Tube Fitting			M: Protocol Station
				7: ⅜” Tube Fitting			Q: Protocol Purge Station*
				8: Diaphragm Valve ⅛” Tube Fitting			
				9: Diaphragm Valve ¼” FPT			
			*Maximum inlet pressure 4500 PSIG (310 BAR) with PCTFE Seat Capsule®	A: ⅜” BSP Right Hand Fitting		CGA DIN 477 BS 341 and others available	580
				B: Diaphragm Valve ⅜” Tube Fitting			
				C: ⅜” BSP Left Hand Fitting			*Not available with 4500 PSIG max inlet pressure
				D: 6mm Brass Hose Barb (not available if A=4 or 5)			
				G: ⅛” Stainless Steel Tube Fitting			
				H: ¼” Stainless Steel Tube Fitting			
				M: 6mm Tube Fitting			
				S: Diaphragm Valve 6mm Tube Fitting			

Related Options

Stock No.	Description
550-0002	Panel Mount Kit
550-0001	Captured Vent Kit
476-0002	Helium Leak Certification

412 Series Regulator

Dual Stage

Brass Barstock Body

Six-Port Configuration

316L Stainless Steel Diaphragm

412-1331 shown

The 412 Series regulators are intended for primary pressure control of non-corrosive, high purity or liquefied gases for applications requiring constant pressure control and delivery regardless of supply pressure variations.

Features

- Brass barstock body
  Smooth surface finish
- Front panel-mountable
  Easy installation
- 10 micron filtration in both stages
  Fail-safe seat performance
- Pressure ranges 0-15 to 0-250 PSIG
  Broad range of applications

Typical Applications

- EPA Protocol gases
- Gas and liquid chromatography
- High purity carrier gases
- Zero, span, and calibration gases
- High purity chamber pressurization

400 Series Advantage

- Metal-to-metal diaphragm seal
  No possibility of gas contamination
- Capsule® seat
  Increased serviceability and life
- 316L stainless steel diaphragm
  No inboard diffusion
- Orientable captured vent capable
  Safety in any installation
- Low wetted surface area
  Minimal purge requirements
- Field-adjustable pressure limit
  Safeguard downstream equipment
- Pipe away relief valve
  Safely vents exhaust gases

Materials

Body
Brass barstock

Bonnet
Brass barstock

Seat
PTFE
PCTFE with 4500 PSIG inlet option

Filter
10 micron sintered bronze

Diaphragm
316L stainless steel

Internal Seals
PTFE

Specifications

Maximum Inlet Pressure
3000 PSIG (210 BAR)
4500 PSIG (310 BAR) optional

Temperature Range
-40°F to 140°F (-40°C to 60°C)

Gauges
2” diameter brass

Ports
¼” FPT

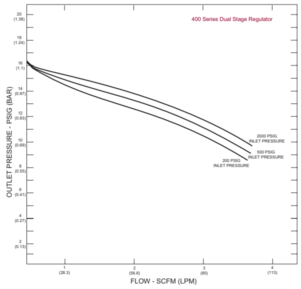
Helium Leak Integrity
1 x 10^{-9} scc/sec

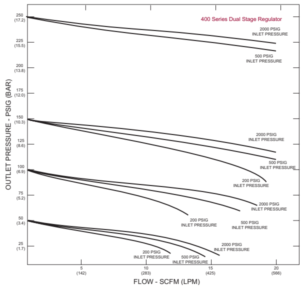
Cv
0.1

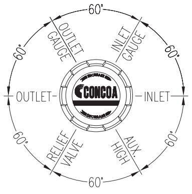
Weight (412-2331-580)
5.3 lbs. (2.40 kg)

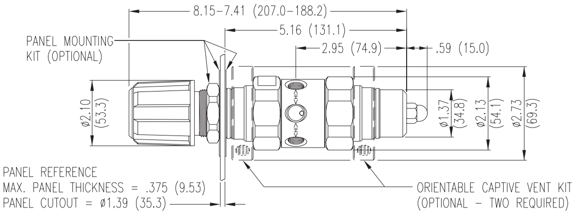
400 Series Regulators

Technical Information









Ordering Information

412	A		B	C	D	-Inlet	Options
Series 412	Outlet Pressure	Outlet Gauge	Inlet Gauge	Outlet Assemblies	Assembly/ Gauges	Inlet Connections	Installed Options
	1: 0-15	30"-0-30 PSIG	0: None	0: ¼" FPT Port	0: Bare Body	000: ¼" FPT	A: Protocol Alarm Station (110V)
	2: 0-50	30"-0-100 PSIG	3: 0-4000 PSIG	1: ¼" MPT	1: Standard Assembly (PSIG/kPa Gauges)	TF2: ⅛" Tube	B: Protocol Alarm Station (220V)
	3: 0-100	30"-0-200 PSIG	5: 0-1000 PSIG	2: ¼" Tube Fitting	2: Standard Assembly (BAR/PSIG Gauges)	TF4: ¼" Tube	C: Protocol Switchover Station
	4: 0-250	0-400 PSIG	6: 0-300 PSIG	3: Diaphragm Valve ¼" Tube Fitting	4: Cleanroom Assembly (PSIG/kPa Gauges)	TF6: ⅜" Tube	D: Deep Purge*
	7: 0-150	30"-0-200 PSIG	7: 0-400 PSIG	4: Diaphragm Valve ¼" MPT	5: Cleanroom Assembly (BAR/PSIG Gauges)	M06: 6mm Tube	G: Protocol Switchover Station with Alarm (110V)
			8: 0-6000 PSIG*	5: Needle Valve ¼" MPT			H: Protocol Switchover Station with Alarm (220V)
			*Maximum inlet pressure 4500 PSIG (310 BAR) with PCTFE Seat Capsule®	6: ⅛" Tube Fitting		CGA 350 DIN 477 BS 341 and others available	M: Protocol Station
				7: ⅜" Tube Fitting			Q: Protocol Purge Station*
				8: Diaphragm Valve ⅛" Tube Fitting			*Not available with 4500 PSIG max inlet pressure
				9: Diaphragm Valve ¼" FPT			
				A: ⅜" BSP Right Hand Fitting			
				B: Diaphragm Valve ⅜" Tube Fitting			
				C: ⅜" BSP Left Hand Fitting			
				D: 6mm Brass Hose Barb (not available if A=4 or 5)			
				G: ⅛" Stainless Steel Tube Fitting			
				H: ¼" Stainless Steel Tube Fitting			
				M: 6mm Tube Fitting			
				S: Diaphragm Valve 6mm Tube Fitting			

Related Options

Stock No.	Description
550-0002	Panel Mount Kit
550-0001	Captured Vent Kit
476-0002	Helium Leak Certification

412 Series Regulator

Dual Stage

Brass Barstock Body

Six-Port Configuration

316L Stainless Steel Diaphragm

412-1331 shown

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Features

- Brass barstock body
  Smooth surface finish
- Front panel-mountable
  Easy installation
- 10 micron filtration in both stages
  Fail-safe seat performance
- Pressure ranges 0-15 to 0-250 PSIG
  Broad range of applications

Typical Applications

- EPA Protocol gases
- Gas and liquid chromatography
- High purity carrier gases
- Zero, span, and calibration gases
- High purity chamber pressurization

400 Series Advantage

- Metal-to-metal diaphragm seal
  No possibility of gas contamination
- Capsule® seat
  Increased serviceability and life
- 316L stainless steel diaphragm
  No inboard diffusion
- Orientable captured vent capable
  Safety in any installation
- Low wetted surface area
  Minimal purge requirements
- Field-adjustable pressure limit
  Safeguard downstream equipment
- Pipe away relief valve
  Safely vents exhaust gases

Materials

Body
Brass barstock

Bonnet
Brass barstock

Seat
PTFE
PCTFE with 4500 PSIG inlet option

Filter
10 micron sintered bronze

Diaphragm
316L stainless steel

Internal Seals
PTFE

Specifications

Maximum Inlet Pressure
3000 PSIG (210 BAR)
4500 PSIG (310 BAR) optional

Temperature Range
-40°F to 140°F (-40°C to 60°C)

Gauges
2” diameter brass

Ports
¼” FPT

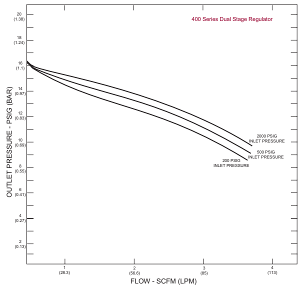
Helium Leak Integrity
1 x 10^{-9} scc/sec

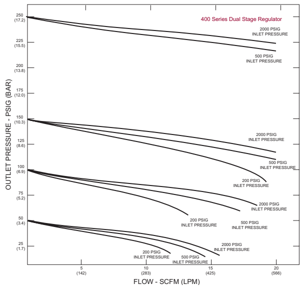
Cv
0.1

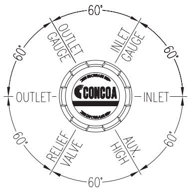
Weight (412-2331-580)
5.3 lbs. (2.40 kg)

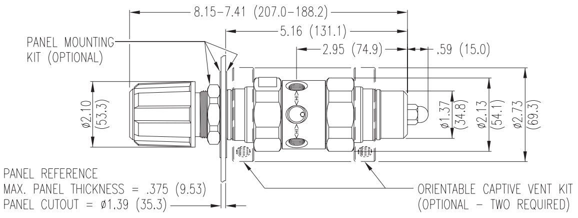
400 Series Regulators

Technical Information









Ordering Information

412	A		B	C	D	-Inlet	Options
Series 412	Outlet Pressure	Outlet Gauge	Inlet Gauge	Outlet Assemblies	Assembly/ Gauges	Inlet Connections	Installed Options
	1: 0-15	30"-0-30 PSIG	0: None	0: ¼" FPT Port	0: Bare Body	000: ¼" FPT	A: Protocol Alarm Station (110V)
	2: 0-50	30"-0-100 PSIG	[✓ 3: 0-4000 PSIG]	1: ¼" MPT	[✓ 1: Standard Assembly (PSIG/kPa Gauges)]	TF2: ⅛" Tube	B: Protocol Alarm Station (220V)
	[✓ 3: 0-100]	30"-0-200 PSIG	5: 0-1000 PSIG	2: ¼" Tube Fitting	2: Standard Assembly (BAR/PSIG Gauges)	TF4: ¼" Tube	C: Protocol Switchover Station
	4: 0-250	0-400 PSIG	6: 0-300 PSIG	3: Diaphragm Valve ¼" Tube Fitting	4: Cleanroom Assembly (PSIG/kPa Gauges)	TF6: ⅜" Tube	D: Deep Purge*
	7: 0-150	30"-0-200 PSIG	7: 0-400 PSIG	[✓ 4: Diaphragm Valve ¼" MPT]	5: Cleanroom Assembly (BAR/PSIG Gauges)	M06: 6mm Tube	G: Protocol Switchover Station with Alarm (110V)
			8: 0-6000 PSIG*	5: Needle Valve ¼" MPT			H: Protocol Switchover Station with Alarm (220V)
				6: ⅛" Tube Fitting			M: Protocol Station
				7: ⅜" Tube Fitting			Q: Protocol Purge Station*
				8: Diaphragm Valve ⅛" Tube Fitting			
				9: Diaphragm Valve ¼" FPT		[✓ CGA 350] DIN 477 BS 341 and others available	
			*Maximum inlet pressure 4500 PSIG (310 BAR) with PCTFE Seat Capsule®	A: ⅜" BSP Right Hand Fitting			
				B: Diaphragm Valve ⅜" Tube Fitting			
				C: ⅜" BSP Left Hand Fitting			*Not available with 4500 PSIG max inlet pressure
				D: 6mm Brass Hose Barb (not available if A=4 or 5)			
				G: ⅛" Stainless Steel Tube Fitting			
				H: ¼" Stainless Steel Tube Fitting			
				M: 6mm Tube Fitting			
				S: Diaphragm Valve 6mm Tube Fitting			

Related Options

Stock No.	Description
550-0002	Panel Mount Kit
550-0001	Captured Vent Kit
476-0002	Helium Leak Certification

412 Series Regulator

Dual Stage

Brass Barstock Body

Six-Port Configuration

316L Stainless Steel Diaphragm


412-1331 shown

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- Pressure ranges 0-15 to 0-250 PSIG
  Broad range of applications

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- EPA Protocol gases
- Gas and liquid chromatography
- High purity carrier gases
- Zero, span, and calibration gases
- High purity chamber pressurization

400 Series Advantage

- Metal-to-metal diaphragm seal
  No possibility of gas contamination
- Capsule® seat
  Increased serviceability and life
- 316L stainless steel diaphragm
  No inboard diffusion
- Orientable captured vent capable
  Safety in any installation
- Low wetted surface area
  Minimal purge requirements
- Field-adjustable pressure limit
  Safeguard downstream equipment
- Pipe away relief valve
  Safely vents exhaust gases

Materials

Body
Brass barstock

Bonnet
Brass barstock

Seat
PTFE
PCTFE with 4500 PSIG inlet option

Filter
10 micron sintered bronze

Diaphragm
316L stainless steel

Internal Seals
PTFE

Specifications

Maximum Inlet Pressure
3000 PSIG (210 BAR)
4500 PSIG (310 BAR) optional

Temperature Range
-40°F to 140°F (-40°C to 60°C)

Gauges
2” diameter brass

Ports
¼” FPT

Helium Leak Integrity
1 x 10^{-9} scc/sec

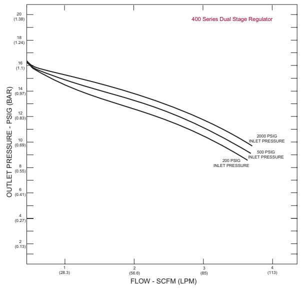
Cv
0.1

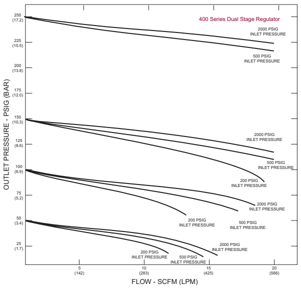
Weight (412-2331-580)
5.3 lbs. (2.40 kg)

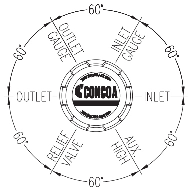
400 Series Regulators

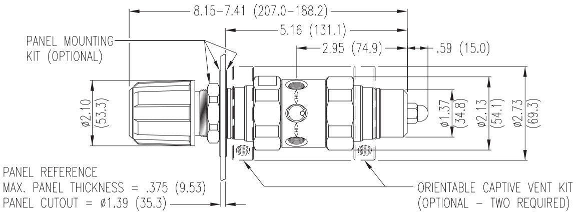
CONCOA
PRECISION GAS CONTROLS

Technical Information









Ordering Information

412	A		B	C	D	-Inlet	Options
Series 412	Outlet Pressure	Outlet Gauge	Inlet Gauge	Outlet Assemblies	Assembly/ Gauges	Inlet Connections	Installed Options
	1: 0-15	30”-0-30 PSIG	0: None	0: ¼” FPT Port	0: Bare Body	000: ¼” FPT	A: Protocol Alarm Station (110V)
	2: 0-50	30”-0-100 PSIG	[✓ 3: 0-4000 PSIG]	1: ¼” MPT	[✓ 1: Standard Assembly (PSIG/kPa Gauges)]	TF2: ⅛” Tube	B: Protocol Alarm Station (220V)
	[✓ 3: 0-100]	30”-0-200 PSIG	5: 0-1000 PSIG	2: ¼” Tube Fitting	2: Standard Assembly (BAR/PSIG Gauges)	TF4: ¼” Tube	C: Protocol Switchover Station
	4: 0-250	0-400 PSIG	6: 0-300 PSIG	3: Diaphragm Valve ¼” Tube Fitting	4: Cleanroom Assembly (PSIG/kPa Gauges)	TF6: ⅜” Tube	D: Deep Purge*
	7: 0-150	30”-0-200 PSIG	7: 0-400 PSIG	[✓ 4: Diaphragm Valve ¼” MPT]	5: Cleanroom Assembly (BAR/PSIG Gauges)	M06: 6mm Tube	G: Protocol Switchover Station with Alarm (110V)
			8: 0-6000 PSIG*	5: Needle Valve ¼” MPT			H: Protocol Switchover Station with Alarm (220V)
				6: ⅛” Tube Fitting			M: Protocol Station
				7: ⅜” Tube Fitting			Q: Protocol Purge Station*
				8: Diaphragm Valve ⅛” Tube Fitting			
				9: Diaphragm Valve ¼” FPT		[✓ CGA] 320 DIN 477 BS 341 and others available	
			*Maximum inlet pressure 4500 PSIG (310 BAR) with PCTFE Seat Capsule®	A: ⅜” BSP Right Hand Fitting			
				B: Diaphragm Valve ⅜” Tube Fitting			
				C: ⅜” BSP Left Hand Fitting			*Not available with 4500 PSIG max inlet pressure
				D: 6mm Brass Hose Barb (not available if A=4 or 5)			
				G: ⅛” Stainless Steel Tube Fitting			
				H: ¼” Stainless Steel Tube Fitting			
				M: 6mm Tube Fitting			
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Related Options

Stock No.	Description
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550-0001	Captured Vent Kit
476-0002	Helium Leak Certification

412 Series Regulator

Dual Stage

Brass Barstock Body

Six-Port Configuration

316L Stainless Steel Diaphragm

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412-1331 shown

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  Minimal purge requirements
- Field-adjustable pressure limit
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Bonnet
Brass barstock

Seat
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PCTFE with 4500 PSIG inlet option

Filter
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Diaphragm
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Internal Seals
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Specifications

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4500 PSIG (310 BAR) optional

Temperature Range
-40°F to 140°F (-40°C to 60°C)

Gauges
2” diameter brass

Ports
¼” FPT

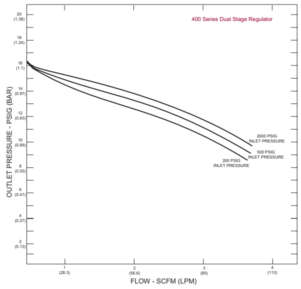
Helium Leak Integrity
1 x 10^{-9} scc/sec

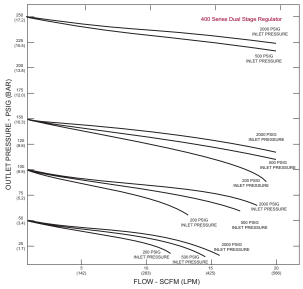
Cv
0.1

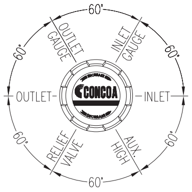
Weight (412-2331-580)
5.3 lbs. (2.40 kg)

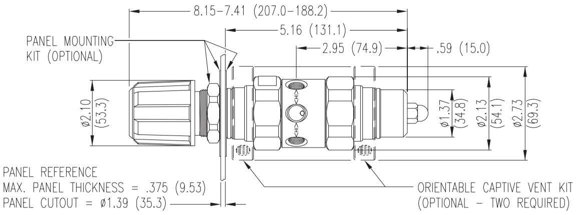
400 Series Regulators

Technical Information









Ordering Information

412	A		B	C	D	-Inlet	Options
Series 412	Outlet Pressure	Outlet Gauge	Inlet Gauge	Outlet Assemblies	Assembly/ Gauges	Inlet Connections	Installed Options
	1: 0-15	30”-0-30 PSIG	0: None	0: ¼” FPT Port	0: Bare Body	000: ¼” FPT	A: Protocol Alarm Station (110V)
	2: 0-50	30”-0-100 PSIG	3: 0-4000 PSIG	1: ¼” MPT	1: Standard Assembly (PSIG/kPa Gauges)	TF2: ⅛” Tube	B: Protocol Alarm Station (220V)
	3: 0-100	30”-0-200 PSIG	5: 0-1000 PSIG	2: ¼” Tube Fitting	2: Standard Assembly (BAR/PSIG Gauges)	TF4: ¼” Tube	C: Protocol Switchover Station
	4: 0-250	0-400 PSIG	6: 0-300 PSIG	3: Diaphragm Valve ¼” Tube Fitting	4: Cleanroom Assembly (PSIG/kPa Gauges)	TF6: ⅜” Tube	D: Deep Purge*
	7: 0-150	30”-0-200 PSIG	7: 0-400 PSIG	4: Diaphragm Valve ¼” MPT	5: Cleanroom Assembly (BAR/PSIG Gauges)	M06: 6mm Tube	G: Protocol Switchover Station with Alarm (110V)
			8: 0-6000 PSIG*	5: Needle Valve ¼” MPT			H: Protocol Switchover Station with Alarm (220V)
				6: ⅛” Tube Fitting			M: Protocol Station
				7: ⅜” Tube Fitting			Q: Protocol Purge Station*
				8: Diaphragm Valve ⅛” Tube Fitting			
				9: Diaphragm Valve ¼” FPT			
			*Maximum inlet pressure 4500 PSIG (310 BAR) with PCTFE Seat Capsule®	A: ⅜” BSP Right Hand Fitting		CGA 580 DIN 477 BS 341 and others available	*Not available with 4500 PSIG max inlet pressure
				B: Diaphragm Valve ⅜” Tube Fitting			
				C: ⅜” BSP Left Hand Fitting			
				D: 6mm Brass Hose Barb (not available if A=4 or 5)			
				G: ⅛” Stainless Steel Tube Fitting			
				H: ¼” Stainless Steel Tube Fitting			
				M: 6mm Tube Fitting			
				S: Diaphragm Valve 6mm Tube Fitting			

Related Options

Stock No.	Description
550-0002	Panel Mount Kit
550-0001	Captured Vent Kit
476-0002	Helium Leak Certification

ADI 2062J

CONCOA®

Certified ISO 9001

Regulators

INSTALLATION AND OPERATION INSTRUCTIONS

Before Installing or Operating, Read and Comply with These Instructions

Controls Corporation of America
1501 Harpers Road • Virginia Beach, VA 23454
To Order Call 1-800-225-0473 or 757-422-8330 • Fax 757-422-3125
www.concoa.com

May 2003
Supersedes January 2002

Warning: An appropriately sized pressure relief device downstream of the regulator should be installed in your system to prevent damage to equipment and/or injury to personnel should an internal failure of the regulator occur.

Warning: Maximum allowable working pressure indicated on product labeling is for the regulator only. Ratings for peripherals/accessories may be less than the pressure indicated on the product label. Do not exceed the pressure ratings of the attached peripherals/accessories and the regulator's maximum allowable working pressure. Please contact your gas supplier for more information.

Warning: for regulators with tube fittings, select the appropriate tubing. Use seamless tubing with the proper consideration given to wall thickness and material. Please contact your gas supplier for more information.

USER RESPONSIBILITY

This equipment will perform in conformity with the description contained in this manual and accompanying labels and/or inserts when installed, operated, maintained, and repaired in accordance with the instructions provided. This equipment must be checked periodically. Improperly working equipment should not be used. Parts that are broken, missing, worn, distorted or contaminated, should be replaced immediately. CONCOA recommends that a telephone or written request for service advice be made to CONCOA Customer Service in Virginia Beach, Virginia, PHONE: 1-800-225-0473, FAX: 1-757-422-3125, or E-MAIL: e-mail@concoa.com.

This equipment or any of its parts should not be altered without prior written approval by CONCOA. The user of this equipment shall have the sole responsibility for any malfunction that results from improper use, faulty maintenance, damage, improper repair, or alteration by anyone other than CONCOA or a service facility designated by CONCOA.

CUSTOMER SERVICE

In the event of equipment failure, call CONCOA Customer Service. Please be prepared to provide the model number and serial number of the equipment involved, in addition to some details regarding its application.

Things to consider before removing the regulator from the box....

1. Know the properties and special handling requirements of the gas being used. Many gases are quite dangerous (flammable, toxic, corrosive, simple asphyxiant, or oxidizers). Equipment failure or misuse may lead to problems such as a release of gas through the relief valve or regulator diaphragm. Proper safety measures should be established to handle these and other component failures.
2. Be sure that the assembly purchased is suitable for the gas and type of service intended. The system label provides the following information:
    a. Model number
    b. Serial number
    c. Maximum inlet pressure

   Be sure that the equipment received conforms to the order specifications. The user is responsible for selecting equipment compatible with the gas in use, and conditions of pressure, temperature, flow, etc. Selection information can be found in CONCOA technical data sheets. In addition, CONCOA representatives are trained to aid in the selection process.

3. Inspect the assembly upon receipt to be sure that there is no damage or contamination. Pay particular attention to connecting threads. While CONCOA assembles system components to exacting leak-tight standards, the customer should also inspect for any loosening of parts that may occur in shipping or installation. Loose parts may be dangerously propelled from an assembly. If there are adverse signs (leakage or other malfunction), return the assembly to the supplier. While it is advised that soiled regulators be returned for cleaning, simple external dust or grease may be removed by a clean cloth and if required with aqueous detergent suitable for the application. If there are signs of internal contamination, return to the supplier.
4. Before system start-up, it is recommended that all systems be pressure tested, leak tested, and purged with an inert gas such as nitrogen. To accomplish this with connections other than a CGA 580, it will be necessary to use an adapter. The recommended use of an adapter is for temporary use, for start-up and system checks only. Adapters should never be used on a permanent basis.

   If the regulator includes gas specific inlet connections, their purpose is to prevent usage on the wrong gases. Adaptation or alteration for use on other gases can be dangerous, and is not recommended.

GENERAL SAFETY PRACTICES

Comply with precautions listed in C.G.A. Pamphlet P-1, Safe Handling of Compressed Gases in Containers.

Consult the cylinder distributor for the proper use of cylinders and for any restrictions on their use (such as flow rate and temperature requirements).

Never use an open flame when leak testing.

Always open valves slowly when high-pressure gases are being used.

Always be sure that a cylinder contains the correct gas before connecting it to any regulator.

Always leak-test any manifold or distribution pipeline before using.

Always be sure that the gas in the system is the correct gas for the intended use.

For the United States, some applicable safety rules and precautions are listed below:

1. American National Standards Institute standard Z49.1, Safety in Welding and Cutting, American Welding Society, 2501 NW Seventh Street, Miami, Florida 33125
2. N.F.P.A. Standard 51, Oxygen-Fuel Gas systems for Welding and Cutting, N.F.P.A., 470 Atlantic Avenue, Boston, Massachusetts 02210
3. N.F.P.A. Standard 51B, Cutting and Welding Processes (same address as #2).
4. CONCOA publication ADE 872, Safety Precautions in Welding and Cutting.
5. Local Ordinances
6. O.S.H.A. Standard 29 CFR
7. C.G.A. Pamphlet C-4, American National Standard Method of Marking Portable Compressed Gas Containers to Identify the Material Contained.
8. C.G.A. Pamphlet G-4, Oxygen – Information on the properties, manufacture, transportation, storage, handling, and use of oxygen.
9. C.G.A. Pamphlet G-4.1, Equipment Cleaned for oxygen service.
10. C.G.A. Pamphlet G-4.4, Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems.
11. C.G.A. Pamphlet G-5, Hydrogen – Information on the properties, manufacture, transportation, storage, handling, and use of hydrogen.
12. C.G.A. Pamphlet G-6, Carbon Dioxide – Information on the properties, manufacture, transportation, storage, handling, and use of carbon dioxide.
13. C.G.A. Pamphlet G-6.1, Standard for Low Pressure Carbon Dioxide Systems at Consumer Sites.
14. C.G.A. Pamphlet P-1, Safe Handling of Compressed Gases in Containers.
15. C.G.A. Safety Bulletin SB-2, Oxygen Deficient Atmospheres.

*C.G.A. pamphlets can be obtained from the Compressed Gas Association, 1235 Jefferson Davis Highway, Arlington, VA 22202-3239, (703) 979-0900. Publications: (703) 979-4341. Fax: (703) 979-0134.

INSTALLATION

Please observe the previously mentioned safety precautions before actual installation.

1.1 Before removing the cylinder cap, move the cylinder of gas to the work site:

- a. Secure cylinder to floor, wall or bench with appropriate chain or stand to prevent toppling.
- b. Remove the cylinder cap.
- c. Be sure the cylinder valve is tightly closed (clockwise).
- d. Remove the cylinder valve plug, if any.
- e. Inspect the cylinder valve and threads for damage or contamination.

1.2 Following procedures below, secure the regulator inlet connector to the outlet connector on the cylinder. Use an open-end wrench, not a pipe wrench.

- a. The connection should be easily threaded. Do not force. If it is not easy, you may have the wrong regulator for the gas you are using.
- b. LEFT HAND THREADS are used on some inlet connectors and are indicated by a notch in the middle of the hex nut.
- c. GASKETS are used on some inlet connectors. If so, it will be provided with the regulator. Be sure the gasket is in good shape. Do not overtighten to avoid squashing the gasket into the gas line. You may want to order an extra supply of these gaskets from your gas supplier.
- d. Never use oil or grease on regulator or cylinder fittings, as you may contaminate pure gases, or create a fire hazard.

1.3 Close the regulator by turning the pressure control knob, or handle, counterclockwise. As the control knob is closed, turning should become easier.

1.4 Shut the regulator outlet valve (if supplied) by turning the knob on the valve clockwise.

1.5 Observing the following procedures; make connections from the regulator outlet to your downstream equipment.

a. BE SURE TO CONSIDER ALL FACTORS WHEN SELECTING MATERIALS. For example, if you have both high pressure and corrosive service, select material that is suitable for both.

b. Do not use oil or grease on fittings, especially not on oxidizing gas service equipment.

c. Be sure that all fittings are secure and leak tight. Teflon tape should be used on pipe fittings, but avoid impinging on the gas stream. Before applying Teflon tape, inspect the NPT threads and if necessary, clean the fitting to remove any dirt or thread sealant that remains on the threads. Start the Teflon tape on the second thread as shown above; make sure the tape does not overlap the end of the fitting. As the tape is wrapped in the direction of the thread spiral, pull tightly on the end of tape so that the tape conforms to the threads. Apply two overlapping layers of Teflon tape. Cut off the excess tape and press the end firmly into the threads.

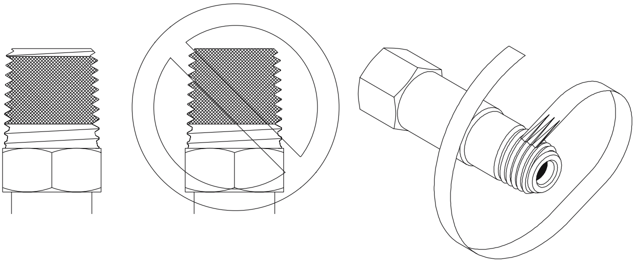


Figure 1. Tape Installation procedures.

d. CAPTURED VENT SPRING CASE. Some regulators have captured vent spring cases. If you are using corrosive, toxic or flammable gases, be sure to connect suitable tubing from the vent fitting to a safe discharge area. Consult instructions for captured vent kit for installation.

e. RELIEF VALVE. Some regulators are equipped with a relief valve. The purpose of a relief valve is to protect the regulator and it components. If there is pressure sensitive equipment downstream of the regulator it is recommended that a relief valve be installed in the line to protect this equipment. If you are using toxic, corrosive, or flammable gases, it is recommended that the exhaust from the valve be piped to a safe discharge area.

f. PURGE DEVICES (Optional). If your regulator includes a purge, review the safety operation in the specific instruction manual for your regulator. Purge devices are highly recommended when using toxic or corrosive gases.

OPERATION

Read the “Safety” and “Installation” sections before operating your equipment.

2.1 It is advised that high purity systems be thoroughly purged before use.

2.2 The regulator adjusting knob should be turned fully counterclockwise (see 1.3) and the outlet valve should be closed (see 1.4).

2.3 Put on safety glasses and gloves.

2.4 Position yourself with the cylinder between you and the regulator. Keep hands off the regulator while opening the cylinder valve.

2.5 To avoid damage to regulator parts, slowly open the cylinder valve. Observe the high pressure gauge for a rise in pressure up to full cylinder pressure.

2.6 Observe all connections for leaks.

- a. An approved leak detection solution may be applied to the connections, if compatible to your usage. Leaks are indicated by bubbling.
- b. To further check for leaks, or if you cannot use the leak detection solution, reclose the cylinder valve for five minutes, and observe the high pressure gauge for a drop in pressure. If so indicated, recheck the CGA connection and all other high pressure port connections.

2.7 (Open the cylinder valve fully in order to form a good seal at the cylinder valve packing.) Keep the valve hand wheel or wrench on the open cylinder valve at all times to allow prompt emergency shutoff.

2.8 Adjust to the desired working pressure by turning the pressure control knob or handle clockwise, while observing the delivery pressure gauge for the approximate desired setting.

- a. Do not exceed the maximum delivery pressure indicated on the regulator label.
- b. Again check for leaks on the low pressure ports.
- c. Check the delivery pressure gauge for any drop in pressure. If a drop is indicated, check all low pressure ports for leakage.

2.9 Again set the delivery pressure, open the outlet valve if any, and check your system for leaks and otherwise proper functioning.

a. With gas flowing through your system, some adjustment to delivery pressure may be required.

b. TWO-STAGE REGULATORS. After the above final setting of delivery pressure, no further adjustment should be required as the cylinder depletes.

c. SINGLE-STAGE REGULATORS. After the above final setting of delivery pressure, you may have to periodically adjust delivery pressure as the cylinder depletes.

d. As a general rule, a cylinder should be considered EMPTY when the cylinder pressure drops to a value of two (2) times the delivery pressure or less. This avoids the possibility of dangerous suck-back conditions. However, particular system requirements may indicate greater or less margin than the recommendation. Contact your CONCOA representative if you have any questions.

SHUTDOWN AND DISASSEMBLY

As indicated in the “Operation” section, a cylinder should be regarded as empty when the cylinder pressure has dropped to twice the delivery pressure or less. This will avoid the possibility of dangerous suck-back conditions, where other system gases are pulled back into the regulator and cylinder.

3.1 BRIEF SHUTDOWN (less than 30 minutes). Simply close the regulator outlet valve (if supplied). If the regulator does not have an outlet valve use procedure 3.2.

3.2 EXTENDED SHUTDOWN (beyond 30 minutes).

a. NORMALLY OPEN SYSTEMS or COMPLETE SYSTEM DISASSEMBLY. This section applies when there is no concern about entry of astmospheric gases into the system.

1. Close the gas cylinder valve.
2. Shut down any other gas supplies which may be connected to your system.
3. Turn the adusting knob clockwise and open the outlet valve to drain the line through your usage points. Both regulator gauges should descend to zero.
4. With HAZARDOUS GASES run an inert purging gas through the regulator and system before disassembly.
5. After venting (and purging when applicable), turn the adjusting knob fully counterclockwise and close the outlet valve.
6. Disconnect downstream equipment.
7. In disassembling, slowly loosen the cylinder valve connection,

while listening for gas seepage. If leaking is evident, retighten the connection, and check for effective closing of the cylinder valve.

8. Cap the cylinder after disconnecting the regulator. Mark the cylinder “EMPTY” if this is the case, and move it to the storage area for return cylinders.
9. If HAZARDOUS GASES have been used, and there has not been a purging procedure as recommended, some benefit can be gained by directing a stream of dry nitrogen through the fully opened regulator. When using HAZARDOUS GASES or when in a CONFINED AREA, be sure to provide a safe discharge area when clearing the regulator.
10. Install a new cylinder, if called for.
11. When a regulator is out of service, close the pressure control knob by turning counterclockwise until the spring tension relieves, and close the outlet valve. Also cap open ends of the regulator, or if removed, store it in a plastic bag to prevent contamination, especially by unobserved particulate buildup inside the regulator.

b. ISOLATED GAS SYSTEMS. Some practices (especially on high purity systems), demand that ambient air be excluded from the system. There are several methods in use:

1. Seal the usage gas in the system.*
2. Exert a vacuum on the system after shutdown.
3. Replace the system gas with an inert gas.

*This method should not be used with hazardous gases for more than a brief time.

3.3 CYLINDER CHANGE - ISOLATED GAS SYSTEMS. For cylinder change on ISOLATED GAS SYSTEMS, a valve upstream of the regulator is required, and is provided when an upstream purge devices such as the CONCOA Deep Purge is used.

a. Tightly close the gas cylinder valve.
b. Close the valve upstream of the regulator (the center or master valve on the Deep Purge).
c. With hazardous gases, purge the cylinder valve cavity using procedures contained in the specific instruction manual for your purge assembly.
d. Follow steps 3.2a 7, 8, and 9.
e. Method 3.2b 2, maintaining a vacuum after shutdown, requires

that the system be well sealed, as any leaks will pull impurities into the system.

f. Method 3.2b 3, filling the system with an inert gas, provides the advantage of maintaining positive pressure on the system, greatly reducing the probability of entry of impurities.

General

A unit which is not functioning properly should not be used until all required repairs have been completed and the unit has been tested to ascertain that it is in proper operating order.

SERVICE

It is recommended that all servicing be done by a service facility authorized by CONCOA. Contact the CONCOA Customer Service Department in Virginia Beach or the nearest CONCOA District Sales Office for assistance.

If so advised, the unit should be sent to a service facility authorized by CONCOA, adequately packaged, in the original shipping container if possible, and shipped prepaid, with a statement of observed deficiency. The gas service that the equipment has been subjected to must be clearly identified. All equipment must be purged before shipment to protect the transporter and service personnel. The purging is especially important if the equipment has been in hazardous or corrosive gas service. Return trip transportation charges are to be paid by Buyer. In all cases other than where warranty is applicable, repairs will be made at current list price for the replacement part(s) plus a reasonable labor charge.

Test regulator for leaks on a routine schedule.

Trouble Shooting

Symptoms	Probable Cause
1. Gas leakage at the regulator outlet when the adjusting screw is turned fully counterclockwise.	1. Seat leak or creep, have regulator repaired.
2. With no flow through the system (downstream valves closed), outlet pressure increases steadily above the set pressure.	2. Seat leak or creep, have regulator repaired.
3. Gas leakage from spring case or bonnet.	3. Diaphragm failure, have regulator repaired.
4. Excess drop in outlet pressure with regulator flow open.	4. Blockage in seat assembly or inlet filter. Have regulator repaired.
5. Gas leakage from any pipe thread joint.	5. Loose fitting, remove connection clean, reapply Teflon tape and retighten.
6. Gas leakage from relief valve.	6. Possible faulty relief valve, replace. Possible seat leak or creep, have repaired.
7. Inconsistent repeat reading	7. Seat sticking, have regulator repaired. Possible bad pressure gauge.
8. Inlet or outlet pressure gauge does not return to zero with no pressure applied to the regulator	8. Gauge has suffered physical damage, replace gauge.

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Warranty Information

This equipment is sold by CONTROLS CORPORATION OF AMERICA under the warranties set forth in the following paragraphs. Such warranties are extended only with respect to the purchase of this equipment directly from CONTROLS CORPORATION OF AMERICA or its Authorized Distributors as new merchandise and are extended to the first Buyer thereof other than for the purpose of resale.

For a period of one (1) year from the date of original delivery (90 days in corrosive service) to Buyer or to Buyer's order, this equipment is warrantied to be free from functional defects in materials and workmanship and to conform to the description of this equipment contained in this manual and any accompanying labels and/or inserts, provided that the same is properly operated under conditions of normal use and that regular periodic maintenance and service is performed or replacements made in accordance with the instructions provided. The foregoing warranties shall not apply if the equipment has been repaired: other than by CONTROLS CORPORATION OF AMERICA or a designated service facility or in accordance with written instructions provided by CONTROLS CORPORATION OF AMERICA, or altered by anyone other than CONTROLS CORPORATION OF AMERICA, or if the equipment has been subject to abuse, misuse, negligence or accident.

CONTROLS CORPORATION OF AMERICA's sole and exclusive obligation and Buyer's sole and exclusive remedy under the above warranties is limited to repairing or replacing, free of charge, at CONTROLS CORPORATION OF AMERICA's option, the equipment or part, which is reported to its Authorized Distributor from whom purchased, and which if so advised, is returned with a statement of the observed deficiency, and proof of purchase of equipment or part not later than seven (7) days after the expiration date of the applicable warranty, to the nearest designated service facility during normal business hours, transportation charges prepaid, and which upon examination, is found not to comply with the above warranties. Return trip transportation charges for the equipment or part shall be paid by Buyer.

CONTROLS CORPORATION OF AMERICA SHALL NOT BE OTHERWISE LIABLE FOR ANY DAMAGES INCLUDING BUT NOT LIMITED TO: INCIDENTAL DAMAGES, CONSEQUENTIAL DAMAGES, OR SPECIAL DAMAGES, WHETHER SUCH DAMAGES RESULT FROM NEGLIGENCE, BREACH OF WARRANTY OR OTHERWISE.

THERE ARE NO EXPRESS OR IMPLIED WARRANTIES WHICH EXTEND BEYOND THE WARRANTIES HEREINABOVE SET FORTH. CONTROLS CORPORATION OF AMERICA MAKES NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO THE EQUIPMENT OR PARTS THEREOF.

ADI 2062J

CONCOA®

Certified ISO 9001

Controls Corporation of America
1501 Harpers Road • Virginia Beach, VA 23454
To Order Call 1-800-225-0473 or 757-422-8330 • Fax 757-422-3125
www.concoa.com

VR7 Series

316L SS or Brass,
Pressure Relief Valve

Customer Value Proposition:

The VR7 Series is an economical relief valve designed to vent excess pressure from a regulator should a minor seat leak occur. This valve is recommended for use with regulators to protect the regulator and outlet pressure gauge and is not intended for applications where repeated or frequent venting is required.

- Choice of seal materials for system compatibility.
- Hex body provides wrench flats.
- Available with a variety of connections.
- Cleaned for O_2 service.

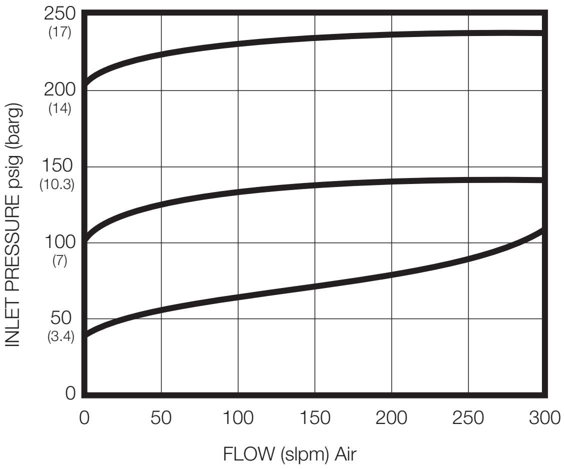
Note: The VR7 ***SHOULD ONLY*** be used to protect Article 3, Paragraph 3 category equipment as defined in Pressure Equipment Directive 97/23/EC Dated 29, May 1997.

Contact Information:

Parker Hannifin Corporation
Veriflo Division
250 Canal Blvd
Richmond, California 94804

phone 510 235 9590
fax 510 232 7396
veriflo.sales@parker.com

www.parker.com/veriflo



Flow Curve

Veriflo

ENGINEERING **YOUR** SUCCESS.

VR7 Series

Ordering Information

Build an VR7 Series Pressure Relief Valve by replacing the numbered symbols with an option from the corresponding tables below.

		1	2	3	4
Sample:	**VR7**	**44MF**	**1**	**S**	**V**

Finished Order: **VR744MF1SV**

1 Connection (Inlet & Outlet)

[✓ 44MF = 1/4" NPTM x 1/4" NPTF]
4FSF = 1/4" FS Female x 1/4" NPTF
Available for Stainless Steel body Only
4FSM = 1/4" FS Male x 1/4" NPTF
Available for Stainless Steel body Only

2 Adjustable Range

1 = 10 - 20 psig
[✓ 2 = 20 - 100 psig]
3 = 100 - 250 psig
4 = 250 - 500 psig

NOTE: After relieving, service is required.

3 Body Material

S = 316L Stainless Steel
[✓ B = Brass]

4 Seal

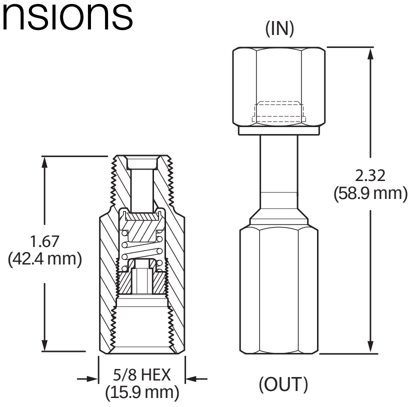
K = FFKM
[✓ V = FKM]

Specifications

Materials of Construction	
Wetted	
Body Options	316L Stainless Steel (std) or Brass
Seal	FKM or FFKM
Spring	302 Stainless Steel
Poppet Options	PCTFE (std) or Brass
Screw Options	316L Stainless Steel (std) or Delrin
Operating Conditions	
Maximum Pressure	750 psig (52 barg)
Temperature	-30°F to 400°F (-35°C to 204°C)
Adjustable Ranges	10 - 20 psig (0.6 - 1.4 barg) 20 - 100 psig (1.4 - 7 barg) 100 - 250 psig (7 - 17 barg) 250 - 500 psig (17 - 34 barg)

For additional information on materials of construction, functional performance and operating conditions, please contact factory.

Dimensions



Functional Performance	
Flow Capacity	C_V 0.37
Approx. Weight	2.0 oz. (0.06 kg)

OFFER OF SALE:

The items described in this document are hereby offered for sale by Parker-Hannifin Corporation, its subsidiaries or its authorized distributors. This offer and its acceptance are governed by the provisions stated in the detailed "Offer of Sale" elsewhere in this document or available at www.parker.com/veriflo

⚠ WARNING USER RESPONSIBILITY

FAILURE OR IMPROPER SELECTION OR IMPROPER USE OF THE PRODUCTS DESCRIBED HEREIN OR RELATED ITEMS CAN CAUSE DEATH, PERSONAL INJURY AND PROPERTY DAMAGE. THIS DOCUMENT IS FOR REFERENCE ONLY. PLEASE CONSULT FACTORY FOR LATEST PRODUCT DRAWINGS AND SPECIFICATIONS

This document and other information from Parker-Hannifin Corporation, its subsidiaries and authorized distributors provide product or system options for further investigation by users having technical expertise.

The user, through its own analysis and testing, is solely responsible for making the final selection of the system and components and assuring that all performance, endurance, maintenance, safety and warning requirements of the application are met. The user must analyze all aspects of the application, follow applicable industry standards, and follow the information concerning the product in the current product catalog and in any other materials provided from Parker or its subsidiaries or authorized distributors.

To the extent that Parker or its subsidiaries or authorized distributors provide component or system options based upon data or specifications provided by the user, the user is responsible for determining that such data and specifications are suitable and sufficient for all applications and reasonably foreseeable uses of the components or systems.

Proposition 65 Warning: This product contains chemicals known to the state of California to cause cancer or birth defects or other reproductive harm.

LitPN: 25000069 Date of Issue 11/2010

Parker Veriflo

ENGINEERING YOUR SUCCESS.

NES Project: 11-116
GSI 3537 – H2T Injection Equipment
Former Atlas Missile Site – York, NE

Section 4 – Mixing Components

BV-101 to 901 ½” & 1” Ball Valves - Nibco Model NIBTFPA600-12 Specifications

BV-301 & 302 (H2) 3-Way Ball Valves – Apollo 7060301 Specifications

FM-101 to 501 Brooks Flowmeter Summary

FM-101 Flowmeter – Brooks Model 1358 Specifications – N2

FM-201 to 501 Flowmeter – Brooks Model 1355E & 1350E Specifications – Propane, H2, CO2, He

Brooks Model 1358 Operating Instructions – N2

Brooks Model 1350e & 1355e Operating Instructions – Propane, H2, CO2, He

CV-101 to 105 Concoa Model 532-3922 Specifications

PI-901 Pressure Gauge Concoa Model 550-0201 Specifications

Brass Ball Valves

Two-Piece Body • Full Port • Blowout-Proof Stem • PTFE Seats

¼"-2" 600 PSI/41.4 Bar Non-Shock Cold Working Pressure
2½"-4" 400 PSI/27.6 Bar Non-Shock Cold Working Pressure

CONFORMS TO MSS SP-110 • CSA CERTIFIED TO ASME B16.44 AND CR91-002 (THREADED ¼"-4") • UL LISTED (THREADED ¼"-4") • IAPMO LISTED TO NSF/ANSI 61-8

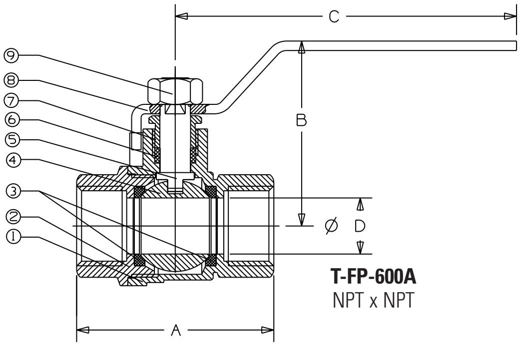
T-FP-600A
Threaded

S-FP-600A
Solder

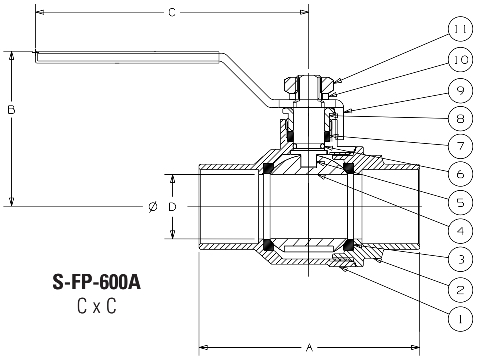
MATERIAL LIST

PART	SPECIFICATION
1. Body	Forged Brass² CU > 57%
2. End Cap	Forged Brass² CU > 57%
3. Ball Seat	PTFE
4. Ball	Brass, Chrome Plated
5. Stem	Brass
6. O-Ring (Stem Seal)*	Fluorocarbon (FKM)
7. Stem Packing	PTFE
8. Packing Nut	Brass
9. Lever Handle¹	Steel, Plated
10. Lock Washer*	Stainless Steel
11. Handle Nut¹	Stainless Steel

Note: * Parts 6 and 10 are applicable of S-FP-600A only.
[1] Due to Standard Approvals, Lever Handles and Nuts are not interchangeable between Solder and Threaded. There are no handle options at this time.
[2] For Material Certification, contact NIBCO Technical Services.



T-FP-600A
NPT x NPT



S-FP-600A
C x C

DIMENSIONS—WEIGHTS—QUANTITIES

Size		Dimensions T-FP-600A A		S-FP-600A A		T-FP-600A B		S-FP-600A B		T-FP-600A C		S-FP-600A C		Port D		T-FP-600A		S-FP-600A		T-FP-600A	S-FP-600N
In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	Lbs.	Kg.	Lbs.	Kg.	Ctn. Qty.	Ctn. Qty.
¼	8	1.76	45	—	—	1.73	44	—	—	3.54	90	—	—	.39	10	.33	.15	—	—	18	—
⅜	10	1.76	45	1.75	44	1.73	44	1.58	40	3.54	90	3.78	96	.39	10	.33	.14	.38	.17	18	18
½	15	2.05	52	2.01	51	1.92	49	1.78	45	3.54	90	3.78	96	.59	15	.44	.20	.40	.18	18	18
¾	20	2.26	60	2.74	70	2.09	53	2.13	54	3.78	96	3.98	101	.75	19	.66	.30	.67	.30	12	12
1	25	2.76	70	3.35	85	2.56	65	2.52	64	4.53	115	4.41	112	.98	25	1.10	.50	1.12	.51	6	6
1¼	32	3.31	84	3.78	96	2.95	75	2.65	67	4.53	115	5.04	128	1.26	32	1.57	.71	1.49	.67	4	4
1½	40	3.66	93	4.42	112	3.35	85	3.12	79	5.51	140	6.22	158	1.57	40	2.40	1.09	2.38	1.08	2	2
2	50	4.18	106	5.34	136	3.68	93	3.41	87	5.51	140	6.22	158	1.97	50	3.37	1.53	3.62	1.64	2	2
2½	65	5.38	137	6.28	160	4.76	121	4.76	121	8.66	220	8.66	220	2.56	65	7.60	3.45	6.36	2.88	3	3
3	75	6.04	153	7.15	182	5.08	129	5.08	129	8.66	220	8.66	220	2.95	75	9.36	4.24	8.32	3.77	2	2
4	100	7.39	188	—	—	5.87	149	—	—	9.61	244	—	—	3.89	99	16.85	7.64	—	—	1	—

*** S-FP-600A ⅜" - 2" (S1), 2 ½" - 3" (S2)**
*** T-FP-600A ¼" - 4" (S2)**

70-600 Series

3-Way Diversion Bronze Ball Valve

Threaded, 400 psig WOG, Cold Non-Shock.

FEATURES

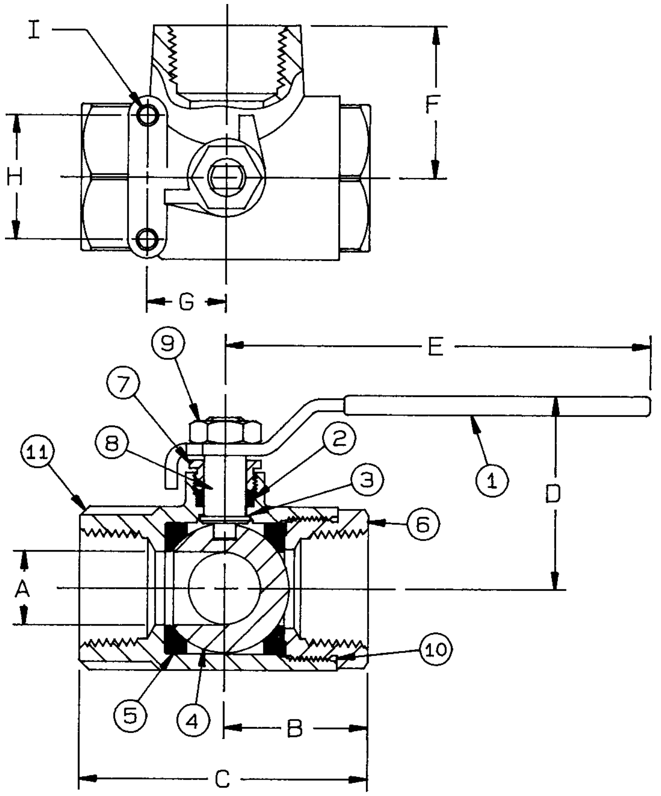
- Two piece body
- Reinforced seats
- Blow-out-proof stem design
- Adjustable packing gland

STANDARD MATERIAL LIST

1. Lever and grip	Steel, zinc plated w/vinyl	7. Gland nut	B16
2. Stem packing	MPTFE	8. Stem	B16
3. Stem bearing	RPTFE	9. Lever nut	Steel, zinc plated
4. Ball	B16, chrome plated	10. Body seal (1-1/2" to 2")	PTFE
5. Seat (2)	RPTFE	11. Body	B584-C84400
6. Retainer	B16 (1/4" to 1") B584-C84400 (1-1/4" to 2")		

VARIATIONS AVAILABLE:

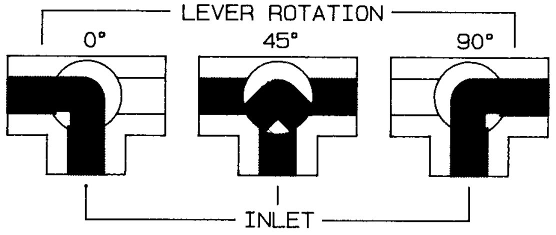
70-640 Series (316 SS Ball & Stem)



OPTIONS AVAILABLE:

(SUFFIX)	OPTION	SIZES
-02-	Stem Grounded	1/4" to 2"
-03-	1-1/4" CS Stem Extension	1/4" to 2"
-04-	2-1/4" CS Stem Extension	1/4" to 2"
-05-	Plain Ball	1/4" to 2"
-10-	SS Lever & Nut	1/4" to 2"
-17-	Rough Chrome Plated - Bronze Valves	1/4" to 2"
-21-	UHMWPE Seats (Non-PTFE)	1/4" to 2"
-24-	Graphite Packing	1/4" to 2"
-27-	SS Latch-Lock Lever & Nut	1/4" to 2"
-35-	VTFE Trim	1/4" to 2"
-49-	Assembled Dry	1/4" to 2"
-50-	2-1/4" CS Locking Stem Extension	1/4" to 2"
-56-	Multifill Seats & Packing	1/4" to 2"
-57-	Oxygen Cleaned	1/4" to 2"
-60-	Grounded Ball & Stem	1/4" to 2"
-P01-	BSPP (Parallel) Thread Connection	1/4" to 2"
-T01-	BSPT (Tapered) Thread Connection	1/4" to 2"

FLOW PATTERN



NOTE: Open port pressure must exceed Closed port pressure.

