ENGINEER'S REPORT

INTERIM REMEDIAL MEASURE FOR GROUNDWATER
and
REMEDIAL ACTION WORK PLAN FOR SUB-SLAB VAPOR EXTRACTION

for

AMERICAN CLEANERS, KINGSTON
734 Ulster Avenue
Kingston, NY 12401

NYSDEC Site Number V-00601-3

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I, Jolanda G. Jansen certify that I am currently a NYS registered professional engineer and that this Interim Remedial Measure for Groundwater and Remedial Action Work Plan for Sub-Slab Vapor Extraction was prepared in accordance with all applicable statutes and regulations and in substantial conformance with the DER Technical Guidance for Site Investigation and Remediation (DER-10).

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List of Attachments

Calculation Sheet 1.
Table 1. Storm Drain Soil Sampling Laboratory Results
Table 2. Sub-Slab Soil Sampling Laboratory Results
Table 3. Sub-Slab Soil Vapor Sampling Laboratory Results
Table 4. Summary of Groundwater Sampling Results (Nov. 2013)
Table 5. Design Parameters for Bioremediation and Bioaugmentation
Figure 1-1. Site Location Map (USGS 7.5 Minute Quadrangles)
Figure 1-2. Ulster County Real Property Tax Map Location of SBL 48.58-0-17
Figure 1. Storm Drain Soil Sample Location Sketch Map
Figure 2. Location of Vapor Extraction Points
Figure 3. Location of Vapor Extraction Points and Vacuum Points
Figure 4. Estimates of Air Flow from Vacuum Measurements on Regenerative Blower Performance Curve (Fuji Electric VFC400-5T)
Figure 5-3. Isopach Map and PCE Concentrations (from RIR, 2009)
Figure 5. Tetrachloroethylene Concentrations Detected in Groundwater (2007 to 2013)
Figure 6. Proposed Locations of Bioremediaion Injection Points

Appendices

1. Report: American Cleaners, Kingston SUB-SLAB VACUUM TESTING, August 5, 2013
2. Fuji Electric Ring Compressor Specification Sheet VFC400-5T (2 pages)
3. Report: Microbial Insights, October 5, 2012 (2 pages)
4. Graphs for Slug Testing and Hydraulic Conductivity Measurements (4 pages)
5. BaroBall^{TM} Specification Sheet (2 pages), Initiatives Online (Volume 6, Fall 2001),
   Passive Soil Vapor Extraction (PSVE) for VOC Remediation at the Metallurgical Laboratory (MetLab) Progress Report, Brian D. Riha, June 2005.
   Enhancements for Passive Vapor Extraction: The Hanford Study, M.G. Ellerd, *at al,* Ground Water, Vol. 37, No. 3, May-June 1999*.*
6. Regenesis 3-D Microemulsion (3DMe™) Brochure
7. Regenesis Bio-Dechlor Inoculum Plus (BDI PLUS™) Brochure
8. Regenesis 3-D Microemulsion (3DMe™) MSDS
9. Regenesis Bio-Dechlor Inoculum Plus (BDI PLUS™) MSDS
10. Regenesis 3-D Microemulsion (3DMe™) Application Instructions
11. Regenesis Bio-Dechlor Inoculum Plus (BDI PLUS™) Application Instructions
12. Health and Safety Plan
13. Community Air Monitoring Plan
14. Project Personnel
15. York Analytical Laboratory Reports (CD ROM and Dec 2013 Report)
    Number 13I0888: Storm Drain Soil Sampling: September 23, 2013
    Number 13C0810: Sub-Slab Soil Sampling: March 25, 2013
    Number 13C0768: Sub-Slab Soil Vapor Sampling: March 25, 2013
    Number 13K0219: Groundwater Sampling: November 3-6, 2013

1.0 Introduction and Purpose

The American Cleaners site at Kingston, NY has been in the volunteer cleanup program since March 17, 2003. In 2013 significant progress was made in evaluating level of tetrachloroethylene (PCE) contamination in three media (1) soil in the vicinity of the stormwater drainage grate behind the building, (2) sub-slab soil and vapor conditions beneath the concrete floor, and (3) groundwater on-site and off-site. Based on the volatile organic compound (VOC) laboratory analyses for those media, the levels of detected PCE can now be compared with soil vapor guidance values, soil cleanup standards, and groundwater standards. Based on such comparisons, remedial action may be appropriate. Remedial actions for cleanup of sub-slab media and groundwater are proposed and specific remedies described. Concomitant plans associated with the remedial work are included for health and safety plan, community air monitoring plan, and quality assurance/ quality control plan. Also monitoring remedial progress is proposed and a schedule established for remedial action and monitoring.

1.1 Site Description

American Cleaners of Kingston is actually located in the Town of Ulster, about 0.35 miles north of the Kingston City Boundary at 734 Ulster Avenue, which is also known as Albany Avenue (Figure 1-1). The Town of Ulster is the shopping center for Ulster County because most of the shopping and commercial development in the 1980s to present has occurred in the Town, which geographically wraps around the northern, northwestern and southwestern area of the City of Kingston (County seat of Ulster County). The Section Block and Lot (SBL) number designated for the American Cleaners property is 48.58-0-17 on the Ulster County Real Property Tax Map (Figure 1-2). The parcel is located on the east side of Ulster Avenue north of the cross street Stahlman Place entering Ulster Avenue from the west and south of Mentnech Court also entering Ulster Avenue from the west. The 0.44-acre parcel has 100 feet of road frontage and a depth of approximately 194 feet between Ulster Avenue on the west and the Conrail railroad tracks on the east. In the Real Property Tax database, the land-use is classified as “484” indicated as a “one-story small structure.”

Neighboring properties include Merchant Wine and Liquor Store to the north, Meineke Muffler to the south, Pauline’s Restaurant directly across Ulster Avenue, and Resource Center for Accessible Living to the northwest across the street. The site parcel and neighboring properties are generally flat at an approximate elevation of 175 feet above sea level. Pauline’s Restaurant has had two new owners in the past three years and is vacant at this time. Behind the restaurant, a spa is located in the former auto repair building.

1.2 Site History

In 1982, the American Cleaners property was purchased by Mr. Erez Halevah. Previously a house was situated on the southwest corner of the parcel. The roof of the house can be seen on the historical air photo from 1978 included in the EDR database search provided in Appendix B (of the Remedy Selection Report, 2010). In 1982, Mr Halevah designed and constructed a one-story building, specifically for operation of a dry-cleaning establishment. From 1982 to date, the building has been in continuous operation for dry-cleaning and customer drop-off and pick-up. The design for dry-cleaning services was planned with a customer counter across the front of the store and five 4-foot deep by 5-foot wide trenches running from the front of the store to the rear. Cleaning, washing, drying, steaming and pressing equipment is placed around the perimeter of the store. The trenches are designed to provide maximum hanging capacity on three tiers of clothes rods running from front to back. The clothes-hanger rods can be reached by the employees to store and retrieve customers' garments.

The chemical of concern, Tetrachloroethylene (or tetrachloroethene or perchlorethylene and known in the vernacular as "perc" or "PCE"), has been used at the site since 1982. Unintentional and unregulated releases of PCE began in 1982 when PCE-saturated filters were placed in the dumpster outside the back of the building for disposal with trash and garbage. The dry-cleaning processing equipment was updated periodically on the following schedule:

1982-1992 First Generation Equipment
1992-1997 Third Generation Equipment
1997-Present Fourth Generation Equipment

A fire occurred in 1991 in a machine called a "Sniffer" along the north inside wall near the back of the store. The "Sniffer" collected fumes from the air during daily operations. The collected fumes were distilled to recover and reuse the PCE. The secondary source area of contamination (identified in Section 6.1 of the RIR) originated from a spill associated with the fire.

An 18-wheeler trailer was brought to the site in 2002 or 2003 with a load of wire coat hangers for use in the store. The trailer was placed on the back of the property parallel to the railroad tracks. The trailer was removed in 2008 for soil sampling beneath the former location. The primary source area of contamination (identified in Section 6.1) is associated with the location of the trailer, although it is not known if any PCE storage took place in the trailer. The trailer location may have been an earlier location of the dumpster.

1.3 Previous Investigations

The remedial investigation and remedial action selection reports listed below were prepared by Mid-Hudson Geosciences based on previous work documented in the following work plans and reports prepared by Berninger Environmental:

- ***Interim Findings & Proposed Supplemental Investigation*** (Berninger, Sep. 2005)
- ***Interim Remedial Measure Work Plan*** (Berninger, Dec. 2007) .
- ***Interim Findings & Proposed Supplemental*** Investigation (Berninger, Mar. 2008) .
- ***Supplemental Investigation Work Plan*** (Berninger, May 2008) .
- ***Proposed Supplemental Investigation Work Plan*** (Berninger, Sep. 2008) .

- ***Remedial Investigation Report*** (Mid-Hudson Geosciences, December 31, 2009)
- ***Remedial Action Selection Report*** (Mid-Hudson Geosciences, August 13, 2010)

In 2012, DEC required a New York State Licensed Professional Engineer to participate in project development. Jansen Engineering, PLLC has provided engineering services in the subsequent work products:

- ***Interim Remedial Measure Work Plan: On-site Sampling & VES*** (Jansen Engineering, PLLC and Mid-Hudson Geosciences, August 17, 2012)
- ***Supplemental Investigation and Soil Vapor Extraction Pilot Test Work Plan*** (Jansen Engineering, PLLC and Mid-Hudson Geosciences, September 19, 2012)
- ***Revised Off-Site Groundwater Investigation, Response to Comments of July 9, 2012 and Inclusion of New Information and Map*** (letter report, Jansen Engineering, PLLC and Mid-Hudson Geosciences, September 19, 2012)
- ***Report: Summary of Results from On-site American Cleaners: Supplemental Investigation and Soil Vapor Extraction Pilot Test Work Plan*** (Jansen Engineering, PLLC and Mid-Hudson Geosciences, December 3, 2013)

1.4 Summary of Remedy

Two remedies are needed for the American Cleaners Kingston site: one to mitigate sub-slab soil vapors accumulating under the concrete floor of the building and a second to breakdown PCE and daughter products to ethenes in the groundwater. Passive venting is proposed for the sub-slab vapor remediation. Bioremediation with bioaugmentation is proposed for the groundwater. Regenesis products will be injected into the top 5 feet of groundwater on-site and the active emulsion and bacteria will migrate downgradient with groundwater. Injection points will be along the western and northern property boundary and some in the backyard with horizontal distance of 15 feet between points.

1.5 Contemplated Use

The building was originally built for a dry cleaning establishment with special features such as a utility trench around the interior of the exterior wall and the 4 foot by 4-foot long trenches in the floor of the building, constructed to maximize space for clothing on hangers. The intent of the owner is to continue use in the dry cleaning business with adjustments for customer preference and needs

2.0 Work Plan Objective and Rationale

Three remedial action objectives were identified to attain the goal of restoring the site to pre-contaminant conditions to the extent feasible in the Remedial Investigation Report (Section 8.4). At a minimum, the remedies shall eliminate or mitigate all significant threats to public health and the environment presented by the contamination identified at the site through the proper application of scientific and engineering principles. The following protective remedial objectives were considered appropriate, if significant threats to public health can be substantiated:

Remedial Action Objective #1 - Public Health Protection of Groundwater

- § Prevent people from drinking groundwater with contaminant levels exceeding drinking water standards.
- § Prevent contact with contaminated groundwater.

§ Prevent inhalation of contaminants from groundwater.

Remedial Action Objective #2 - Environmental Protection of Groundwater

§ Restore the groundwater aquifer to meet ambient groundwater quality criteria, to the extent feasible.

§ Prevent discharge of contaminated groundwater to surface water.

For each of the preventive objectives for groundwater, mitigating measures already exist because the groundwater is at a depth of 9 to 12 feet below grade and the groundwater does not discharge to surface water. The restorative measure may not be needed if the site groundwater is similar in quality to the ambient groundwater in the neighborhood.

Remedial Action Objective #3 - Public Health of Soil Vapor Intrusion

§ Mitigate impacts to public health resulting from existing, or potential for, soil vapor intrusion into the indoor air of buildings at or near the site.

To date, on neighboring properties, all air sampling has shown that all indoor air quality is within the NYSDOH Guideline for PCE of 100 µg/m^3, equivalent to 15 ppbv. Hence, there is no need to mitigate soil vapor concentrations of PCE on neighboring properties.

More recent sampling of sub-slab conditions was accomplished in 2013. In this report the laboratory analyses are compared with previous levels of PCE trapped under the American Cleaners building. Remedial measures will be described and specified to mitigate the sub-slab PCE concentrations to bring the site into compliance with the NYSDOH Guidance value for PCE.

3.0 Investigations and Remedy Selection

Laboratory and field results for sampling of soil, soil vapor, and groundwater are presented and evaluated to establish the need for remediation. The selection of the appropriate remediation is described.

3.1 On-Site Storm Drain Investigation and No Need for Remediation

Sampling of soils near the storm drain directly behind the American Cleaners Kingston building was recommended by NYSDEC to assess soil conditions. The procedures and locations for sampling were provided in the ***Supplemental Investigation & SVE Pilot Test Work Plan (SI&SVEPTWP**,* September 2012)*.* The storm drain sampling event of September 23, 2013 was reported in the ***Summary of Results from On-site American Cleaners (SRAC,*** December 2013). Seven soils samples were collected from the four Geoprobe® borings and split with NYSDEC. The analytical results by US EPA method SW 846 8260B for volatile organic compounds are reported by York Analytical Laboratories in Report No: 13I0888, dated 10/02/13. DEC has never disclosed laboratory results for the split samples. The four soil boring locations are shown on Figure 1 and the analytical results are summarized in Table 1.

The following observations and conclusions were included in the ***SRAC*** (Dec. 2013):

- Review of the lab report indicates that the small concentrations of PCE found in the soil samples are below the 1300 parts per billion soil cleanup action level.
- The highest concentration was 1100, and the others were ND or less than 100.
- As indicated by their presence in the trip blank, small concentrations of acetone and methyl chloride detected in the soil samples are likely lab contaminants.
- Since all concentrations detected are below the soil cleanup action level, soil remediation is not required.

3.2. On-Site Sub-Slab Investigation and Proposed Remedial Concept

The sub-slab investigation included three types of sampling: (1) natural soil beneath the slab and construction material, (2) soil vapor from the pore space within the construction material and deeper natural sediment, and (3) vapor extraction pilot testing to measure permeability of sub-slab materials.

3.2.1 Sub-Slab Soil Sampling: March 25, 2013

Sampling of soils beneath the concrete slab inside the American Cleaners Kingston building was necessary to assess potential sub-slab contaminant conditions. The procedures and locations for installing four vapor extraction points were provided in the ***SI&SVEPTWP*** (Sep. 2012). The sub-slab soil sampling event of March 25, 2013 was reported in the ***SRAC*** (Dec. 2013). Four soil samples were collected from the natural soil from four borings below the concrete and sub-slab construction material. The analyses by US EPA method SW 846 8260B for volatile organic compounds are reported by York Analytical Laboratories in Report No: 13C0810, 04/02/2013. The four soil vapor extraction point locations are shown on Figure 2 and the analytical results are summarized in Table 2.

The following observations and conclusions were included in the summary report (Dec. 2013):

- The chemical of concern Tetrachloroethylene was not detected in soil samples from XP2 and XP3. Very low estimated concentrations of 7.2J and 9.9J were detected in soil samples from XP1 and XP4, respectively. Comparison of these soil analyses and the following soil vapor analyses indicates that the majority of sub-slab VOCs is in the form of vapors and not attached to or associated with soil particles.
- As indicated by its presence in the trip blank, small concentrations of acetone detected in the soil samples are likely a lab contaminant.

3.2.2 Sub-Slab Soil Vapor Sampling: March 25, 2013

Sampling of vapors beneath the concrete slab inside the American Cleaners Kingston building was necessary to assess potential sub-slab contaminant conditions. The procedures and locations for installing four vapor extraction points were provided in the ***SI&SVEPTWP*** (Sep. 2012). The sub-slab vapor sampling event of March 25, 2013 was reported in the ***SRAC*** (Dec. 2013). Four vapor samples were collected using Summa canisters from the extraction point screened intervals including the sub-slab construction material and top of the natural sandy soil. The analyses by US EPA method TO15 full list of volatile organic compounds for 6-Liter Summa Canister are reported by York Analytical Laboratories in Report No: 13C0768, 04/04/2013. The four soil vapor extraction point locations are shown on Figure 2 and the analytical results are summarized in Table 3.

The following observations, conclusions and recommendation were included in the ***SRAC*** (Dec. 2013):

- Tetrachloroethylene was detected in all four vapor samples at concentrations ranging from 1300 to 22,000 µg/m^3.
- Helium was injected into the bucket sealed to the floor around the extraction point to make sure that the gas in the sample was coming from below the slab. Helium gas was not detected in any of the 4 Summa canisters indicating that the samples came from beneath the slab.
- The presence of the VOC vapors beneath the slab and spotty VOC concentrations in soil samples from the same locations suggests that the vapors originate from the underlying groundwater. The materials vaporize from the groundwater, migrate upward, and are trapped under the building slab.
- The sample from XP2 by the back door also has measurable concentrations of Trichloroethylene and cis1,2-Dichloroethylene, which are both breakdown products of Tetrachloroethylene. The presence of these compounds indicates that some natural degradation of Tetrachloroethylene is occurring beneath the slab.
- Table 3 shows that the four soil vapor samples had PCE concentrations of 2300, 22,000, 12,000, and 1300 µg/m^3, for XP1 to XP4, respectively. Comparison of Table 3 with Soil Vapor/Indoor Air Matrix 2 (Final NYSDOH CEH BEEI Soil Vapor Intrusion Guidance, 2006) indicates that mitigation is appropriate for all four locations because the PCE concentrations are greater than 1000 µg/m^3 and the values of indoor air concentrations are essentially insignificant. For that reason, sub-slab vapor extraction pilot testing was recommended and conducted.

3.2.3 Sub-Slab Vapor Extraction Pilot Testing: August 5, 2013

Sub-slab vapor extraction pilot testing inside the American Cleaners Kingston building was necessary to assess potential mitigation of sub-slab contaminant conditions. The ***SI&SVEPTWP*** (Sep. 2012) presented the procedures for pilot testing the permeability of the sub-slab materials through the four vapor extraction points. The eight pilot tests conducted on August 5, 2013 are reported in the ***SRAC*** (Dec. 2013) and described in Appendix 1 of this report. Locations of the extraction points (XPs) and vacuum measuring points (VPs) are shown on Figure 3.

The following interpretations of the testing were provided in the ***SRAC*** (Dec. 2013):

- Tests 1 to 4 were determined to be invalid because the flow meter was discovered to not be working correctly on Test 5. It was quite likely the meter was not working correctly on the first 4 tests; consequently, those results were deemed invalid.
- To replace the flow meter, a manometer was constructed with water in a bucket and a tube connected to the suction line. The vacuum was measured in inches of water as the difference between height of water in the tube and the water level in the bucket. The vacuum reading was converted to flow in standard cubic feet per minute (SCFM) using the performance curve of the regenerative blower (Figure 4).
- Test 5. A vacuum of 39 inches of water and air flow of 42 SCFM was maintained on XP4 for one hour.
- A vapor pressure measuring point VP1 was drilled through the slab 5 feet across the floor and southwest of XP2.
- Test 6, when a vacuum of 40 inches H_2O (39 SCFM) was applied to XP2, a small vacuum of 0.07 inches of H_2O was measured at VP1 at a distance of 5 feet to the southwest.
- VP2 was drilled through the slab part way between XP1 and XP3.
- Test 7, when a vacuum of 43 inches H_2O (27 SCFM) was applied to XP1, essentially no vacuum was detected at VP2 at a distance of 7 feet 2 inches toward XP3.
- Test 8, when a vacuum of 43 inches H_2O (32 SCFM) was applied to XP3, a small vacuum of 0.04 inches of H_2O was measured at VP2 at a distance of 8 feet 9 inches toward XP1.

The following conclusions were drawn from the vapor extraction pilot testing:

- The construction material beneath the concrete slab was observed to be a mixture of particle sizes.
- The pilot testing indicates that the material is well packed and has low permeability to vapors. The vacuum field drops off substantially within 5 feet of the extraction points with a 1-horsepower regenerative blower.
- The 1-horse power blower is a reasonable size to evacuate vapors from porous media under the slab of this size building. However, in the American Cleaners Kingston building, the sub-slab material is not very permeable with respect to gas or vapor.
- Increasing the horsepower of the regenerative blower is not likely to significantly increase the radius of the vacuum field because it varies with the inverse square of the distance.
- The slab creates a barrier to upward migration and flow of volatile gases; otherwise, they would not be trapped there.
- Because the slab presents a barrier to vertical movement of vapors and because within the loose, but packed material, vapor permeability is virtually below the practical limit of measurability; the slab should not be penetrated or compromised.
- Annual testing of volatile organic gases in the work environment has shown continuous compliance with NYSDEC regulations and operational standards for dry cleaning plants. That testing indicates that the air in the work environment is not considered injurious to the employees.

The following remedial mitigation measure is recommended based on the pilot testing:

- Because ventilation of the sub-slab with a regenerative blower is not feasible, the 4 extraction points, installed through the slab and sub-slab fill material into the natural sandy soil, are proposed as a passive means to remove vapors which make their way to the four points. Each of the extraction points will be vented to and through the roof and capped with BaroBall^{TM} fittings to facilitate release of vapors to the atmosphere. The vapors can be monitored to record the concentrations of vapor until an asymptotic decline is observed. At that time, the system can be decommissioned and monitoring will cease.

3.3 On-Site and Off-Site Groundwater Investigation and Proposed Remedial Concept

Evaluation of groundwater conditions has included on-site and off-site groundwater sampling and laboratory testing for volatile organic compounds, testing for the presence of *Dehalococcoides* sp bacteria in groundwater, and slug testing to estimate hydraulic conductivity of the water-bearing sands.

3.3.1 Sampling Groundwater for Natural Remediation Microbes: October 1, 2012

To determine whether bacteria capable of dechlorinating PCE and daughter products were present, a sampling kit was obtained from Microbial Insights. On October 1, 2012 a groundwater sample was obtained from monitoring well MW6, the shallow well a few feet behind the back door of the American Cleaners building. The sample was shipped overnight to the lab and the laboratory report (Microbial Insights, 10/05/2012) indicated “No dechlorinating bacteria detected” (2 page report included in Appendix 3).

The following conclusion was drawn from the laboratory report:

- No natural dechlorinating bacteria were detected in the groundwater sample obtained from MW6 using the laboratory protocol. MW6 is the shallow monitoring well in the area where the highest concentrations of VOC contamination was detected in the past. If bioremediation is considered for cleanup of the PCE in groundwater, bioaugmentation would be required to supply bacteria capable of dechlorinating the PCE and daughter products.

3.3.2 Hydraulic Conductivity Measurements from Slug Tests: October 1, 2012

Slug tests were conducted in monitoring wells MW1, MW2, MW4, MW5, and MW6. Recovery of the water level was very rapid within a few seconds after injection or withdrawal of a slug of known volume. A continuous recording transducer was placed in the bottom of the well to record water levels. After testing, the water level data was searched to find the rapid changes and recovery of the water level in the wells. Graphic analyses are included in Appendix 4. These estimates of hydraulic conductivity may be useful in estimating travel times for injected groundwater remedial fluids from locations on-site to downgradient PCE plume monitoring wells and sampling locations.

The following conclusion was drawn from the hydraulic conductivity testing:

- Recovery of the wells is on the order of 3 to 13 seconds when a slug of known volume is inserted or withdrawn from the water table. Such rapid recovery indicates very permeable sandy conditions with hydraulic conductivity averaging 3 x 10^{-4} ft/sec equal to 8.8 x 10^{-3} cm/sec within the range of silty sand and clean sand (Freeze and Cherry, 1979, Table 2.2 page 29) and silty sands, fine sands and well sorted sands (Fetter, 1980, Table 4.3, page 80).

3.3.3 Groundwater Sampling for VOCs in on-site and off-site Monitoring Wells and Geoprobe® Locations along Lincoln Park Place

Historical groundwater sampling was mapped in Figure 5-3 of the Remedial Investigation Report (2009) showing a bifurcated plume with one section flowing northwest from the northern area and another sub-plume flowing west from the southern part of the site. The concentrations of PCE shown on that map are a compilation of groundwater sampling from Geoprobe® borings and monitoring wells from 2005 to 2009. The water table is about 10 feet below ground surface and its gradient is approximately -0.003 to the west-northwest.

More recent groundwater sampling has been accomplished over the past few years with installation of five monitoring wells on parcels directly across Ulster Avenue, and most recently by sampling groundwater at three locations with Geoprobe® on Lincoln Park Place, and on-site sampling of six monitoring wells (Figure 5). As shown on that map, PCE concentrations in groundwater are from sampling on November 3 to 6, 2013. The 14 groundwater analyses by US EPA method SW 846 8260B for volatile organic compounds are reported by York Analytical Laboratories in Report No: 13K0219, 11/18/2013. Laboratory results for 14 samples, 1 duplicate sample, and two blanks are summarized in Table 4. By comparison of Figure 5-3 and Figure 5, PCE concentrations show reduction both on-site and on parcels across the street.

The following conclusions were drawn from examination of historical and recent sampling events:

- On-site groundwater concentrations of PCE have diminished from 2007 to 2009 and to 2013, except at MW5 where concentrations have remained at approximately 50 µg/L.
- On the west side of Albany/Ulster Avenue, groundwater PCE concentrations are generally low, less than 50 µg/L, except at MW8 in front of the rear RCAL building where PCE was measured at 150 µg/L. Another analyte not previously detected at the site, 1,1,2-Trichloroethane was also detected in MW8 at a concentration of 5.1 µg/L. That compound may be from some source other than American Cleaners.
- On Lincoln Park Place, the highest PCE-concentration of 47 µg/L was detected at 16 feet in sample LP1 between the driveways at #746 and #752.

The following recommendations were included in the ***SRAC*** (Dec. 2013):

- ***No Additional Groundwater Wells or Borings:*** The stratigraphic levels that have been sampled for groundwater on-site and off-site are 11 to 16 feet and 20 to 25 feet below the nearly flat land surface. Farther from American Cleaners and beyond the homes on the west side of Lincoln Park Place, the ground surface drops off steeply to the floodplain level of the Esopus Creek, farther to the west. The strata which have been sampled are eroded away at the edge of the floodplain by higher waters of the Esopus Creek during periods of flooding. For that reason sampling farther to the west from the east side of Lincoln Park Place is not recommended. Because the measured PCE concentrations are representative of the migrating groundwater, sampling 200 or 300 feet downgradient between Lincoln Park Place and the drop-off is not likely to gain significant information.

- ***Natural Attenuation and Degradation:*** Tetrachlorethylene concentrations at the American Cleaners site are declining. No other VOC was detected except 1,1,2-Trichloroethane at MW8. PCE concentrations are summarized as
4 locations ND
2 locations less than 10 µg/L
7 locations between 10 and 50 µg/L
1 location at 150 µg/L
Groundwater in this area is not used for potable water because the entire area is served by the City of Kingston Water Department. Given such low concentrations, remedial measures may not be effective. Similar levels are below concentrations found at locations where various forms of treatment have been implemented and completed (see 2010 ROD for Revonak Dry Cleaners, New Paltz, NY).

3.3.4. Consideration of In-situ Remediation of PCE in Groundwater

On a conference call on February 27, 2014, DEC made it clear that no matter what PCE concentrations are detected in monitoring wells, a remedial action must be selected and implemented for groundwater at the American Cleaners Kingston site. Two common methods of remediation were considered: (1) chemical oxidation or (2) bioremediation with or without bioaugmentation. Because current concentrations of PCE range from ND to 150 µg/L or parts per billion with an average of 25 µg/L, a method of treating such low concentrations of PCE over a fairly large area was sought. Treatment of such low concentrations is considered “polishing” because it is usually employed after much higher concentrations of VOCs have been reduced by a rapid acting industrial strength chemical agent. The existing “Plume” is approximately 800 feet long and widening from a “point” source behind the AC building to a width of approximately 400 feet at Lincoln Park Place. The appropriate remedy is similar to finding a needle in a haystack and destroying it. The injected treatment fluid will have to find low concentrations of PCE molecules in a sandy water-bearing zone with a depth of approximately 10 feet over an area of 160,000 square feet, or a volume of 1,600,000 cubic feet of saturated groundwater. The reactivity of a chemical oxidation agent or virility of bacterial dechlorinating emulsion will have to be long-lived to move with natural groundwater flow from the on-site injection borings to off-site contaminated locations. Once the remedial agents reach the PCE-contaminants, the chemical oxidation or biological dechlorination will have to occur. Downgradient movement of the treatment products may take up to five years to travel from the site to locations across the street on to Lincoln Park Place, and on toward the Esopus Creek floodplain. For that reason, a long lasting remedy is needed to cleanup the low level plume.

Chemical Oxidation was considered using a Regenesis product called PersulOX. After serious consideration and working on a plan to inject that material into the ground at American Cleaners, that remedy was disqualified because in a webinar on April 30, 2014, two managers (Drew Baird and Scott Mullin) at Regenesis stated that chemical oxidation with PersulfOX or RegenOX is not appropriate to “polish” groundwater or rid groundwater of such low concentrations of VOCs detected at the American Cleaners site. Also PersulfOX is highly corrosive and caustic and requires special handling. The persistence of PersulfOX in the groundwater is of limited time and space and often requires more than one injection.

By comparison, bioremediation using Regenesis products appears have a high probability for cleanup of the low PCE concentrations both on-site and off-site over a period of two to five years.

3.3.5. Selected Remedy: Bioremediation and Bioaugmentation

Because bioremediation is suitable for “polishing” and the chemical oxidation remedies are not, and there is no detection of *Dehalococcoides* sp bacteria in the groundwater, bioremediation with bioaugmentation is the selected remedy for groundwater. Bioaugmentation is the addition of live bacteria culture to the groundwater in addition to regular bioremediation by injection of a reducing environment with emulsion oils.

4.0 Remedial Action Plans and Specifications

Previous investigations have shown that off-site soil vapor and soils, both on-site and off-site do not require remedial measures. At this time, the remediation of sub-slab vapors and groundwater are appropriate to meet Standards, Criteria, and Guidance values (SCGs).

The NYSDOH air guidance value for tetracholorethene (aka tetrachloroethylene) is 100 mcg/m^3 and for trichloroethene is 5 mcg/m^3**.** The sub-slab vapor concentrations and indoor air concentrations are compared with the matrices in the ***Final NYSDOH CEH BEEI Soil Vapor Intrusion Guidance*** document, (October 2006, pages 39, 52-56) to determine the necessity of mitigation or monitoring.

The groundwater SCGs are protective of groundwater via the soil to groundwater migration pathway (i.e., soil leaching and groundwater transport). For groundwater, standards and/or guidance values from the NYSDEC (1998) Technical and Operational Guidance Series (TOGS) 1.1.1 Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations were used to identify constituents of potential concern. Specifically, Class GA standards and guidance values of 5 μg/L was used to screen groundwater data for exceedances of the chemical of

concern, Tetrachloroethylene (PCE). That standard and guidance value is considered protective of drinking water sources.
The following sections describe proposed remedial measures to meet the SCOs for sub-slab vapors and groundwater at the American Cleaners, Kingston, NY site.

4.1 On-Site Sub-Slab Proposed Remedial Action and Monitoring

Annual testing of volatile organic gases in the work environment has shown continuous compliance with NYSDEC regulations and operational standards for dry cleaning plants. Since that testing indicates that the air in the work environment is not considered injurious to the employees, the lowest concentrations PCE (<3 $\mu g/m^3$) and TCE (<0.25 $\mu g/m^3$) were used in the matrix determination tables for deciding that mitigation measures are appropriate for treatment of the sub-slab vapors. As mentioned above Table 3 shows that the sub-slab vapor samples had PCE concentrations of 2300, 22,000, 12,000, and 1300 $\mu g/m^3$, for XP1 to XP4, respectively. Comparison of Table 3 with Soil Vapor/Indoor Air Matrix 2 (Final NYSDOH CEH BEEI Soil Vapor Intrusion Guidance, 2006) indicates that mitigation is appropriate for all four locations because the PCE concentrations are greater than 1000 $\mu g/m^3$ and the values of indoor air concentrations are essentially insignificant. Table 3 also shows that sub-slab vapor concentrations of TCE were ND, 150, 49, and ND for the 4 sampling points, respectively. Sub-slab vapor and indoor air TCE concentrations were compared in accordance with Matrix 1 and mitigation is appropriate for that TCE as well as PCE.

4.1.1 Sub-Slab Passive Vapor Venting Installation

The pilot testing indicates that the material is well packed and has low permeability to vapors. Because the slab presents a barrier to vertical movement of vapors and because within the loose, but packed material, vapor permeability is virtually below the practical limit of measurability; the slab should not be penetrated or compromised. For that reason a passive means of mitigation has been chosen. The NYSDOH guidance document references and suggests using methods used for radon mitigation. However, without good permeability below the slab, pilot testing indicates that no mechanical blower will be effective at removing vapors.

Venting the four extraction points to the ceiling and through the roof and vented using BaroBall™ is a simple and effective technology. Documentation of two government operated sites using the BaroBall™ in passive vapor extraction systems is provided in Appendix 5.

The two systems are described in an online posting called ***Initiatives Online*** (Volume 8 ▪ Fall 2001) in an article entitled “Going Natural with Passive Soil Vapor Extraction.”

> “PSVE has been used as an interim remediation strategy at DOE waste sites contaminated with chlorinated solvents. PSVE requires minimal operation and maintenance, making it a low-cost alternative to pump-and-treat systems or a cost-effective polishing technology. The Savannah River Site and the Hanford Site are currently using PSVE to remove chlorinated contaminants. SRS installed 24 PSVE wells at one site to remove trichloroethylene (TCE) and perchloroethylene (PCE). According to

> Joseph Rossabi, a researcher at SRS, "Since September 1996, more than 240 pounds of chlorinated organic contaminants—180 pounds of TCE and 60 pounds of PCE—have been removed using PSVE. To date, close to 90 percent of the volatile contaminants have been removed from the system."
>
> Rossabi adds that the barometric flow rates for a typical well at SRS are generally low (28 to 280 liters per minute). "However, if the concentration of the contaminant in the gas phase is high, mass removal by PSVE can be as much as 1–2 kilograms per day, per well."
>
> Low-cost techniques, again based on natural processes, can increase mass removal. Enhancements can include the addition of wind-powered turbine vacuum pumps, one-way mechanical valves, and solar heat injection.
>
> The Hanford Site is using PSVE as a polishing technology. Hanford installed eight PSVE wells in 1999 to remove the remaining TCE and PCE after active (pump-enhanced) soil vapor extraction removed 167,551 pounds of the contaminants at a waste site. These PSVE wells began operating in 2000, and data is being collected to determine the effect the wells are having on contaminants."

4.1.2 System Monitoring

Summa canister testing can be used as an effective means of monitoring the concentrations of volatile organic compounds in the sub-slab area. Summa testing is recommended at two year intervals after an initial round of testing all four extraction points one year after installation of the BaroBall™ system. A sampling port will be place in the PVC riser about 3.5 to 4 feet above the floor. A note below the matrix tables (pages 53, 55) states "Mitigation is considered a temporary measure implemented to address exposures related to soil vapor intrusion until contaminated environmental media are remediated." The remediation of the groundwater is expected to show a decline in concentrations of VOCs accumulating under the building slab from the underlying groundwater. Bioremediation and augmentation injection points behind the building should have a positive impact on reducing sub-slab VOC contamination levels. When PCE and TCE are detected below the NYSDOH guidance values of 100 and 5 $\mu g/m^3$, respectively; the system will be decommissioned with DEC approval.

4.2 On-Site and Off-Site Groundwater and Proposed Remedial Action

Characteristics of the Regenesis products are provided here. The processes of mixing and injection of those products into the top five feet of the water table are described using the Geoprobe®. Monitoring of the movement of the materials in the groundwater will be accomplished by measuring water quality parameters in the monitoring wells. Groundwater sampling will show changes in concentration of PCE. Criteria for the identifying the successful cleanup of on-site and off-site groundwater are described below.

4.2.1 Regenesis Bioremediation and Bioaugmentation Products

Two Regenesis products are considered appropriate to treat the groundwater beneath the American Cleaners site and downgradient properties: 3-D Microemulsion and Bio-Dechlor Inoculum.