3-WAY DIVERSION BRONZE BALL VALVE

NUMBER	SIZE	A	B	C	D	E	F	G	H	I	Wt.
70-601-01	1/4"	.43	1.09	2.25	1.87	3.88	1.18	.875	1.37	10-24	.91
70-602-01	3/8"	.50	1.09	2.25	1.87	3.88	1.18	.875	1.37	10-24	.88
70-603-01	1/2"	.50	1.09	2.25	1.87	3.87	1.18	.875	1.37	10-24	.76
70-604-01	3/4"	.68	1.48	2.97	2.08	4.78	1.62	.875	1.37	10-24	1.65
70-605-01	1"	.87	1.59	3.20	2.18	4.78	1.68	.875	1.37	10-24	2.15
70-606-01	1-1/4"	1.01	1.99	3.98	2.72	5.43	2.09	.937	1.50	1/4-20	3.85
70-607-01	1-1/2"	1.26	2.19	4.38	2.90	5.43	2.38	.937	1.50	1/4-20	5.22
70-608-01	2"	1.50	2.34	4.66	3.00	5.43	2.50	.937	1.50	1/4-20	6.20

For Pressure/Temperature Ratings,Refer to Page M-8, Graph No. 3

Cv FACTORS
87A-100 & 88A-100 SERIES

SIZE	1-1/2"	2"	2-1/2"	3"	4"	6"	8"	10"(1)
FULL OPEN	86	104	234	375	673	1099	1902	3890

Cv FACTORS
87A-200 & 88A-200 SERIES

SIZE	1/2"	3/4"	1"	1-1/2"	2"	2-1/2"	3"	4"	6"	8"	10"(1)
FULL OPEN	15	19	75	195	410	545	1021	2016	4837	9250	15170

(1) Calculated Data

Cv FACTORS
9A-100, 90-100, 91-100, 92-100, 93-100 & 96-100 SERIES

SIZE		1/4"	3/8"	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"
OPEN	90°	8.3	6.7	5.7	10	16	25	40	62

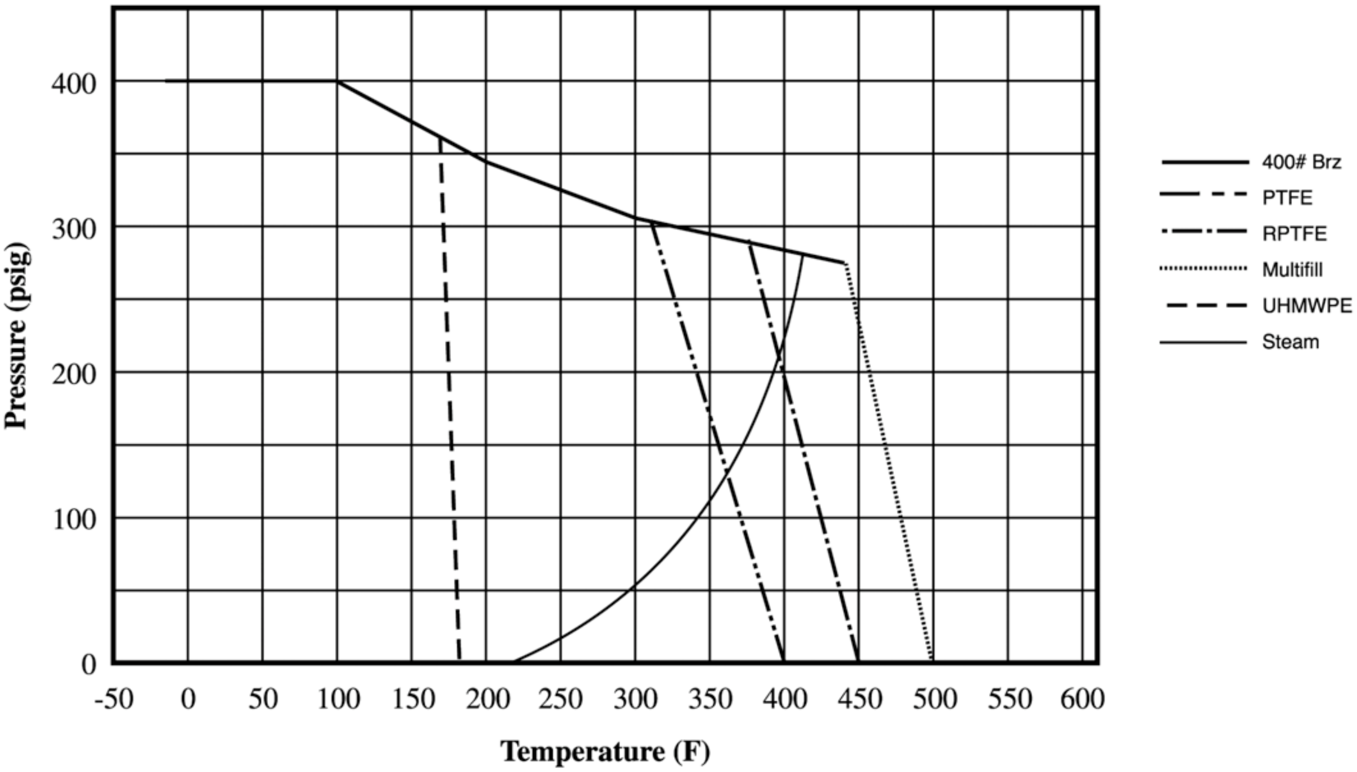
Cv FACTORS
70-600 & 76-600 SERIES

SIZE	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"
FULL OPEN	5.4	12	14	21	34	47

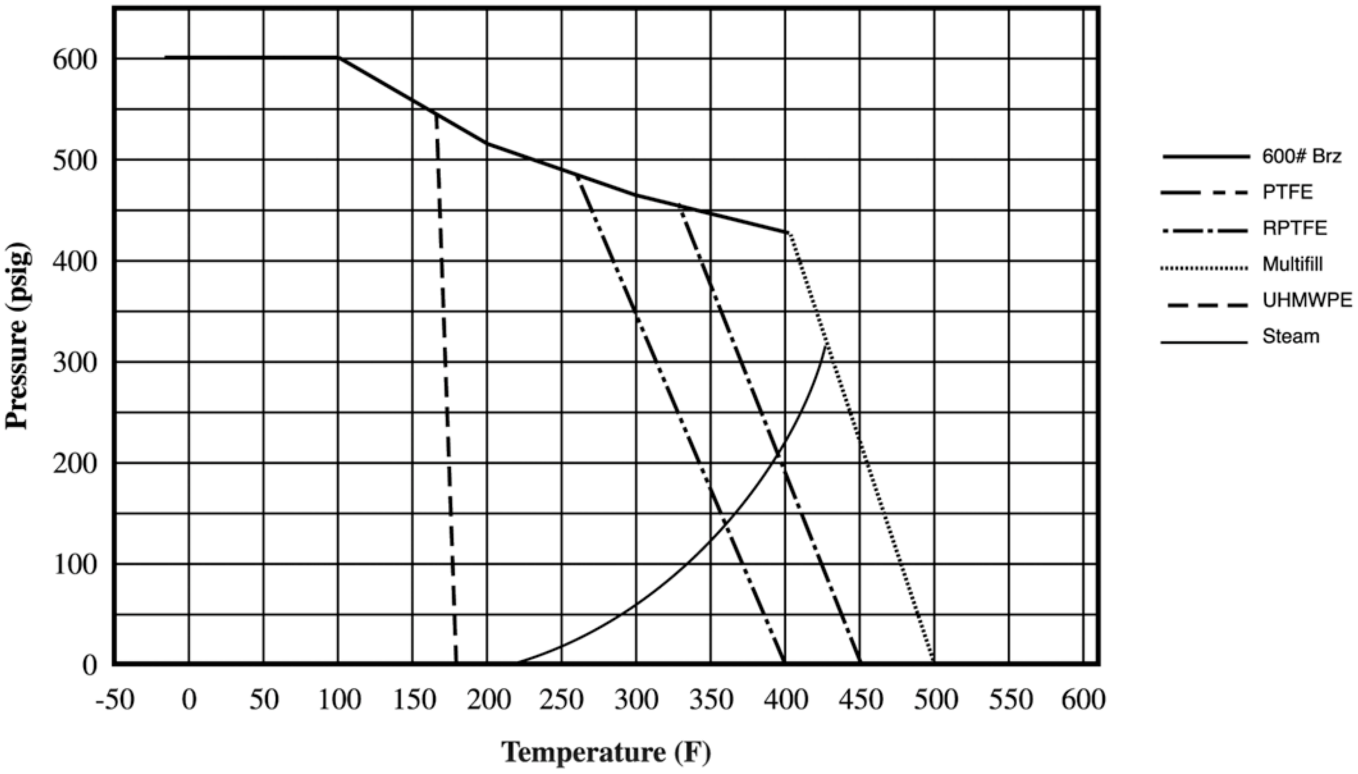
Cv FACTORS
"72" SERIES

SIZE	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"
FULL OPEN	26	48	65	125	170	216

400# Bronze P-T Rating
(Graph 3)



600# Bronze P-T Rating
(Graph 4)



I414500.B

Installation, Operation And Maintenance Guide For Apollo 3-Way Diversion
Conbraco Industries, Inc.

**** CAUTION ****

BEFORE INSTALLATION: Insure that the component materials of the Valve are compatible with the media, with regard to corrosiveness, pressure, and temperature. Valves must be installed in piping systems that comply with the applicable ANSI B31 Standard. Special considerations must be taken with respect to pipeline expansions and contractions and the media expansions and contractions within the piping system.
NOTE: THIS IS A DIVERSION VALVE, open port pressure must exceed closed port pressure.

STORAGE AND PROTECTION

Valve should be stored in its original shipping container until just prior to installation with any protection means in place and protected from the environment or any other potential damaging affects.

THREADED END INSTALLATION

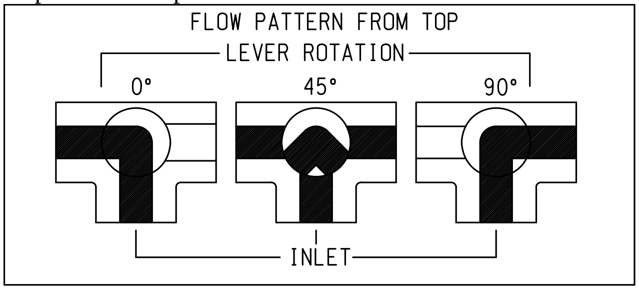
1. Pipe connections to be threaded into these valves should be accurately threaded, clean and free of foreign material or metal shavings.
2. TFE pipe tape is recommended for use as the pipe joint sealant, especially in stainless steel valves. This material should be applied to the manufacturers specification.
3. Use two wrenches when making the pipe joint. Apply one wrench on the hex pads nearest the joint being tightened to prevent breaking the retainer-to-body seal.

SOLDER END INSTALLATION

1. Piping connections to be soldered into these valves should be cut square and then cleaned with an appropriate cleaner or flux.
2. These valves are designed to be soft soldered. Apply heat with the flame directed *AWAY* from the center of the valve body. Excessive heat can harm the TFE seats and packing. SOLDERING TEMPERATURE NOT TO EXCEED 500°F. Adjust packing after joints are cool.

OPERATION

The valve levers are marked showing proper flow direction in respect to lever position at extreme end of lever travel.



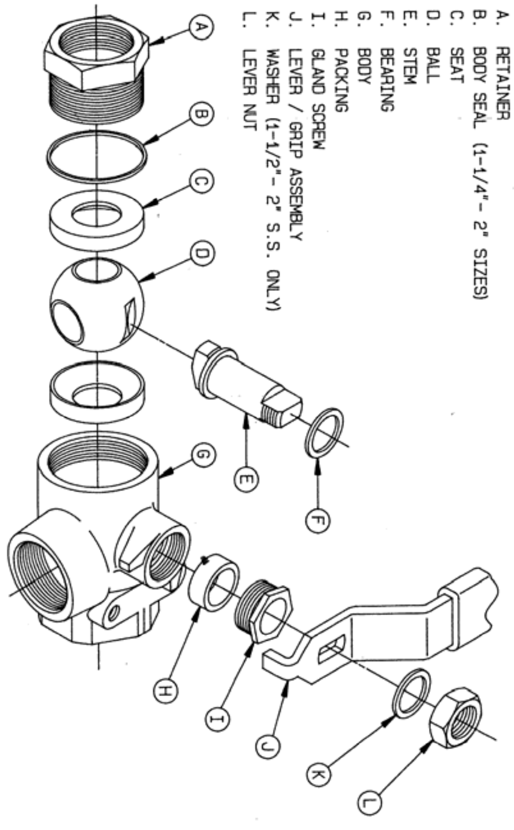
MAINTENANCE

Tightening the gland screw clockwise can compensate for normal stem packing wear. If all the adjustment to the packing gland screw has been made, remove the lever and packing gland screw and add one or two replacement bearings on top of the old packing. Reassemble the lever and packing gland screw.

***CAUTION:** Do not disassemble valve while under pressure or with entrapped hazardous fluids therein.*

General repair of the valve can be made by:
1. Remove valve from system. Turn valve lever to position shown on exploded view. (Clockwise)
2. Remove retainer by turning counter-clockwise.
3. Remove top seat.
4. Push ball out of body with finger.
5. Remove lever nut by turning counter-clockwise. Lever assembly can then be lifted off stem.
6. Remove packing gland screw by turning counter-clockwise and push stem down into body to remove.
7. Remove all seats and seals. To facilitate removal of the stem packing, cut with knife.
8. Replace all seats and seals as furnished in the Service Kit. Inspect the ball and stem for excessive wear or damage and replace if necessary.
9. Reverse the above procedure to reassemble. Make certain to install the lever, ball and stem in the position shown in the exploded view. Use Loctite Hydraulic Sealant or equal on the retainer threads.

NOTE: VALVES IN OXYGEN SERVICE CAN ONLY BE SEALED WITH A COMPATIBLE SEALANT.



Item Description	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)
Model Number	1358F1B2FC3D1A	1355EH2CCLN1A	1355EG2CCLN1A	1350EP2BCLN1A	1355EA2EALM1A	1350EP2ECLN1A	1355EH2BCLN1A
Fluid Type	Nitrogen gas (N_2)	Propane Gas (C3H8)	Hydrogen gas (H_2)	Hydrogen gas (H_2)	Carbon Dioxide gas (CO_2)	Helium gas (He)	"Air"
Flow Rate	1 to 10 scfm	0.13 to 1.3 scfm	0.2 to 2.0 scfm	0.71 to 7.1 scfm	0.011 - 0.11 scfm	0.88 TO 8.7 scfm	0.15 to 1.5 scfm
Operating Inlet Pressure	50 psig	50 psig	50 psig	50 psig	50 psig	50 psig	15 psig
Operating Outlet Pressure	15 psig	15 psig	15 psig	15 psig	15 psig	15 psig	0 psig
Operating Temperature	70 °F	70 °F	70 °F	70 °F	70 °F	70 °F	55 F
Float Material	316 S.S.	Sapphire	Sapphire	316 s.s.	Sapphire	tantalum	316 S.S.
Scale Type	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm
Accuracy	+/- 10% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%	+/- 10% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%	+/- 10% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%
Packing Material	Viton	Viton	Viton	Viton	Buna-N	Viton	Viton
O-ring Material	Viton	Viton	Viton	Viton	Buna-N	Viton	Viton
Fitting & Adapter Material	brass	brass	brass	brass	brass	brass	brass
Connection Size & Type	3/8" FNPT with locknut	1/4" FNPT with locknut	1/4" FNPT with locknut	1/4" FNPT with locknut	1/4" FNPT with locknut	1/4" NPT locknut	1/4" FNPT with locknut
Valve Material & Type	brass, std. needle	brass, NRS #6	brass, NRS #6	brass, NRS #6	brass, NRS #6	BRASS NRS 6	brass, NRS #6
Connection Orientation	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back

Data Sheet
DS-VA-1358-eng
March, 2008

Brooks® Model 1358

Sho-Rate™ "50" Size 8 Flow Indicator Model 1358

- Ten-to-one rangeability
- Heavy-wall, precision bore borosilicate glass metering tube
- A wide range of scales on the metering tube
- Tube removable without disconnecting the instrument
- Interchangeable tubes and floats
- Piping connections rotatable through 360° at 90° intervals
- Easily panel mounted
- Single tube or multi-tube configurations available

DESCRIPTION

The Brooks® Sho-Rate "50" Series of low flow indicators provides a cost-effective means of flow indication where the accuracy requirements are not severe. Available options include an integral needle control valve as well as flow controllers piped to the inlet or outlet of the meter.

SPECIFICATIONS

Pressure Ratings:
200 psig (1,378 kPa) at temperatures up to 250°F (121°C). Fluid temperatures below 32°F (0°C) will cause frosting of the glass metering tube. Consult factory for applications below this temperature.

Pressure Equipment Directive (PED) 97/23/EC:
Flowmeters mentioned in this document are Sound Engineering Practice (SEP).

Scales:
Type (Standard): Fused on meter tube
Length: 75 mm, nominal
Graduations:
  Standard: direct read on tube in gpm water or scfm air.
  Optional: special direct read decal on tube. Consult factory for available ranges. Direct read on metal scale plate mounted beside tube.

Standard accuracy: ±10% of full scale from 100% to 10% of scale reading.

Repeatability: 0.5% full scale

Model 1358-V Sho-Rate "50" Meter with optional Needle Control Valve

Rangeability: Ten to one

Connections:
Standard: Horizontal female 3/8" NPT threaded adaptors.
Optional: Horizontal female 3/8" NPT threaded adaptors with locknut for front of panel mounting.

Materials of Construction:
Metering Tubes:
Borosilicate glass

Float: 316 stainless steel

End Fittings:
Chrome plated brass or 316 stainless steel

Side Plates:
Standard: Black anodized aluminum
Optional: 316 stainless steel

Window:
Scratch resistant, UV stabilized polycarbonate

Back Cover: Milk white polycarbonate

Float Stops: Stainless steel

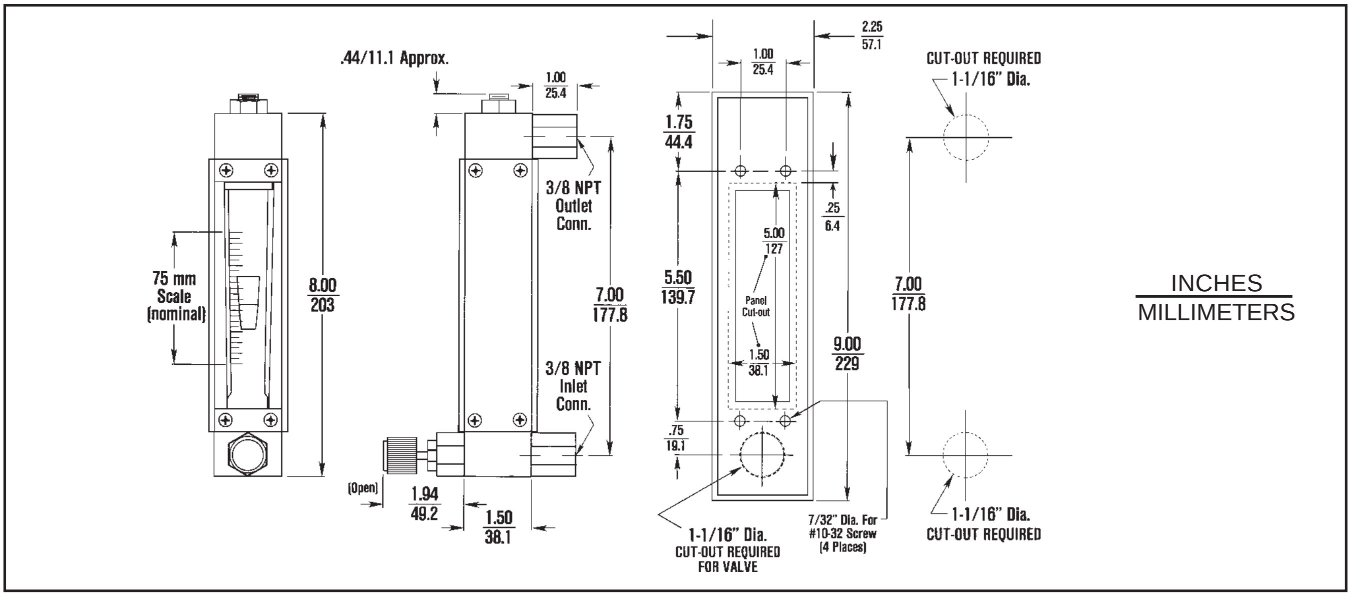


Figure 1 Dimensions

Tube Packing:
Standard: Neoprene™ (Brass meters), Viton-A® fluoroelastomers (316 stainless steel meters).
Optional: Teflon®, EPM

O-rings:
Standard: Buna-N (Brass meters), Viton-A fluoroelastomers
Optional (316 stainless steel meters): EPM, Kalrez®

Protective Tube Sleeve:
UV stabilized polycarbonate

Dimensions
See Figure 1

OPTIONAL EQUIPMENT

Integrally mounted needle control valve on inlet or outlet
Flush panel mounting bezel
Front of panel mounting locknuts
Externally piped flow controller and needle valve (see DS-VA-FC-eng)
Multi-tube construction up to six tubes

ORDERING INFORMATION

To order, please specify:
1. Model Number (see chart)
2. Materials of Construction
3. Scale Data
4. Complete Metering Data: Type of fluid; maximum, minimum and normal flows; operating temperature; operating back pressure; specific gravity
5. Options, if desired
6. For ranges other than above, consult factory

Table 1 Capacities

Water (gpm)	Maximum Flow Rate Pressure Drop Without Valve Inches W.C.	 Pressure Drop With Valve Inches W. C.	Float
0.8	12.6	13.6	8-RV-8
1.5	22.2	27.0	8-RJ-10
2.5	61.0	85.2	8-RJ-23
3.5	88.7	121.0	8-RJ-30
5.0	172	238.0	8-RJ-39

Air (scfm)	Pressure Drop W.C. Without Valve Inches	Pressure Drop W.C. With Valve Inches	Float
3.4	14.34	15.5	8-RV-8
6.0	25.34	30.8	8-RJ-10
12.0	69.34	97.3	8-RJ-23
15.0	101.34	138.3	8-RJ-30

NOTE: All air flows are at 14.7 psia and 70°F.

Table 2 Size 8 Sho-Rate Model Number Code

MODEL CODE	SIZE 8 SHO-RATE FLOW INDICATOR
1358F	Sho-Rate "50," Size 8

CODE	TUBE
1	R-8M-75-1 (Cut-Off)
9	No Tube

CODE	FLOAT (316 STAINLESS STEEL)
A	8-RV-8
B	8-RJ-10
C	8-RJ-23
D	8-RJ-30
E	8-RJ-39
W	Special
Y	No Float

CODE	SCALE TYPE/SIDE PLATE ARRANGEMENT
1	Scale on Tube (Plain Side Plates)
2	Aluminum Detachable Scale Mounted to Right Side Plate
3	Dual Aluminum Detachable Scales
4	Stainless Steel Detachable Scale Mounted to Right Side Plate
5	Dual Stainless Steel Detachable Scales

CODE	SCALE INSCRIPTION
A	No Inscription
B	MM Scale
C	0-100 Linear
D	SCFM Air @ 70°F psia, Standard 10% Accuracy
E	GPM Liquid Specific Gravity 1.0, Viscosity 1.0 cP, Standard 10% Accuracy
F	Special Inscription, Standard 10% Accuracy
G	Special Calibration, 10% Full Scale Air
H	Special Calibration, 10% Full Scale Water
J	Special Calibration, 10% Full Scale Oil
K	Special Calibration, 5% Full Scale Air
L	Special Calibration, 5% Full Scale Water
M	Special Calibration, 5% Full Scale Oil

CODE	TUBE PACKING AND O-RING MATERIALS FOR METER/VALVE[1]
A	Neoprene Tube Packing, Buna O-ring
B	Viton Tube Packing, Buna O-ring
C	Viton Tube Packing, Viton O-ring
D	Viton Tube Packing, EPM O-ring
E	Viton Tube Packing, Kalrez O-ring
F	Teflon Tube Packing, Buna O-ring
G	Teflon Tube Packing, Viton O-ring
H	Teflon Tube Packing, EPM O-ring
J	Teflon Tube Packing, Kalrez O-ring
K	EPM Tube Packing, EPM O-ring
L	No Packing[2] , Buna-O-ring
M	No Packing[2], Viton O-ring
N	No Packing[2], EPM O-ring
P	No Packing[2], Kalrez O-ring

Table 2 Size 8 Sho-Rate Model Number Code (Continued)

CODE	FITTING & ADAPTER MATERIAL[3]/PROCESS CONNECTION SIZE & TYPE
1	3/8" NPT Connection, Brass Fitting & Adapter
2	3/8" NPT Connection, 316 Stainless Steel Fitting & Adapter
3	Thd. 3/8" NPT with Locknut Connection, Brass Fitting & Adapter
4	Thd. 3/8" NPT with Locknut Connection, 316 Stainless Steel Fitting & Adapter
5	No Adapter[3], Brass Fitting
6	No Adapter[3], 316 Stainless Steel Fitting
7	3/8" NPT Connection, Brass Fitting, 316 Stainless Steel Adapter
8	3/8" NPT Connection, 316 Stainless Steel Fitting, Brass Adapter
9	Thd. 3/8" NPT with Locknut Connection, Brass Fitting, 316 Stainless Steel Adapter
A	Thd. 3/8" NPT with Locknut Connection, 316 Stainless Steel Fitting, Brass Adapter

CODE	VALVE CONFIGURATION
A	No Valve (Plain End Fitting on Inlet)
B	Standard Stainless Steel Needle Valve on Inlet
C	Standard Stainless Steel Needle Valve on Outlet
D	Standard Brass Needle Valve on Inlet
E	Standard Brass Needle Valve on Outlet
F[4]	Mounted to 8810 Flow Controller
G[4]	Mounted to 8910 Flow Controller
H[4]	Mounted to 8830 Flow Controller
J	Standard Valve Cavity with Stainless Steel Valve Plug
K	Standard Valve Cavity without Valve or Plug

CODE	CONNECTION ORIENTATION
1	Inlet Port Back, Outlet Port Back
2	Inlet Port Back, Outlet Port Front
3	Inlet Port Back, Outlet Port Right
4	Inlet Port Back, Outlet Port Left
5	Inlet Port Front, Outlet Port Back
6	Inlet Port Front, Outlet Port Front
7	Inlet Port Front, Outlet Port Right
8	Inlet Port Front, Outlet Port Left
9	Inlet Port Right, Outlet Port Back
A	Inlet Port Right, Outlet Port Front
B	Inlet Port Right, Outlet Port Right
C	Inlet Port Right, Outlet Port Left
D	Inlet Port Left, Outlet Port Back
E	Inlet Port Left, Outlet Port Front
F	Inlet Port Left, Outlet Port Right
G	Inlet Port Left, Outlet Port Left

CODE	ACCESSORIES (ONE OR TWO-DIGIT FIELD)
A	None
B	Plastic Bezel
C	Stainless Steel Side Plates
D	Degrease for Oxygen Service
E	Triangular Base Plate with Spirit Level
G	No Brooks Identification

1358	1	C	3	D	C	8	B	C	D	Typical Model Number

NOTES:

[1] If valve is not required, select proper O-ring material for meter only.
[2] If tube is not required, select proper O-ring material coded L through P.
[3] If no adapter is required, select proper code for end fitting material only.
[4] Flow Controller must be a second-line item on customer's order.

TRADEMARKS

Brooks	Brooks Instrument, LLC
Kalrez	DuPont Performance Elastomers
Neoprene	E. I. DuPont de Nemours & Co.
Sho-Rate	Brooks Instrument, LLC
Teflon	E. I. DuPont de Nemours & Co.
Viton	DuPont Performance Elastomers

HELP DESK

In case you need technical assistance:

Americas	☎ 1-888-554-FLOW
Europe	☎ +(31) 318 549 290
Within Netherlands	☎ 0318 549 290
Asia	☎ +011-81-3-5633-7100

Due to Brooks Instrument's commitment to continuous improvement of our products, all specifications are subject to change without notice.

ISO 9001 QUALITY SYSTEM

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BROOKS® INSTRUMENT

Data Sheet
DS-VA-1350E-eng
April, 2011

Sho-Rate™ "50" Model 1350E and Sho-Rate™ "150" Model 1355E Flowmeters

FEATURES AND BENEFITS

- Heavy-wall, precision bore, borosilicate glass metering tubes
- A wide range of scales on the metering tube with contrasting background for easy readability
- Tubes sealed on compression gasket by threaded seal spindle
- Tubes removable without disconnecting instrument
- Integral float stops prevent loss of float during tube removal
- Interchangeable tubes and floats

DESCRIPTION

The Sho-Rate 1350 and 1355 Series of low flow indicators provides a cost-effective means of flow indication for both 5% (Model 1355) and 10% (Model 1350) accuracy requirements. Available options include the Standard or NRS™ integral needle control valves, as well as flow controllers on the inlet or outlet.

SPECIFICATIONS

Capacities

1350 Series: Refer to Tables 1 or 2, or 3 and 4
1355 Series: Refer to Tables 3 and 4, or 5

Accuracy

1350 Series Standard: Accuracy of ±10% of full scale
1355 Series Standard: ±5% of full scale

Repeatability

0.5% full scale

Pressure Equipment Directive (97/23/EC)

Note: Equipment falls under Sound Engineering Practice (SEP) according to the directive.

Pressure/Temperature

200 psig at temperatures 33°F to 250°F

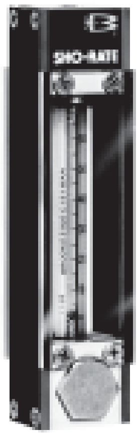
Pressure Drop

Inquire at factory

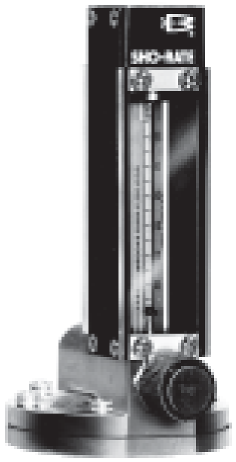
Flow Meter Assembly

Scales

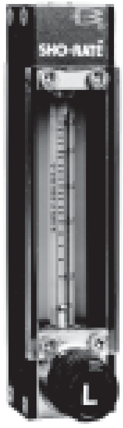
1350 Series:
Length: 65 mm, nominal
Graduations: Standard: R-65mm, or R-100 linear reference scale with air or water calibration table.



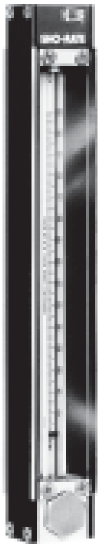
Model 1350E Sho-Rate "50" (No valve)



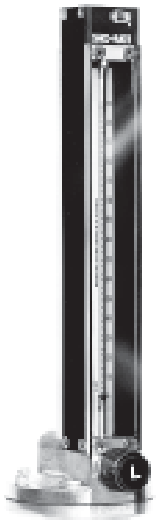
Model 1350E-8800 Sho-Rate "50" with optional integral flow controller



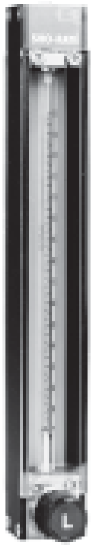
Model 1350E Sho-Rate "50" with optional needle valve



Model 1355E Sho-Rate "150" (No valve)



Model 1355E-8800 Sho-Rate "150" with optional integral flow controller



Model 1355E Sho-Rate "150" with optional needle valve

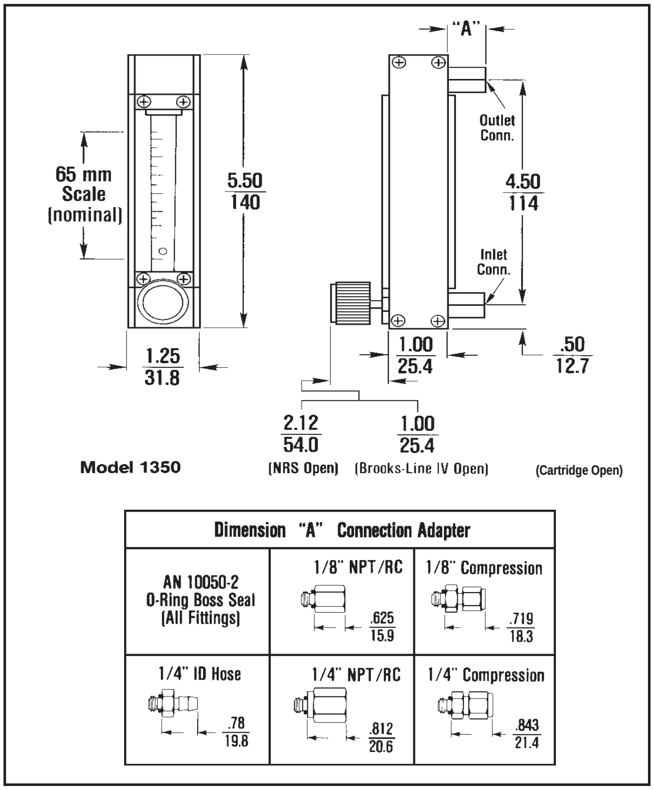


Figure 1 Dimensions - Sho-Rate 1350E

1355 Series:
Length: 150mm, nominal
Graduations: Standard: R-150 mm, or R-100 linear reference scale with air or water calibration table.
Optional: for either 65 mm or 150 mm direct reading scale, ceramic ink fused on glass tube or metal scale plate mounted beside tube
Type: Standard: Ceramic ink fused on meter tube with contrasting yellow background

Materials of Construction
Metering Tubes: Borosilicate glass

Floats: Glass, 316 stainless steel, sapphire, Carboloy®, tantalum

Structural Members:
End fittings: Chrome plated brass, black anodized aluminum, 316 stainless steel

Side Plates:
Standard: Black anodized aluminum
Optional: 316 stainless steel

Window: Clear polycarbonate; Back Window: Milk white polycarbonate

Float Stops:
Standard: Teflon®
Optional: 316 Stainless Steel

Tube Packing:
Standard: Buna-N (Brass and aluminum meters), Viton-A® fluoroelastomers (316 stainless steel meters)
Optional: Teflon, EPM (also known as EPR)

O-rings:
Standard: Buna-N (Brass and aluminum meters), Viton-A fluoroelastomers (316 stainless steel meters)
Optional: Teflon (not available with needle valves), EPM, Kalrez®

Connections
Standard: Horizontal female 1/8" NPT threaded adapters with locknuts for front of panel mounting

Dimensions
Refer to Figures 1, 2 and 4

Optional Equipment
Standard integral flow control valve on inlet or outlet (See DS-VA-CART-eng).

NRS integral flow control valve on inlet or outlet (See DS-VA-8503-eng). These valves are particularly suitable for precise control requirements, and are recommended for flow rates below 500 sccm of Air (@STP) or 10 cc/min water.

Flush mounting bezels in aluminum

Threaded adapters and locknuts for front of panel mounting (standard with 1/8" NPT)
1/8" and 1/4" compression fittings
1/4" female NPT connections
1/4" ID serrated hose connections
Base plates, without level

Ordering Information (Refer to Table 6)

1. Model
2. Size, connections, type
3. Quantity required
4. Fluid
5. Minimum, normal and maximum operating temperature
6. Minimum, normal and maximum operating pressure (inlet and outlet)
7. Minimum, normal and maximum flow rate
8. Materials of construction
   a. End fittings
   b. Side plates
   c. Bezel
   d. Elastomers
9. Fluid
10. Fluid specific gravity
11. Fluid viscosity
12. Unusual system conditions (For ranges and pressure drops other than those listed, consult factory).
13. Optional equipment
   a. Valve type and location
   b. Flow controller and type

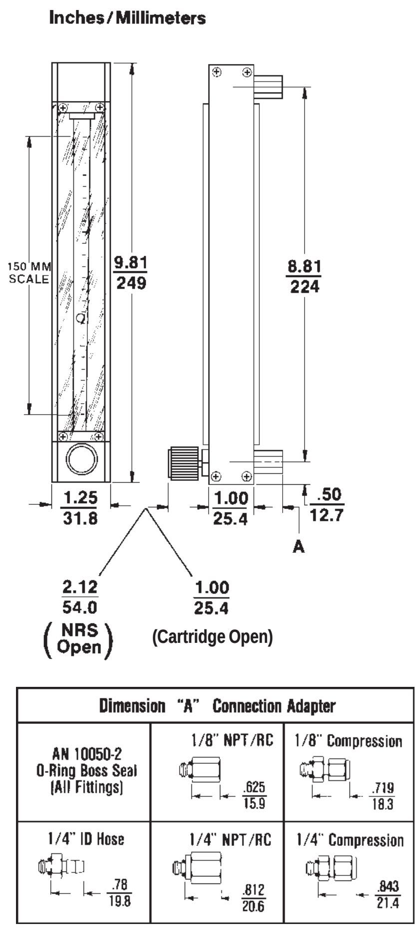
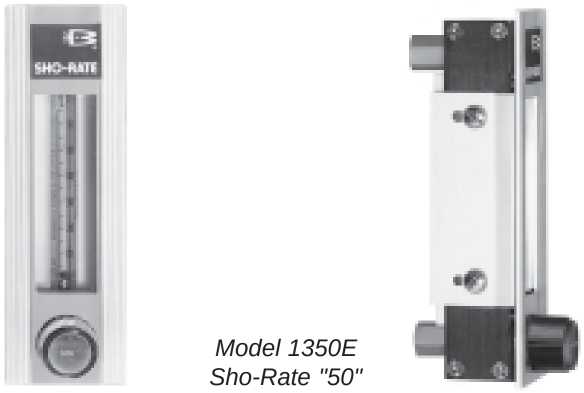


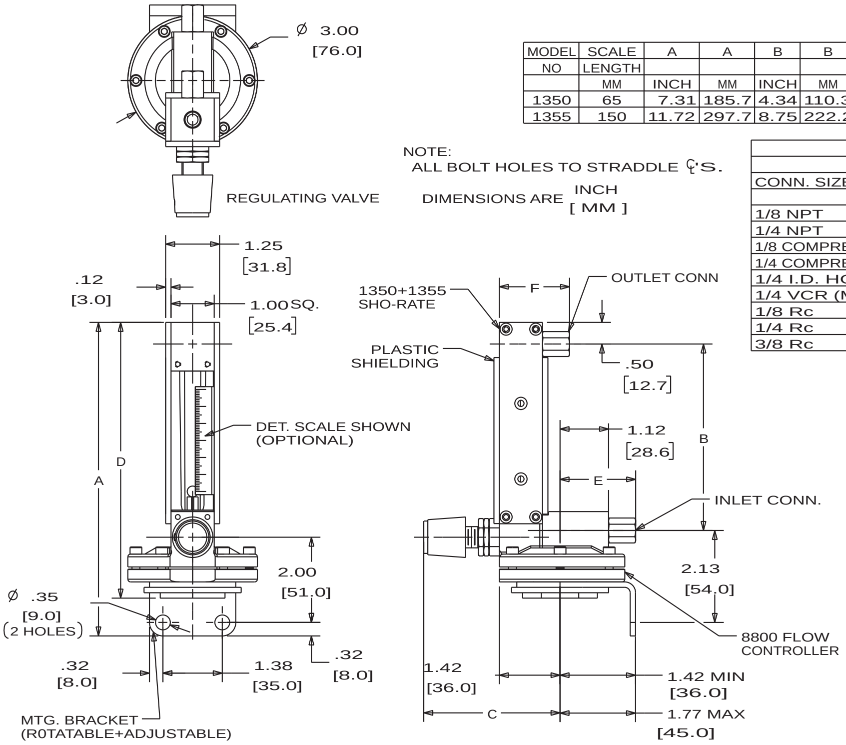
Figure 2 Dimensions - Sho-Rate 1355E



Model 1350E
Sho-Rate "50"
with optional needle valve and flush mounting bezel

Figure 3 Optional Equipment

Models 1350E and 1355E



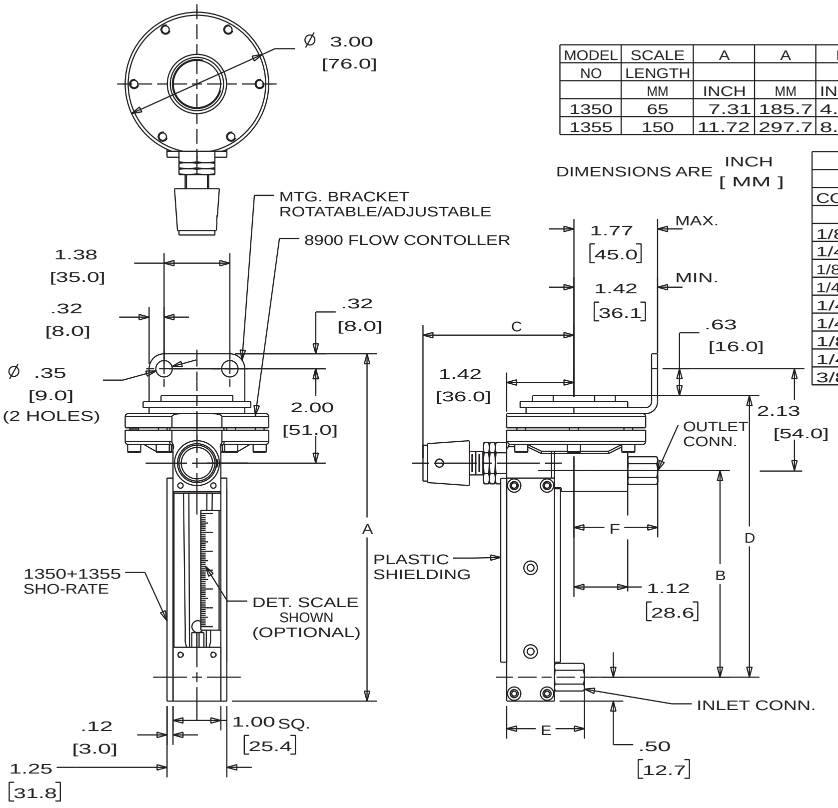
NOTE:
ALL BOLT HOLES TO STRADDLE ℄'S.

DIMENSIONS ARE INCH [MM]

MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.72	43.7	1.62	41.1
1/4 NPT	1.12	28.6	1.81	46.0
1/8 COMPRESSION	1.91	48.5	1.81	46.0
1/4 COMPRESSION	2.04	51.8	1.94	49.3
1/4 I.D. HOSE	1.82	46.2	1.72	43.7
1/4 VCR (M)	N/A	N/A	2.06	52.3
1/8 Rc	1.91	48.5	1.62	41.1
1/4 Rc	1.91	48.5	1.81	46.0
3/8 Rc	2.35	53.1	2.09	53.1

Model 1350E-8800
Controller on Inlet



DIMENSIONS ARE INCH [MM]

MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.62	41.1	1.72	43.7
1/4 NPT	1.81	46.0	1.12	28.6
1/8 COMPRESSION	1.81	46.0	1.91	48.5
1/4 COMPRESSION	1.94	49.3	2.04	51.8
1/4 I.D. HOSE	1.72	43.7	1.82	46.2
1/4 VCR (M)	2.06	52.3	N/A	N/A
1/8 Rc	1.62	41.1	1.91	48.5
1/4 Rc	1.81	46.0	1.91	48.5
3/8 Rc	2.09	53.1	2.35	59.7

Model 1350E-8900
(Controller on Outlet)

Figure 4 Dimensions - Sho-Rate 1350E & 1355E with Integral Flow Controller

Table 1 Capacities for Sho-Rate Model 1350E Rib Guided Tubes, Spherical Floats

	RIBBED TUBES, SPHERICAL FLOATS									
METER SIZE	TUBE NO.	FLOAT MATERIAL	MAXIMUM FLOW RATE							
			WATER				AIR*			
			GPH	CODE	LPH	CODE	SCFH	CODE	NLPH	CODE
2	R-2-65-A	GLASS	0.011	JB6	0.042	JB9	0.13	JB7	3.4	JB8
		SAPPHIRE	0.022	JC4	0.085	JC2	0.18	JC3	5.0	JC1
		STN. STL.	0.046	JC8	0.18	JC5	0.34	JC7	9.0	JC6
		CARBOLOY	0.10	JB4	0.38	JB5	0.65	JB2	17.0	JB3
		TANTALUM	0.11	JD2	0.42	JC9	0.70	JD1	19.0	JD3
	R-2-65-B	GLASS	0.013	KB8	0.048	KB2	0.15	KB7	4.0	KB9
		SAPPHIRE	0.026	KC1	0.10	KD3	0.22	KC2	5.5	KC3
		STN. STL.	0.06	KC5	0.22	KC6	0.42	KC7	11.0	KC8
		CARBOLOY	0.12	KB4	0.48	KB5	0.80	KB3	22.0	KB6
		TANTALUM	0.13	KD2	0.50	KD5	0.85	KD4	22.0	KD1
	R-2-65-C	GLASS	0.11	LB9	0.42	LB7	0.95	LB6	24.0	LB8
		SAPPHIRE	0.15	LC1	0.6	LC2	1.3	LC3	34.0	LC4
		STN. STL.	0.38	LC7	1.4	LC8	2.0	LC9	50.0	LC6
		CARBOLOY	0.65	LB3	2.4	LB2	3.0	LB4	80.0	LB5
		TANTALUM	0.65	LD1	2.6	LD2	3.2	LD3	85.0	LD4
	R-2-65-D	GLASS	0.65	MB9	2.4	MB7	3.8	MB8	100	MC1
		SAPPHIRE	0.95	MC2	3.6	MC3	5.0	MC4	130	MC5
		STN. STL.	1.60	MC7	6.0	MD1	7.5	MC6	200	MC8
		CARBOLOY	2.40	MB5	9.0	MB2	11.0	MB3	280	MB4
		TANTALUM	2.60	MD5	10.0	MD6	12.0	MD2	300	MD4
6	R-6-65-A	GLASS	2.40	NB8	8.5	NB7	13.0	NC1	340	NB9
		SAPPHIRE	3.40	NC4	13.0	NC3	17.0	NC6	460	NC5
		STN. STL.	5.50	ND1	20.0	ND3	26.0	NC9	650	ND2
		CARBOLOY	8.50	NB2	32.0	NB3	36.0	NB5	950	NB6
		TANTALUM	9.0	ND6	34.0	ND5	38.0	ND7	1000	ND4
	R-6-65-B	GLASS	8.0	PB9	30.0	PB8	44.0	PC1	1100	PB7
		SAPPHIRE	12.0	PC5	44.0	PC3	60.0	PC4	1500	PC2
		STN. STL.	19.0	PD1	70.0	PC9	85.0	PC8	2200	PC6
		CARBOLOY	28.0	PB3	100	PB2	130	PB6	3400	PB4
		TANTALUM	30.0	PD7	110	PD6	140	PD5	3600	PD4

Table 2 Capacities for Sho-Rate Model 1350E Plain Tapered Tubes, Spherical Floats

	PLAIN TAPER TUBES, SPHERICAL FLOATS						
TUBE AND FLOAT	SCFH AIR*	Press. Drop ** Inches W.C.	CODE	TUBE AND FLOAT	GPH WATER	Press. Drop ** Inches W.C.	CODE
1-65A GLASS	1.2	1.0	AB4	1-65C GLASS	0.14	1.8	AB5
2-65A GLASS	1.9	2.2	BA7	2-65C STN. STL.	0.5	4.0	DA5
2-65B STN. STL	5.0	10.8	CA4	2-65D STN. STL.	1.0	19.5	CA8
3-65A GLASS	6.0	12.4	EB4	3-65C GLASS	0.7	22.3	EB9
3-65B STN. STL	10	10.1	EB8	3-65D STN. STL	1.6	18.3	EC1
4-65A GLASS	12	10.4	FC3	4-65C GLASS	2.0	18.7	FD3
4-65B STN. STL	18	25	FC8	4-65D STN. STL	4.0	45	FD6
5-65A GLASS	45	60	GB6	5-65C GLASS	9.0	109	GC4
5-65B STN. STL	80	214	GC1	5-65D STN. STL	17	385	GC5
6-65A GLASS	55	73	HB8	6-65C GLASS	11	132	HC7
6-65B STN. STL	90	292	HC5	6-65D STN. STL	20	525	HD1
6-65E CARBOLOY	120	400	HD3	6-65F CARBOLOY	30	890	HD4

*** FLOW RATES ARE MAXIMUM VALUES. AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F**
**** PRESSURE DROPS ARE APPROXIMATE**

TRADEMARKS

Brooks	Brooks Instrument, LLC
Carboloy	General Electric Co.
Kalrez	DuPont Performance Elastomers
NRS	Brooks Instrument, LLC
Sho-Rate	Brooks Instrument, LLC
Teflon	E.I. DuPont de Nemours & Co.
Viton-A	DuPont Performance Elastomers

Table 3 Tube and Float Code, Detachable Scale Option, 1st Digit

FIRST DIGIT FOR DETACHABLE SCALE CONFIGURATION		
CODE	MODEL 1350 TUBE	MODEL 1355 TUBE
A	1-65	R-2-15-A
B	2-65A	R-2-15-AA
C	2-65B & D	
D	2-65C	R-2-15-B
E	3-65	R-2-15-C
F	4-65	R-2-15-D
G	5-65	R-6-15-A
H	6-65	R-6-15-B
J	R-2-65-A	R-2-15-AAAA
K	R-2-65-B	
L	R-2-65-C	
M	R-2-65-D	
N	R-6-65-A	
P	R-6-65-B	
Y	NO TUBE	NO TUBE

Table 4 Tube and Float Code, Detachable Scale Option, 2nd & 3rd Digits

SECOND AND THIRD DIGITS FOR DETACHABLE SCALE CONFIGURATION						
		DETACHABLE SCALE INSCRIPTION				
METER ACCURACY	FLOAT MATERIAL	MM	0-100 LINEAR	SPECIAL SINGLE SCALE	SPECIAL DUAL SCALE	BLANK SCALE
STANDARD	GLASS	1A	1N	2A	2N	3A
(1350-10%)	STN. STL.	1B	1P	2B	2P	3B
(1355- 5%)	SAPPHIRE	1C	1Q	2C	2Q	3C
	CARBOLOY	1D	1R	2D	2R	3D
	TANTALUM	1E	1S	2E	2S	3E
CALIBRATED **	GLASS	1G	1U	2G	2U	
(1350-5%)	STN. STL.	1H	1V	2H	2V	
(1355-2%)	SAPPHIRE	1J	1W	2J	2W	
	CARBOLOY	1K	1X	2K	2X	
	TANTALUM	1L	1Y	2L	2Y	
N/A	NONE	9A	9B			9C

Table 5 Capacities for Sho-Rate Model 1355E Rib Guided Tubes, Spherical Floats

CAPACITIES (RIB GUIDE TUBES, SPHERICAL FLOATS) - FOR USE WITH 1355 SERIES ONLY							
			MAXIMUM FLOW RATE *		MODEL CODE - SCALE ON TUBE		
METER SIZE	TUBE NO.	FLOAT MATERIAL	WATER (CC/MIN.)	AIR	0-150 MM	10-100%	0-100 LINEAR
2	R-2-15-AAAA	GLASS	0.59	50 SCC/M	JA6		JA1
		SAPPHIRE	1.1	79 SCC/M	JA8		JA3
		STN. STL.	2.6	150 SCC/M	JA7		JA2
		CARBOLOY	5.2	280 SCC/M	JA9		JA4
		TANTALUM	5.8	310 SCC/M	JB1		JA5
	R-2-15-AA	GLASS	1.11	88 SCC/M	BA6		BA1
		SAPPHIRE	2.15	136 SCC/M	BA8		BA3
		STN. STL.	4.93	258 SCC/M	BA7		BA2
		CARBOLOY	9.33	439 SCC/M	BA9		BA4
		TANTALUM	10.4	478 SCC/M	BB1		BA5
	R-2-15-D	GLASS	5.75	380 SCC/M	FA6		FA1
		SAPPHIRE	10.5	518 SCC/M	FA8		FA3
		STN. STL.	20.6	832 SCC/M	FA7		FA2
		CARBOLOY	33.2	1240 SCC/M	FA9		FA4
		TANTALUM	35.9	1320 SCC/M	FB1	LIQ. GAS	FA5
	R-2-15-A	GLASS	16.6	.83 SLPM	AA6	AB7 AC3	AA1
		SAPPHIRE	26.3	1.1 SLPM	AA8	AB9 AC4	AA3
		STN. STL.	46.2	1.69 SLPM	AA7	AB8 AC6	AA2
		CARBOLOY	70.8	2.44 SLPM	AA9	AC1 AC5	AA4
		TANTALUM	75.9	2.6 SLPM	AB1	AC2 AC7	AA5
	R-2-15-B	GLASS	52.8	2.37 SLPM	DA6	DB2	DA1
		SAPPHIRE	79.7	3.08 SLPM	DA8	DB4	DA3
		STN. STL.	133	4.7 SLPM	DA7	DB3	DA2
		CARBOLOY	199	6.7 SLPM	DA9	DB5	DA4
		TANTALUM	212	7.1 SLPM	DB1	DB6	DA5
	R-2-15-C	GLASS	84.6	3.9 SLPM	EA6	EB2	EA1
		SAPPHIRE	129	5.1 SLPM	EA8	EB4	EA3
		STN. STL.	218	7.6 SLPM	EA7	EB3	EA2
		CARBOLOY	326	10.6 SLPM	EA9	EB5	EA4
		TANTALUM	349	11.3 SLPM	EB1	EB6	EA5
6	R-6-15-A	GLASS	200	8.7 SLPM	GA6	GB2	GA1
		SAPPHIRE	297	11.2 SLPM	GA8	GB4	GA3
		STN. STL.	493	16.6 SLPM	GA7	GB3	GA2
		CARBOLOY	726	23.2 SLPM	GA9	GB5	GA4
		TANTALUM	772	24.6 SLPM	GB1	GB6	GA5
	R-6-15-B	GLASS	573	23.9 SLPM	HA6	HB2	HA1
		SAPPHIRE	851	30.2 SLPM	HA8	HB4	HA3
		STN. STL.	1350	43.8 SLPM	HA7	HB3	HA2
		CARBOLOY	1950	61.2 SLPM	HA9	HB5	HA4
		TANTALUM	2060	64.7 SLPM	HB1	HB6	HA5

NOTE: ALL AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F.