Appendix Numbers in this Report for Regenesis Products			
	Brochure	MSDS	Application Instructions
3-D Microemulsion (3DMe™)	5	7	9
Bio-Dechlor Inoculum Plus (BDI Plus™)	6	8	10

3-D Microemulsion (3DMe™) is a factory emulsified electron-donor material used to facilitate anaerobic reductive dechlorination of chlorinated solvents by microbial action in groundwater. The product is a mixture of organic chemicals classified as HRC-PED (Hydrogen Release Compound – Partitioning Electron Donor). The mixture is made up of neutralized fatty acids, glycerol tripolylactate, and glycerol. 3-D Microemulsion is a liquid with a consistency similar to milk. The emulsion is characterized by three stages of active ingredients with three overlapping periods of time release for each electron donor material

(1) lactate,	0 to 1 year
(2) polylactate	0.3 to 2.2 years
(3) free fatty acids with fatty acid esters.	1 to 5 years

This characteristic is most cost effective because it will create an anaerobic reducing environment for a significant period of time while the material migrates downgradient with natural groundwater flow.

The 3-D Microemulsion product is mixed with water and injected into Geoprobe® borings. The material is generally innocuous with neutral pH and non-corrosive and non-caustic properties. The most hazardous characteristic of the product is that if it is spilled, it can be very slippery on surfaces; but it can be easily washed off with water. The material readily degrades and hydrolyses within hours. The product is diluted with water before it is injected into the subsurface.

Bio-Dechlor Inoculum (BDI Plus™) is a mixture of ***Dehalococcoides sp*** bacteria. Regenesis indicates that it "has been shown to stimulate rapid and complete dechlorination of compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC)." Members of the genus ***Dehalococcoides*** are capable of driving the dechlorination chain of reactions of chloroethenes, such as PCE, to the end product of harmless ethane. At this time, it is not known exactly which dechlor species are associated with each sequential breakdown reaction, but the Regenesis inoculum consists of several species and is proven effective at promoting the entire breakdown of PCE to ethane.

The BDI Plus product is a murky, yellow to gray liquid with a musty odor. The live bacteria culture comes in a keg or canister pressurized to 10 to15 psi with nitrogen to maintain a reducing (non-oxygen) environment in the container. The container must be kept at 2° to 3°C until the material is injected into the ground. The culture is miscible with water, so it can be diluted to appropriate levels at the site. The water that the culture is mixed with is first aerated with nitrogen to remove the oxygen from the water to make sure the water will maintain the anaerobic conditions for the survival of the bacteria.

4.2.2 Bioremediation and Bioaugmentation by Subsurface Injection

Regenesis recommends injection of the liquid bioremediation mixtures of emulsion and bacteria into the top five feet of the sandy aquifer using direct push equipment (Geoprobe®). The injection points are recommended to be placed 15 feet apart as shown in Figure 6. Sixteen injection points are arranged on the property to cover the original back yard source and the perimeter of the site where groundwater is migrating off-site to the north, northwest, and west. The instructions for handling and mixing the Regenesis products are included in Appendix 9 and 10. Actually, each injection location consists of two Geoprobe® borings, one for injection of the emulsion and a second for the injection of the bacteria.

All of the injection points for emulsion will be installed and treated first. One day for mobilization and setup will be required followed by about 4 days of injection. Then the injection of the bacteria will require a second mobilization and is expected to take much less time because the volume to be injected is significantly less.

The 3DMe™ will be delivered to the site in four 400 pound drums. The 12 liters of BDI plus™ bacteria culture will be delivered in one or more coolers with nitrogen-pressurized canisters. A separate batch of bioremedial material will be mixed for each injection point according to the Regenesis application instructions.

Regenesis has recommended injection of 100 pounds (13 gallons) of 3DMe™ for each injection point (Table 5). Regenesis recommends dilution of the factory shipped product in the range of 1 percent to 10 percent. A dilution of approximately 2.5 percent has been calculated to fill the available pore space in a cylinder around the axis of the injection boring with a vertical length of 5 feet and a radius of 7.5 feet, assuming a porosity of 7 percent in the sandy water-bearing zone (Calculation Sheet 1). The 2.5 percent dilution will be made by mixing 13 gallons of 3DMe™ with 507 gallons of water for a total of 520 gallons per injection point (Table 5). In an ideal aquifer, the entire pore space of the cylinder around the vertical injection interval would be filled to the perimeter of the adjacent injection points. In that manner, a front of bioremedial material will move down gradient similar to the movement of the PCE from former spills at the site. Pumping and slug testing has shown that the water table is very difficult to depress and the hydraulic conductivity is high. The slug testing shows very rapid recovery on the order of 2 to 4 seconds. Those tests suggest that the sandy aquifer can accept a high volume of low concentration emulsion. However, the actual capability of the formation to accept the water in a timely manner will determine the dilution factor. Hence, the actual percent of the 3DMe™ will be determined empirically in the first injection wells.

When the Geoprobe® assembly is in place, the vertical zone of 3DMe™ injection will be the top 5 feet of the aquifer (approximately 10 to 15 feet below ground surface). The rate of injection will be determined by the capability of the sandy aquifer to accept the rate of flow. Assuming injection of approximately 500 gallons per point, the following table summarizes the required time for pumping rates.

Comparison of Injection Rates & Times	
Pumping Rate of Injection	Time to Inject 500 gallons
5 gpm	100 minutes
10 gpm	50 minutes
15 gpm	33 minutes
20 gpm	25 minutes

Regenesis recommends a ratio of BDI plus to water of 1 liter to 10 gallons, or for our specific site 0.75 liters to 7.5 gallons of water. The water for BDI plus™ has to be aerated with nitrogen to assure that the water is oxygen free. Only 120 gallons of the nitrogen treated water will be needed for the 16 injection points. However, since it is recommended to fill the annular space with water to prevent air from reaching the bacteria, additional water aerated with nitrogen will be needed for that purpose. The water can be aerated while the boring is being advanced with the Geoprobe®. The inoculum solution is injected at a rate of 1 gallon per foot, while raising the rod in one foot intervals.

4.2.3 Monitoring of Bioremediation On-site and Off-site

Monitoring the movement of remedial chemicals and cultures will be achieved with two types of groundwater testing: (1) monitoring of field parameters using a Horiba U-10 and other electronic meters; and (2) groundwater sampling and laboratory analyses for VOCs using US EPA method SW 846 8260B.

4.2.3.1 Field Parameter Monitoring

After the bioremediation products are placed in the aquifer, the groundwater will be monitored to detect the movement of the reducing emulsion and bacteria entrained in the natural groundwater flow system. Since the injection points are on-site, the products should be detected first in the on-site monitoring wells. Water quality parameters such as Oxidation-Reduction Potential (ORP), Dissolved Oxygen (DO), pH, and Sulfate Ion Concentration will be measured with field instrumentation prior to injection and at one month intervals after injection. Periodic measurement of those parameters should indicate the arrival of the reducing environment of the 3-DMicroemulsion and associated bacteria in downgradient locations. Typical plume arrival is expected with a build-up followed by decline in water quality parameters and PCE concentrations. That phenomenon is a result of the processes of hydrodynamic dispersion and diffusion while the reducing emulsion mixes with the natural groundwater system and arrives at the sampling point somewhat diluted with higher concentrations following.

4.2.3.2 Groundwater Sampling

Groundwater sampling shall be on a 15 month schedule, which will allow for seasonal variation and allow time for migration of the remedial materials from the site of injection to downgradient monitoring wells to the west and northwest. For each sampling event, the existing monitoring wells, six on-site and five off-site will be sampled and analyzed for Volatile Organic Compounds by US EPA Method SW846-8260B.

It is expected that the PCE concentrations will comply with the groundwater standard of 5 µg/L, first in the on-site monitoring wells and later in the off-site monitoring wells.

Additional sampling of groundwater along Lincoln Park Place will not be planned until evidence of reduction of PCE concentration are found in the off-site monitoring wells on the west side of Ulster Avenue. Based on observed travel times from on-site injection to observed changes in water quality parameters in downgradient monitoring wells, estimates of travel times to Lincoln Park Place will be made. The estimated travel time will be used to schedule one groundwater sampling at Lincoln Park Place using the Geoprobe® at three previously sampled locations as well as a point to the north. That groundwater sampling event will be scheduled to detect very low concentrations in the range of ND to10 µg/L PCE. If concentrations are within two standard deviations above the drinking water standard of 5 µg/L and the water quality parameters indicate the presence of the reducing environment, the groundwater will be considered remediated.

5.0 Concomitant Procedural Plans

Concomitant procedural plans include the contributory plans associated with the remedial action work plan such as the QA/QC Plan, the Health and Safety Plan, and the Community Air Monitoring Plan as described or referenced below.

5.1 QA/QC Plan

The quality assurance/ quality control plan is concerned with the laboratory analytical procedures for the specific samples for the subject site. Data validation is the process of reviewing the lab procedures to assure the precision and accuracy and usability of the VOC concentrations reported by the laboratory.

5.1.1 Sub-Slab Vapor Monitoring

York Analytical Laboratories, or another NYSDOH-certified laboratory will be preparing the Summa Canisters and analyzing the samples for Volatile Organic Compounds using EPA method TO-15. The Summa canister will be connected with flexible tubing to the sampling port(s) constructed in the vertical PVC exhaust lines.

Category B (NY ASP B) laboratory deliverables will be requested from the lab and a Data Usability Summary Report (DUSR) will be prepared by a data validation expert.

5.1.2 Groundwater Sampling

Groundwater sampling of monitoring wells and Geoprobe® borings will be accomplished with the low flow procedure, measuring water quality parameters until stabilization, and then collecting the water sample in VOA vials. A NYSDOH environmental laboratory approved program (ELAP)-approved laboratory will analyze the groundwater samples for Volatile Organic Compounds using EPA method SW-846-8260B. NYSDEC Category B analytical data will be requested on the chain of custody. In addition to the monitoring well samples, duplicate, MS, MSD, trip and equipment blanks will be sent to the lab.

The final laboratory report and Category B (NY ASP B) laboratory deliverables will be sent to a Data Validation subcontractor to prepare a Data Usability Summary Report (DUSR). Such report will identify and discuss any pertinent data limitations for use of the data.

Groundwater samples will be obtained from the 6 on-site and 5 off-site monitoring wells using the US EPA Low Stress (Low Flow) Purging and Sampling Procedure for Collection of Ground Water Samples from Monitoring Wells (US EPA Region 1, July 30, 1996, Revision). A peristaltic pump and dedicated or new tubing will be used to purge each well prior to sampling. The method produces a limited amount of purge water while achieving equilibrium of water quality parameters by repeated measurements and a very low pumping rate, thereby assuring a fresh sample of groundwater from the surrounding formation. The following steps describe the method:

- At 3-5 minute intervals, depth to water is measured with a water level indicator
- Rate of flow and volume of water pumped is measured with a calibrated 1000-milliliter cylinder and a watch with second hand;
- Pumping rate of flow is established at 0.1 to 0.4 liters per minute using a variable speed peristaltic pump with dedicated ¼ inch (inner diameter) tubing, pre-measured for each well;
- For the same time interval, water quality parameters are measured including pH, conductivity, turbidity, dissolved oxygen, temperature, and oxidation reduction potential, During the purging process, stabilization of field indicator parameters includes less than the following percentage change over three sets of successive measurements made with the Horiba:
    Turbidity 10%
    Dissolved Oxygen 10%
    Specific Conductance 3%
    Temperature 3%
    PH + / - 0.1 units
    ORP / Eh +/- 10 millivolts.
- After about 20 minutes, when the water quality parameters usually stabilize, samples are collected in 40-milliliter glass vials with HCl preservative.
- After measuring those water quality parameters, the purge water is saved for disposal.
- Quality Assurance samples are collected as follows: one trip blank originating from York Laboratories, one equipment blank passed through a length of clean ¼-inch (inner diameter) tubing, matrix spike and matrix spike duplicate samples.

- All samples are shipped with ice paks and chain of custody to York Analytical Laboratories for analyses by US EPA Method 8260 for the full list of analytes. The NYSDEC ASP Category B data package will be requested.
- A small sample of water will be collected and used to analyze for sulfate ions Using a portable field meter (Hanna Instruments Colorimetery / Refractometry HI 96751and Reagent HI 93751).
- Water Levels are measured after the completion of sampling.

5.2 Health and Safety Plan

The Health and Safety Plan for field work at the American Cleaners Kingston location has been updated for the ***SI&SVEPTWP*** (Sep. 2012) and is included here as Appendix 12.

5.3 Community Air Monitoring Plan

The Community Air Monitoring Air Plan for field work at the American Cleaners Kingston location has been updated for the ***SI&SVEPTWP*** (Sep. 2012) and is included here as Appendix 13.

6.0 Schedule

Separate schedules are provided for the two remediation technologies and their respective media: (1) Passive Sub-Slab Vapor Extraction and (2) Bioremediation and Bioaugmentation of Groundwater. Successful remediation of the two media will be tested, documented, and reported separately.

6.1 Passive Sub-Slab Vapor Extraction Schedule

Start of remedial activities will be based on receipt of approval from NYS DEC. Installation of the sub-slab venting system can begin within 3 weeks of approval.

Concentrations of VOCs will be measured with Summa Canister testing for each of the four extraction points on a 15-month schedule beginning one year after installation of the system. The 15-month schedule is designed to detect seasonal variation in concentrations.

6.2. Bioremediation and Bioaugmentation of Groundwater Schedule

Injection of the Bioremedial 3-DMicroemulsion material can start within 6 weeks of approval. That allows time for shipment of the product from Regenesis and assembling all of the tanks and pumps and other apparatus to inject the material through the Geoprobe® rods, and allows time to get this project onto the Driller’s schedule. Injection of the microemulsion is estimated to take 4 to 8 days depending on the dilution of the product. Injection of the Regenesis Bio-Dechlor Inoculum Plus™ will require a second mobilization of the Geoprobe® with significantly less equipment and will require 2 to 4 days.

Measurement of water quality parameters will be taken in all monitoring wells prior to injection and within a week after injection of the bioremediation products. Water quality parameters will be measured approximately 9 times in the calendar year (close to a monthly schedule allowing for vacation and weather interruptions) to trace the predicted movement of the reducing environment and bacteria toward down gradient wells using field instruments. The groundwater sampling schedule for monitoring wells will be every 5 quarters (every 15 months) for Volatile Organic Compounds analyzed by US EPA method SW846 8260B. Once reducing conditions are detected on the west side of Ulster Avenue, the schedule may be adjusted depending on migration times. The 15-month schedule is designed to detect seasonal variation in concentrations.

7.0 Reporting

Sampling reports will be prepared and transmitted to DEC within 6 weeks of receipt of laboratory reports. Measurement of field parameters will be submitted within a week of data collection and will be summarized for all reports in each successive report to determine if there are any trends in the data.

As mentioned above, the sub-slab vapor extraction and the groundwater bioremediation will be reported separately. The periodic reports will summarize all of the measurements to date so that trends can be easily identified. When evidence of remediation is observed, permission from DEC will be requested to close and decommission the appropriate phase of cleanup.

A Supplemental Remedial Investigation Report or a Final Engineer’s Report will be prepared to summarize all of the remedial work and sampling, and data validation.

8.0 Project Organization

Resumes for project engineer, Jolanda G. Jansen, P.E.; project manager, Katherine J. Beinkafner, Ph.D., CPG; and Geoprobe® owner-operator Todd Syska are included in Appendix 14: Investigation Personnel. See the bottom of page 1 in the Health and Safety Plan Appendix 12) for more information on organization.

9.0 References

BaroBall™ Product Spec Sheet from Dunham Geo Slope Indicator

Final Guidance for Evaluating Soil Vapor Intrusion in New York State, October 2006, New York State Department of Health, Center for Environmental Health, Bureau of Environmental Exposure Investigation, 92 pages.

FINAL DER-10 TECHNICAL GUIDANCE FOR SITE INVESTIGATION AND REMEDIATION, May 3, 2010, New York State Department of Environmental Conservation, Division of Environmental Remediation, 232 pages.

Ellred, M.G., J.W. Massemann, D.P. Schwaegler, and V.J. Robay (May-June 1999) “Enhancements for Passive Vapor Extraction: The Hanford Study,” Ground Water, Vol. 37, No.3. pages 427 – 437.

“Going Natural with Passive Soil Vapor Extraction.” ***Initiatives Online*** (Volume 8 ▪ Fall 2001)

Riha, Brian D. (June 2005) “Passive Soil Vapor Extraction (PSVE) for VOC Remediation at the Metallurgical Laboratory (MetLab) June 2005 Progress Report,” Savanah River National Laboratory WSRC-TR-2005-00268, 38 pages.

US EPA Low Stress (Low Flow) Purging and Sampling Procedure for Collection of Ground Water Samples from Monitoring Wells (US EPA Region 1, July 30, 1996, Revision)

Record of Decision: Revonak Dry Cleaners, State Superfund Project and the New Paltz Plaza Voluntary Cleanup Program Project Site No. V00087-3, New Paltz (T), Ulster County, New York, Site No. 356021, January 2010 (27 pages).

Calculation Sheet 1

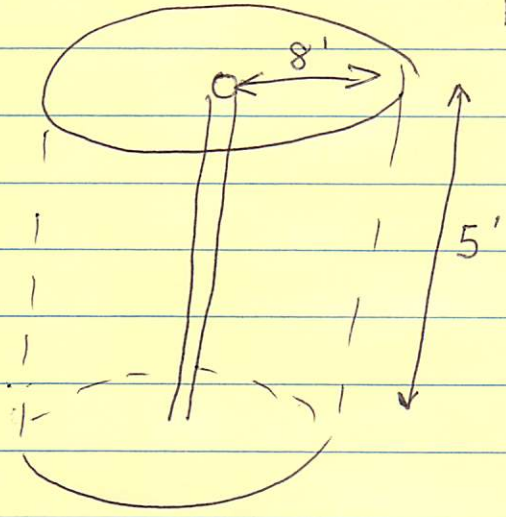
Find: Volume of pore space for Injection

Given: 15-foot Injection Point Spacing

Vertical injection interval = 5 feet

Use 8-foot radius

Porosity, assume 7%



not to scale

$A = \pi r^2$

$3.14 \cdot 8^2 = 200.96$ sq ft

$V = \text{Area} \times \text{Depth}$

$200.96 \times 5 = 1004.8$ cuft

$\text{Pore Volume} = V \times \text{Porosity}$

$1004.8 \times 0.07 = 70.3$ cuft

Pore Volume in Gallons

70.3 cuft × 7.48 gal/cuft = 526 gallons

~ 500 gallons of emulsion will fill pore space in ideal injection cylinder

KJB
6/5/14

Table 1
Storm Drain Soil Sampling Laboratory Results
Units of Measurement are µg/kg dry parts per billion (ppb)
American Cleaners, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3
Sampling Date: September 23, 2013
Laboratory Analysis by US EPA Method SW-846-8260C for 8260 List
York Analytical Laboratories, Inc. 129 Research Drive, Stratford, CT 06615
Laboratory Report: 13I0888 10/02/13
Omitted Compounds were Not Detected (ND)
Sampling Conducted by Jansen Engineering, PLLC and
Mid-Hudson Geosciences

Sample ID	Depth	Acetone	Methylene chloride	Tetrachloro-ethylene	Trichloro-ethylene
West S1	0.5-1	ND	17 J,B	1100	15
West S2	3-3.75	ND	ND	ND	ND
West S3	5-6	7.3 J,B	14 J,B	24	ND
West S4	9.5-10.5	11 J,B	14 J,B	210	ND
East N1	1-1.5	ND	15 J,B	220	ND
East N2	5.5-6.5	ND	18 J,B	110	ND
East N3	9-10	12 J,B	24 J,B	260	ND
Field Blank		ND	2.8 J	ND	ND
Trip Blank		3.5 J	2.5 J	ND	ND

Notes:
ND = Not Detected at MDL
J = Detected below reporting limit (RL), but greater than Method Detection Limit (MDL), Considered an estimated value
B =Analyte found in blank

Table 2
Sub-Slab Soil Sampling Laboratory Results
Units of Measurement µg/kg dry = parts per billiion (ppb)
American Cleaners, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site: V-00601-3
Sampling Date: March 25, 2013
Laboratory Analysis by US EPA Method SW846-8260B for 8260 List
York Analytical Laboratories, Inc. 129 Research Drive, Stratford, CT 06615
Laboratory Report 13C0810 04/02/2013
Omitted Compounds were Not Detected (ND)
Sampling Conducted by Jansen Engineering, PLLC and Mid-Hudson Geosciences

	Sampling Points			
Analyte	XP1 Back Left Corner	XP2 Inside Back Door on Right side as entering	XP3 Left Back behind last Pressing Station	XP4 Right of Front Door behind Counter
Tetracholoethylene	7.2 J	ND	ND	9.9 J
Acetone	11 J,B	14 J,B	13 J,B	24 J,B

Notes:
ND = Not Detected at MDL
J = Detected below reporting limit (RL), but greater than Method Detection Limit (MDL)
Considered and estimated value
B =Analyte found in blank
Trip Blank contained Naphthalene (Moth Balls) @ 1.3 µg/kg J
Field Blank (Equipment Blank) all VOCs were ND

Table 3
Sub-Slab Soil Vapor Sampling Laboratory Results
American Cleaners, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3
Sampling Date: March 25, 2013
Laboratory Analysis by US EPA Method TO15 Full List for 6-Liter Summa Canisters
Helium was the Leak Detection Gas analyzed by GC/TCD ND @ 0.95% MDL Dilution 1.902
York Analytical Laboratories, Inc. 129 Research Drive, Stratford, CT 06615
Laboratory Report 13C0768 04/04/2013
Omitted Compounds were Not Detected (ND)
Tentatively Identified Compounds were ND in all cases
Sampling Conducted by Jansen Engineering, PLLC and Mid-Hudson Geosciences

	Sampling Points			
Analyte	XP1 Back Left Corner	XP2 Inside Back Door on Right side as entering	XP3 Left Back behind last Pressing Station	XP4 Right of Front Door behind Counter
Tetracholoethylene	2300 μg/m^3	22000 μg/m^3	17000 μg/m^3	1300 μg/m^3
Helium	ND	ND	ND	ND
Trichloroethelene	ND	150 μg/m^3	49 μg/m^3	ND
cis1,2-Dichloroethylene	ND	29 μg/m^3	ND	ND
Chloroform	ND	27 μg/m^3	ND	ND
Acetone	ND	14 μg/m^3	69 μg/m^3	84 μg/m^3
Dichlorofluoromethane	ND	ND	ND	21 μg/m^3

Table 4
Summary Groundwater Sampling Laboratory Results
Units of Measurement are µg/L or ppb
American Cleaners, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3
Sampling Date: November 3-6, 2013
Laboratory Analysis by US EPA Method SW846-8260B for 8260 List
York Anaytical Laboratories , Inc. 129 Research Drive, Stratford, CT 06615
Report 13K0219, 11/18/13
Omitted compounds were Not Detected (ND)
Sampling Conducted by Jansen Engineering, PCCL and Mid-Hudson Geosciences

Well	Total Depth	Tetrachloroethylene	1,1,2-Trichloroethane	Location
On-site Monitoring Wells				
MW1	16.9	6.5	ND	In front of AC, south along Street
MW2	16.4	13	ND	Directly In front of AC, beside sidewalk opposite Storm Drain in street
MW5*	16.9	50	ND	In front of AC, close to sign pole on North side
MW4	32.6	7.4	ND	Behind AC 41 inches out from SE corner of shed
MW3*	16.3	ND	ND	Behind AC, about 10 feet northeast of NE corner of building
MW3 Dup*	16.3	ND	ND	Behind AC, about 10 feet northeast of NE corner of building
MW6	16.1	14	ND	Behind AC, 8 feet out from SE corner of shed
West Side of Ulster/Albany Avenue				
MW9	16	17	ND	About 38 feet southeast of Left front corner of Spa
MW16	25	ND	ND	5 feet toward road from MW9
MW7	16	28	ND	About 29 feet northeast of right front corner of Spa
MW17	25	ND	ND	Half way between Restaurant and Spa
MW8	16	150	5.1	In front of RCAL back building, to left of front door
Geoprobe Samples along Lincoln Park Place				
LP1	16	47	ND	Between driveways close to Road, #752-#746
LP2	25	18	ND	Near Stop Sign, #732 Lincoln Park Place
LP3	16	ND	ND	Near Stop Sign, #732 Lincoln Park Place

Notes:

Acetone detected in MW16 at 3.3 J µg/L and in Trip Blank at 2.6 µg/L.
Dup indicates duplicate sample
Sample from MW5 was labeled MW3 on chain of custody and laboratory report
Sample from MW3 was labeled MW5 on chain of custody and laboratory report
Sample from MW3 Dup was labeled MW5 Dup on chain of custody and laboratory report
All information here is the corrected and the same as Figure 5 map.

Table 5: Design Parameters for Bioremediation with Bioaugmentation

Using Regenesis Products
At American Cleaners, Kingston, NY

Note: The variable amount of water for dilution of the 3DMicroemulsion will be determined emphirically in the field

Design Specifications

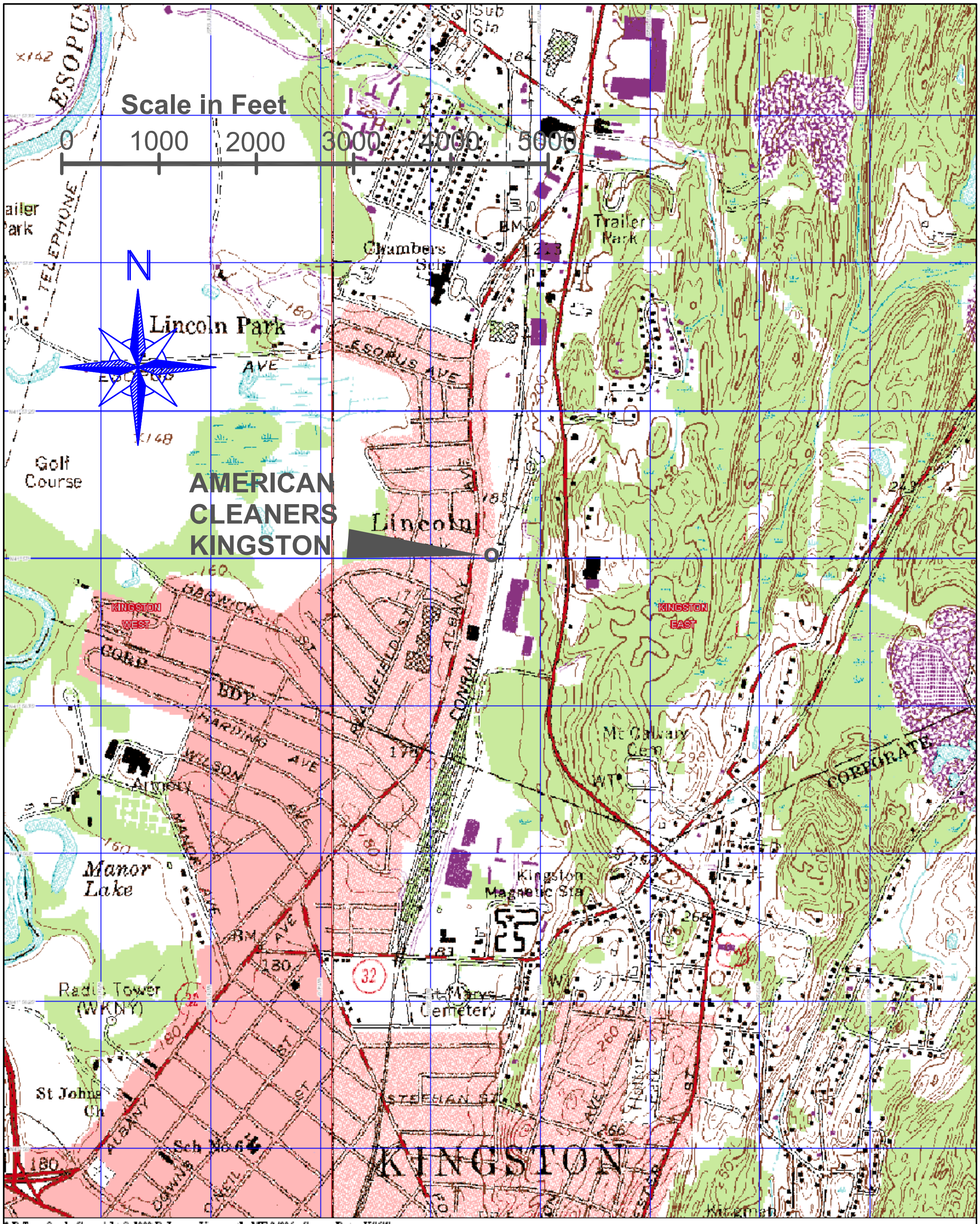
Injection Point Spacing	15 feet
Number of Injection Points	16
Top of Injection Interval (water table)	10 feet below surface
Bottom of Injection Interval	15 feet below surface
Vertical Treatment Interval	5 feet
Linear Footage of Geoprobe® Drilling	
For Injecton of Both Products	240 feet
For Separate Injection of 2 Products	480 feet

Product Quantities

3DMicroemulsion	1600 pounds in four 55 gallon drums, 400 pounds per drum
Bio-Dechlor Inoculum Plus	12 liters

Field Mixing / Injection Ratios

3DMicroemulsion		***Water***			***Product + Water***	
Per Injection Point	For 16 Total Points	Variable	Per Injection Point	For 16 Total Points	Per Point	For 16 Points
13 gallons	208 gallons	For 10% solution	117 gallons	1872 gallons	130 gallons	2080 gallons
(= 100 pounds)	(= 1600 pounds)	For 1% solution	1287 gallons	20592 gallons	1300 gallons	20800 gallons
		Optimal For 2.5% solution	507 gallons	8112 gallons	520 gallons	8320 gallons
Bio-Dechlor Innoculum Plus						
Per Injection Point	For 16 Total Points		Per Injection Point	For 16 Total Points	Per Point	For 16 Points
0.75 liters	12 liters	Re: Instructions	7.5 gallons	120 gallons	7.7 gallons	123.2 gallons
(= 0.1875 gallons)	(= 3 gallons)					



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS

450 ft Scale: 1 : 16,000 Detail: 14-6 Datum: WGS84

Figure 1-1, Site Location Map (USGS 7.5 Minute Quadrangles)

American Cleaners Inc, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3 December 31, 2009

Mid-Hudson Geosciences
Katherine J. Beinkafner, PhD, CPG #6611
1003 Route 44/55, PO Box 332, Clintondale, NY 12515
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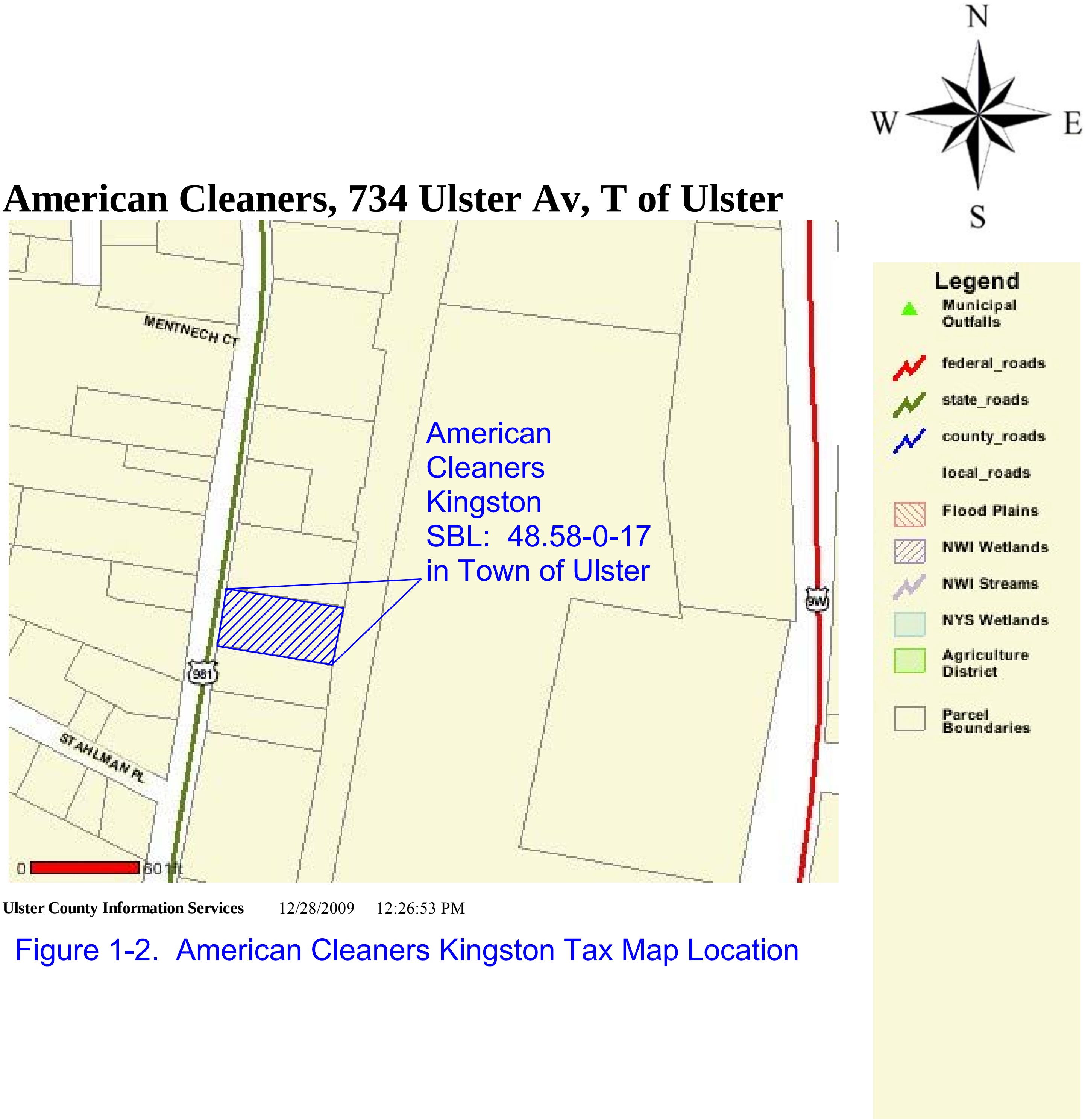

Ulster County Information Services 12/28/2009 12:26:53 PM

Figure 1-2. American Cleaners Kingston Tax Map Location

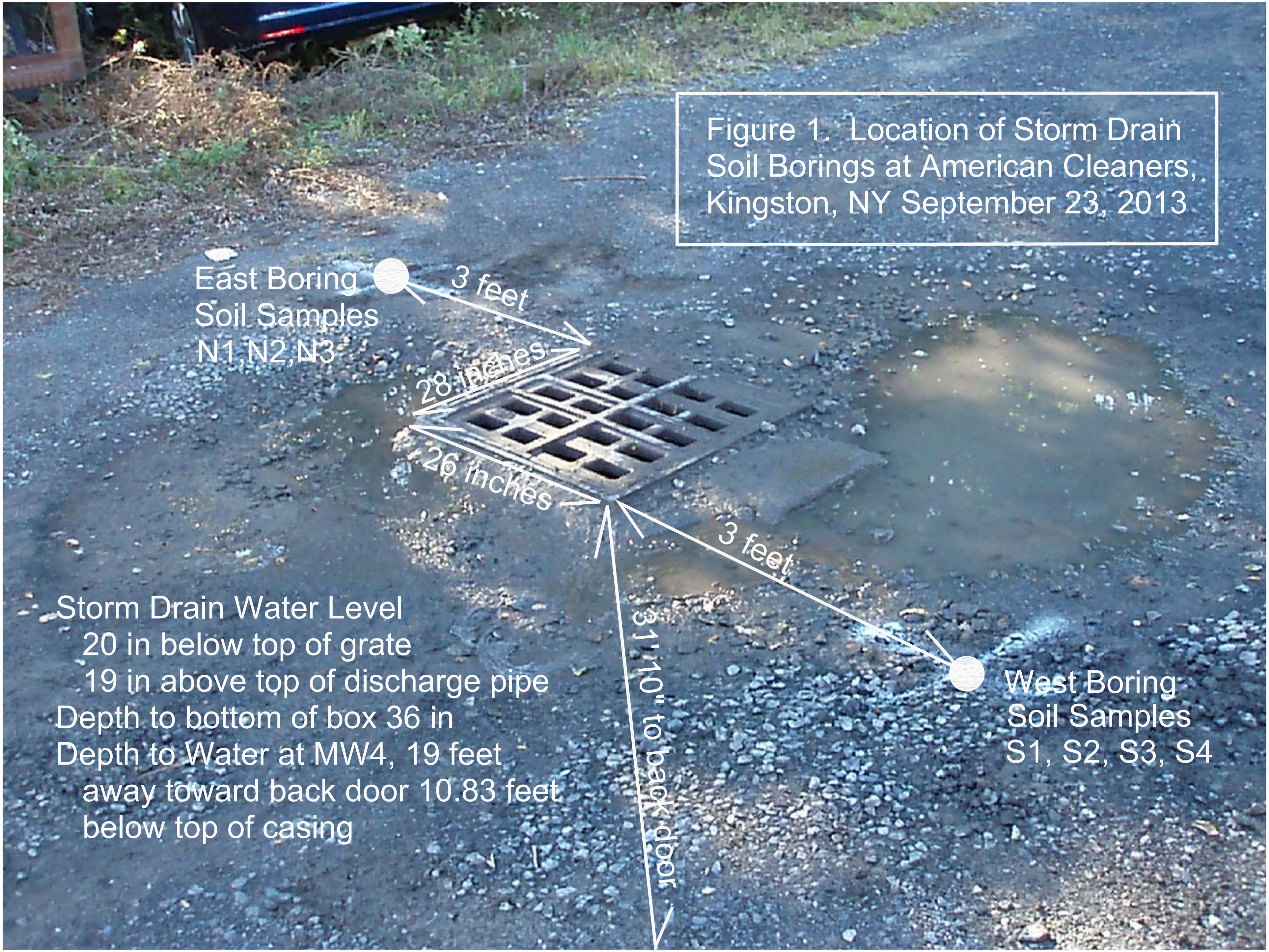

Figure 1. Location of Storm Drain Soil Borings at American Cleaners, Kingston, NY September 23, 2013

Storm Drain Water Level
20 in below top of grate
19 in above top of discharge pipe
Depth to bottom of box 36 in
Depth to Water at MW4, 19 feet away toward back door 10.83 feet below top of casing

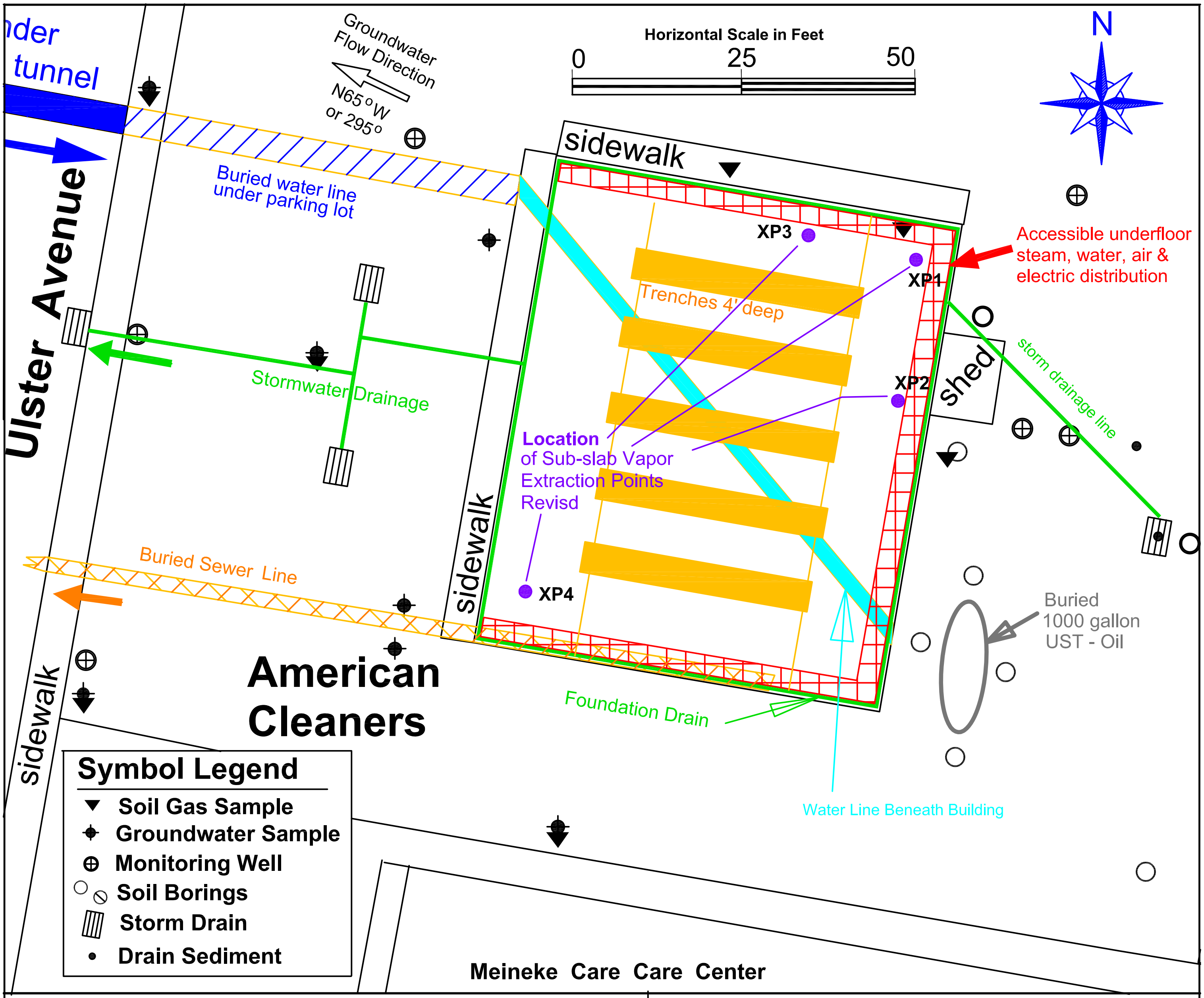

Figure 2. Location of Sub-Slab Vapor Extraction Points on Site Plan of Building showing Features Constructed for Dry-Cleaning Operations
American Cleaners Inc, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3 December 31, 2009
Revised November 2013

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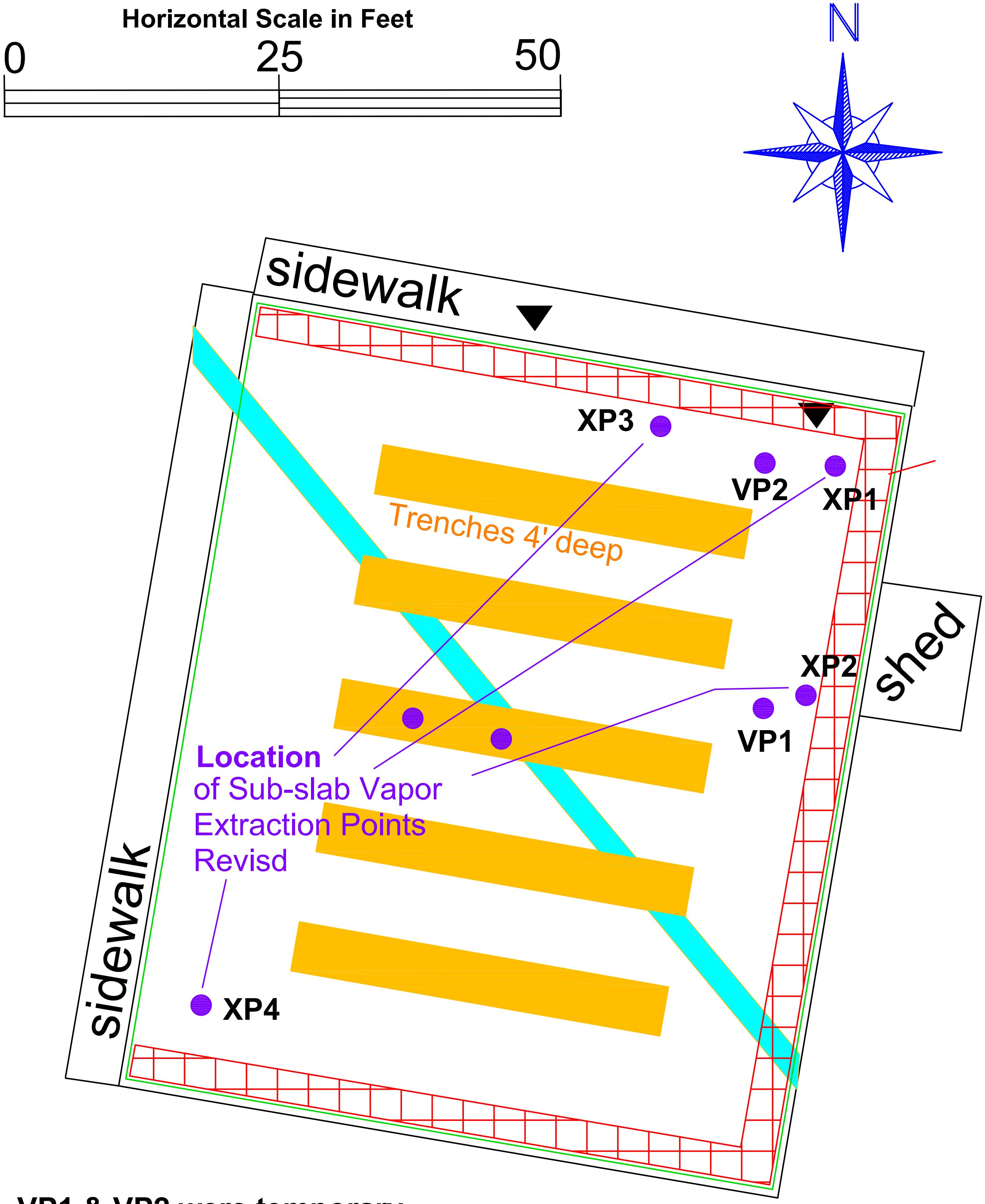

VP1 & VP2 were temporary vacuum measuring points

Figure 3. Location of Vacuum and Sub-Slab Vapor Extraction Points on Site Plan of Building showing Features Constructed for Dry-Cleaning Operations
American Cleaners Inc, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3 December 31, 2009
Revised November 2013

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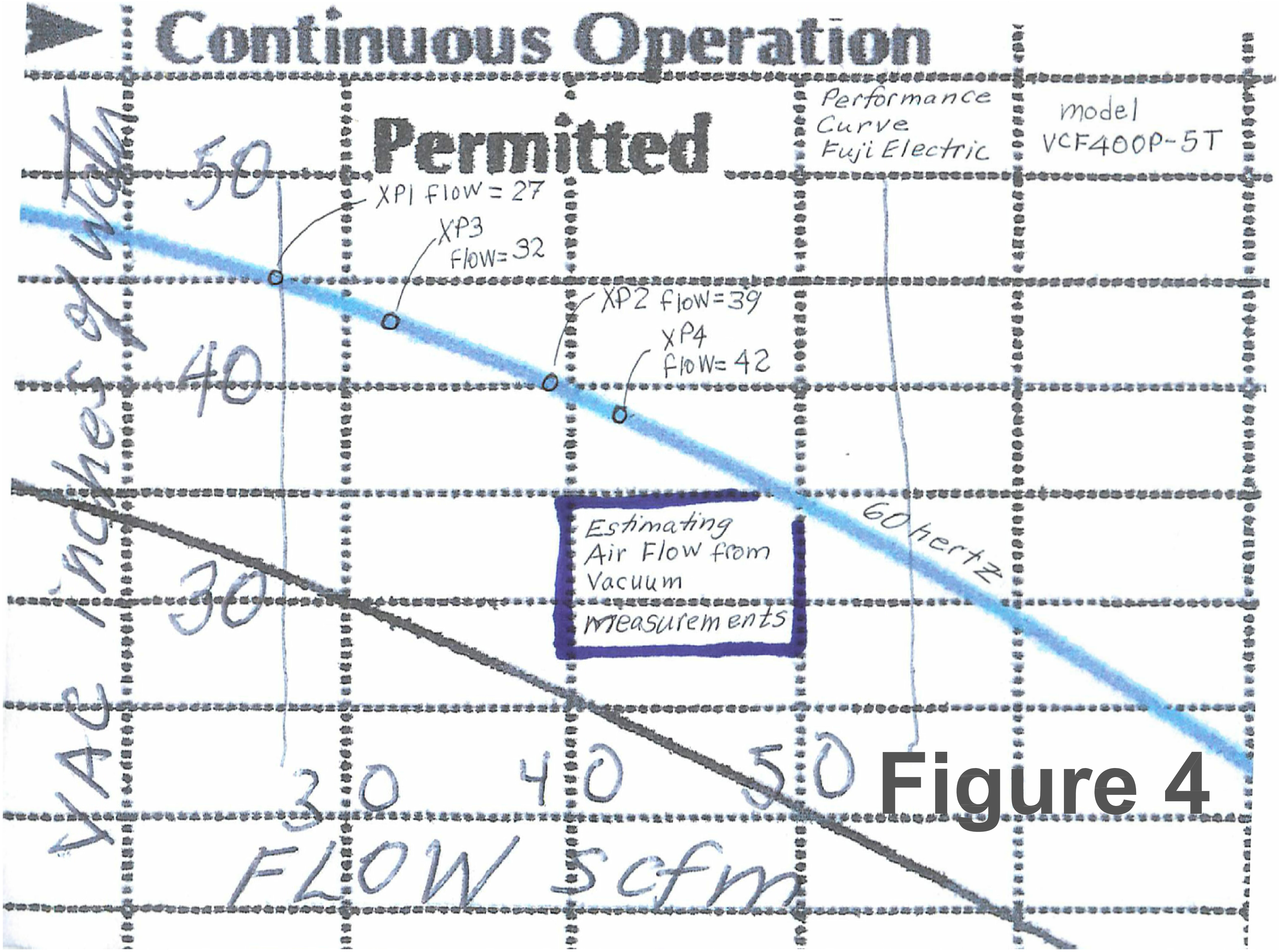
Continuous Operation
Permitted
Performance Curve Fuji Electric
model VCF400P-5T
XP1 flow = 27
XP3 flow = 32
XP2 flow = 39
XP4 flow = 42
60 hertz
Estimating Air Flow from Vacuum measurements
50
40
30
VAC inches of water
30
40
50
FLOW scfm

Figure 4

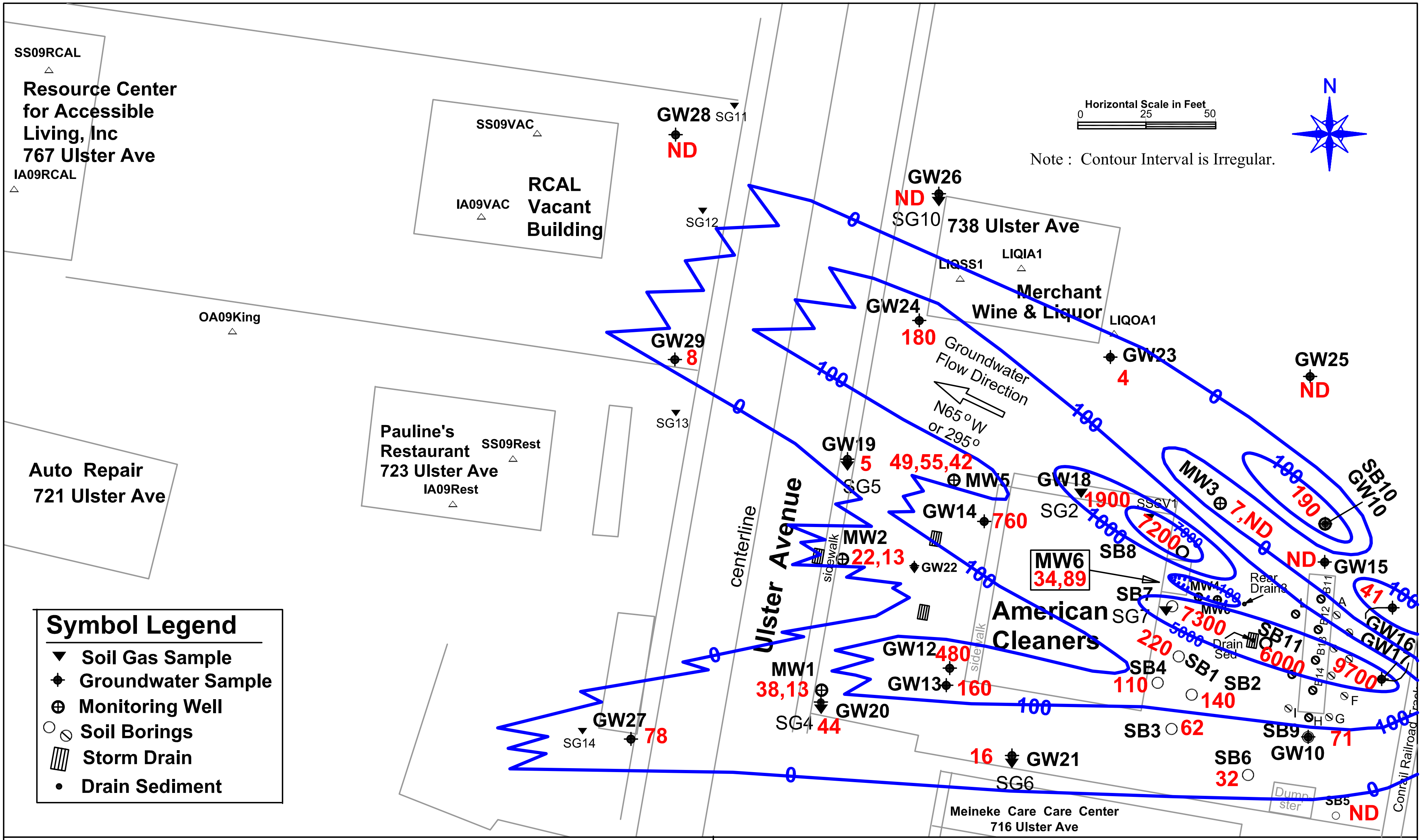

Figure 5-3. Isopleth Map and PCE Concentrations (ug/L) Detectd in Groundwater between 9.5 and 16 feet below ground surface.
American Cleaners Inc, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3 December 31, 2009

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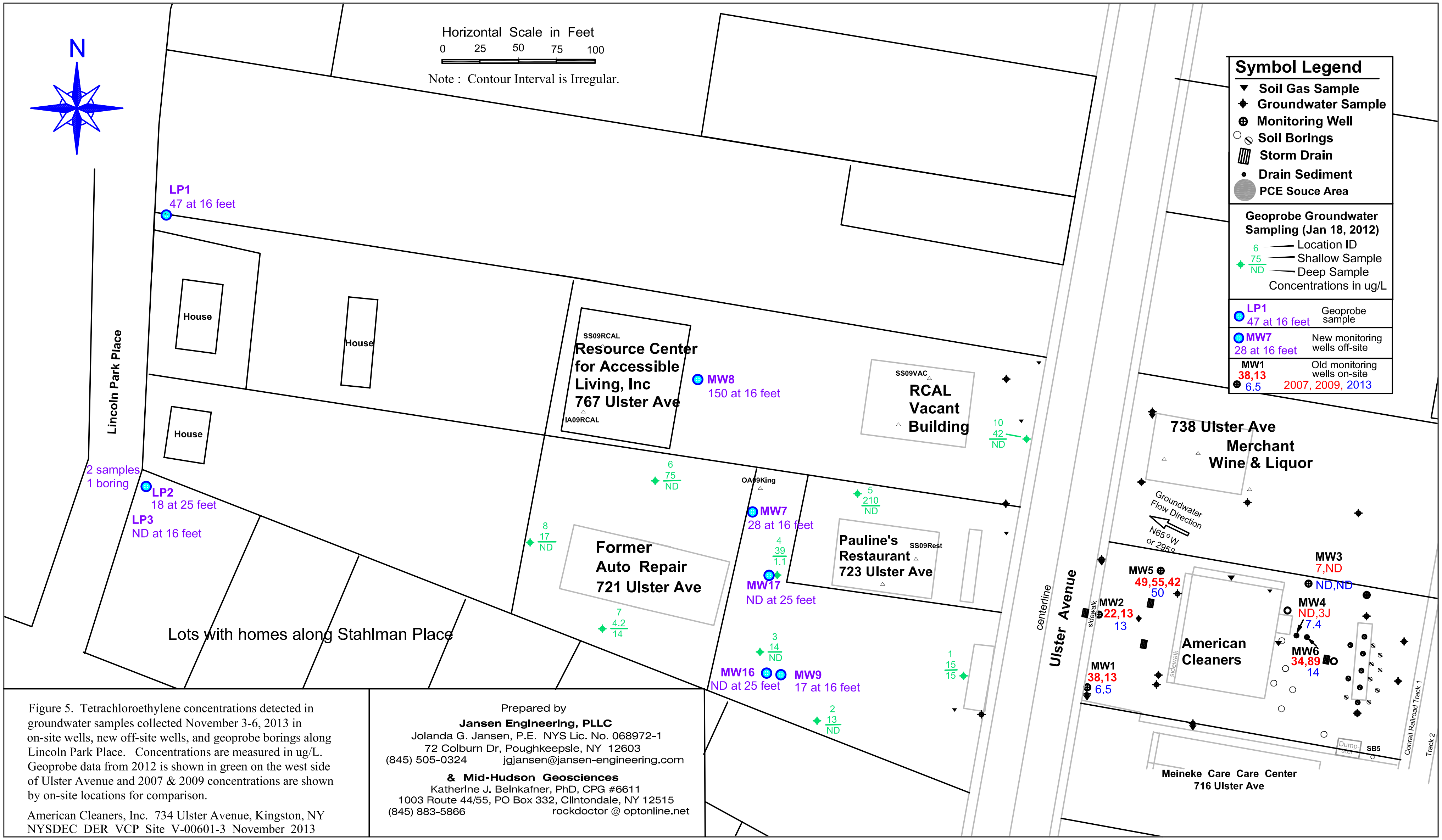

Figure 5. Tetrachloroethylene concentrations detected in groundwater samples collected November 3-6, 2013 in on-site wells, new off-site wells, and geoprobe borings along Lincoln Park Place. Concentrations are measured in ug/L. Geoprobe data from 2012 is shown in green on the west side of Ulster Avenue and 2007 & 2009 concentrations are shown by on-site locations for comparison.

American Cleaners, Inc. 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3 November 2013

Prepared by
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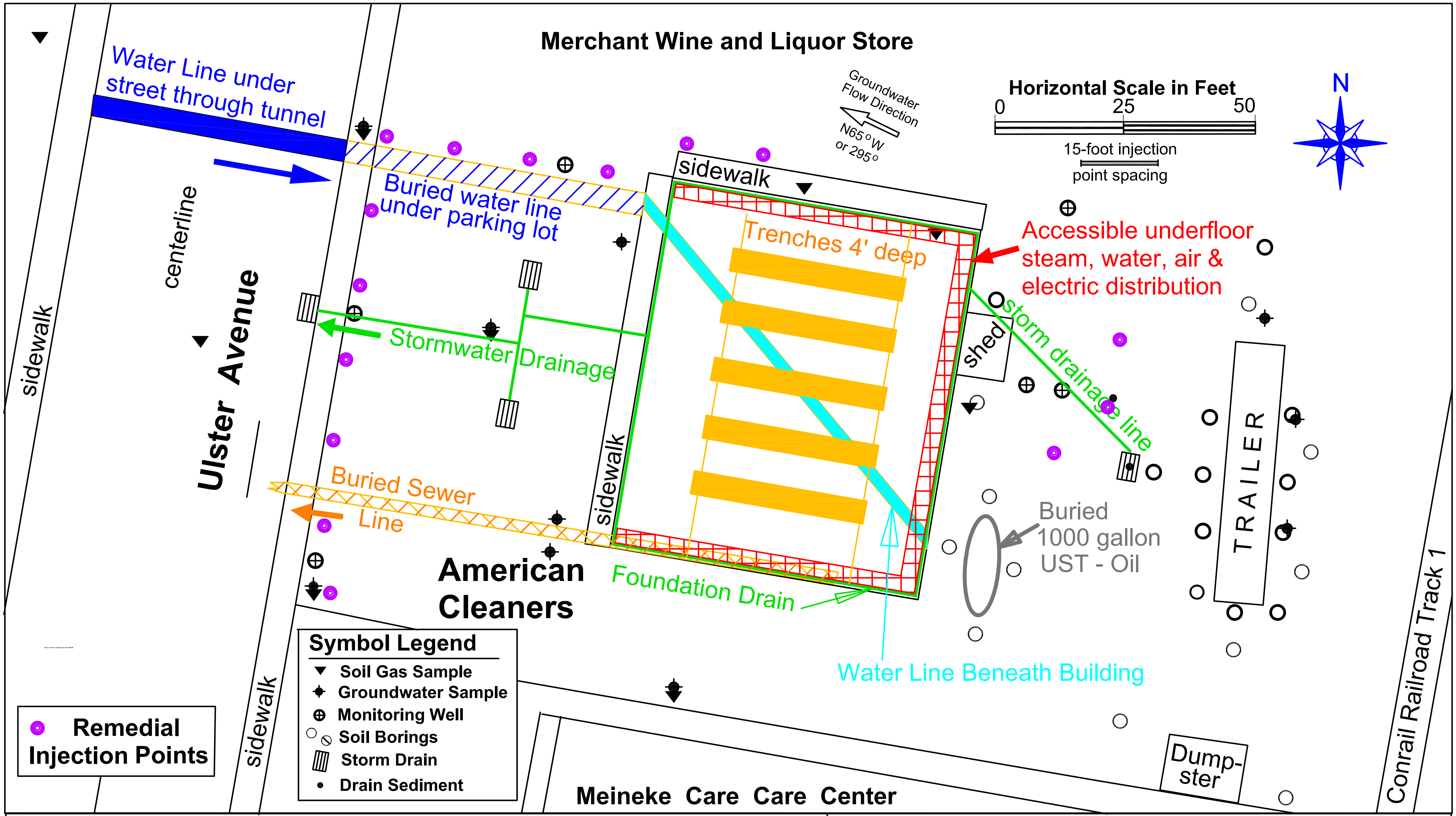

Figure 6. Site Plan showing proposed locations of remedial injection points with 15-foot spacing.
American Cleaners Inc, 734 Ulster Avenue, Kingston, NY
NYSDEC DER VCP Site V-00601-3 April 28, 2014

Prepared by
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American Cleaners, Kingston, NY SUB-SLAB VACUUM TESTING, August 5, 2013

At approximately 9:45AM, PID measurements were taken from the top of each of the four extraction points using the MiniRAE 2000 photoionization detector (calibrated this morning).

XP1	XP2	XP3	XP4	Background
0.8 ppm	0.2 ppm	1.6 ppm	0.8 ppm	0.3 ppm

Test 1: XP2 (near the back door) 10AM -- Later determined INVALID

At 10:10 AM, in the process of hooking up the 1 horsepower Fuji Electric Regenerative Blower (also called a ring compressor) model VFC400-5T (running single phase 115v, 60 hertz), the air flow was tested as each piece was added to the blower system:

(1) Blower, no hose,	82 scfm
(2) Blower, 25 feet of green hose	75 scfm
(3) Blower, 25 feet hose, elbow & 1-inch adapter	70 scfm.

The Blower was mounted outdoors on the tailgate of a truck and the hose was connected to XP2.

Time	XP2 Flow scfm	XP2 Vac	XP1 Vac	XP3 Vac	XP4 Vac (inches of water)
10:20AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
10:30AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
10:40AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
10:50AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01

Test 2: XP3 (near iron station on north wall) 11:00AM-- Later determined INVALID

At 11:05AM, in the process of hooking up the 1 horsepower Fuji Electric Blower, the air flow was tested as each piece was added to the blower system:

(1) Blower, 75 feet of green hose	55 scfm
(2) Blower, 75 feet hose, elbow & 1-inch adapter	50 scfm.

Time	XP3 Flow scfm	XP3 Vac	XP1 Vac	XP2 Vac	XP4 Vac (inches of water)
11:10AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01

Test 3: XP1 (northeast corner) 11:15AM-- Later determined INVALID

The same hardware (75 feet of hose and adapters) was used for this test as for Test 2.

Time	XP2 Flow scfm	XP2 Vac	XP1 Vac	XP3 Vac	XP4 Vac (inches of water)
11:20AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01

Test 4: XP2 Retest to run for an hour 11:30AM to 12:30PM --Later determined INVALID

Time	XP2 Flow scfm	XP2 Vac	XP1 Vac	XP3 Vac	XP4 Vac (inches of water)
11:30AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
11:40AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
11:50AM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
12:00n	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
12:10PM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
12:20PM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01
12:30PM	below zero	> 20	+/- 0.01	+/- 0.01	+/- 0.01

Test 5: XP4 (Southeast front corner of Building behind counter) 12:45-1:50PM

Because the pressure gauge was not in the correct range and the air flow meter got clogged with sand, during this test, a practical means of measuring the vacuum was set up with a bucket of water and a plastic hose over the top of the door, so that the inches of water in the tube upward from the top of the water in the bucket could be measured. As a result, the direct measurement of vacuum could be measured and the corresponding air flow could be estimated from the performance curve for the regenerative blower.

Time	XP4 Vac	XP4 est Flow scfm	XP1 Vac	XP2 Vac	XP3 Vac (inches of water)
12:45PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
12:55PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
1:05PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
1:15PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
1:25PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
1:35PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
1:45PM	39	42	+/- 0.01	+/- 0.01	+/- 0.01
1:50PM	turn off blower				

When the blower was turned on, fine sand grains were blown out of the fan discharge. The origin of the sand grains was likely the natural sediment encountered in the soil sampling at the time of installation of the extraction point. The flow meter stopped working and sand was found in the connectors to the hose. During this test, it was decided that perhaps, the flow meter may not have been working correctly all day, so it was decided to return to XP2 and conduct another one hour test using direct vacuum measurement with the bucket, water and tubing.

Test 6: XP2 with a measuring point 5 feet southwest

This test showed more accurate results than earlier Tests 1 and 4 because the vacuum was measured using the bucket, water, and tubing. The in-line flow meter appears to have not been working correctly during those two tests. Once it was established that a vacuum was developing around XP2 and air flow was about 40 scfm, a vacuum observation point VP1 was drilled through the concrete slab 5 feet southwest of XP2 to measure the local vacuum field around XP2.

Time	XP2 Vac	XP2 est Flow scfm	XP1 Vac	XP3 Vac	XP4 Vac	VP1 Vac
2:25PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	--
2:35PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	--
2:45PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	0.07
2:55PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	0.07
3:05PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	0.07
3:15PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	0.07
3:25PM	40	39	+/- 0.01	+/- 0.01	+/- 0.01	0.07
3:35PM	turn off blower					

When a vacuum was applied to XP2, a vacuum of 0.07 inches of water was detected in VP1 at a distance of five feet.

A set of PID measurement were taken at each of the extraction points at 3:45PM.

XP1	XP2	XP3	XP4	Background
1.98 ppm	2.6 ppm	2.6 ppm	0.8 ppm	0.2 ppm

Test 7: XP1 with a vacuum measuring point 7'2" west toward XP3

Another vacuum measuring point was drilled through the concrete approximately midway between XP1 and XP3 to test the vacuum field around those extraction points. VP2 is 86 inches from XP1 and 105 inches from XP3.

Time	XP1 Vac	XP1 est Flow scfm	XP2 Vac	XP3 Vac	XP4 Vac	VP2 Vac
3:40PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
3:50PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
4:00PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
4:10PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
4:20PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
4:30PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
4:40PM	45	27	+/- 0.01	+/- 0.01	+/- 0.01	+/- 0.01
4:40PM	turn off blower					

When the blower was applied to XP1, essentially no vacuum was detected at VP2 at a distance of 7 feet 2 inches.

Test 8: XP3 with a vacuum measuring point 8'9" east toward XP1

VP2 was placed midway between XP1 and XP3 so it could be used to monitor the vacuum field during tests of both extraction points.

Time	XP3 Vac	XP3 est Flow scfm	XP1 Vac	XP2 Vac	XP4 Vac	VP2 Vac
4:45PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
4:55PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
5:05PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
5:15PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
5:25PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
5:35PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
5:45PM	43	32	+/- 0.01	+/- 0.01	+/- 0.01	0.04
5:45PM	turn off blower					

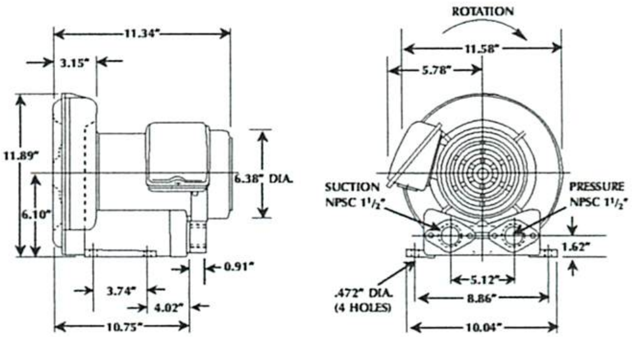
When the vacuum was applied to XP3, a vacuum of 0.04 inches of water was detected at VP2 about 8 feet 9 inches away.

Notes:
Scfm standard cubic feet per minute, unit measurement for air flow
Vac = vacuum measured in inches of water
+/- 0.01 indicates that the electronic vacuum gauge is reading a low vacuum at it's lower limit of measurement in inches of water, essentially no vacuum.
PID measurements were taken to measure the concentration of VOCs in the sub-slab pore space at each of the extraction points.

VFC40

RING COMPRESSOR

The VFC40 is a single-stage ring compressor with a maximum pressure of 54.5 in. H_2O, a maximum vacuum of 50 in. H_2O, and a maximum capacity of 98 SCFM. It comes complete with a direct-drive, 1 horsepower, TEFC motor capable of operating on a wide range of voltages, and on 50 or 60 Hz. A pilot-duty thermal protector is standard equipment on all 3-phase and 1-phase models. All versions have NEMA class B insulation, are UL recognized, CSA certified, and CE. 575V units are CSA certified only.



SPECIFICATIONS

			Voltage	Amps (Max. Rated)	Amps (Locked Rotor)	Max. Pressure	Max. Vacuum	Max. Airflow	Min. Airflow	Max. Temp Rise (ΔT)	Weight
	Model No.	Hz	Low Voltage/High Voltage			in. H_2O	in. H_2O	SCFM	SCFM	°F(°C)	lbs.(kg)
1 Phase	VFC400P-5T	60	115/230	8.6/4.3	24/12	54.5	50	98	3.5	119(65)	51(23)
		50	110/220	6.0/3.0	22/11	40	37	84	3.5	101(55)	
3 Phase	VFC400A-7W	60	200-240/400-480	3.3-2.8/1.7-1.4	15-16.5/7.4-8.2	54.5	50	98	3.5	119(65)	47.5(21.5)
		50	190-230/380-460	2.2-2.4/1.1-1.2	16.5-18.5/8.3-9.2	40	37	84	3.5	101(55)	
	VFC400A-5W	60	575	1.3	7.2	54.5	50	98	3.5	119(65)	47.5(21.5)

ACCESSORIES

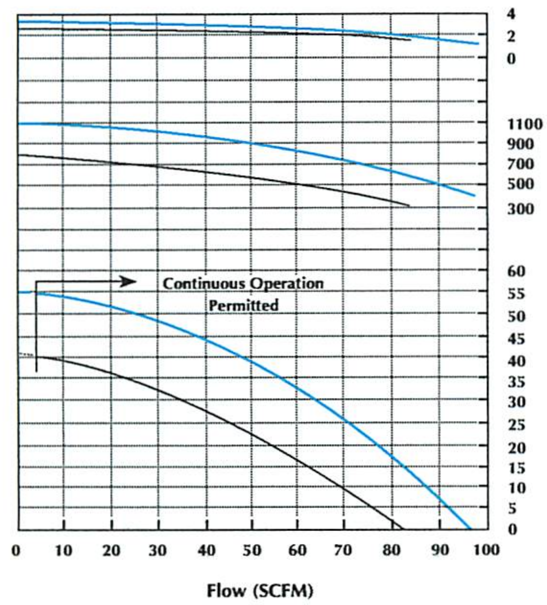
Description	Vacuum Relief Valve	Pressure Relief Valve	Inlet Filter	Inlet Filter Cover	Inlet Filter/Receiver	Exhaust Silencer/Muffler
Model No.	VV4	PV4	F-45	C-45	R30P1.5	VFY-024A

NOTE: Maximum allowable time at deadhead is 120 seconds.