*** FLOW RATES SHOWN ARE MAXIMUM CAPACITIES**
DIRECT READ SCALES MAY END AT SLIGHTLY DIFFERENT MAXIMUM FLOWS.

Table 6 Ordering Information and Model Code

MODEL	PURGE FLOWMETER
1350E	65 MM TUBE, SIZES 2-6
1355E	150 MM TUBE, SIZES 2-6

CODE	TUBE, SCALE AND FLOAT
___	MODEL 1350 OR 1355 DETACHABLE SCALE - SEE TABLES 3 & 4
___	MODEL 1350 - SEE TABLE 1 OR 2
___	MODEL 1355 - SEE TABLE 5

CODE	TUBE PACKING	O-RING MATERIAL (METER/VALVE ASSEMBLY)
A	BUNA -N	BUNA-N (STD FOR ALUMINUM AND BRASS METERS)
B	VITON	BUNA-N
C	VITON	VITON (STD FOR STN. STL. METERS)
D	VITON	TEFLON/KALREZ (KALREZ O-RINGS IN VALVE OR CONTROLLER)
E	VITON	EPM
F	VITON	KALREZ
G	TEFLON	BUNA-N
H	TEFLON	VITON
J	TEFLON	TEFLON/KALREZ (KALREZ O-RINGS IN VALVE OR CONTROLLER)
K	TEFLON	EPM
L	TEFLON	KALREZ
M	EPM	EPM
N	BUTYL	BUTYL
P	NO PACKING	BUNA-N
Q	NO PACKING	VITON
R	NO PACKING	TEFLON/KALREZ (KALREZ O-RINGS IN VALVE OR CONTROLLER)
S	NO PACKING	EPM
T	NO PACKING	KALREZ
U	NO PACKING	BUTYL

CODE	FITTING AND ADAPTER MATERIAL/PROCESS CONNECTION SIZE AND TYPE
A	BRASS/ 1/8" NPT
D	BRASS/ THD 1/8" NPT WITH LOCKNUTS (STANDARD)
G	BRASS/ 1/4" NPT (STD WITH FLOW CONTROLLER)
L	BRASS/ THD 1/4" NPT WITH LOCKNUTS
P	BRASS/ 1/8" COMPRESSION
S	BRASS/ THD 1/8" COMPRESSION WITH LOCKNUTS
V	BRASS/ 1/4" COMPRESSION
Y	BRASS/ THD 1/4" COMPRESSION WITH LOCKNUTS
2	BRASS/ 1/4" I.D. HOSE
5	BRASS/ NO ADAPTOR-INTEGRAL 5/16-24 THD
E	ALUMINUM/ THD 1/8" NPT WITH LOCKNUTS (STANDARD)
H	ALUMINUM/ 1/4" NPT (STD WITH FLOW CONTROLLER)
6	ALUMINUM/ NO ADAPTOR-INTEGRAL 5/16-24 THD
C	316 STAINLESS STEEL/ 1/8" NPT
F	316 STAINLESS STEEL/ THD 1/8" NPT WITH LOCKNUTS (STANDARD)
J	316 STAINLESS STEEL/ 1/4" NPT (STD WITH FLOW CONTROLLER)
N	316 STAINLESS STEEL/ THD 1/4" NPT WITH LOCKNUTS
R	316 STAINLESS STEEL/ 1/8" COMPRESSION
U	316 STAINLESS STEEL/ THD 1/8 COMPRESSION WITH LOCKNUTS
X	316 STAINLESS STEEL/ 1/4" COMPRESSION
1	316 STAINLESS STEEL/ THD 1/4" COMPRESSION WITH LOCKNUTS
4	316 STAINLESS STEEL/ 1/4" I.D. HOSE
7	316 STAINLESS STEEL/ NO ADAPTER INTEGRAL 5/16-24 THD
8	316 STAINLESS STEEL/ 1/4" VCR
T	316 STAINLESS STEEL/ THD 1/8" Rc WITH LOCKNUTS
W	316 STAINLESS STEEL/ THD 1/4" Rc WITH LOCKNUTS
3	316 STAINLESS STEEL/ THD 3/8" Rc WITH LOCKNUTS

Table 6 Ordering Information and Model Code Continued

CODE	VALVE TYPE
A	VALVE PLUG
B	STANDARD VALVE - BRASS - LOW FLOW
C	STANDARD VALVE - BRASS - MEDIUM FLOW
D	STANDARD VALVE - BRASS - HIGH FLOW
E	STANDARD VALVE - 316 STAINLESS STEEL - LOW FLOW
F	STANDARD VALVE - 316 STAINLESS STEEL - MEDIUM FLOW
G	STANDARD VALVE - 316 STAINLESS STEEL - HIGH FLOW
H	NRS-BRASS #1
J	NRS-BRASS #2
K	NRS-BRASS #3
L	NRS-BRASS #4
M	NRS-BRASS #5
N	NRS-BRASS #6
P	NRS - 316 STAINLESS STEEL #1
Q	NRS - 316 STAINLESS STEEL #2
R	NRS - 316 STAINLESS STEEL #3
S	NRS - 316 STAINLESS STEEL #4
T	NRS - 316 STAINLESS STEEL #5
U	NRS - 316 STAINLESS STEEL #6
V	TO INTEGRALLY MOUNTED FLOW CONTROLLER (NOTE 1 & NOTE 3)
W	STANDARD VALVE CAVITY - NO VALVE ASSEMBLY OR PLUG
X	NO VALVE CAVITY (MUST USE CODE 9 BELOW FOR VALVE CAVITY LOCATION)
1	C-VALVE - 316 STAINLESS STEEL - LOW FLOW - SPECIAL
2	C-VALVE - 316 STAINLESS STEEL - MEDIUM FLOW - SPECIAL
3	C-VALVE - 316 STAINLESS STEEL - HIGH FLOW - SPECIAL

CODE	VALVE CAVITY LOCATION	CONNECTION ORIENTATION	
1	INLET	IN-BACK,	OUT-BACK (STD)
5	OUTLET	IN-BACK,	OUT-BACK (STD)
9	NONE	IN-BACK,	OUT-BACK

CODE	ACCESSORIES - 1,2, OR 3 DIGIT FIELD
A	NONE
B	ALUMINUM FLUSH MOUNTING BEZEL
E	TRIPOD BASE WITHOUT SPIRIT LEVEL (NOTE 2)
J	DEGREASE FOR OXYGEN SERVICE
L	STAINLESS STEEL SIDE PLATES
M	STAINLESS STEEL SPRING FLOAT STOPS
N	CALIBRATE FOR NIST TRACEABILITY (10%, 1350; 5%, 1355)
Q	NO BROOKS IDENTIFICATION

1350E	LC7	C	F	A	1	A	TYPICAL MODEL CODE

NOTES:

1 FLOW CONTROLLERS TO HAVE SEPARATE MODEL CODE AND BE A SECOND LINE ITEM ON ORDER

2 THREADED ADAPTERS AND LOCKNUTS MUST BE SPECIFIED

3 FLOW CONTROLLERS NOT AVAILABLE WITH THREADED ADAPTERS AND LOCKNUTS

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6718 WX Ede, Netherlands
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Installation and Operation Manual
X-VA-1358-eng
Part Number: 541B041AAG
February,2011

Model 1358
Sho-Rate^{TM} "50",
Size 8, Flow Indicator

Model 1358-V
Sho-Rate "50" Meter
with optional Needle
Control Valve

Installation and Operation Manual
X-VA-1358-eng
Part Number: 541B041AAG
February, 2011

Model 1358

Essential Instructions
Read before proceeding!

Brooks Instrument designs, manufactures and tests its products to meet many national and international standards. These products must be properly installed, operated and maintained to ensure they continue to operate within their normal specifications. The following instructions must be adhered to and integrated into your safety program when installing, operating and maintaining Brooks Instrument products.

- To ensure proper performance, use qualified personnel to install, operate, update, program and maintain the product.
- Read all instructions prior to installing, operating and servicing the product. If this instruction manual is not the correct manual, please see back cover for local sales office contact information. Save this instruction manual for future reference.

⚠ **WARNING: Do not operate this instrument in excess of the specifications listed in the Instruction and Operation Manual. Failure to heed this warning can result in serious personal injury and / or damage to the equipment.**

- If you do not understand any of the instructions, contact your Brooks Instrument representative for clarification.
- Follow all warnings, cautions and instructions marked on and supplied with the product.
- Install your equipment as specified in the installation instructions of the appropriate instruction manual and per applicable local and national codes. Connect all products to the proper electrical and pressure sources.
- Operation: (1) Slowly initiate flow into the system. Open process valves slowly to avoid flow surges. (2) Check for leaks around the flow meter inlet and outlet connections. If no leaks are present, bring the system up to the operating pressure.
- Please make sure that the process line pressure is removed prior to service. When replacement parts are required, ensure that qualified people use replacement parts specified by Brooks Instrument. Unauthorized parts and procedures can affect the product's performance and place the safe operation of your process at risk. Look-alike substitutions may result in fire, electrical hazards or improper operation.
- Ensure that all equipment doors are closed and protective covers are in place to prevent electrical shock and personal injury, except when maintenance is being performed by qualified persons.

⚠ **WARNING: For liquid flow devices, if the inlet and outlet valves adjacent to the devices are to be closed for any reason, the devices must be completely drained. Failure to do so may result in thermal expansion of the liquid that can rupture the device and may cause personal injury.**

European Pressure Equipment Directive (PED)

All pressure equipment with an internal pressure greater than 0.5 bar (g) and a size larger than 25mm or 1" (inch) falls under the Pressure Equipment Directive (PED).

- The Specifications Section of this manual contains instructions related to the PED directive.
- Meters described in this manual are in compliance with EN directive 97/23/EC.
- All Brooks Instrument Flowmeters fall under fluid group 1.
- Meters larger than 25mm or 1" (inch) are in compliance with PED category I, II or III.
- Meters of 25mm or 1" (inch) or smaller are Sound Engineering Practice (SEP).

European Electromagnetic Compatibility (EMC)

The Brooks Instrument (electric/electronic) equipment bearing the CE mark has been successfully tested to the regulations of the Electro Magnetic Compatibility (2004/108/EC (EMC directive 89/336/EEC)).
Special attention however is required when selecting the signal cable to be used with CE marked equipment.
Quality of the signal cable, cable glands and connectors:
Brooks Instrument supplies high quality cable(s) which meets the specifications for CE certification.
If you provide your own signal cable you should use a cable which is overall completely screened with a 100% shield.
“D” or “Circular” type connectors used should be shielded with a metal shield. If applicable, metal cable glands must be used providing cable screen clamping.
The cable screen should be connected to the metal shell or gland and shielded at both ends over 360 Degrees.
The shield should be terminated to an earth ground.
Card Edge Connectors are standard non-metallic. The cables used must be screened with 100% shield to comply with CE certification.
The shield should be terminated to an earth ground.
For pin configuration : Please refer to the enclosed Instruction Manual.

ESD (Electrostatic Discharge)

⚠ **CAUTION: This instrument contains electronic components that are susceptible to damage by static electricity. Proper handling procedures must be observed during the removal, installation or other handling of internal circuit boards or devices.**

Handling Procedure:

1. Power to unit must be removed.
2. Personnel must be grounded, via a wrist strap or other safe, suitable means before any printed circuit card or other internal device is installed, removed or adjusted.
3. Printed circuit cards must be transported in a conductive container. Boards must not be removed from protective enclosure until immediately before installation. Removed boards must immediately be placed in protective container for transport, storage or return to factory.

Comments

This instrument is not unique in its content of ESD (electrostatic discharge) sensitive components. Most modern electronic designs contain components that utilize metal oxide technology (NMOS, SMOS, etc.). Experience has proven that even small amounts of static electricity can damage or destroy these devices. Damaged components, even though they appear to function properly, exhibit early failure.

Installation and Operation Manual
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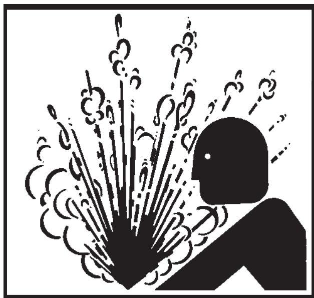
Model 1358



⚠ WARNING

GLASS TUBE EXPLOSION HAZARD

Plastic protective sleeve must remain over glass tube.

Fasten meter windows securely.

Do not operate above pressure and temperature limits.

Avoid pressure and flow surges.

Do not service or repair while pressurized.

Read and understand instruction manual.

Failure to comply could result in serious personal injury or property damage.

⚠ WARNING

GLASS TUBE EXPLOSION HAZARD

Protective sleeve must remain over glass tube.
Fasten meter windows securely.
Failure to comply could result in serious personal injury or property damage.

Dear Customer,

We appreciate this opportunity to service your flow measurement and control requirements with a Brooks Instrument device. Every day, flow customers all over the world turn to Brooks Instrument for solutions to their gas and liquid low-flow applications. Brooks provides an array of flow measurement and control products for various industries from biopharmaceuticals, oil and gas, fuel cell research and chemicals, to medical devices, analytical instrumentation, semiconductor manufacturing, and more.

The Brooks product you have just received is of the highest quality available, offering superior performance, reliability and value to the user. It is designed with the ever changing process conditions, accuracy requirements and hostile process environments in mind to provide you with a lifetime of dependable service.

We recommend that you read this manual in its entirety. Should you require any additional information concerning Brooks products and services, please contact your local Brooks Sales and Service Office listed on the back cover of this manual or visit www.BrooksInstrument.com

Yours sincerely,
Brooks Instrument

Contents

Model 1358

Figures

Tables

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1-1 Description

The Brooks® Sho-Rate "50" Series of low flow indicators provides a cost-effective means of flow indication where the accuracy requirements are not severe. Available options include an integral needle control valve as well as flow controllers piped to the inlet or outlet of the meter.

1-2 Design Features

- Ten-to-one rangeability
- Heavy-wall, precision bore borosilicate glass metering tube
- A wide range of scales on the metering tube
- Tube removable without disconnecting the instrument
- Interchangeable tubes and floats
- Piping connections rotatable through 360° at 90° intervals
- Easily panel mounted

1-3 Specifications

⚠ WARNING

Do not operate this instrument in excess of the specifications listed below. Failure to heed this warning can result in serious personal injury and/or damage to the equipment.

⚠ WARNING

Glass metering tubes are designed for operation up to the maximum operating pressures and temperatures as specified herein. Due to the inherent brittle characteristics of glass and conditions beyond our control, tube breakage could result even within specified operating conditions. Do not use glass tube meters with fluids that are toxic, or chemically react with glass such as water above 140°F, steam, alkalis, flourine, hydrofluoric acid, or molten metal. Failure to heed warning can result in serious personal injury and/or damage to the equipment.

Pressure Ratings
200 psig (1,378 kPa) at temperatures up to 250°F (121°C). Fluid temperatures below 32°F (0°C) will cause frosting of the glass metering tube. Consult factory for applications below this temperature.

Pressure Equipment Directive (PED) 97/23/EC:
Flowmeters mentioned in this instruction manual are Sound Engineering Practice (SEP).

Scales

Type (Standard): Fused on meter tube
Length: 75 mm, nominal
Graduations:
  Standard: direct read on tube in gpm water or scfm air.
  Optional: special direct read decal on tube. Consult factory for available ranges. Direct read on metal scale plate mounted beside tube.

Capacities and Pressure Drops

Refer to Table 1-1

Standard accuracy:

±10% of full scale from 100% to 10% of scale reading.

Repeatability

0.5% full scale

Rangeability

Ten to one

Table 1-1 Capacities

	Maximum Flow Rate		
Water (gpm)	**Pressure Drop Without Valve Inches W.C.**	**Pressure Drop With Valve Inches W. C.**	**Float**
0.8	12.6	13.6	8-RV-8
1.5	22.2	27.0	8-RJ-10
2.5	61.0	85.2	8-RJ-23
3.5	88.7	121.0	8-RJ-30
5.0	172	238.0	8-RJ-39
Air (scfm)	**Pressure Drop Without Valve Inches W.C.**	**Pressure Drop With Valve Inches W.C.**	**Float**
3.4	14.34	15.5	8-RV-8
6.0	25.34	30.8	8-RJ-10
12.0	69.34	97.3	8-RJ-23
15.0	101.34	138.3	8-RJ-30

NOTE: All air flows are at 14.7 psia and 70°F.

Connections

Standard: Horizontal female 3/8" NPT threaded adaptors.
Optional: Horizontal female 3/8" NPT threaded adaptors with locknut for front of panel mounting.

Dimensions

See Figure 1-1

Materials of Construction:

Metering Tube

Borosilicate glass

Protective Tube Sleeve
UV stabilized polycarbonate

⚠ WARNING

GLASS TUBE EXPLOSION HAZARD

Plastic protective sleeve must remain over glass tube. (Meter sizes 7 -13 only)
Fasten meter windows securely.
Do not operate above pressure and temperature limits.
Avoid pressure and flow surges.
Do not service or repair while pressurized.
Read and understand instruction manual.
Failure to comply could result in serious personal injury or property damage.

Float
316 stainless steel

End Fittings
Chrome plated brass or 316 stainless steel

Side Plates
Standard: Black anodized aluminum
Optional: 316 stainless steel

Window
Scratch resistant, UV stabilized polycarbonate

⚠WARNING

GLASS TUBE EXPLOSION HAZARD

Protective sleeve must remain over glass tube. Fasten meter windows securely. Failure to comply could result in serious personal injury or property damage.

Back Cover
Milk white polycarbonate

Float Stops
Stainless steel

Tube Packing
Standard: Neoprene® (Brass meters), Viton-A® fluoroelastomers (316 stainless steel meters).
Optional: Teflon®, EPM

O-rings
Standard: Buna-N (Brass meters), Viton-A
Optional: (316 stainless steel meters): EPM, Kalrez®

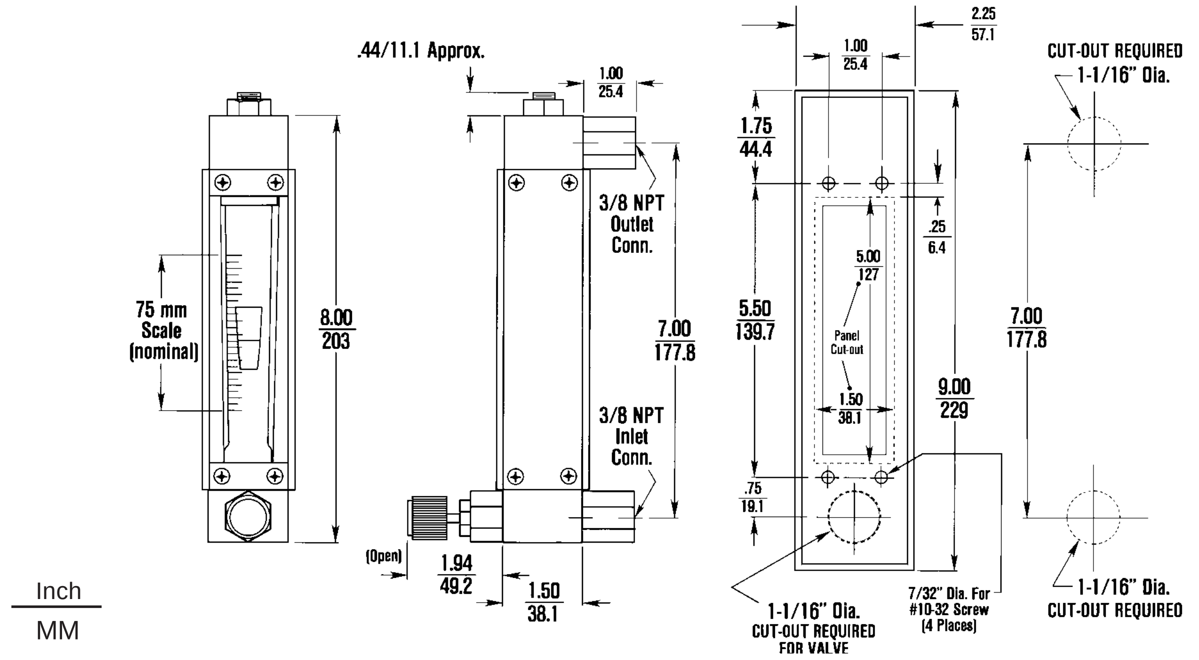

Figure 1-1 Model 1358 Dimensions

1-4 Optional Equipment

Mounting
Flush panel mounting bezel
Front of panel mounting locknuts

Standard Needle Valve
The standard needle valve can be supplied integrally mounted or externally piped to the inlet or outlet of the instrument.

Flow Contollers
Flow controllers can be supplied integrally mounted or externally piped to the inlet or outlet of the instrument. For the flow controller's complete instruction manual go to our website: **BrooksInstrument.com**, select Documentation, Precision Valves & Flow Controllers, select FC8800, or FC8900.

2-1 Receipt of Equipment

When the instrument is received, the outside packing case should be checked for damage incurred during shipment. If the packing case is damaged, the local carrier should be notified at once regarding his liability. A report should be submitted to your nearest Product Service Department.

Brooks Instrument
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Tokyo, 136-0073 Japan
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Fax +81 (0) 3 5633 7101
Email: BrooksAs@BrooksInstrument.com

Remove the envelope containing the packing list. Carefully remove the instrument from the packing case. Make sure spare parts are not discarded with the packing materials. Inspect for damaged or missing parts.

2-2 Recommended Storage Practice

If intermediate or long-term storage of equipment is required, it is recommended that the equipment be stored in accordance with the following:

a. Within the original shipping container.

b. Stored in a sheltered area, preferably a warm, dry, heated warehouse.

c. Ambient temperature of 70° F (21° C) nominal, 109° F (43° C) maximum, 45° F (7° C) minimum.

d. Relative humidity 45% nominal, 60% maximum, 25% minimum.

Upon removal from storage a visual inspection should be conducted to verify the condition of equipment is "as received".

2-3 Return Shipment

Prior to returning any instrument to the factory, contact your nearest Brooks location for a Return Materials Authorization Number (RMA#). This can be obtained from one of the following locations:

Brooks Instrument
407 W. Vine Street
P.O. Box 903
Hatfield, PA 19440 USA
Toll Free (888) 554 FLOW (3569)
Tel (215) 362 3700
Fax (215) 362 3745
E-mail: BrooksAm@BrooksInstrument.com
www.BrooksInstrument.com

Brooks Instrument
Neonstraat 3
6718 WX Ede, Netherlands
P.O. Box 428
6710 BK Ede, Netherlands
Tel +31 (0) 318 549 300
Fax +31 (0) 318 549 309
E-mail: BrooksEu@BrooksInstrument.com

Brooks Instrument
1-4-4 Kitasuna Koto-Ku
Tokyo, 136-0073 Japan
Tel +81 (0) 3 5633 7100
Fax +81 (0) 3 5633 7101
Email: BrooksAs@BrooksInstrument.com

Any instrument returned to Brooks requires completion of Form RPR003-1, Brooks Instrument Decontamination Statement, as well as, a Material Safety Data Sheet (MSDS) for the fluid(s) used in the instrument. This is required before any Brooks Personnel can begin processing. Copies of the form can be obtained from any Brooks Instrument location listed above.

2-4 Transit Precautions

To safeguard against damage during transit, transport the instrument to the installation site in the same container used for transportation from the factory if circumstances permit.

2-5 Installation

A. Location
For proper operation the Model 1358 must be mounted within 6 degrees of true vertical. The inlet connection to the flowmeter is in the bottom end fitting. The connections are normally horizontal female NPT. The use of a level is recommended to assure vertical positioning. Piping must be adequately supported to prevent undue strain on the flowmeter.

B. Piping Arrangement
It is recommended that bypass piping be installed around the flowmeter so it may be isolated from the process line for servicing and cleaning. Refer to Figure 2-1 for a typical installation.

⚠ CAUTION

Do not allow the float to fall out of the metering tube. A damaged Float will affect the accuracy of the meter. Be careful not to break the tube by pulling on it at an extreme angle or applying excessive force.

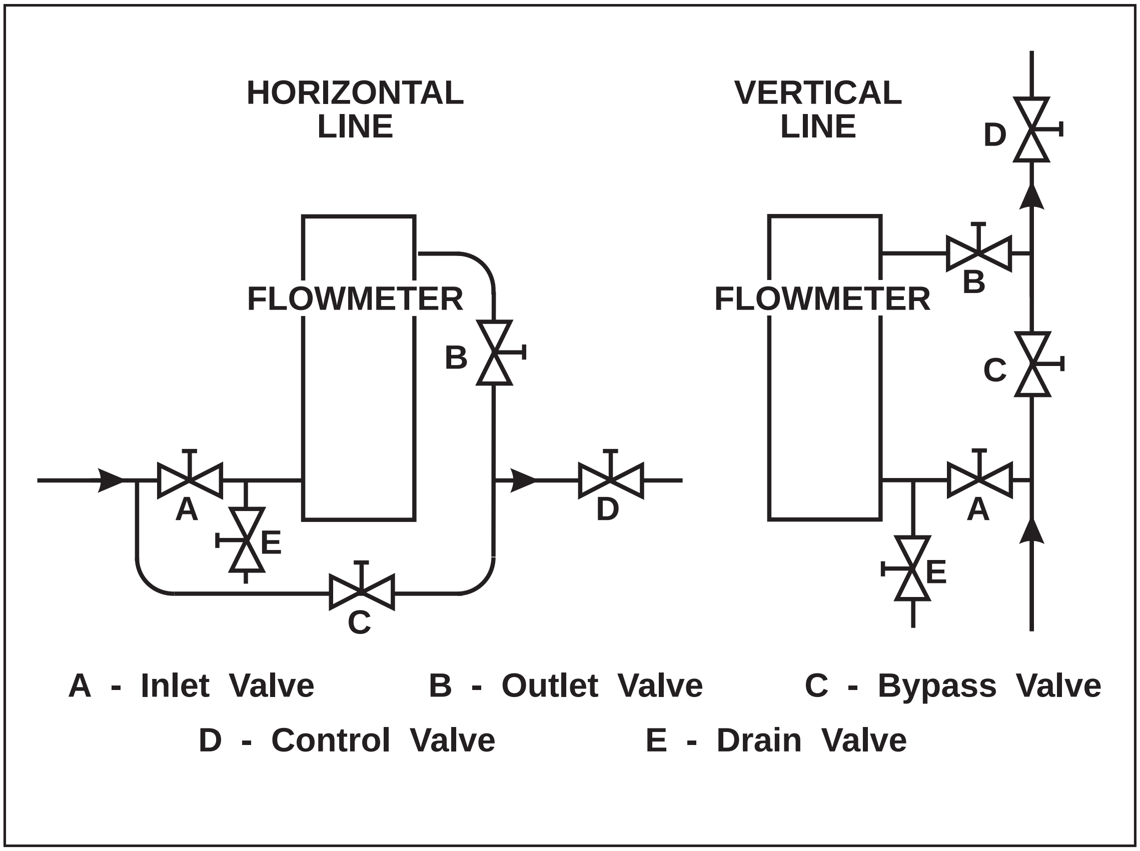
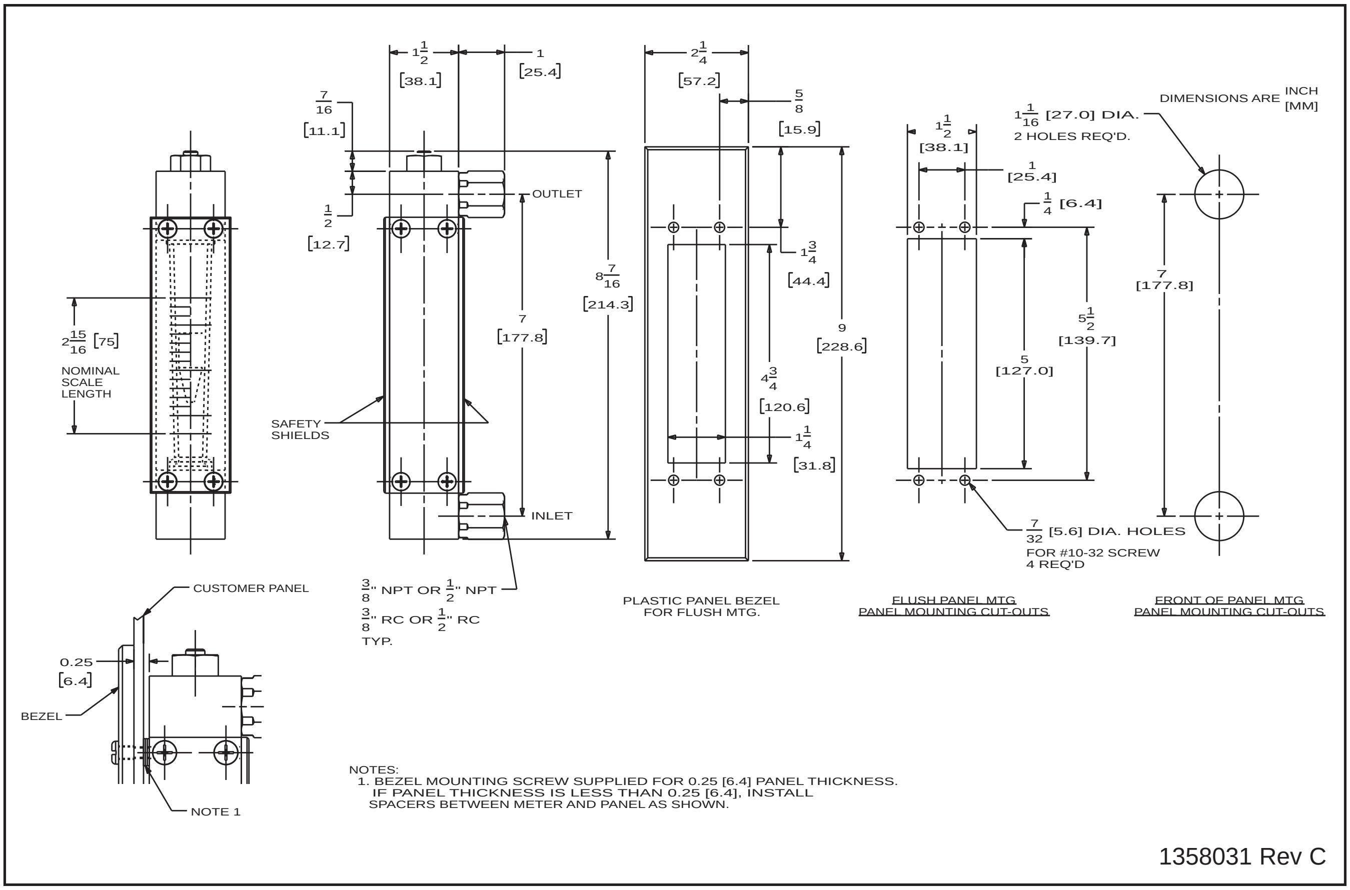


Figure 2-1 Typical Bypass Installation

⚠ WARNING

If the inlet and outlet valves adjacent to the flowmeter are to be closed for any reason, the flowmeter must be completely drained. Failure to do so may result in thermal expansion of the liquid which can cause rupture of the meter and possible personal injury.



NOTES:
1. BEZEL MOUNTING SCREW SUPPLIED FOR 0.25 [6.4] PANEL THICKNESS. IF PANEL THICKNESS IS LESS THAN 0.25 [6.4], INSTALL SPACERS BETWEEN METER AND PANEL AS SHOWN.

Figure 2-2 Front Panel Mounting

3-1 Operating Instructions

After the flowmeter has been properly installed in the system, it is ready for operation.

⚠ WARNING

GLASS TUBE EXPLOSION HAZARD

Plastic protective sleeve must remain over glass tube. (Meter sizes 7 -13 only)
Fasten meter windows securely.
Do not operate above pressure and temperature limits.
Avoid pressure and flow surges.
Do not service or repair while pressurized.
Read and understand instruction manual.
Failure to comply could result in serious personal injury or property damage.

To initiate flow through a flowmeter using bypass piping, refer to Figure 3-1.

1. Close flowmeter isolation valves (A) and (B).
2. Fully open bypass valve (C) and slightly open control valve (D).
3. Initiate process flow. When flow has stabilized, fully open isolation valve (B), then slowly open isolation valve (A) fully.
4. Close bypass valve (C).
5. Regulate process flow using control valve (D).
6. If meter is left in bypass configuration, open drain valve (E) to prevent tube damage caused by thermal expansion of the process liquid.

⚠ WARNING

If the inlet and outlet valves adjacent to the flowmeter are to be closed for any reason, the flowmeter must be completely drained. Failure to do so may result in thermal expansion of the liquid which can cause rupture of the meter and possible personal injury.

⚠ WARNING

GLASS TUBE EXPLOSION HAZARD

Protective sleeve must remain over glass tube. Fasten meter windows securely. Failure to comply could result in serious personal injury or property damage.

Rate of flow is indicated by reading the increments inscribed on the metering tube or direct etched scale parallel with the metering edge of the float. For the correct reading edge of the float, refer to Figure 3-2.

⚠ CAUTION

A built-in needle control valve may be provided to control the flow through the flowmeter. These control valves are designed for fine control. Excessive tightening may damage the valve seat and limit its effectiveness as a control valve. If tight shut-off is required, it is recommended that a separate shut-off valve be installed in the line immediately before the flowmeter.

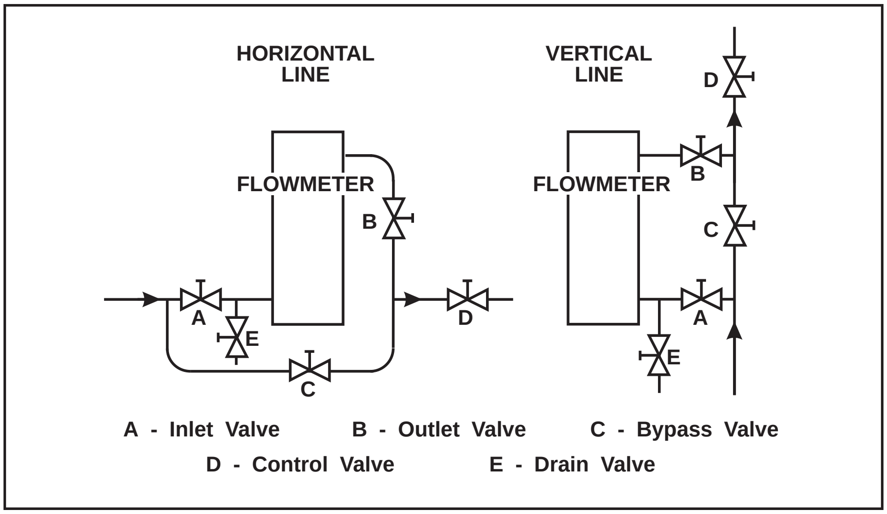


Figure 3-1 Typical Bypass Installation

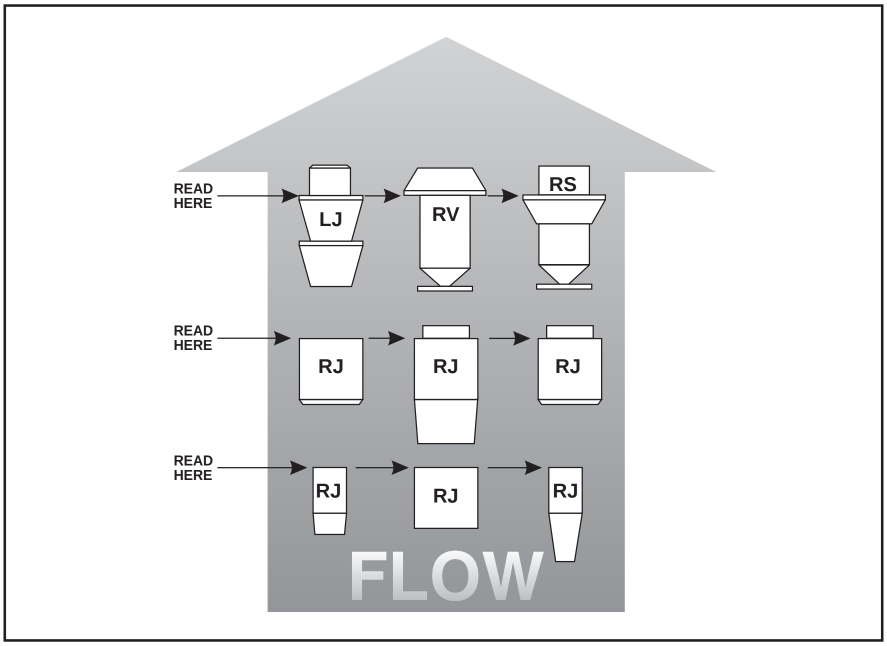


Figure 3-2 Reading Edge of floats

4-1 General

⚠ WARNING

METER/CONTROLLER SEAL COMPATIBILITY

Products in this manual may contain metal or elastomeric seals, gaskets, O-rings or valve seats. It is the "user's" responsibility to select materials that are compatible with their process and process conditions. Using materials that are not compatible with the process or process conditions could result in the Meter or Controller leaking process fluid outside the pressure boundary of the device, resulting in personnel injury or death.

It is recommended that the user check the Meter or Controller on a regular schedule to ensure that it is leak free as both metal and elastomeric seals, gaskets, O-rings and valve seats may change with age, exposure to process fluid, temperature, and /or pressure.

Model 1358 flowmeters require little maintenance except routine cleaning. It is necessary to remove the flowmeter from the line for tube and float cleaning. The tube and float may be cleaned with a soft absorbent swab. To disassemble the flowmeter proceed as follows:

a. Remove the front and rear window shields.
b. Loosen the seal spindle or jack screw by turning it counterclockwise with a 5/32" hex wrench.
c. The tube may now be canted out of the meter housing.
d. Remove the polycarbonate sleeve surrounding the flow tube.
e. Remove the float and float stops from the tube.

⚠ CAUTION

Do not allow the float to fall out of the metering tube. A damaged float will affect the accuracy of the meter. Be careful not to break the tube by pulling on it at an extreme angle or applying excessive force.

f. Using a suitable solvent, carefully swab and flush the inside of the metering tube. Clean the float and blow dry all parts thoroughly.
g. The packing seats may now be removed. It is recommended that the packing be replaced each time the meter is serviced.

h. With the metering tube out, the seal spindle or jack screw may be rotated clockwise for removal. It should not be necessary to remove the seal spindle unless the O-ring which seals the spindle requires replacement. The O-ring may be used as long as it is not torn or distorted.

i. The needle control valve assembly may be removed by turning the valve body counterclockwise. The valve seat, stem and packing then may be removed easily from the valve body for cleaning or replacement.

Reassemble the flowmeter as follows:

a. Use the reverse of Steps a through e of the disassembly procedure to reassemble the meter.

b. Prior to installing the needle control valve assembly make certain that the valve stem is turned completely counterclockwise (fully open position) to prevent damage to the valve seat.

⚠ WARNING

Pressure test the meter before returning it to service. Hydrostatic pressure testing should be performed by qualified personnel or serious injury and/or damage to the equipment can result.

5-1 General

When ordering parts please specify:
Brooks Serial Number, Model Number, Part Number, Description and Quantity. Refer to Figures 5-1 and Tables 5-1.

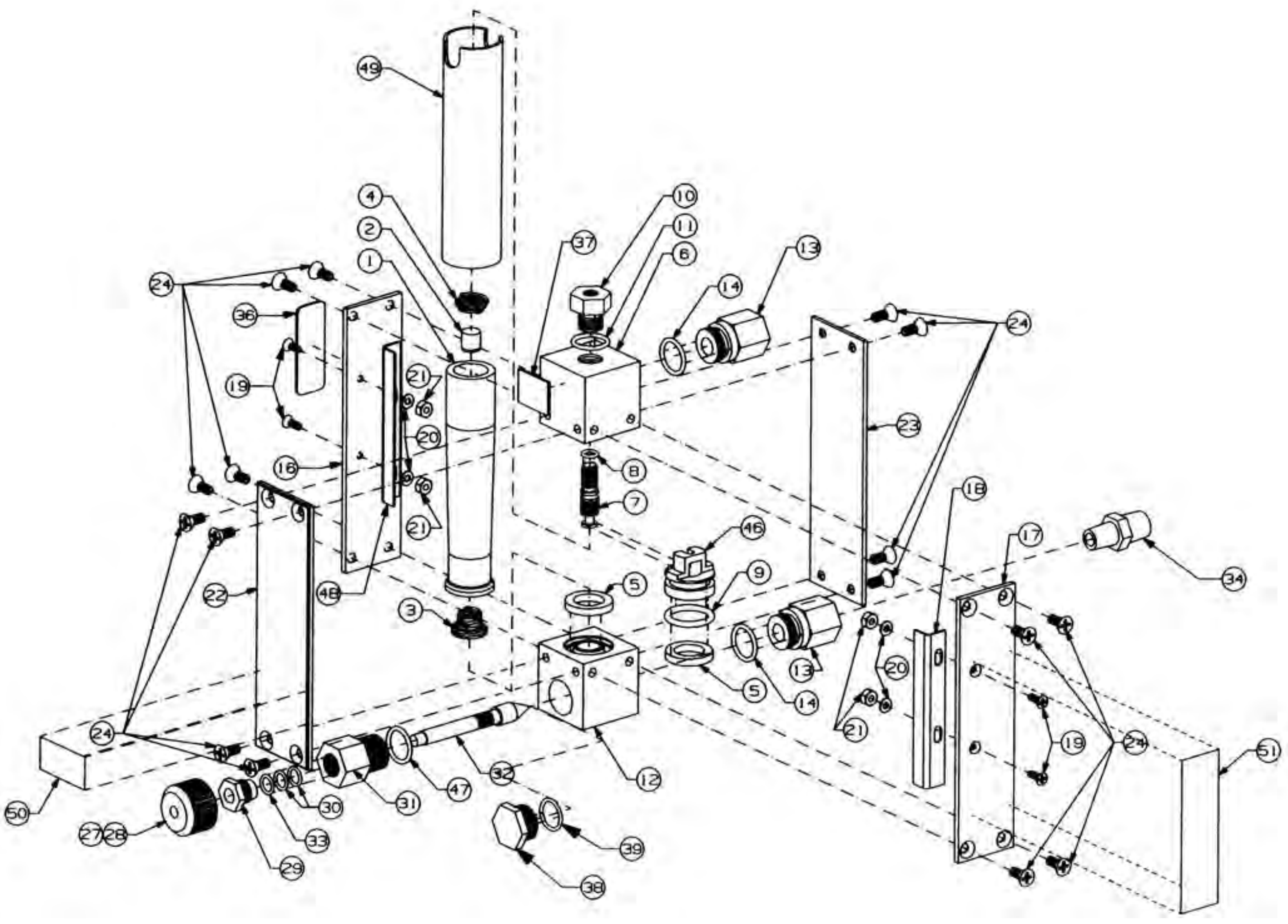


Figure 5-1 Exploded View, Size 8 Model 1358 Brooks Sho-Rate

Table 5-1 Model 1358 Parts List

REF NO	QTY	DESCRIPTION	PART NO
1	1	GLASS METERING TUBE	PER S/N
2	1	316 S.S. FLOAT	
		8-RV-8	S346B148BMA
		8-RJ-10	349D078BMA
		8-RJ-23	349D080BMA
		8-RJ-30	349D077BMA
		8-RJ-39	349D076BMA
3	1	INLET FLOAT STOP	
		SPRING FLOAT STOP 0.8, 3.5 & 5 GPM	820B253BMA
		SPRING FLOAT STOP 1.5 & 2.5 GPM	820B254BMA
4	1	OUTLET FLOAT STOP	
		SPRING FLOAT STOP 0.8, 3.5 & 5 GPM	820B253BMA
		SPRING FLOAT STOP 1.5 & 2.5 GPM	820B254BMA
5	2	TUBE SEAL PACKING	
		VITON	589B043QTA
		EPM	589B043SYA
		NEOPRENE	589B043TDA
		TEFLON	589B241QMA
6	1	SEAL END FITTING	
		316 SS	325G001BMF
		BRASS	325G001GGL
7	1	SEAL SPINDLE	
		316 SS	817A055BMA
		BRASS	817A055GGJ
8	1	SEAL SPINDLE O-RING	
		VITON	375B010QTA
		BUNA-N	375B010SUA
		EPM	375B010SYA
		KALREZ	375B010TTA
9	1	SEAL PLUG O-RING	
		VITON	375B211QTA
		BUNA-N	375B211SUA
		EPM	375B211SYA
		KALREZ	375B211TTA
10	1	JACKSCREW PLUG	
		316 SS	618J005BMA
		BRASS	618J005GGJ
11	1	JACKSCREW PLUG O-RING	
		VITON	375B905QTA
		BUNA-N	375B905SUA
		EPM	375B905SYA
		KALREZ	375B905TTA
12	1	VALVE END FITTING	
		W/VALVE: 316 SS	325H002BMF
		W/VALVE: BRASS	325H002GGL
		W/VALVE, FOR BASEPLATE: 316 SS	325H064BMF
		W/VALVE, FOR BASEPLATE: BRASS	325H064GGL
		NO VALVE: 316 SS	325J006BMF
		NO VALVE: BRASS	325J006GGL

Table 5-1 Model 1358 Parts List (Continued)

13	2	ADAPTER	
		3/8" NPT ADAPTER, NO LOCKNUT: 316 SS	014C023BMA
		3/8" NPT ADAPTER, NO LOCKNUT: BRASS	014C023GGJ
		3/8" NPT ADAPTER, FOR LOCKNUT: 316 SS	014C034BMA
		3/8" NPT ADAPTER, FOR LOCKNUT: BRASS	014C034GGJ
		1/2" NPT ADAPTER, NO LOCKNUT: 316 SS	014C028BME
		1/2" NPT ADAPTER, NO LOCKNUT: BRASS	014C028GGJ
14	2	ADAPTER O-RING	
		VITON	375B908QTA
		BUNA-N	375B908SUA
		EPM	375B908SYA
		KALREZ	375B908TTA
15	2	LOCKNUT FOR FRONT OF PANEL MOUNTING	573B018AC0
16	1	LEFT SIDE PLATE	
		SS SIDE PLATE	614A008BMF
		ALUMINUM SIDE PLATE	614A008FBJ
		SS SIDE PLATE FOR LEFT DET. SCALE	614A175BMF
		ALUMINUM SIDE PLATE FOR LEFT DET. SCALE	614A175FBJ
17	1	RIGHT SIDE PLATE	
		SS SIDE PLATE	614A008BMF
		ALUMINUM SIDE PLATE	614A008FBJ
		SS SIDE PLATE FOR RIGHT DET. SCALE	614A174BMF
		ALUMINUM SIDE PLATE FOR RIGHT DET. SCALE	614A174FBJ
18	1	RIGHT DETACHABLE SCALE	PER S/N
19	2	SCALE SCREW	753L267CEA
20	2	SCALE WASHER	962A006AWA
21	2	SCALE NUT	573D012AWA
22	1	FRONT WINDOW	794A012NZ%
23	1	BACK WINDOW	615A012PBA
24	16	SCREWS-SIDE PLATES & WINDOWS	753L424AWA
25	1	PLASTIC BEZEL	
		BEZEL, W/VALVE	075B013NZD
		BEZEL, NO VALVE	075B025NZD
26	4	BEZEL MOUNTING SCREW	753A429AWA
27	1	VALVE KNOB	498C080NCQ
28	1	VALVE KNOB COVER	219Z237NCQ
29	1	VALVE PACKING NUT	573R012GGJ
30	2	VALVE O-RING	
		VITON	375B011QTA
		BUNA-N	375B011SUA
		EPM	375B011SYA
		KALREZ	375B011TTA

Table 5-1 Model 1358 Parts List (Continued)

31	1	VALVE BONNET	
		316 SS	950Z067BMA
		BRASS	950Z067GGJ
32	1	VALVE STEM	949Z198BMA
33	1	VALVE BACKING O-RING	375B011QMA
34	1	REDUCING BUSHING	
		3/8" NPT TO 1/4" NPT, SS	014B231BMA
		3/8" NPT TO 1/4" NPT, BRASS	014B231GGA
		3/8" NPT TO 3/4" NPT, SS	014B234BMA
36	1	WARNING LABEL	502Z969MYA
37	1	LOGO LABEL	502C329AAA
38	1	VALVE PLUG	618Q005BMA
39	1	VALVE PLUG O-RING	
		VITON	375B908QTA
		BUNA-N	375B908SUA
		EPM	375B908SYA
		KALREZ	375B908TTA
40	1	TRIANGULAR BASE PLATE	594B064NQA
41	1	SPIRIT LEVEL FOR BASEPLATE	515B011AAA
42	3	THUMB SCREW FOR BASEPLATE	753H404GGL
43	1	STANDOFF FOR BASEPLATE	830Z001GGH
44	1	SCREW FOR BASEPLATE	751E510AWA
45	2	SNAP PLUG FOR BASEPLATE	620Z172AAA
46	1	SEAL PLUG	
		316 SS	618Z021BMA
		BRASS	618Z021GGJ
47	1	VALVE BONNET O-RING	
		VITON	375B908QTA
		BUNA-N	375B908SUA
		EPM	375B908SYA
		KALREZ	375B908TTA
48	1	LEFT DETACHABLE SCALE	PER S/N
49	1	PROTECTIVE PLASTIC SLEEVE	794Z133NZA
REF NO	**QTY.**	**LABEL**	
50	1	WARNING LABEL	502Y449MYA
51	1	WARNING LABEL	502Y445MYA

LIMITED WARRANTY

Seller warrants that the Goods manufactured by Seller will be free from defects in materials or workmanship under normal use and service and that the Software will execute the programming instructions provided by Seller until the expiration of the earlier of twelve (12) months from the date of initial installation or eighteen (18) months from the date of shipment by Seller. Products purchased by Seller from a third party for resale to Buyer ("Resale Products") shall carry only the warranty extended by the original manufacturer.

All replacements or repairs necessitated by inadequate preventive maintenance, or by normal wear and usage, or by fault of Buyer, or by unsuitable power sources or by attack or deterioration under unsuitable environmental conditions, or by abuse, accident, alteration, misuse, improper installation, modification, repair, storage or handling, or any other cause not the fault of Seller are not covered by this limited warranty, and shall be at Buyer's expense.

Goods repaired and parts replaced during the warranty period shall be in warranty for the remainder of the original warranty period or ninety (90) days, whichever is longer. This limited warranty is the only warranty made by Seller and can be amended only in a writing signed by an authorized representative of Seller.

BROOKS SERVICE AND SUPPORT

Brooks is committed to assuring all of our customers receive the ideal flow solution for their application, along with outstanding service and support to back it up. We operate first class repair facilities located around the world to provide rapid response and support. Each location utilizes primary standard calibration equipment to ensure accuracy and reliability for repairs and recalibration and is certified by our local Weights and Measures Authorities and traceable to the relevant International Standards.

Visit www.BrooksInstrument.com to locate the service location nearest to you.

START-UP SERVICE AND IN-SITU CALIBRATION

Brooks Instrument can provide start-up service prior to operation when required.

For some process applications, where ISO-9001 Quality Certification is important, it is mandatory to verify and/or (re)calibrate the products periodically. In many cases this service can be provided under in-situ conditions, and the results will be traceable to the relevant international quality standards.

CUSTOMER SEMINARS AND TRAINING

Brooks Instrument can provide customer seminars and dedicated training to engineers, end users and maintenance persons.

Please contact your nearest sales representative for more details.

HELP DESK

In case you need technical assistance:

Americas	☎ 1 888 554 FLOW
Europe	☎ +31 (0) 318 549 290
Asia	☎ +81 (0) 3 5633 7100

Due to Brooks Instrument's commitment to continuous improvement of our products, all specifications are subject to change without notice.

TRADEMARKS

Brooks	Brooks Instrument, LLC
Kalrez	DuPont Performance Elastomers
Neoprene	E.I. DuPont de Nemours & Co.
Sho-Rate	Brooks Instrument, LLC
Teflon	E.I. DuPont de Nemours & Co.
Viton-A	DuPont Performance Elastomers

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Installation and Operation Manual
X-VA-1350E-eng
Part Number: 541B082AAG
April, 2011

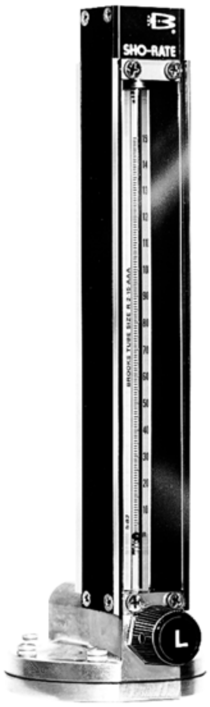
Sho-Rate™ "50" Model 1350E and Sho-Rate™ "150" Model 1355E Sizes 2-6 Flowmeters

Model 1350E
Sho-Rate "50"
(no valve)

Model 1350E
Sho-Rate "50"
With optional Integral
flow controller

Model 1350E
Sho-Rate "50"
With optional
needle valve

Model 1355E
Sho-Rate "150"
(no valve)



Model 1355E
Sho-Rate "150"
With optional Integral
flow controller

Model 1355E
Sho-Rate "150"
With optional
needle valve

www.BrooksInstrument.com

BROOKS®
INSTRUMENT

Installation and Operation Manual
X-VA-1350E-eng
Part Number: 541B082AAG
April, 2011

Models 1350E and 1355E

Essential Instructions
Read before proceeding!

Brooks Instrument designs, manufactures and tests its products to meet many national and international standards. These products must be properly installed, operated and maintained to ensure they continue to operate within their normal specifications. The following instructions must be adhered to and integrated into your safety program when installing, operating and maintaining Brooks Instrument products.

- To ensure proper performance, use qualified personnel to install, operate, update, program and maintain the product.
- Read all instructions prior to installing, operating and servicing the product. If this instruction manual is not the correct manual, please see back cover for local sales office contact information. Save this instruction manual for future reference.

⚠ **WARNING: Do not operate this instrument in excess of the specifications listed in the Instruction and Operation Manual. Failure to heed this warning can result in serious personal injury and / or damage to the equipment.**

- If you do not understand any of the instructions, contact your Brooks Instrument representative for clarification.
- Follow all warnings, cautions and instructions marked on and supplied with the product.
- Install your equipment as specified in the installation instructions of the appropriate instruction manual and per applicable local and national codes. Connect all products to the proper electrical and pressure sources.
- Operation: (1) Slowly initiate flow into the system. Open process valves slowly to avoid flow surges. (2) Check for leaks around the flow meter inlet and outlet connections. If no leaks are present, bring the system up to the operating pressure.
- Please make sure that the process line pressure is removed prior to service. When replacement parts are required, ensure that qualified people use replacement parts specified by Brooks Instrument. Unauthorized parts and procedures can affect the product's performance and place the safe operation of your process at risk. Look-alike substitutions may result in fire, electrical hazards or improper operation.
- Ensure that all equipment doors are closed and protective covers are in place to prevent electrical shock and personal injury, except when maintenance is being performed by qualified persons.

⚠ **WARNING: For liquid flow devices, if the inlet and outlet valves adjacent to the devices are to be closed for any reason, the devices must be completely drained. Failure to do so may result in thermal expansion of the liquid that can rupture the device and may cause personal injury.**

European Pressure Equipment Directive (PED)

All pressure equipment with an internal pressure greater than 0.5 bar (g) and a size larger than 25mm or 1" (inch) falls under the Pressure Equipment Directive (PED).

- The Specifications Section of this manual contains instructions related to the PED directive.
- Meters described in this manual are in compliance with EN directive 97/23/EC.
- All Brooks Instrument Flowmeters fall under fluid group 1.
- Meters larger than 25mm or 1" (inch) are in compliance with PED category I, II or III.
- Meters of 25mm or 1" (inch) or smaller are Sound Engineering Practice (SEP).

European Electromagnetic Compatibility (EMC)

The Brooks Instrument (electric/electronic) equipment bearing the CE mark has been successfully tested to the regulations of the Electro Magnetic Compatibility (2004/108/EC (EMC directive 89/336/EEC)).

Special attention however is required when selecting the signal cable to be used with CE marked equipment.

Quality of the signal cable, cable glands and connectors:

Brooks Instrument supplies high quality cable(s) which meets the specifications for CE certification.

If you provide your own signal cable you should use a cable which is overall completely screened with a 100% shield.

“D” or “Circular” type connectors used should be shielded with a metal shield. If applicable, metal cable glands must be used providing cable screen clamping.

The cable screen should be connected to the metal shell or gland and shielded at both ends over 360 Degrees.

The shield should be terminated to an earth ground.

Card Edge Connectors are standard non-metallic. The cables used must be screened with 100% shield to comply with CE certification.

The shield should be terminated to an earth ground.

For pin configuration : Please refer to the enclosed Instruction Manual.

ESD (Electrostatic Discharge)

⚠ **CAUTION: This instrument contains electronic components that are susceptible to damage by static electricity. Proper handling procedures must be observed during the removal, installation or other handling of internal circuit boards or devices.**

Handling Procedure:

1. Power to unit must be removed.
2. Personnel must be grounded, via a wrist strap or other safe, suitable means before any printed circuit card or other internal device is installed, removed or adjusted.
3. Printed circuit cards must be transported in a conductive container. Boards must not be removed from protective enclosure until immediately before installation. Removed boards must immediately be placed in protective container for transport, storage or return to factory.

Comments

This instrument is not unique in its content of ESD (electrostatic discharge) sensitive components. Most modern electronic designs contain components that utilize metal oxide technology (NMOS, SMOS, etc.). Experience has proven that even small amounts of static electricity can damage or destroy these devices. Damaged components, even though they appear to function properly, exhibit early failure.

Dear Customer,

We appreciate this opportunity to service your flow measurement and control requirements with a Brooks Instrument device. Every day, flow customers all over the world turn to Brooks Instrument for solutions to their gas and liquid low-flow applications. Brooks provides an array of flow measurement and control products for various industries from biopharmaceuticals, oil and gas, fuel cell research and chemicals, to medical devices, analytical instrumentation, semiconductor manufacturing, and more.

The Brooks product you have just received is of the highest quality available, offering superior performance, reliability and value to the user. It is designed with the ever changing process conditions, accuracy requirements and hostile process environments in mind to provide you with a lifetime of dependable service.