VFC40 PERFORMANCE DATA

KEY
— 60 Hz
— 50 Hz

PRESSURE

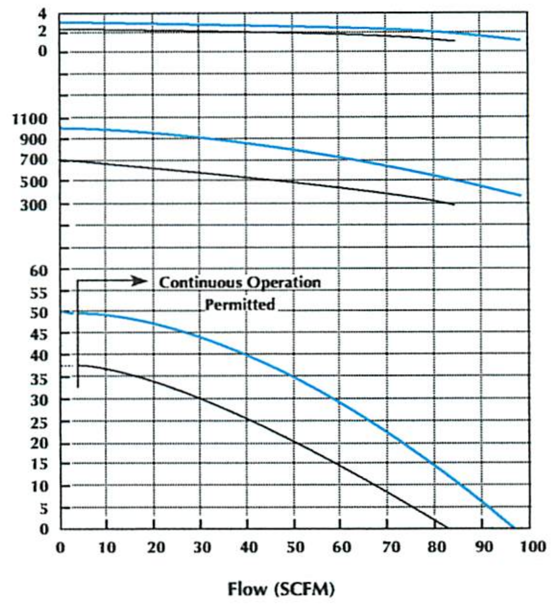


AMPS
(230 V/3 PH)

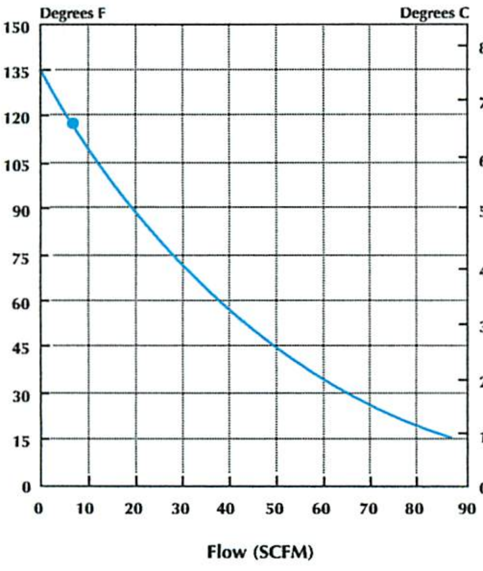
WATTS

STATIC
PRESSURE
(Inches of Water)

VACUUM

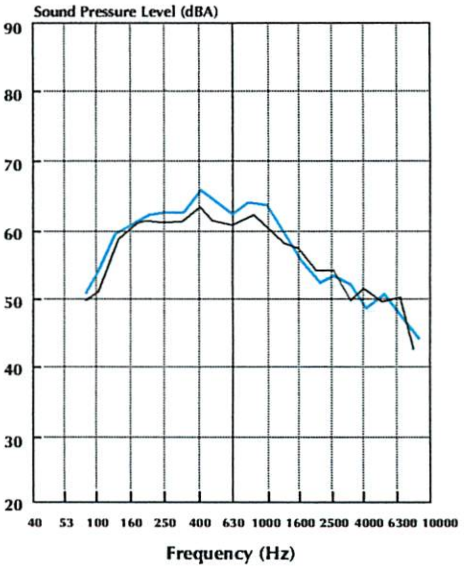


TEMPERATURE RISE



Max. Air Temperature is Value Marked •
plus 40 Degrees C Ambient Temperature

SOUND LEVEL



*Measured at distance of 1.0 meter

microbialinsights

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Client: Katherine Beinkafner
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Clintondale, NY 12515

Phone: 845-883-5866

Fax:

Identifier: 007JJ **Date Rec:** 10/02/2012 **Report Date:** 10/05/2012

Client Project #: **Client Project Name:** American Cleaners Kingston

Purchase Order #:

Analysis Requested: CENSUS

Reviewed By:

MICROBIAL INSIGHTS, INC.

CENSUS

2340 Stock Creek Blvd. Rockford, TN 37853-3044
Tel. (865) 573-8188 Fax. (865) 573-8133

Client:	**Mid-Hudson Geosciences**	**MI Project Number:**	**007JJ**
Project:	American Cleaners Kingston	Date Received:	10/02/2012

Sample Information

Client Sample ID:	**AC Kingston MW6**
Sample Date:	10/01/2012
Units:	cells/mL
Analyst:	RW

Dechlorinating Bacteria

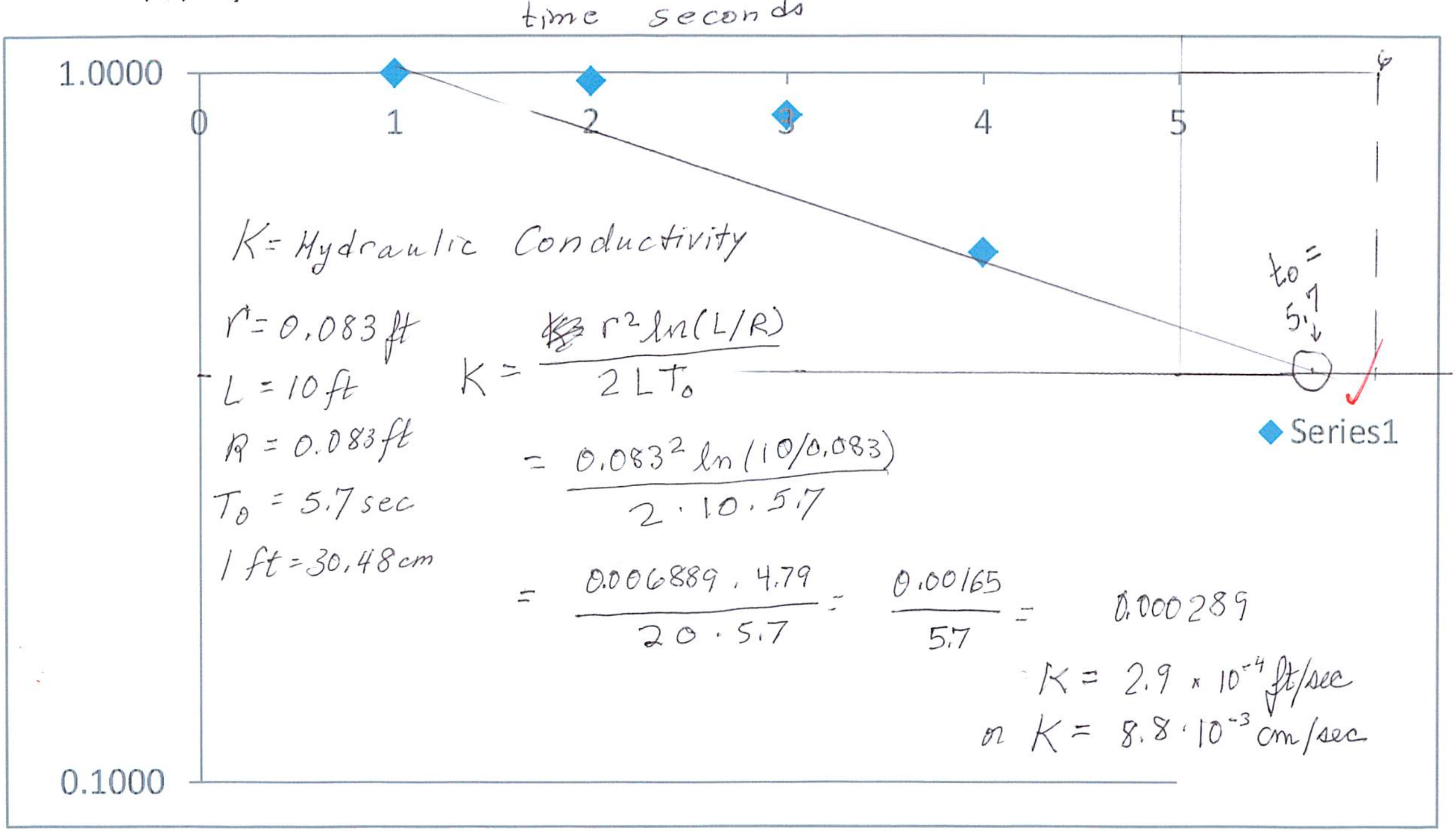
Dehalococcoides spp.	*DHC*	<3.00E-01

Legend:

NA = Not Analyzed NS = Not Sampled J = Estimated gene copies below PQL but above LQL I = Inhibited
< = Result not detected

Slug Test Graphic Analysis: Hvorslev Method

MW4 12:55



K = Hydraulic Conductivity

r = 0.083 ft
L = 10 ft
R = 0.083 ft
T_0 = 5.7 sec
1 ft = 30.48 cm

$$K = \frac{r^2 \ln(L/R)}{2 L T_0}$$

$$= \frac{0.083^2 \ln(10/0.083)}{2 \cdot 10 \cdot 5.7}$$

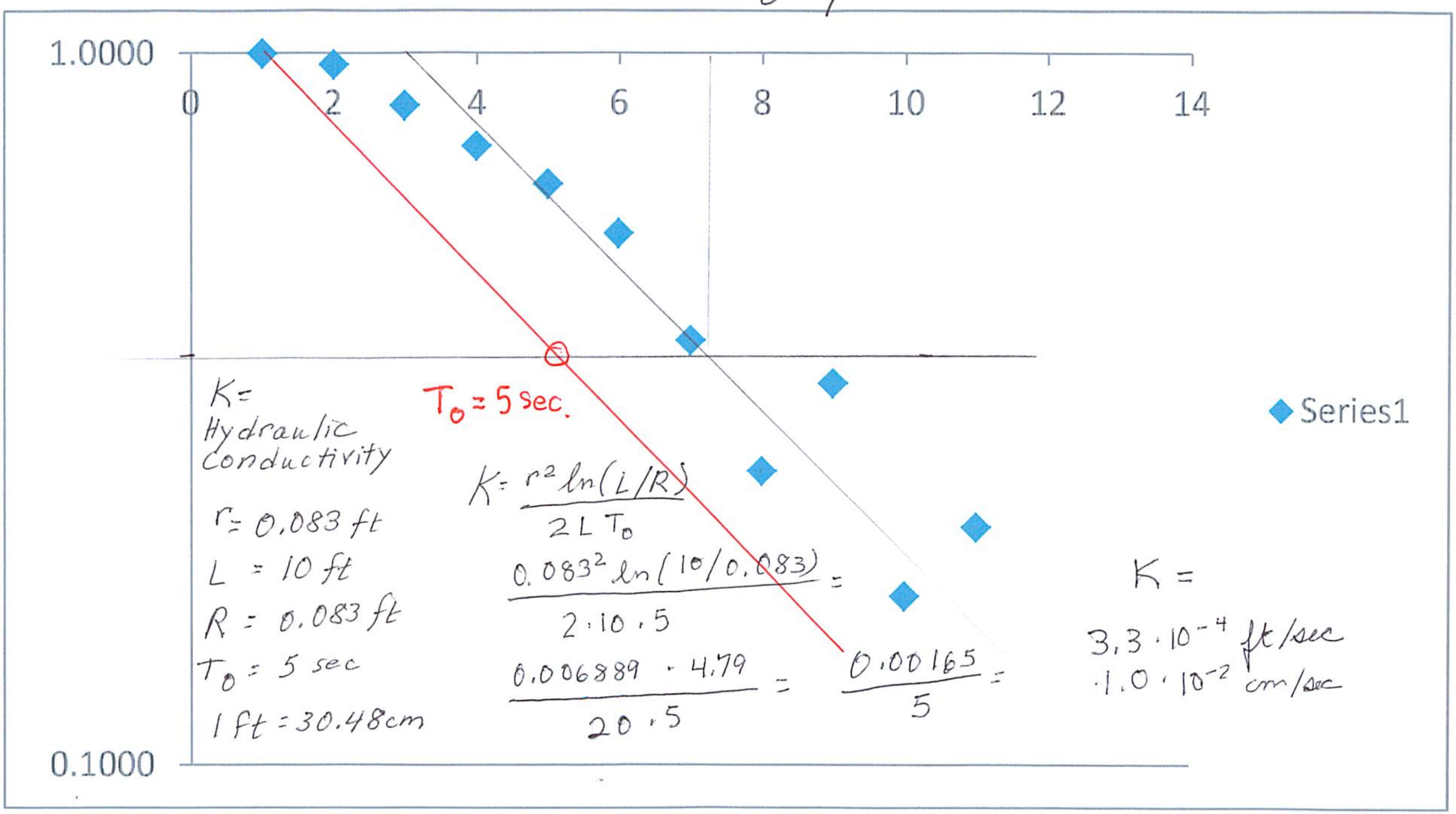
$$= \frac{0.006889 \cdot 4.79}{20 \cdot 5.7} = \frac{0.00165}{5.7} = 0.000289$$

$K = 2.9 \times 10^{-4}$ ft/sec
or $K = 8.8 \cdot 10^{-3}$ cm/sec

Slug Test Graphic Analysis: Hvorslev Method

MW4 12:58

$T_0 = 7$



K = Hydraulic Conductivity

r = 0.083 ft

L = 10 ft

R = 0.083 ft

T_0 = 5 sec

1 ft = 30.48cm

$$K = \frac{r^2 \ln(L/R)}{2 L T_0}$$

$$\frac{0.083^2 \ln(10/0.083)}{2 \cdot 10 \cdot 5} =$$

$$\frac{0.006889 \cdot 4.79}{20 \cdot 5} = \frac{0.00165}{5} =$$

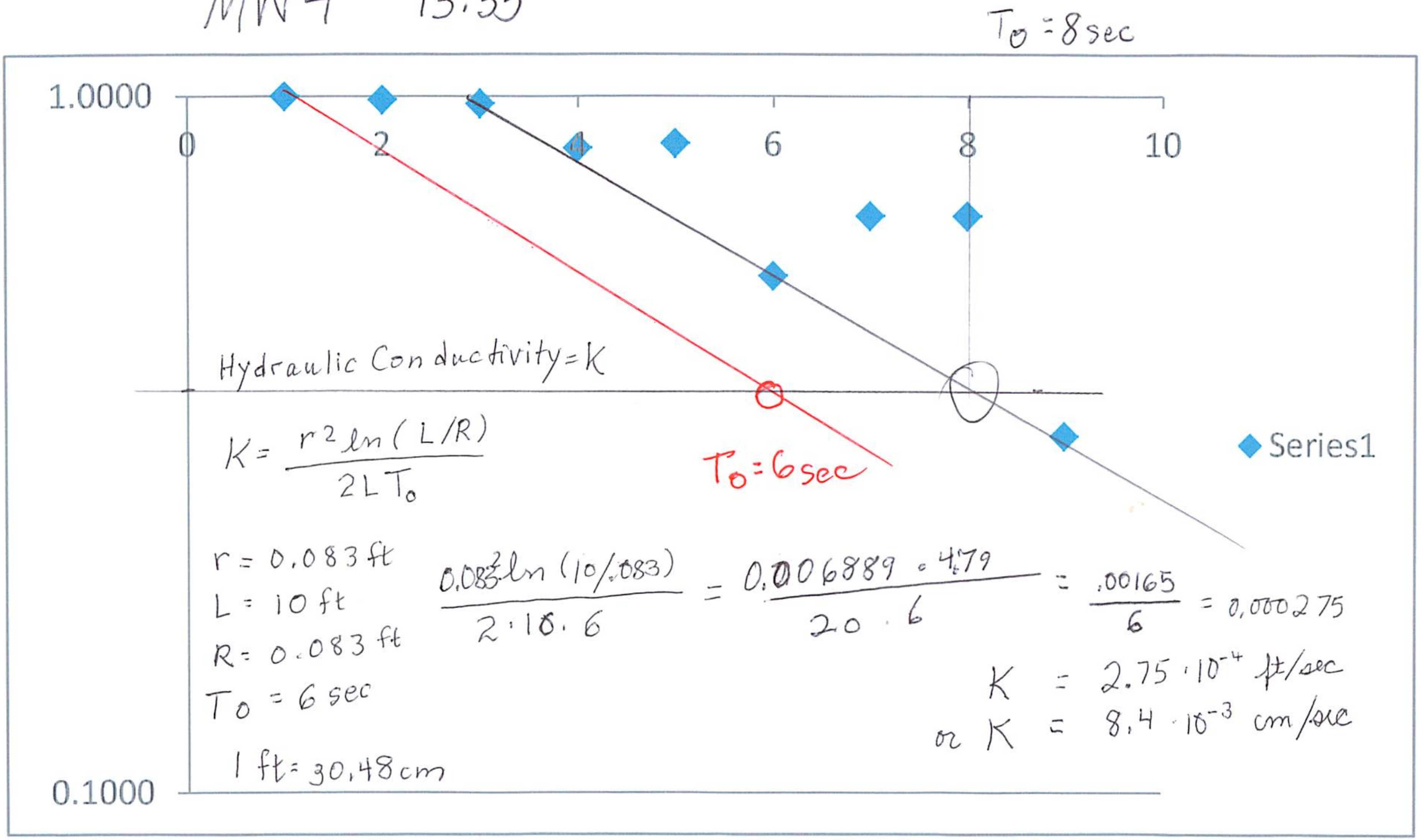
K =

$3.3 \cdot 10^{-4}$ ft/sec

$\cdot 1.0 \cdot 10^{-2}$ cm/sec

Slug Test Graphic Analysis: Hvorslev Method

MW4 13:55



Hydraulic Conductivity = K

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

r = 0.083 ft
L = 10 ft
R = 0.083 ft
To = 6 sec

1 ft = 30.48 cm

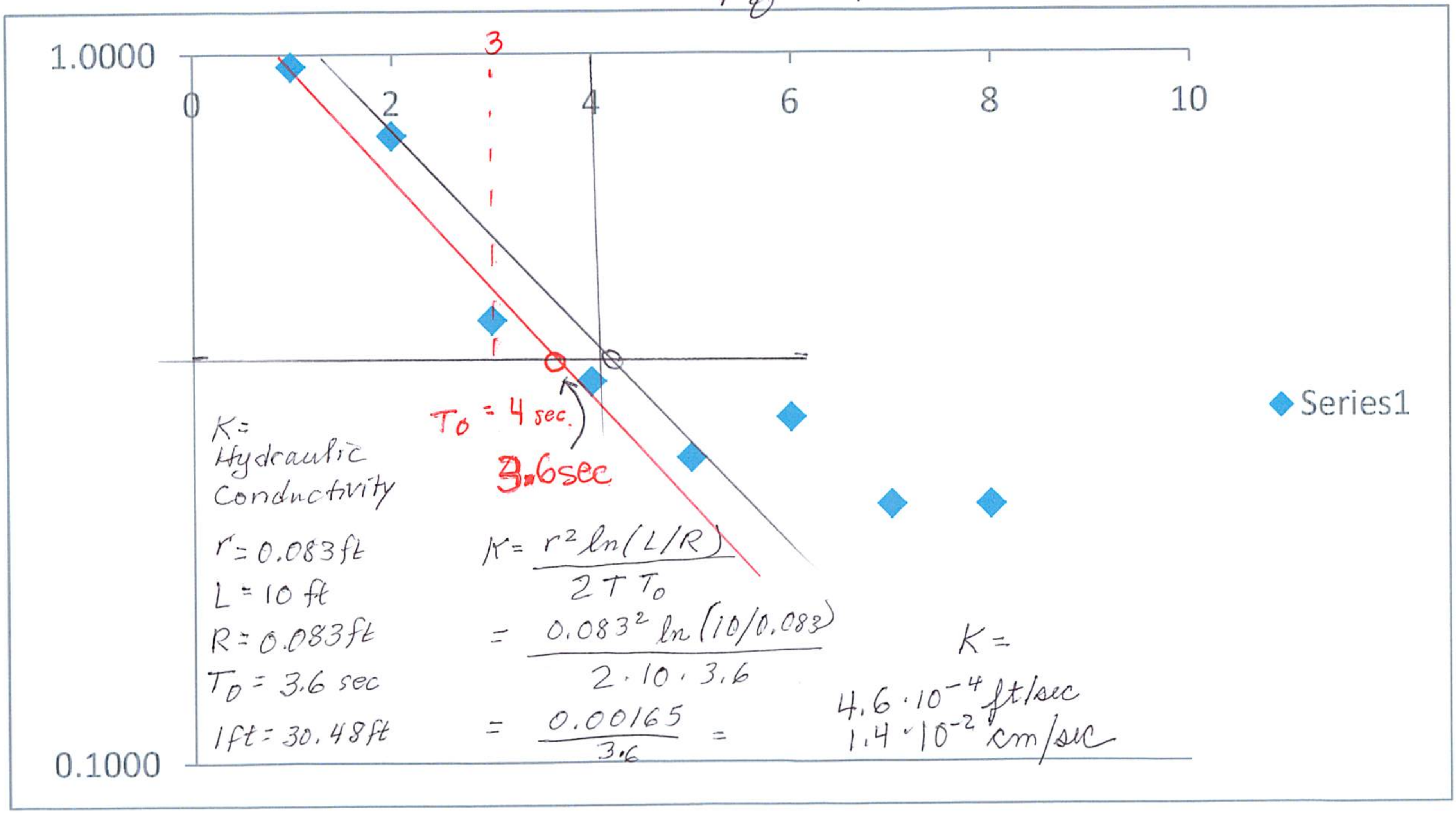
$$\frac{0.083^2 \ln(10/.083)}{2 \cdot 10 \cdot 6} = \frac{0.006889 \cdot 4.79}{20 \cdot 6} = \frac{.00165}{6} = 0.000275$$

$K = 2.75 \cdot 10^{-4}$ ft/sec
or $K = 8.4 \cdot 10^{-3}$ cm/sec

Slug Test Graphic Analysis: Hvorslev Method

MW5 16:12

$T_0 = 4 sec$



K = Hydraulic Conductivity

r = 0.083ft

L = 10 ft

R = 0.083ft

$T_0 = 3.6$ sec

1ft = 30.48ft

$$K = \frac{r^2 \ln(L/R)}{2 T T_0} = \frac{0.083^2 \ln(10/0.083)}{2 \cdot 10 \cdot 3.6} = \frac{0.00165}{3.6} =$$

K =

$4.6 \cdot 10^{-4}$ ft/sec

$1.4 \cdot 10^{-2}$ cm/sec

DGSI
DURHAM GEO SLOPE INDICATOR

Environmental and Geotechnical Products

BaroBall™

The BaroBall control valve allows natural soil gas to flow out of an underground well, while restricting air flow from the surface into the well.


BaroBall™, Standard and Inverted

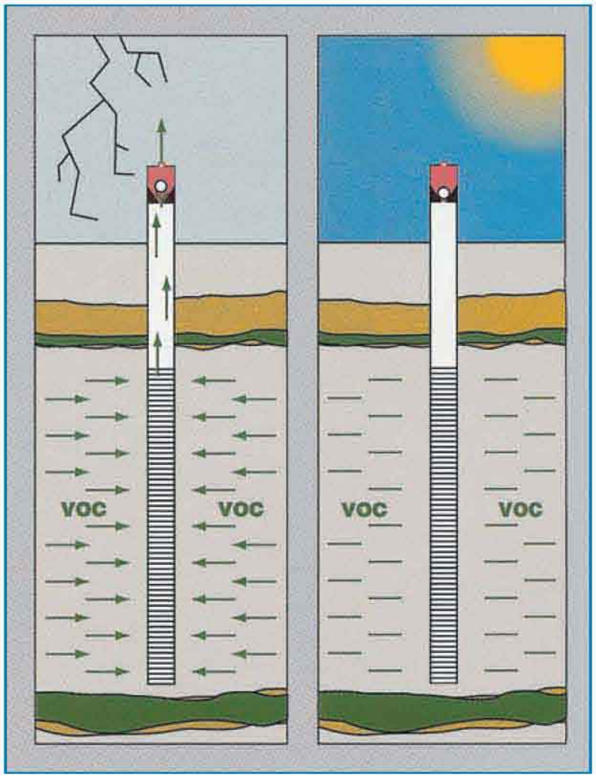
Benefits:

- **Increase efficiency.** Compared with ordinary passive venting, BaroBall may double the rate of contaminant removal by preventing the dilution of contaminants with fresh air from the surface.
- **Can be used in multiple flow configurations.** The BaroBall can be modified for gas extraction or air injection, permitting barometric pumping to be used for plume control or oxygen injection in bioremediation systems.
- **Increases the accuracy of soil gas measurements.** The BaroBall prevents surface air from entering a well and diluting gas concentrations in the subsurface. This allows retrieval and analysis of actual ambient soil gas concentrations.
- **No power source or pressure sensing required.** The BaroBall is actuated and sustained by the naturally produced pressure gradients between the surface and subsurface.
- **Rugged, durable construction.** The BaroBall has only one moving part. Unattended operation for an extended period of time can be expected.
- **High skill level not required for installation.** The BaroBall can be properly installed by any field technician.
- **Small and unobtrusive.** The BaroBall is cylindrically shaped, three inches in diameter and approximately three inches tall (76 x 83 mm). It can be installed with a low profile and will not stand out from the surrounding landscape.

Applications:

Passive Soil Vapor Extraction and in situ bioremediation.

The BaroBall is a low-cost, low maintenance valve that responds to the natural fluctuations of atmospheric pressure to enhance significantly the removal of volatile organic compounds from contaminated sites that use barometric pumping as a remediation technique.



Atmospheric pressure lower than pressure in the well: VOCs can escape.

Atmospheric pressure higher than pressure in the well: VOCs cannot escape.

Description:

The BaroBall™ is a patented* control valve that harnesses natural fluctuations in atmospheric pressures to create a pumping method that passively removes vapors from the unsaturated soil zone (Passive Soil Vapor Extraction).This technology has been demonstrated at the Savannah River National Laboratory to increase removal rates by up to 50%. Natural atmospheric pressure fluctuations are transmitted through the unsaturated subsurface resulting in pressure differential between the surface and subsurface. When the zones are directly connected by a well placed in the vadose zone, the pressure differentials will result in flow into or out of the well depending on the BaroBall configuration used.

The BaroBall is installed at the top of the well casing to permit gas flow in one direction. The BaroBall has been used in conjunction with the FAP Plus™ pump during LNAPL recovery. The addition of the passive SVE can improve LNAPL recovery depending on the soil and site conditions. Other applications include the final polishing for an active SVE system where removal rates have been substantially reduced to the point where SVE system operation costs are very high. Inverted BaroBall installations have been used to allow air flow into the subsurface, but prevent air escape to improve in-situ bioremediation.

The BaroBall has been used to provide plume control of methane production at landfills. It can be used with the SolarSPARGE for sparging.

Operation:

Use of barometric pumping to remediate contaminated soils is growing as a finishing technique when active extraction is no longer cost effective due to low contaminant diffusion. It also is used as an interim measure or when funds are unavailable for more expensive systems.

While check valves are currently available, none is suitable for the low pressure requirements of a barometric pumping system. The cracking pressure of these valves is typically seven to 10 millibars, much higher than could be produced by natural pressure differences.

Electrically operated valves are available but are undesirable because of their high costs and maintenance.

The BaroBall conforms to the low-cost, low-maintenance philosophy of barometric pumping through its simple construction, use of low-maintenance, durable materials and its ability to be used for extended, unattended operations. It now allows the remediation of many sites whose pollution levels do not justify the use of currently available, costly remediation technologies.

SPECIFICATIONS	
Input Power	Natural atmospheric pressure fluctuations
Cracking Pressure	As little as on millibar change in atmospheric pressure
Operating Temperature	Ambient air temperature of -40°F to +140°F (-40°C to +60°C)
Remediation Rate	Site specific. Typical flow rates of 0.1 to 1.0 scfm (0.05 to 0.47 dm^3/s)
Size	Designed to slide into a 2-in PVC Sch 40 casing. Thread Connection: 1 inch NPT. May be fitted to larger wells by using common PVC adapter fittings.
Max. Well Depth	Site specific. To the top of the water table.
Dimensions	3-in diameter x 3.25-in length (76 x 83 mm)

ORDERING INFORMATION		
TR-965	Standard BaroBall™ for soil gas extraction	2 lb
TR-966	Inverted BaroBall™ for atmospheric air injection	2 lb

Accessories:

BaroBall can be used on all kinds of vadose zone wells with appropriate reducer or expander pipe sections. Not supplied.

Common Questions:

On what size well can the BaroBall be installed?

Any size well will accommodate installation. The BaroBall's smallest aperture is one inch and will therefore introduce minimal flow losses for barometric pumping systems.

What kind of contaminant removal can I expect?

This depends solely on the concentration of contaminants in the gas and the flow rate through the well. Typical barometric pumping flow rates range from 0.1 to 1.0 scfm (0.05 to 0.4 7 dm^3/s) depending on the permeability of the formation, the length of the well screen and the diameter of the well. Flows as high as 10 scfm (4.7 dm^3/s) have been measured. Removal rates as high as 2.2 lb (1 kg) per day per well in highly contaminated sites have been measured.

How often will the wells be removing contaminants?

The duty cycle of barometric pumping is 50 percent. If there is another driving force at the site (such as methane buoyancy and pressurization at the landfill) the duty cycle will increase.

BaroBall™ is a trademark of Westinghouse Savannah River Company, LLC.

* U.S. Patent No. 5,641,245 and 6,425,298 and Canadian Patent No. 2,221,770 have been issued on the BaroBall.

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Going

Photos provided by Savannah River Site

A PSVE well with a BaroBall valve

A growing trend in environmental remediation is the use of natural processes. As we increase our knowledge about the ways nature cleanses itself, we're developing more remedial approaches that take advantage of natural phenomena. These approaches, such as bioremediation and phytoremediation, are reducing the costs of cleanup and intruding less on the environment. Another example of such an approach is passive soil vapor extraction, which is based on natural venting cycles between the surface and subsurface. When atmospheric pressure is higher than the subsurface's pressure, air is induced to flow through wells into the subsurface. Conversely, when atmospheric pressure is lower then subsurface pressure, air flows out of wells into the atmosphere, taking with it chlorinated solvents in the gas phase.

Passive soil vapor extraction (PSVE, Tech ID 56), also known as barometric pumping, is part of the Subsurface Contaminants Focus Area inventory of technologies. PSVE wells function like active air injection or extraction wells but do not use mechanical pumps. At any given time, the atmospheric pressure at the surface and the soil gas pressure in the subsurface area are different. If these two zones are connected by a vadose zone well, the pressure differential results in flow either into or out of the well. If the subsurface contains volatile organic compounds in the gaseous phase, the flow out of the well will result in the removal of the contaminants without mechanical pumping.

Natural atmospheric pressure fluctuations are transmitted through the unsaturated subsurface and are controlled by the permeability of the soil. The majority of the PSVE flow is achieved in the coarser, more permeable zones of the soil. The mass transfer of the contaminant to the coarser zones of the soil limits removal of contaminants from fine-grained sediments.

PSVE systems at Savannah River and Hanford

PSVE has been used as an interim remediation strategy at DOE waste sites contaminated with chlorinated solvents. PSVE requires minimal operation and maintenance, making it a low-cost alternative to pump-and-treat systems or a cost-effective polishing technology. The Savannah River Site and the Hanford Site are currently using PSVE to remove chlorinated contaminants. SRS installed 24 PSVE wells at one site to remove trichloroethylene (TCE) and perchloroethylene (PCE). According to Joseph Rossabi, a researcher at SRS, "Since September 1996, more than 240 pounds of chlorinated organic contaminants—180 pounds of TCE and 60 pounds of PCE—have been removed using PSVE. To date, close to 90 percent of the volatile contaminants have been removed from the system."

Rossabi adds that the barometric flow rates for a typical well at SRS are generally low (28 to 280 liters per minute). "However, if the concentration of the contaminant in the gas phase is high, mass removal by PSVE can be as much as 1–2 kilograms per day, per well."

Low-cost techniques, again based on natural processes, can increase mass removal. Enhancements can include the addition of wind-powered turbine vacuum pumps, one-way mechanical valves, and solar heat injection.

The Hanford Site is using PSVE as a polishing technology. Hanford installed eight PSVE wells in 1999 to remove the remaining TCE and PCE after active (pump-enhanced) soil vapor extraction removed 167,551 pounds of the contaminants at a waste site. These PSVE wells began operating in 2000, and data is being collected to determine the effect the wells are having on contaminants.

PSVE requires installing extraction wells within the polluted area, using either conventional drilling methods or direct penetration equipment. When installed with a direct penetration rig, the wells are threaded with a steel push tip onto the well pipe. These pipes are pushed through the soil with steel rods and are designed to access the appropriate portion of the unsaturated zone to effectively remove contaminants. The PSVE wells are typically placed vertically, but horizontal wells can also be used.

BaroBall enhances contaminant removal

PSVE systems are more effective when airflow into wells is shut off. A simple one-way valve called the Baroball, (Tech ID 3117) developed by Westinghouse Savannah River Company, does just that. “One-way valves significantly increase the effectiveness of barometric pumping by preventing the inflow of air into the venting well when atmospheric pressures reverse, a condition that can reduce contaminant removal by diluting and dispersing the pollutant,” Rossabi said.


Baroball valve

The BaroBall valve, commercially available through Durham Geo Enterprises, uses a ping-pong ball in a conical seat to permit gas flow in one direction with a minimal pressure requirement (approximately 1 millibar) and to effectively prevent gas flow in the reverse direction. The valve attaches directly to the well casing at the surface.


Dennis Jackson of SRS examines natural flow out of a well with the help of a BaroBall.

Depending on the configuration, the valve can also be used to inject air and/or nutrients into the subsurface to enhance bioremediation; to control or confine the movement of a subsurface gas-phase plume in the vadose zone; or to passively transfer solar-heated, water-saturated air into the subsurface to enhance volatilization in the subsurface.

Recent modifications to the BaroBall valve let field technicians measure the volume of air passing through the valve without hindering the valve’s operation. The new design consists of a tapered column that permits the ping-pong ball to rise in the column in proportion to the flow rate. By periodically recording these flows along with vapor concentrations, technicians can evaluate the overall performance of the passive remediation system. When accelerated remediation techniques are used in conjunction with barometric pumping, the use of the BaroBall valve with the flow measurement feature can provide evidence of increased flow, indicating the effectiveness of these combined techniques.

PSVE is very effective at removing contaminants from the unsaturated zone. The extracted vapors sometimes require treatment, but costs for treating extracted vapors are low compared to the costs of technologies requiring excavation. Vapors extracted by PSVE are typically treated using carbon adsorption, incineration, catalytic oxidation, or condensation. Carbon adsorption is the most commonly used treatment for contaminated vapors. The type of treatment chosen depends on which contaminants are present and their concentrations.

For more information about PSVE or the BaroBall, contact Joseph Rossabi at (803) 725-5220, joseph.rossabi@srs.gov or Brian Riha at (803) 557-7807, brian.riha@srs.gov.

WSRC-TR-2005-00268

Passive Soil Vapor Extraction (PSVE) for VOC Remediation at the Metallurgical Laboratory (MetLab) June 2005 Progress Report

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June 2005

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Savannah River Site
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Table of Contents

List of Tables

List of Figures

Executive Summary

The passive soil vapor extraction (PSVE) system at the MetLab of the Savannah River Site has been operating since May 1998. The concentration trend results to date indicate the technology is performing effectively and is protective of the environment. Well concentrations are decreasing and contour maps of the vadose zone soil gas plume show a decrease in the extent of the plume. In the 7 years of operation approximately 270 pounds of chlorinated organic contaminants have been removed by natural barometric pumping of wells fitted with BaroBall™ valves.

Mass removal during this time frame is primarily attributed to residual contamination in the coarse grained material and contaminant mass transfer from the finer grained zones to coarse zones where the majority of the PSVE flow is achieved. Removal from the fine grained sediments will be limited by the mass transfer from these zones to the coarse grained zones.

The majority of the well concentrations are less than 1 ppmv. Less than 4 lbs PCE and 3 lbs TCE are expected to be removed in calendar year 2005 compared to 65 lbs PCE and 40 lbs TCE removed during the first year of operation. Declining concentrations and mass removal rates indicate PSVE has significantly reduced the solvent source area.

The PSVE system has required minimal operating and maintenance costs and can be expected to operate continuously for the life span of the remediation with little or no intervention.

The PSVE system is performing well in a cost-effective manner. It is recommended that this system be allowed to continue operating to complete the remediation and to continue monitoring activities to verify and monitor the anticipated contaminant removal rates.

Background

Site Description

The Metallurgical Laboratory (MetLab) waste unit is located in the A/M areas of the Savannah River Site (SRS). During the 1950's to the early 1980's, solvents were used in MetLab facilities to degrease fuel and target tubes prior to use in other facilities at SRS. The solvents used during this period were primarily trichloroethylene (TCE) and tetrachloroethylene (PCE) with minor amounts of other solvents. Building 717-A is at the center of the soil gas plume and currently houses a machine shop. A site map showing buildings and wells is provided in Figure 1.

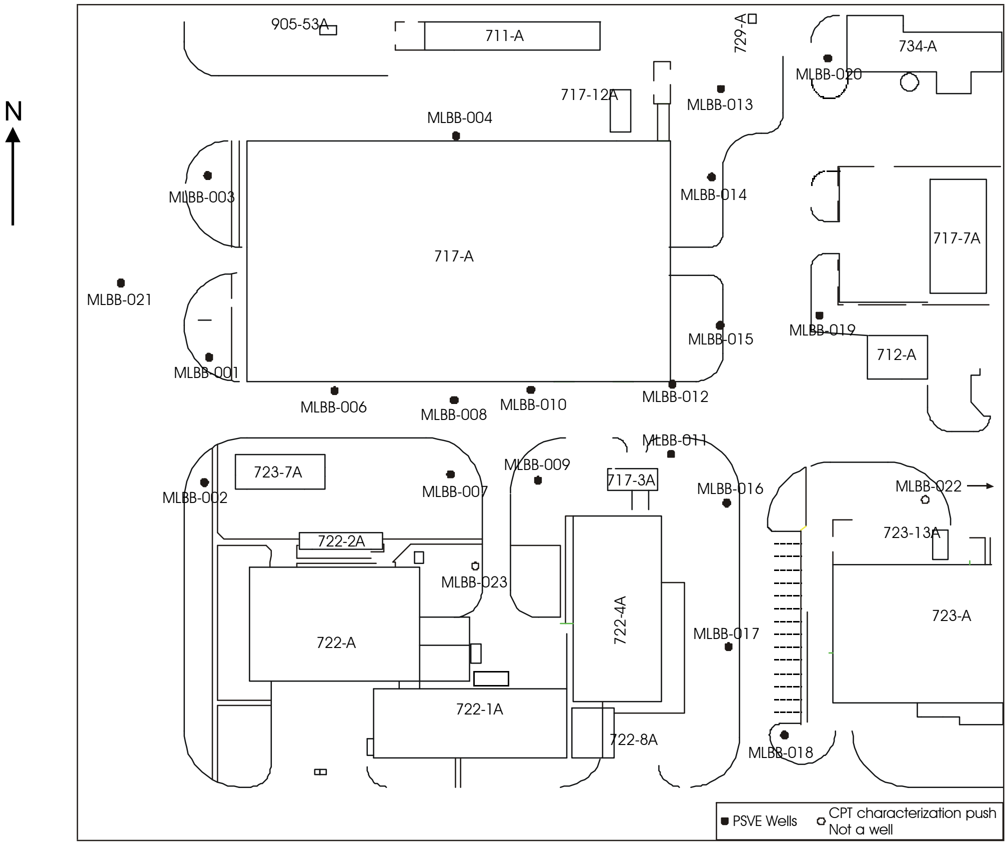

Figure 1 – MetLab Site Map

Previous Characterization Efforts

The MetLab characterization was initiated to determine the vertical and lateral extent of contaminants in the vadose zone to aid in determining the source of groundwater contamination in the area. MetLab Phase I consisted of installation of seven groundwater monitoring wells and completion of one soil boring near the MetLab Hazardous Waste Management Facility (HWMF). TCE and PCE sediment concentrations in the vadose zone ranged from below detection (<0.001 μg/g) to 0.068 μg/g and 0.025 μg/g respectively (Van Pelt and Dunbar, 1995). MetLab Phase II included six cone penetrometer test (CPT) characterization and soil gas pushes and groundwater sample collection at three locations. TCE and PCE soil gas concentrations ranged from below detection to 15.1 ppmv and 7.2 ppmv respectively (Pemberton et al., 1996).

During MetLab Phase III, soil gas samples were collected at twenty-nine locations using a (CPT) truck around the metallurgical manufacturing facility in M-Area. This work expanded lateral vadose zone characterization north and east of the MetLab HWMF. The highest soil gas concentrations were found in an isolated area near Building 717-A. Concentrations ranged from 88.4 ppmv TCE and 121.6 PCE ppmv near 717-A to non-detect levels at the north end of the characterization area. Other contaminants (e.g. 1,1,1 trichloroethane (TCA), Freon 113, degradation by-products) were also present in the soil gas samples at lower concentrations (Pemberton et al., 1997).

Additional characterization was completed in FY00 to evaluate the concentration of the soil gas plume on the south and west sides of the PSVE well field. One well was installed and two soil gas pushes were completed. The maximum soil gas concentrations observed from both CPT soil gas pushes were 3.0 ppmv PCE, 3.5 ppmv TCE, and 4.5 ppmv Freon 113. Additional wells were not installed due to the low concentrations. Based on the new characterization data and the monitoring results from the existing wells, the current well system adequately bounds the soil gas plume (Riha et al., 2000).

The apparent source term is located on the south side of Building 717-A. The low contaminant concentrations measured in the soil gas (<15 ppmv) at the CPT locations on the north and east side of Building 717-A, indicate that the soil gas plume has probably migrated from the apparent source on the south side of Building 717-A. If other solvent source areas were present near the CPT pushes, much higher soil gas concentrations would be expected. The most likely source of this solvent gas plume is from minor degreasing operations associated with Building 717-A.

Geology

The SRS is underlain by a thick wedge (approximately 1000 ft) of unconsolidated Tertiary and Cretaceous sediments consisting primarily of sands, clayey sands, and sandy clays. Three fine grain layers in the vadose zone at the MetLab are located at approximately 0-15 ft, 60 ft and 80 ft below ground surface. The upper zone is defined as the ‘upland unit’. This unit is fairly consistent across the SRS A/M Areas and is made up of a very low permeability, high porosity, high water content mix of sand, silt and clay and ranges from 10-50 ft thick at the SRS. Most facilities at the SRS were built on the ‘upland unit’, which has shown to entrap solvent for over 20-30 years (approximate time since releases ceased). The 60 and 80 ft layers are interbedded and range in thickness from approximately 1 to 15 ft. The water table at the site is approximately 140 ft below the ground surface. CPT soil classification logs from two borings (MLBB-022 and MLBB-023) at the MetLab are provided in Figure 2

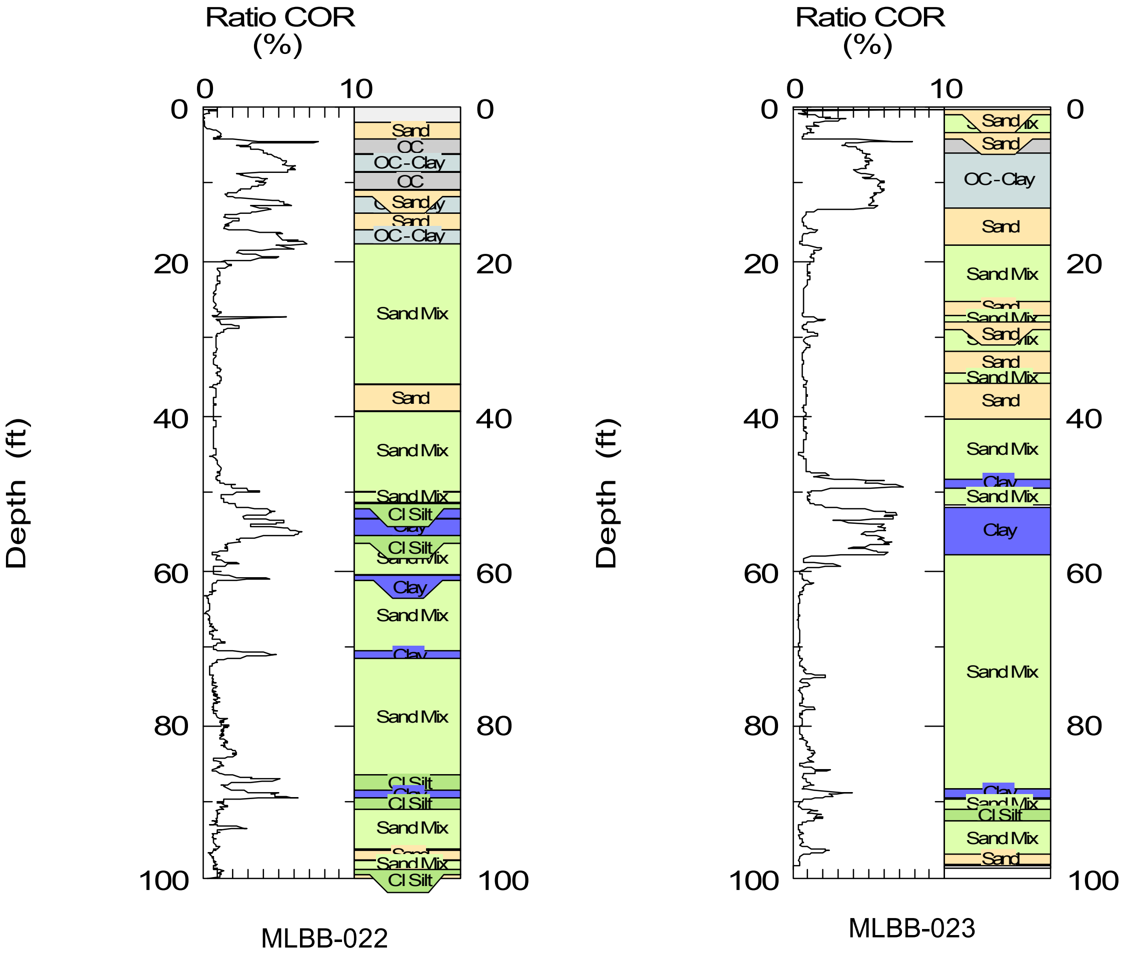

Figure 2 – CPT Soil Classification for MLBB-022 and MLBB-023

Original PSVE Well Installation

Nineteen vadose zone wells (MLBB-001 to MLBB-004 and MLBB-006 to MLBB-021, see Appendix A) were installed at the MetLab using direct push with a CPT truck after the Phase III characterization. MLBB-005 was not installed due to underground interferences. The wells were installed by threading a steel push tip onto the PVC screen and pushing the tip with the steel CPT rods in the center of the PVC, effectively pulling the PVC well down with the push tip. The CPT rods are removed and the 6 inch long steel push tip and well remain in the ground.

The wells were installed so the formation was compressed against the outer surface of the casing and screen, leaving no annular space. This seal is verified by sustained gas pressure differences between the surface and subsurface. The wells were installed with continuous screens from 20 to 80 feet below surface. Concrete pads were installed around the wells at the surface.

Technology Description - Barometric Pumping

At numerous sites across the country, wells with open intervals in the unsaturated zone have been observed to "breathe" or to inhale ambient air from the surface and to exhale soil gas to the atmosphere. This process results from the difference in atmospheric pressure and the pressure in the subsurface. Barometric pressure changes, caused by diurnal fluctuations and weather events, are propagated through the subsurface with attenuation and delay induced by stratum permeability changes and depth. For example, low-permeability layers exhibit low gas flow rates and require a longer period of time to equilibrate with a change in atmospheric pressure. This produces the damped and delayed pressure response. At the SRS, the magnitude of the differential pressure increases with depth due to the depositional layering of the sediments. Passive soil vapor extraction (PSVE) enhances and harnesses this natural process as a remediation technique for removing volatile contaminants from the vadose zone.

A plot showing surface and subsurface pressures and the typical diurnal (short) and weather (long) generated differential pressure is shown in Figure 3. Flow is out of the PSVE wells when the subsurface pressure is greater than the atmospheric (surface) pressure and the PSVE flow rate is directly proportional to the magnitude of the differential pressure. By connecting these zones via a vadose zone well, the differential pressure will result in flow either into or out of the well. If the soil gas in the subsurface contains volatile organic compounds (VOCs), flow out of the well will result in the removal of those contaminants from the subsurface without mechanical pumping. The outflow events can be viewed as pulsed soil vapor extraction events.

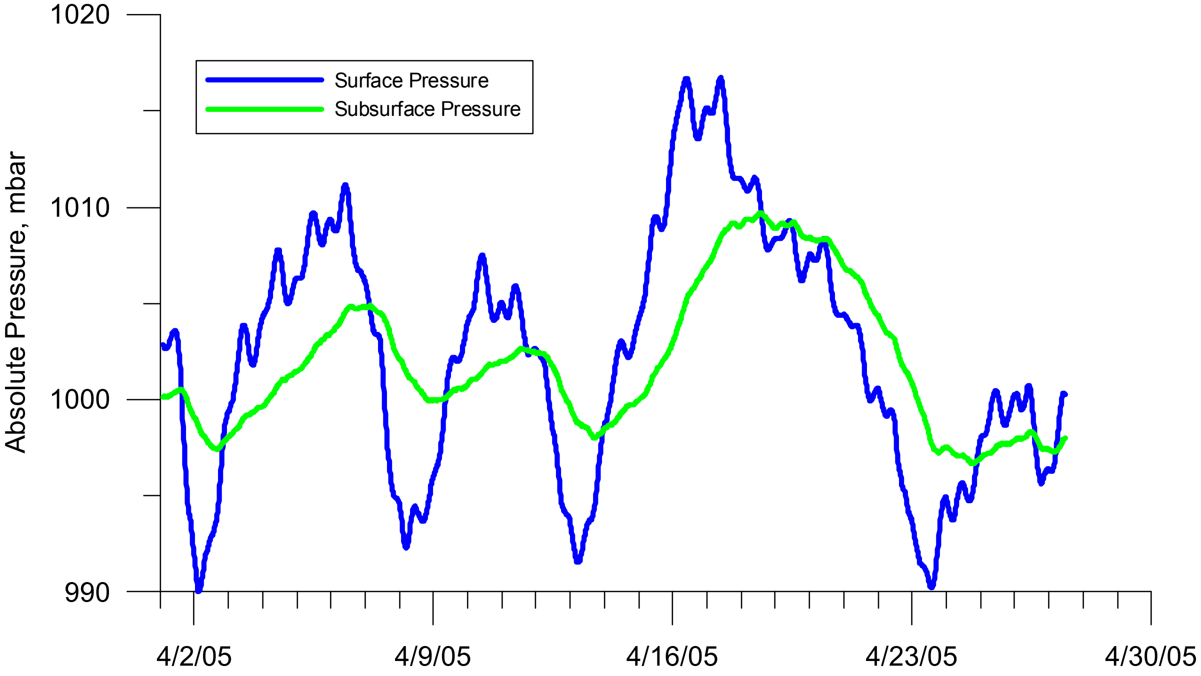

Figure 3 – Atmospheric and Subsurface Pressure Relation at Well MLBB-021

This phenomena has been observed for more than a century; the first reference in the literature is an article in Science (Fairbanks, 1896). The duration of flow events (either flow into the well or flow out of the well) can be several days continuously but, as expected by mass balance considerations, the average time of flow in is equal to the average time of flow out. The flow rates for a typical well are generally low compared to active soil vapor extraction (ASVE0. Mass removal can be enhanced with installation of one way mechanical valves to prevent spread and movement of contaminated soil gas away from the well during inflow and provide a stepped or pulsed removal of vapor from the subsurface.

The BaroBall™ (U.S. Patent #5,641,245) is a device developed and patented by WSRC specifically for barometric pumping applications. It uses a lightweight ball in a conical seat to permit gas flow in one direction with a minimal pressure requirement (approximately 1 mbar), but effectively prevents gas flow in the reverse direction. The BaroBall device is attached directly to the top of the well casing at the surface.

The PSVE approach directly addresses three critical components of the VOC contaminated soil problem:

1. <u>Containment</u>: Soil vapor extraction can directly address the source term at contaminated sites. Decreasing the source term decreases the potential for contaminant transport, which contains the plume. In addition, advective flow will move the vapor to the well and then the surface when controlling flow with one-way valves. The density driven component of gas flow is dominated by the advective component in these situations. Finally, by decreasing the contaminant vapor concentration near the vent well, diffusive flow will move the contaminant toward the well rather than toward the groundwater.
2. <u>Primary Removal</u>: In a situation where a very high removal rate is not required, interim action is required, vapor concentrations are low, or in locations away from the center of the plume, passively vented wells may be a cost-effective alternative to ASVE (mechanical pumping).
3. <u>Long-Term Stewardship</u>: After an initial large mass removal, continuing the pumping of an ASVE system at a rate faster than the contaminant's kinetic mass transfer rate into the vapor phase will result in decreased concentrations in the vented flow. At this point, passive venting is likely to be much more cost-effective than an active system per kilogram of contaminant vapor removed.

Application of this technology is directed to any site where volatile substances (chlorinated solvents, petroleum products, etc.) have contaminated the vadose zone. Natural pressure fluctuations and their damped and delayed transmission through the subsurface occur in all environments, but are particularly well-suited to sites with large vadose zones or substantial low permeability layers that increase the damping and delay of the atmospheric pressure signal.

Field scale studies have been ongoing at SRS, the Hanford site and the Idaho National Environmental Engineering Lab for approximately six years, and a field scale implementation of the technology for control of subsurface methane migration using a combination of passive injection and extraction was installed at a landfill in Richmond County, Georgia. In addition several other contaminated sites, both public and private, have implemented barometric pumping remediation programs with the BaroBall. The 1996 start of PSVE at the SRS Miscellaneous Chemical Basin was the first implementation to directly target the removal of the vadose zone source term.

Methods

Well Vapor Sampling and Analysis Methods

Soil vapor samples were collected at MetLab during barometric pumping outflow events. Three methods were used for gas sampling and were performed in accordance with work instruction WI-ERTS-0013 ‘Sampling Passive Soil Vapor Extraction (PSVE) Wells for VOC Analysis’. The sampling methods in the work instruction are briefly described below.

1. **Well vapor sampling using Tedlar gas sample bags –** This method collects gas samples in Tedlar bags by placing a cap with a tube fitting on the venting well head and filling the bag. This method is primarily used as confirmation sampling for the other two methods.
2. **Well vapor sampling using an Infrared Photo-Acoustic Spectroscopy (IRPAS) Field Screening Instrument –** This method uses a field screening instrument to directly sample and analyze soil gas from the venting well head.
3. **Well vapor sampling using glass vials –** This method collects gas samples in 20 ml glass vials by placing a cap with a tube on the venting well and filling the glass vial inside a thin walled plastic bag, sealing the bag and then crimping the vial closed.

VOC Analysis of Soil Vapor Samples

Tedlar bag laboratory analyses were performed in accordance with WSRC Manual L14.1 Procedure 2-106, “Procedure for the Operation and Calibration of Gas Chromatographs Used for the Analysis of Gas Phase Samples”. The IRPAS field analyzer provides screening level data for TCE, PCE and carbon dioxide (CO_2). The instrument is operated according to the manufacturer’s operational manual and an operation check is done according WI-ERTS-0013. Glass vial laboratory analysis was performed in accordance with WSRC Manual L14.1, Procedure 2-143 ‘Procedure for the Calibration and Sample Analysis of Agilent Gas Chromatographic Systems with the Automatic Sampler’. The analysis results from the different methods are comparable based on the data objectives of evaluating concentration trends of variable data.

Data Quality Objectives

Generally, the screening data obtained must support the evaluation of remediation effectiveness. Soil gas sample analysis was performed in accordance with WSRC

Manual L14.1 Procedure 2-106, “Procedure for the Operation and Calibration of Gas Chromatographs Used for the Analysis of Gas Phase Samples” and WSRC Manual L14.1, Procedure 2-143 ‘Procedure for the Calibration and Sample Analysis of Agilent Gas Chromatographic Systems with the Automatic Sampler’. Minimum detection limits (MDL) and minimum quantification limits (MQL) for the Savannah River National Laboratory (SRNL) for the methods are provided in Table 1 and Table 2. The detection limits for the IRPAS field analyzer is approximately 1 ppmv for PCE and TCE. Data from the gas analysis were reviewed for completeness and accuracy using professional judgment and previous experience at the MetLab. Results were compared to prior gas samples at the MetLab, results from confirmation samples (Tedlar bag method), and calibration standards.

Table 1 – Gas Analysis Limits for Tedlar Bag Method (L14.1, Procedure 2-106)

Compound	**MDL (ppmv)**	**MQL (ppmv)**
1,1 DCE	0.071	0.119
Carbon Tetrachloride (CCl_4)	0.001	0.002
Choloroform	0.010	0.017
cis-DCE	0.919	1.532
Freon-11	0.001	0.001
Freon-113	0.004	0.007
PCE	0.002	0.003
1,1,1 Trichloroethane (TCA)	0.004	0.006
TCE	0.008	0.013
Toluene	0.488	0.813
trans-DCE	0.609	1.015
Vinyl Chloride	0.736	1.227

Table 2 – Gas Analysis Limits for Gas Vial Method (L14.1, Procedure 2-143)

Compound	**MDL (ppmv)**	**MQL (ppmv)**
Benzene	0.2	0.3
Carbon Tetrachloride (CCl_4)	0.0005	0.001
Chloroform	0.005	0.009
cis-DCE	0.4	0.6
Freon-11	0.0005	0.001
Freon-113	0.003	0.01
Methylene Chloride	0.4	0.7
PCE	0.0006	0.001
TCA	0.002	0.003
TCE	0.004	0.006
Toluene	0.1	0.2
trans-DCE	0.4	0.7

Results and Discussion

PSVE Well Vapor Concentration Trends

Well vapor concentration measurements show mass removal and a concentration decrease in the vadose zone at the MetLab. Wellhead samples were collected during outflow events using the methods described above. Although IRPAS data was collected at times, the data was not used for concentration trend evaluations due to the precision of the measurements. The precision of the instrument was decreased due to measurement interference caused by Freon-113 and the low concentrations encountered with time. The IRPAS detection limit for PCE and TCE is approximately 1 ppmv without interference with Freon-113 and concentrations have decreased significantly over time. Comparison with the two gas chromatograph (GC) methods showed the IRPAS results overestimated the PCE and TCE concentrations with a dependence on the Freon-113 concentrations. Only the two GC methods were used for reporting purposes for this progress report.

Soil gas concentrations measured over this seven year time period show an exponentially declining concentration as is expected based on a conceptual model of mass transfer from the liquid or aqueous phase in the fine grained zones to the gas phase in the coarse grain sediments. The GC data during this time period were exponential fitted to determine a concentration decay constant (*k*) and temporal concentrations were estimated using the following equation.

$$C_{vt} = C_{v0}e^{-kt}$$

where

C_{vt} = PSVE well vapor concentration at time t (ppmv)
C_{v0} = initial PSVE well concentration on 1-Jun-98 (ppmv)
k = fitted exponential decay constant (day^{-1})
t = time in days

Selected concentration data along with the fitted equation and correlation coefficient (quality of fit) from several wells are shown in Figure 4 and Figure 5. Plots of the concentration data and exponential fitted lines for each PSVE well are provided in Appendix B. The variability of individual well vapor concentration measurements may be caused by several factors including extended rainfall (change in permeability and migration), duration of no flow events, duration and intensity of outflow events, and time of sample collection during the outflow event (mass transfer effects).

Since the IRPAS data were not as accurate as desired, the fitted equations were projected back to the start of the PSVE (June 1998) to estimate size and concentration of the soil gas plume and mass removal. The parameters for the exponential concentration decline equations and the yearly PSVE well concentration from the equations are provided in Table 3 and Table 4. The GC data are provided in Appendix C.

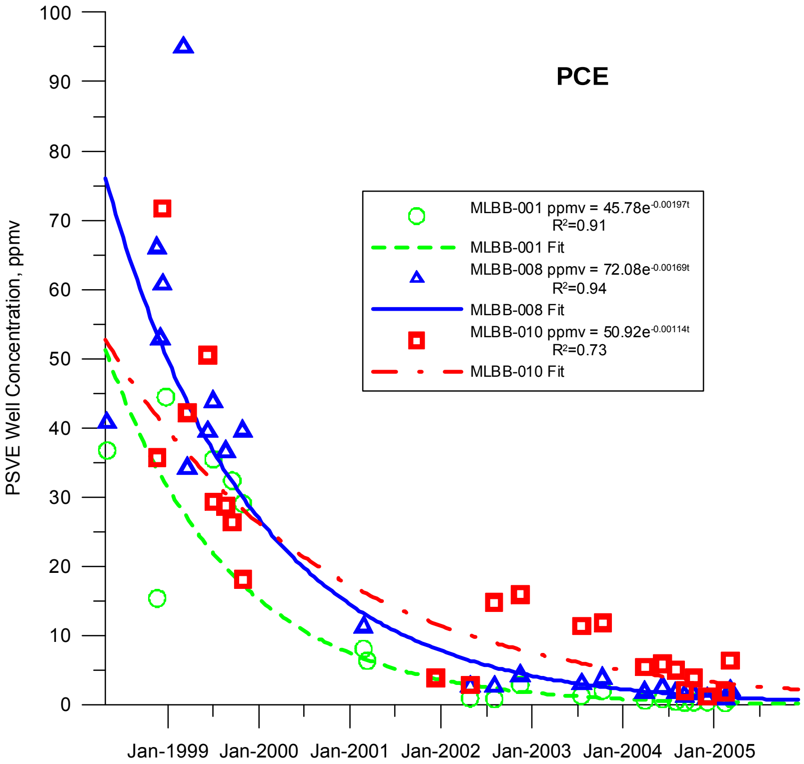

Figure 4 – PCE Well Vapor Concentration Trends for MetLab Vadose Zone Plume

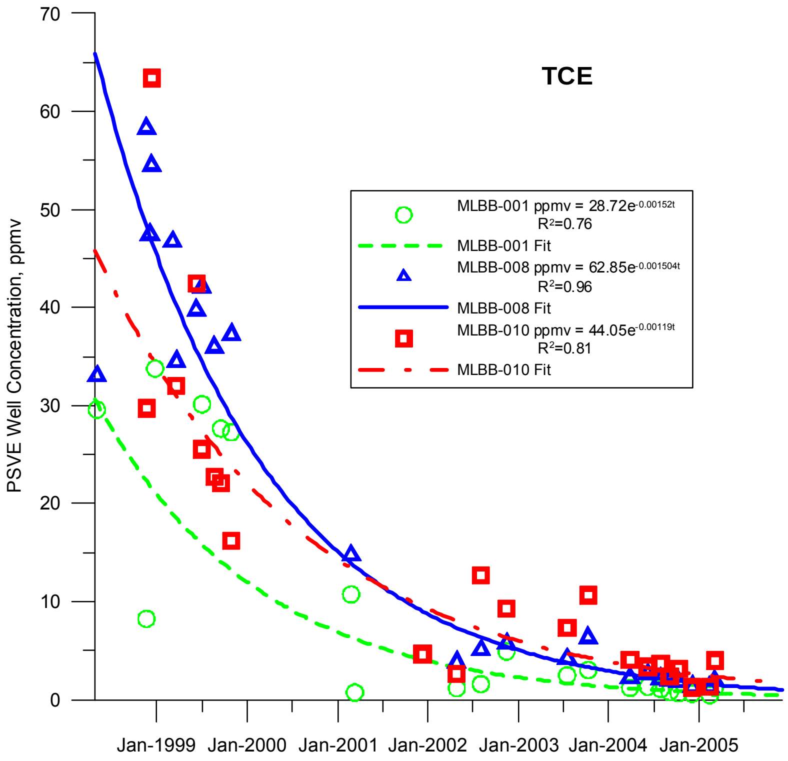

Figure 5 – TCE Well Vapor Concentration Trends for MetLab Vadose Zone Plume

Table 3 – Fitted PCE Concentration Data by Well for the MetLab Vadose Zone Plume

Well ID	Decay Constant *k*	PCE Well Vapor Concentration, ppmv							
		1-Jun-98	1-Jun-99	1-Jun-00	1-Jun-01	1-Jun-02	1-Jun-03	1-Jun-04	1-Jun-05
MLBB-001	-1.965E-03	45.78	22.35	10.89	5.31	2.59	1.27	0.62	0.30
MLBB-002	-1.269E-03	13.20	8.31	5.22	3.29	2.07	1.30	0.82	0.51
MLBB-003	-1.743E-03	7.48	3.96	2.09	1.11	0.59	0.31	0.16	0.09
MLBB-004	-1.641E-03	15.33	8.42	4.62	2.54	1.40	0.77	0.42	0.23
MLBB-006	-1.574E-03	41.67	23.46	13.19	7.42	4.18	2.35	1.32	0.74
MLBB-007	-1.387E-03	17.87	10.77	6.48	3.91	2.36	1.42	0.85	0.52
MLBB-008	-1.690E-03	72.08	38.90	20.95	11.31	6.10	3.29	1.77	0.96
MLBB-009	-1.558E-03	27.50	15.57	8.81	4.99	2.83	1.60	0.90	0.51
MLBB-010	-1.135E-03	50.92	33.65	22.21	14.68	9.70	6.41	4.23	2.80
MLBB-011	-1.648E-03	11.78	6.46	3.53	1.94	1.06	0.58	0.32	0.17
MLBB-012	-8.349E-04	44.92	33.12	24.40	17.99	13.26	9.78	7.20	5.31
MLBB-013	-7.972E-04	1.09	0.81	0.61	0.45	0.34	0.25	0.19	0.14
MLBB-014	-9.573E-04	3.22	2.27	1.60	1.13	0.79	0.56	0.39	0.28
MLBB-015	-8.604E-04	15.09	11.02	8.05	5.88	4.29	3.14	2.29	1.67
MLBB-016	-1.150E-03	3.55	2.33	1.53	1.01	0.66	0.43	0.29	0.19
MLBB-017	-8.422E-04	2.92	2.15	1.58	1.16	0.85	0.63	0.46	0.34
MLBB-018	-6.247E-04	0.86	0.68	0.54	0.43	0.35	0.27	0.22	0.17
MLBB-019	-1.423E-03	5.54	3.30	1.96	1.16	0.69	0.41	0.24	0.15
MLBB-020	-1.142E-03	2.14	1.41	0.93	0.61	0.40	0.27	0.18	0.12

C_{vt} (ppmv) = $C_{v0}e^{(-kt)}$ where C_{v0} is the concentration on 1-Jun-98 and t is time in days

Table 4 – Fitted TCE Concentration Data by Well for the MetLab Vadose Zone Plume

Well ID	Decay Constant *k*	Well Vapor TCE Concentration, ppmv							
		1-Jun-98	1-Jun-99	1-Jun-00	1-Jun-01	1-Jun-02	1-Jun-03	1-Jun-04	1-Jun-05
MLBB-001	-1.516E-03	28.72	16.51	9.48	5.45	3.13	1.80	1.03	0.59
MLBB-002	-9.707E-04	9.38	6.58	4.61	3.24	2.27	1.59	1.12	0.78
MLBB-003	-1.491E-03	5.79	3.36	1.95	1.13	0.66	0.38	0.22	0.13
MLBB-004	-1.594E-03	3.53	1.97	1.10	0.61	0.34	0.19	0.11	0.06
MLBB-006	-1.153E-03	30.89	20.28	13.30	8.73	5.73	3.76	2.47	1.62
MLBB-007	-1.119E-03	13.53	9.00	5.97	3.97	2.64	1.75	1.16	0.77
MLBB-008	-1.504E-03	62.85	36.30	20.93	12.09	6.98	4.03	2.32	1.34
MLBB-009	-1.341E-03	27.68	16.97	10.38	6.36	3.90	2.39	1.46	0.90
MLBB-010	-1.189E-03	44.05	28.55	18.48	11.97	7.76	5.03	3.25	2.11
MLBB-011	-1.077E-03	8.55	5.77	3.89	2.63	1.77	1.20	0.81	0.55
MLBB-012	-1.315E-03	32.98	20.41	12.62	7.81	4.83	2.99	1.85	1.14
MLBB-013	-7.763E-04	0.88	0.66	0.50	0.37	0.28	0.21	0.16	0.12
MLBB-014	-8.747E-04	1.87	1.36	0.98	0.72	0.52	0.38	0.27	0.20
MLBB-015	-1.327E-03	9.82	6.05	3.72	2.29	1.41	0.87	0.54	0.33
MLBB-016	-7.005E-04	3.63	2.81	2.18	1.68	1.30	1.01	0.78	0.61
MLBB-017	-3.955E-04	2.93	2.54	2.20	1.90	1.64	1.42	1.23	1.07
MLBB-018	-5.786E-04	0.30	0.24	0.20	0.16	0.13	0.10	0.08	0.07
MLBB-019	-1.166E-03	3.41	2.23	1.46	0.95	0.62	0.41	0.27	0.17
MLBB-020	-1.164E-03	1.27	0.83	0.54	0.35	0.23	0.15	0.10	0.06

C_{vt} (ppmv) = $C_{v0}e^{(-kt)}$ where C_{v0} is the concentration on 1-Jun-98 and t is time in days

Yearly concentration contour plots of TCE and PCE well concentrations from 6/98 to 6/05 are provided in Figure 6, Figure 7, Figure 8, and Figure 9. The wells have long screens (60 ft) so these plots show a general representation of the soil gas plume at the unit. Over the 7 years of PSVE with Baroball flow enhancement, the soil gas plume has decreased in concentration and size. The contours were created using the fitted exponential equations. These contour plots show the PSVE is decreasing the size and mass of the plume and is adequately covering the soil gas plume.