We recommend that you read this manual in its entirety. Should you require any additional information concerning Brooks products and services, please contact your local Brooks Sales and Service Office listed on the back cover of this manual or visit www.BrooksInstrument.com

Yours sincerely,
Brooks Instrument

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Section 1 Introduction

Section 2 Installation

Section 3 Operation

Section 4 Maintenance

Section 5 Parts List

Figures

Tables

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1-1 Description

The Sho-Rate Flowmeters are variable area, glass tube, flow rate indicating meters. The basic elements are a tapered glass metering tube and a metering float. Features include quick and simple removal or installation of the tube and float while the meter remains in the process piping.

1-2 Specifications

⚠ WARNING

Do not operate this instrument in excess of the specifications listed below. Failure to heed this warning can result in serious personal injury and/or damage to the equipment.

⚠ WARNING

Glass metering tubes are designed for operation up to the maximum operating pressures and temperatures as specified herein. Due to the inherent brittle characteristics of glass and conditions beyond our control, tube breakage could result even within specified operating conditions. Do not use glass tube meters with fluids that are toxic, or chemically react with glass such as water above 140° F, steam, alkalis, fluorine, hydrofluoric acid, or molten metal. Failure to heed warning can result in serious personal injury and/or damage to the equipment.

Capacities
1350 Series: Refer to Tables 1-1 or 1-2, or 1-3 and 1-4
1355 Series: Refer to Tables 1-3 and 1-4, or 1-5

Accuracy
1350 Series Standard: Accuracy of ±10% of full scale
1355 Series Standard: ±5% of full scale

Repeatability
0.5% full scale

Pressure Equipment Directive (97/23/EC)
Note: Equipment falls under Sound Engineering Practice (SEP) according to the directive.

Pressure/Temperature
200 psig at temperatures 33°F to 250°F

Pressure Drop
Inquire at factory

Flow Meter Assembly

Scales

1350 Series:
Length: 65 mm, nominal
Graduations: Standard: R-65mm, or R-100 linear reference scale with air or water calibration table.
1355 Series:
Length: 150mm, nominal
Graduations: Standard: R-150 mm, or R-100 linear reference scale with air or water calibration table. Optional: for either 65 mm or 150 mm direct reading scale, ceramic ink fused on glass tube or metal scale plate mounted beside tube
Type: Standard: Ceramic ink fused on meter tube with contrasting yellow background

Materials of Construction

⚠ CAUTION

It is the user's responsibility to select and approve all materials of construction. Careful attention to metallurgy, engineered materials and elastomeric materials is critical to safe operation.

Metering Tubes: Borosilicate glass
Floats: Glass, 316 stainless steel, sapphire, Carboloy®, tantalum

Structural Members:

End fittings: Chrome plated brass, black anodized aluminum, 316 stainless steel

Side Plates:
Standard: Black anodized aluminum
Optional: 316 stainless steel

Window: Clear polycarbonate; Back Window: Milk white polycarbonate

Float Stops:
Standard: Teflon®
Optional: 316 Stainless Steel

Tube Packing:
Standard: Buna-N (Brass and aluminum meters), Viton-A® fluoroelastomers (316 stainless steel meters)
Optional: Teflon® , EPM (also known as EPR)

O-rings:
Standard: Buna-N (Brass and aluminum meters), Viton-A fluoroelastomers (316 stainless steel meters)
Optional: Teflon (not available with needle valves), EPM, Kalrez®

Connections

Standard: Horizontal female 1/8" NPT threaded adapters with locknuts for front of panel mounting

Dimensions

Refer to Figures 2-2, 2-3 and 2-4

Table 1-1 Capacities for Sho-Rate Model 1350E Rib Guided Tubes, Spherical Floats

	RIBBED TUBES, SPHERICAL FLOATS									
METER SIZE	**TUBE NO.**	**FLOAT MATERIAL**	**MAXIMUM FLOW RATE**							
			WATER				**AIR***			
			GPH	**CODE**	**LPH**	**CODE**	**SCFH**	**CODE**	**NLPH**	**CODE**
2	R-2-65-A	GLASS	0.011	JB6	0.042	JB9	0.13	JB7	3.4	JB8
		SAPPHIRE	0.022	JC4	0.085	JC2	0.18	JC3	5.0	JC1
		STN. STL.	0.046	JC8	0.18	JC5	0.34	JC7	9.0	JC6
		CARBOLOY	0.10	JB4	0.38	JB5	0.65	JB2	17.0	JB3
		TANTALUM	0.11	JD2	0.42	JC9	0.70	JD1	19.0	JD3
	R-2-65-B	GLASS	0.013	KB8	0.048	KB2	0.15	KB7	4.0	KB9
		SAPPHIRE	0.026	KC1	0.10	KD3	0.22	KC2	5.5	KC3
		STN. STL.	0.06	KC5	0.22	KC6	0.42	KC7	11.0	KC8
		CARBOLOY	0.12	KB4	0.48	KB5	0.80	KB3	22.0	KB6
		TANTALUM	0.13	KD2	0.50	KD5	0.85	KD4	22.0	KD1
	R-2-65-C	GLASS	0.11	LB9	0.42	LB7	0.95	LB6	24.0	LB8
		SAPPHIRE	0.15	LC1	0.6	LC2	1.3	LC3	34.0	LC4
		STN. STL.	0.38	LC7	1.4	LC8	2.0	LC9	50.0	LC6
		CARBOLOY	0.65	LB3	2.4	LB2	3.0	LB4	80.0	LB5
		TANTALUM	0.65	LD1	2.6	LD2	3.2	LD3	85.0	LD4
	R-2-65-D	GLASS	0.65	MB9	2.4	MB7	3.8	MB8	100	MC1
		SAPPHIRE	0.95	MC2	3.6	MC3	5.0	MC4	130	MC5
		STN. STL.	1.60	MC7	6.0	MD1	7.5	MC6	200	MC8
		CARBOLOY	2.40	MB5	9.0	MB2	11.0	MB3	280	MB4
		TANTALUM	2.60	MD5	10.0	MD6	12.0	MD2	300	MD4
6	R-6-65-A	GLASS	2.40	NB8	8.5	NB7	13.0	NC1	340	NB9
		SAPPHIRE	3.40	NC4	13.0	NC3	17.0	NC6	460	NC5
		STN. STL.	5.50	ND1	20.0	ND3	26.0	NC9	650	ND2
		CARBOLOY	8.50	NB2	32.0	NB3	36.0	NB5	950	NB6
		TANTALUM	9.0	ND6	34.0	ND5	38.0	ND7	1000	ND4
	R-6-65-B	GLASS	8.0	PB9	30.0	PB8	44.0	PC1	1100	PB7
		SAPPHIRE	12.0	PC5	44.0	PC3	60.0	PC4	1500	PC2
		STN. STL.	19.0	PD1	70.0	PC9	85.0	PC8	2200	PC6
		CARBOLOY	28.0	PB3	100	PB2	130	PB6	3400	PB4
		TANTALUM	30.0	PD7	110	PD6	140	PD5	3600	PD4

*** FLOW RATES GIVEN ARE MAXIMUM VALUES. AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F.**

Table 1-2 Capacities for Sho-Rate Model 1350E Plain Tapered Tubes, Spherical Floats

	PLAIN TAPER TUBES, SPHERICAL FLOATS						
TUBE AND FLOAT	**SCFH AIR***	**Press. Drop ** Inches W.C.**	**CODE**	**TUBE AND FLOAT**	**GPH WATER**	**Press. Drop ** Inches W.C.**	**CODE**
1-65A GLASS	1.2	1.0	AB4	1-65C GLASS	0.14	1.8	AB5
2-65A GLASS	1.9	2.2	BA7	2-65C STN. STL.	0.5	4.0	DA5
2-65B STN. STL	5.0	10.8	CA4	2-65D STN. STL.	1.0	19.5	CA8
3-65A GLASS	6.0	12.4	EB4	3-65C GLASS	0.7	22.3	EB9
3-65B STN. STL	10	10.1	EB8	3-65D STN. STL	1.6	18.3	EC1
4-65A GLASS	12	10.4	FC3	4-65C GLASS	2.0	18.7	FD3
4-65B STN. STL	18	25	FC8	4-65D STN. STL	4.0	45	FD6
5-65A GLASS	45	60	GB6	5-65C GLASS	9.0	109	GC4
5-65B STN. STL	80	214	GC1	5-65D STN. STL	17	385	GC5
6-65A GLASS	55	73	HB8	6-65C GLASS	11	132	HC7
6-65B STN. STL	90	292	HC5	6-65D STN. STL	20	525	HD1
6-65E CARBOLOY	120	400	HD3	6-65F CARBOLOY	30	890	HD4

*** FLOW RATES ARE MAXIMUM VALUES. AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F**
**** PRESSURE DROPS ARE APPROXIMATE**

Table 1-3 Tube and Float Code, Detachable Scale Option, 1st Digit

FIRST DIGIT FOR DETACHABLE SCALE CONFIGURATION		
CODE	**MODEL 1350 TUBE**	**MODEL 1355 TUBE**
A	1-65	R-2-15-A
B	2-65A	R-2-15-AA
C	2-65B & D	
D	2-65C	R-2-15-B
E	3-65	R-2-15-C
F	4-65	R-2-15-D
G	5-65	R-6-15-A
H	6-65	R-6-15-B
J	R-2-65-A	R-2-15-AAAA
K	R-2-65-B	
L	R-2-65-C	
M	R-2-65-D	
N	R-6-65-A	
P	R-6-65-B	
Y	NO TUBE	NO TUBE

Table 1-4 Tube and Float Code, Detachable Scale Option, 2nd & 3rd Digits

METER ACCURACY	FLOAT MATERIAL	DETACHABLE SCALE INSCRIPTION				
		MM	0-100 LINEAR	SPECIAL SINGLE SCALE	SPECIAL DUAL SCALE	BLANK SCALE
STANDARD (1350-10%) (1355- 5%)	GLASS	1A	1N	2A	2N	3A
	STN. STL.	1B	1P	2B	2P	3B
	SAPPHIRE	1C	1Q	2C	2Q	3C
	CARBOLOY	1D	1R	2D	2R	3D
	TANTALUM	1E	1S	2E	2S	3E
	*ALUMINUM	1F	1T	2F	2T	3F
CALIBRATED (1350-5%) (1355-2%)	GLASS	1G	1U	2G	2U	
	STN. STL.	1H	1V	2H	2V	
	SAPPHIRE	1J	1W	2J	2W	
	CARBOLOY	1K	1X	2K	2X	
	TANTALUM	1L	1Y	2L	2Y	
	*ALUMINUM	1M	1Z	2M	2Z	
N/A	NONE	9A	9B			9C

***ALUMINUM SPOOL FLOAT FOR 15 CC/MIN AIR AVAILABLE ONLY WITH R-2-15-AAA TUBE**

1-3 Optional Equipment

Standard Needle Valve

The standard needle valve can be supplied integrally mounted to the inlet or outlet of the instrument. For more details on the needle valve go to our website: **BrooksInstrument.com**, select Documentation, Precision Valves & Flow Controllers, select Brooks-Line IV, CART, 8503 or 8504 valves.

Flow Contollers

Flow controllers can be supplied integrally mounted to the inlet or outlet of the instrument. For the flow controller's complete instruction manual go to our website: **BrooksInstrument.com**, select Documentation, Precision Valves & Flow Controllers, select FC8800, or FC8900.

Table 1-5 Capacities for Sho-Rate Model 1355E Rib Guided Tubes, Spherical Floats

CAPACITIES (RIB GUIDE TUBES, SPHERICAL FLOATS) - FOR USE WITH 1355 SERIES ONLY							
			MAXIMUM FLOW RATE *		MODEL CODE - SCALE ON TUBE		
METER SIZE	TUBE NO.	FLOAT MATERIAL	WATER (CC/MIN.)	AIR	0-150 MM	10-100%	0-100 LINEAR
2	R-2-15-AAAA	GLASS	0.59	50 SCC/M	JA6		JA1
		SAPPHIRE	1.1	79 SCC/M	JA8		JA3
		STN. STL.	2.6	150 SCC/M	JA7		JA2
		CARBOLOY	5.2	280 SCC/M	JA9		JA4
		TANTALUM	5.8	310 SCC/M	JB1		JA5
	R-2-15-AA	GLASS	1.11	88 SCC/M	BA6		BA1
		SAPPHIRE	2.15	136 SCC/M	BA8		BA3
		STN. STL.	4.93	258 SCC/M	BA7		BA2
		CARBOLOY	9.33	439 SCC/M	BA9		BA4
		TANTALUM	10.4	478 SCC/M	BB1		BA5
	R-2-15-D	GLASS	5.75	380 SCC/M	FA6		FA1
		SAPPHIRE	10.5	518 SCC/M	FA8		FA3
		STN. STL.	20.6	832 SCC/M	FA7		FA2
		CARBOLOY	33.2	1240 SCC/M	FA9		FA4
		TANTALUM	35.9	1320 SCC/M	FB1	LIQ. GAS	FA5
	R-2-15-A	GLASS	16.6	.83 SLPM	AA6	AB7 AC3	AA1
		SAPPHIRE	26.3	1.1 SLPM	AA8	AB9 AC4	AA3
		STN. STL.	46.2	1.69 SLPM	AA7	AB8 AC6	AA2
		CARBOLOY	70.8	2.44 SLPM	AA9	AC1 AC5	AA4
		TANTALUM	75.9	2.6 SLPM	AB1	AC2 AC7	AA5
	R-2-15-B	GLASS	52.8	2.37 SLPM	DA6	DB2	DA1
		SAPPHIRE	79.7	3.08 SLPM	DA8	DB4	DA3
		STN. STL.	133	4.7 SLPM	DA7	DB3	DA2
		CARBOLOY	199	6.7 SLPM	DA9	DB5	DA4
		TANTALUM	212	7.1 SLPM	DB1	DB6	DA5
	R-2-15-C	GLASS	84.6	3.9 SLPM	EA6	EB2	EA1
		SAPPHIRE	129	5.1 SLPM	EA8	EB4	EA3
		STN. STL.	218	7.6 SLPM	EA7	EB3	EA2
		CARBOLOY	326	10.6 SLPM	EA9	EB5	EA4
		TANTALUM	349	11.3 SLPM	EB1	EB6	EA5
6	R-6-15-A	GLASS	200	8.7 SLPM	GA6	GB2	GA1
		SAPPHIRE	297	11.2 SLPM	GA8	GB4	GA3
		STN. STL.	493	16.6 SLPM	GA7	GB3	GA2
		CARBOLOY	726	23.2 SLPM	GA9	GB5	GA4
		TANTALUM	772	24.6 SLPM	GB1	GB6	GA5
	R-6-15-B	GLASS	573	23.9 SLPM	HA6	HB2	HA1
		SAPPHIRE	851	30.2 SLPM	HA8	HB4	HA3
		STN. STL.	1350	43.8 SLPM	HA7	HB3	HA2
		CARBOLOY	1950	61.2 SLPM	HA9	HB5	HA4
		TANTALUM	2060	64.7 SLPM	HB1	HB6	HA5

NOTE: ALL AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F.

* FLOW RATES SHOWN ARE MAXIMUM CAPACITIES
DIRECT READ SCALES MAY END AT SLIGHTLY DIFFERENT MAXIMUM FLOWS.

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2-1 Receipt of Equipment

When the equipment is received, the outside of the packing case should be checked for any damage incurred during shipment. If the packing case is damaged, the local carrier should be notified at once regarding his liability. Remove the envelope containing the shipping list. Carefully remove the equipment from the packing case and inspect for any damaged or missing parts.

In the event that the meter is damaged during shipment, the Product Service Department, Brooks Instrument,LLC, Hatfield, PA 19440 should be contacted to obtain a return shipment form.

Brooks Instrument
407 W. Vine Street
P.O. Box 903
Hatfield, PA 19440 USA
Toll Free (888) 554 FLOW (3569)
Tel (215) 362 3700
Fax (215) 362 3745
E-mail: BrooksAm@BrooksInstrument.com
www.BrooksInstrument.com

Brooks Instrument
Neonstraat 3
6718 WX Ede, Netherlands
P.O. Box 428
6710 BK Ede, Netherlands
Tel +31 (0) 318 549 300
Fax +31 (0) 318 549 309
E-mail: BrooksEu@BrooksInstrument.com

Brooks Instrument
1-4-4 Kitasuna Koto-Ku
Tokyo, 136-0073 Japan
Tel +81 (0) 3 5633 7100
Fax +81 (0) 3 5633 7101
Email: BrooksAs@BrooksInstrument.com

2-2 Unpacking

Carefully unpack the meter and inspect it for any damage that may have occurred during shipment. The flowmeters are shipped completely assembled and tested. It should not be necessary to tighten or adjust any of the parts when it is received.

2-3 Return Shipment

Do not return any assembly or part without a Return Materials Report. The Return Materials Report is available from all District Sales Offices and the Product Service Department, Hatfield, PA 19440. Information describing the problem, corrective action, if any, and the work to be accomplished at the factory must be included.

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Neonstraat 3
6718 WX Ede, Netherlands
P.O. Box 428
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E-mail: BrooksEu@BrooksInstrument.com

Brooks Instrument
1-4-4 Kitasuna Koto-Ku
Tokyo, 136-0073 Japan
Tel +81 (0) 3 5633 7100
Fax +81 (0) 3 5633 7101
Email: BrooksAs@BrooksInstrument.com

2-4 Recommended Storage Practice

If intermediate or long term storage is required for equipment, as supplied by Brooks Instrument, it is recommended that said equipment be stored in accordance with the following:

a. Within the original shipping container.
b. Stored in a sheltered area, preferably a warm, dry heated warehouse.
c. Ambient temperature 70°F (21.0°C) nominal 110°F maximum/45°F minimum (43°C maximum/7.1°C minimum).
d. Relative humidity 45% nominal 60% maximum/25% minimum.

Upon removal from storage, a visual inspection should be conducted to verify the condition of equipment is "as received". If the equipment has been in storage for an excess of two (2) years or in conditions in excess of those recommended, all pressure boundary seals should be replaced and the device subject to a hydrostatic/pneumatic pressure test to 150% of rated pressure.

2-5 Installation (See Figures 2-1, 2-2, 2-3, 2-4 and 2-5)

The flowmeter should be mounted within 6° of true vertical. The inlet connection to the flowmeter is in the bottom end fitting. The connections are normally horizontal, female NPT. Be sure the piping is adequately supported to prevent undue strain on the meter.

⚠ WARNING

If the inlet and outlet valves adjacent to the flowmeter are to be closed for any reason, the flowmeter must be completely drained. Failure to do so may result in thermal expansion of the liquid which can cause rupture of the meter and possible personal injury.

⚠ CAUTION

Care must be taken in the system piping to this instrument to prevent sudden excessive pressure or flow surges. Protective devices should be installed upstream from this instrument, such as flow controllers, pressure regulators, pressure snubbers and rupture discs.

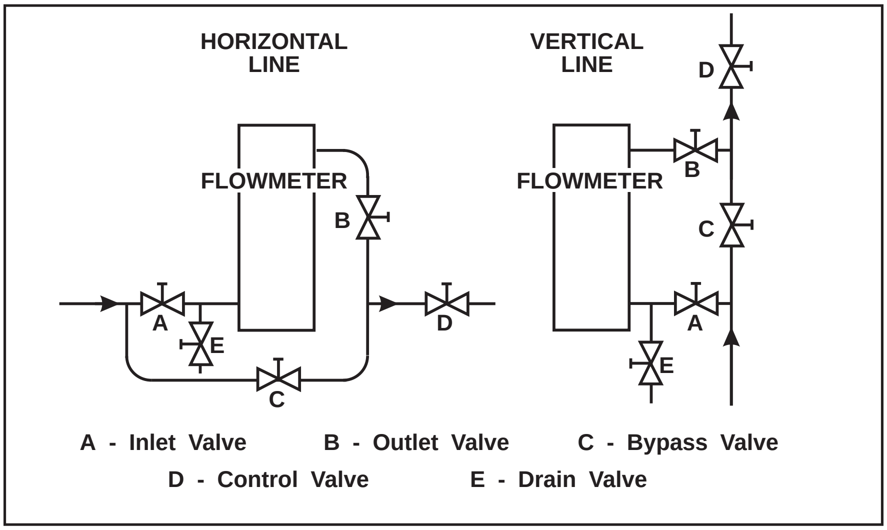
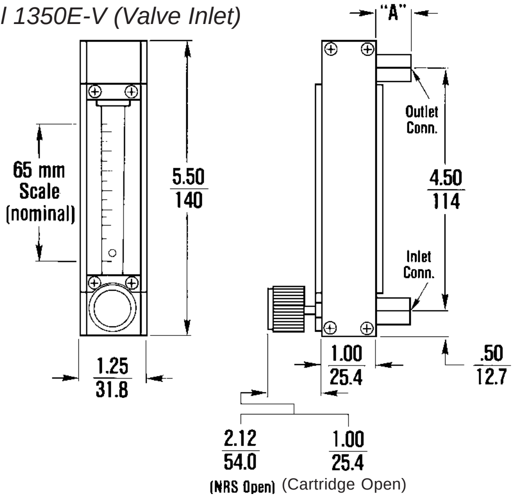
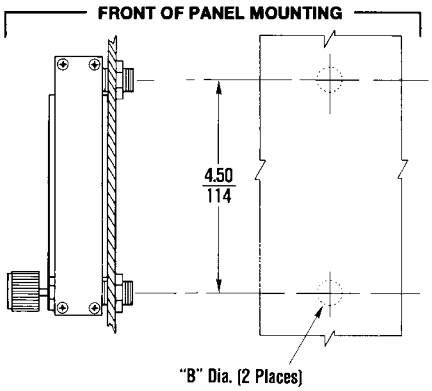


Figure 2-1 Typical Flowmeter Installation

It is recommended that a final leak test of the system plumbing and meter be performed before subjecting it to process fluid.
(See Section 4, Paragraph 4-2, e.)

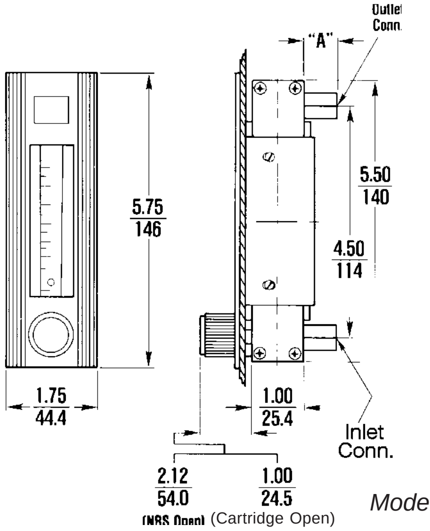
Model 1350E-V (Valve Inlet)

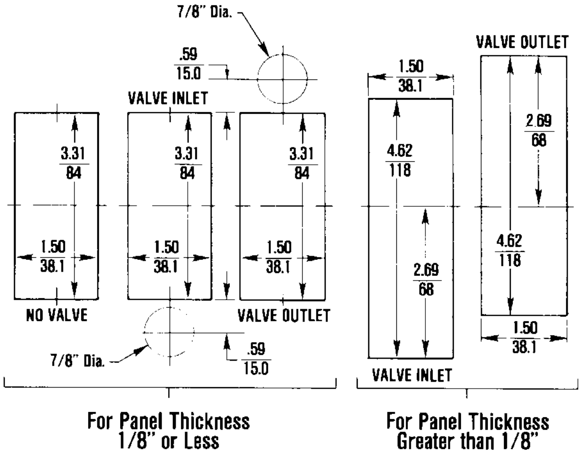




Thread Adapters & Lock Nuts

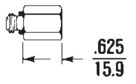
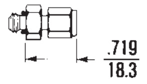
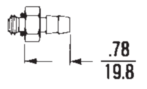
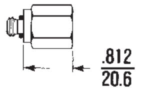
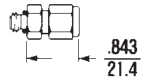
Conn. Adapter	1/8" NPT	1/4" NPT
"B" Dia.	.59/15.1	.88/22.2





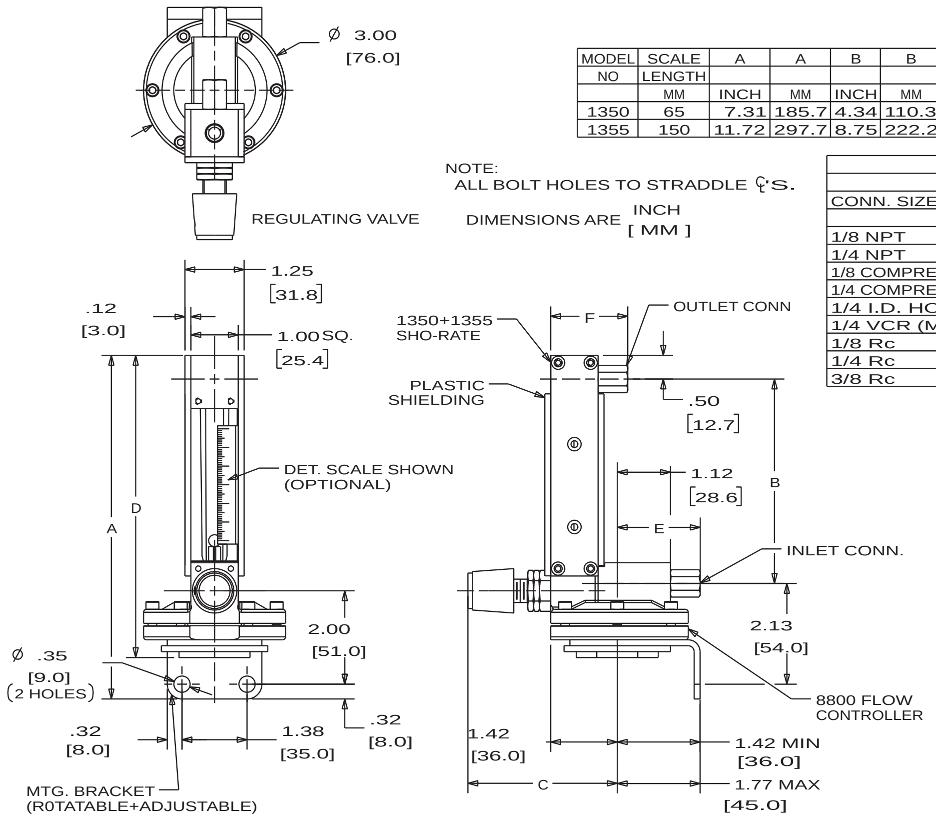
(Remove rear shield, if furnished, when mounting on panels thicker than 1/4".)

Model 1350E-VB (Valve Inlet with Aluminum Bezel)

Dimension "A" Connection Adapter		
AN 10050-2 O-Ring Boss Seal (All Fittings)	1/8" NPT/RC  .625 15.9	1/8" Compression  .719 18.3
1/4" ID Hose  .78 19.8	1/4" NPT/RC  .812 20.6	1/4" Compression  .843 21.4

Inches/Milimeters

Figure 2-2 Dimensions - Sho-Rate 1350E



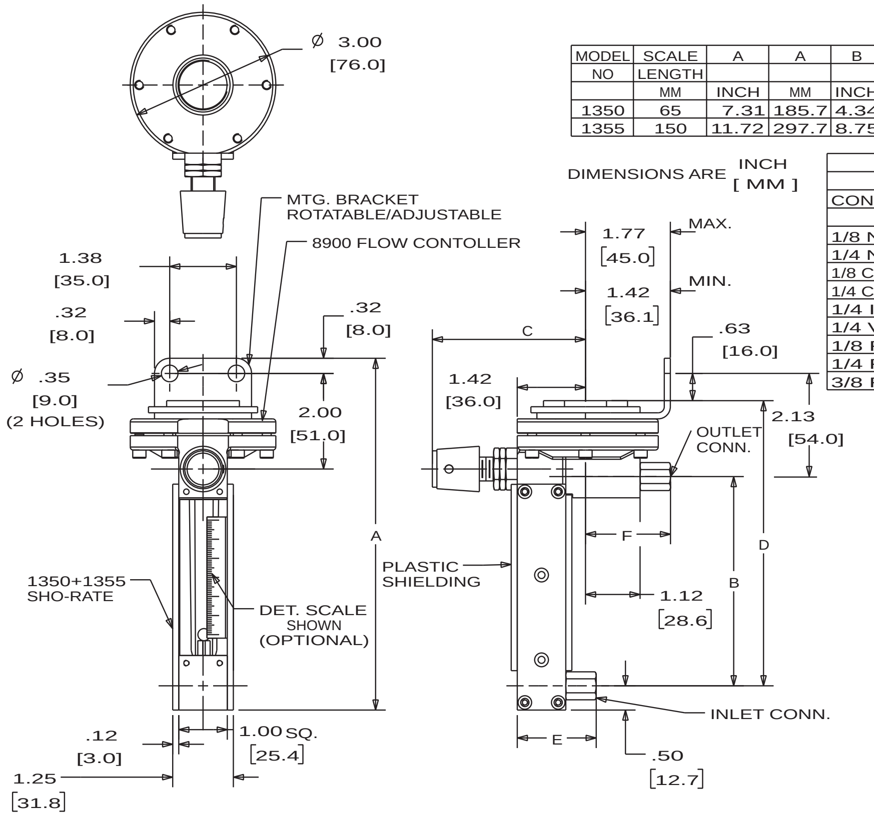
MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

NOTE:
ALL BOLT HOLES TO STRADDLE ℄'S.

DIMENSIONS ARE INCH [MM]

	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.72	43.7	1.62	41.1
1/4 NPT	1.12	28.6	1.81	46.0
1/8 COMPRESSION	1.91	48.5	1.81	46.0
1/4 COMPRESSION	2.04	51.8	1.94	49.3
1/4 I.D. HOSE	1.82	46.2	1.72	43.7
1/4 VCR (M)	N/A	N/A	2.06	52.3
1/8 Rc	1.91	48.5	1.62	41.1
1/4 Rc	1.91	48.5	1.81	46.0
3/8 Rc	2.35	53.1	2.09	53.1

Model 1350E-8800
(Controller on Inlet)



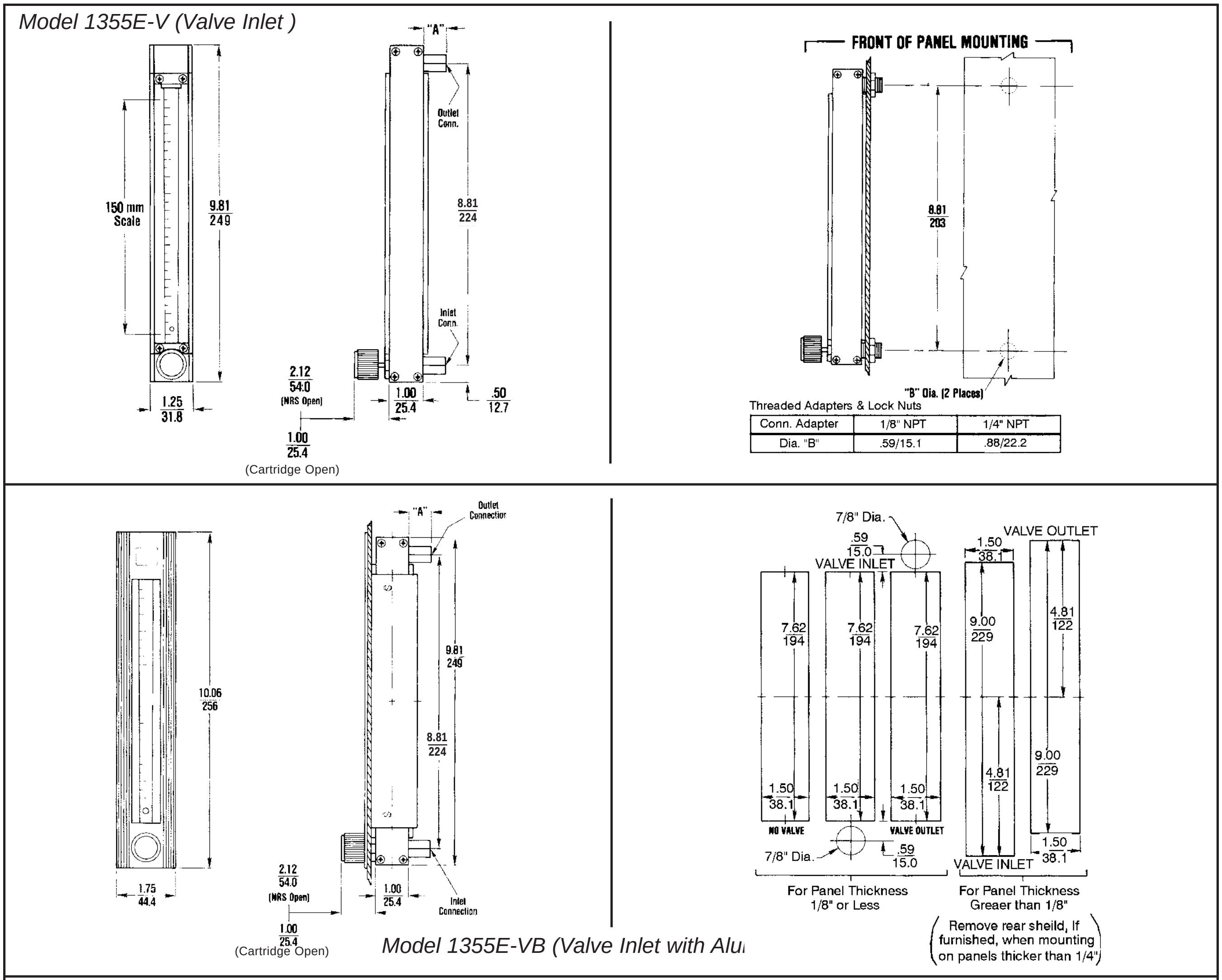
MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

DIMENSIONS ARE INCH [MM]

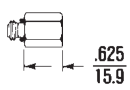
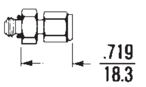
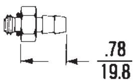
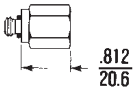
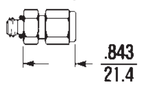
	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.62	41.1	1.72	43.7
1/4 NPT	1.81	46.0	1.12	28.6
1/8 COMPRESSION	1.81	46.0	1.91	48.5
1/4 COMPRESSION	1.94	49.3	2.04	51.8
1/4 I.D. HOSE	1.72	43.7	1.82	46.2
1/4 VCR (M)	2.06	52.3	N/A	N/A
1/8 Rc	1.62	41.1	1.91	48.5
1/4 Rc	1.81	46.0	1.91	48.5
3/8 Rc	2.09	53.1	2.35	59.7

Model 1350E-8900
(Controller on Outlet)

Figure 2-3 Dimensions - Sho-Rate 1350E & 1355E with Integral Flow Controller



Conn. Adapter	1/8" NPT	1/4" NPT
Dia. "B"	.59/15.1	.88/22.2

Dimension "A" Connection Adapter		
AN 10050-2 **O-Ring Boss Seal** **(All Fittings)**	**1/8" NPT/RC**  .625 / 15.9	**1/8" Compression**  .719 / 18.3
1/4" ID Hose  .78 / 19.8	**1/4" NPT/RC**  .812 / 20.6	**1/4" Compression**  .843 / 21.4

Inches/Milimeters

Figure 2-4 Dimensions - Sho-Rate 1355E

3-1 Operation

After the flowmeter has been installed in the flow system, it is ready for operation. An optional built-in needle control valve may be provided to control the flow through the flowmeter. These control valves are designed for fine control. Excessive tightening may damage the valve seat and limit its effectiveness as a control valve. If tight shut-off is required, it is recommended that a separate shut-off valve should be installed in the line immediately before the flowmeter.

Flow indication is measured using the center of the spherical float as the reference point.

⚠ WARNING

During operation, do not exceed pressure and temperature specifications. Failure to heed this warning may result in serious personal injury and/or damage to the equipment.

⚠ CAUTION

Any sudden change in system pressure may cause mechanical damage to elastomer materials. Damage can occur when there is a rapid expansion of fluid that has permeated elastomer materials. The user must take the necessary precautions to avoid such conditions.

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4-1 Disassembly and Cleaning

⚠ WARNING

METER/CONTROLLER SEAL COMPATIBILITY

Products in this manual may contain metal or elastomeric seals, gaskets, O-rings or valve seats. It is the "user's" responsibility to select materials that are compatible with their process and process conditions. Using materials that are not compatible with the process or process conditions could result in the Meter or Controller leaking process fluid outside the pressure boundary of the device, resulting in personnel injury or death.

It is recommended that the user check the Meter or Controller on a regular schedule to ensure that it is leak free as both metal and elastomeric seals, gaskets, O-rings and valve seats may change with age, exposure to process fluid, temperature, and /or pressure.

It is recommended the user periodically inspect the tube and float, and clean if necessary. Dirt or foreign materials adhering to the tube and float may cause inaccuracy and sticking of the float. The metering tube (Borosilicate glass) and related parts may be cleaned with any solvent which does not attack glass. To disassemble use the following procedures:

a. Remove the plastic window and back plate.
b. Loosen the seal spindle or jack screw by turning it counterclockwise with a 5/32" hex wrench. The tube may now be canted out of the meter housing.
c. On meter sizes 1 through 6, the tube, float and float stops may be cleaned as an assembly or may be diassembled for cleaning. Using a small hook, remove either Teflon® float stop from the metering tube and remove the float. Be careful not to chip the tube.
d. Packing seats and packing inserts may now be removed.
e. With the metering tube out, the seal spindle or jack screw may be rotated clockwise for removal. It should not be necessary to remove the seal spindle unless the O-ring which seals the spindle requires replacement. The O-ring may be used as long as it is not torn or distorted.
f. The needle control valve assembly may be removed by turning the valve body counterclockwise. The valve seat, stem and packing then may be removed easily from the valve body for cleaning or replacement.

4-2 Reassembly Procedure

a. Use the reverse of Steps a through f of the disassembly procedure to reassemble the meter.

b. Prior to installing the needle control valve assembly make certain that the valve stem is turned completely counterclockwise (full open position) to prevent damage to the valve seat. Packing seats should be examined for damage or deterioration and replaced if necessary.

c. When replacing the packing seats in the flowmeter body be sure the packing inserts are approximately 1/16" above the top of the packing seat. Also be certain the tube seats firmly on the packing seats and does not overlap onto the end block.

d. The seal spindle serves to axially compress the tube seat gasket and exert a uniform pressure on the metering tube to prevent any possibility of leakage. Do not overtighten the seal spindle.

e. After the flowmeter has been reassembled, it is important that it be leak tested with air at a minimum pressure of 15 psig at room temperature.

   To detect leaks, brush soapy water around all possible leak points (tube packing, connections, and seal spindle) and check if bubbles are being formed. Should a leak be detected, tighten that particular joint to see if the leak can be stopped. If the leak persists, disassemble the area involved and check for dirt or damaged elastomer. Clean and replace elastomer.

5-1 General

When ordering parts please specify:
Brooks Serial Number
Model Number
Part Number
Description and Quantity
(Refer to Figure 5-1 and Table 5-1)

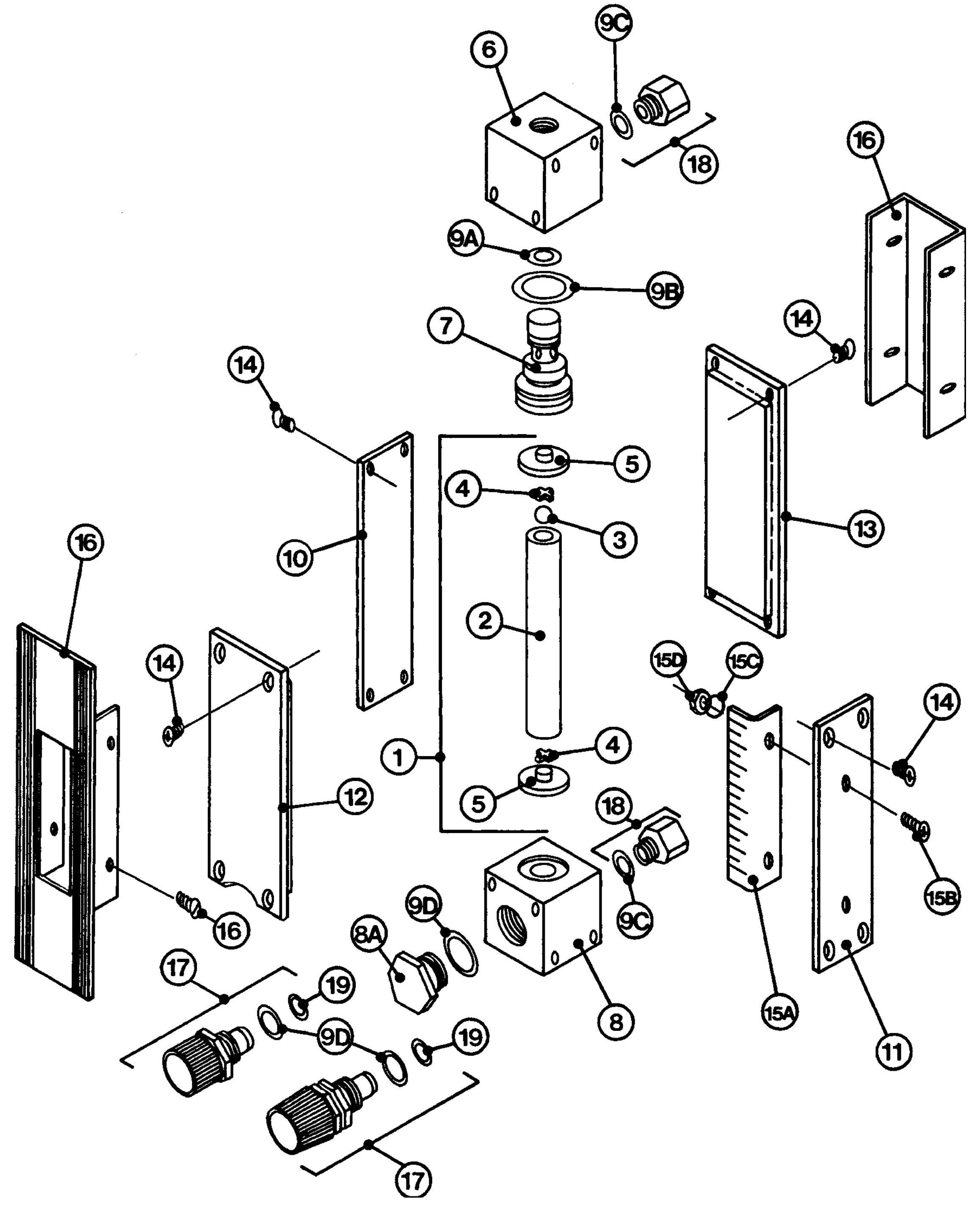

Figure 5-1 Parts Drawing Sho-Rate Models 1350E and 1355E

Table 5-1 Parts List - Sho-Rate Models 1350E and 1355E

Ref. No.	Qty.	Description
1*	1	Metering Tube Assembly
2	1	Glass Metering Tube
3	1	Ball Float (Size 1,5-1350 Only) Size 1 3/32" Glass Size 1 3/32" 316 SS Size 2 1/8" Glass Size 2 1/8" Sapphire Size 2 1/8" 316 SS Size 2 1/8" Carboloy Size 2 1/8" Tantalum Size 5 7/32" Glass Size 5 7/32" 316 SS Size 6 1/4" Glass Size 6 1/4" Sapphire Size 6 1/4" 316 SS Size 6 1/4" Carboloy Size 6 1/4" Tantalum
4	1	Inlet & Outlet Teflon Float Stops
5	1	Inlet/Outlet Tube Packing
6	1	Seal End Fitting (Outlet) Aluminum Brass 316 SS
7	1	Seal Spindle Aluminum Brass 316 SS
8	1	Valve End Fitting (Inlet) Aluminum Brass 316 SS
8A	1	Valve Plug Aluminum Brass 316 SS
9A*	1	Upper Seal Spindle O-ring Buna Viton Teflon
9B*	1	Lower Seal Spindle O-ring Buna Viton Teflon
9C	2	Adapter O-ring Buna Viton Teflon
9D*	1	Plug O-ring Buna Viton Teflon
10	1	Side Plate (STD) 1350 Aluminum STN. STL. 1355 Aluminum STN. STL.
11	1	Side Plate 1350 Standard Aluminum STN. STL. For Detached Scale Aluminum STN. STL.
11	1	(Cont'd)1355 Standard Aluminum Stn. Stl. For Detached Scale Aluminum Stn. Stl.
12	1	Front Shield 1350 1355
13	1	Back Plate 1350 1355
14	16	Side Plate & Shield Screw
15A	1	Aluminum Det. D/R Scale
15B	2	Stn. Stl. Scale Screws
15C	2	Stn. Stl. Scale Washers
15D	2	Stn. Stl. Scale Nuts
16	1	Aluminum Bezel 1350 (No Valve) 1350 (With Valve) 1355 (No Valve) 1355 (With Valve)
17	1	Optional Valve Assembly Cartridge Valve Brass/Buna-N - Low Brass/Buna-N - Med Brass/Buna-N - Hi 316 S.S/Viton - Low 316 S.S/Viton - Med 316 S.S/Viton - Hi NRS Valve Brass/Buna-N - Size 1 Brass/Buna-N - Size 2 Brass/Buna-N - Size 3 Brass/Buna-N - Size 4 Brass/Buna-N - Size 5 Brass/Buna-N - Size 6 316 S.S./Viton - Size 1 316 S.S./Viton - Size 2 316 S.S./Viton - Size 3 316 S.S./Viton - Size 4 316 S.S./Viton - Size 5 316 S.S./Viton - Size 6
18	2	1/8" NPT Thd. Adapter w/Locknut Aluminum w/Buna Brass w/Buna 316 SS w/Viton 1/8" NPT Adapter Aluminum w/Buna Brass w/Buna 316 SS w/ Viton 1/4" NPT Adapter Aluminum w/Buna Brass w/Buna 316 SS w/Viton 1/8" Compression Adapter Brass w/Buna 316 SS w/Viton 1/4" Compression Adapter Brass w/Buna 316 SS w/Viton 1/4" I.D. Hose Adapter Aluminum w/Buna Brass w/Buna 316 SS w/Viton
19*	1	Orifice O-ring NRS Buna-N Viton Cartridge Valve Buna-N Viton

*Recommended Spare Parts

LIMITED WARRANTY

Seller warrants that the Goods manufactured by Seller will be free from defects in materials or workmanship under normal use and service and that the Software will execute the programming instructions provided by Seller until the expiration of the earlier of twelve (12) months from the date of initial installation or eighteen (18) months from the date of shipment by Seller. Products purchased by Seller from a third party for resale to Buyer (“Resale Products”) shall carry only the warranty extended by the original manufacturer.

All replacements or repairs necessitated by inadequate preventive maintenance, or by normal wear and usage, or by fault of Buyer, or by unsuitable power sources or by attack or deterioration under unsuitable environmental conditions, or by abuse, accident, alteration, misuse, improper installation, modification, repair, storage or handling, or any other cause not the fault of Seller are not covered by this limited warranty, and shall be at Buyer’s expense.

Goods repaired and parts replaced during the warranty period shall be in warranty for the remainder of the original warranty period or ninety (90) days, whichever is longer. This limited warranty is the only warranty made by Seller and can be amended only in a writing signed by an authorized representative of Seller.

BROOKS SERVICE AND SUPPORT

Brooks is committed to assuring all of our customers receive the ideal flow solution for their application, along with outstanding service and support to back it up. We operate first class repair facilities located around the world to provide rapid response and support. Each location utilizes primary standard calibration equipment to ensure accuracy and reliability for repairs and recalibration and is certified by our local Weights and Measures Authorities and traceable to the relevant International Standards.

Visit www.BrooksInstrument.com to locate the service location nearest to you.

START-UP SERVICE AND IN-SITU CALIBRATION

Brooks Instrument can provide start-up service prior to operation when required.

For some process applications, where ISO-9001 Quality Certification is important, it is mandatory to verify and/or (re)calibrate the products periodically. In many cases this service can be provided under in-situ conditions, and the results will be traceable to the relevant international quality standards.

CUSTOMER SEMINARS AND TRAINING

Brooks Instrument can provide customer seminars and dedicated training to engineers, end users and maintenance persons.

Please contact your nearest sales representative for more details.

HELP DESK

In case you need technical assistance:

Americas	☎ 1 888 554 FLOW
Europe	☎ +31 (0) 318 549 290
Asia	☎ +81 (0) 3 5633 7100

Due to Brooks Instrument's commitment to continuous improvement of our products, all specifications are subject to change without notice.

TRADEMARKS

Brooks	Brooks Instrument, LLC
Kalrez	DuPont Performance Elastomer
NRS	Brooks Instrument, LLC
Sho-Rate	Brooks Instrument, LLC
Teflon	E.I. DuPont de Nemours & Co.
Viton-A	DuPont Performance Elastomer

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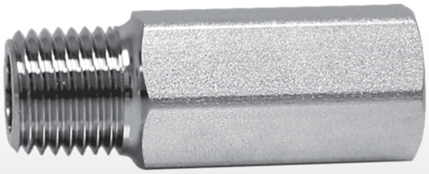
F +81 (0) 3 5633 7101
E-Mail BrooksAs@BrooksInstrument.com

Adjustable Relief Valves

The 534 Series adjustable relief valves are designed for use with high purity gas systems as protection for low pressure components of systems sensitive to over pressurization. Most commonly, these controls are found as relief valves for regulators, relief valves for line systems, and relief valves for distribution systems.

A variety of adjustable ranges affords a wide selection of applications in several different services. Adjustments to the factory-set relief pressure can be made easily using a ⅛" Allen wrench.



Materials and Specifications

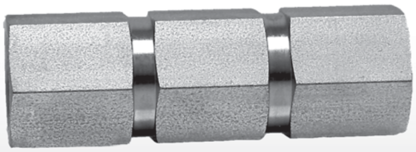
- Spring
  302 stainless steel
- Poppet
  304 stainless steel
- Cv
  0.37
- Inlet Connection
  ¼" MPT
- Outlet Connection
  ¼" FPT
- Weight
  0.1 lbs. (0.05 kg)

Ordering Information

534	A	9	2	D	-PSIG
Series 534	Material	9: N/A	2: N/A	Pressure Range	Please specify factory set pressure
	2: Brass Barstock Body and Fittings (Viton® Seals)			1: 10 to 20 PSIG	
	4: 316L Stainless Steel Barstock Body and Fittings (Viton® Seals)			2: 20 to 100 PSIG	
	5: 316L Stainless Steel Barstock Body and Fittings (Kalrez® Seals)			3: 100 to 250 PSIG	
				4: 250 to 500 PSIG	

Check Valves

The 532 Series check valves are designed for use in high purity gas systems as protection against reverse flow in sensitive operations. Most commonly, these controls are found in services associated with cylinder gases, low pressure gases, in switchover systems, and in manifold systems. The brass and stainless steel models have a cracking pressure of 1 PSIG.



Materials and Specifications

- Maximum Pressure
  3000 PSIG (200 BAR)
- Flow Rate @ 10 PSIG
  47 lpm air
- Spring
  302 stainless steel
- Poppet
  304 stainless steel
- Weight
  0.25 lbs. (0.1 kg)

Ordering Information

Stock No.	End Fittings	Body	Fittings	Seals
532-3922	¼" FPT x ¼" FPT	Brass Barstock	Brass Barstock	Viton®
532-3924	¼" FPT x ¼" FPT	316L Stainless Steel Barstock	316L Stainless Steel Barstock	Ethylene Propylene
532-3824	¼" FPT x ¼" FPT	316L Stainless Steel Barstock	316L Stainless Steel Barstock	Viton®
532-3842	¼" FPT x ¼" FPT	Brass Barstock	Brass Barstock	Viton®
532-3834	¼" FPT x ¼" FPT	316L Stainless Steel Barstock	316L Stainless Steel Barstock	Ethylene Propylene
532-3844	¼" FPT x ¼" FPT	316L Stainless Steel Barstock	316L Stainless Steel Barstock	Viton®

Flowmeters, Purges, Valves & Accessories

400 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2” diameter brass or 316L stainless steel for use especially on regulators such as the 400 Series brass and 316L stainless steel regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount.

2” Brass

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0201	550-0300
30”-0-100 PSIG	550-0202	550-0302
30”-0-200 PSIG	550-0203	550-0303
0-300 PSIG	550-0204	550-0304
0-400 PSIG	550-0205	550-0305
0-1000 PSIG	550-0206	550-0306
0-4000 PSIG	550-0208	550-0308
0-6000 PSIG	550-0209	550-0309

2” 316L Stainless Steel

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0221	550-0320
30”-0-100 PSIG	550-0222	550-0322
30”-0-200 PSIG	550-0223	550-0323
0-300 PSIG	550-0224	550-0324
0-400 PSIG	550-0225	550-0325
0-1000 PSIG	550-0226	550-0326
0-4000 PSIG	550-0228	550-0328
0-6000 PSIG	550-0229	550-0329

300 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2” diameter chrome-plated brass or chrome-plated brass with 316L stainless steel wetted parts for use especially on regulators such as the 300 Series chrome-plated brass and 316L stainless steel regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount. UL listed, Cleaned for oxygen service, ANSI B40.1.

2” Brass (with chrome-plated case)

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0267	550-0367
30”-0-100 PSIG	550-0268	550-0368
30”-0-200 PSIG	550-0269	550-0369
0-300 PSIG	550-0273	550-0373
0-400 PSIG	550-0270	841-0545
0-1000 PSIG	550-0271	550-0371
0-4000 PSIG	550-0263	841-0546
0-6000 PSIG	550-0272	550-0372

2” 316L Stainless Steel (with chrome-plated case)

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0621	550-0720
30”-0-100 PSIG	550-0622	550-0722
30”-0-200 PSIG	550-0623	550-0723
0-300 PSIG	550-0624	550-0724
0-400 PSIG	550-0625	550-0725
0-1000 PSIG	550-0626	550-0726
0-4000 PSIG	550-0628	550-0728
0-6000 PSIG	550-0629	550-0729

200 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2½” diameter chrome-plated brass for use especially on regulators such as the 200 Series chrome-plated brass regulators, and the 483, 485 and 492 Series brass ultra high flow regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount. UL listed, Cleaned for oxygen service, ANSI B40.1.

2½” Brass (with chrome-plated case and stem)

Pressure Range	PSIG/kPa	BAR/PSIG
0-30 PSIG	550-0241	550-0291
0-60 PSIG	550-0242	550-0292
0-200 PSIG	550-0243	550-0293
0-400 PSIG	550-0245	550-0295
0-600 PSIG	550-0250	550-0299

Pressure Range	PSIG/kPa	BAR/PSIG
0-1000 PSIG	550-0246	550-0296
0-4000 PSIG	550-0248	550-0298
0-6000 PSIG	550-0249	550-0297
0-30 PSIG (Redline)	550-0240	550-0290

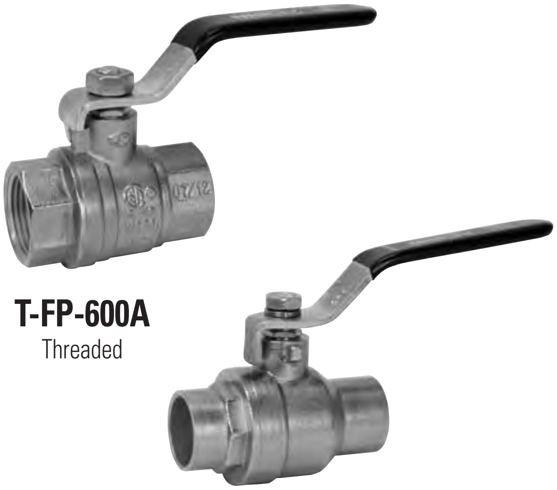
Section 5 – Injection Manifold Components

Brass Ball Valves

Two-Piece Body • Full Port • Blowout-Proof Stem • PTFE Seats

¼"-2" 600 PSI/41.4 Bar Non-Shock Cold Working Pressure
2½"-4" 400 PSI/27.6 Bar Non-Shock Cold Working Pressure

CONFORMS TO MSS SP-110 • CSA CERTIFIED TO ASME B16.44 AND CR91-002 (THREADED ¼"-4") • UL LISTED (THREADED ¼"-4") • IAPMO LISTED TO NSF/ANSI 61-8



T-FP-600A
Threaded

S-FP-600A
Solder

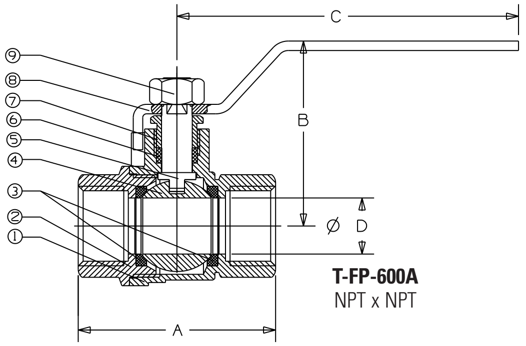
MATERIAL LIST

PART	SPECIFICATION
1. Body	Forged Brass[2] CU > 57%
2. End Cap	Forged Brass[2] CU > 57%
3. Ball Seat	PTFE
4. Ball	Brass, Chrome Plated
5. Stem	Brass
6. O-Ring (Stem Seal)*	Fluorocarbon (FKM)
7. Stem Packing	PTFE
8. Packing Nut	Brass
9. Lever Handle[1]	Steel, Plated
10. Lock Washer*	Stainless Steel
11. Handle Nut[1]	Stainless Steel

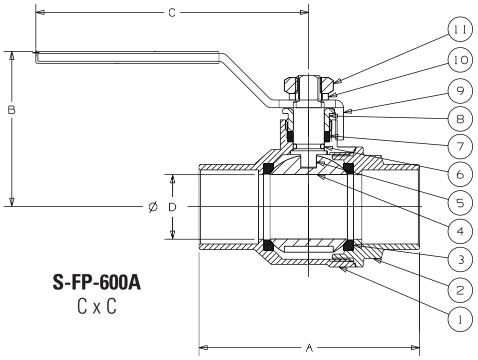
Note: * Parts 6 and 10 are applicable of S-FP-600A only.

[1] Due to Standard Approvals, Lever Handles and Nuts are not interchangeable between Solder and Threaded. There are no handle options at this time.

[2] For Material Certification, contact NIBCO Technical Services.



T-FP-600A
NPT x NPT



S-FP-600A
C x C

DIMENSIONS—WEIGHTS—QUANTITIES

Size		Dimensions																			
		T-FP-600A A		S-FP-600A A		T-FP-600A B		S-FP-600A B		T-FP-600A C		S-FP-600A C		Port D		T-FP-600A		S-FP-600A		T-FP-600A	S-FP-600N
In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	Lbs.	Kg.	Lbs.	Kg.	Ctn. Qty.	Ctn. Qty.
¼	8	1.76	45	—	—	1.73	44	—	—	3.54	90	—	—	.39	10	.33	.15	—	—	18	—
⅜	10	1.76	45	1.75	44	1.73	44	1.58	40	3.54	90	3.78	96	.39	10	.36	.14	.38	.17	18	18
½	15	2.05	52	2.01	51	1.92	49	1.78	45	3.54	90	3.78	96	.59	15	.44	.20	.40	.18	18	18
¾	20	2.36	60	2.74	70	2.09	53	2.13	54	3.78	96	3.98	101	.75	19	.66	.30	.67	.30	12	12
1	25	2.76	70	3.35	85	2.56	65	2.52	64	4.53	115	4.41	112	.98	25	1.10	.50	1.12	.51	6	6
1¼	32	3.31	84	3.78	96	2.95	75	2.65	67	4.53	115	5.04	128	1.26	32	1.57	.71	1.49	.67	4	4
1½	40	3.66	93	4.42	112	3.35	85	3.12	79	5.51	140	6.22	158	1.57	40	2.40	1.09	2.38	1.08	2	2
2	50	4.18	106	5.34	136	3.68	93	3.41	87	5.51	140	6.22	158	1.97	50	3.37	1.53	3.62	1.64	2	2
2½	65	5.38	137	6.28	160	4.76	121	4.76	121	8.66	220	8.66	220	2.56	65	7.60	3.45	6.36	2.88	3	3
3	75	6.04	153	7.15	182	5.08	129	5.08	129	8.66	220	8.66	220	2.95	75	9.36	4.24	8.32	3.77	2	2
4	100	7.39	188	—	—	5.87	149	—	—	9.61	244	—	—	3.89	99	16.85	7.64	—	—	1	—

*** S-FP-600A ⅜" - 2" (S1), 2½" - 3" (S2)**
*** T-FP-600A ¼" - 4" (S2)**

Item Description	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)	variable are flow meter (rotameter)
Model Number	1358F1B2FC3D1A	1355EH2CCLN1A	1355EG2CCLN1A	1350EP2BCLN1A	1355EA2EALM1A	1350EP2ECLN1A	1355EH2BCLN1A
Fluid Type	Nitrogen gas (N_2)	Propane Gas (C3H8)	Hydrogen gas (H_2)	Hydrogen gas (H_2)	Carbon Dioxide gas (CO_2)	Helium gas (He)	"Air"
Flow Rate	1 to 10 scfm	0.13 to 1.3 scfm	0.2 to 2.0 scfm	0.71 to 7.1 scfm	0.011 - 0.11 scfm	0.88 TO 8.7 scfm	0.15 to 1.5 scfm
Operating Inlet Pressure	50 psig	50 psig	50 psig	50 psig	50 psig	50 psig	15 psig
Operating Outlet Pressure	15 psig	15 psig	15 psig	15 psig	15 psig	15 psig	0 psig
Operating Temperature	70 °F	70 °F	70 °F	70 °F	70 °F	70 °F	55 F
Float Material	316 S.S.	Sapphire	Sapphire	316 s.s.	Sapphire	tantalum	316 S.S.
Scale Type	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm	detachable, scfm
Accuracy	+/- 10% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%	+/- 10% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%	+/- 10% F.S. from 100% to 10%	+/- 5% F.S. from 100% to 10%
Packing Material	Viton	Viton	Viton	Viton	Buna-N	Viton	Viton
O-ring Material	Viton	Viton	Viton	Viton	Buna-N	Viton	Viton
Fitting & Adapter Material	brass	brass	brass	brass	brass	brass	brass
Connection Size & Type	3/8" FNPT with locknut	1/4" FNPT with locknut	1/4" FNPT with locknut	1/4" FNPT with locknut	1/4" FNPT with locknut	1/4" NPT locknut	1/4" FNPT with locknut
Valve Material & Type	brass, std. needle	brass, NRS #6	brass, NRS #6	brass, NRS #6	brass, NRS #6	BRASS NRS 6	brass, NRS #6
Connection Orientation	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back	Inlet - back / Outlet - back

Data Sheet
DS-VA-1350E-eng
April, 2011

Sho-Rate™ "50" Model 1350E and Sho-Rate™ "150" Model 1355E Flowmeters

FEATURES AND BENEFITS

- Heavy-wall, precision bore, borosilicate glass metering tubes
- A wide range of scales on the metering tube with contrasting background for easy readability
- Tubes sealed on compression gasket by threaded seal spindle
- Tubes removable without disconnecting instrument
- Integral float stops prevent loss of float during tube removal
- Interchangeable tubes and floats

DESCRIPTION

The Sho-Rate 1350 and 1355 Series of low flow indicators provides a cost-effective means of flow indication for both 5% (Model 1355) and 10% (Model 1350) accuracy requirements. Available options include the Standard or NRS™ integral needle control valves, as well as flow controllers on the inlet or outlet.

SPECIFICATIONS

Capacities

1350 Series: Refer to Tables 1 or 2, or 3 and 4
1355 Series: Refer to Tables 3 and 4, or 5

Accuracy

1350 Series Standard: Accuracy of ±10% of full scale
1355 Series Standard: ±5% of full scale

Repeatability

0.5% full scale

Pressure Equipment Directive (97/23/EC)

Note: Equipment falls under Sound Engineering Practice (SEP) according to the directive.

Pressure/Temperature

200 psig at temperatures 33°F to 250°F

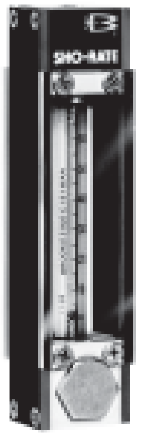
Pressure Drop

Inquire at factory

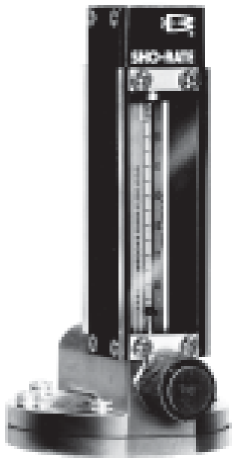
Flow Meter Assembly

Scales

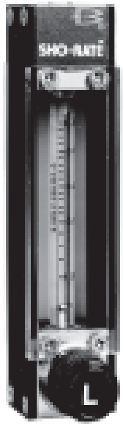
1350 Series:
Length: 65 mm, nominal
Graduations: Standard: R-65mm, or R-100 linear reference scale with air or water calibration table.



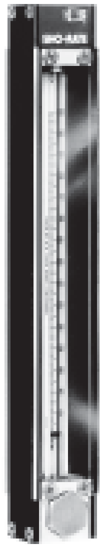
Model 1350E Sho-Rate "50" (No valve)



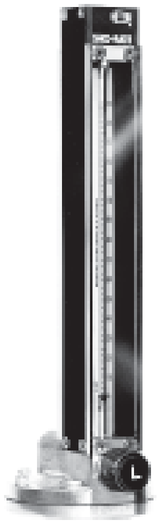
Model 1350E-8800 Sho-Rate "50" with optional integral flow controller



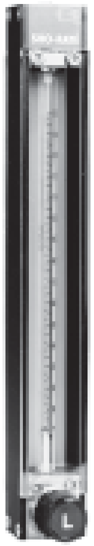
Model 1350E Sho-Rate "50" with optional needle valve



Model 1355E Sho-Rate "150" (No valve)



Model 1355E-8800 Sho-Rate "150" with optional integral flow controller



Model 1355E Sho-Rate "150" with optional needle valve

Models 1350E and 1355E

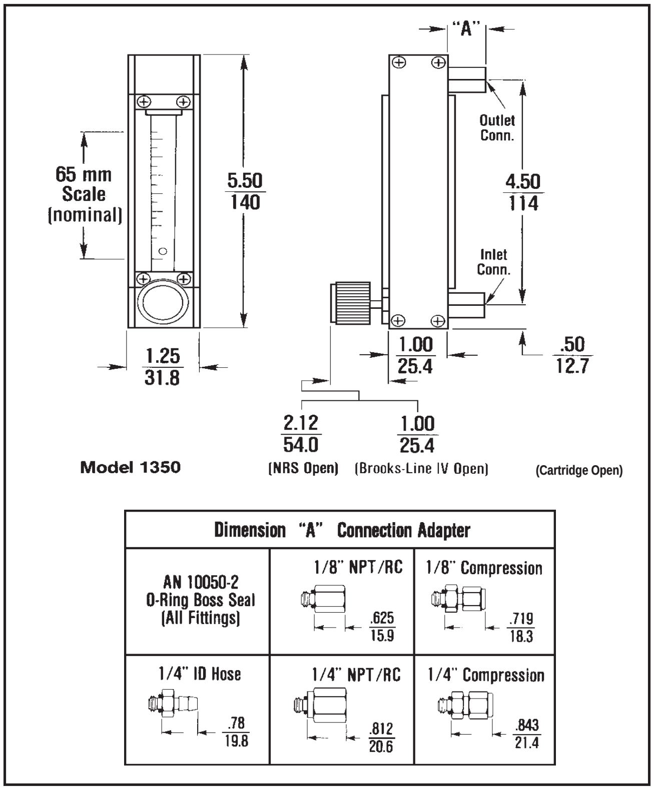


Figure 1 Dimensions - Sho-Rate 1350E

1355 Series:
Length: 150mm, nominal
Graduations: Standard: R-150 mm, or R-100 linear reference scale with air or water calibration table.
Optional: for either 65 mm or 150 mm direct reading scale, ceramic ink fused on glass tube or metal scale plate mounted beside tube
Type: Standard: Ceramic ink fused on meter tube with contrasting yellow background

Materials of Construction
Metering Tubes: Borosilicate glass

Floats: Glass, 316 stainless steel, sapphire, Carboloy®, tantalum

Structural Members:
End fittings: Chrome plated brass, black anodized aluminum, 316 stainless steel

Side Plates:
Standard: Black anodized aluminum
Optional: 316 stainless steel

Window: Clear polycarbonate; Back Window: Milk white polycarbonate

Float Stops:
Standard: Teflon®
Optional: 316 Stainless Steel

Tube Packing:
Standard: Buna-N (Brass and aluminum meters), Viton-A® fluoroelastomers (316 stainless steel meters)
Optional: Teflon, EPM (also known as EPR)

O-rings:
Standard: Buna-N (Brass and aluminum meters), Viton-A fluoroelastomers (316 stainless steel meters)
Optional: Teflon (not available with needle valves), EPM, Kalrez®

Connections
Standard: Horizontal female 1/8" NPT threaded adapters with locknuts for front of panel mounting

Dimensions
Refer to Figures 1, 2 and 4

Optional Equipment
Standard integral flow control valve on inlet or outlet (See DS-VA-CART-eng).

NRS integral flow control valve on inlet or outlet (See DS-VA-8503-eng). These valves are particularly suitable for precise control requirements, and are recommended for flow rates below 500 sccm of Air (@STP) or 10 cc/min water.

Flush mounting bezels in aluminum

Threaded adapters and locknuts for front of panel mounting (standard with 1/8" NPT)
1/8" and 1/4" compression fittings
1/4" female NPT connections
1/4" ID serrated hose connections
Base plates, without level

Ordering Information (Refer to Table 6)

1. Model
2. Size, connections, type
3. Quantity required
4. Fluid
5. Minimum, normal and maximum operating temperature
6. Minimum, normal and maximum operating pressure (inlet and outlet)
7. Minimum, normal and maximum flow rate
8. Materials of construction
   a. End fittings
   b. Side plates
   c. Bezel
   d. Elastomers
9. Fluid
10. Fluid specific gravity
11. Fluid viscosity
12. Unusual system conditions (For ranges and pressure drops other than those listed, consult factory).
13. Optional equipment
    a. Valve type and location
    b. Flow controller and type

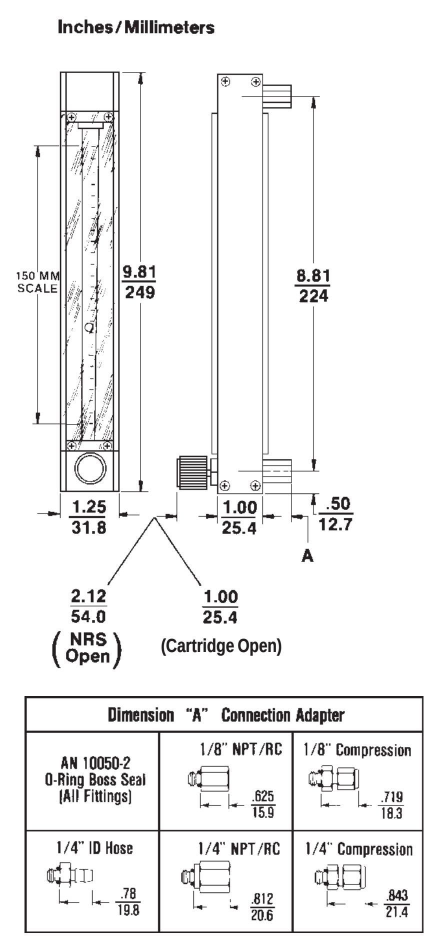
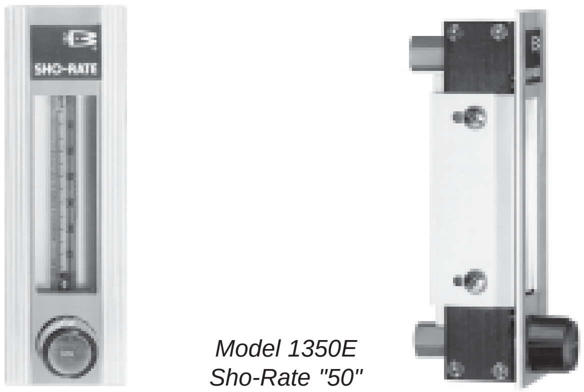


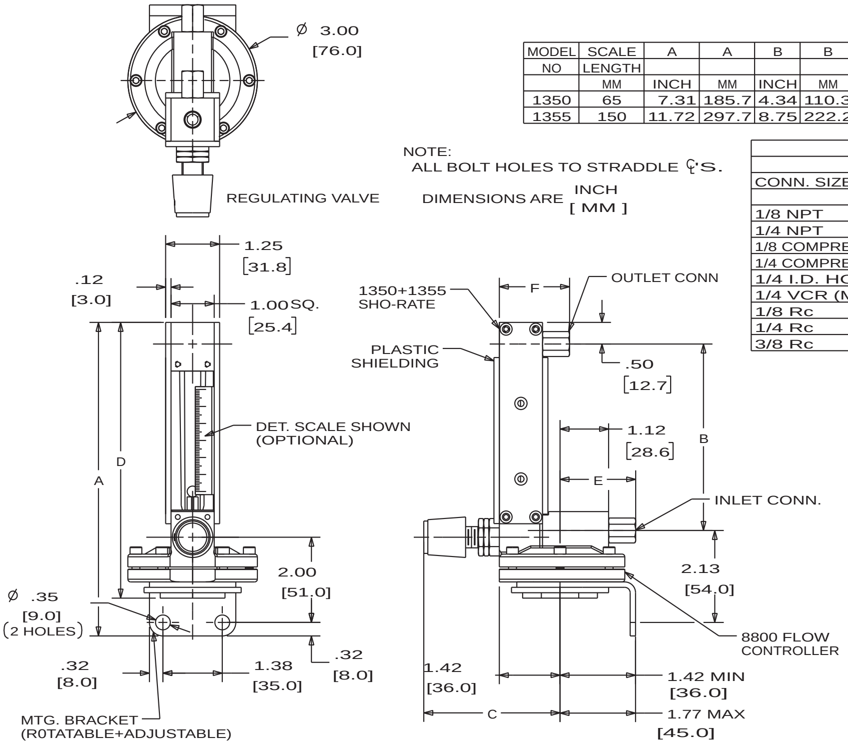
Figure 2 Dimensions - Sho-Rate 1355E



Model 1350E
Sho-Rate "50"
with optional needle valve and flush mounting bezel

Figure 3 Optional Equipment

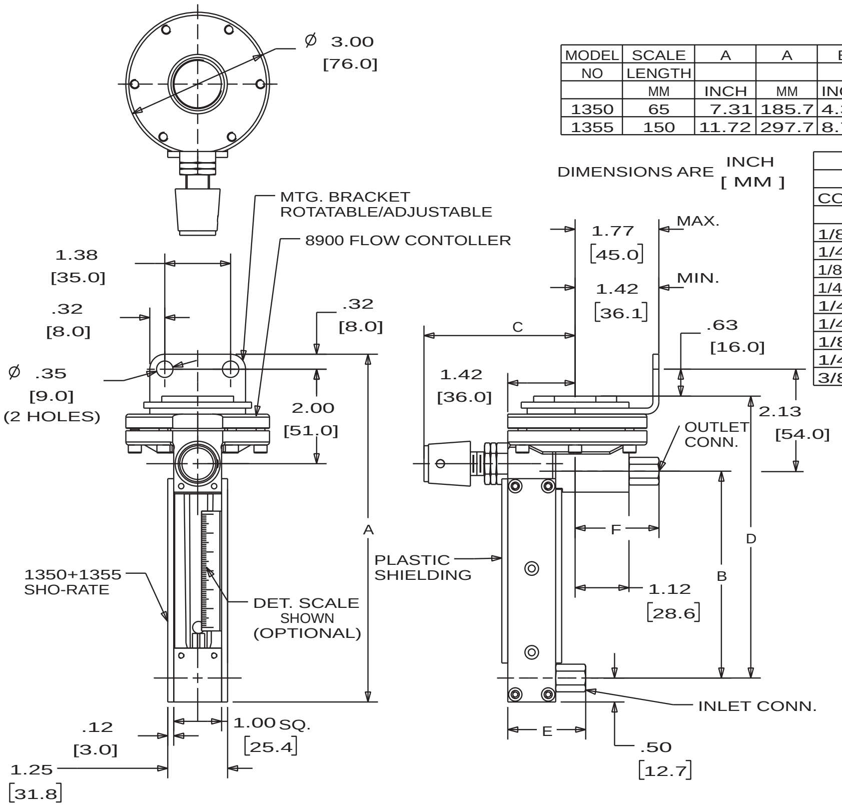
Models 1350E and 1355E



MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.72	43.7	1.62	41.1
1/4 NPT	1.12	28.6	1.81	46.0
1/8 COMPRESSION	1.91	48.5	1.81	46.0
1/4 COMPRESSION	2.04	51.8	1.94	49.3
1/4 I.D. HOSE	1.82	46.2	1.72	43.7
1/4 VCR (M)	N/A	N/A	2.06	52.3
1/8 Rc	1.91	48.5	1.62	41.1
1/4 Rc	1.91	48.5	1.81	46.0
3/8 Rc	2.35	53.1	2.09	53.1

Model 1350E-8800
Controller on Inlet



MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.62	41.1	1.72	43.7
1/4 NPT	1.81	46.0	1.12	28.6
1/8 COMPRESSION	1.81	46.0	1.91	48.5
1/4 COMPRESSION	1.94	49.3	2.04	51.8
1/4 I.D. HOSE	1.72	43.7	1.82	46.2
1/4 VCR (M)	2.06	52.3	N/A	N/A
1/8 Rc	1.62	41.1	1.91	48.5
1/4 Rc	1.81	46.0	1.91	48.5
3/8 Rc	2.09	53.1	2.35	59.7

Model 1350E-8900
(Controller on Outlet)

Figure 4 Dimensions - Sho-Rate 1350E & 1355E with Integral Flow Controller

Table 1 Capacities for Sho-Rate Model 1350E Rib Guided Tubes, Spherical Floats

	RIBBED TUBES, SPHERICAL FLOATS									
METER SIZE	TUBE NO.	FLOAT MATERIAL	MAXIMUM FLOW RATE							
			WATER				AIR*			
			GPH	CODE	LPH	CODE	SCFH	CODE	NLPH	CODE
2	R-2-65-A	GLASS	0.011	JB6	0.042	JB9	0.13	JB7	3.4	JB8
		SAPPHIRE	0.022	JC4	0.085	JC2	0.18	JC3	5.0	JC1
		STN. STL.	0.046	JC8	0.18	JC5	0.34	JC7	9.0	JC6
		CARBOLOY	0.10	JB4	0.38	JB5	0.65	JB2	17.0	JB3
		TANTALUM	0.11	JD2	0.42	JC9	0.70	JD1	19.0	JD3
	R-2-65-B	GLASS	0.013	KB8	0.048	KB2	0.15	KB7	4.0	KB9
		SAPPHIRE	0.026	KC1	0.10	KD3	0.22	KC2	5.5	KC3
		STN. STL.	0.06	KC5	0.22	KC6	0.42	KC7	11.0	KC8
		CARBOLOY	0.12	KB4	0.48	KB5	0.80	KB3	22.0	KB6
		TANTALUM	0.13	KD2	0.50	KD5	0.85	KD4	22.0	KD1
	R-2-65-C	GLASS	0.11	LB9	0.42	LB7	0.95	LB6	24.0	LB8
		SAPPHIRE	0.15	LC1	0.6	LC2	1.3	LC3	34.0	LC4
		STN. STL.	0.38	LC7	1.4	LC8	2.0	LC9	50.0	LC6
		CARBOLOY	0.65	LB3	2.4	LB2	3.0	LB4	80.0	LB5
		TANTALUM	0.65	LD1	2.6	LD2	3.2	LD3	85.0	LD4
	R-2-65-D	GLASS	0.65	MB9	2.4	MB7	3.8	MB8	100	MC1
		SAPPHIRE	0.95	MC2	3.6	MC3	5.0	MC4	130	MC5
		STN. STL.	1.60	MC7	6.0	MD1	7.5	MC6	200	MC8
		CARBOLOY	2.40	MB5	9.0	MB2	11.0	MB3	280	MB4
		TANTALUM	2.60	MD5	10.0	MD6	12.0	MD2	300	MD4
6	R-6-65-A	GLASS	2.40	NB8	8.5	NB7	13.0	NC1	340	NB9
		SAPPHIRE	3.40	NC4	13.0	NC3	17.0	NC6	460	NC5
		STN. STL.	5.50	ND1	20.0	ND3	26.0	NC9	650	ND2
		CARBOLOY	8.50	NB2	32.0	NB3	36.0	NB5	950	NB6
		TANTALUM	9.0	ND6	34.0	ND5	38.0	ND7	1000	ND4
	R-6-65-B	GLASS	8.0	PB9	30.0	PB8	44.0	PC1	1100	PB7
		SAPPHIRE	12.0	PC5	44.0	PC3	60.0	PC4	1500	PC2
		STN. STL.	19.0	PD1	70.0	PC9	85.0	PC8	2200	PC6
		CARBOLOY	28.0	PB3	100	PB2	130	PB6	3400	PB4
		TANTALUM	30.0	PD7	110	PD6	140	PD5	3600	PD4

Table 2 Capacities for Sho-Rate Model 1350E Plain Tapered Tubes, Spherical Floats

	PLAIN TAPER TUBES, SPHERICAL FLOATS						
TUBE AND FLOAT	SCFH AIR*	Press. Drop ** Inches W.C.	CODE	TUBE AND FLOAT	GPH WATER	Press. Drop ** Inches W.C.	CODE
1-65A GLASS	1.2	1.0	AB4	1-65C GLASS	0.14	1.8	AB5
2-65A GLASS	1.9	2.2	BA7	2-65C STN. STL.	0.5	4.0	DA5
2-65B STN. STL	5.0	10.8	CA4	2-65D STN. STL.	1.0	19.5	CA8
3-65A GLASS	6.0	12.4	EB4	3-65C GLASS	0.7	22.3	EB9
3-65B STN. STL	10	10.1	EB8	3-65D STN. STL	1.6	18.3	EC1
4-65A GLASS	12	10.4	FC3	4-65C GLASS	2.0	18.7	FD3
4-65B STN. STL	18	25	FC8	4-65D STN. STL	4.0	45	FD6
5-65A GLASS	45	60	GB6	5-65C GLASS	9.0	109	GC4
5-65B STN. STL	80	214	GC1	5-65D STN. STL	17	385	GC5
6-65A GLASS	55	73	HB8	6-65C GLASS	11	132	HC7
6-65B STN. STL	90	292	HC5	6-65D STN. STL	20	525	HD1
6-65E CARBOLOY	120	400	HD3	6-65F CARBOLOY	30	890	HD4

*** FLOW RATES ARE MAXIMUM VALUES. AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F**
**** PRESSURE DROPS ARE APPROXIMATE**

TRADEMARKS

Brooks	Brooks Instrument, LLC
Carboloy	General Electric Co.
Kalrez	DuPont Performance Elastomers
NRS	Brooks Instrument, LLC
Sho-Rate	Brooks Instrument, LLC
Teflon	E.I. DuPont de Nemours & Co.
Viton-A	DuPont Performance Elastomers

Table 3 Tube and Float Code, Detachable Scale Option, 1st Digit

FIRST DIGIT FOR DETACHABLE SCALE CONFIGURATION		
CODE	MODEL 1350 TUBE	MODEL 1355 TUBE
A	1-65	R-2-15-A
B	2-65A	R-2-15-AA
C	2-65B & D	
D	2-65C	R-2-15-B
E	3-65	R-2-15-C
F	4-65	R-2-15-D
G	5-65	R-6-15-A
H	6-65	R-6-15-B
J	R-2-65-A	R-2-15-AAAA
K	R-2-65-B	
L	R-2-65-C	
M	R-2-65-D	
N	R-6-65-A	
P	R-6-65-B	
Y	NO TUBE	NO TUBE

Table 4 Tube and Float Code, Detachable Scale Option, 2nd & 3rd Digits

SECOND AND THIRD DIGITS FOR DETACHABLE SCALE CONFIGURATION						
		DETACHABLE SCALE INSCRIPTION				
METER ACCURACY	FLOAT MATERIAL	MM	0-100 LINEAR	SPECIAL SINGLE SCALE	SPECIAL DUAL SCALE	BLANK SCALE
STANDARD (1350-10%) (1355- 5%)	GLASS	1A	1N	2A	2N	3A
	STN. STL.	1B	1P	2B	2P	3B
	SAPPHIRE	1C	1Q	2C	2Q	3C
	CARBOLOY	1D	1R	2D	2R	3D
	TANTALUM	1E	1S	2E	2S	3E
CALIBRATED ** (1350-5%) (1355-2%)	GLASS	1G	1U	2G	2U	
	STN. STL.	1H	1V	2H	2V	
	SAPPHIRE	1J	1W	2J	2W	
	CARBOLOY	1K	1X	2K	2X	
	TANTALUM	1L	1Y	2L	2Y	
N/A	NONE	9A	9B			9C

Table 5 Capacities for Sho-Rate Model 1355E Rib Guided Tubes, Spherical Floats

CAPACITIES (RIB GUIDE TUBES, SPHERICAL FLOATS) - FOR USE WITH 1355 SERIES ONLY								
			MAXIMUM FLOW RATE *		MODEL CODE - SCALE ON TUBE			
METER SIZE	TUBE NO.	FLOAT MATERIAL	WATER (CC/MIN.)	AIR	0-150 MM	10-100%		0-100 LINEAR
2	R-2-15-AAAA	GLASS	0.59	50 SCC/M	JA6			JA1
		SAPPHIRE	1.1	79 SCC/M	JA8			JA3
		STN. STL.	2.6	150 SCC/M	JA7			JA2
		CARBOLOY	5.2	280 SCC/M	JA9			JA4
		TANTALUM	5.8	310 SCC/M	JB1			JA5
	R-2-15-AA	GLASS	1.11	88 SCC/M	BA6			BA1
		SAPPHIRE	2.15	136 SCC/M	BA8			BA3
		STN. STL.	4.93	258 SCC/M	BA7			BA2
		CARBOLOY	9.33	439 SCC/M	BA9			BA4
		TANTALUM	10.4	478 SCC/M	BB1			BA5
	R-2-15-D	GLASS	5.75	380 SCC/M	FA6			FA1
		SAPPHIRE	10.5	518 SCC/M	FA8			FA3
		STN. STL.	20.6	832 SCC/M	FA7			FA2
		CARBOLOY	33.2	1240 SCC/M	FA9			FA4
		TANTALUM	35.9	1320 SCC/M	FB1	LIQ.	GAS	FA5
	R-2-15-A	GLASS	16.6	.83 SLPM	AA6	AB7	AC3	AA1
		SAPPHIRE	26.3	1.1 SLPM	AA8	AB9	AC4	AA3
		STN. STL.	46.2	1.69 SLPM	AA7	AB8	AC6	AA2
		CARBOLOY	70.8	2.44 SLPM	AA9	AC1	AC5	AA4
		TANTALUM	75.9	2.6 SLPM	AB1	AC2	AC7	AA5
	R-2-15-B	GLASS	52.8	2.37 SLPM	DA6	DB2		DA1
		SAPPHIRE	79.7	3.08 SLPM	DA8	DB4		DA3
		STN. STL.	133	4.7 SLPM	DA7	DB3		DA2
		CARBOLOY	199	6.7 SLPM	DA9	DB5		DA4
		TANTALUM	212	7.1 SLPM	DB1	DB6		DA5
	R-2-15-C	GLASS	84.6	3.9 SLPM	EA6	EB2		EA1
		SAPPHIRE	129	5.1 SLPM	EA8	EB4		EA3
		STN. STL.	218	7.6 SLPM	EA7	EB3		EA2
		CARBOLOY	326	10.6 SLPM	EA9	EB5		EA4
		TANTALUM	349	11.3 SLPM	EB1	EB6		EA5
6	R-6-15-A	GLASS	200	8.7 SLPM	GA6	GB2		GA1
		SAPPHIRE	297	11.2 SLPM	GA8	GB4		GA3
		STN. STL.	493	16.6 SLPM	GA7	GB3		GA2
		CARBOLOY	726	23.2 SLPM	GA9	GB5		GA4
		TANTALUM	772	24.6 SLPM	GB1	GB6		GA5
	R-6-15-B	GLASS	573	23.9 SLPM	HA6	HB2		HA1
		SAPPHIRE	851	30.2 SLPM	HA8	HB4		HA3
		STN. STL.	1350	43.8 SLPM	HA7	HB3		HA2
		CARBOLOY	1950	61.2 SLPM	HA9	HB5		HA4
		TANTALUM	2060	64.7 SLPM	HB1	HB6		HA5

NOTE: ALL AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F.

*** FLOW RATES SHOWN ARE MAXIMUM CAPACITIES**
DIRECT READ SCALES MAY END AT SLIGHTLY DIFFERENT MAXIMUM FLOWS.

Table 6 Ordering Information and Model Code

MODEL	PURGE FLOWMETER
1350E	65 MM TUBE, SIZES 2-6
1355E	150 MM TUBE, SIZES 2-6

CODE	TUBE, SCALE AND FLOAT
___	MODEL 1350 OR 1355 DETACHABLE SCALE - SEE TABLES 3 & 4
___	MODEL 1350 - SEE TABLE 1 OR 2
___	MODEL 1355 - SEE TABLE 5

CODE	TUBE PACKING	O-RING MATERIAL (METER/VALVE ASSEMBLY)
A	BUNA -N	BUNA-N (STD FOR ALUMINUM AND BRASS METERS)
B	VITON	BUNA-N
C	VITON	VITON (STD FOR STN. STL. METERS)
D	VITON	TEFLON/KALREZ (KALREZ O-RINGS IN VALVE OR CONTROLLER)
E	VITON	EPM
F	VITON	KALREZ
G	TEFLON	BUNA-N
H	TEFLON	VITON
J	TEFLON	TEFLON/KALREZ (KALREZ O-RINGS IN VALVE OR CONTROLLER)
K	TEFLON	EPM
L	TEFLON	KALREZ
M	EPM	EPM
N	BUTYL	BUTYL
P	NO PACKING	BUNA-N
Q	NO PACKING	VITON
R	NO PACKING	TEFLON/KALREZ (KALREZ O-RINGS IN VALVE OR CONTROLLER)
S	NO PACKING	EPM
T	NO PACKING	KALREZ
U	NO PACKING	BUTYL

CODE	FITTING AND ADAPTER MATERIAL/PROCESS CONNECTION SIZE AND TYPE
A	BRASS/ 1/8" NPT
D	BRASS/ THD 1/8" NPT WITH LOCKNUTS (STANDARD)
G	BRASS/ 1/4" NPT (STD WITH FLOW CONTROLLER)
L	BRASS/ THD 1/4" NPT WITH LOCKNUTS
P	BRASS/ 1/8" COMPRESSION
S	BRASS/ THD 1/8" COMPRESSION WITH LOCKNUTS
V	BRASS/ 1/4" COMPRESSION
Y	BRASS/ THD 1/4" COMPRESSION WITH LOCKNUTS
2	BRASS/ 1/4" I.D. HOSE
5	BRASS/ NO ADAPTOR-INTEGRAL 5/16-24 THD
E	ALUMINUM/ THD 1/8" NPT WITH LOCKNUTS (STANDARD)
H	ALUMINUM/ 1/4" NPT (STD WITH FLOW CONTROLLER)
6	ALUMINUM/ NO ADAPTOR-INTEGRAL 5/16-24 THD
C	316 STAINLESS STEEL/ 1/8" NPT
F	316 STAINLESS STEEL/ THD 1/8" NPT WITH LOCKNUTS (STANDARD)
J	316 STAINLESS STEEL/ 1/4" NPT (STD WITH FLOW CONTROLLER)
N	316 STAINLESS STEEL/ THD 1/4" NPT WITH LOCKNUTS
R	316 STAINLESS STEEL/ 1/8" COMPRESSION
U	316 STAINLESS STEEL/ THD 1/8 COMPRESSION WITH LOCKNUTS
X	316 STAINLESS STEEL/ 1/4" COMPRESSION
1	316 STAINLESS STEEL/ THD 1/4" COMPRESSION WITH LOCKNUTS
4	316 STAINLESS STEEL/ 1/4" I.D. HOSE
7	316 STAINLESS STEEL/ NO ADAPTER INTEGRAL 5/16-24 THD
8	316 STAINLESS STEEL/ 1/4" VCR
T	316 STAINLESS STEEL/ THD 1/8" Rc WITH LOCKNUTS
W	316 STAINLESS STEEL/ THD 1/4" Rc WITH LOCKNUTS
3	316 STAINLESS STEEL/ THD 3/8" Rc WITH LOCKNUTS

Table 6 Ordering Information and Model Code Continued

CODE	VALVE TYPE
A	VALVE PLUG
B	STANDARD VALVE - BRASS - LOW FLOW
C	STANDARD VALVE - BRASS - MEDIUM FLOW
D	STANDARD VALVE - BRASS - HIGH FLOW
E	STANDARD VALVE - 316 STAINLESS STEEL - LOW FLOW
F	STANDARD VALVE - 316 STAINLESS STEEL - MEDIUM FLOW
G	STANDARD VALVE - 316 STAINLESS STEEL - HIGH FLOW
H	NRS-BRASS #1
J	NRS-BRASS #2
K	NRS-BRASS #3
L	NRS-BRASS #4
M	NRS-BRASS #5
N	NRS-BRASS #6
P	NRS - 316 STAINLESS STEEL #1
Q	NRS - 316 STAINLESS STEEL #2
R	NRS - 316 STAINLESS STEEL #3
S	NRS - 316 STAINLESS STEEL #4
T	NRS - 316 STAINLESS STEEL #5
U	NRS - 316 STAINLESS STEEL #6
V	TO INTEGRALLY MOUNTED FLOW CONTROLLER (NOTE 1 & NOTE 3)
W	STANDARD VALVE CAVITY - NO VALVE ASSEMBLY OR PLUG
X	NO VALVE CAVITY (MUST USE CODE 9 BELOW FOR VALVE CAVITY LOCATION)
1	C-VALVE - 316 STAINLESS STEEL - LOW FLOW - SPECIAL
2	C-VALVE - 316 STAINLESS STEEL - MEDIUM FLOW - SPECIAL
3	C-VALVE - 316 STAINLESS STEEL - HIGH FLOW - SPECIAL

CODE	VALVE CAVITY LOCATION	CONNECTION ORIENTATION	
1	INLET	IN-BACK,	OUT-BACK (STD)
5	OUTLET	IN-BACK,	OUT-BACK (STD)
9	NONE	IN-BACK,	OUT-BACK

CODE	ACCESSORIES - 1,2, OR 3 DIGIT FIELD
A	NONE
B	ALUMINUM FLUSH MOUNTING BEZEL
E	TRIPOD BASE WITHOUT SPIRIT LEVEL (NOTE 2)
J	DEGREASE FOR OXYGEN SERVICE
L	STAINLESS STEEL SIDE PLATES
M	STAINLESS STEEL SPRING FLOAT STOPS
N	CALIBRATE FOR NIST TRACEABILITY (10%, 1350; 5%, 1355)
Q	NO BROOKS IDENTIFICATION

1350E	LC7	C	F	A	1	A	TYPICAL MODEL CODE

NOTES:
1 FLOW CONTROLLERS TO HAVE SEPARATE MODEL CODE AND BE A SECOND LINE ITEM ON ORDER
2 THREADED ADAPTERS AND LOCKNUTS MUST BE SPECIFIED
3 FLOW CONTROLLERS NOT AVAILABLE WITH THREADED ADAPTERS AND LOCKNUTS

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Installation and Operation Manual
X-VA-1350E-eng
Part Number: 541B082AAG
April, 2011

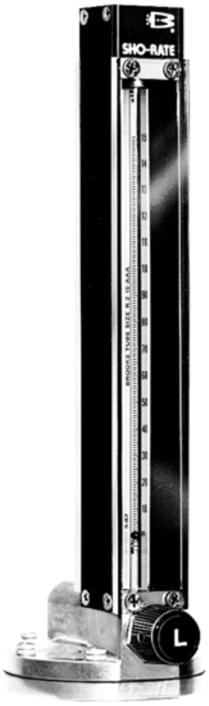
Sho-Rate™ "50" Model 1350E and Sho-Rate™ "150" Model 1355E Sizes 2-6 Flowmeters


Model 1350E
Sho-Rate "50"
(no valve)


Model 1350E
Sho-Rate "50"
With optional Integral
flow controller


Model 1350E
Sho-Rate "50"
With optional
needle valve


Model 1355E
Sho-Rate "150"
(no valve)


Model 1355E
Sho-Rate "150"
With optional Integral
flow controller


Model 1355E
Sho-Rate "150"
With optional
needle valve

BROOKS®
INSTRUMENT

Installation and Operation Manual
X-VA-1350E-eng
Part Number: 541B082AAG
April, 2011

Models 1350E and 1355E

Essential Instructions
Read before proceeding!

Brooks Instrument designs, manufactures and tests its products to meet many national and international standards. These products must be properly installed, operated and maintained to ensure they continue to operate within their normal specifications. The following instructions must be adhered to and integrated into your safety program when installing, operating and maintaining Brooks Instrument products.

- To ensure proper performance, use qualified personnel to install, operate, update, program and maintain the product.
- Read all instructions prior to installing, operating and servicing the product. If this instruction manual is not the correct manual, please see back cover for local sales office contact information. Save this instruction manual for future reference.

⚠ **WARNING: Do not operate this instrument in excess of the specifications listed in the Instruction and Operation Manual. Failure to heed this warning can result in serious personal injury and / or damage to the equipment.**

- If you do not understand any of the instructions, contact your Brooks Instrument representative for clarification.
- Follow all warnings, cautions and instructions marked on and supplied with the product.
- Install your equipment as specified in the installation instructions of the appropriate instruction manual and per applicable local and national codes. Connect all products to the proper electrical and pressure sources.
- Operation: (1) Slowly initiate flow into the system. Open process valves slowly to avoid flow surges. (2) Check for leaks around the flow meter inlet and outlet connections. If no leaks are present, bring the system up to the operating pressure.
- Please make sure that the process line pressure is removed prior to service. When replacement parts are required, ensure that qualified people use replacement parts specified by Brooks Instrument. Unauthorized parts and procedures can affect the product's performance and place the safe operation of your process at risk. Look-alike substitutions may result in fire, electrical hazards or improper operation.
- Ensure that all equipment doors are closed and protective covers are in place to prevent electrical shock and personal injury, except when maintenance is being performed by qualified persons.

⚠ **WARNING: For liquid flow devices, if the inlet and outlet valves adjacent to the devices are to be closed for any reason, the devices must be completely drained. Failure to do so may result in thermal expansion of the liquid that can rupture the device and may cause personal injury.**

European Pressure Equipment Directive (PED)

All pressure equipment with an internal pressure greater than 0.5 bar (g) and a size larger than 25mm or 1" (inch) falls under the Pressure Equipment Directive (PED).

- The Specifications Section of this manual contains instructions related to the PED directive.
- Meters described in this manual are in compliance with EN directive 97/23/EC.
- All Brooks Instrument Flowmeters fall under fluid group 1.
- Meters larger than 25mm or 1" (inch) are in compliance with PED category I, II or III.
- Meters of 25mm or 1" (inch) or smaller are Sound Engineering Practice (SEP).

European Electromagnetic Compatibility (EMC)

The Brooks Instrument (electric/electronic) equipment bearing the CE mark has been successfully tested to the regulations of the Electro Magnetic Compatibility (2004/108/EC (EMC directive 89/336/EEC)).
Special attention however is required when selecting the signal cable to be used with CE marked equipment.

Quality of the signal cable, cable glands and connectors:
Brooks Instrument supplies high quality cable(s) which meets the specifications for CE certification.
If you provide your own signal cable you should use a cable which is overall completely screened with a 100% shield.
“D” or “Circular” type connectors used should be shielded with a metal shield. If applicable, metal cable glands must be used providing cable screen clamping.
The cable screen should be connected to the metal shell or gland and shielded at both ends over 360 Degrees.
The shield should be terminated to an earth ground.
Card Edge Connectors are standard non-metallic. The cables used must be screened with 100% shield to comply with CE certification.
The shield should be terminated to an earth ground.
For pin configuration : Please refer to the enclosed Instruction Manual.

ESD (Electrostatic Discharge)

⚠ **CAUTION: This instrument contains electronic components that are susceptible to damage by static electricity. Proper handling procedures must be observed during the removal, installation or other handling of internal circuit boards or devices.**

Handling Procedure:

1. Power to unit must be removed.
2. Personnel must be grounded, via a wrist strap or other safe, suitable means before any printed circuit card or other internal device is installed, removed or adjusted.
3. Printed circuit cards must be transported in a conductive container. Boards must not be removed from protective enclosure until immediately before installation. Removed boards must immediately be placed in protective container for transport, storage or return to factory.

Comments
This instrument is not unique in its content of ESD (electrostatic discharge) sensitive components. Most modern electronic designs contain components that utilize metal oxide technology (NMOS, SMOS, etc.). Experience has proven that even small amounts of static electricity can damage or destroy these devices. Damaged components, even though they appear to function properly, exhibit early failure.

Installation and Operation Manual
X-VA-1350E-eng
Part Number: 541B082AAG
April, 2011

Models 1350E and 1355E

Dear Customer,

We appreciate this opportunity to service your flow measurement and control requirements with a Brooks Instrument device. Every day, flow customers all over the world turn to Brooks Instrument for solutions to their gas and liquid low-flow applications. Brooks provides an array of flow measurement and control products for various industries from biopharmaceuticals, oil and gas, fuel cell research and chemicals, to medical devices, analytical instrumentation, semiconductor manufacturing, and more.

The Brooks product you have just received is of the highest quality available, offering superior performance, reliability and value to the user. It is designed with the ever changing process conditions, accuracy requirements and hostile process environments in mind to provide you with a lifetime of dependable service.

We recommend that you read this manual in its entirety. Should you require any additional information concerning Brooks products and services, please contact your local Brooks Sales and Service Office listed on the back cover of this manual or visit www.BrooksInstrument.com

Yours sincerely,
Brooks Instrument

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Contents

Models 1350E and 1355E

Section 1 Introduction

Section 2 Installation

Section 3 Operation

Section 4 Maintenance

Section 5 Parts List

Figures

Tables

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1-1 Description

The Sho-Rate Flowmeters are variable area, glass tube, flow rate indicating meters. The basic elements are a tapered glass metering tube and a metering float. Features include quick and simple removal or installation of the tube and float while the meter remains in the process piping.

1-2 Specifications

⚠ WARNING

Do not operate this instrument in excess of the specifications listed below. Failure to heed this warning can result in serious personal injury and/or damage to the equipment.

⚠ WARNING

Glass metering tubes are designed for operation up to the maximum operating pressures and temperatures as specified herein. Due to the inherent brittle characteristics of glass and conditions beyond our control, tube breakage could result even within specified operating conditions. Do not use glass tube meters with fluids that are toxic, or chemically react with glass such as water above 140° F, steam, alkalis, fluorine, hydrofluoric acid, or molten metal. Failure to heed warning can result in serious personal injury and/or damage to the equipment.

Capacities
1350 Series: Refer to Tables 1-1 or 1-2, or 1-3 and 1-4
1355 Series: Refer to Tables 1-3 and 1-4, or 1-5

Accuracy
1350 Series Standard: Accuracy of ±10% of full scale
1355 Series Standard: ±5% of full scale

Repeatability
0.5% full scale

Pressure Equipment Directive (97/23/EC)
Note: Equipment falls under Sound Engineering Practice (SEP) according to the directive.

Pressure/Temperature
200 psig at temperatures 33°F to 250°F

Pressure Drop
Inquire at factory

Flow Meter Assembly

Scales

1350 Series:
Length: 65 mm, nominal
Graduations: Standard: R-65mm, or R-100 linear reference scale with air or water calibration table.
1355 Series:
Length: 150mm, nominal
Graduations: Standard: R-150 mm, or R-100 linear reference scale with air or water calibration table. Optional: for either 65 mm or 150 mm direct reading scale, ceramic ink fused on glass tube or metal scale plate mounted beside tube
Type: Standard: Ceramic ink fused on meter tube with contrasting yellow background

Materials of Construction

⚠ CAUTION

It is the user's responsibility to select and approve all materials of construction. Careful attention to metallurgy, engineered materials and elastomeric materials is critical to safe operation.

Metering Tubes: Borosilicate glass
Floats: Glass, 316 stainless steel, sapphire, Carboloy®, tantalum

Structural Members:

End fittings: Chrome plated brass, black anodized aluminum, 316 stainless steel

Side Plates:
Standard: Black anodized aluminum
Optional: 316 stainless steel

Window: Clear polycarbonate; Back Window: Milk white polycarbonate

Float Stops:
Standard: Teflon®
Optional: 316 Stainless Steel

Tube Packing:
Standard: Buna-N (Brass and aluminum meters), Viton-A® fluoroelastomers (316 stainless steel meters)
Optional: Teflon® , EPM (also known as EPR)

O-rings:
Standard: Buna-N (Brass and aluminum meters), Viton-A fluoroelastomers (316 stainless steel meters)
Optional: Teflon (not available with needle valves), EPM, Kalrez®

Connections

Standard: Horizontal female 1/8" NPT threaded adapters with locknuts for front of panel mounting

Dimensions
Refer to Figures 2-2, 2-3 and 2-4

Table 1-1 Capacities for Sho-Rate Model 1350E Rib Guided Tubes, Spherical Floats

	RIBBED TUBES, SPHERICAL FLOATS									
METER SIZE	**TUBE NO.**	**FLOAT MATERIAL**	**MAXIMUM FLOW RATE**							
			WATER				**AIR***			
			GPH	**CODE**	**LPH**	**CODE**	**SCFH**	**CODE**	**NLPH**	**CODE**
2	R-2-65-A	GLASS	0.011	JB6	0.042	JB9	0.13	JB7	3.4	JB8
		SAPPHIRE	0.022	JC4	0.085	JC2	0.18	JC3	5.0	JC1
		STN. STL.	0.046	JC8	0.18	JC5	0.34	JC7	9.0	JC6
		CARBOLOY	0.10	JB4	0.38	JB5	0.65	JB2	17.0	JB3
		TANTALUM	0.11	JD2	0.42	JC9	0.70	JD1	19.0	JD3
	R-2-65-B	GLASS	0.013	KB8	0.048	KB2	0.15	KB7	4.0	KB9
		SAPPHIRE	0.026	KC1	0.10	KD3	0.22	KC2	5.5	KC3
		STN. STL.	0.06	KC5	0.22	KC6	0.42	KC7	11.0	KC8
		CARBOLOY	0.12	KB4	0.48	KB5	0.80	KB3	22.0	KB6
		TANTALUM	0.13	KD2	0.50	KD5	0.85	KD4	22.0	KD1
	R-2-65-C	GLASS	0.11	LB9	0.42	LB7	0.95	LB6	24.0	LB8
		SAPPHIRE	0.15	LC1	0.6	LC2	1.3	LC3	34.0	LC4
		STN. STL.	0.38	LC7	1.4	LC8	2.0	LC9	50.0	LC6
		CARBOLOY	0.65	LB3	2.4	LB2	3.0	LB4	80.0	LB5
		TANTALUM	0.65	LD1	2.6	LD2	3.2	LD3	85.0	LD4
	R-2-65-D	GLASS	0.65	MB9	2.4	MB7	3.8	MB8	100	MC1
		SAPPHIRE	0.95	MC2	3.6	MC3	5.0	MC4	130	MC5
		STN. STL.	1.60	MC7	6.0	MD1	7.5	MC6	200	MC8
		CARBOLOY	2.40	MB5	9.0	MB2	11.0	MB3	280	MB4
		TANTALUM	2.60	MD5	10.0	MD6	12.0	MD2	300	MD4
6	R-6-65-A	GLASS	2.40	NB8	8.5	NB7	13.0	NC1	340	NB9
		SAPPHIRE	3.40	NC4	13.0	NC3	17.0	NC6	460	NC5
		STN. STL.	5.50	ND1	20.0	ND3	26.0	NC9	650	ND2
		CARBOLOY	8.50	NB2	32.0	NB3	36.0	NB5	950	NB6
		TANTALUM	9.0	ND6	34.0	ND5	38.0	ND7	1000	ND4
	R-6-65-B	GLASS	8.0	PB9	30.0	PB8	44.0	PC1	1100	PB7
		SAPPHIRE	12.0	PC5	44.0	PC3	60.0	PC4	1500	PC2
		STN. STL.	19.0	PD1	70.0	PC9	85.0	PC8	2200	PC6
		CARBOLOY	28.0	PB3	100	PB2	130	PB6	3400	PB4
		TANTALUM	30.0	PD7	110	PD6	140	PD5	3600	PD4

*** FLOW RATES GIVEN ARE MAXIMUM VALUES. AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F.**

Table 1-2 Capacities for Sho-Rate Model 1350E Plain Tapered Tubes, Spherical Floats

	PLAIN TAPER TUBES, SPHERICAL FLOATS						
TUBE AND FLOAT	**SCFH AIR***	**Press. Drop ** Inches W.C.**	**CODE**	**TUBE AND FLOAT**	**GPH WATER**	**Press. Drop ** Inches W.C.**	**CODE**
1-65A GLASS	1.2	1.0	AB4	1-65C GLASS	0.14	1.8	AB5
2-65A GLASS	1.9	2.2	BA7	2-65C STN. STL.	0.5	4.0	DA5
2-65B STN. STL	5.0	10.8	CA4	2-65D STN. STL.	1.0	19.5	CA8
3-65A GLASS	6.0	12.4	EB4	3-65C GLASS	0.7	22.3	EB9
3-65B STN. STL	10	10.1	EB8	3-65D STN. STL	1.6	18.3	EC1
4-65A GLASS	12	10.4	FC3	4-65C GLASS	2.0	18.7	FD3
4-65B STN. STL	18	25	FC8	4-65D STN. STL	4.0	45	FD6
5-65A GLASS	45	60	GB6	5-65C GLASS	9.0	109	GC4
5-65B STN. STL	80	214	GC1	5-65D STN. STL	17	385	GC5
6-65A GLASS	55	73	HB8	6-65C GLASS	11	132	HC7
6-65B STN. STL	90	292	HC5	6-65D STN. STL	20	525	HD1
6-65E CARBOLOY	120	400	HD3	6-65F CARBOLOY	30	890	HD4

*** FLOW RATES ARE MAXIMUM VALUES. AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F**
**** PRESSURE DROPS ARE APPROXIMATE**

Table 1-3 Tube and Float Code, Detachable Scale Option, 1st Digit

FIRST DIGIT FOR DETACHABLE SCALE CONFIGURATION		
CODE	**MODEL 1350 TUBE**	**MODEL 1355 TUBE**
A	1-65	R-2-15-A
B	2-65A	R-2-15-AA
C	2-65B & D	
D	2-65C	R-2-15-B
E	3-65	R-2-15-C
F	4-65	R-2-15-D
G	5-65	R-6-15-A
H	6-65	R-6-15-B
J	R-2-65-A	R-2-15-AAAA
K	R-2-65-B	
L	R-2-65-C	
M	R-2-65-D	
N	R-6-65-A	
P	R-6-65-B	
Y	NO TUBE	NO TUBE

Table 1-4 Tube and Float Code, Detachable Scale Option, 2nd & 3rd Digits

METER ACCURACY	FLOAT MATERIAL	DETACHABLE SCALE INSCRIPTION				
		MM	**0-100 LINEAR**	**SPECIAL SINGLE SCALE**	**SPECIAL DUAL SCALE**	**BLANK SCALE**
STANDARD (1350-10%) (1355- 5%)	GLASS	1A	1N	2A	2N	3A
	STN. STL.	1B	1P	2B	2P	3B
	SAPPHIRE	1C	1Q	2C	2Q	3C
	CARBOLOY	1D	1R	2D	2R	3D
	TANTALUM	1E	1S	2E	2S	3E
	*ALUMINUM	1F	1T	2F	2T	3F
CALIBRATED (1350-5%) (1355-2%)	GLASS	1G	1U	2G	2U	
	STN. STL.	1H	1V	2H	2V	
	SAPPHIRE	1J	1W	2J	2W	
	CARBOLOY	1K	1X	2K	2X	
	TANTALUM	1L	1Y	2L	2Y	
	*ALUMINUM	1M	1Z	2M	2Z	
N/A	NONE	9A	9B			9C

***ALUMINUM SPOOL FLOAT FOR 15 CC/MIN AIR AVAILABLE ONLY WITH R-2-15-AAA TUBE**

1-3 Optional Equipment

Standard Needle Valve

The standard needle valve can be supplied integrally mounted to the inlet or outlet of the instrument. For more details on the needle valve go to our website: **BrooksInstrument.com**, select Documentation, Precision Valves & Flow Controllers, select Brooks-Line IV, CART, 8503 or 8504 valves.