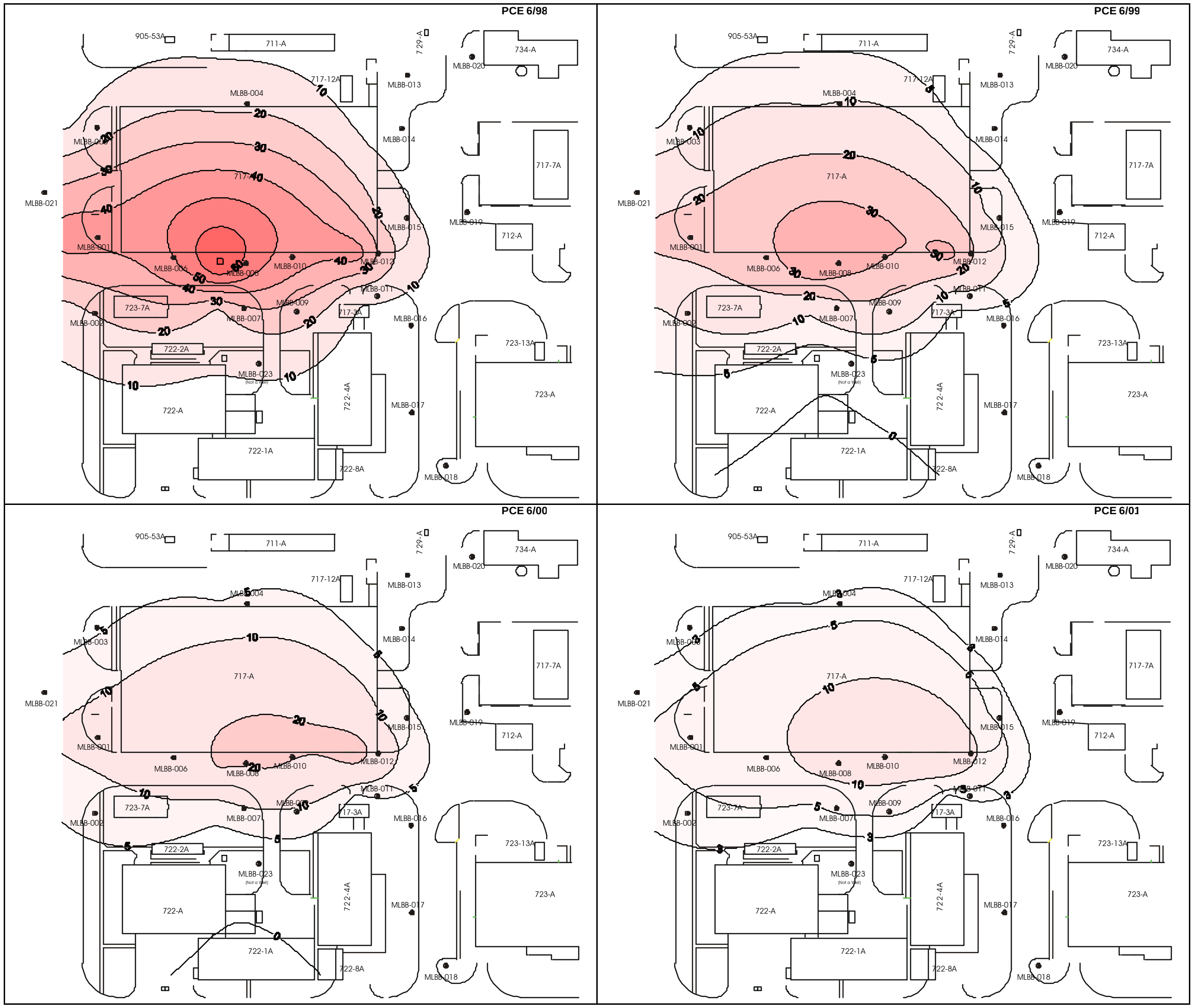

Figure 6 – PCE Contour Plots in ppmv (1998-2001)

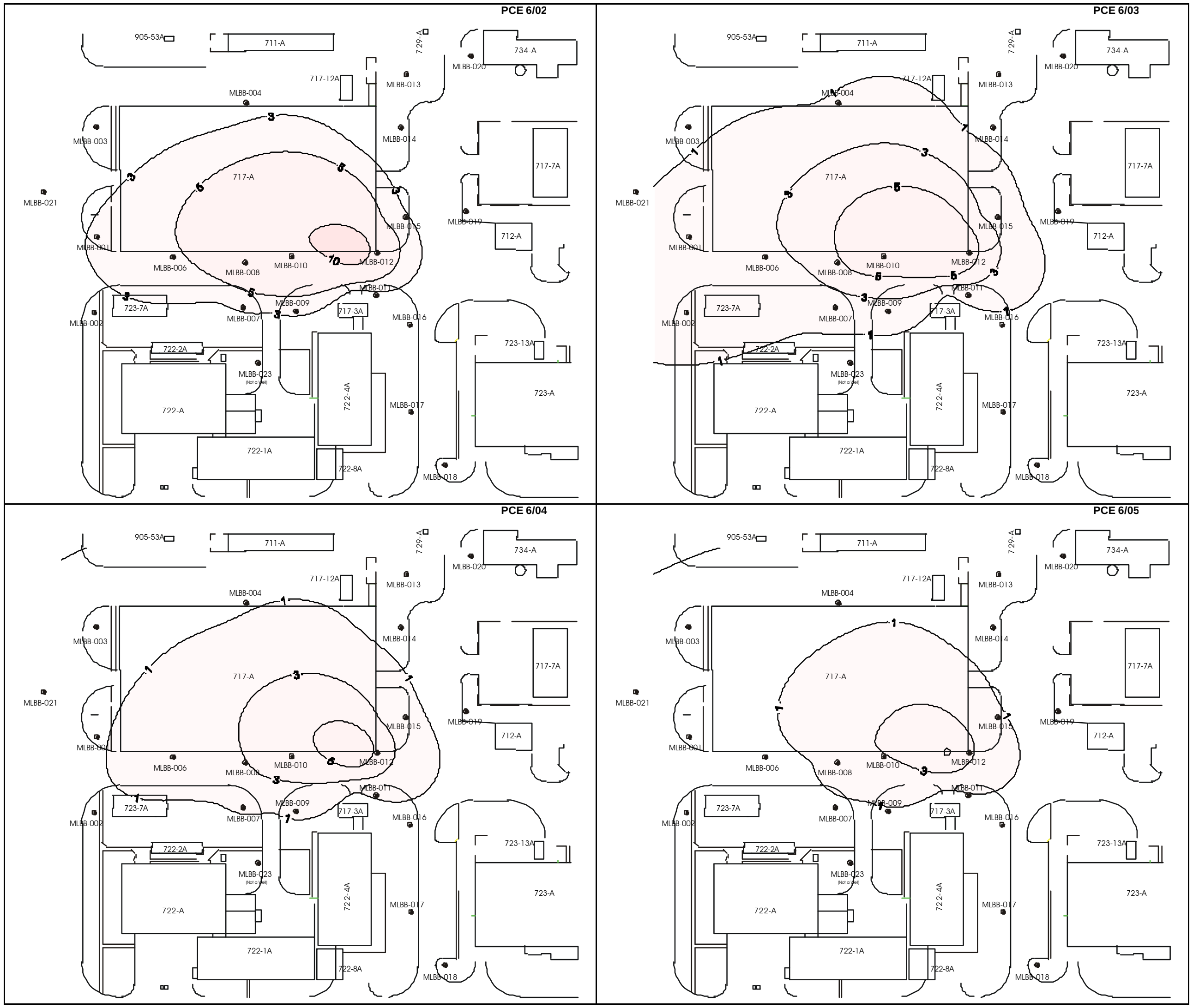

Figure 7 – PCE Contour Plots in ppmv (2002-2005)

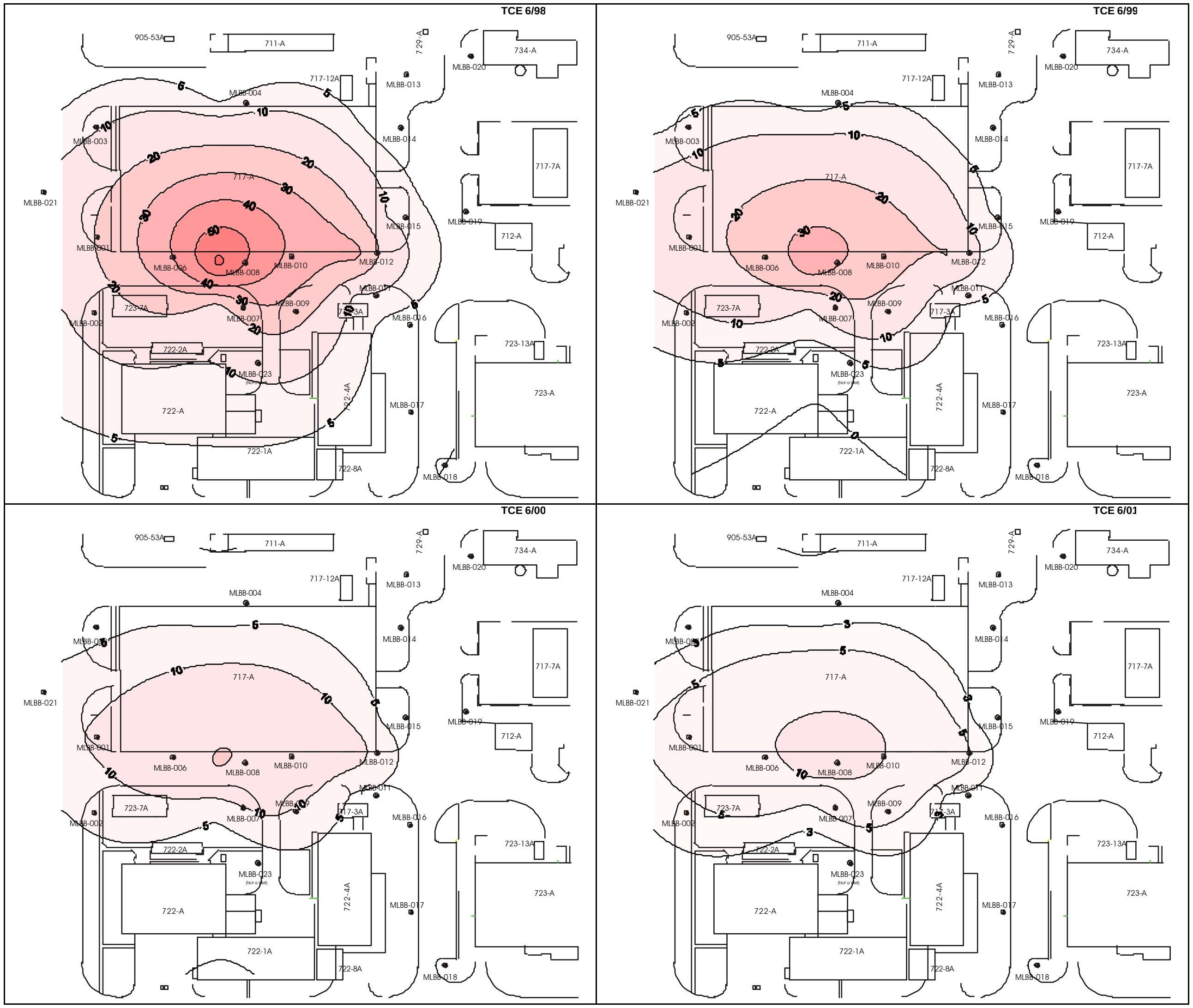

Figure 8 – TCE Contour Plots in ppmv (1998-2001)

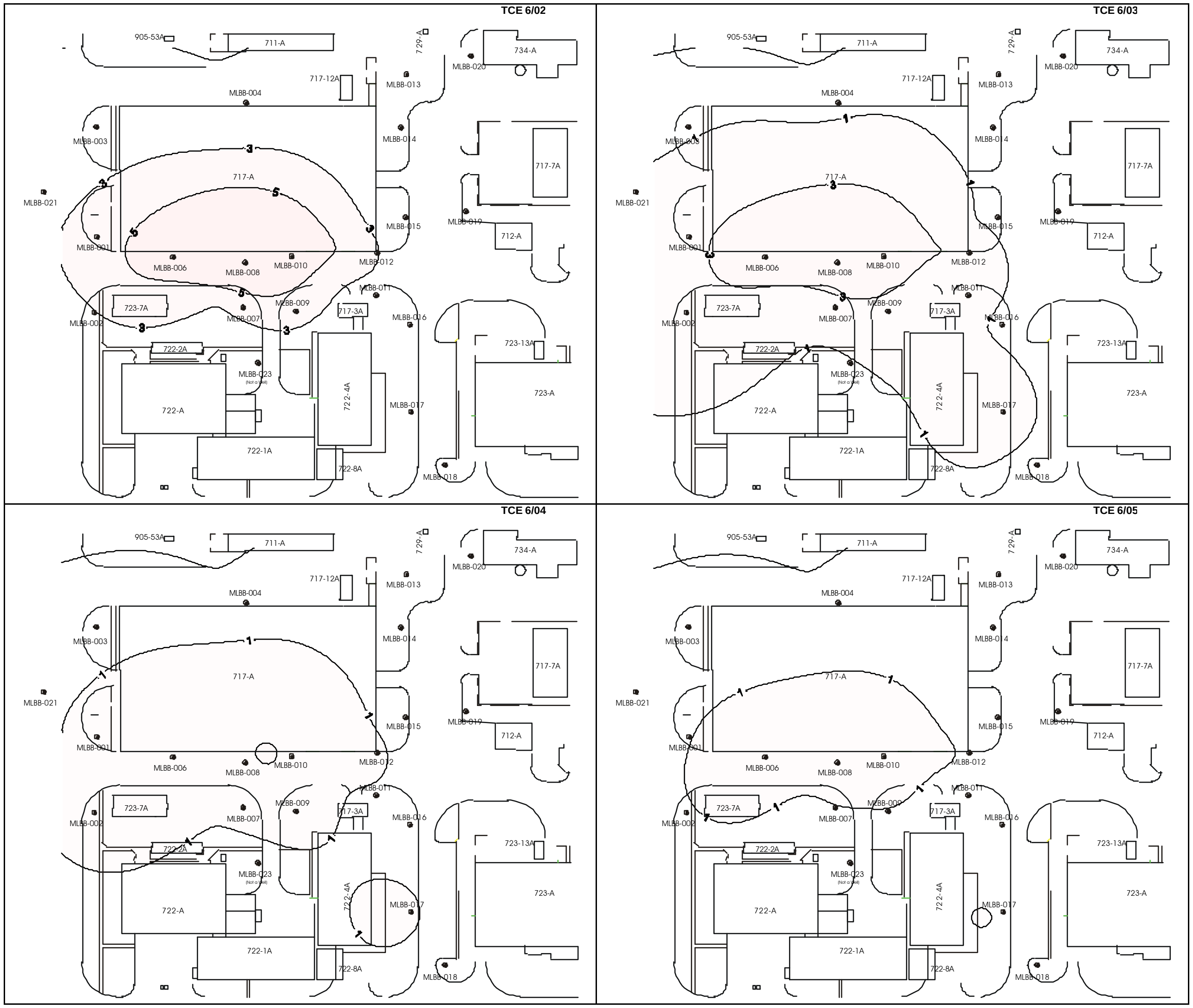

Figure 9 – TCE Contour Plots in ppmv (2002-2005)

Mass Removal Estimation

Based on the concentration curves for the19 wells installed at MetLab, the mass of contaminants removed can be estimated. The assumptions include a uniform average flow rate of 1 cfm (ft^3/min) out of all of the wells based on measured flow from other PSVE wells, initial concentrations estimated from the concentration trends on 6/1/98 and final concentration projected using the rate constants from approximately 7 years of monitoring. Physically observed vapor flow and concentration measurements indicate mass removal from the vadose zone at the MetLab.

Well flow rates have not been measured at the MetLab so PSVE flow rates from nearby wells are used for estimating the mass removal. The average flow measured from 2 inch diameter PSVE wells at the Miscellaneous Chemical Basin and near the M-Area Basin is approximately 2 cfm during outflow events. Since soil gas is removed 50% of the time with barometric pumping, the continuous average flow out of the wells is 1 cfm. The area under the removal curves is calculated and multiplied by the flow rate to obtain the mass of contaminant removed. Mass removal was calculated monthly. The total mass removed at the MetLab for a given time period is the sum of the mass removed from the individual wells.

The cumulative calculated mass removal for each well and the total system by year is presented in Table 5 and Table 6. Graphs showing the monthly mass removal and cumulative mass removed since the inception of PSVE at the MetLab are presented in Figure 10. The data tables and graphs clearly show the decline in the rate of mass removal as the source term is diminished. Based on these analyses it is estimated that less than 3 lbs TCE and 4 lbs PCE will be removed in calendar year 2005.

After 7 years of PSVE approximately 100 lbs TCE and 160 lbs PCE have been removed by the natural barometric pumping of wells fitted with BaroBall valves. The mass removal estimates are approximate since the flow rates are estimated and the concentration data are based on exponential fits of the data set.

Table 5 – Cumulative PCE Mass Removed by Well

	Cumulative PCE Mass Removed, lbs						
Well ID	1-Jun-99	1-Jun-00	1-Jun-01	1-Jun-02	1-Jun-03	1-Jun-04	1-Jun-05
MLBB-001	7.05	10.50	12.18	13.00	13.40	13.59	13.69
MLBB-002	2.31	3.76	4.67	5.24	5.61	5.83	5.98
MLBB-003	1.20	1.83	2.17	2.35	2.44	2.49	2.52
MLBB-004	2.50	3.88	4.63	5.05	5.28	5.40	5.47
MLBB-006	6.88	10.76	12.94	14.17	14.86	15.25	15.46
MLBB-007	3.05	4.90	6.01	6.67	7.08	7.32	7.46
MLBB-008	11.66	17.96	21.35	23.18	24.17	24.70	24.99
MLBB-009	4.55	7.14	8.60	9.43	9.89	10.16	10.31
MLBB-010	9.11	15.15	19.12	21.75	23.49	24.64	25.40
MLBB-011	1.92	2.97	3.55	3.86	4.04	4.13	4.18
MLBB-012	8.50	14.79	19.40	22.81	25.32	27.18	28.54
MLBB-013	0.21	0.36	0.48	0.57	0.63	0.68	0.72
MLBB-014	0.59	1.02	1.31	1.52	1.67	1.77	1.84
MLBB-015	2.84	4.92	6.44	7.55	8.36	8.95	9.38
MLBB-016	0.63	1.05	1.32	1.50	1.62	1.70	1.75
MLBB-017	0.55	0.96	1.26	1.48	1.64	1.76	1.84
MLBB-018	0.17	0.30	0.41	0.50	0.57	0.62	0.66
MLBB-019	0.94	1.50	1.83	2.03	2.15	2.22	2.26
MLBB-020	0.38	0.64	0.80	0.91	0.98	1.03	1.06
Total PCE Removed, lbs	65.06	104.40	128.48	143.56	153.16	159.41	163.51

Table 6 – Cumulative TCE Mass Removed by Well

	Cumulative TCE Mass Removed, lbs						
Well ID	1-Jun-99	1-Jun-00	1-Jun-01	1-Jun-02	1-Jun-03	1-Jun-04	1-Jun-05
MLBB-001	3.80	5.99	7.24	7.96	8.37	8.61	8.75
MLBB-002	1.37	2.34	3.01	3.48	3.81	4.05	4.21
MLBB-003	0.77	1.22	1.48	1.63	1.71	1.76	1.79
MLBB-004	0.46	0.72	0.86	0.94	0.99	1.01	1.02
MLBB-006	4.37	7.24	9.12	10.35	11.16	11.69	12.04
MLBB-007	1.92	3.21	4.06	4.62	5.00	5.25	5.41
MLBB-008	8.33	13.15	15.92	17.52	18.45	18.98	19.29
MLBB-009	3.78	6.10	7.52	8.39	8.92	9.24	9.44
MLBB-010	6.18	10.20	12.79	14.47	15.56	16.27	16.73
MLBB-011	1.23	2.06	2.61	2.99	3.24	3.42	3.53
MLBB-012	4.52	7.33	9.06	10.13	10.79	11.20	11.46
MLBB-013	0.13	0.23	0.31	0.37	0.41	0.44	0.46
MLBB-014	0.28	0.48	0.63	0.73	0.81	0.87	0.91
MLBB-015	1.34	2.17	2.68	3.00	3.19	3.31	3.38
MLBB-016	0.56	0.99	1.33	1.59	1.79	1.94	2.06
MLBB-017	0.48	0.89	1.25	1.56	1.83	2.06	2.26
MLBB-018	0.05	0.09	0.12	0.14	0.16	0.18	0.19
MLBB-019	0.48	0.80	1.00	1.14	1.22	1.28	1.32
MLBB-020	0.18	0.30	0.37	0.42	0.46	0.48	0.49
Total TCE Removed, lbs	40.23	65.48	81.35	91.43	97.88	102.05	104.77

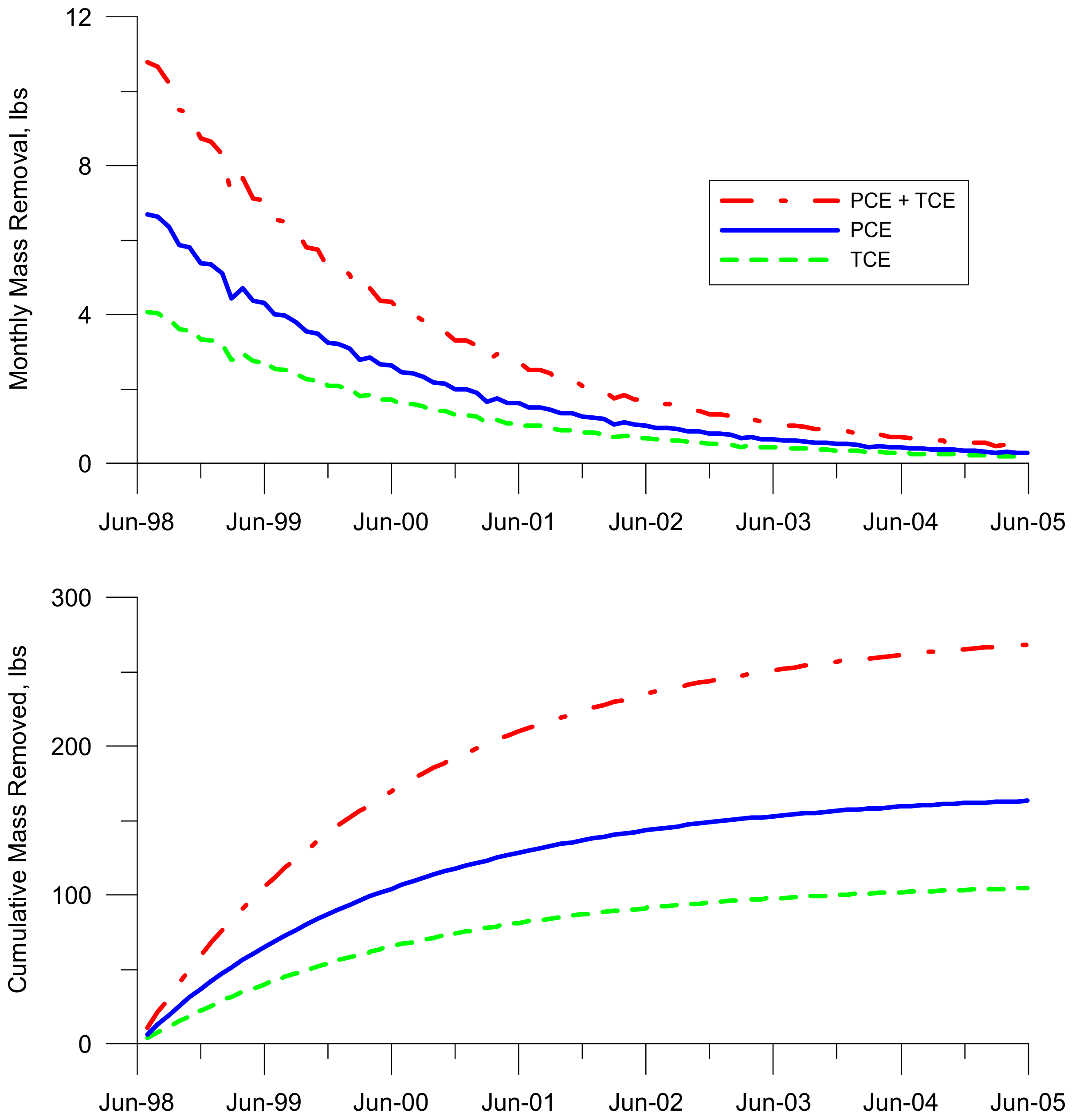

Figure 10 – Monthly and Cumulative Mass Removed for the MetLab Vadose Zone Plume

Performance Metric for PSVE

An indicator that PSVE is preventing VOC migration to the water table is evidence that the mass in the vadose zone is decreasing. At the SRS PSVE sites, the primary hypothesis for PSVE effectiveness is declining PSVE concentrations. Thus, the metric uses indirect evidence that the PSVE is removing VOCs as fast as they are released by diffusion and before they migrate to the water table.

The easiest and best way to validate PSVE as effective is to verify stable or declining concentration trends from the PSVE wells. At the MetLab these trends indicate the attenuation capacity of PSVE equals or exceeds the contaminant loading and minimizes the impact to the groundwater. The author believes that once these conditions are met, the remediation will progress and minimal monitoring and maintenance will be required.

Conclusions

The analyses of the PSVE system at the MetLab of the SRS indicate the technology is performing effectively. Well concentrations are decreasing and contour maps of the vadose zone soil gas plume show a decrease in the extent of the plume. In the 7 years of operation approximately 270 pounds of chlorinated organic contaminants have been removed by natural barometric pumping of wells fitted with BaroBall valves.

The majority of the well concentrations are less than 1 ppmv. Less than 4 lbs PCE and 3 lbs TCE are expected to be removed in calendar year 2005 compared to 65 lbs PCE and 40 lbs TCE removed during the first year of operation. Declining concentrations and mass removal rates indicate PSVE has significantly reduced the solvent source area.

The PSVE system has required minimal operating and maintenance costs and can be expected to operate continuously with little intervention.

Recommendations

The PSVE system is performing well in a cost-effective manner. The system should continue operating to complete the remediation.

Quarterly PSVE well monitoring is recommended due to the variability of individual point measurements.

References

Fairbanks, H. A. 1896. "Notes on a Breathing Gas Well." Science **3**: 693.

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Pemberton, B. E., J. Rossabi and B. D. Riha. 1997. MetLab Phase III Characterization Report. Westinghouse Savannah River Company. Aiken, SC. WSRC-RP-97-4.

Riha, B. D., J. Rossabi and W. K. Hyde. 2000. Metallurgical Laboratory (MetLab) Treatability Study: An Analysis of Passive Soil Vapor Extraction Wells (PSVE), June 2000 Update. Westinghouse Savannah River Company. Aiken, SC. WSRC-TR-2000-00182.

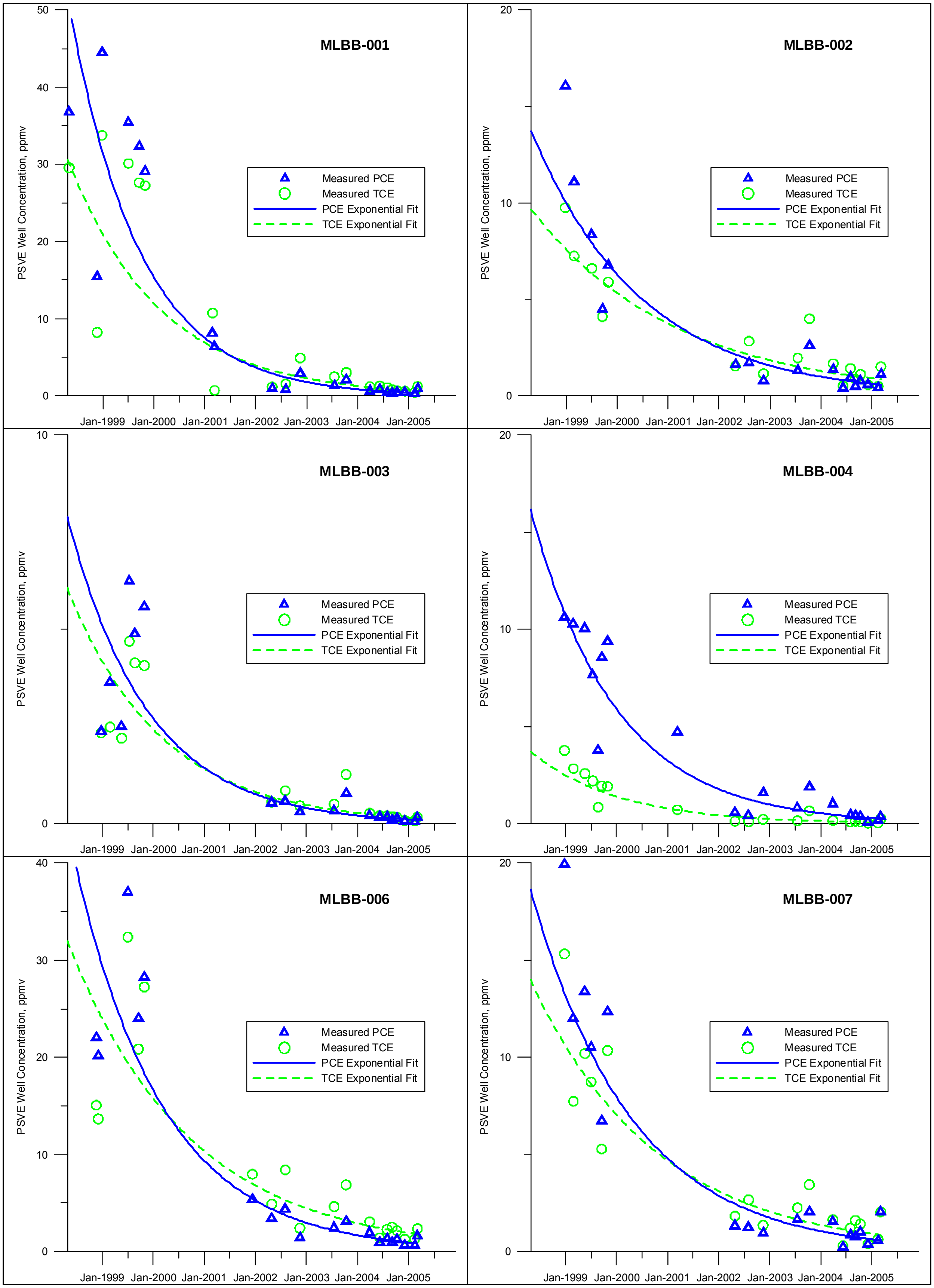
Van Pelt, R. S. and T. Dunbar. 1995. A/M Area Metallurgical Laboratory: Summary of Phase I Characterization - Well Installation, Cone Penetrometer Testing, and Soil Core for Headspace Analysis. Westinghouse Savannah River Company. Aiken, SC. WSRC-RP-95-1553.

APPENDIX A – Well and CPT Boring Coordinates

Well ID	Easting	Northing
MLBB-001	50675	104777
MLBB-002	50671.75	104687.5
MLBB-003	50674	104907
MLBB-004	50851.39	104935.4
MLBB-006	50764.68	104753.1
MLBB-007	50847.57	104693.3
MLBB-008	50850.04	104746.6
MLBB-009	50910	104689
MLBB-010	50904.78	104753.9
MLBB-011	51005	104708
MLBB-012	51006	104758
MLBB-013	51040.5	104969.1
MLBB-014	51034	104906
MLBB-015	51040	104800
MLBB-016	51044.75	104673
MLBB-017	51046	104570
MLBB-018	51086	104507
MLBB-019	51111	104807
MLBB-020	51117	104991
MLBB-021	50613.6	104817.3
MLBB-022*	51290.7	104680.2
MLBB-023*	50866.6	104629.6

*CPT Borings – not wells

APPENDIX B – PSVE Well Concentration Trends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PSVE Well Concentration, ppmv
0
10
20
30
40
50
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
MLBB-002
PSVE Well Concentration, ppmv
0
10
20
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
MLBB-003
PSVE Well Concentration, ppmv
0
10
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
MLBB-004
PSVE Well Concentration, ppmv
0
10
20
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
MLBB-006
PSVE Well Concentration, ppmv
0
10
20
30
40
Jan-1999
Jan-2000
Jan-2001
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Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
MLBB-007
PSVE Well Concentration, ppmv
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10
20
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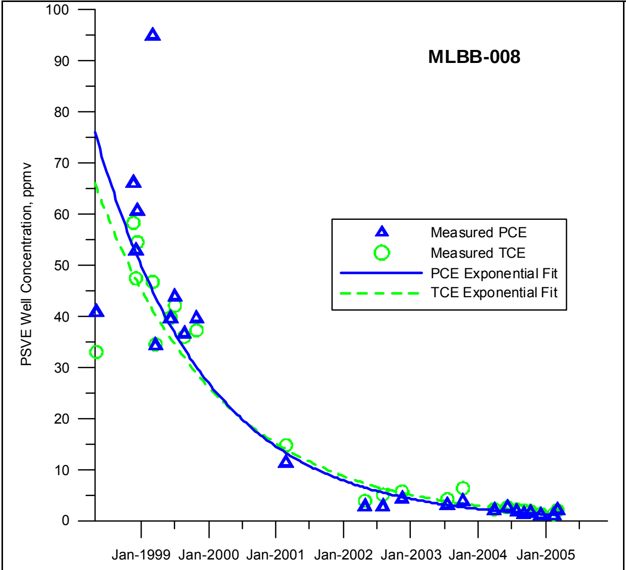
Measured TCE
PCE Exponential Fit
TCE Exponential Fit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PSVE Well Concentration, ppmv
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10
20
30
40
50
60
70
80
90
100
Jan-1999
Jan-2000
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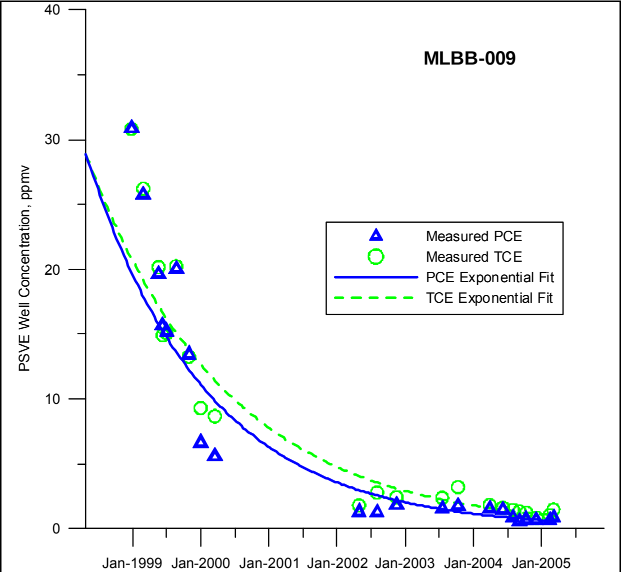
Measured TCE
PCE Exponential Fit
TCE Exponential Fit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PSVE Well Concentration, ppmv
0
10
20
30
40
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
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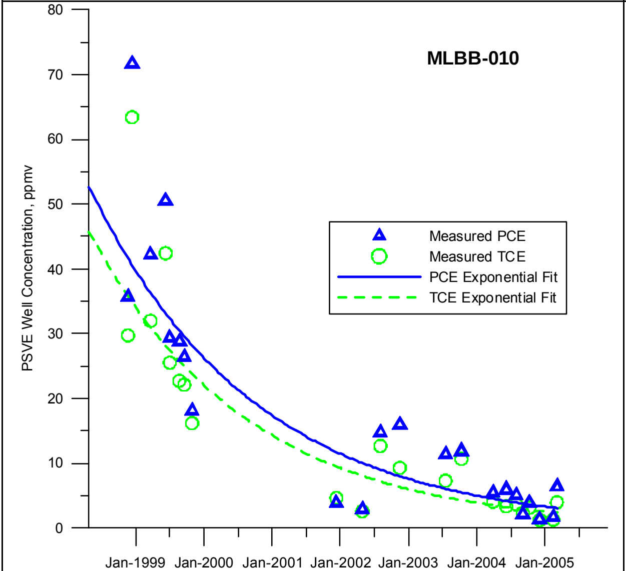
Measured TCE
PCE Exponential Fit
TCE Exponential Fit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0
10
20
30
40
50
60
70
80
Jan-1999
Jan-2000
Jan-2001
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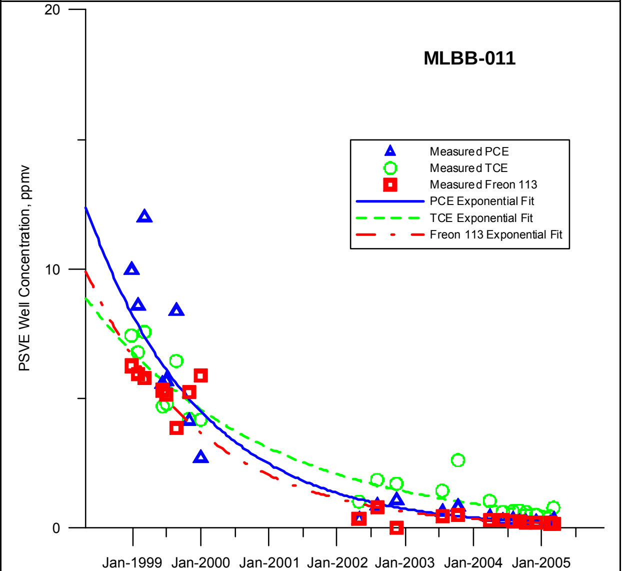
Measured TCE
PCE Exponential Fit
TCE Exponential Fit


MLBB-011
PSVE Well Concentration, ppmv
0
10
20
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
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Measured TCE
Measured Freon 113
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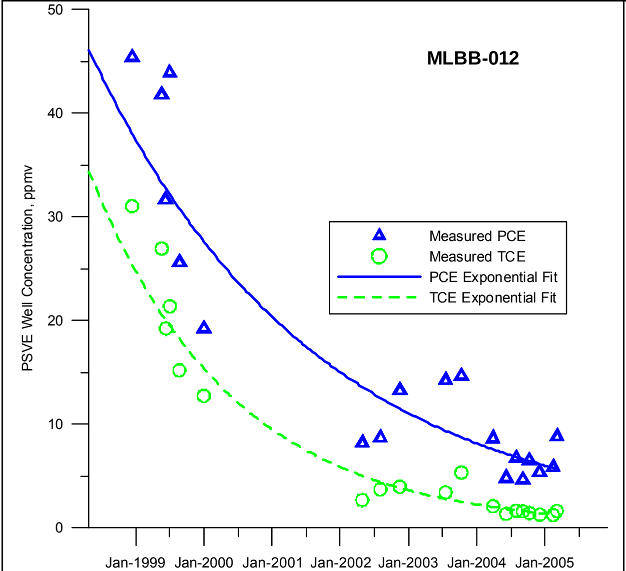
TCE Exponential Fit
Freon 113 Exponential Fit


MLBB-012
PSVE Well Concentration, ppmv
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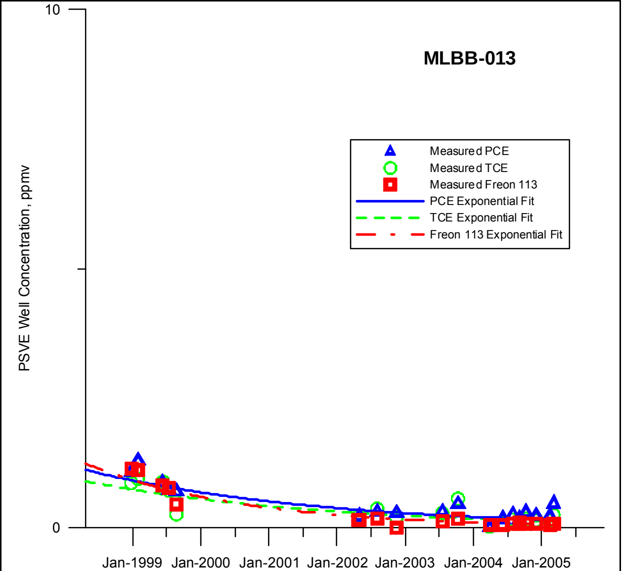
20
30
40
50
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit


MLBB-013
PSVE Well Concentration, ppmv
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Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
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Measured Freon 113
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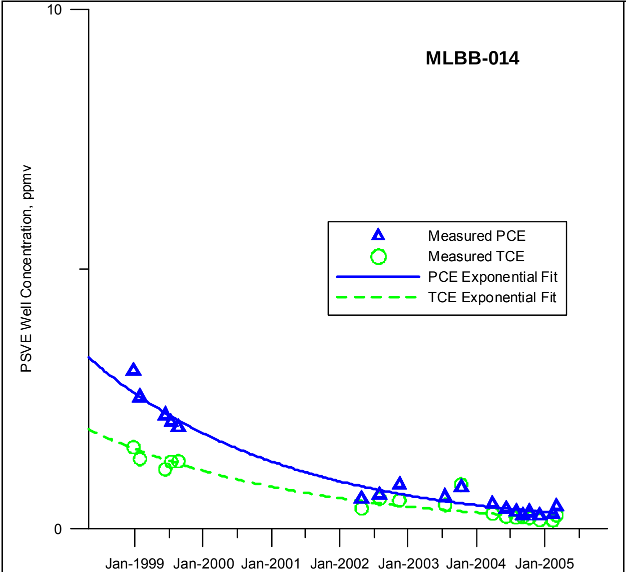
TCE Exponential Fit
Freon 113 Exponential Fit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PSVE Well Concentration, ppmv
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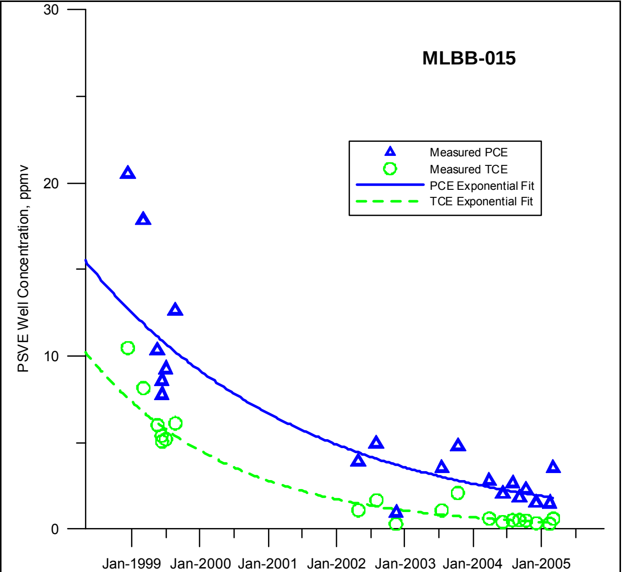
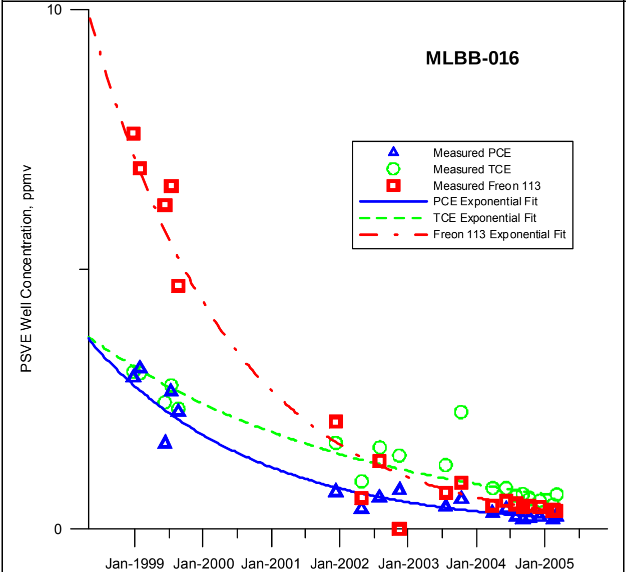
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005