Flow Contollers

Flow controllers can be supplied integrally mounted to the inlet or outlet of the instrument. For the flow controller's complete instruction manual go to our website: **BrooksInstrument.com**, select Documentation, Precision Valves & Flow Controllers, select FC8800, or FC8900.

Table 1-5 Capacities for Sho-Rate Model 1355E Rib Guided Tubes, Spherical Floats

CAPACITIES (RIB GUIDE TUBES, SPHERICAL FLOATS) - FOR USE WITH 1355 SERIES ONLY								
			MAXIMUM FLOW RATE *		MODEL CODE - SCALE ON TUBE			
METER SIZE	TUBE NO.	FLOAT MATERIAL	WATER (CC/MIN.)	AIR	0-150 MM	10-100%		0-100 LINEAR
2	R-2-15-AAAA	GLASS	0.59	50 SCC/M	JA6			JA1
		SAPPHIRE	1.1	79 SCC/M	JA8			JA3
		STN. STL.	2.6	150 SCC/M	JA7			JA2
		CARBOLOY	5.2	280 SCC/M	JA9			JA4
		TANTALUM	5.8	310 SCC/M	JB1			JA5
	R-2-15-AA	GLASS	1.11	88 SCC/M	BA6			BA1
		SAPPHIRE	2.15	136 SCC/M	BA8			BA3
		STN. STL.	4.93	258 SCC/M	BA7			BA2
		CARBOLOY	9.33	439 SCC/M	BA9			BA4
		TANTALUM	10.4	478 SCC/M	BB1			BA5
	R-2-15-D	GLASS	5.75	380 SCC/M	FA6			FA1
		SAPPHIRE	10.5	518 SCC/M	FA8			FA3
		STN. STL.	20.6	832 SCC/M	FA7			FA2
		CARBOLOY	33.2	1240 SCC/M	FA9			FA4
		TANTALUM	35.9	1320 SCC/M	FB1	LIQ.	GAS	FA5
	R-2-15-A	GLASS	16.6	.83 SLPM	AA6	AB7	AC3	AA1
		SAPPHIRE	26.3	1.1 SLPM	AA8	AB9	AC4	AA3
		STN. STL.	46.2	1.69 SLPM	AA7	AB8	AC6	AA2
		CARBOLOY	70.8	2.44 SLPM	AA9	AC1	AC5	AA4
		TANTALUM	75.9	2.6 SLPM	AB1	AC2	AC7	AA5
	R-2-15-B	GLASS	52.8	2.37 SLPM	DA6	DB2		DA1
		SAPPHIRE	79.7	3.08 SLPM	DA8	DB4		DA3
		STN. STL.	133	4.7 SLPM	DA7	DB3		DA2
		CARBOLOY	199	6.7 SLPM	DA9	DB5		DA4
		TANTALUM	212	7.1 SLPM	DB1	DB6		DA5
	R-2-15-C	GLASS	84.6	3.9 SLPM	EA6	EB2		EA1
		SAPPHIRE	129	5.1 SLPM	EA8	EB4		EA3
		STN. STL.	218	7.6 SLPM	EA7	EB3		EA2
		CARBOLOY	326	10.6 SLPM	EA9	EB5		EA4
		TANTALUM	349	11.3 SLPM	EB1	EB6		EA5
6	R-6-15-A	GLASS	200	8.7 SLPM	GA6	GB2		GA1
		SAPPHIRE	297	11.2 SLPM	GA8	GB4		GA3
		STN. STL.	493	16.6 SLPM	GA7	GB3		GA2
		CARBOLOY	726	23.2 SLPM	GA9	GB5		GA4
		TANTALUM	772	24.6 SLPM	GB1	GB6		GA5
	R-6-15-B	GLASS	573	23.9 SLPM	HA6	HB2		HA1
		SAPPHIRE	851	30.2 SLPM	HA8	HB4		HA3
		STN. STL.	1350	43.8 SLPM	HA7	HB3		HA2
		CARBOLOY	1950	61.2 SLPM	HA9	HB5		HA4
		TANTALUM	2060	64.7 SLPM	HB1	HB6		HA5

NOTE: ALL AIR FLOWS ARE AT 14.7 PSIA AND 70 DEGREES F.

*** FLOW RATES SHOWN ARE MAXIMUM CAPACITIES**
DIRECT READ SCALES MAY END AT SLIGHTLY DIFFERENT MAXIMUM FLOWS.

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2-1 Receipt of Equipment

When the equipment is received, the outside of the packing case should be checked for any damage incurred during shipment. If the packing case is damaged, the local carrier should be notified at once regarding his liability. Remove the envelope containing the shipping list. Carefully remove the equipment from the packing case and inspect for any damaged or missing parts.

In the event that the meter is damaged during shipment, the Product Service Department, Brooks Instrument,LLC, Hatfield, PA 19440 should be contacted to obtain a return shipment form.

Brooks Instrument
407 W. Vine Street
P.O. Box 903
Hatfield, PA 19440 USA
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Tel (215) 362 3700
Fax (215) 362 3745
E-mail: BrooksAm@BrooksInstrument.com
www.BrooksInstrument.com

Brooks Instrument
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P.O. Box 428
6710 BK Ede, Netherlands
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Brooks Instrument
1-4-4 Kitasuna Koto-Ku
Tokyo, 136-0073 Japan
Tel +81 (0) 3 5633 7100
Fax +81 (0) 3 5633 7101
Email: BrooksAs@BrooksInstrument.com

2-2 Unpacking

Carefully unpack the meter and inspect it for any damage that may have occurred during shipment. The flowmeters are shipped completely assembled and tested. It should not be necessary to tighten or adjust any of the parts when it is received.

2-3 Return Shipment

Do not return any assembly or part without a Return Materials Report. The Return Materials Report is available from all District Sales Offices and the Product Service Department, Hatfield, PA 19440. Information describing the problem, corrective action, if any, and the work to be accomplished at the factory must be included.

Brooks Instrument
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Hatfield, PA 19440 USA
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Tel (215) 362 3700
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Fax +81 (0) 3 5633 7101
Email: BrooksAs@BrooksInstrument.com

2-4 Recommended Storage Practice

If intermediate or long term storage is required for equipment, as supplied by Brooks Instrument, it is recommended that said equipment be stored in accordance with the following:

a. Within the original shipping container.
b. Stored in a sheltered area, preferably a warm, dry heated warehouse.
c. Ambient temperature 70°F (21.0°C) nominal 110°F maximum/45°F minimum (43°C maximum/7.1°C minimum).
d. Relative humidity 45% nominal 60% maximum/25% minimum.

Upon removal from storage, a visual inspection should be conducted to verify the condition of equipment is "as received". If the equipment has been in storage for an excess of two (2) years or in conditions in excess of those recommended, all pressure boundary seals should be replaced and the device subject to a hydrostatic/pneumatic pressure test to 150% of rated pressure.

2-5 Installation (See Figures 2-1, 2-2, 2-3, 2-4 and 2-5)

The flowmeter should be mounted within 6° of true vertical. The inlet connection to the flowmeter is in the bottom end fitting. The connections are normally horizontal, female NPT. Be sure the piping is adequately supported to prevent undue strain on the meter.

⚠ WARNING

If the inlet and outlet valves adjacent to the flowmeter are to be closed for any reason, the flowmeter must be completely drained. Failure to do so may result in thermal expansion of the liquid which can cause rupture of the meter and possible personal injury.

⚠ CAUTION

Care must be taken in the system piping to this instrument to prevent sudden excessive pressure or flow surges. Protective devices should be installed upstream from this instrument, such as flow controllers, pressure regulators, pressure snubbers and rupture discs.

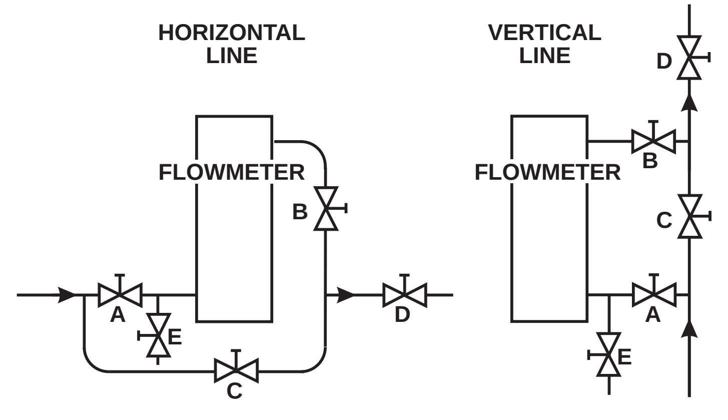
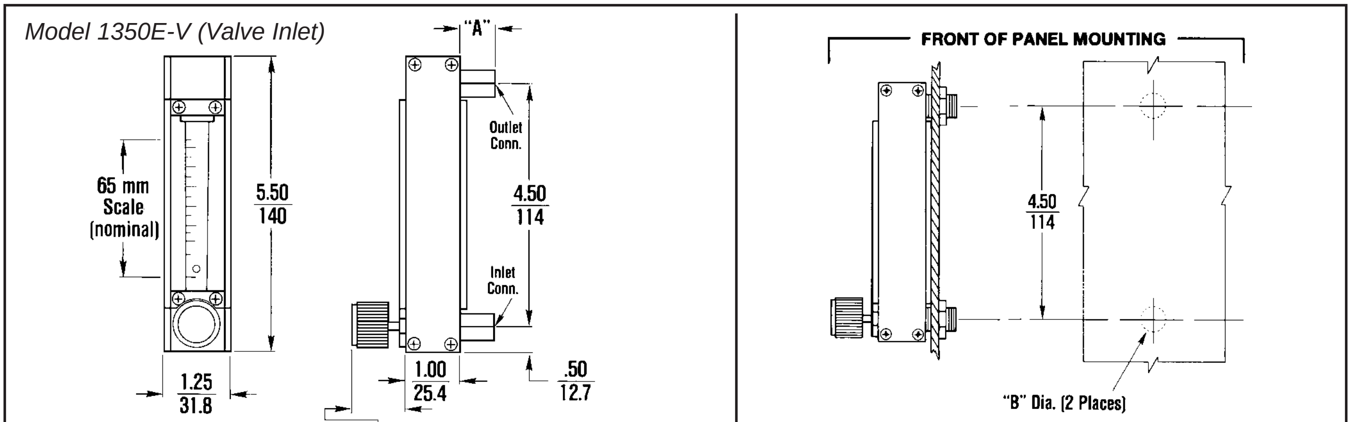


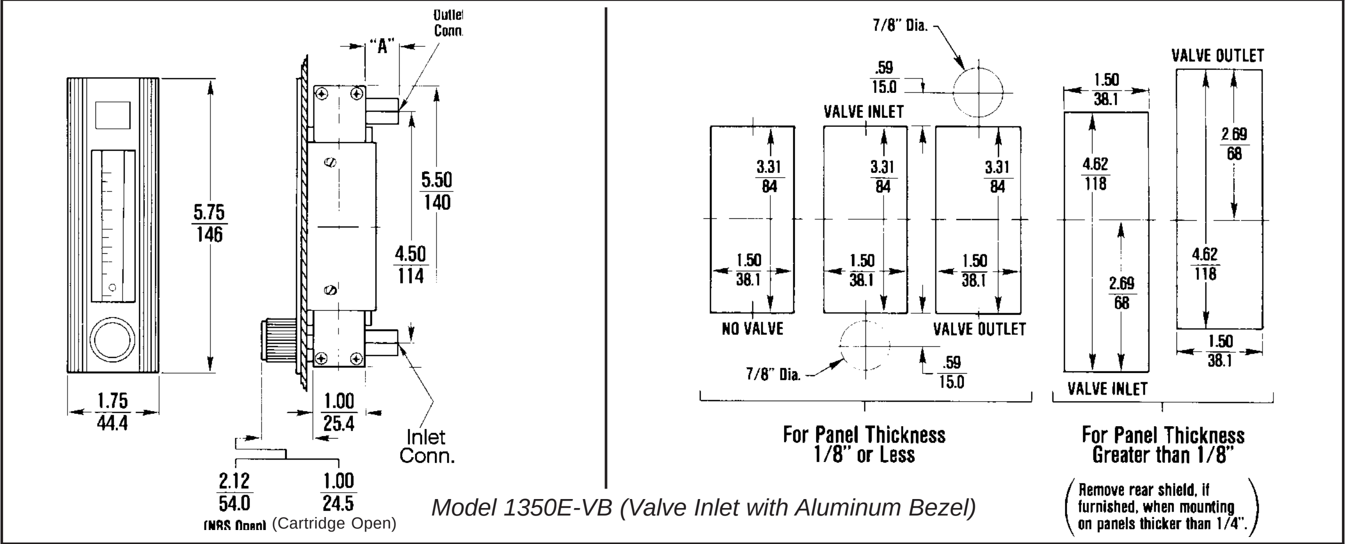
Figure 2-1 Typical Flowmeter Installation

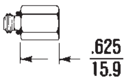
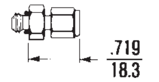
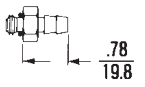
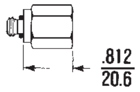
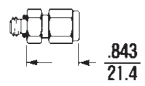
It is recommended that a final leak test of the system plumbing and meter be performed before subjecting it to process fluid.
(See Section 4, Paragraph 4-2, e.)


Model 1350E-V (Valve Inlet)

Thread Adapters & Lock Nuts

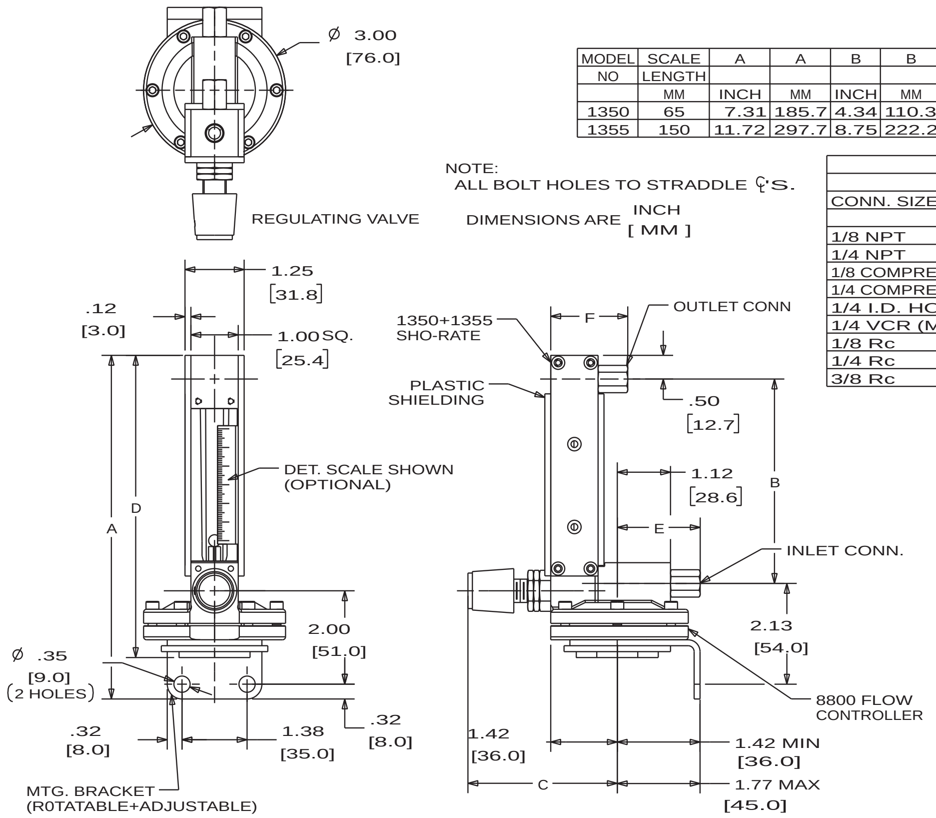
Conn. Adapter	1/8" NPT	1/4" NPT
"B" Dia.	.59/15.1	.88/22.2


Model 1350E-VB (Valve Inlet with Aluminum Bezel)

Dimension "A" Connection Adapter		
AN 10050-2 O-Ring Boss Seal (All Fittings)	**1/8" NPT/RC**  	**1/8" Compression** 
1/4" ID Hose  	**1/4" NPT/RC**  	**1/4" Compression** 

Inches/Milimeters

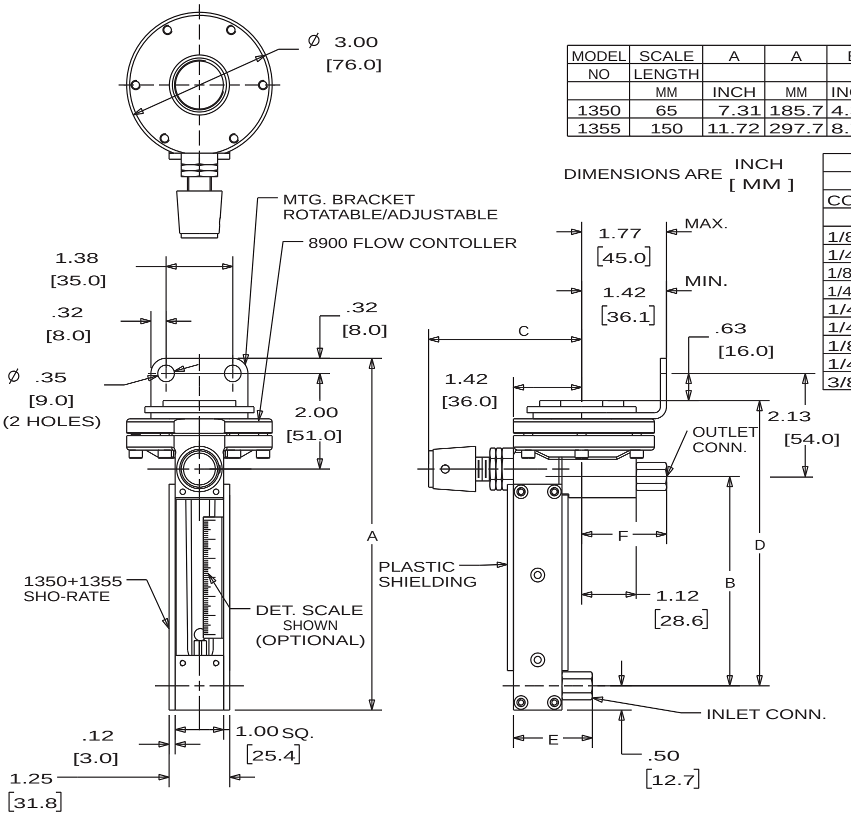
Figure 2-2 Dimensions - Sho-Rate 1350E



MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.72	43.7	1.62	41.1
1/4 NPT	1.12	28.6	1.81	46.0
1/8 COMPRESSION	1.91	48.5	1.81	46.0
1/4 COMPRESSION	2.04	51.8	1.94	49.3
1/4 I.D. HOSE	1.82	46.2	1.72	43.7
1/4 VCR (M)	N/A	N/A	2.06	52.3
1/8 Rc	1.91	48.5	1.62	41.1
1/4 Rc	1.91	48.5	1.81	46.0
3/8 Rc	2.35	53.1	2.09	53.1

Model 1350E-8800
(Controller on Inlet)



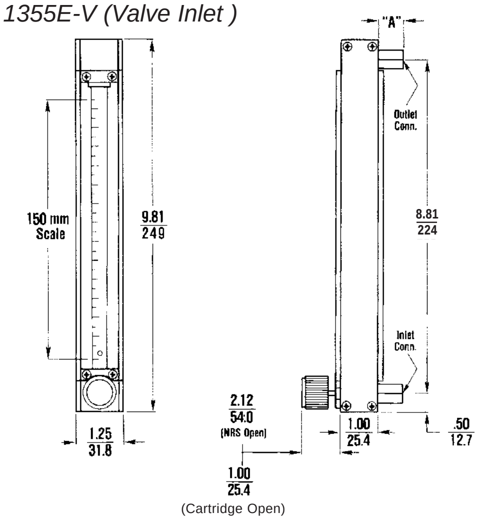
MODEL	SCALE	A	A	B	B	C	C	C	C	D	D
NO	LENGTH					OPEN	OPEN	CLSD	CLSD		
	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM	INCH	MM
1350	65	7.31	185.7	4.34	110.3	2.50	63.5	2.17	55.2	6.38	162.0
1355	150	11.72	297.7	8.75	222.2	2.50	63.5	2.17	55.2	10.78	273.8

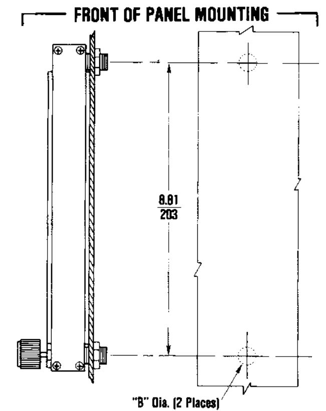
	INLET CONN.	INLET CONN.	OUTLET CONN.	OUTLET CONN.
CONN. SIZE	E	E	F	F
	INCH	MM	INCH	MM
1/8 NPT	1.62	41.1	1.72	43.7
1/4 NPT	1.81	46.0	1.12	28.6
1/8 COMPRESSION	1.81	46.0	1.91	48.5
1/4 COMPRESSION	1.94	49.3	2.04	51.8
1/4 I.D. HOSE	1.72	43.7	1.82	46.2
1/4 VCR (M)	2.06	52.3	N/A	N/A
1/8 Rc	1.62	41.1	1.91	48.5
1/4 Rc	1.81	46.0	1.91	48.5
3/8 Rc	2.09	53.1	2.35	59.7

Model 1350E-8900
(Controller on Outlet)

Figure 2-3 Dimensions - Sho-Rate 1350E & 1355E with Integral Flow Controller

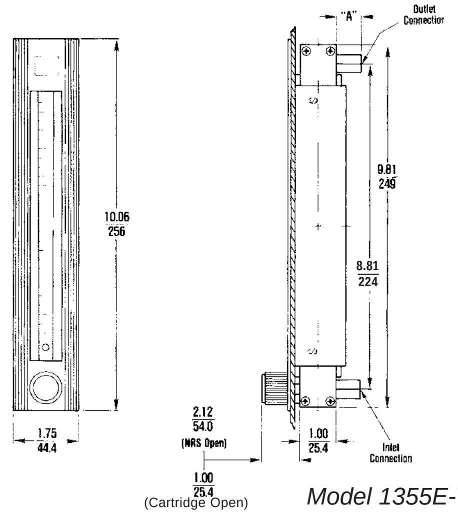
Model 1355E-V (Valve Inlet)



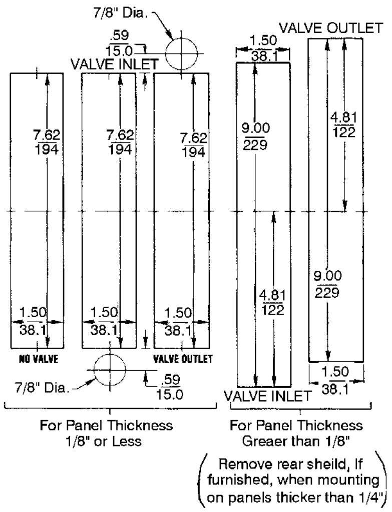


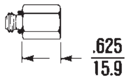
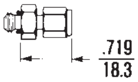
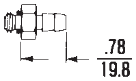
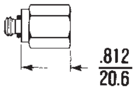
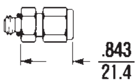
Threaded Adapters & Lock Nuts

Conn. Adapter	1/8" NPT	1/4" NPT
Dia. "B"	.59/15.1	.88/22.2



Model 1355E-VB (Valve Inlet with Alu



Dimension "A" Connection Adapter		
AN 10050-2 O-Ring Boss Seal (All Fittings)	1/8" NPT/RC  .625/15.9	1/8" Compression  .719/18.3
1/4" ID Hose  .78/19.8	1/4" NPT/RC  .812/20.6	1/4" Compression  .843/21.4

Inches/Milimeters

Figure 2-4 Dimensions - Sho-Rate 1355E

3-1 Operation

After the flowmeter has been installed in the flow system, it is ready for operation. An optional built-in needle control valve may be provided to control the flow through the flowmeter. These control valves are designed for fine control. Excessive tightening may damage the valve seat and limit its effectiveness as a control valve. If tight shut-off is required, it is recommended that a separate shut-off valve should be installed in the line immediately before the flowmeter.

Flow indication is measured using the center of the spherical float as the reference point.

⚠ WARNING

During operation, do not exceed pressure and temperature specifications. Failure to heed this warning may result in serious personal injury and/or damage to the equipment.

⚠ CAUTION

**Any sudden change in system pressure may cause mechanical damage to elastomer materials. Damage can occur when there is a rapid expansion of fluid that has permeated elastomer materials.
The user must take the necessary precautions to avoid such conditions.**

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4-1 Disassembly and Cleaning

⚠ WARNING

METER/CONTROLLER SEAL COMPATIBILITY

Products in this manual may contain metal or elastomeric seals, gaskets, O-rings or valve seats. It is the "user's" responsibility to select materials that are compatible with their process and process conditions. Using materials that are not compatible with the process or process conditions could result in the Meter or Controller leaking process fluid outside the pressure boundary of the device, resulting in personnel injury or death.

It is recommended that the user check the Meter or Controller on a regular schedule to ensure that it is leak free as both metal and elastomeric seals, gaskets, O-rings and valve seats may change with age, exposure to process fluid, temperature, and /or pressure.

It is recommended the user periodically inspect the tube and float, and clean if necessary. Dirt or foreign materials adhering to the tube and float may cause inaccuracy and sticking of the float. The metering tube (Borosilicate glass) and related parts may be cleaned with any solvent which does not attack glass. To disassemble use the following procedures:

a. Remove the plastic window and back plate.
b. Loosen the seal spindle or jack screw by turning it counterclockwise with a 5/32" hex wrench. The tube may now be canted out of the meter housing.
c. On meter sizes 1 through 6, the tube, float and float stops may be cleaned as an assembly or may be diassembled for cleaning. Using a small hook, remove either Teflon® float stop from the metering tube and remove the float. Be careful not to chip the tube.
d. Packing seats and packing inserts may now be removed.
e. With the metering tube out, the seal spindle or jack screw may be rotated clockwise for removal. It should not be necessary to remove the seal spindle unless the O-ring which seals the spindle requires replacement. The O-ring may be used as long as it is not torn or distorted.
f. The needle control valve assembly may be removed by turning the valve body counterclockwise. The valve seat, stem and packing then may be removed easily from the valve body for cleaning or replacement.

4-2 Reassembly Procedure

a. Use the reverse of Steps a through f of the disassembly procedure to reassemble the meter.

b. Prior to installing the needle control valve assembly make certain that the valve stem is turned completely counterclockwise (full open position) to prevent damage to the valve seat. Packing seats should be examined for damage or deterioration and replaced if necessary.

c. When replacing the packing seats in the flowmeter body be sure the packing inserts are approximately 1/16" above the top of the packing seat. Also be certain the tube seats firmly on the packing seats and does not overlap onto the end block.

d. The seal spindle serves to axially compress the tube seat gasket and exert a uniform pressure on the metering tube to prevent any possibility of leakage. Do not overtighten the seal spindle.

e. After the flowmeter has been reassembled, it is important that it be leak tested with air at a minimum pressure of 15 psig at room temperature.

   To detect leaks, brush soapy water around all possible leak points (tube packing, connections, and seal spindle) and check if bubbles are being formed. Should a leak be detected, tighten that particular joint to see if the leak can be stopped. If the leak persists, disassemble the area involved and check for dirt or damaged elastomer. Clean and replace elastomer.

5-1 General

When ordering parts please specify:
Brooks Serial Number
Model Number
Part Number
Description and Quantity
(Refer to Figure 5-1 and Table 5-1)

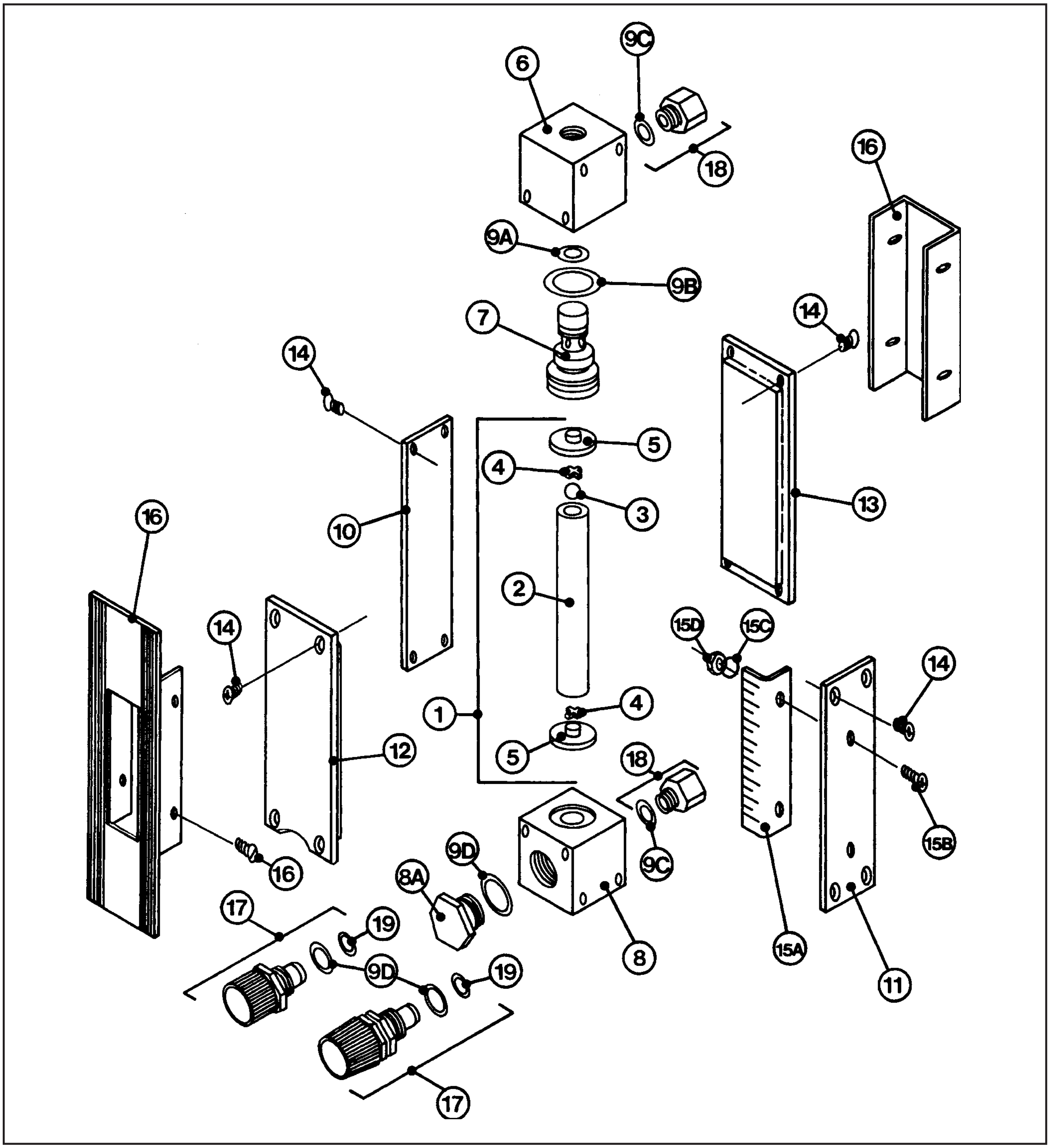

Figure 5-1 Parts Drawing Sho-Rate Models 1350E and 1355E

Table 5-1 Parts List - Sho-Rate Models 1350E and 1355E

Ref. No.	Qty.	Description
1*	1	Metering Tube Assembly
2	1	Glass Metering Tube
3	1	Ball Float (Size 1,5-1350 Only) Size 1 3/32" Glass Size 1 3/32" 316 SS Size 2 1/8" Glass Size 2 1/8" Sapphire Size 2 1/8" 316 SS Size 2 1/8" Carboloy Size 2 1/8" Tantalum Size 5 7/32" Glass Size 5 7/32" 316 SS Size 6 1/4" Glass Size 6 1/4" Sapphire Size 6 1/4" 316 SS Size 6 1/4" Carboloy Size 6 1/4" Tantalum
4	1	Inlet & Outlet Teflon Float Stops
5	1	Inlet/Outlet Tube Packing
6	1	Seal End Fitting (Outlet) Aluminum Brass 316 SS
7	1	Seal Spindle Aluminum Brass 316 SS
8	1	Valve End Fitting (Inlet) Aluminum Brass 316 SS
8A	1	Valve Plug Aluminum Brass 316 SS
9A*	1	Upper Seal Spindle O-ring Buna Viton Teflon
9B*	1	Lower Seal Spindle O-ring Buna Viton Teflon
9C	2	Adapter O-ring Buna Viton Teflon
9D*	1	Plug O-ring Buna Viton Teflon
10	1	Side Plate (STD) 1350 Aluminum STN. STL. 1355 Aluminum STN. STL.
11	1	Side Plate 1350 Standard Aluminum STN. STL. For Detached Scale Aluminum STN. STL.
11	1	(Cont'd)1355 Standard Aluminum Stn. Stl. For Detached Scale Aluminum Stn. Stl.
12	1	Front Shield 1350 1355
13	1	Back Plate 1350 1355
14	16	Side Plate & Shield Screw
15A	1	Aluminum Det. D/R Scale
15B	2	Stn. Stl. Scale Screws
15C	2	Stn. Stl. Scale Washers
15D	2	Stn. Stl. Scale Nuts
16	1	Aluminum Bezel 1350 (No Valve) 1350 (With Valve) 1355 (No Valve) 1355 (With Valve)
17	1	Optional Valve Assembly Cartridge Valve Brass/Buna-N - Low Brass/Buna-N - Med Brass/Buna-N - Hi 316 S.S/Viton - Low 316 S.S/Viton - Med 316 S.S/Viton - Hi NRS Valve Brass/Buna-N - Size 1 Brass/Buna-N - Size 2 Brass/Buna-N - Size 3 Brass/Buna-N - Size 4 Brass/Buna-N - Size 5 Brass/Buna-N - Size 6 316 S.S./Viton - Size 1 316 S.S./Viton - Size 2 316 S.S./Viton - Size 3 316 S.S./Viton - Size 4 316 S.S./Viton - Size 5 316 S.S./Viton - Size 6
18	2	1/8" NPT Thd. Adapter w/Locknut Aluminum w/Buna Brass w/Buna 316 SS w/Viton 1/8" NPT Adapter Aluminum w/Buna Brass w/Buna 316 SS w/ Viton 1/4" NPT Adapter Aluminum w/Buna Brass w/Buna 316 SS w/Viton 1/8" Compression Adapter Brass w/Buna 316 SS w/Viton 1/4" Compression Adapter Brass w/Buna 316 SS w/Viton 1/4" I.D. Hose Adapter Aluminum w/Buna Brass w/Buna 316 SS w/Viton
19*	1	Orifice O-ring NRS Buna-N Viton Cartridge Valve Buna-N Viton

*Recommended Spare Parts

LIMITED WARRANTY

Seller warrants that the Goods manufactured by Seller will be free from defects in materials or workmanship under normal use and service and that the Software will execute the programming instructions provided by Seller until the expiration of the earlier of twelve (12) months from the date of initial installation or eighteen (18) months from the date of shipment by Seller. Products purchased by Seller from a third party for resale to Buyer ("Resale Products") shall carry only the warranty extended by the original manufacturer.

All replacements or repairs necessitated by inadequate preventive maintenance, or by normal wear and usage, or by fault of Buyer, or by unsuitable power sources or by attack or deterioration under unsuitable environmental conditions, or by abuse, accident, alteration, misuse, improper installation, modification, repair, storage or handling, or any other cause not the fault of Seller are not covered by this limited warranty, and shall be at Buyer's expense.

Goods repaired and parts replaced during the warranty period shall be in warranty for the remainder of the original warranty period or ninety (90) days, whichever is longer. This limited warranty is the only warranty made by Seller and can be amended only in a writing signed by an authorized representative of Seller.

BROOKS SERVICE AND SUPPORT

Brooks is committed to assuring all of our customers receive the ideal flow solution for their application, along with outstanding service and support to back it up. We operate first class repair facilities located around the world to provide rapid response and support. Each location utilizes primary standard calibration equipment to ensure accuracy and reliability for repairs and recalibration and is certified by our local Weights and Measures Authorities and traceable to the relevant International Standards.

Visit www.BrooksInstrument.com to locate the service location nearest to you.

START-UP SERVICE AND IN-SITU CALIBRATION

Brooks Instrument can provide start-up service prior to operation when required.

For some process applications, where ISO-9001 Quality Certification is important, it is mandatory to verify and/or (re)calibrate the products periodically. In many cases this service can be provided under in-situ conditions, and the results will be traceable to the relevant international quality standards.

CUSTOMER SEMINARS AND TRAINING

Brooks Instrument can provide customer seminars and dedicated training to engineers, end users and maintenance persons.

Please contact your nearest sales representative for more details.

HELP DESK

In case you need technical assistance:

Americas	☎ 1 888 554 FLOW
Europe	☎ +31 (0) 318 549 290
Asia	☎ +81 (0) 3 5633 7100

Due to Brooks Instrument's commitment to continuous improvement of our products, all specifications are subject to change without notice.

TRADEMARKS

Brooks	Brooks Instrument, LLC
Kalrez	DuPont Performance Elastomer
NRS	Brooks Instrument, LLC
Sho-Rate	Brooks Instrument, LLC
Teflon	E.I. DuPont de Nemours & Co.
Viton-A	DuPont Performance Elastomer

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F +31 (0) 318 549 309
E-Mail BrooksEu@BrooksInstrument.com

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Tokyo, 136-0073 Japan
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F +81 (0) 3 5633 7101
E-Mail BrooksAs@BrooksInstrument.com

Flowmeters, Purges, Valves & Accessories

400 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2” diameter brass or 316L stainless steel for use especially on regulators such as the 400 Series brass and 316L stainless steel regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount.

2” Brass

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0201	550-0300
30”-0-100 PSIG	550-0202	550-0302
30”-0-200 PSIG	550-0203	550-0303
0-300 PSIG	550-0204	550-0304
0-400 PSIG	550-0205	550-0305
0-1000 PSIG	550-0206	550-0306
0-4000 PSIG	550-0208	550-0308
0-6000 PSIG	550-0209	550-0309

2” 316L Stainless Steel

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0221	550-0320
30”-0-100 PSIG	550-0222	550-0322
30”-0-200 PSIG	550-0223	550-0323
0-300 PSIG	550-0224	550-0324
0-400 PSIG	550-0225	550-0325
0-1000 PSIG	550-0226	550-0326
0-4000 PSIG	550-0228	550-0328
0-6000 PSIG	550-0229	550-0329

300 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2” diameter chrome-plated brass or chrome-plated brass with 316L stainless steel wetted parts for use especially on regulators such as the 300 Series chrome-plated brass and 316L stainless steel regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount. UL listed, Cleaned for oxygen service, ANSI B40.1.

2” Brass (with chrome-plated case)

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0267	550-0367
30”-0-100 PSIG	550-0268	550-0368
30”-0-200 PSIG	550-0269	550-0369
0-300 PSIG	550-0273	550-0373
0-400 PSIG	550-0270	841-0545
0-1000 PSIG	550-0271	550-0371
0-4000 PSIG	550-0263	841-0546
0-6000 PSIG	550-0272	550-0372

2” 316L Stainless Steel (with chrome-plated case)

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0621	550-0720
30”-0-100 PSIG	550-0622	550-0722
30”-0-200 PSIG	550-0623	550-0723
0-300 PSIG	550-0624	550-0724
0-400 PSIG	550-0625	550-0725
0-1000 PSIG	550-0626	550-0726
0-4000 PSIG	550-0628	550-0728
0-6000 PSIG	550-0629	550-0729

200 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2½” diameter chrome-plated brass for use especially on regulators such as the 200 Series chrome-plated brass regulators, and the 483, 485 and 492 Series brass ultra high flow regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount. UL listed, Cleaned for oxygen service, ANSI B40.1.

2½” Brass (with chrome-plated case and stem)

Pressure Range	PSIG/kPa	BAR/PSIG
0-30 PSIG	550-0241	550-0291
0-60 PSIG	550-0242	550-0292
0-200 PSIG	550-0243	550-0293
0-400 PSIG	550-0245	550-0295
0-600 PSIG	550-0250	550-0299

Pressure Range	PSIG/kPa	BAR/PSIG
0-1000 PSIG	550-0246	550-0296
0-4000 PSIG	550-0248	550-0298
0-6000 PSIG	550-0249	550-0297
0-30 PSIG (Redline)	550-0240	550-0290

Flowmeters, Purges, Valves & Accessories

400 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2” diameter brass or 316L stainless steel for use especially on regulators such as the 400 Series brass and 316L stainless steel regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount.

2” Brass

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0201	550-0300
30”-0-100 PSIG	550-0202	550-0302
30”-0-200 PSIG	550-0203	550-0303
0-300 PSIG	550-0204	550-0304
0-400 PSIG	550-0205	550-0305
0-1000 PSIG	550-0206	550-0306
0-4000 PSIG	550-0208	550-0308
0-6000 PSIG	550-0209	550-0309

2” 316L Stainless Steel

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0221	550-0320
30”-0-100 PSIG	550-0222	550-0322
30”-0-200 PSIG	550-0223	550-0323
0-300 PSIG	550-0224	550-0324
0-400 PSIG	550-0225	550-0325
0-1000 PSIG	550-0226	550-0326
0-4000 PSIG	550-0228	550-0328
0-6000 PSIG	550-0229	550-0329

300 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2” diameter chrome-plated brass or chrome-plated brass with 316L stainless steel wetted parts for use especially on regulators such as the 300 Series chrome-plated brass and 316L stainless steel regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount. UL listed, Cleaned for oxygen service, ANSI B40.1.

2” Brass (with chrome-plated case)

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0267	550-0367
30”-0-100 PSIG	550-0268	550-0368
30”-0-200 PSIG	550-0269	550-0369
0-300 PSIG	550-0273	550-0373
0-400 PSIG	550-0270	841-0545
0-1000 PSIG	550-0271	550-0371
0-4000 PSIG	550-0263	841-0546
0-6000 PSIG	550-0272	550-0372

2” 316L Stainless Steel (with chrome-plated case)

Pressure Range	PSIG/kPa	BAR/PSIG
30”-0-30 PSIG	550-0621	550-0720
30”-0-100 PSIG	550-0622	550-0722
30”-0-200 PSIG	550-0623	550-0723
0-300 PSIG	550-0624	550-0724
0-400 PSIG	550-0625	550-0725
0-1000 PSIG	550-0626	550-0726
0-4000 PSIG	550-0628	550-0728
0-6000 PSIG	550-0629	550-0729

200 Series Regulator Gauges

These 550 Series gauges allow the user to monitor pressure in systems. They are available in 2½” diameter chrome-plated brass for use especially on regulators such as the 200 Series chrome-plated brass regulators, and the 483, 485 and 492 Series brass ultra high flow regulators. For convenient mounting, all 550 Series gauges are ¼” NPT bottom mount. UL listed, Cleaned for oxygen service, ANSI B40.1.

2½” Brass (with chrome-plated case and stem)

Pressure Range	PSIG/kPa	BAR/PSIG
0-30 PSIG	550-0241	550-0291
0-60 PSIG	550-0242	550-0292
0-200 PSIG	550-0243	550-0293
0-400 PSIG	550-0245	550-0295
0-600 PSIG	550-0250	550-0299

Pressure Range	PSIG/kPa	BAR/PSIG
0-1000 PSIG	550-0246	550-0296
0-4000 PSIG	550-0248	550-0298
0-6000 PSIG	550-0249	550-0297
0-30 PSIG (Redline)	550-0240	550-0290

Bourdon Tube Pressure Gauge
Type 111.11 Compressed Gas Regulator Gauge
Standard Series

Applications

- Compressed gas regulators
- Beverage dispensing machines
- Suitable for all media that will not obstruct the pressure system or attack copper alloy parts

Special features

- UL-listed (UL-252a or UL-404)
- Polished brass or gold-painted steel case
- Cleaned for use in oxygen service

Standard features

Design
ASME B40.100

Sizes
1½”, 2” & 2½” (41, 53 & 68 mm)

Accuracy class
± 3/2/3% of span (ASME B40.100 Grade B)

Ranges
Vacuum / Compound to 200 psi
Pressure from 15 psi to 6,000 psi
or other equivalent units of pressure or vacuum

Working pressure
Steady: 3/4 of full scale value
Fluctuating: 2/3 of full scale value
Short time: full scale value

Operating temperature
Ambient: -40°F to 140°F (-40°C to 60°C)
Media: 140°F (+60°C) maximum

Temperature error
Additional error when temperature changes from reference temperature of 68°F (20°C) ±0.4% for every 18°F (10°C) rising or falling. Percentage of span.

Pressure connection
Material: Copper-Alloy
Lower Mount (LM): 1½”, 2” and 2½”
Center Back Mount (CBM); 1½”and 2”
1/8” NPT, ¼” NPT, limited to wrench flat area

Bourdon Tube Pressure Gauge Type 111.11

Bourdon Tube
Material: copper alloy
15 psi to 600 psi: C-type (low copper content)
800 psi to 6,000 psi: helical

Movement
Copper alloy

Dial
White aluminum with stop pin and black lettering
“USE NO OIL” in red

Pointer
Black aluminum, non-adjustable

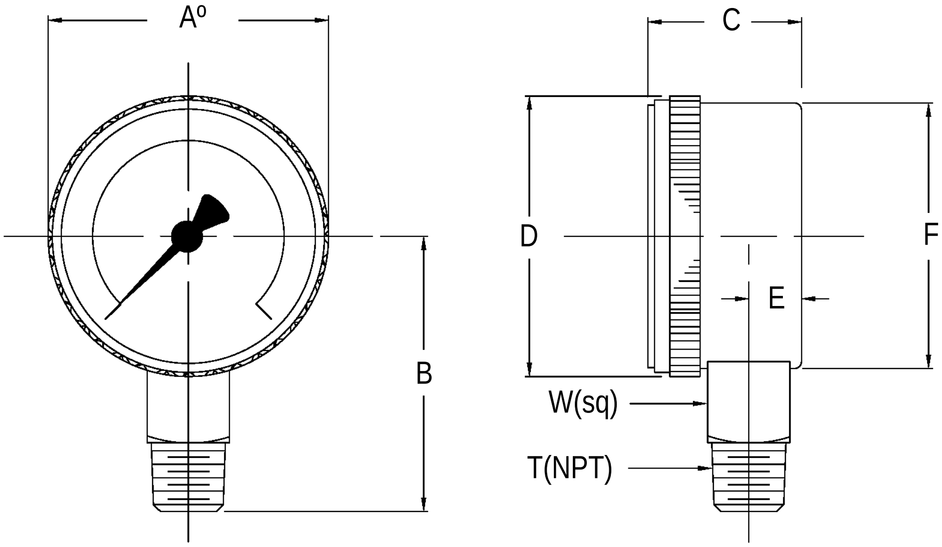
Case
1½”: gold-painted steel
2” & 2½”: polished brass or gold-painted steel

Window
Twist-lock clear polycarbonate

Optional Extras

- Brass restrictor (Std. for ranges 1,500 psi and higher)
- Special case colors
- Nickel-plated socket
- Chrome-plated steel case
- Chrome-plated ABS case
- Black ABS case
- Stainless steel case (2” size only)
- Special threaded connection
- Custom dial layout
- Heat sealed bag, thread cap and “oxygen cleaned” label
- Other pressure scales available:
  bar, kPa, MPa, kg/cm^2 and dual scales

Dimensions - 1½”, 2” and 2½” Lower Mount (LM)

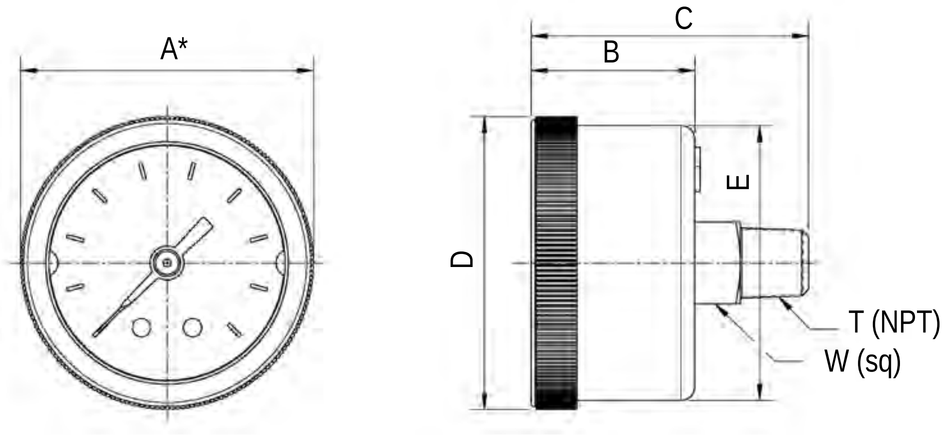


A^0 - Nominal case size

Size										
		A^0	B	C[1]	D	E[1]	F	T	W	Weight
1.5”	mm	41	36.6	24	42.9	9	40	-	12	
	in	1.5	1.44	0.94	1.69	0.35	1.57	1/8”	0.47	0.14 lb
2”	mm	53	54	29	58	10.5	53.5	-	14	
	in	2.0	2.12	1.14	2.28	0.42	2.11	1/4”	0.55	0.24 lb
2.5”	mm	68	60	31	72.4	12	67.6	-	14	
	in	2.5	2.36	1.22	2.85	0.47	2.66	1/4”	0.55	0.33 lb

[1] For 2½“ painted steel case, C dimension changes to 1.14“ (29 mm), and E dimension changes to 0.35“ (9 mm)

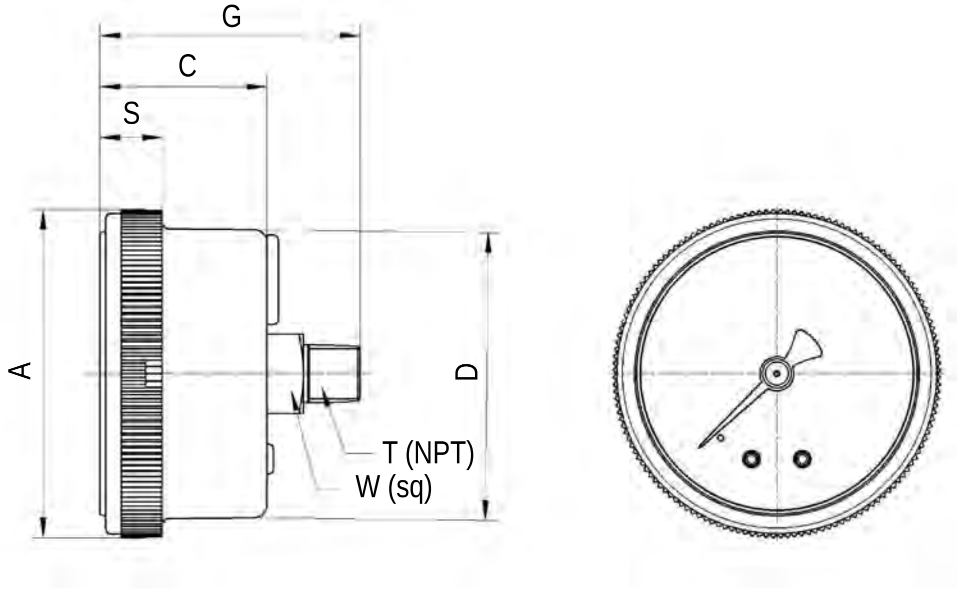
Dimensions - 1½” Center Back Mount (CBM)



* = nominal size

Size									
		A*	B	C	D	E	T	W	Weight
1.5”	mm	41	24	40.6	42.9	40.6	-	12	
	in	1.5	0.94	1.60	1.69	1.6	1/8”	0.47	0.14 lb

Dimensions - 2” Center Back Mount (CBM)



Size									
		A	C	D	G	S	T	W	Weight
2”	mm	57.8	29	50.7	48.3	11	-	14	
	in	2.275	1.14	2	1.9	0.43	1/8” or 1/4”	0.44	0.24 lb

Ordering information

Pressure gauge model / Nominal size / Scale range / Size of connection / Optional extras required
Specifications and dimensions given in this leaflet represent the state of engineering at the time of printing.
Modifications may take place and materials specified may be replaced by others without prior notice.

WIKA Instrument Corporation
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Lawrenceville, GA 30043
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Fax (770) 338-5118
E-Mail info@wika.com
www.wika.com

NES Project: 11-116
GSI 3537 – H2T Injection Equipment
Former Atlas Missile Site – York, NE

Section 6 – Well Head Connections

BV-1101 to 1902 ½” Ball Valves - Nibco Model NIBTFPA600-12 Specifications

PI-1103 to 1903 Pressure Gauges Dwyer Model LPG2-D9942N Specifications

2 Ear SS Hose Clamps – Grainger / Oetiker Model 4E602 Specifications

Pincer for Hose Clamps – Grainger / Oetiker Model 4E607 Specifications

Brass Ball Valves

Two-Piece Body • Full Port • Blowout-Proof Stem • PTFE Seats

¼"-2" 600 PSI/41.4 Bar Non-Shock Cold Working Pressure
2½"-4" 400 PSI/27.6 Bar Non-Shock Cold Working Pressure

CONFORMS TO MSS SP-110 • CSA CERTIFIED TO ASME B16.44 AND CR91-002 (THREADED ¼"-4") • UL LISTED (THREADED ¼"-4") • IAPMO LISTED TO NSF/ANSI 61-8

T-FP-600A
Threaded

S-FP-600A
Solder

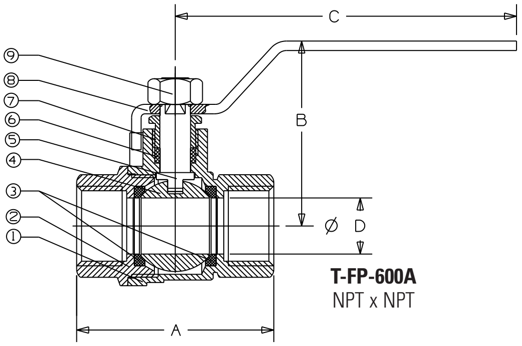
MATERIAL LIST

PART	SPECIFICATION
1. Body	Forged Brass² CU > 57%
2. End Cap	Forged Brass² CU > 57%
3. Ball Seat	PTFE
4. Ball	Brass, Chrome Plated
5. Stem	Brass
6. O-Ring (Stem Seal)*	Fluorocarbon (FKM)
7. Stem Packing	PTFE
8. Packing Nut	Brass
9. Lever Handle¹	Steel, Plated
10. Lock Washer*	Stainless Steel
11. Handle Nut¹	Stainless Steel

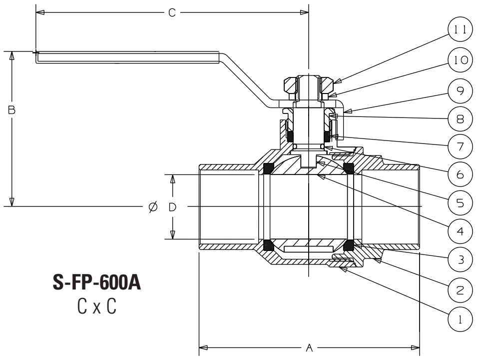
Note: * Parts 6 and 10 are applicable of S-FP-600A only.

[1] Due to Standard Approvals, Lever Handles and Nuts are not interchangeable between Solder and Threaded. There are no handle options at this time.

[2] For Material Certification, contact NIBCO Technical Services.



T-FP-600A
NPT x NPT



S-FP-600A
C x C

DIMENSIONS—WEIGHTS—QUANTITIES

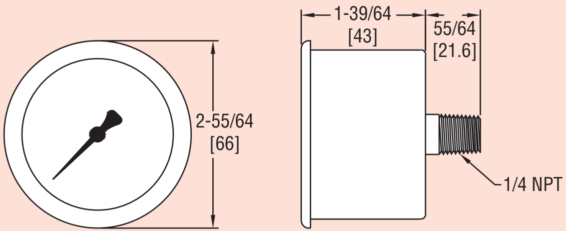
Size		Dimensions T-FP-600A A		S-FP-600A A		T-FP-600A B		S-FP-600A B		T-FP-600A C		S-FP-600A C		Port D		T-FP-600A		S-FP-600A		T-FP-600A	S-FP-600N
In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	In.	mm.	Lbs.	Kg.	Lbs.	Kg.	Ctn. Qty.	Ctn. Qty.
¼	8	1.76	45	—	—	1.73	44	—	—	3.54	90	—	—	.39	10	.33	.15	—	—	18	—
⅜	10	1.76	45	1.75	44	1.73	44	1.58	40	3.54	90	3.78	96	.39	10	.30	.14	.38	.17	18	18
½	15	2.05	52	2.01	51	1.92	49	1.78	45	3.54	90	3.78	96	.59	15	.44	.20	.40	.18	18	18
¾	20	2.36	60	2.74	70	2.09	53	2.13	54	3.78	96	3.98	101	.75	19	.66	.30	.67	.30	12	12
1	25	2.76	70	3.35	85	2.56	65	2.52	64	4.53	115	4.41	112	.98	25	1.10	.50	1.12	.51	6	6
1¼	32	3.31	84	3.78	96	2.95	75	2.65	67	4.53	115	5.04	128	1.26	32	1.57	.71	1.49	.67	4	4
1½	40	3.66	93	4.42	112	3.35	85	3.12	79	5.51	140	6.22	158	1.57	40	2.40	1.09	2.38	1.08	2	2
2	50	4.18	106	5.34	136	3.68	93	3.41	87	5.51	140	6.22	158	1.97	50	3.37	1.53	3.62	1.64	2	2
2½	65	5.38	137	6.28	160	4.76	121	4.76	121	8.66	220	8.66	220	2.56	65	7.60	3.45	6.36	2.88	3	3
3	75	6.04	153	7.15	182	5.08	129	5.08	129	8.66	220	8.66	220	2.95	75	9.36	4.24	8.32	3.77	2	2
4	100	7.39	188	—	—	5.87	149	—	—	9.61	244	—	—	3.89	99	16.85	7.64	—	—	1	—

*** S-FP-600A ⅜" - 2" (S1), 2 ½" - 3" (S2)**
*** T-FP-600A ¼" - 4" (S2)**

Series
LPG2

Low Pressure Gage

1.5% Accuracy, 2.5″ Chrome Case with Back Connection



The Series LPG2 Low Pressure Gages possess inches of water column scales with 1.5% accuracy. The 2.5″ LPG2 gages are designed with chrome plated steel housings and twist lock plastic lenses. Units are ideal for air and gases compatible with brass. Units can withstand temperatures of -40 to 140°F (-40 to 60°C). A wide offering of ranges are available from vacuum to 10 psi. Units come with a 1/4″ male NPT center back connection.

Model	Range
LPG2-D7242N	-15-0″ w.c.
LPG2-D7342N	-30-0″ w.c
LPG2-D7742N	-100-0″ w.c.
LPG2-D8042N	0-10″ w.c.
LPG2-D8142N	0-15″ w.c.
LPG2-D8242N	0-30″ w.c.
LPG2-D8442N	0-60″ w.c.
LPG2-D8642N	0-100″ w.c.
LPG2-D9942N	0-5 psi
LPG2-D0042N	0-10 psi

SPECIFICATIONS

Service: Air and compatible gases.
Wetted Materials: Brass socket and internals.
Housing: Chrome-plated case.
Lens: Plastic.
Accuracy: 1.5%.
Pressure Limit: 110% of full scale.
Temperature Limits: -40 to 140°F (-40 to 60°C).
Size: 2.5″ (63 mm).
Process Connection: 1/4″ male NPT center back entry.
Weight: 10.24 oz (290 g).

www.oetiker.com

Technical Data Sheet

1-Ear Clamps, 2-Ear Clamps
Product Group 153/154, 101 & 151

OETIKER®

Connecting Technology

Compact one-piece clamp: for robust, secure connections, miniature sizes
Clamp ear: fast and simple installation, visible deformation provides evidence of proper closure
Deburred edges: reduced risk of damage to parts being clamped
With insert
Pre-shaped insert: effective and powerful all-round seal

1-Ear Clamps Product Group 153/154

Material
153 Stainless Steel, Material no. 1.4301/UNS S30400
154 Clamp: Stainless Steel, Material no. 1.4301/UNS S30400
Insert: Stainless Steel, Material no. 1.4310/UNS S30100

Size range
153 3.3 – 30.7 mm
154 2.9 – 30.0 mm

Some sizes are only available if an appropriate minimum quantity is ordered.

Process

The manufacturing process for OETIKER 1-Ear and 2-Ear Clamps commences with the spiral roll-forming and welding of raw material into lengths of tube, a technique developed to obtain a robust, continuous welded ring.

OETIKER 1-Ear Clamps with insert

This type of clamp combines the geometry and properties of the 1-Ear Clamp with an insert made of stainless steel.

These clamps are ideal for demanding applications involving soft or hard rubbers and plastics. The thin-walled insert ring (up to 0.3 mm thick), with an oval protrusion that locates in the ear space, bridges the ear gap and ensures almost uniform compression around the whole circumference of a clamp.

Edge condition

Burrs generated during the shearing and forming processes are entirely eliminated in a barrel-finishing operation.

Closure

By using an OETIKER closing tool to pinch the clamp ear, the diameter of the clamp is reduced. This diameter reduction is proportional to the ear width.

The maximum reduction in diameter is given by the formula:

$$\text{Max. diameter reduction} = \frac{\text{Ear-width (s)}}{\pi}$$

2-Ear version: extended clamping range
Compact one-piece clamp: for robust, secure connections
Clamp ear: fast and simple installation, visible deformation provides evidence of proper closure
Deburred edges: reduced risk of damage to parts being clamped

2-Ear Clamps
Product Group 101 & 151

Material

101	Steel, Material no. 1.0338/SAE 1008/1010, zinc-plated
151	Stainless Steel, Material no. 1.4301/UNS S30400

Size range

4.1 – 46.0 mm

Some sizes are only available if an appropriate minimum quantity is ordered.

OETIKER 2-Ear Clamps

The ears of these clamps do not have a dimple and nearly double the clamping range, compared to the 1-ear clamp. 2 ears provide a degree of elasticity to accommodate changes in size of the parts being joined, such as that which may be caused by thermal expansion or vibration.

Installation techniques are similar to those for 1-Ear Clamps, but the force applied when closing the second ear may react against the opposing closed ear and make a second crimping operation necessary. For perfect sealing, the ears must be adequately closed during installation.

Assembly recommendations

The ears of these clamps should be closed with the recommended, uniform force (known as force priority). This method will result in a constant, reproducible stress within the clamp material, without overloading either the clamp or the parts being assembled. The nominal diameter of the clamp should always be chosen so that, when installed with the correct clamping force, the ears are almost closed.

Complete process monitoring and 100% process documentation are available using the “Electronically Controlled Pneumatic Power Tool” OETIKER ELK 01.

Closing force

The following table shows the average applied closing force for different material dimensions.

Average applied closing force

Material dimensions	Closing force (N)		Manual pincer*	Recommended pneumatic pincer**
	Zinc-plated steel	Stainless		
Product Group 153				
03.3 – 11.0	–	1400	14100082, 14100083	HO 2000
11.3 – 20.7	–	2300	14100082, 14100083	HO 3000
21.0 – 30.7	–	2800	14100082, 14100083	HO 3000
Product Group 154				
03.3 – 11.8	–	1500	14100082, 14100083	HO 2000
12.0 – 20.7	–	2500	14100082, 14100083	HO 3000
21.0 – 30.7	–	3600	14100082, 14100083	HO 4000
Product Group 101 & 151				
0041 – 1720	2200	2500	14100082, 14100083	HO 3000
1922 – 4346	3400	3600	14100082, 14100083	HO 4000

* 14100082 Standard pincer
14100083 Standard pincer with side jaws
** With appropriate closing force setting

Important note

These figures are intended as a guide, they may vary depending on the type and tolerances of parts being clamped. To ensure optimum clamp selection, we recommend making functional tests with several assemblies.

Order information

1-Ear Clamps, stainless

Item No.	Ref. No.	Ear width inside (mm)	Size range (mm)
15300000	03.3R	1.4	2.9 – 3.3
15300001	03.5R	1.4	3 – 3.5
15300002	04.1R	2.5	3.3 – 4.1
15300054	04.6R	3	3.8 – 4.6
15300003	05.1R	3.2	4.1 – 5.1
15300055	05.6R	3.2	4.6 – 5.6
15300004	06.1R	3.2	5.1 – 6.1
15300005	06.6R	3.2	5.6 – 6.6
15300006	07.0R	3	6.1 – 7
15300007	07.5R	3.5	6.5 – 7.5
15300008	08.0R	4	6.8 – 8
15300009	08.3R	4	7.1 – 8.3
15300010	08.7R	4	7.5 – 8.7
15300011	09.0R	5	7.5 – 9
15300012	09.5R	5	8.1 – 9.5
15300013	10.0R	5	8.5 – 10
15300014	10.5R	5	9.1 – 10.5
15300015	11.0R	5.5	9.3 – 11
15300016	11.3R	5.5	9.6 – 11.3
15300017	11.8R	5.5	10.1 – 11.8
15300018	12.0R	6.5	10.1 – 12
15300019	12.3R	6.5	10.3 – 12.3
15300020	12.8R	6.5	10.8 – 12.8

1-Ear Clamps, stainless

Item No.	Ref. No.	Ear width inside (mm)	Size range (mm)
15300021	13.3R	6.5	11.3 – 13.3
15300022	13.8R	6.5	11.8 – 13.8
15300023	14.0R	6.5	12 – 14
15300024	14.5R	6.5	12.5 – 14.5
15300025	15.0R	6.5	13 – 15
15300026	15.5R	6.5	13.5 – 15.5
15300027	16.0R	7	13.8 – 16
15300028	16.5R	8	14 – 16.5
15300029	16.8R	7	14.6 – 16.8
15300030	17.5R	7	15.3 – 17.5
15300031	18.5R	7	16.3 – 18.5
15300032	19.5R	7.5	17.2 – 19.5
15300033	20.0R	7.5	17.7 – 20
15300034	20.7R	9	17.9 – 20.7
15300035	21.0R	7.5	18.7 – 21
15300036	21.8R	7.5	19.5 – 21.8
15300037	22.5R	8.5	19.9 – 22.5
15300038	23.5R	8.5	21 – 23.5
15300040	24.5R	9	21.7 – 24.5
15300041	25.5R	9	22.7 – 25.5
15300043	26.3R	8.5	23.6 – 26.3
15300044	27.0R	9.5	24.1 – 27
15300045	30.7R	11	27.2 – 30.7

Order information

1-Ear Clamps with insert, stainless

Item No.	Ref. No.	Ear width inside (mm)	Size range (mm)
15400010	03.3RER	1.4	2.5 – 2.9
15400011	03.5RER	1.4	2.7 – 3.1
15400012	04.1RER	2.5	2.9 – 3.7
15400063	04.6RER	3	3.4 – 4.2
15400013	05.1RER	3.2	3.7 – 4.7
15400064	05.6RER	3.2	4.2 – 5.2
15400014	06.1RER	3.2	4.7 – 5.7
15400015	06.6RER	3.2	5.2 – 6.2
15400016	07.0RER	3	5.6 – 6.5
15400017	07.5RER	3.5	5.9 – 7
15400018	08.0RER	4	6.3 – 7.5
15400019	08.3RER	4	6.6 – 7.8
15400020	08.7RER	4	7 – 8.2
15400021	09.0RER	5	7 – 8.5
15400022	09.5RER	5	7.5 – 9
15400023	10.0RER	5	8 – 9.5
15400024	10.5RER	5	8.5 – 10
15400025	11.0RER	5.5	8.8 – 10.5
15400026	11.3RER	5.5	9.1 – 10.8
15400027	11.8RER	5.5	9.6 – 11.3
15400028	12.0RER	6.5	9.5 – 11.5
15400029	12.3RER	6.5	9.8 – 11.8
15400030	12.8RER	6.5	10.3 – 12.3
15400031	13.3RER	6.5	10.6 – 12.6
15400032	13.8RER	6.5	11.1 – 13.1
15400033	14.0RER	6.5	11.3 – 13.3
15400034	14.5RER	6.5	11.8 – 13.8
15400035	15.0RER	6.5	12.3 – 14.3
15400036	15.5RER	6.5	12.8 – 14.8
15400037	16.0RER	7	13.1 – 15.3
15400038	16.5RER	8	13.2 – 15.8
15400039	16.8RER	7	13.9 – 16.1
15400040	17.5RER	7	14.6 – 16.8
15400041	18.5RER	7	15.6 – 17.8
15400042	19.5RER	7.5	16.5 – 18.8
15400043	20.0RER	7.5	17.1 – 19.3
15400044	20.7RER	9	17.1 – 20
15400045	21.0RER	7.5	18 – 20.3
15400046	21.8RER	7.5	18.8 – 21.1
15400065	22.5RER	8.5	19.2 – 21.8
15400048	23.5RER	8.5	20.2 – 22.8
15400049	24.5RER	9	21 – 23.8
15400050	25.5RER	9	22 – 24.8
15400051	26.3RER	8.5	23 – 25.6
15400052	27.0RER	9.5	23.3 – 26.3
15400053	30.7RER	11	26.5 – 30

2-Ear Clamps, zinc-plated

Item No.	Ref. No.	Size range (mm)
10100000	0041	3.1 – 4.1
10100001	0045	3.5 – 4.5
10100002	0305	3.4 – 5
10100004	0507	5 – 7
10100008	0709	7 – 9
10100011	0811	8.1 – 11
10100016	1113	10.8 – 13
10100019	1315	12.5 – 15
10100022	1517	14 – 17
10100097	1619	16 – 19
10100027	1720	16.2 – 20
10100029	1922	18 – 22
10100030	2023	19 – 23
10100032	2225	21 – 25
10100034	2327	22.5 – 27
10100035	2528	24 – 28
10100037	2731	26.3 – 31
10100041	3134	29.3 – 34
10100043	3437	32 – 37
10100045	3740	35 – 40
10100047	4043	37.6 – 43
10100049	4346	40.6 – 46

2-Ear Clamps, stainless

Item No.	Ref. No.	Size range (mm)
15100000	0041R	3.1 – 4.1
15100001	0045R	3.5 – 4.5
15100002	0305R	3.4 – 5
15100003	0507R	5 – 7
15100004	0709R	7 – 9
15100023	0811R	8 – 11
15100006	1113R	11 – 13
15100007	1315R	12.5 – 15
15100008	1517R	14 – 17
15100010	1720R	16.2 – 20
15100011	1922R	18.1 – 22
15100012	2023R	19.1 – 23
15100013	2225R	21.1 – 25
15100014	2327R	22.5 – 27
15100015	2528R	24 – 28
15100016	2731R	26.3 – 31
15100018	3134R	29.3 – 34
15100019	3437R	32 – 37
15100020	3740R	35 – 40
15100021	4043R	37.6 – 43
15100022	4346R	40.6 – 46

Connecting Technology

Ear Clamps Installation Instructions

The careful selection and installation of OETIKER clamps is of the utmost importance for their performance in a specific application. This brief description is intended only as an initial guide to the most important points. For detailed information on selection and installation, please see the technical data sheet for the relevant product group.
OETIKER will be happy to help you to make the right choice for your specific application, If you provide us with the relevant application samples and as much information as possible about your application, we can recommend the best product type, diameter and installation to suit your needs.

Installation

Only OETIKER recommended tools should be used to close OETIKER clamp ears, and they should be closed with a uniform, recommended force. The closing force must be the parameter that determines when closure is complete. This method ensures positive stress on the hose which does not result in excessive compression or expansion of the band material. The visible deformation of the clamp ear provides a visible and instant check that closure has been carried out.
Please note that, unless otherwise stated, OETIKER Clamps and Rings can be used only once. Once removed, they can no longer be reused and should be discarded.

Radial and axial installation of Clamps

Individual variants of the closure geometry of Stepless® Ear Clamps enable larger diameters to be opened so that they can be installed radially. This enables them to be used on parts which are already installed or assembled – i.e. for repair and maintenance work.

Installation Examples

Position a properly-sized ear clamp on the hose fitted with a hose stem. Close clamp ear fully.

Using standard jaw pincer for Ear Clamps

When space is restricted, use a side jaw pincers and hold it parallel to the hose during closure

Using an OETIKER Pneumatic Pincer

To remove a clamp, place the pincer jaws across the ear and cut through it

To remove a Stepless Ear Clamp, grasp the strip end with the pincer and pull it away

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix K: Statistical Analyses of Pre-Treatment and Post-Treatment Soil Data

Statistical Analyses of Pre-Treatment and Post-Treatment Soil Data for TCE and cis-DCE

SUMMARY

Statistical analyses and hypothesis testing were performed on the TCE and cis-DCE soil concentrations from 48 samples collected during pre- and post-treatment soil sampling events. Mr. Thomas Georgian from the Omaha District USACE provided an independent expert technical support with several of the statistical analyses. Both t-test and Mann-Whitney analyses show that there is approximately 90% confidence that the post-TCE concentrations are significantly less than the pre-TCE concentrations. Median TCE concentration decreased from approximately 8 µg/kg to some value less than the Reporting Limit (RL), which equals about 6 µg/kg. The difference between the medians is relatively small. The difference between the medians is estimated to be between 0 and 10 µg/kg. The data sets are characterized by large variability (e.g., extreme positive outliers) and relatively large number of non-detects, which tends to adversely affects the power of statistical tests to detect differences.

Non-detects were censored to the laboratory's RLs for the statistical evaluations that were done rather than substituting multiples of the RLs or MDLs as surrogate values for non-detects, as this distorts the data sets, potentially producing false positives or false negatives. The sample median of the pre-treatment soil data set is equal to about 8 µg/kg; the sample median of the post-treatment data set is some value less than the Reporting Limit (RL), which equals about 6 µg/kg. However, given the large variability and proportion of non-detects observed for both data sets, this is not a statistically significant difference at the 95% level of confidence. However, there is about a 90% probability that the post-treatment TCE soil concentrations are significantly less than the pre-treatments results.

Similar analyses were performed for cis-DCE and the results show that there is greater than a 90% but less than a 95% probability that the post-treatment cis-DCE soil concentrations are greater than the pre-treatment cis-DCE soil concentrations. Median cis-DCE concentration increased from approximately 17 µg/kg to 40 µg/kg. The difference between the pre-treatment and post-treatment median concentrations ranges from 0 to 35 ug/kg.

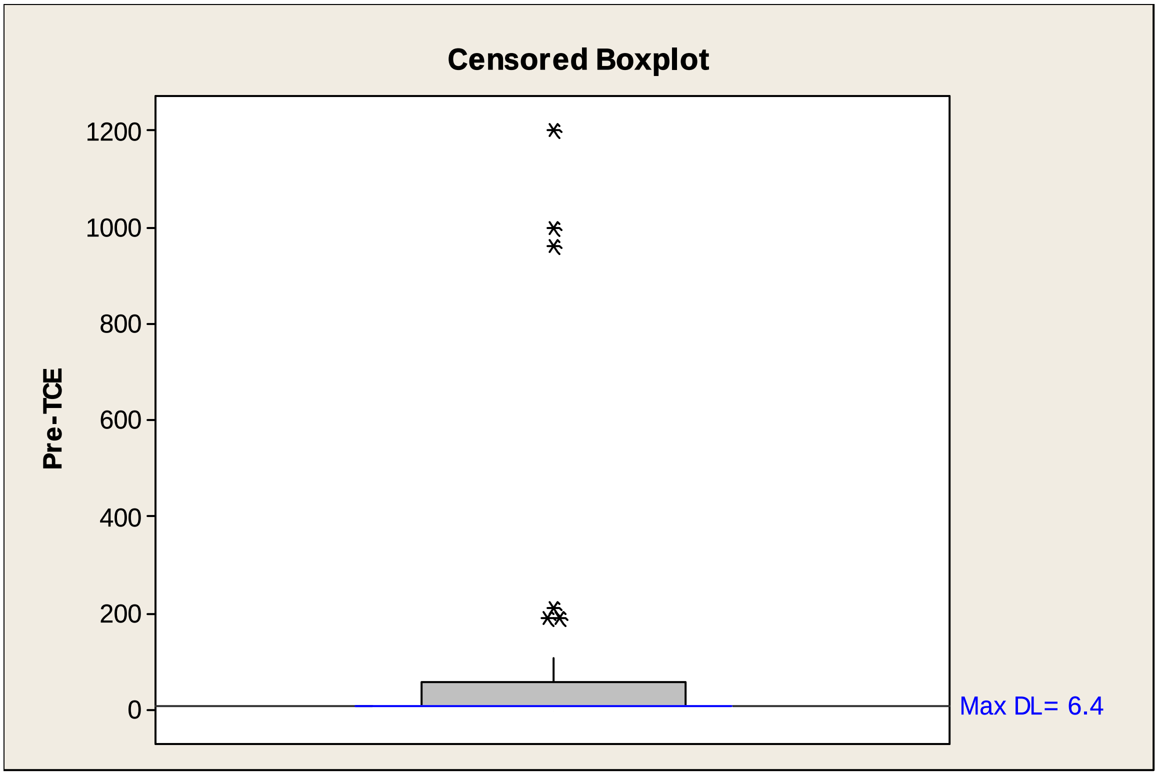
Non-detects were censored to the laboratory's RLs for the statistical evaluations that were done rather than substituting multiples of the RLs or MDLs as surrogate values for non-detects, as this distorts the data sets, potentially producing false positives or false negatives. The sample median of the pre-treatment DCE soil data set is 17 µg/kg. The sample median of the post-treatment DCE data set is 39.5 µg/kg. However, given the large variability for both data sets, the difference between the medians is not significant at the 95% level of confidence. There is greater than a 90% probability but less than a 95% probability that the post-treatment DCE soil concentrations are significantly greater than the pre-treatments concentrations.

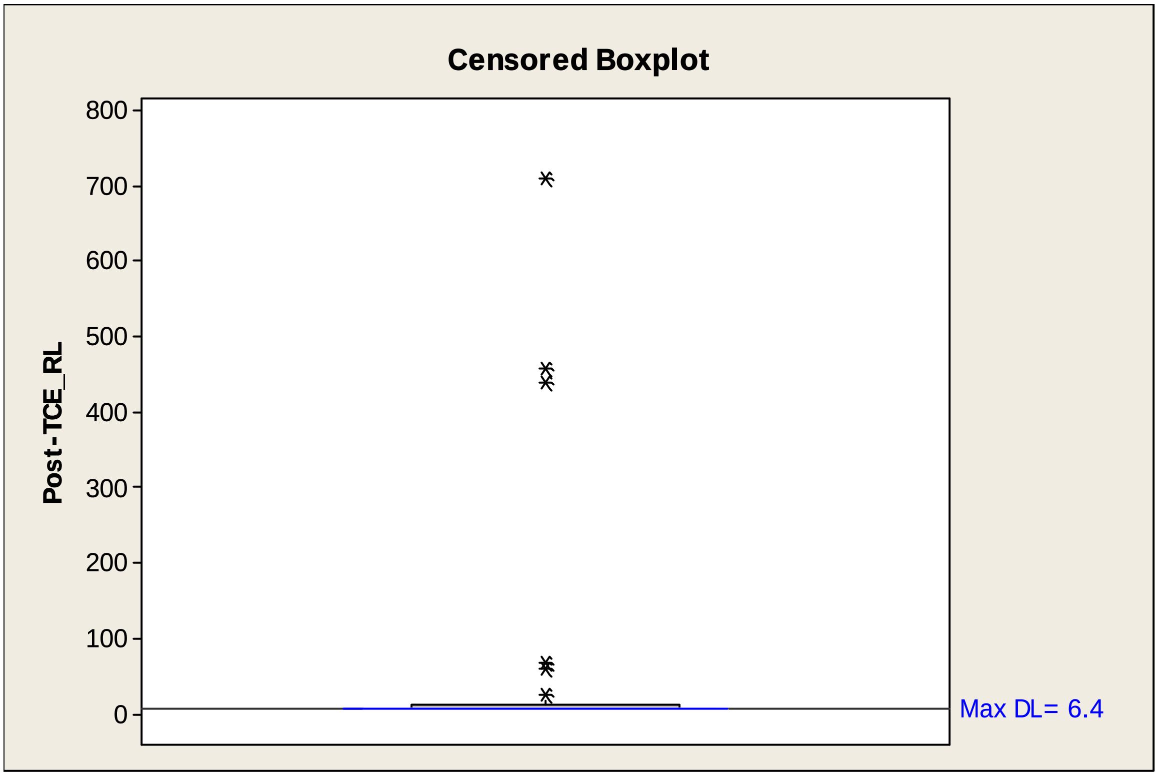
48 Sample Pairs (All Data)

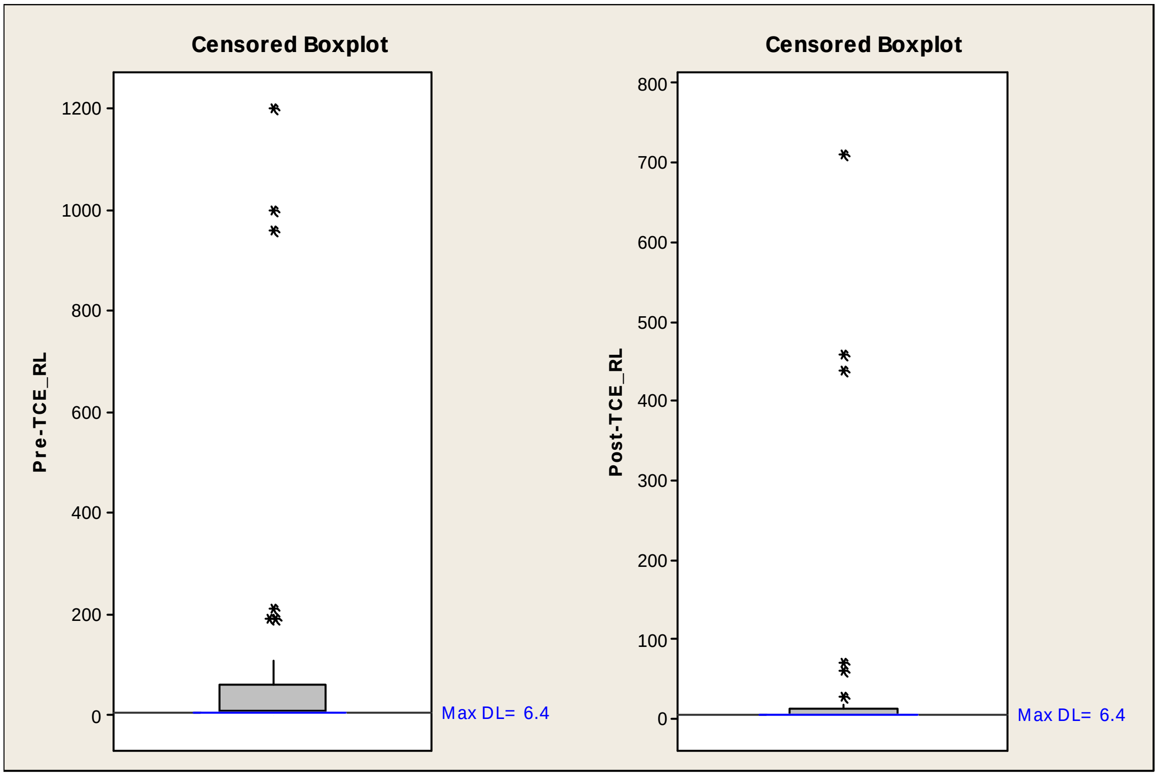
Input Data							
TCE-pre	**D_TCE-pre**	**TCE-post**	**D_TCE-post**	**DCE-pre**	**D_DCE-pre**	**DCE-post**	**D_DCE-post**
5.9	0	6.0	0	5.9	0	6	0
10	1	4.1	1	15	1	6.6	1
71	1	18	1	450	1	1,200	1
11	1	17	1	9.5	1	13	1
5.9	0	5.9	0	5.9	0	5.9	0
6.0	0	6.0	0	4.2	1	6	0
190	1	6	1	410	1	98	1
210	1	19	1	140	1	130	1
6.0	0	6.2	0	25	1	140	1
6.2	0	3.8	1	470	1	75	1
34	1	11	1	35	1	15	1
6.0	0	5.8	0	1.5	1	5.8	0
6.0	0	2.5	1	6	0	3.8	1
95	1	27	1	220	1	21	1
6.4	0	460	1	230	1	1,100	1
8.4	1	710	1	7.4	1	580	1
5.9	0	6.1	0	5.9	0	6.1	0
2.4	1	62	1	3.7	1	350	1
1,000	1	12	1	640	1	1,300	1
1,200	1	11	1	1,300	1	34	1
6.1	0	5.9	0	6.1	0	5.9	0
24	1	6.0	0	470	1	48	1
57	1	19	1	730	1	550	1
960	1	440	1	620	1	980	1
6.0	0	6.0	0	6	0	7.6	1
67	1	70	1	120	1	520	1
6.3	0	6.4	0	610	1	460	1
14	1	11	1	5	1	24	1
6.0	0	6.0	0	8.1	1	6	0
110	1	2.8	1	73	1	110	1
23	1	16	1	38	1	130	1
190	1	14	1	65	1	51	1
6.0	0	6.0	0	6	0	110	1
6.2	0	11	1	6.2	0	44	1
21	1	13	1	38	1	110	1
12	1	7.1	1	6.1	0	24	1
6.1	0	5.9	0	6.1	0	20	1
6.1	0	5.9	0	19	1	3.8	1
7.3	1	6.2	0	38	1	170	1
61	1	8.7	1	24	1	230	1
6.2	0	6.2	0	6.2	0	11	1
6.1	0	6.1	0	6.1	0	10	1
3.5	1	6.3	0	2.6	1	22	1
6.1	0	6.1	0	6.1	0	11	1
6.0	0	6.2	0	2.9	1	35	1
37	1	6.3	0	2,100	1	1,200	1
62	1	14	1	19	1	54	1
10	1	4.2	1	6.6	1	6	0

Note: Non-detect reported to the Reporting Limit (RL), which is also referred to as the “Detection Limit” (DL). 0=Non-Detect, 1=Detect (This coding was used to do statistical evaluations using ProUCL. All concentration units are µg/Kg.

TCE


Censored Boxplot
Pre-TCE
1200
1000
800
600
400
200
0
Max DL= 6.4


Censored Boxplot
Post-TCE_RL
800
700
600
500
400
300
200
100
0
Max DL= 6.4



The (censored) box plots of the pre-treatment and post-treat soil TCE results shown above suggest the median pre-treatment TCE concentration is slightly larger than the median TCE post-treatment soil concentration. Note that all non-detects were reported at the laboratory's Reporting Limits (RLs) for all the statistical evaluations that were done. However, the two data sets both exhibit very positively skewed distributions with a number of large outliers, suggesting that the medians may not be significantly different. Therefore, statistical tests were done to compare the two data sets. The results of these evaluations are summarized below. **No significant differences were detected at the 95% level of confidence for any of the hypothesis tests that were done to compare the pre-treatment and post-treatment data sets.**

Mann-Whitney/Wilcoxon Test

```
    N  Median
0  48    7.85
1  48   -1.00
```

(Median is less than the maximum RL = 6.4)

```
Point estimate for ETA1-ETA2 is 0.00
95.0 Percent CI for ETA1-ETA2 is (0.00,10.98)
W = 2500.5
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.2075
The test is significant at 0.1738 (adjusted for ties)

Use tie adjustment.  All values below 6.4 were set = -1.
If a median = -1, it means the median is <6.4
```

For a one-sided test, p = 0.104 (the p-value that was adjusted for ties is divided by two). No significant difference at 95% level of confidence. However, there is about a 90% probability that the post-treatment TCE soil concentrations are significantly less than the pre-treatments results.

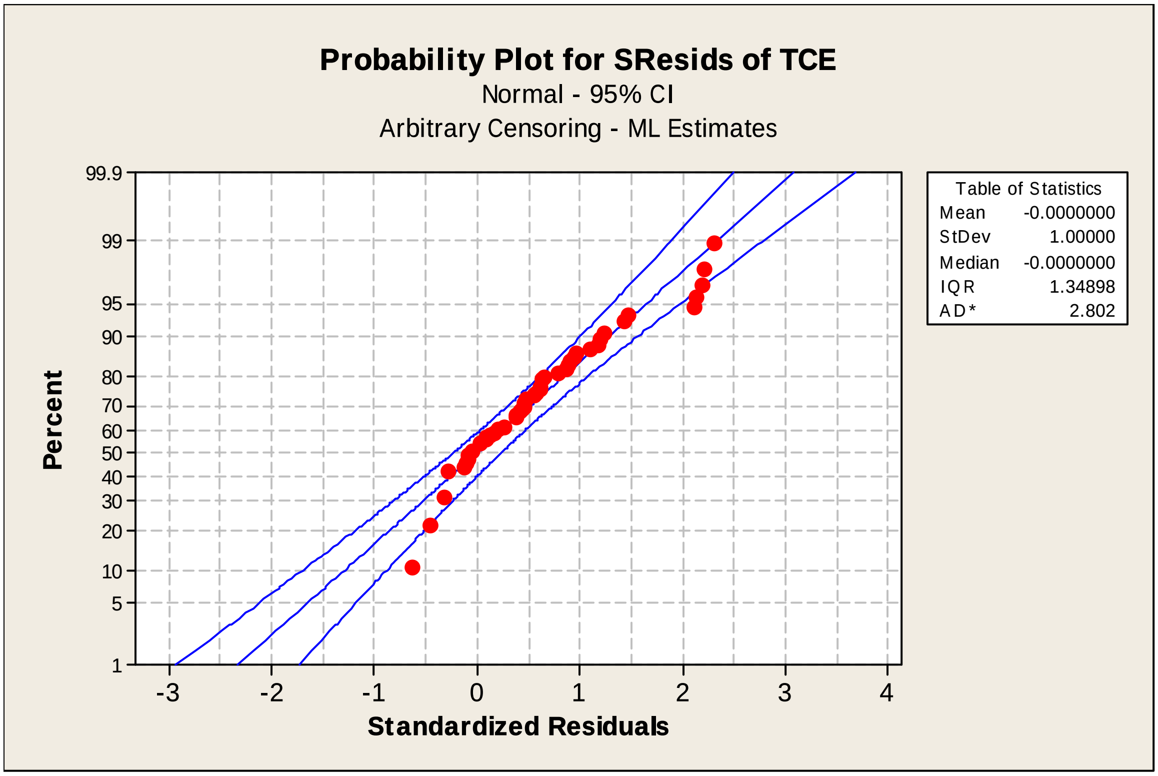
Regression with Life Data: TCE versus Condition (Maximum Likelihood method to compare the two data sets)

Regression with Life Data: TCE versus Condition

```
Response Variable Start: TCE  End: TCE RL
Censoring Information     Count
Uncensored value             54
Interval censored value      42
Estimation Method: Maximum Likelihood
Distribution:   Lognormal
Relationship with accelerating variable(s):   Linear
Regression Table
                      Standard                     95.0% Normal CI
Predictor       Coef     Error       Z       P     Lower      Upper
Intercept    2.23034  0.341322    6.53   0.000   1.56136    2.89931
Condition  -0.609926  0.469728   -1.30   0.194  -1.53058    0.310723   (No difference)
Scale        2.11617  0.220224                   1.72572    2.59498

Log-Likelihood = -325.554
Anderson-Darling (adjusted) Goodness-of-Fit
Standardized Residuals = 2.802
```

The slope coefficient of -0.6 estimates the difference between the two means and the statistic Z (--1.3) whether it is significantly different from zero. The p-value of 0.194 indicates that there is no significant difference between the pre-treatment and post-treatment geometric means at the 95% level of confidence.



Most of the points fall within the 95% confidence boundaries. Two or three points fall outside this interval, suggesting there is some deviation from normality for the residuals of the log-transformed results. Deviation from normality reduces the power of the test to detect a difference between the two data sets.

Distribution Analysis: TCE by Condition (Generalized Wilcoxon test)

```
Variable: 2000-TCE
Condition = 0
Censoring Information  Count
Uncensored value          27
Right censored value      21
Censoring value: d = 1
Nonparametric Estimates
Characteristics of Variable
            Standard   95.0% Normal CI
Mean(MTTF)     Error    Lower    Upper
   1905.16   37.3357  1831.98  1978.33

Median = 1991.6
IQR = 57.5  Q1 = 1939  Q3 = 1996.5

Kaplan-Meier Estimates
         Number  Number     Survival  Standard   95.0% Normal CI
  Time  at Risk  Failed  Probability     Error     Lower    Upper
 800.0       48       1     0.979167  0.020615  0.938762  1.00000
1000.0       47       1     0.958333  0.028842  0.901803  1.00000
1040.0       46       1     0.937500  0.034939  0.869022  1.00000
1790.0       45       1     0.916667  0.039893  0.838478  0.99486
1810.0       44       2     0.875000  0.047735  0.781441  0.96856
1890.0       42       1     0.854167  0.050942  0.754321  0.95401
1905.0       41       1     0.833333  0.053791  0.727904  0.93876
1929.0       40       1     0.812500  0.056337  0.702082  0.92292
1933.0       39       1     0.791667  0.058618  0.676778  0.90656
1938.0       38       1     0.770833  0.060665  0.651933  0.88973
1939.0       37       1     0.750000  0.062500  0.627502  0.87250
1943.0       36       1     0.729167  0.064142  0.603450  0.85488
1963.0       35       1     0.708333  0.065606  0.579749  0.83692
1966.0       34       1     0.687500  0.066902  0.556374  0.81863
1976.0       33       1     0.666667  0.068041  0.533308  0.80003
1977.0       32       1     0.645833  0.069031  0.510535  0.78113
1979.0       31       1     0.625000  0.069877  0.488043  0.76196
1986.0       30       1     0.604167  0.070585  0.465822  0.74251
1988.0       29       1     0.583333  0.071159  0.443864  0.72280
1989.0       28       1     0.562500  0.071603  0.422161  0.70284
1990.0       27       2     0.520833  0.072106  0.379508  0.66216
1991.6       25       1     0.500000  0.072169  0.358552  0.64145
1992.7       24       1     0.479167  0.072106  0.337841  0.62049
1996.5        2       1     0.239583  0.173205  0.000000  0.57906
1997.6        1       1     0.000000  0.000000  0.000000  0.00000
```

Distribution Analysis: 2000-TCE by Condition

```
Variable: 2000-TCE
Condition = 1
Censoring Information  Count
Uncensored value          27
Right censored value      21
Censoring value: d = 1
Nonparametric Estimates
Characteristics of Variable
            Standard   95.0% Normal CI
Mean(MTTF)     Error    Lower    Upper
   1956.90   19.3760  1918.92  1994.88

Median = 1995.8
IQR = 10.2  Q1 = 1986  Q3 = 1996.2
```

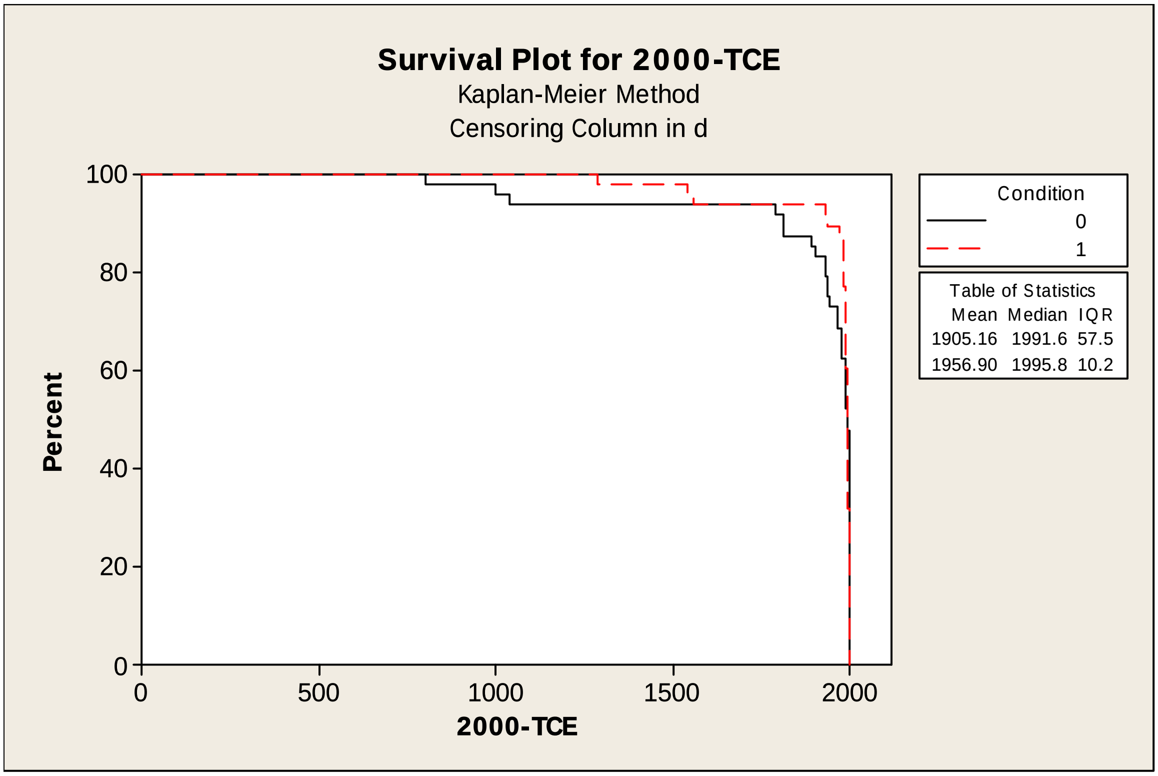
```
Kaplan-Meier Estimates
         Number  Number     Survival  Standard   95.0% Normal CI
  Time  at Risk  Failed  Probability     Error     Lower    Upper
1290.0       48       1     0.979167  0.020615  0.938762  1.00000
1540.0       47       1     0.958333  0.028842  0.901803  1.00000
1560.0       46       1     0.937500  0.034939  0.869022  1.00000
1930.0       45       1     0.916667  0.039893  0.838478  0.99486
1938.0       44       1     0.895833  0.044092  0.809415  0.98225
1973.0       43       1     0.875000  0.047735  0.781441  0.96856
1981.0       42       2     0.833333  0.053791  0.727904  0.93876
1982.0       40       1     0.812500  0.056337  0.702082  0.92292
1983.0       39       1     0.791667  0.058618  0.676778  0.90656
1984.0       38       1     0.770833  0.060665  0.651933  0.88973
1986.0       37       2     0.729167  0.064142  0.603450  0.85488
1987.0       35       1     0.708333  0.065606  0.579749  0.83692
1988.0       34       1     0.687500  0.066902  0.556374  0.81863
1989.0       33       4     0.604167  0.070585  0.465822  0.74251
1991.3       29       1     0.583333  0.071159  0.443864  0.72280
1992.9       28       1     0.562500  0.071603  0.422161  0.70284
1994.0       17       1     0.529412  0.074646  0.383109  0.67571
1995.8        5       1     0.423529  0.111959  0.204093  0.64297
1995.9        4       1     0.317647  0.124335  0.073955  0.56134
1996.2        3       1     0.211765  0.119770  0.000000  0.44651
1997.2        2       1     0.105882  0.095874  0.000000  0.29379
1997.5        1       1     0.000000  0.000000  0.000000  0.00000
```

Distribution Analysis: 2000-TCE by Condition

```
Comparison of Survival Curves
Test Statistics
Method    Chi-Square  DF  P-Value
Log-Rank     0.30433   1    0.581
Wilcoxon     1.66212   1    0.197
```

(No difference)

For a one-sided test the p-value is divided by two; p-value = 0.0985. To generate the survival curves shown below, all the TCE concentrations were subtracted from an arbitrary value (2000) that is larger than the maximum detected TCE concentration (1200). This transforms the left-censored ("less than") TCE concentrations (non-detects) to right-censored ("greater than") values to generate survival curves. The test compares the survival curves for the pre-treatment (coded "0") and post-treatment (coded "1") soil VOC results.



Gehan test using ProUCL

Raw Statistics

	Pre	Post
Number of Valid Data	48	48
Number of Non-Detect Data	21	21
Number of Detect Data	27	27
Minimum Non-Detect	5.9	5.8
Maximum Non-Detect	6.4	6.4
Percent Non detects	43.75%	43.75%
Minimum Detected	2.4	2.5
Maximum Detected	1200	710
Mean of Detected Data	166.3	73.86
Median of Detected Data	37	13
SD of Detected Data	326.8	172.6

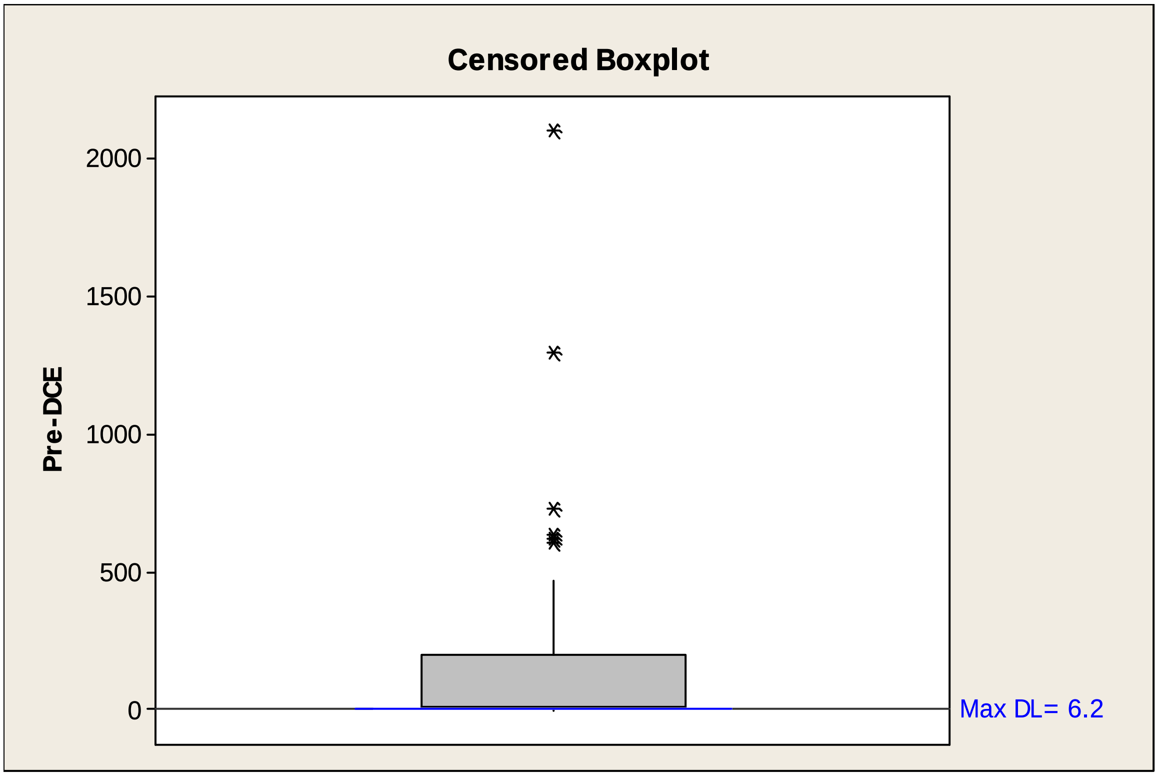
Pre-treatment vs. Post-treatment using the Gehan Test

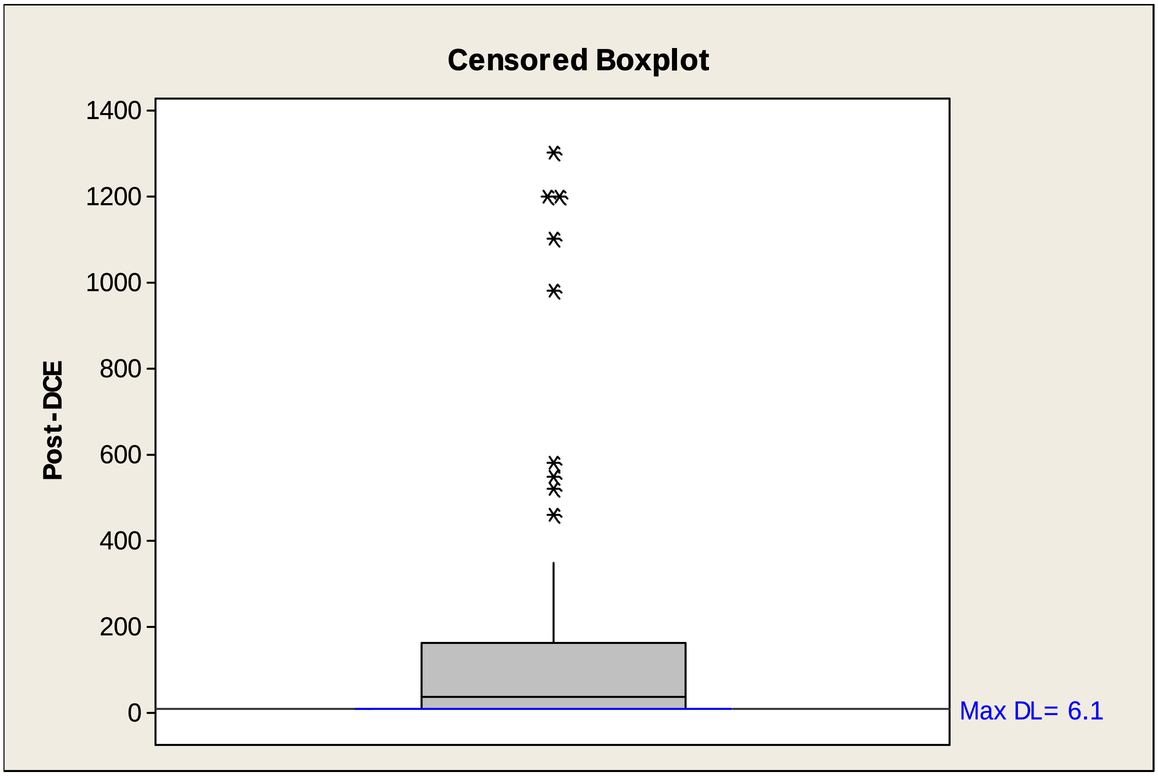
H_0: Mean/Median of Pre-treatment Data ≤ Mean/Median of Post-Treatment Data

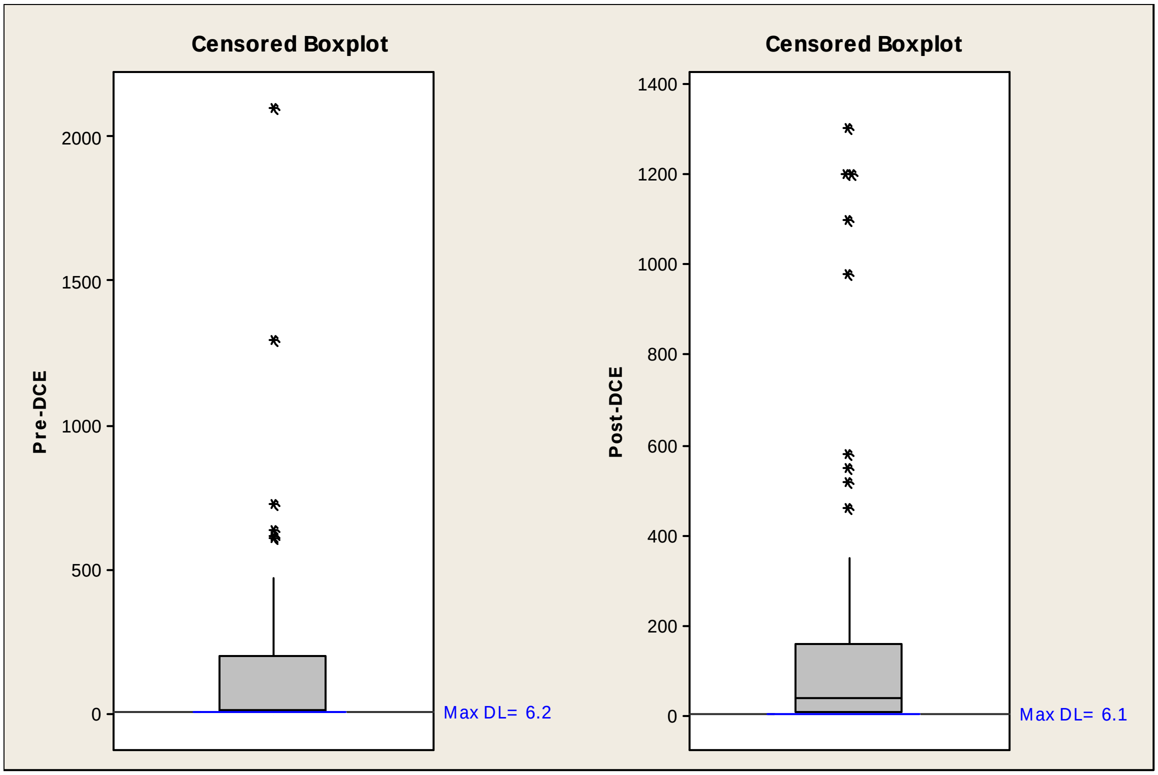
H_1: Mean/Median of Pre-treatment Data > Mean/Median of Post-Treatment Data

Gehan z Test Value	1.255
Critical z (0.95)	1.645
P-Value	0.105

cis-DCE


Censored Boxplot
Pre-DCE
2000
1500
1000
500
0
Max DL= 6.2


Censored Boxplot
Post-DCE
1400
1200
1000
800
600
400
200
0
Max DL= 6.1



The (censored) box plots of the pre-treatment and post-treat soil DCE results shown above suggest the median pre-treatment DCE concentration is slightly smaller than the median DCE post-treatment concentration. Note that all non-detects were reported at the laboratory's Reporting Limits (RLs) for all the statistical evaluations that were done. However, the two data sets both exhibit very positively skewed distributions with a number of large outliers, suggesting that the medians may not be significantly different. Therefore, statistical tests were done to compare the two data sets. The results of these evaluations are summarized below. **No significant differences were detected at the 95% level of confidence for any of the hypothesis tests that were done to compare the pre-treatment and post-treatment data sets.**

Mann-Whitney/Wilcoxon Test

```
    N  Median
0  48    17.0
1  48    39.5

Point estimate for ETA1-ETA2 is -11.0
95.0 Percent CI for ETA1-ETA2 is (-35.0,-0.0)
W = 2130.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1478
The test is significant at 0.1422 (adjusted for ties)

Use tie adjustment.  All values below 6.2 were set = -1.
If a median = -1, it means the median is <6.2
```

For a one-sided test, p = 0.0711 (the p-value that was adjusted for ties is divided by two). There is greater than a 90% probability but less than a 95% probability that the post-treatment DCE soil concentrations are significantly greater than the pre-treatments concentrations.