MLBB-015
PSVE Well Concentration, ppmv
30
20
10
0
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005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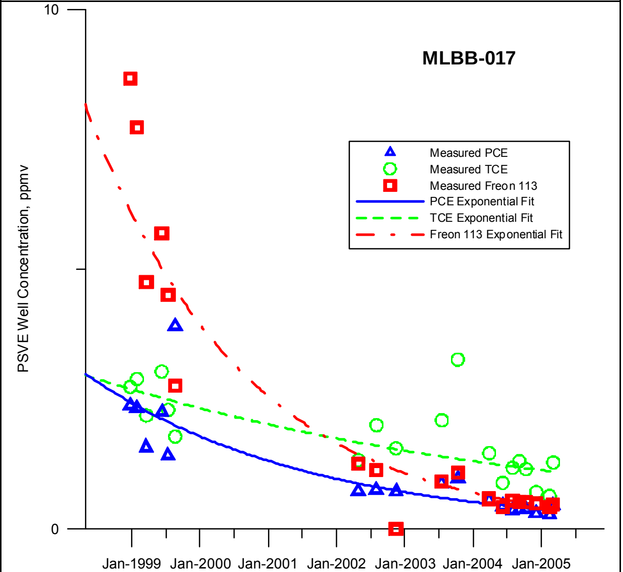
PSVE Well Concentration, ppmv
10
0
Measured PCE
Measured TCE
Measured Freon 113
PCE Exponential Fit
TCE Exponential Fit
Freon 113 Exponential Fit
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005


MLBB-017
PSVE Well Concentration, ppmv
10
0
Measured PCE
Measured TCE
Measured Freon 113
PCE Exponential Fit
TCE Exponential Fit
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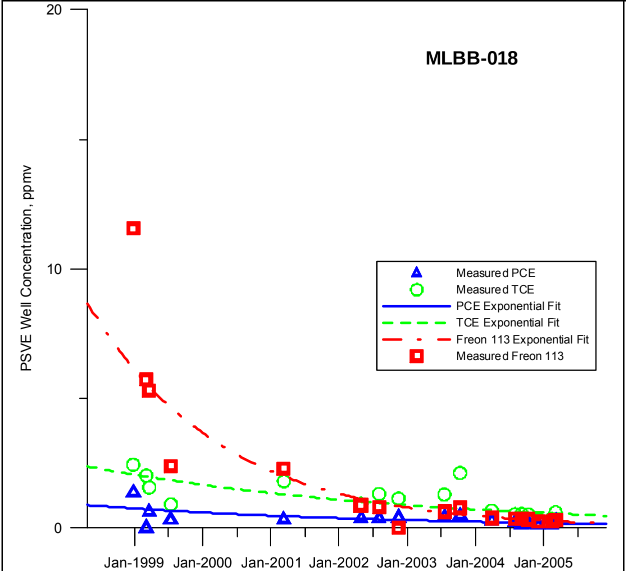
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005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PSVE Well Concentration, ppmv
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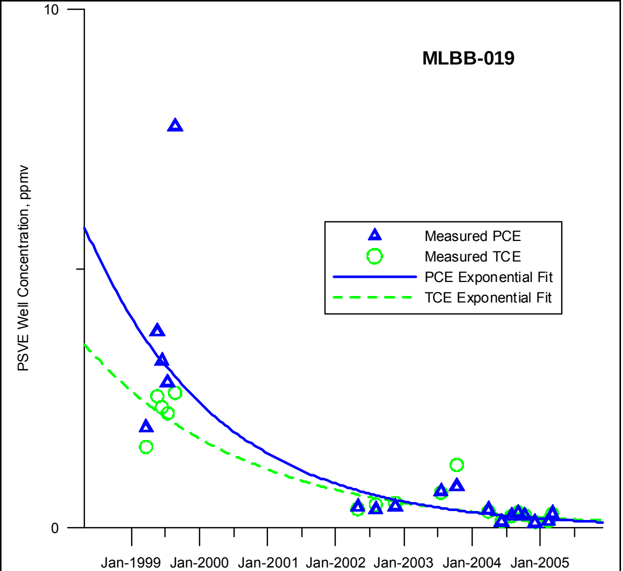
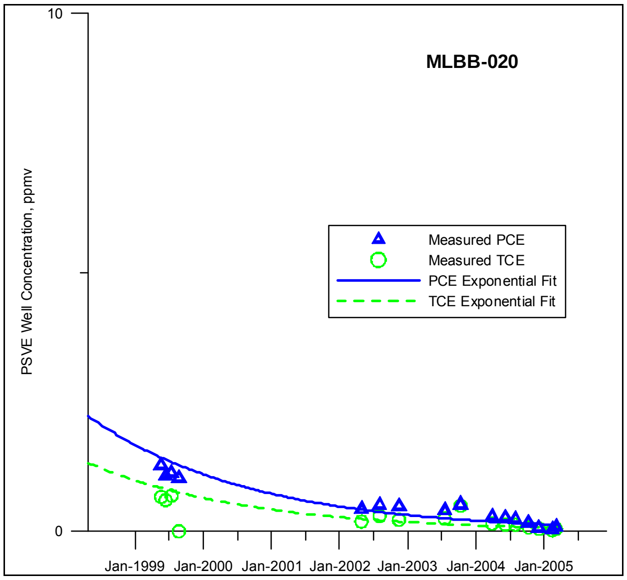
10
0
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
Freon 113 Exponential Fit
Measured Freon 113
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005


MLBB-019
PSVE Well Concentration, ppmv
10
0
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005


MLBB-020
PSVE Well Concentration, ppmv
10
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Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit

APPENDIX C – Well Vapor Concentrations

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-001	10/14/1997	0.38	55.41	38.19
	5/8/1998	0.16	36.75	29.56
	11/24/1998	0.08	15.41	8.23
	12/29/1998	0.25	44.47	33.75
	7/7/1999	0.57	35.48	30.12
	9/21/1999	0.48	32.38	27.64
	11/2/1999	0.36	29.10	27.26
	2/28/2001	0.24	8.11	10.73
	3/15/2001	0.41	6.38	0.72
	5/1/2002	0.05	0.99	1.16
	8/6/2002	0.04	0.87	1.57
	11/18/2002	0.00	2.89	4.91
	7/21/2003	0.06	1.34	2.48
	10/14/2003	0.04	2.10	3.01
	3/31/2004	0.05	0.64	1.21
	6/10/2004	0.02	0.85	1.30
	8/2/2004	0.05	0.50	1.08
	9/7/2004	0.04	0.33	0.79
	10/13/2004	0.04	0.43	0.65
	12/7/2004	0.05	0.43	0.60
	2/16/2005	0.04	0.29	0.45
	3/8/2005	0.04	0.93	1.22
MLBB-002	12/29/1998	0.64	16.06	9.75
	3/3/1999	0.75	11.09	7.24
	7/7/1999	1.04	8.36	6.61
	9/21/1999	0.57	4.50	4.11
	11/2/1999	0.69	6.76	5.89
	5/1/2002	0.09	1.62	1.54
	8/6/2002	0.10	1.74	2.83
	11/18/2002	0.00	0.78	1.15
	7/21/2003	0.07	1.30	1.96
	10/14/2003	0.09	2.60	3.99
	3/31/2004	0.08	1.37	1.68
	6/10/2004	0.06	0.41	0.52
	8/2/2004	0.09	0.96	1.42
	9/7/2004	0.07	0.51	0.87
	10/13/2004	0.07	0.77	1.11
	12/7/2004	0.07	0.58	0.57
	2/16/2005	0.06	0.42	0.49
	3/8/2005	0.07	1.13	1.51

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-003	12/29/1998	0.05	2.37	2.34
	3/3/1999	0.10	3.64	2.48
	5/24/1999	0.10	2.51	2.20
	7/19/1999	0.27	6.25	4.69
	8/27/1999	0.05	4.88	4.14
	11/2/1999	0.16	5.58	4.07
	5/1/2002	0.06	0.54	0.56
	8/6/2002	0.05	0.57	0.85
	11/18/2002	0.00	0.30	0.46
	7/21/2003	0.04	0.33	0.50
	10/14/2003	0.05	0.78	1.26
	3/31/2004	0.03	0.21	0.27
	6/10/2004	0.03	0.17	0.20
	8/2/2004	0.03	0.17	0.20
	9/7/2004	0.03	0.09	0.18
	10/13/2004	0.03	0.13	0.16
	12/7/2004	0.02	0.06	0.08
	2/16/2005	0.02	0.05	0.07
	3/8/2005	0.02	0.16	0.17
MLBB-004	12/29/1998	1.27	10.64	3.76
	3/3/1999	1.37	10.28	2.84
	5/24/1999	1.42	10.05	2.58
	7/19/1999	0.94	7.64	2.20
	8/27/1999	0.07	3.77	0.85
	9/21/1999	0.95	8.56	1.95
	11/2/1999	0.90	9.37	1.92
	3/15/2001	0.42	4.71	0.72
	5/1/2002	0.89	0.57	0.12
	8/6/2002	0.04	0.41	0.10
	11/18/2002	0.00	1.58	0.22
	7/21/2003	0.01	0.81	0.14
	10/14/2003	0.09	1.88	0.66
	3/31/2004	0.05	1.03	0.16
	8/2/2004	0.04	0.44	0.10
	9/7/2004	0.05	0.40	0.12
	10/13/2004	0.04	0.38	0.10
	12/7/2004	0.01	0.09	0.03
	2/16/2005	0.01	0.19	0.04
	3/8/2005	0.06	0.38	0.25

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-006	11/24/1998	0.11	22.02	15.06
	12/8/1998	0.10	20.18	13.66
	7/7/1999	0.34	37.02	32.38
	9/21/1999	0.36	24.03	20.85
	11/2/1999	0.33	28.23	27.25
	12/14/2001	0.17	5.33	7.95
	5/1/2002	0.13	3.43	4.87
	8/6/2002	0.10	4.36	8.41
	11/18/2002	0.00	1.43	2.41
	7/21/2003	0.08	2.46	4.63
	10/14/2003	0.10	3.14	6.87
	3/31/2004	0.07	1.97	3.06
	6/10/2004	0.04	0.90	1.43
	8/2/2004	0.07	1.34	2.28
	9/7/2004	0.07	0.97	2.50
	10/13/2004	0.06	1.24	2.14
	12/7/2004	0.05	0.64	1.29
	2/16/2005	0.05	0.65	1.28
	3/8/2005	0.06	1.59	2.35
MLBB-007	12/29/1998	2.29	19.94	15.32
	3/3/1999	1.60	11.99	7.73
	5/24/1999	2.78	13.38	10.20
	7/7/1999	2.31	10.52	8.73
	9/21/1999	1.08	6.72	5.28
	11/2/1999	2.24	12.36	10.35
	5/1/2002	0.34	1.33	1.83
	8/6/2002	0.26	1.24	2.66
	11/18/2002	0.00	0.98	1.35
	7/21/2003	0.19	1.66	2.25
	10/14/2003	0.24	2.05	3.44
	3/31/2004	0.14	1.55	1.64
	6/10/2004	0.04	0.23	0.30
	8/2/2004	0.12	0.85	1.20
	9/7/2004	0.14	0.78	1.60
	10/13/2004	0.13	1.01	1.42
	12/7/2004	0.05	0.38	0.41
	2/16/2005	0.07	0.57	0.63
	3/8/2005	0.13	2.04	2.05

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-008	5/8/1998	0.47	40.75	33.01
	11/24/1998	0.83	66.03	58.27
	12/8/1998	0.64	52.90	47.43
	12/16/1998	0.75	60.70	54.49
	3/9/1999	1.00	94.95	46.71
	3/25/1999	0.70	34.19	34.49
	6/14/1999	0.51	39.50	39.75
	7/7/1999	1.26	43.78	42.06
	8/26/1999	0.74	36.60	35.96
	11/2/1999	1.17	39.60	37.23
	2/28/2001	0.39	11.31	14.73
	5/1/2002	0.25	2.69	3.82
	8/6/2002	0.12	2.66	5.06
	11/18/2002	0.00	4.29	5.71
	7/21/2003	0.15	3.01	4.18
	10/14/2003	0.20	3.83	6.33
	3/31/2004	0.10	1.88	2.21
	6/10/2004	0.09	2.55	2.58
	8/2/2004	0.10	1.74	2.12
	9/7/2004	0.10	1.33	2.00
	10/13/2004	0.09	1.62	1.81
	12/7/2004	0.09	1.01	1.32
	2/16/2005	0.07	0.92	1.26
	3/8/2005	0.08	2.10	1.97
MLBB-009	12/29/1998	4.89	30.84	30.82
	3/3/1999	4.85	25.73	26.21
	5/24/1999	4.64	19.61	20.16
	6/15/1999	4.43	15.63	14.90
	7/7/1999	5.01	15.22	15.05
	8/26/1999	2.13	20.01	20.23
	11/2/1999	3.77	13.44	13.26
	1/4/2000	4.07	6.62	9.29
	3/20/2000	3.05	5.56	8.66
	5/1/2002	0.46	1.29	1.79
	8/6/2002	0.37	1.24	2.78
	7/21/2003	0.27	1.57	2.37
	10/14/2003	0.28	1.75	3.21
	3/31/2004	0.16	1.52	1.81
	6/10/2004	0.14	1.43	1.61
	8/2/2004	0.16	0.85	1.44
	9/7/2004	0.14	0.56	1.32
	10/13/2004	0.14	0.70	1.24
	12/7/2004	0.14	0.64	0.85
	2/16/2005	0.11	0.65	1.04
	3/8/2005	0.13	0.85	1.46

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-010	11/24/1998	1.72	35.68	29.72
	12/16/1998	0.99	71.69	63.39
	3/25/1999	0.07	42.20	31.96
	6/14/1999	0.42	50.53	42.41
	7/7/1999	2.24	29.39	25.52
	8/26/1999	0.44	28.73	22.73
	9/21/1999	2.04	26.35	22.11
	11/2/1999	2.36	18.12	16.19
	12/14/2001	0.62	3.95	4.62
	5/1/2002	0.28	2.91	2.59
	8/6/2002	0.28	14.80	12.66
	11/18/2002	0.00	15.99	9.28
	7/21/2003	0.17	11.43	7.29
	10/14/2003	0.22	11.86	10.64
	3/31/2004	0.11	5.46	4.04
	6/10/2004	0.05	5.93	3.31
	8/2/2004	0.11	5.07	3.65
	9/7/2004	0.10	2.12	2.33
	10/13/2004	0.10	3.92	3.14
	12/7/2004	0.08	1.28	1.23
	2/16/2005	0.06	1.77	1.28
	3/8/2005	0.09	6.38	3.97
MLBB-011	12/29/1998	6.26	9.94	7.43
	2/2/1999	5.95	8.59	6.78
	3/9/1999	5.78	12.00	7.56
	6/15/1999	5.32	5.57	4.69
	7/7/1999	5.15	5.68	4.79
	8/26/1999	3.86	8.36	6.44
	11/2/1999	5.23	4.14	4.20
	1/4/2000	5.88	2.71	4.18
	5/1/2002	0.38	0.33	1.02
	8/6/2002	0.78	0.86	1.86
	11/18/2002	0.00	1.07	1.71
	7/21/2003	0.47	0.64	1.44
	10/14/2003	0.50	0.80	2.62
	3/31/2004	0.31	0.43	1.05
	6/10/2004	0.29	0.28	0.62
	8/2/2004	0.26	0.31	0.65
	9/7/2004	0.25	0.20	0.67
	10/13/2004	0.21	0.23	0.61
	12/7/2004	0.23	0.21	0.51
	2/16/2005	0.19	0.19	0.45
	3/8/2005	0.18	0.31	0.78

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-012	12/16/1998	0.64	45.41	31.04
	5/24/1999	0.95	41.77	26.95
	6/15/1999	0.85	31.63	19.24
	7/7/1999	0.99	43.93	21.38
	8/26/1999	0.76	25.59	15.19
	1/4/2000	1.05	19.20	12.74
	5/1/2002	0.45	8.19	2.68
	8/6/2002	0.33	8.69	3.72
	11/18/2002	0.00	13.23	3.97
	7/21/2003	0.41	14.24	3.42
	10/14/2003	0.53	14.62	5.34
	3/31/2004	0.30	8.65	2.08
	6/10/2004	0.26	4.82	1.36
	8/2/2004	0.29	6.74	1.65
	9/7/2004	0.27	4.65	1.59
	10/13/2004	0.27	6.50	1.44
	12/7/2004	0.27	5.36	1.27
	2/16/2005	0.23	5.84	1.25
	3/8/2005	0.26	8.78	1.63
MLBB-013	12/29/1998	1.14	1.09	0.87
	2/2/1999	1.11	1.29	0.95
	6/16/1999	0.81	0.87	0.89
	7/19/1999	0.78	0.74	0.72
	8/27/1999	0.46	0.70	0.26
	5/1/2002	0.16	0.22	0.23
	8/6/2002	0.18	0.32	0.37
	11/18/2002	0.00	0.29	0.21
	7/21/2003	0.13	0.32	0.29
	10/14/2003	0.17	0.46	0.56
	3/31/2004	0.06	0.01	0.02
	6/10/2004	0.06	0.17	0.10
	8/2/2004	0.09	0.26	0.16
	9/7/2004	0.09	0.18	0.17
	10/13/2004	0.09	0.30	0.18
	12/7/2004	0.08	0.23	0.15
	2/16/2005	0.06	0.23	0.14
	3/8/2005	0.08	0.47	0.25

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-014	12/29/1998	0.85	3.04	1.57
	2/2/1999	0.72	2.54	1.35
	6/16/1999	0.70	2.19	1.15
	7/19/1999	0.60	2.06	1.30
	8/27/1999	0.53	1.96	1.30
	5/1/2002	0.17	0.57	0.39
	8/6/2002	0.16	0.65	0.58
	11/18/2002	0.00	0.85	0.55
	7/21/2003	0.12	0.61	0.46
	10/14/2003	0.16	0.80	0.85
	3/31/2004	0.09	0.49	0.29
	6/10/2004	0.08	0.39	0.23
	8/2/2004	0.09	0.33	0.22
	9/7/2004	0.08	0.26	0.23
	10/13/2004	0.08	0.32	0.21
	12/7/2004	0.08	0.25	0.17
	2/16/2005	0.07	0.29	0.16
	3/8/2005	0.08	0.43	0.26
MLBB-015	12/16/1998	1.81	20.53	10.46
	3/9/1999	2.06	17.83	8.13
	5/24/1999	2.29	10.31	5.99
	6/15/1999	2.58	8.57	5.38
	6/16/1999	2.61	7.75	5.05
	7/7/1999	2.37	9.24	5.18
	8/27/1999	1.44	12.63	6.10
	5/1/2002	0.42	3.90	1.08
	8/6/2002	0.41	4.92	1.66
	11/18/2002	0.00	0.92	0.29
	7/21/2003	0.22	3.52	1.07
	10/14/2003	0.29	4.77	2.07
	3/31/2004	0.15	2.76	0.60
	6/10/2004	0.10	2.01	0.39
	8/2/2004	0.13	2.64	0.50
	9/7/2004	0.13	1.80	0.50
	10/13/2004	0.12	2.26	0.48
	12/7/2004	0.10	1.48	0.34
	2/16/2005	0.09	1.47	0.29
	3/8/2005	0.11	3.51	0.59

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-016	12/29/1998	7.62	2.92	3.03
	2/2/1999	6.95	3.10	3.00
	6/15/1999	6.24	1.65	2.44
	7/19/1999	6.61	2.65	2.77
	8/26/1999	4.69	2.26	2.32
	12/14/2001	2.07	0.71	1.66
	5/1/2002	0.60	0.38	0.92
	8/6/2002	1.31	0.60	1.57
	11/18/2002	0.00	0.74	1.42
	7/23/2003	0.70	0.42	1.23
	10/14/2003	0.89	0.57	2.25
	3/31/2004	0.45	0.32	0.79
	6/10/2004	0.54	0.39	0.79
	8/2/2004	0.48	0.24	0.64
	9/7/2004	0.42	0.19	0.67
	10/13/2004	0.44	0.21	0.58
	12/7/2004	0.42	0.23	0.54
	2/16/2005	0.36	0.18	0.46
	3/8/2005	0.35	0.25	0.66
MLBB-017	12/29/1998	8.68	2.38	2.74
	2/2/1999	7.73	2.33	2.89
	3/25/1999	4.76	1.58	2.19
	6/15/1999	5.70	2.26	3.04
	7/19/1999	4.51	1.42	2.30
	8/26/1999	2.76	3.91	1.78
	5/1/2002	1.26	0.73	1.33
	8/6/2002	1.13	0.76	2.00
	11/18/2002	0.00	0.72	1.56
	7/21/2003	0.92	0.88	2.09
	10/14/2003	1.08	0.97	3.27
	3/31/2004	0.58	0.56	1.46
	6/10/2004	0.42	0.44	0.89
	8/2/2004	0.55	0.37	1.18
	9/7/2004	0.53	0.37	1.31
	10/13/2004	0.52	0.38	1.16
	12/7/2004	0.49	0.30	0.71
	2/16/2005	0.43	0.28	0.64
	3/8/2005	0.47	0.45	1.28

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-018	12/29/1998	11.56	1.37	2.44
	3/9/1999	5.74	0.00	2.02
	3/25/1999	5.31	0.64	1.56
	7/19/1999	2.39	0.31	0.91
	3/15/2001	2.29	0.33	1.80
	5/1/2002	0.87	0.38	0.93
	8/6/2002	0.82	0.36	1.31
	11/18/2002	0.00	0.40	1.13
	7/21/2003	0.63	0.44	1.29
	10/14/2003	0.78	0.48	2.12
	3/31/2004	0.38	0.29	0.67
	8/2/2004	0.36	0.21	0.53
	9/7/2004	0.34	0.14	0.54
	10/13/2004	0.33	0.20	0.52
	12/7/2004	0.24	0.11	0.32
	2/16/2005	0.25	0.11	0.33
	3/8/2005	0.32	0.25	0.61
MLBB-019	3/25/1999	0.78	1.93	1.56
	5/24/1999	1.19	3.79	2.54
	6/17/1999	1.21	3.22	2.33
	7/19/1999	1.33	2.81	2.21
	8/27/1999	1.74	7.74	2.61
	5/1/2002	0.34	0.40	0.36
	8/6/2002	0.28	0.35	0.45
	11/18/2002	0.00	0.42	0.48
	7/21/2003	0.25	0.70	0.68
	10/14/2003	0.29	0.79	1.21
	3/31/2004	0.12	0.35	0.32
	6/10/2004	0.05	0.11	0.13
	8/2/2004	0.10	0.23	0.23
	9/7/2004	0.00	0.28	0.30
	10/13/2004	0.10	0.24	0.25
	12/7/2004	0.05	0.10	0.12
	2/16/2005	0.06	0.13	0.13
	3/8/2005	0.09	0.27	0.27

Well ID	Sample Date	Freon 113 ppmv	PCE ppmv	TCE ppmv
MLBB-020	5/24/1999	1.16	1.27	0.66
	6/17/1999	1.00	1.08	0.60
	7/19/1999	1.24	1.13	0.69
	8/27/1999	0.00	1.03	0.00
	5/1/2002	0.20	0.43	0.19
	8/6/2002	0.20	0.51	0.30
	11/18/2002	0.00	0.49	0.22
	7/21/2003	0.14	0.40	0.25
	10/14/2003	0.18	0.52	0.49
	3/31/2004	0.11	0.29	0.15
	6/10/2004	0.09	0.26	0.13
	8/2/2004	0.10	0.23	0.13
	10/13/2004	0.09	0.16	0.08
	12/7/2004	0.05	0.07	0.05
	2/16/2005	0.01	0.03	0.02
	3/8/2005	0.03	0.09	0.05

Enhancements for Passive Vapor Extraction: The Hanford Study

by Michael G. Ellerd[a], Joel W. Massmann[b], Daniel P. Schwaegler[c], and Virginia J. Rohay[d]

Abstract

Passive vapor extraction involves wells that are screened in the unsaturated zone and open to the atmosphere. Gas will flow out of the subsurface through the open well during periods of low barometric pressure. Field and modeling studies have been completed to evaluate enhancements for a passive vapor extraction system at a site contaminated with carbon tetrachloride on the Hanford nuclear reservation near Richland, Washington. During a 38-hour period of low barometric pressure, approximately 500 m^3 of air were vented from the subsurface. Approximately 27 grams of carbon tetrachloride were removed from the subsurface during this same outflow event. On an annual basis, more than 15 kilograms of carbon tetrachloride have been removed from each of several passive extraction wells. Computer simulations based on the field data indicate that surface covers smaller than 30 m radius will result in relatively small enhancements of flow. However, with larger surface seals (i.e., up to 90 m radius), volumetric flow rates more than doubled. Simulations showed that check valves might increase the rate at which subsurface gases are extracted by a factor of nearly three. These estimates are sensitive to dispersion coefficients. If not properly designed, filters used to treat effluent gases from passive extraction systems can significantly reduce the effectiveness of these systems.

Introduction

Soil vapor extraction has become a common technology for treating subsurface soils contaminated with volatile organic compounds. The popularity of this technology is due in part to the low cost of vapor extraction relative to other available technologies, especially when contamination occurs relatively deep below the ground surface. Vapor extraction also offers considerable flexibility in terms of installation and operation. This flexibility allows systems to be adjusted during the course of remediation to improve mass removal efficiency.

The efficiency of these systems depends upon how readily the contaminants enter the vapor phase through mass transfer and how readily the vapor phase is then removed from the subsurface through mass transport. Volatile and semivolatile compounds will enter the vapor phase by desorption from the soil particles, through volatilization from the soil water, and by evaporation from nonaqueous phase liquids (NAPLs) such as petroleum products and liquid solvents. The contamination that is most easily volatilized is removed first and the effluent concentrations typically will decrease with time.

Most systems are operated as active extraction systems in which pressure gradients and airflow are induced through extraction wells using mechanical blowers or pumps. In passive vapor extraction systems, pressure gradients and airflow develop as the result of fluctuations in barometric pressure (Weeks 1978). These pressure fluctuations can be used to induce airflow in the subsurface through the use of wells that are open to the atmosphere. While active vapor extraction is a commonly used method for primary removal of volatile organic contaminants from the subsurface, passive vapor extraction can be used as a polishing technique after the NAPL and other readily available contaminants have been removed by an active system. Passive vapor extraction can also be applied efficiently to low-permeability media where diffusion controls the release of contaminants and for semivolatile organic compounds that have lower rates of mass transfer.

A passive vapor extraction system, in the most simple case, involves a well that is screened in the unsaturated zone and open to the atmosphere. Gas will flow out of the subsurface through the open well when the subsurface gas pressure is greater than barometric pressure. If the subsurface gas is contaminated with organic vapors, the contaminated gas that exits the well will dissipate into the atmosphere. Gas will flow into the subsurface through the open well when the barometric pressure is greater than the subsurface gas pressure. The gas that enters the subsurface during these high-pressure events is typically free of contaminant vapors. The result of passive vapor extraction is a net flow of contaminated gas out of the subsurface. References that describe the effects of

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barometric pressures on subsurface gas movement include Clements and Wilkening (1974), Kimball and Lemon (1972), and Nilson et al. (1991).

The effectiveness of passive vapor extraction systems is particularly sensitive to site geology. Sites with thick unsaturated zones or sites with higher permeability layers that are confined by lower permeability layers will be most amenable to passive vapor extraction. This includes sites with natural or artificial surface covers. Fluctuations in barometric pressure induce horizontal pressure gradients in systems with natural or artificial covers, and in turn result in the net extraction of subsurface vapor (Massmann and Farrier 1992).

Enhancements have been suggested to improve the efficiency of passive extraction systems by increasing the net flux of contaminated gas out of the subsurface through an extraction well (Rohay 1996). Specifically, the return flow of atmospheric gas into the subsurface can be prevented by capping the well during periods of high barometric pressure, and the pressure gradient between the atmosphere and the subsurface can be increased by adding an impermeable surface seal in the vicinity of the extraction well. Concerning the emission of contaminated vapors, adsorptive filters can be used to reduce the flux of contaminants to the atmosphere. This paper describes field and modeling studies that have been completed to evaluate these types of enhancements for a passive vapor extraction system at a site contaminated with carbon tetrachloride on the Hanford nuclear reservation near Richland, Washington. The approach used and the findings that resulted from these evaluations are relevant for systems at other sites in which passive vapor extraction is either planned or is in operation.

The Hanford Carbon Tetrachloride Site

Contamination History

The Hanford nuclear reservation is a former U.S. Department of Energy plutonium production facility in the Columbia Plateau of south-central Washington State. Carbon tetrachloride was used to recover plutonium from aqueous waste streams in the 200-West area of the Hanford site. The carbon tetrachloride, which is a volatile organic compound, was discharged to subsurface infiltration facilities as a dense nonaqueous phase liquid and also as a dissolved constituent in waste water. It is estimated that 17,000 m^3 of radioactive aqueous waste containing approximately 280 m^3 of carbon tetrachloride were released into the subsurface from 1955 to 1973. As much as 65% of the carbon tetrachloride may have been retained as residual contamination in the unsaturated zone (WHC 1993). A ground water plume of dissolved carbon tetrachloride now extends more than 10 km^2 beneath the 200-West area.

Geology and Hydrology

The carbon tetrachloride site encompasses approximately 280,000 m^2 in the 200-West area of the Hanford facility. The 200-West area, which is relatively flat and sparsely vegetated, receives an annual average of 16 cm of precipitation. Surface runoff accounts for approximately 3% of the precipitation, and less than 1% of the precipitation infiltrates to ground water (Rohay and Johnson 1991).

The depth to the water table at the carbon tetrachloride site is approximately 66 m. The stratigraphy in the unsaturated zone, which is summarized in Figure 1, consists of relatively permeable sand and gravel interrupted by a less-permeable interval composed of silty sand and carbonate-rich sand and gravel. This less-permeable zone is informally referred to as the caliche layer. The caliche layer effectively divides the unsaturated zone into two segments: an upper zone from the ground surface to the top of the caliche layer and a lower zone from the caliche layer to the water table. The upper zone consists of the Hanford Formation, which is composed of intervals of gravel and sand. The thickness of this unit in the area of the carbon tetrachloride contamination is approximately 40 m. The caliche layer, which extends from approximately 40 to 45 m depth, is composed of an interval of silty sand referred to as the early Palouse soil overlying a carbonate-rich interval called the Plio-Pleistocene unit. Beneath the caliche layer is the Ringold Formation. This unit extends to the Columbia River basalt bedrock and is composed of gravel and sand intervals that interfinger with fine-grained silt and clay deposits. The Ringold Formation is approximately 130 m thick at the carbon tetrachloride contamination site. The uppermost interval consists of gravel; the water table lies within this upper gravel interval 20 m below the caliche layer. Air conductivity values reported for the stratigraphic units within the unsaturated zone range from 6×10^{-7} cm/s (effective permeability = 8×10^{-11} cm2) for the caliche layer to 3×10^{-1} cm/s (effective permeability = 5×10^{-5} cm^2) for the gravel intervals of the Hanford Formation. Moisture content in the unsaturated zone in the 200-West area ranges from less than 1% to 30%. The average moisture content measured in the Hanford and Ringold Formations is 5%. The geology and hydrogeology of the Hanford site is described in more detail in Newcomer et al. (1996); Rohay et al. (1993); Piepho et al. (1993); Rohay et al. (1994); Rohay and Johnson (1991).

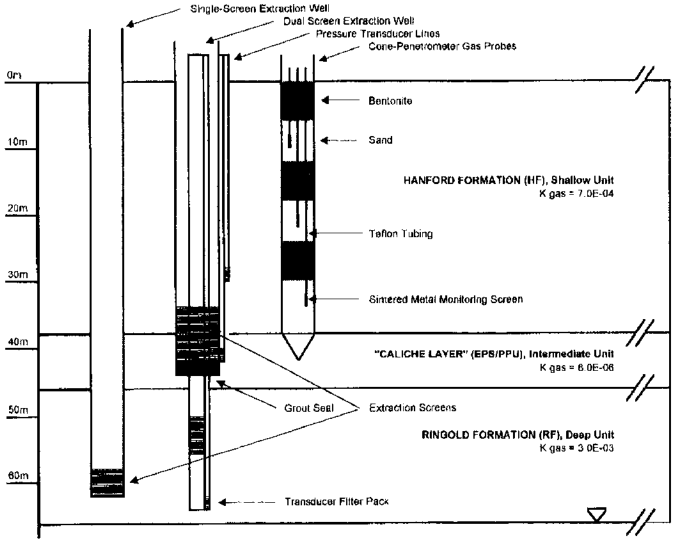

Figure 1. Geometry and stratigraphy of the flow field and monitoring well configurations.

Configurations for Subsurface Monitoring Wells

Figure 1 illustrates examples of three principal types of monitoring configurations that were used in the passive vapor extraction study. The configuration shown on the left of Figure 1 consists of a stainless steel, 15 cm diameter well with a single screened interval. The configuration in the center of Figure 1 has two screened intervals; one above the caliche layer and one below the caliche layer. A grout seal is placed in the annular space between the well casings for the shallow and deep screens. The screened intervals can be isolated from one another with an inflatable packer. Three pressure transducer access lines consisting of 0.3 cm diameter stainless steel tubing are attached to the exterior of the well casing. A 1 m long

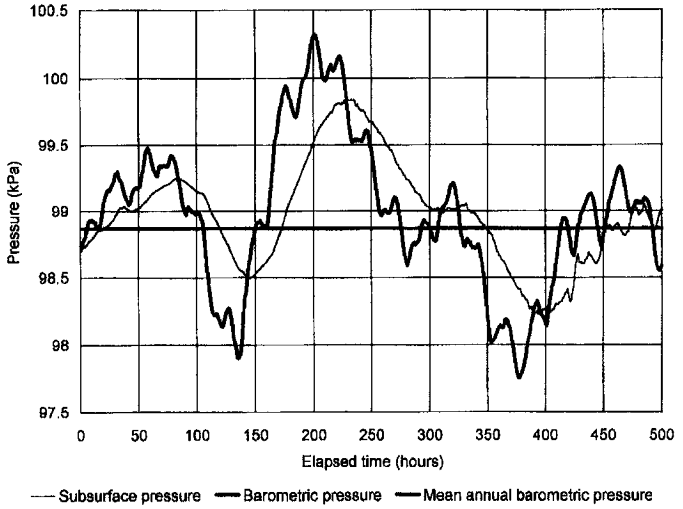

Figure 2. Barometric pressure and subsurface pressure measured in a well beneath the caliche layer.