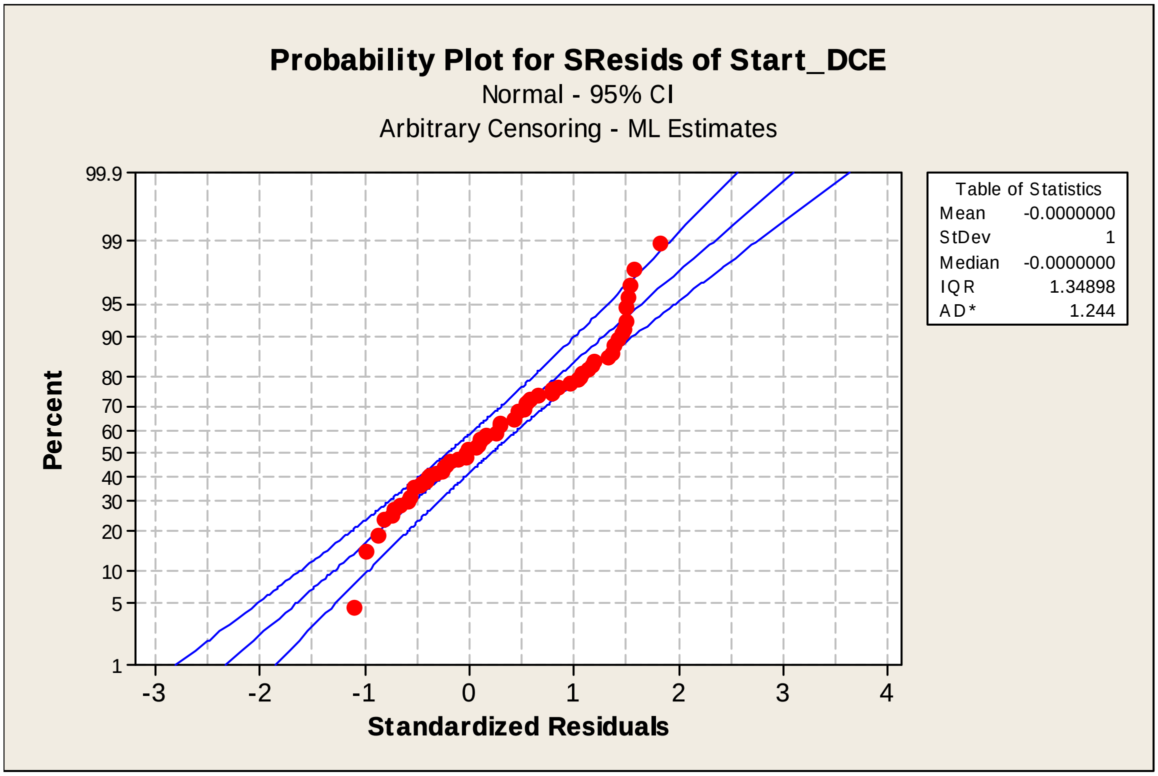
Regression with Life Data: TCE versus Condition (Maximum Likelihood method to compare the two data sets)

Regression with Life Data: Start_DCE versus Condition

```
Response Variable Start: Start_DCE  End: DCE
Censoring Information    Count
Uncensored value            74
Interval censored value     22
Estimation Method: Maximum Likelihood
Distribution:   Lognormal
Relationship with accelerating variable(s):   Linear
Regression Table
                     Standard                    95.0% Normal CI
Predictor       Coef    Error      Z      P      Lower     Upper
Intercept    2.97476 0.350130   8.50  0.000    2.28852   3.66100
Condition   0.647657 0.487427   1.33  0.184  -0.307684   1.60300
Scale        2.31677 0.199869                  1.95636   2.74357

Log-Likelihood = -495.902
Anderson-Darling (adjusted) Goodness-of-Fit
Standardized Residuals = 1.244
```

The slope coefficient of 0.6 estimates the difference between the two means and the statistic Z (1.3) whether it is significantly different from zero. The p-value of 0.184 indicates that there is no significant difference between the pre-treatment and post-treatment geometric means at the 95% level of confidence. However, the S-shaped curve and several points that fall outside of the 95% confidence interval suggest there is a deviation from normality, which reduces the power of the test to detect a difference between the two data sets.



Distribution Analysis: 2200-DCE by Condition (Generalized Wilcoxon test)

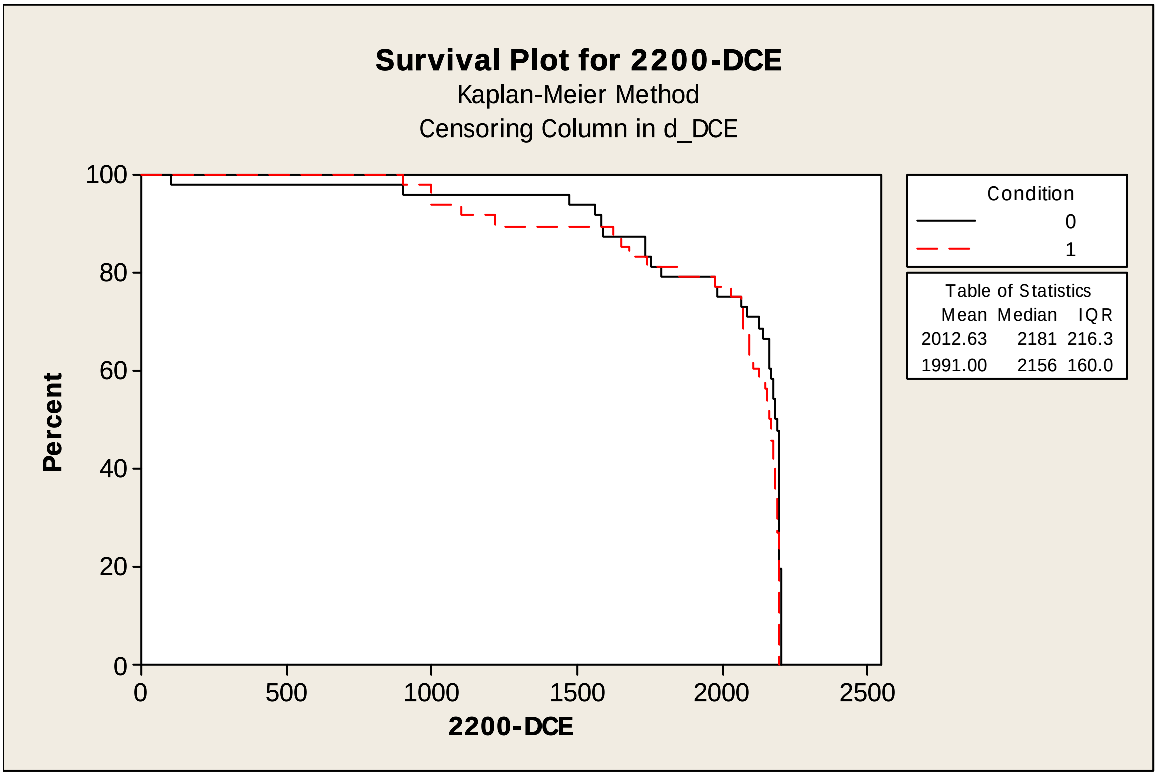
```
Variable: 2200-DCE
Condition = 1
Censoring Information  Count
Uncensored value          40
Right censored value       8
Censoring value: d_DCE = 1
Nonparametric Estimates
Characteristics of Variable
            Standard   95.0% Normal CI
Mean(MTTF)     Error    Lower    Upper
   1991.00   52.0645  1888.95  2093.04
Median = 2156
IQR = 160  Q1 = 2030  Q3 = 2190

Kaplan-Meier Estimates
         Number  Number     Survival   Standard   95.0% Normal CI
  Time  at Risk  Failed  Probability      Error     Lower    Upper
 900.0       48       1     0.979167  0.0206152  0.938762  1.00000
1000.0       47       2     0.937500  0.0349386  0.869022  1.00000
1100.0       45       1     0.916667  0.0398928  0.838478  0.99486
1220.0       44       1     0.895833  0.0440918  0.809415  0.98225
1620.0       43       1     0.875000  0.0477352  0.781441  0.96856
1650.0       42       1     0.854167  0.0509424  0.754321  0.95401
1680.0       41       1     0.833333  0.0537914  0.727904  0.93876
1740.0       40       1     0.812500  0.0563367  0.702082  0.92292
1850.0       39       1     0.791667  0.0586179  0.676778  0.90656
1970.0       38       1     0.770833  0.0606646  0.651933  0.88973
2030.0       37       1     0.750000  0.0625000  0.627502  0.87250
2060.0       36       1     0.729167  0.0641422  0.603450  0.85488
2070.0       35       2     0.687500  0.0669023  0.556374  0.81863
2090.0       33       3     0.625000  0.0698771  0.488043  0.76196
2102.0       30       1     0.604167  0.0705852  0.465822  0.74251
2125.0       29       1     0.583333  0.0711594  0.443864  0.72280
2146.0       28       1     0.562500  0.0716027  0.422161  0.70284
2149.0       27       1     0.541667  0.0719178  0.400710  0.68262
2152.0       26       1     0.520833  0.0721061  0.379508  0.66216
2156.0       25       1     0.500000  0.0721688  0.358552  0.64145
2165.0       24       1     0.479167  0.0721061  0.337841  0.62049
2166.0       23       1     0.458333  0.0719178  0.317377  0.59929
2176.0       22       2     0.416667  0.0711594  0.277197  0.55614
2178.0       20       1     0.395833  0.0705852  0.257489  0.53418
2179.0       19       1     0.375000  0.0698771  0.238043  0.51196
2180.0       18       1     0.354167  0.0690309  0.218869  0.48946
2185.0       17       1     0.333333  0.0680414  0.199975  0.46669
2187.0       16       1     0.312500  0.0669023  0.181374  0.44363
2189.0       15       2     0.270833  0.0641422  0.145117  0.39655
2190.0       13       1     0.250000  0.0625000  0.127502  0.37250
2192.4       12       1     0.229167  0.0606646  0.110266  0.34807
2193.4       11       1     0.208333  0.0586179  0.093444  0.32322
2196.2        2       2     0.000000  0.0000000  0.000000  0.00000
```

Distribution Analysis: 2200-DCE by Condition

```
Comparison of Survival Curves
Test Statistics
Method    Chi-Square  DF  P-Value
Log-Rank     3.98836   1    0.046
Wilcoxon     2.21315   1    0.137
```

For a one-sided test the p-value is divided by two; p-value = 0.0685. To generate the survival curves shown below, all the DCE concentrations were subtracted from an arbitrary value (2200) that is larger than the maximum detected DCE concentration (1200). This transforms the left-censored ("less than") DCE concentrations (non-detects) to right-censored ("greater than") values to generate survival curves. The test compares the survival curves for the pre-treatment (coded "0") and post-treatment (coded "1") soil VOC results.



Gehan test using ProUCL

Raw Statistics

	Post	Pre
Number of Valid Data	48	48
Number of Non-Detect Data	8	13
Number of Detect Data	40	35
Minimum Non-Detect	5.8	5.9
Maximum Non-Detect	6.1	6.2
Percent Non detects	16.67%	27.08%
Minimum Detected	3.8	1.5
Maximum Detected	1300	2100
Mean of Detected Data	250	255.7
Median of Detected Data	64.5	38
SD of Detected Data	381.8	436.4

Pre-treatment vs. Post-treatment using the Gehan Test

H_0: Mean/Median of Post-Treatment Data ≤ Mean/Median of Pre-Treatment Data

H_1: Mean/Median of Post-Treatment Data > Mean/Median of Pre-Treatment Data

Gehan z Test Value	1.456
Critical z (0.95)	1.645
P-Value	0.0727

Environmental Security Technology Certification Program
(ESTCP)

Enhanced Attenuation of Unsaturated Chlorinated Solvent Source Zones Using Direct Hydrogen Delivery

ESTCP Project ER-1027

Appendix L: Supplemental Data – Vapor Monitoring

- **Tracer Test Vapor Monitoring**
- **Gas Injection Phase: Analytical Results**
- **Gas Injection Phase: Vapor Monitoring Results**

Tracer Test Vapor Monitoring

Table L1: Soil vapor monitoring results - Day 1 of helium tracer test, June 2011

Well ID	He	Pressure before the rotameter	Pressure after the rotameter	Flow rate
	%	psig	psig	scfm
IW-1S	10.1	12	12	0.12
IW-1M	9.7	12.5	11.5	0.27
IW-1D	9.8	12.5	12	0.07
W-2S	9.4	12	11	0.12
IW-2M	9.9	12	12	0.27
IW-2D	9.5	12	11.5	0.11
IW-3S	9.7	12	11.5	0.26
IW-3M	9.2	12.5	12	0.14
IW-3D	9.7	12	11.5	0.25
Ambient Air	0.005	-	-	-

Table L2: Soil vapor monitoring results - Day 1 of helium tracer test, June 2011

Well ID	Distance from IW	He	CH_4	CO_2	O_2	Bal.	LEL	Barometric Pressure	Relative Pressure
	ft	%	%	%	%	%	%CH4	in - Hg	in - H2O
MW-1S	17.0	0.1	0.0	1.3	17.3	81.4	0	28.29	0.06
MW-1M	16.0	0.0	0.2	3.7	0.0	96.1	4	28.29	0.06
MW-1D	15.0	0.0	0.0	0.0	6.3	93.7	0	28.29	0.06
MW-2S	18.0	0.0	0.2	3.8	15.8	80.2	3	28.29	0.06
MW-2M	18.0	0.0	0.1	2.1	16.0	81.8	2	28.29	0.06
MW-2D	20.0	0.0	0.1	2.7	14.8	82.4	2	28.29	0.06
MW-3S	14.0	0.1	0.0	4.1	15.8	80.1	0	28.29	0.06
MW-3M	15.0	0.0	0.3	1.5	18.0	80.2	5	28.29	0.06
MW-3D	16.0	0.0	0.1	2.0	19.1	78.8	2	28.29	0.06
MW-4S	19.0	0.1	0.0	2.2	14.1	83.7	0	28.31	0.04
MW-4M	20.0	0.0	0.0	0.8	16.0	83.2	0	28.31	0.04
MW-4D	18.0	0.0	0.1	1.0	16.5	82.4	1	28.31	0.04
MW-5S	10.0	4.9	0.0	4.8	0.1	95.1	0	28.31	0.04
MW-5M	10.0	5.0	0.1	1.3	0.0	98.6	1	28.31	0.04
MW-5D	10.0	6.2	0.3	9.3	0.0	90.4	6	28.31	0.04
MW-6S	15.0	0.0	0.1	5.3	2.3	92.3	1	28.31	0.04
MW-6M	15.0	0.1	0.2	3.1	8.7	88.0	3	28.31	0.04
MW-6D	15.0	0.2	0.0	0.9	16.8	82.3	0	28.31	0.04
MW-7S	20.0	0.0	0.0	0.8	19.1	80.1	0	28.31	0.04
MW-7M	20.0	0.0	0.1	0.6	18.2	81.1	2	28.31	0.04
MW-7D	20.0	0.0	0.0	0.9	19.7	79.4	0	28.31	0.04
MW-8S	40.0	0.0	0.0	0.9	19.6	79.5	0	28.31	0.04
MW-8M	40.0	0.0	0.2	1.8	18.7	79.3	3	28.31	0.04
MW-8D	40.0	0.0	0.4	0.0	18.2	81.4	5	28.31	0.04
MW-9S	28.0	0.0	0.1	2.7	12.8	84.4	2	28.31	0.04
MW-9M	31.0	0.0	0.4	0.6	16.1	82.9	7	28.31	0.04
MW-9D	32.0	0.0	0.6	1.8	18.4	79.2	11	28.31	0.04

Table L3: Soil vapor monitoring results - Day 4 of helium tracer test, June 2011

Well ID	He	Pressure before the rotameter	Pressure after the rotameter	Flow rate
	%	psig	psig	scfm
IW-1S	10.4	12	12	0.10
IW-1M	9.4	12	11.25	0.22
IW-1D	9.6	12	12	0.05
W-2S	9.3	12	11	0.10
IW-2M	10.0	12.5	11	0.24
IW-2D	9.8	11.75	11.75	0.08
IW-3S	9.6	11.5	11	0.26
IW-3M	10.0	12	11.75	0.10
IW-3D	9.6	11.5	10.25	0.24
Ambient Air	0.005	-	-	-

Table L4: Soil vapor monitoring results - Day 4 of helium tracer test, June 2011

Well ID	Distance from IW	He	CH_4	CO_2	O_2	Bal.	LEL	Barometric Pressure	Relative Pressure
	ft	%	%	%	%	%	%CH4	in - Hg	in - H2O
MW-1S	17.0	1.1	0.1	1.5	17.6	80.8	2	27.87	2.65
MW-1M	16.0	0.9	0.1	0.0	2.9	97.0	2	27.87	2.65
MW-1D	15.0	0.6	0.1	0.0	8.4	91.5	2	27.87	2.65
MW-2S	18.0	0.2	0.1	6.4	3.5	89.9	2	27.87	2.65
MW-2M	18.0	0.1	0.3	0.4	16.7	82.5	4	27.87	2.65
MW-2D	20.0	0.1	0.3	0.2	19.3	80.0	5	27.87	2.65
MW-3S	14.0	4.7	0.2	7.8	2.1	89.8	3	27.87	2.65
MW-3M	15.0	2.9	0.8	1.0	6.8	91.2	15	27.87	2.65
MW-3D	16.0	1.8	0.2	0.3	18.9	80.5	4	27.87	2.65
MW-4S	19.0	1.9	0.2	4.5	4.1	90.9	4	27.87	2.65
MW-4M	20.0	0.3	0.6	1.8	9.4	88.4	10	27.87	2.65
MW-4D	18.0	0.1	0.4	0.7	14.9	83.9	8	27.87	2.65
MW-5S	10.0	5.4	0.1	4.9	3.2	91.6	3	27.87	2.65
MW-5M	10.0	5.7	0.3	0.8	2.6	95.9	5	27.87	2.65
MW-5D	10.0	6.1	0.6	2.7	0.6	96.1	12	27.87	2.65
MW-6S	15.0	4.6	0.1	3.9	6.2	89.5	1	27.87	2.65
MW-6M	15.0	3.2	0.2	1.2	10.3	88.0	4	27.87	2.65
MW-6D	15.0	4.2	0.0	0.7	17.0	82.2	2	27.87	2.65
MW-7S	20.0	0.7	0.1	0.9	6.9	92.0	4	27.87	2.65
MW-7M	20.0	0.6	0.2	0.7	6.3	92.8	5	27.87	2.65
MW-7D	20.0	0.0	0.1	0.7	18.2	80.9	2	27.87	2.65
MW-8S	40.0	1.0	0.1	0.3	12.9	86.6	2	27.87	2.65
MW-8M	40.0	0.8	0.1	1.4	13.5	84.8	2	27.87	2.65
MW-8D	40.0	0.3	0.2	0.2	13.4	86.4	3	27.87	2.65
MW-9S	28.0	0.9	0.2	2.7	9.6	87.5	4	27.87	2.65
MW-9M	31.0	0.0	0.5	0.6	7.6	91.2	9	27.87	2.65
MW-9D	32.0	0.6	0.7	1.2	6.0	92.0	12	27.87	2.65

Table L5: Soil vapor monitoring results - Day 7 of helium tracer test, June 2011

Well ID	He	Pressure before the rotameter	Pressure after the rotameter	Flow rate
	%	psig	psig	scfm
IW-1S	9.7	12.25	12.5	0.10
IW-1M	9.4	12.75	11.75	0.22
IW-1D	8.9	12.5	12.5	0.05
W-2S	9.2	12.5	11.5	0.10
IW-2M	9.4	12.3	11.25	0.26
IW-2D	9.6	12.25	12.0	0.08
IW-3S	9.7	12.25	11.5	0.30
IW-3M	9.7	12.5	11.25	0.12
IW-3D	9.3	12	12.0	0.26
Ambient Air	0.007	-	-	-

Table L6: Soil vapor monitoring results - Day 7 of helium tracer test, June 2011

Well ID	Distance from IW	He	CH_4	CO_2	O_2	Bal.	LEL	Barometric Pressure	Relative Pressure
	ft	%	%	%	%	%	%CH4	in - Hg	in - H2O
MW-1S	17.0	0.4	0.0	6.0	11.2	82.8	0	28.13	0.01
MW-1M	16.0	0.3	0.0	0.1	4.2	95.7	0	28.13	0.01
MW-1D	15.0	0.1	0.0	0.1	9.4	90.5	0	28.13	0.01
MW-2S	18.0	0.1	0.0	6.8	5.8	87.2	0	28.13	0.01
MW-2M	18.0	0.1	0.1	0.3	19.7	79.9	1	28.13	0.01
MW-2D	20.0	0.1	0.0	0.2	20.6	79.1	0	28.13	0.01
MW-3S	14.0	4.6	0.0	8.8	0.0	91.2	0	28.13	0.01
MW-3M	15.0	3.5	0.6	1.2	8.7	89.3	11	28.13	0.01
MW-3D	16.0	2.5	0.0	0.2	20.7	79.0	0	28.13	0.01
MW-4S	19.0	2.2	0.0	5.3	5.1	89.5	0	28.13	0.01
MW-4M	20.0	0.4	0.0	0.1	21.9	77.9	0	28.13	0.01
MW-4D	18.0	0.5	0.2	0.6	17.9	81.2	3	28.13	0.01
MW-5S	10.0	6.1	0.0	6.1	3.1	90.7	0	28.13	0.01
MW-5M	10.0	5.0	0.0	0.3	18.2	81.8	0	28.13	0.01
MW-5D	10.0	5.4	0.3	2.4	0.0	97.3	6	28.13	0.01
MW-6S	15.0	4.9	0.0	4.5	6.6	88.7	0	28.13	0.01
MW-6M	15.0	3.0	0.1	1.3	12.0	86.5	1	28.13	0.01
MW-6D	15.0	5.1	0.0	1.0	16.7	82.2	0	28.13	0.01
MW-7S	20.0	0.7	0.0	1.2	6.5	92.2	0	28.13	0.01
MW-7M	20.0	0.3	0.1	0.8	10.2	88.9	1	28.13	0.01
MW-7D	20.0	0.5	0.0	0.9	18.1	80.9	0	28.13	0.01
MW-8S	40.0	1.1	0.0	0.4	14.6	84.9	0	28.13	0.01
MW-8M	40.0	0.0	0.0	1.7	13	85.2	0	28.13	0.01
MW-8D	40.0	0.1	0.0	0.4	11.7	87.8	0	28.13	0.01
MW-9S	28.0	1.4	0.1	2.9	10.3	86.6	1	28.13	0.01
MW-9M	31.0	1.1	0.4	0.7	10.3	88.6	7	28.13	0.01
MW-9D	32.0	2.4	1.0	1.6	6.5	90.8	21	28.13	0.01

Gas Injection Phase: Analytical Results

Table L7: Soil vapor monitoring results, H_2T implementation phase, August 2011

SAMPLE NAME	TCE	cis-1,2-DCE	trans-1,2-DCE	VC	Ethene	Ethane	Propane	Methane	1,1,1-TCA
MW-1S	0.006	<0.01	<0.01	<1	1.85	40.31	61.29	83.6	<0.005
MW-1S DUP	0.010	0.02	<0.01	<1	1.96	42.96	65.58	88.7	<0.005
MW-1M	562.439	363.19	11.24	<3	5.89	55.34	332.83	45.9	<0.005
MW-1D	32.040	44.64	2.39	<1	1.05	81.17	396.25	63.6	<0.005
MW-2S	0.036	0.53	0.13	<1	2.56	71.70	315.15	332.7	<0.005
MW-2M	0.280	24.66	0.82	<1	0.95	6.98	43.41	114.2	<0.005
MW-2D	0.282	0.38	0.06	<1	0.12	0.66	4.07	29.8	<0.005
MW-3S	0.101	1.35	0.23	<1	4.94	3757.79	38104.24	2040.0	<0.005
MW-3M	1.521	1.49	0.12	<1	16.59	119.29	23.92	851.0	<0.005
MW-3D	0.286	0.13	0.04	<1	1.27	11.16	94.90	239.2	<0.005
MW-4S	1.173	66.68	7.84	<1	12.89	4470.93	51757.50	1450.0	<0.005
MW-4M	7.292	35.26	1.14	<1	0.55	6.11	107.08	100.6	<0.005
MW-4D	0.914	0.76	0.14	<1	0.37	2.73	29.16	177.3	<0.005
MW-5S	0.004	2.86	0.27	<1	11.85	3385.76	32723.48	475.4	<0.005
MW-5M	2.018	1.72	0.12	<1	0.10	13.74	73.78	32.6	<0.005
MW-5M DUP	31.661	19.83	1.05	<1	6.56	32.12	36.96	7730.0	<0.005
MW-5D	5.960	3.39	0.19	<1	<0.02	451.06	5753.50	37.9	<0.005
MW-6S	0.117	13.12	2.24	<1	14.34	2412.93	21087.64	604.5	<0.005
MW-6M	1.273	3.01	0.08	<1	0.45	8.60	88.64	131.7	<0.005
MW-6D	1.249	0.06	0.02	<1	<0.02	2598.18	19276.40	170.7	<0.005
MW-7S	0.039	3.93	0.60	<1	7.62	4282.49	47414.06	1580.0	<0.005
MW-7M	1.392	6.20	0.20	<1	0.08	9.49	221.29	92.9	<0.005
MW-7D	0.577	<0.01	<0.01	<1	<0.02	1945.22	11366.48	141.1	<0.005
MW-8S	0.013	<0.01	<0.01	<1	0.04	19.88	292.58	5.8	<0.005
MW-8M	0.408	0.24	0.02	<1	0.19	27.85	85.39	21.7	<0.005
MW-8D	0.024	0.01	<0.01	<1	<0.02	40.25	334.06	265.4	<0.005
MW-9S	0.009	160.07	9.04	<3	51.02	116.63	169.99	156.4	<0.005
MW-9M	6.937	1.97	0.36	<1	0.12	0.81	10.32	3.0	<0.005
MW-9D	2.680	0.29	0.17	<1	0.19	0.91	7.64	314.9	<0.005
MW-9D DUP	2.755	0.39	0.15	<1	0.81	5.12	1.48	2880.0	<0.005
FB -UP	<0.005	<0.01	<0.01	<1	<0.02	<0.02	<0.02	2.0	<0.005
FB-DOWN	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.06	2.0	<0.005

TCE: Trichloroethene, cis-1,2-DCE: cis-1,2-Dichloroethene, trans-1,2-DCE: trans-1,2-Dichloroethene, VC: Vinyl Chloride, 1,1,1-TCA, 1,1,1-Trichloroethane. All concentrations are in ppmv.

Table L8: Soil vapor monitoring results, H_2T implementation phase, October 2011

SAMPLE NAME	TCE	cis - DCE	trans-1,2-DCE	VC	ETHENE	ETHANE	PROPANE	METHANE	1,1,1-TCA
MW-1S	<0.005	<0.01	<0.01	<1	4.56	313.81	1012.54	161.8	<0.005
MW-1M	10.494	9.71	0.32	<1	1.49	3.53	6.37	49.8	<0.005
MW-1D	26.881	37.53	1.55	<1	0.67	51.49	460.47	35.7	<0.005
MW-2S	0.065	1.06	0.28	<1	4.77	1,262.09	16,484.56	1,730.0	<0.005
MW-2S-Dup	0.067	1.08	0.28	<1	4.88	1,262.91	16,966.90	1,640.0	<0.005
MW-2M	0.166	22.49	0.78	<1	1.22	15.34	251.26	168.3	<0.005
MW-2D	0.098	0.24	0.04	<1	2.26	12.96	155.89	134.4	<0.005
MW-3S	0.122	1.67	0.34	<1	5.91	3,574.74	42,673.05	5,220.0	<0.005
MW-3M	7.519	6.52	0.39	<1	10.52	121.25	39.66	9,920.0	<0.005
MW-3D	0.600	0.45	0.07	<1	0.47	10.02	135.52	39.8	<0.005
MW-4S *	0.047	7.71	0.67	<2	1.88	560.27	2,560.58	806.5	<0.005
MW-4M	18.331	81.52	3.38	<1	0.07	0.46	7.65	11.4	<0.005
MW-4D	0.286	0.46	0.07	<1	0.88	3.86	17.86	297.4	<0.005
MW-5S	0.007	6.48	0.94	<1	14.79	3,548.56	42,199.25	4,310.0	<0.005
MW-5M	1.527	1.25	0.15	<1	3.87	19.18	26.78	7,570.0	<0.005
MW-5M-Dup	1.975	1.53	0.15	<1	7.32	43.36	273.57	7,510.0	<0.005
MW-5D	16.417	9.00	0.65	<1	<0.02	3,872.60	64,772.34	357.5	<0.005
MW-6S	0.131	16.78	2.62	<1	14.06	3,545.32	35,677.72	3,040.0	<0.005
MW-6M	1.234	3.14	0.13	<1	1.14	18.65	204.49	112.5	<0.005
MW-6D	0.206	0.04	<0.01	<1	<0.02	2,504.99	19,961.04	130.2	<0.005
MW-7S	0.020	2.10	0.45	<1	8.31	3,428.71	50,192.92	3,610.0	<0.005
MW-7M	1.328	4.79	0.39	<1	0.37	21.00	61.18	69.8	<0.005
MW-7D	0.132	<0.01	<0.01	<1	<0.02	2,077.57	10,543.14	99.5	<0.005
MW-7D-Dup	0.177	<0.01	<0.01	<1	<0.02	2,041.72	10,851.51	119.7	<0.005
MW-8S	0.006	<0.01	<0.01	<1	2.58	705.03	8,489.59	23.6	<0.005
MW-8M	0.088	0.04	<0.01	<1	0.14	8.07	27.07	16.7	<0.005
MW-8D	<0.005	<0.01	<0.01	<1	0.40	79.09	1,027.58	175.3	<0.005
MW-9S *	<0.005	19.11	1.33	<1	6.24	22.62	96.10	12.5	<0.005
MW-9M	3.274	0.99	0.11	<1	2.40	8.99	70.35	583.2	<0.005
MW-9D *	1.981	0.31	0.14	<1	1.18	4.03	5.20	725.6	<0.005
FB UP	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.03	2.0	<0.005
FB DOWN	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.18	2.0	<0.005

TCE: Trichloroethene, cis-1,2-DCE: cis-1,2-Dichloroethene, trans-1,2-DCE: trans-1,2-Dichloroethene, VC: Vinyl Chloride, 1,1,1-TCA, 1,1,1-Trichloroethane. All concentrations are in ppmv.

Table L9: Soil vapor monitoring results, H_2T implementation phase, 14 Dec. 2011

SAMPLE NAME	TCE	cis - DCE	trans-1,2-DCE	VC	ETHENE	ETHANE	PROPANE	METHANE	1,1,1-TCA
MW-1S	0.002	0.01	<0.01	<1	4.358	342.574	973.284	179.333	<0.005
MW-1M	7.586	16.98	0.52	<1	2.917	11.179	58.849	67.19	<0.005
MW-1D	23.988	58.88	1.71	<1	0.701	36.722	736.753	44.483	<0.005
MW-2S	0.049	1.32	0.32	<1	6.081	1358.103	17971.411	1797.231	<0.005
MW-2S-Dup	0.038	1.12	0.45	<1	7.223	1412.587	17649.55	1806.393	<0.005
MW-2M	0.162	22.49	1.05	<1	1.412	3.939	106.942	95.873	<0.005
MW-2D	0.093	12.02	0.32	<1	3.745	21.045	457.053	91.133	<0.005
MW-3S	0.126	2.14	0.49	<1	6.876	3784.367	43742.215	5434.358	<0.005
MW-3M	7.079	12.59	0.58	<1	9.622	146.811	123.059	10119.29	<0.005
MW-3D	0.132	0.54	0.46	<1	1.943	85.221	291.058	146.488	<0.005
MW-4S *	0.022	1949.84	0.75	<1	2.67	755.864	2364.347	609.809	<0.005
MW-4M	14.125	125.89	3.47	<1	0.985	3.15	65.989	4.032	<0.005
MW-4D	0.427	1.41	0.09	<1	1.092	4.578	8.504	197.844	<0.005
MW-5S	0.004	10.00	1.27	<1	15.369	3253.412	43064.656	4124.297	<0.005
MW-5M	1.122	2.51	0.41	<1	5.306	41.403	61.18	7670.122	<0.005
MW-5M-Dup	1.184	2.76	0.35	<1	6.545	39.299	54.669	7546.219	<0.005
MW-5D	5.623	19.50	0.98	<1	<0.02	3570.452	63259.396	564.306	<0.005
MW-6S	0.162	19.05	2.95	<1	14.859	4048.78	36147.529	2844.503	<0.005
MW-6M	1.202	14.79	0.47	<1	1.46	21.246	479.147	125.682	<0.005
MW-6D	0.141	0.08	<0.01	<1	<0.02	2612.461	19465.405	170.812	<0.005
MW-7S	0.017	3.47	0.57	<1	3.245	3736.298	51174.523	3699.229	<0.005
MW-7M	1.738	7.94	0.59	<1	1.234	3.995	325.199	166.595	<0.005
MW-7D	0.058	0.66	<0.01	<1	<0.02	978.012	11566.473	46.541	<0.005
MW-7D-Dup	0.064	0.71	<0.01	<1	<0.02	1028.107	11698.222	50.377	<0.005
MW-8S	0.005	0.01	<0.01	<1	3.711	811.126	8221.667	6.138	<0.005
MW-8M	0.069	0.05	<0.01	<1	0.497	32.065	112.558	122.26	<0.005
MW-8D	0.010	0.10	<0.01	<1	2.084	87.024	1088.959	147.044	<0.005
MW-9S *	0.002	25.70	1.39	<1	7.875	32.273	119.328	31.305	<0.005
MW-9M	2.042	8.71	0.19	<1	1.656	114.373	121.563	489.935	<0.005
MW-9D *	0.525	0.79	0.43	<1	2.829	17.389	14.031	933.303	<0.005
FB UP	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.045	2.487	<0.005
FB DOWN	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.052	2.153	<0.005

TCE: Trichloroethene, cis-1,2-DCE: cis-1,2-Dichloroethene, trans-1,2-DCE: trans-1,2-Dichloroethene, VC: Vinyl Chloride, 1,1,1-TCA, 1,1,1-Trichloroethane. All concentrations are in ppmv.

Table L10: Soil vapor monitoring results, post-treatment characterization phase, 29 Dec. 2011

SAMPLE NAME	**TCE**	**cis - DCE**	**trans-1,2-DCE**	**VC**	**ETHENE**	**ETHANE**	**PROPANE**	**METHANE**	**1,1,1-TCA**
MW-1S	0.013	0.031	0.019	<1	0.235	44.026	228.451	156.012	<0.005
MW-1M	6.229	7.466	0.363	<1	12.714	30.574	122.225	263.638	<0.005
MW-1D	78.522	48.404	7.258	<1	0.752	5977.959	71057.867	999	<0.005
MW-2S	0.072	1.426	0.365	<1	4.651	2370.717	35048.957	6500	<0.005
MW-2S-Dup	0.067	1.386	0.361	<1	4.097	2212.443	38591.543	6360	<0.005
MW-2M	0.147	46.958	1.678	<1	1.039	243.743	5557.832	1040	<0.005
MW-2D	2.132	2.816	0.169	<1	0.619	69.882	1454.248	61.444	<0.005
MW-3S	0.134	2.92	0.627	<1	4.28	3811.414	52277.195	9370	<0.005
MW-3M	19.96	26.176	1.062	<1	2.694	36.802	1424.134	120.41	<0.005
MW-3D	0.435	0.406	0.06	<1	0.675	55.176	3323.744	57.182	<0.005
MW-4S *	0.209	60.821	5.373	<1	6.861	3290.801	62041.242	9080	<0.005
MW-4M	4.262	25.119	1.383	<1	6.747	31.374	28.518	7740	<0.005
MW-4D	1.596	2.054	0.217	<1	0.788	90.504	7833.346	51.601	<0.005
MW-5S	0.025	22.488	1.864	<1	8.656	3606.821	61346.383	7744	<0.005
MW-5M	8.325	5.215	0.54	<1	7.942	322.491	1366.68	12330	<0.005
MW-5M-Dup	67.946	45.703	1.853	<1	3.796	249.86	3195.586	4060	<0.005
MW-5D	19.594	43.839	1.11	<1	<0.02	1220.837	85029.75	206.046	<0.005
MW-6S	0.084	21.652	3.033	<1	9.961	3437.651	47269.672	6990	<0.005
MW-6M	3.427	10.726	0.295	<1	0.491	197.564	6247.133	60.176	<0.005
MW-6D	1.16	0.236	0.032	<1	0.369	2919.824	40133.047	690	<0.005
MW-7S	0.038	3.453	0.484	<1	0.044	702.498	48300.848	680	<0.005
MW-7M	5.243	13.132	0.993	<1	0.152	20.761	133.201	69.195	<0.005
MW-7D	1.001	0.014	<0.01	<1	0.08	2451.666	27227.484	375.003	<0.005
MW-7D-Dup	0.899	0.012	<0.01	<1	0.075	2446.795	27136.898	378.958	<0.005
MW-8S	<0.005	<0.01	<0.01	<1	0.022	708.751	3129.854	107.169	<0.005
MW-8M	0.643	0.077	0.05	<1	<0.02	2.022	11.539	12.984	<0.005
MW-8D	0.005	0.022	<0.01	<1	<0.02	595.409	16397.52	98.787	<0.005
MW-9S *	0.005	35.239	2.543	<1	27.056	212.835	1738.648	91.526	<0.005
MW-9M	64.232	24.198	1.542	<1	2.072	7.883	549.606	550	<0.005
MW-9D *	1.019	1.123	0.146	<1	0.731	5.745	44.99	135.177	<0.005
FB UP	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.049	2.148	<0.005
FB DOWN	<0.005	<0.01	<0.01	<1	<0.02	<0.02	0.033	2.073	<0.005

TCE: Trichloroethene, cis-1,2-DCE: cis-1,2-Dichloroethene, trans-1,2-DCE: trans-1,2-Dichloroethene, VC: Vinyl Chloride, 1,1,1-TCA, 1,1,1-Trichloroethane. All concentrations are in ppmv.

Gas Injection Phase: Vapor Monitoring

Table L11: Soil vapor monitoring results, pre-treatment characterization phase, May 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	-	0.0	3.8	15.2	81.0	0.0	28.10	-0.29
MW-1M	16.0	-	0.0	2.2	16.5	81.3	0.0	28.10	-0.30
MW-1D	15.0	-	0.2	6.0	5.9	87.9	4.0	28.10	-0.30
MW-2S	18.0	-	0.0	4.3	14.9	80.8	0.0	28.15	-0.21
MW-2M	18.0	-	0.1	1.6	13.2	85.1	2.0	28.15	-0.24
MW-2D	20.0	-	0.2	3.0	14.1	82.7	4.0	28.16	-0.26
MW-3S	14.0	-	0.0	4.7	14.9	80.4	0.0	28.14	-0.40
MW-3M	15.0	-	0.1	1.6	17.6	80.7	2.0	28.14	-0.46
MW-3D	16.0	-	0.0	2.3	18.0	79.7	0.0	28.15	-0.50
MW-4S	19.0	-	0.0	3.1	13.7	83.2	0.0	28.16	-0.32
MW-4M	20.0	-	0.1	1.2	15.7	83.0	2.0	28.15	-0.35
MW-4D	18.0	-	0.2	2.7	15.2	81.9	4.0	28.14	-0.36
MW-5S	10.0	-	0.0	3.6	17.1	79.3	0.0	28.14	-0.55
MW-5M	10.0	-	0.2	0.9	16.3	82.6	4.0	28.13	-0.55
MW-5D	10.0	-	0.0	2.0	17.9	80.1	0.0	28.13	-0.56
MW-6S	15.0	-	0.0	3.2	17.4	79.4	0.0	28.13	-0.58
MW-6M	15.0	-	0.1	1.9	18.3	79.7	2.0	28.13	-0.54
MW-6D	15.0	-	0.0	1.4	19.1	79.5	0.0	28.13	-0.50
MW-7S	20.0	-	0.0	1.1	18.5	80.4	0.0	28.12	-0.46
MW-7M	20.0	-	0.0	1.0	17.6	81.4	0.0	28.12	-0.44
MW-7D	20.0	-	0.0	1.2	18.9	79.9	0.0	28.12	-0.44
MW-8S	40.0	-	0.0	0.7	19.3	80.0	0.0	28.10	-0.29
MW-8M	40.0	-	0.0	2.1	19.4	78.5	0.0	28.10	-0.30
MW-8D	40.0	-	0.0	0.2	19.5	80.3	0.0	28.11	-0.30
MW-9S	28.0	-	0.0	2.9	13.6	83.5	0.0	28.10	-0.19
MW-9M	31.0	-	0.1	0.5	16.7	82.7	2.0	28.10	-0.19
MW-9D	32.0	-	0.0	2.0	17.8	80.2	0.0	28.11	-0.22

Typical Accuracy:	0-5% volume	5-15% volume	15%-FS	Range
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table L12: Soil vapor monitoring results, H_2T implementation phase, June 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	225	0.0	11.5	1.8	86.7	0	28.18	-0.11
MW-1M	16.0	225	0.1	0.3	9.6	90.0	1	28.18	-0.11
MW-1D	15.0	300	0.0	0.5	9.9	89.5	0	28.18	-0.11
MW-2S	18.0	450	0.0	11	0.3	88.5	0	28.18	-0.11
MW-2M	18.0	750	0.2	0.4	8.2	91.2	4	28.18	-0.11
MW-2D	20.0	125	0.0	0.2	9.4	90.3	0	28.18	-0.11
MW-3S	14.0	1825	67.5	10.3	0.1	22.1	>	28.18	-0.11
MW-3M	15.0	300	0.4	0.9	4.7	94.0	7	28.18	-0.11
MW-3D	16.0	275	0.1	0.3	8.6	91.0	1	28.18	-0.11
MW-4S	19.0	200	43.4	8.4	0.2	48.1	>	28.18	-0.11
MW-4M	20.0	425	0.1	0.3	9.5	90.1	2	28.18	-0.11
MW-4D	18.0	175	0.2	0.6	6.3	92.8	2	28.18	-0.11
MW-5S	10.0	1500	21.1	8.1	0.2	70.7	>	28.18	-0.11
MW-5M	10.0	275	0.1	0.1	10.3	89.4	1	28.18	-0.11
MW-5D	10.0	300	>	1.5	0.2	>	>	28.18	-0.11
MW-6S	15.0	550	7.7	5.8	0.2	86.4	>	28.18	-0.11
MW-6M	15.0	300	0.3	1.7	6.5	91.6	5	28.18	-0.11
MW-6D	15.0	950	2.8	0.7	3.1	93.5	55	28.18	-0.11
MW-7S	20.0	400	20.8	1.8	0.1	77.3	>	28.18	-0.11
MW-7M	20.0	750	0.2	1.3	1.7	96.7	4	28.18	-0.11
MW-7D	20.0	450	0.3	0.8	4.6	94.2	6	28.18	-0.11
MW-8S	40.0	550	0.0	0.5	10.4	89.0	0	28.18	-0.11
MW-8M	40.0	225	0.0	1.3	10.3	87.8	0	28.18	-0.11
MW-8D	40.0	0	0.0	0.3	10.8	88.8	0	28.18	-0.11
MW-9S	28.0	100	0.1	5.6	1.8	92.5	2	28.18	-0.11
MW-9M	31.0	500	0.0	0.0	10.6	89.3	0	28.18	-0.11
MW-9D	32.0	250	1.2	1.2	3.9	93.6	23	28.18	-0.11

> GEM2000 had a very high reading that was out of the instrument's reading range.

Typical Accuracy:	**0-5% volume**	**5-15% volume**	**15%-FS**	**Range**
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table L13: Soil vapor monitoring results, H_2T implementation phase, August 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	700	0.1	15.7	0.0	84.2	2	27.97	0.03
MW-1M	16.0	600	0.4	0.6	8.7	90.3	8	27.97	0.03
MW-1D	15.0	2450	0.2	1.0	9.7	89.1	4	27.97	0.03
MW-2S	18.0	350	0.5	15.0	0.0	84.5	10	27.97	0.03
MW-2M	18.0	850	0.2	0.4	7.7	91.7	5	27.97	0.03
MW-2D	20.0	300	0.2	0.0	8.2	91.6	1	27.97	0.03
MW-3S	14.0	450	>	14.4	0.0	>	>	27.97	0.03
MW-3M	15.0	1775	0.6	0.5	6.4	92.6	12	27.97	0.03
MW-3D	16.0	500	0.3	0.3	8.3	91.1	6	27.97	0.03
MW-4S	19.0	100	>	12.1	0.0	>	>	27.97	0.03
MW-4M	20.0	100	0.9	0.4	8.3	90.4	19	28.03	0.00
MW-4D	18.0	625	0.4	0.1	8.9	90.7	2	28.03	0.00
MW-5S	10.0	2275	>	8.3	0.0	>	>	28.03	-0.02
MW-5M	10.0	750	0.9	1.3	0.0	97.8	18	28.03	-0.02
MW-5D	10.0	900	>	1.5	0.0	>	>	28.03	-0.02
MW-6S	15.0	225	>	7.8	0.0	>	>	28.03	-0.02
MW-6M	15.0	275	0.4	1.1	4.1	94.4	8	28.03	-0.02
MW-6D	15.0	350	>	0.8	2.5	>	>	28.03	-0.02
MW-7S	20.0	100	>	2.9	0.0	>	>	28.03	-0.02
MW-7M	20.0	75	0.6	1.1	3.6	94.7	12	28.03	-0.02
MW-7D	20.0	50	59.0	0.9	3.7	36.4	>	28.03	-0.02
MW-8S	40.0	100	0.3	0.6	0.6	98.5	6	28.03	-0.02
MW-8M	40.0	325	0.0	1.9	3.0	95.1	0	28.03	-0.02
MW-8D	40.0	0	0.0	0.4	1.6	97.9	0	28.03	-0.02
MW-9S	28.0	125	0.2	8.1	0.0	91.7	5	28.03	-0.02
MW-9M	31.0	375	0.0	0.2	8.7	91.1	0	28.03	-0.02
MW-9D	32.0	150	0.3	0.3	3.6	95.8	7	28.03	-0.02

> GEM2000 had a very high reading that was out of the instrument's reading range.

Typical Accuracy:	0-5% volume	5-15% volume	15%-FS	Range
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table L14: Soil vapor monitoring results, H_2T implementation phase, October 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	1325	8.2	14.1	0.2	77.5	>	28.15	-0.8
MW-1M	16.0	1050	3.3	1.2	7.9	87.6	66	28.15	-0.8
MW-1D	15.0	1600	1.0	1.2	9.6	88.2	20	28.15	-0.8
MW-2S	18.0	975	36.6	13.5	0.5	49.4	>	28.15	-0.8
MW-2M	18.0	825	0.5	2.8	7.8	88.9	10	28.15	-0.8
MW-2D	20.0	400	0.9	1.1	8	90	18	28.15	-0.8
MW-3S	14.0	2175	>	15.5	0	>	>	28.15	-0.8
MW-3M	15.0	1975	0.4	2.3	6.1	91.2	8	28.15	-0.8
MW-3D	16.0	400	0.8	2.1	7.2	89.9	16	28.15	-0.8
MW-4S	19.0	325	>	11.1	0.2	>	>	28.15	-0.8
MW-4M	20.0	175	1.2	0.8	9.1	88.9	24	28.15	-0.8
MW-4D	18.0	475	1.1	0.2	9.7	89	22	28.15	-0.8
MW-5S	10.0	3875	>	7.6	0	>	>	28.15	-0.8
MW-5M	10.0	1600	0.5	1.0	0	98.5	10	28.15	-0.8
MW-5D	10.0	1550	>	0.9	0	>	>	28.15	-0.8
MW-6S	15.0	1075	>	6.6	0	>	>	28.15	-0.8
MW-6M	15.0	875	0.6	0.8	3.2	95.4	12	28.15	-0.8
MW-6D	15.0	525	>	0.7	1.4	>	>	28.15	-0.8
MW-7S	20.0	450	0	2.4	0.3	97.3	0	28.15	-0.8
MW-7M	20.0	175	0.9	0.9	2.9	95.3	18	28.15	-0.8
MW-7D	20.0	0	59.1	1.0	3.3	36.6	>	28.15	-0.8
MW-8S	40.0	175	13.4	1.1	0.1	85.4	>	28.15	-0.8
MW-8M	40.0	200	0	1.4	4.1	94.5	0	28.15	-0.8
MW-8D	40.0	0	0	0.2	2.8	97	0	28.15	-0.8
MW-9S	28.0	100	0.2	7.7	0.3	91.8	4	28.15	-0.8
MW-9M	31.0	250	0	0.6	9.5	89.9	0	28.15	-0.8
MW-9D	32.0	75	0.1	0.4	5.4	94.1	2	28.15	-0.8

> GEM2000 had a very high reading that was out of the instrument's reading range.

Typical Accuracy:	**0-5% volume**	**5-15% volume**	**15%-FS**	**Range**
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table L15: Soil vapor monitoring results, H_2T implementation phase, November 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	1425	9.3	15.2	0.4	75.1	>	28.04	-0.12
MW-1M	16.0	1250	5.5	2.1	6.5	85.9	>	28.04	-0.12
MW-1D	15.0	1850	2.4	3.5	10.4	83.7	48	28.04	-0.12
MW-2S	18.0	1575	44.8	12.8	0.7	41.7	>	28.04	-0.12
MW-2M	18.0	1275	5.3	2.4	7.4	84.9	>	28.04	-0.12
MW-2D	20.0	550	7.1	3.5	7.8	81.6	>	28.04	-0.12
MW-3S	14.0	2475	>	17.5	0.2	>	>	28.04	-0.12
MW-3M	15.0	2250	0.9	4.2	6.9	88	18	28.04	-0.12
MW-3D	16.0	775	2.7	3.7	7	86.6	54	28.04	-0.12
MW-4S	19.0	375	>	15.9	0.6	>	>	28.04	-0.12
MW-4M	20.0	250	4.6	2.2	10.1	83.1	92	28.04	-0.12
MW-4D	18.0	800	3.6	3	8.3	85.1	72	28.04	-0.12
MW-5S	10.0	5325	>	8.4	0	>	>	28.04	-0.12
MW-5M	10.0	1725	3.3	6.5	0.3	89.9	66	28.04	-0.12
MW-5D	10.0	1725	>	3.3	0.1	>	>	28.04	-0.12
MW-6S	15.0	1500	>	4.2	0.1	>	>	28.04	-0.12
MW-6M	15.0	1375	1.1	0.9	3.5	94.5	22	28.04	-0.12
MW-6D	15.0	525	>	1.1	2.8	>	>	28.04	-0.12
MW-7S	20.0	875	0.6	1.8	0.9	96.7	12	28.04	-0.12
MW-7M	20.0	550	0.7	0.6	2.2	96.5	14	28.04	-0.12
MW-7D	20.0	225	48.7	0.4	4.5	46.4	>	28.04	-0.12
MW-8S	40.0	400	12.8	0.6	0.3	86.3	>	28.04	-0.12
MW-8M	40.0	625	0	1.1	5.8	93.1	0	28.04	-0.12
MW-8D	40.0	0	0	0.1	4.4	95.5	0	28.04	-0.12
MW-9S	28.0	150	0.1	6.9	1.1	91.9	2	28.04	-0.12
MW-9M	31.0	225	0.1	0.8	10.9	88.2	2	28.04	-0.12
MW-9D	32.0	75	0	0.2	7.7	92.1	0	28.04	-0.12

> GEM2000 had a very high reading that was out of the instrument's reading range.

Typical Accuracy:	**0-5% volume**	**5-15% volume**	**15%-FS**	**Range**
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table L16: Soil vapor monitoring results, H_2T implementation phase, 14 Dec. 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	1350	8.9	13.8	0.2	77.1	>	28.12	0.18
MW-1M	16.0	1275	5.4	2.0	6.3	86.3	>	28.12	0.18
MW-1D	15.0	1775	2.4	3.5	10.4	83.7	48	28.12	0.18
MW-2S	18.0	1550	44.7	12.3	0.6	42.4	>	28.12	0.18
MW-2M	18.0	1275	4.8	1.9	7.3	86	96	28.12	0.18
MW-2D	20.0	575	6.8	3.0	7.4	82.8	>	28.12	0.18
MW-3S	14.0	2400	>	17.3	0.3	>	>	28.12	0.18
MW-3M	15.0	2175	0.5	3.8	6.9	88.8	10	28.12	0.18
MW-3D	16.0	775	2.7	3.3	7.0	87	54	28.12	0.18
MW-4S	19.0	350	>	15.4	0.2	>	>	28.12	0.18
MW-4M	20.0	275	4.1	1.8	9.9	84.2	82	28.12	0.18
MW-4D	18.0	775	3.2	2.6	7.9	86.3	64	28.12	0.18
MW-5S	10.0	5275	>	8.2	0.4	>	>	28.12	0.18
MW-5M	10.0	1725	2.8	6.0	0.2	91	56	28.12	0.18
MW-5D	10.0	1650	>	3.1	0.2	>	>	28.12	0.18
MW-6S	15.0	1450	>	3.8	0.1	>	>	28.12	0.18
MW-6M	15.0	1325	0.8	0.5	3.1	95.6	16	28.12	0.18
MW-6D	15.0	500	>	1.1	2.4	>	>	28.12	0.18
MW-7S	20.0	800	0.2	1.8	0.8	97.2	4	28.12	0.18
MW-7M	20.0	475	0.7	0.5	1.9	96.9	14	28.12	0.18
MW-7D	20.0	225	48.6	0.4	4.2	46.8	>	28.12	0.18
MW-8S	40.0	425	12.7	0.3	0.0	87	>	28.12	0.18
MW-8M	40.0	650	0	0.9	5.5	93.6	0	28.12	0.18
MW-8D	40.0	25	0.1	0.0	3.9	96	2	28.12	0.18
MW-9S	28.0	200	0.2	6.4	1.1	92.3	4	28.12	0.18
MW-9M	31.0	225	0.4	0.6	10.5	88.5	8	28.12	0.18
MW-9D	32.0	50	0.3	0.1	7.7	91.9	6	28.12	0.18

> GEM2000 had a very high reading that was out of the instrument’s reading range.

Typical Accuracy:	**0-5% volume**	**5-15% volume**	**15%-FS**	**Range**
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.

Table L17: Soil vapor monitoring results, post-treatment characterization phase, 29 Dec. 2011

Well ID	Distance from IW	H2	CH4	CO2	O2	Balance	LEL	Barometric Pressure	Relative Pressure
	ft	ppm	%	%	%	%	%	inches Hg	In- H2O
MW-1S	17.0	1425	9.2	12.8	0.1	77.9	>	28.07	-0.14
MW-1M	16.0	1275	6.1	2.1	6.1	85.7	>	28.07	-0.14
MW-1D	15.0	1850	10.0	3.4	10.1	76.5	>	28.07	-0.14
MW-2S	18.0	1525	0.2	12.5	0.6	86.7	4	28.07	-0.14
MW-2M	18.0	1200	7.1	1.9	7.3	83.7	>	28.07	-0.14
MW-2D	20.0	525	7.7	3.4	7.7	81.2	>	28.07	-0.14
MW-3S	14.0	2475	>	17.4	0.1	>	>	28.07	-0.14
MW-3M	15.0	2150	6.7	4	6.7	82.6	>	28.07	-0.14
MW-3D	16.0	700	6.5	3.7	6.6	83.2	>	28.07	-0.14
MW-4S	19.0	350	>	15.5	0.4	>	>	28.07	-0.14
MW-4M	20.0	225	9.7	1.7	9.7	78.9	>	28.07	-0.14
MW-4D	18.0	750	8.2	2.7	7.9	81.2	>	28.07	-0.14
MW-5S	10.0	5325	>	8.2	0.1	>	>	28.07	-0.14
MW-5M	10.0	1650	0.3	6.0	0.1	93.6	6	28.07	-0.14
MW-5D	10.0	1675	>	3	0	>	>	28.07	-0.14
MW-6S	15.0	1475	>	3.9	0.2	>	>	28.07	-0.14
MW-6M	15.0	1350	3.2	0.5	3.2	93.1	64	28.07	-0.14
MW-6D	15.0	475	>	1.1	2.6	>	>	28.07	-0.14
MW-7S	20.0	875	0.8	1.7	0.6	96.9	16	28.07	-0.14
MW-7M	20.0	550	1.8	0.3	2	95.9	36	28.07	-0.14
MW-7D	20.0	150	4.2	0.1	4.3	91.4	84	28.07	-0.14
MW-8S	40.0	425	0.3	0.5	0.2	99	6	28.07	-0.14
MW-8M	40.0	650	5.4	1	5.6	88	>	28.07	-0.14
MW-8D	40.0	25	4.4	0.1	4.2	91.3	88	28.07	-0.14
MW-9S	28.0	100	0.8	6.7	1.1	91.4	16	28.07	-0.14
MW-9M	31.0	250	10.5	0.5	10.7	78.3	>	28.07	-0.14
MW-9D	32.0	75	7.2	0	7.6	85.2	>	28.07	-0.14

> GEM2000 had a very high reading that was out of the instrument's reading range.

Typical Accuracy:	**0-5% volume**	**5-15% volume**	**15%-FS**	**Range**
CH4	±0.3%	±1%	±3% (-100%)	0-70% to specification, 0-100% reading.
CO2	±0.3%	±1%	±3% (-60%)	0-40% to specification, 0-100% reading.
O2	±1%	±1%	±1% (-21%)	0-25% to specification, 0-100% reading.