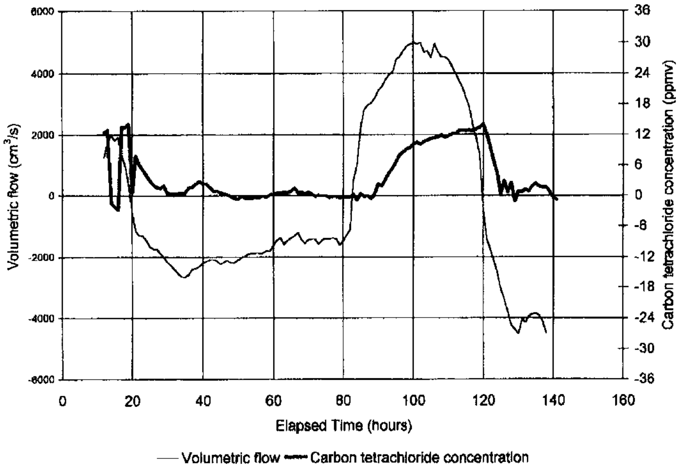

Figure 3. Flow rates and carbon tetrachloride concentrations during a period of barometric pressure fluctuations.

Table 1
Differential Pressure Measurements, June to December 1993

Location	Depth (m)	Positive Differential Pressure (Pascals) Average	Maximum
CPT4	8	20	150
CPT4	15	50	200
CPT4	23	80	400
CPT4	28	80	400
CPT4	33	100	500
W18-252U	34	80	420
W18-247U	36	120	420
W18-247L	49	400	1300
W18-252L	50	420	1650

filter pack was constructed at the bottom of each of these open tubes. The filter packs were isolated from one another with grout. There are 46 drilled wells at the carbon tetrachloride site with configurations similar to what is shown on the left and center of Figure 1. These wells were used to define the stratigraphy summarized in Figure 1.

The third type of monitoring configuration, which is shown on the right of Figure 1, was installed using a cone penetrometer. These probe clusters consist of three to five subsurface probes placed at depths ranging from 2 to 30 m below the ground surface. Each probe is placed in a sand pack and is isolated from the probes above and below by a layer of granular bentonite pellets. The probes are constructed of 10 cm long sintered metal screens attached to a 0.5 cm diameter Teflon® tube that extends to the ground surface.

Fluctuations in Barometric Pressure and Their Observed Effects

Relationship Between Barometric Pressures and Subsurface Pressures

The average barometric pressure at the Hanford nuclear reservation is approximately 98,700 Pascals (Pa). Typical barometric fluctuations due to large-scale weather patterns are on the order of 1000 Pa (Rohay 1996). These fluctuations in barometric pressure cause vertical pressure gradients in subsurface gases as shown in Figure 2. These data are from a drilled well with a screen beneath the caliche layer. Pressure differentials, defined as subsurface pressure minus barometric pressure, are on the order of 1000 Pa at these deeper locations. Table 1 summarizes pressure differentials between the subsurface and the atmosphere over a six-month period. The first seven rows give pressures measured in wells and penetrometer probes that are completed above the caliche layer. The last two rows correspond to wells completed below the caliche layer. These data illustrate that the pressure differentials are generally much larger for monitoring points located beneath the caliche layer.

Relationship Between Barometric Pressures and Carbon Tetrachloride Concentrations

Figure 3 shows data that describe vapor flow and carbon tetrachloride concentration. These data were collected at the same well as those shown in Figure 2. The data from approximately 20 to 80 hours corresponds to a period in which air is flowing into the formation. Approximately 400 m^3 of air entered the subsurface during this 60-hour period. The concentration of carbon tetrachloride in this air is essentially zero because the air entering the well is atmospheric.

At approximately 80 hours the barometric pressure decreased, and the direction of airflow was reversed. Air flowed out of the well for approximately 40 hours, and approximately 500 m^3 of air exited the subsurface during this period. Although air began to flow out of the well at approximately 80 hours, there was a six-hour period where carbon tetrachloride concentration within this air remained essentially zero. The six-hour lag before the carbon tetrachloride concentration began to increase was the result of relatively "clean" air that had entered the subsurface during the previous period of air inflow. Approximately 27 grams of carbon tetrachloride were removed from the subsurface during the outflow event shown in Figure 3. Although the passive extraction system included no engineered enhancements or check valves during this test, it did include a canister of activated carbon to remove the carbon tetrachloride from the vented air.

Table 2 summarizes data that describe the mass flux of carbon tetrachloride out of several wells in the 200-West area. The first three rows correspond to wells with screens above the caliche layer, and the last three rows correspond to wells with screens below the caliche layer. Small canisters of activated carbon were used to remove the carbon tetrachloride from the effluent vapors. These data, which were obtained by analyzing the activated carbon, show that

Table 2
Passive Extraction Rate Measurements, April to October 1993

Location	Depth (m)	Dates	Average Extraction Rate grams/day	kg/yr
W18-248	37	5/93–7/93	1	0.4
W18-246U	37	5/93–9/93	20	7
W18-249	37	4/93–10/93	40	15
W18-246L	50	5/93–9/93	40	15
W18-6	58	4/93–10/93	55	20
W18-7	60	5/93–10/93	45	16

carbon tetrachloride can be removed through individual passive vapor extraction wells at a rate of more than 50 g/day.

Enhancements for Passive Vapor Extraction

Gas Filters

Canisters of granular activated carbon (GAC) can be used to remove contaminants in the effluent vapor from passive vapor extraction systems. These canisters reduce the efficiency of passive extraction systems by introducing additional resistance to gas flow in the wells which tends to dampen the effects of fluctuations in barometric pressures. For the pressures and temperatures typically observed in passive vapor extraction, a modified version of Darcy's law can be used to describe the flow of gas through GAC canisters:

$$Q/A = (\Delta P/\rho g)/\lambda \qquad (1)$$

where Q is the volumetric flow rate ($L^3\ t^{-1}$), A is the area perpendicular to gas flow (L^2), λ is the canister resistance (t), ΔP is the pressure drop across the canister ($M\ L^{-1}\ t^{-2}$), ρ is the gas density ($M\ L^{-3}$), and g is the gravitational constant ($L\ t^{-2}$). The resistance term, λ, is related to the permeability of the activated carbon and the length of the cylinder:

$$\lambda = L/(k\rho g/\mu) \qquad (2)$$

where L is cylinder length (L), k is permeability (L^2), and μ is gas viscosity ($M\ L^{-1}\ t^{-1}$).

Check Valves

Without a check valve, atmospheric air will flow back into the subsurface through an extraction well when barometric pressure is greater than the subsurface gas pressure. Although this does not directly compromise the integrity of the system, the introduction of ambient air to the soil may result in lower concentrations of contaminants being drawn from the soil when the flow direction reverses. This in turn will reduce mass removal rates. In some circumstances, such as the delivery of oxygenated air to subsurface microorganisms, the check valve could be used to allow airflow into, but not out of, the subsurface. It should be noted that in other circumstances, such as when there is NAPL in the vicinity of the extraction well, a check valve may actually reduce the rate of mass removal (Schwaegler 1995).

In typical applications, these check valves will open and close at pressure differentials of less than 50 Pa. Rohay (1996) gives examples of several designs that have been used for check valves. A valve designed at the Idaho National Engineering and Environmental Laboratory uses a light, flat, free-floating piece of plastic inside a pipe to seal against backflow. A second design uses a floating ball check valve developed at the Savannah River site. A table tennis ball rests in a conical seat in a plastic housing; as atmospheric pressure drops and air flows out of the well, the ball lifts up and the valve is open. Solenoid valves that open and close in response to an electrical signal controlled by differential or absolute pressures have also been used as check valves (Rohay 1996).

Surface Covers

Surface covers are intended to reduce vertical flow of atmospheric air into the subsurface and to enhance horizontal flow toward the extraction well by preventing short-circuiting adjacent to extraction wells. These surface seals may also reduce the dilution of contaminant concentrations by preventing clean air from entering the subsurface. Surface seals would be particularly important for relatively shallow systems with permeable soils near the ground surface. By covering the ground surface with an impermeable cover, the differential between surface and subsurface gas pressure will increase for a given fluctuation in barometric pressure.

The Gas Flow Model

Numerical models that simulate flow and transport of subsurface gas were used to evaluate the effectiveness of the enhancements described in the previous section. The gas flow model simulates atmospherically induced subsurface gas flow by means of a fluctuating pressure boundary at both the ground surface and the well screen. The gas transport model simulates mixing of atmospheric and subsurface gas. Estimates of subsurface gas velocities from the gas flow model are used as input to the gas transport model. This section describes the gas flow model and the approach used to calibrate this model. The gas transport model is described in a later section.

Passive extraction enhancements were evaluated by examining their impact on an individual passive extraction well that is assumed to behave independently of neighboring wells. Although there may be interactions among wells in a field-scale system, these interactions would not significantly affect conclusions regarding the relative effectiveness of the various enhancements. An enhancement that improves the effectiveness of an individual well will also improve the effectiveness of the overall system.

Equation of Flow

The differential equation that describes the flow of compressible gases in porous media is nonlinear because of the dependence of density on pressure. However, for systems in which pressure differentials are less than approximately 20,000 Pa, the error associated with assuming constant density is small. The following equation can be used to describe gas flow under these conditions for a two-dimensional, radial flow system similar to what would occur in the vicinity of an extraction well (Massmann 1989):

$$S_s\frac{\partial h}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(K\frac{\partial h}{\partial r}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial h}{\partial z}\right) \qquad (3)$$

where S_s is specific storage for gas flow (L^{-1}), K is gas conductivity ($L\ t^{-1}$), and h is gas head (L). Equation 3 is directly analogous to the equation used to describe transient ground water flow.

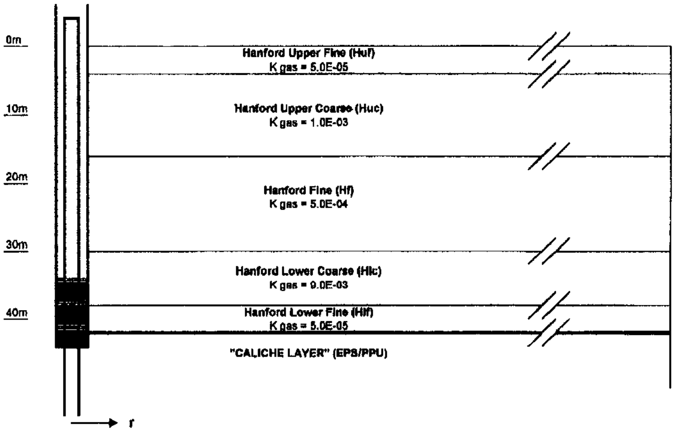

Figure 4. Calibration domain used in the partial-depth model.

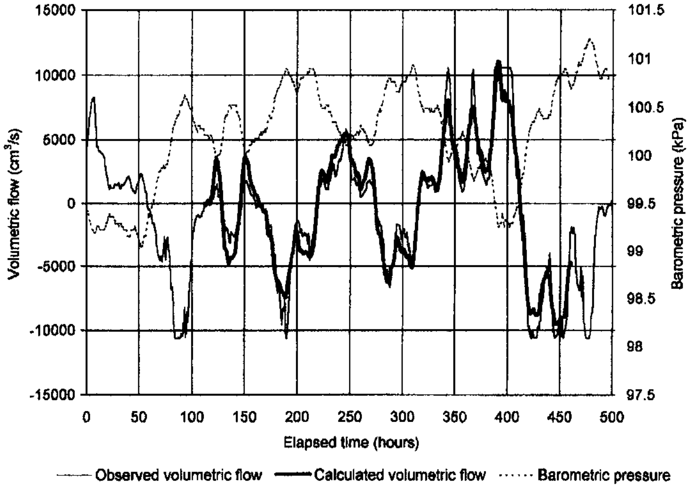

Figure 5. Observed barometric pressure, observed flow rates, and calculated flow rates after calibration for the first 500 hours of data .

Gas head, h, is related to gas pressure, P, by

$$h = \frac{P}{\rho g} + Z \tag{4}$$

where Z is elevation relative to some datum (L).

The gas conductivity in Equation 3 is defined as

$$K = \frac{k\rho g}{\mu} \tag{5}$$

where k is the effective permeability (L^2) and μ is the gas viscosity ($M\,L^{-1}\,t^{-1}$). This expression is generally valid for systems with permeabilities greater than approximately 10^{-10} cm^2, a value typical of silts and clays (Massmann 1989).

The specific storage for gas flow, S_s, is given by (Massmann 1989)

$$S_s = \frac{n_{gas} g W_M}{RT} \tag{6}$$

where n_{gas} is the gas-filled porosity, W_M is the molecular weight of the gas ($M\,mol^{-1}$), R is the universal gas constant ($M\,L^2\,t^{-2}\,T^{-1}\,mol^{-1}$), and T is absolute temperature (T). Temperature effects are assumed negligible. It is likely that gas temperature will quickly equilibrate with subsurface temperature during inflow events so that temperature effects will be negligible within most of the flow field.

Flow-Field Geometry and Boundary Conditions

Two models were used to simulate flow in the vicinity of passive extraction wells: a full-depth model and a partial-depth model. The geometry used in the full-depth model is shown in Figure 1. This geometry was developed based on available stratigraphic data, including well logs from the carbon tetrachloride contamination area. The Hanford Formation was modeled as a single stratigraphic unit with a thickness of 38 m. Because the early Palouse soils (EPS) and the Plio-Pleistocene unit (PPU) both represent relatively low permeability units, they were modeled as a single stratigraphic unit with a combined thickness of 8 m. This combined unit is referred to as the caliche layer or EPS/PPU. The Ringold Formation represents the third and deepest stratigraphic unit with a thickness of 20 m extending to ground water. In this study, the Hanford Formation, caliche layer, and Ringold Formation are designated as the shallow, intermediate, and deep units, respectively. Reported ranges of material property values for these three units are listed in Table 3.

The full-depth model was used in all simulations except those that were intended to evaluate surface covers. Preliminary simulations with the full-depth model showed that the surface covers did not impact flow beneath the caliche layer. A more detailed model of the Hanford Formation was developed to simulate the effects of the surface covers using the geometry and stratigraphy described in Figure 4. The flow field was divided into five stratigraphic layers based on information from well logs. The deepest layer shown in this figure, which is described as the Hanford lower fine, is used to represent the gradation from the Hanford Formation to the caliche layer. It is assigned a relatively low air conductivity value. The upper four layers represent the Hanford Formation identified in Figure 1.

A finite-element computer code was used to simulate gas flow. The ground surface was designated as a fluctuating pressure boundary in both the full-depth and partial-depth models. The well

Table 3
Reported Ranges and Initial Values for the Primary Calibration

Unit	K_{gas} Range (cm/s)	Initial K_{gas} (cm/s)	S_s Range (cm^{-1})	Initial S_s (cm^{-1})
Hanford Formation	$7.1\times10^{-3} - 7.0\times10^{-5}$	5.0×10^{-4}	$2.4\times10^{-7} - 7.6\times10^{-7}$	4.5×10^{-7}
EPS/PPU	$5.9\times10^{-4} - 5.6\times10^{-7}$	1.0×10^{-5}	$4.3\times10^{-7} - 6.0\times10^{-7}$	4.5×10^{-7}
Ringold Formation	$3.2\times10^{-5} - 5.0\times10^{-2}$	5.0×10^{-3}	$1.2\times10^{-7} - 4.5\times10^{-7}$	4.5×10^{-7}

casing was designated as an impermeable boundary, and the exterior boundary distant from the well was designated as a constant pressure boundary in both models. The well screen was treated as a fluctuating-pressure boundary in the full-depth model and as a constant pressure boundary in the partial-depth model. The lower boundary was assumed impermeable for both models. This lower boundary was assumed to be the water table for the full-depth model and the caliche layer for the partial-depth model. The gas conductivity of the caliche layer is several orders of magnitude less than the Hanford Formation (Table 3). The position of the exterior boundary was selected so that it would have a negligible impact on gas velocities calculated in the vicinity of the well. Numerical experiments showed that this could be accomplished by placing the outer boundary at a radius of 2000 m in the full-depth model and at a radius of 350 m in the partial-depth model. Mass balance errors were insignificant using a time step of 1800 seconds in the initial full depth calibration simulation.

Calibration of the Flow Model

Two sets of field data were used to calibrate the gas flow model. The first set, which was used to calibrate the full-depth model, consisted of barometric pressures and gas flow rates collected over a two-month period. The second set of data, which was used to calibrate the partial-depth model, consisted of pressure measurements collected at a series of subsurface gas probes during an active vapor extraction experiment.

Calibration of the Full-Depth Model

The observation well used for the full-depth model was a 15 cm diameter well extending to a depth of 61.5 m, with a screened interval from 58 to 61.5 m. Depth to ground water measured in a neighboring well was approximately 66 m below ground surface. Flow rate and barometric pressure data were collected at one-hour intervals for a total period of 1383 hours beginning at 10:00 a.m. on June 4, 1993. All other wells in the vicinity were capped during this period.

An interval of 500 hours with relatively high barometric stresses and flow rates was selected for the calibration, as shown in Figure 5. Gas flow from the subsurface into the atmosphere was considered positive. Due to instrumentation limitations, volumetric flow rates exceeding approximately 1.0×104 cm^3/s were not recorded. This occurred once during this calibration period at an elapsed time of approximately 400 hours (Figure 5).

Static initial conditions were assumed in the model, but actual subsurface pressures will generally be nonuniform as a result of past barometric events. To minimize the effects of preexisting stresses, the beginning of the calibration period was selected at a time of relatively stable barometric pressure. The calibration period began at an elapsed time of 112 hours into the data set and continued for 350 hours.

The observed and calculated flow rates were compared by calculating the mean absolute error (MAE) according to the following expression:

$$\text{MAE} = \frac{1}{n}\sum \left| (\text{observed flow rate} - \text{calculated flow rate}) \right| \quad (7)$$

where n is the number of data points. A second index used was the percent total volume difference (PTVD) which compares the total calculated and observed well flow volumes:

$$\text{PTVD} = \left(\frac{\text{observed total flow} - \text{calculated total flow}}{\text{observed total flow}} \right) \times 100 \quad (8)$$

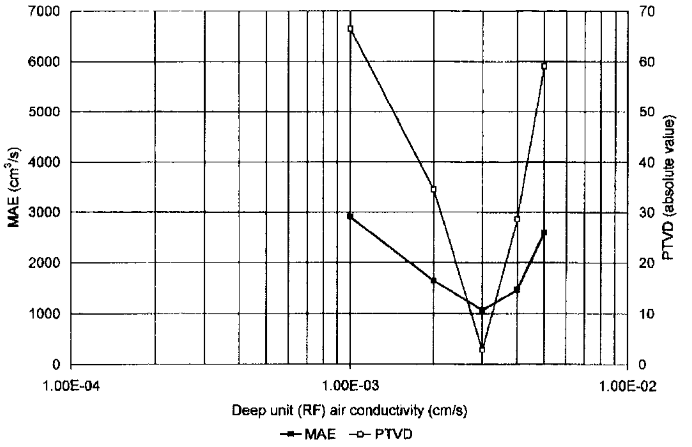

Figure 6a. MAE and |PTVD| for deep unit (Ringold) gas conductivities corresponding to an intermediate unit $K_{gas} = 1.0 \times 10^{-5}$ cm/s and a shallow unit (Hanford) $K_{gas} = 5.0 \times 10^{-4}$ cm/s.

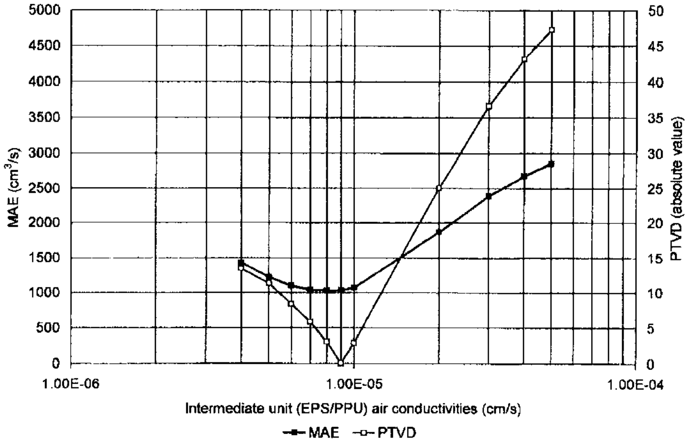

Figure 6b. MAE and |PTVD| for intermediate unit (EPS/PPU) gas conductivities corresponding to a deep unit (Ringold) $K_{gas} = 3.0 \times 10^{-3}$ cm/s and a shallow unit (Hanford) $K_{gas} = 5.0 \times 10^{-4}$ cm/s.

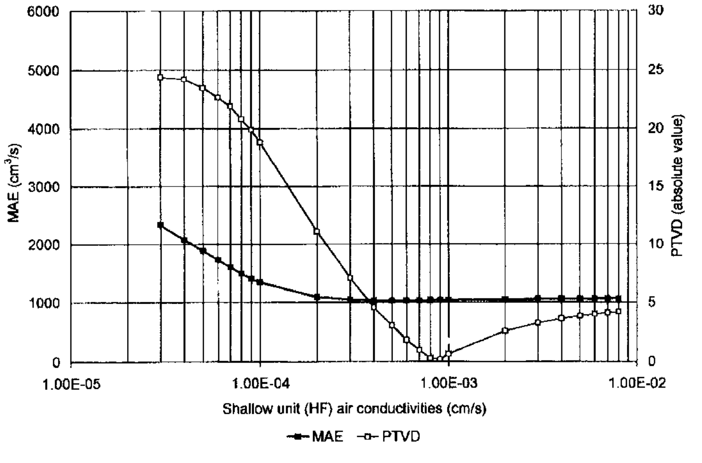

Figure 6c. MAE and |PTVD| for shallow unit (Hanford) gas conductivities corresponding to a deep unit $K_{gas} = 3.0 \times 10^{-3}$ cm/s and an intermediate unit $K_{gas} = 8.0 \times 10^{-6}$ cm/s.

Table 4
Material Property Values from the Primary Calibration

Unit	K_{gas} (cm/s)	S_s (cm^{-1})
Shallow (Hanford Formation)	7.0×10^{-4}	4.5×10^{-7}
Intermediate (EPS/PPU)	8.0×10^{-6}	5.5×10^{-7}
Deep (Ringold Formation)	3.0×10^{-3}	4.5×10^{-7}

The MAE provides a measure of how well the observed and calculated flow rates are temporally in phase. The PTVD, which is obtained by integrating the volumetric flow curves shown in Figure 5, indicates whether the model overestimates or underestimates total flow. A simulation that is slightly out of phase with the observed flow may result in a large value for MAE but a small value for PTVD. To help minimize the effects of prior stresses in the system, the MAE and PTVD statistics were not calculated for the first 50 hours of the calibration interval.

Initial estimates for gas conductivity values were either directly available or were estimated from effective permeability values according to Equation 5 (Piepho et al. 1993; Rohay et al. 1993; Rohay and Johnson 1991). Estimates for initial specific storage values were calculated according to Equation 6 using available gas-filled porosity data (Piepho et al. 1993; Rohay et al. 1993; Rohay and Johnson 1991). The resulting range of material property values and the selected initial values are listed in Table 3.

A preliminary calibration simulation was completed using the initial material property values. The MAE and PTVD for this simulation were 2590 cm^3/s and -59.1, respectively. The calibration was then completed by varying the gas conductivity of one unit while holding constant the gas conductivity of the remaining two units. For the deep unit, the best statistical fit between observed and modeled flow rates occurs with a conductivity value of 3.0×10^{-3} cm/s. The resulting MAE and absolute value of the PTVD for these simulations are plotted in Figure 6a. The optimum conductivity for the intermediate unit is approximately 8.0×10^{-6} cm/s, as shown in Figure 6b. The MAE and PTVD from the shallow unit simulations are plotted in Figure 6c and indicate an optimum of approximately 7.0×10^{-4} cm/s. The data in Figure 6c also indicate that the simulations are relatively insensitive to the shallow unit conductivity provided the value is greater than approximately 3.0×10^{-4} cm/s.

It should be noted that there is a distinct minimum in the graphs showing MAE as a function of gas conductivity values for the deep and middle layers. This was not the case for the gas conductivity value for the shallow zone. No unique value for the shallow zone conductivity can be identified using the MAE as the calibration parameter. Information related to total flow as described by the PTVD parameter is required to identify an optimum conductivity for the shallow layer.

The optimum specific storage values for each unit were established using the same approach as the gas conductivity. The results indicated the optimum S_s value determined for the intermediate unit was 5.5×10^{-7}, but the optimum values for both the deep and shallow units were unchanged from the initial values of 4.5×10^{-7}. All calibrated material property values are listed in Table 4, and the observed and calculated flow rates are plotted in Figure 5. The MAE and the PTVD for the final calibration simulation were 1030 cm^3/s and -2.81, respectively. It should be noted that MAE and PTVD are used to identify which set of input parameters gives the best fit between calculated and observed flow rates. They are not used to argue whether this fit is, in some way, good enough. The results shown in Figure 5 indicate that the calculated flow underestimates some of the highest and lowest observed flow rates, but that the more moderate flows are matched.

Simulations were also conducted to examine effects of the anisotropic gas conductivities for the various stratigraphic units. Changing the radial gas conductivity for the shallow and intermediate units had virtually no effect on flow rates. Changing the vertical gas conductivity for these two units, however, significantly affected flow rates. For the deep unit, the opposite trend was observed; changes in the vertical conductivity had relatively little effect, but changes in the radial gas conductivity had significant effects. These results suggest the calibrated gas conductivity of the shallow and intermediate units are more representative of the vertical gas conductivity, and the calibrated value for the deep unit is more representative of the horizontal gas conductivity.

Calibration of the Partial-Depth Model

The partial depth model was calibrated with data from an active vapor extraction test that was conducted at a well located approximately 75 m from the well used in the full-depth calibration. The construction of the extraction well is similar to what is shown in the center configuration in Figure 1. The upper screen in the well is located above and partially into the caliche layer between 34.5 and 41 m depth. The lower well screen was isolated so that extraction was limited to the shallow unit. A vacuum of approximately 7500 Pa was applied to the top of the well with a resulting flow rate at the well of 4.25 m^3/min. Pressures were monitored using a neighboring subsurface gas probe (right configuration in Figure 1) over a period of eight hours. The monitoring probe used to measure these pressures was located 15.8 m from the extraction well at a depth of 33.2 m.

The vacuum at the well was measured at the ground surface and, consequently, it was necessary to estimate the vacuum at the well screen. This estimation was made according to methods discussed by Miller (1990). The pressure loss due to friction between the top of the well and the well screen was estimated to be between 2500 and 5000 Pa (Ellerd 1994). A frictional loss of 2500 Pa resulted in the best fit between predicted and observed values. Table 5 gives the initial and calibrated values for the stratigraphic intervals shown in Figure 4. A comparison of observed and calculated vacuums for the partial-depth model using these calibrated values is shown in Figure 7.

The calibrated full-depth model was used to calculate flow rates using the next 350-hour interval of the original data. The corresponding MAE and PTVD for this simulation were 1327 cm^3/s and -66.87, respectively. The data indicate that barometric stresses were

Table 5
Initial and Final Material Property Values from the Secondary Calibration

Unit	K_{gas} (cm/s) Initial	K_{gas} (cm/s) Final	S_s (cm^{-1})
Hanford – upper fine	5.0×10^{-4}	5.0×10^{-5}	4.5×10^{-7}
Hanford – upper coarse	1.0×10^{-3}	1.0×10^{-3}	4.5×10^{-7}
Hanford – fine	5.0×10^{-3}	5.0×10^{-4}	4.5×10^{-7}
Hanford – lower coarse	2.0×10^{-3}	9.0×10^{-3}	4.5×10^{-7}
Hanford – lower fine	5.0×10^{-3}	5.0×10^{-5}	5.5×10^{-7}

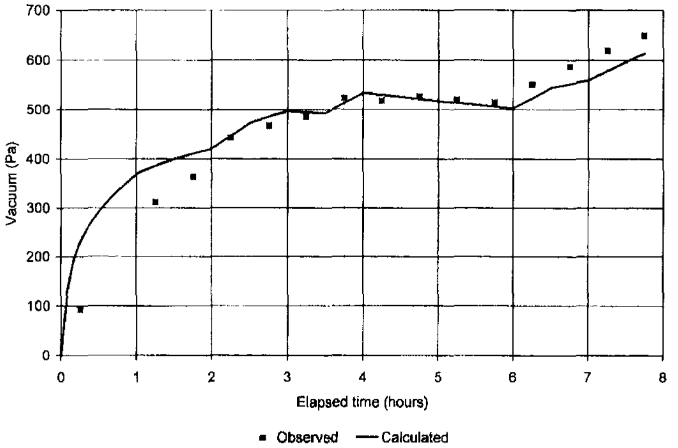

Figure 7. Observed and calculated vacuums for partial-depth model after calibration.

less during this interval than during the initial calibration interval. Consequently, the K of the deep unit was reduced from 3.0×10^{-3} cm/s to 2.0×10^{-3} cm/s, and another simulation was conducted. The MAE and PTVD from this simulation were reduced to 805 cm^3/s and −12.6, respectively. Finally, the model was applied to the last 350-hour interval in the data set. These data contained some of the highest barometric stresses in the data set and required that the deep unit K be increased to 5.0×10^{-3} cm/s to achieve the best fit, which produced MAE and PTVD values of 999 cm^3/s and 4.85, respectively. These results suggest a range of gas conductivity values for the deep unit which yield a mean value approximately consistent with that established during the initial calibration.

The Gas Transport Model

The gas flow model described in the previous section provides estimates of subsurface gas velocities and flow rates. These estimates are used as input to a subsurface transport model to evaluate the exchange of air between the atmosphere and the subsurface. It is important to note the transport model is not used to simulate contaminant transport but rather is used to describe the movement of air that originates in the atmosphere.

Equations for Describing Gas Transport

Gas transport is simulated with the radial advection-dispersion equation (Istok 1989; Sleep and Sykes 1989):

$$\frac{\partial C}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(D_r r\frac{\partial C}{\partial r}\right) + \frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right) - \frac{1}{r}\underset{q}{v_r}\frac{\partial C}{\partial r} - \underset{q}{v_z}\frac{\partial C}{\partial z} \tag{9}$$

where C is concentration ($M\,L^{-3}$), D_r and D_z are the radial and vertical dispersion coefficients, respectively ($L^2\,t^{-1}$), and v_r and v_z are the radial and vertical components of the velocity, respectively ($L\,t^{-1}$). The dispersion coefficients are defined as

$$D_r = \frac{(\alpha_L - \alpha_T)v_r^2}{\underset{q}{|\bar{v}|}\quad q} + \alpha_T\underset{q}{|\bar{v}|} + D^* \tag{10a}$$

$$D_r = \frac{(\alpha_L - \alpha_T)v_z^2}{\underset{q}{|\bar{v}|}\quad q} + \alpha_T\underset{q}{|\bar{v}|} + D^* \tag{10b}$$

where α_L and α_T are the longitudinal and transverse dispersivities (L), D^* is the effective molecular diffusion coefficient ($L^2\,t^{-1}$), and $\underset{q}{|\bar{v}|}$ is the magnitude of the velocity vector ($L\,t^{-1}$).

Equations 9 and 10 are used to simulate the movement of air from the atmosphere into the subsurface. A concentration of 1.0 is arbitrarily used to represent "pure" atmospheric air. The initial subsurface concentrations are assumed to be zero. The concentrations that are calculated using Equations 9 and 10 for a particular time and location in the subsurface thus represent the fraction of the subsurface gas at that location that originated in the atmosphere at the beginning of the simulation.

Flow-Field Geometry and Boundary Conditions

The simulation field used for the full-depth model was also used for the gas transport simulations. The ground surface and exterior boundary were designated as prescribed concentration boundaries with constant concentrations of unity and zero, respectively. The water table and well casing were designated as no-transport boundaries. The designation of the well screen alternated between prescribed concentration and prescribed flux, depending on the direction of gas flow. During periods in which the flow of gas is from the atmosphere into the subsurface, the well screen is designated as a prescribed concentration boundary with a constant concentration of unity. This represents "pure" atmospheric air. When the flow of gas is out of the subsurface through the well, the well screen is designated as a prescribed flux boundary. The flux changes with each successive time step according to the expression:

$$F_r(t) = q_r C(t) \tag{11}$$

where $F_r(t)$ is the flux in the radial direction ($M\,L^{-2}\,t^{-1}$), and C(t) is the fraction of the air in the subsurface that was initially in the atmosphere. Values for specific discharge at the well, q_r, are obtained from the gas flow model. The concentration at the well, C(t), is taken from the previous time step. The time steps were small enough to keep the mass balance errors negligible, as discussed previously.

Material Properties

The material properties required in the transport model include the diffusion coefficient and longitudinal and transverse dispersivities. The diffusion coefficient was assumed equal to 0.02 cm^2/s. This represents a typical value for unconsolidated media (Thorstenson and Pollock 1989). Because concentration data were not available to calibrate dispersivity values, best-guess estimates were used and sensitivity studies were conducted. A value of 300 cm was selected for the longitudinal dispersivity. This represents approximately 10% of the travel distance for atmospheric gas in the vicinity of the passive vapor extraction well. The travel distance was estimated using the transport model with advection only and thus represents some mean or average distance. The transverse dispersivity was selected at 10% of the longitudinal value. It should be noted that in developing the flow model, the geologic layers were assumed to be homogeneous with respect to air conductivity. The dispersivity values used in the transport model are intended to incorporate the effects of smaller-scale heterogeneities that are not included when homogeneous gas conductivity values are assumed for the layers.

A sensitivity study on time steps showed that the value of 1800 s used in the flow simulations produced numerical errors in the transport simulations. Reducing this value to 900 s eliminated the errors. This time step was used in all transport simulations.

Evaluation of Gas Flow Enhancements

Surface Covers

The partial-depth model was used to simulate cover radii of 0, 30, 60, 90, and 1000 m. This model was calibrated using active extraction tests, and is used in this application to evaluate passive extraction due to barometric pressure fluctuations. The surface cover was modeled by changing the top boundary condition of the flow model from fluctuating pressure to impermeable for locations within the radius of the cover. A period of approximately 60 hours beginning at 383 hours into the barometric data shown in Figure 5 was selected because it encompassed relatively sharp changes in barometric pressure. The simulated cumulative flow rates caused by barometric pressure fluctuations for the well are listed in Table 6. These flow rates represent the net flow out of the well during the 60 hours of the simulation. These data indicate that smaller surface covers (i.e., radii of 30 m and less) result in relatively small enhancements of flow from barometric pressure fluctuations. However, with larger surface seals (i.e., up to 90 m radius), volumetric flow rates were more than doubled.

Well Check Valves

A check valve was modeled by modifying the flow model to alternate boundary conditions at the well screen between fluctuating head and impermeable according to a specified control signal. Two series of check valve simulations were conducted, each using a different control signal. In the first series, the control signal was a function of the differential between barometric and subsurface pressure. When the subsurface pressure at the well screen is greater than barometric, the model designates the well screen as a prescribed pressure boundary. Conversely, when the subsurface pressure at the well screen is less than barometric pressure, the well screen is treated as an impermeable boundary. This approach essentially simulates check valves that are open during periods of lower barometric pressure and closed during periods of higher barometric pressure. In the second set of check valve simulations, the control mechanism was simply the magnitude of barometric pressure relative to the mean Hanford barometric pressure. When barometric pressure is less than the Hanford annual average, the valve is assumed open and the well screen is designated as a fluctuating pressure boundary. When the barometric pressure is greater than the Hanford annual average, the valve is assumed closed and the well screen is designated as an impermeable boundary. This approach was used to evaluate a system that had been developed using a solenoid that was activated based on absolute pressure at the ground surface. Frictional losses for the check valves were assumed negligible. Simulations with the flow model show that this is a valid assumption if the resistance of the check valve is less than approximately 500 seconds. The resistance for the types of check valves considered in this study is expected to be considerably less than this value.

Table 6
Results from Gas Flow Simulations for Surface Covers

Surface Cover Radius (m)	Cumulative Well Flow Volume (m^3)	% Increase From No Cover
0	169	0
11	172	2
30	197	16
60	281	66
90	388	129
1000	2040	1100

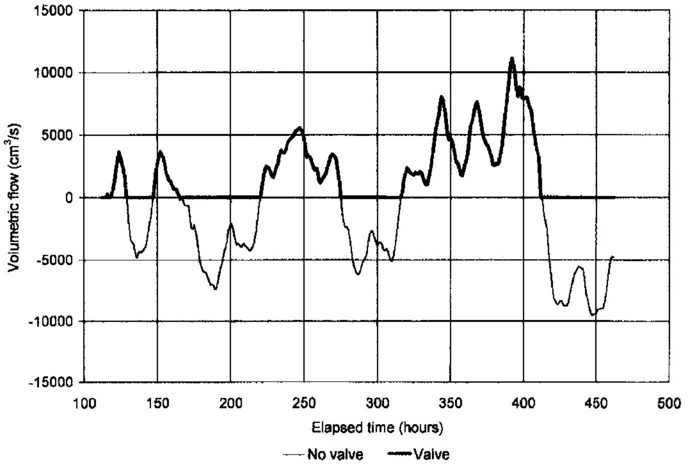

Figure 8a. Calculated volumetric flow with and without a check valve based on pressure differentials (positive flow is out of the well).

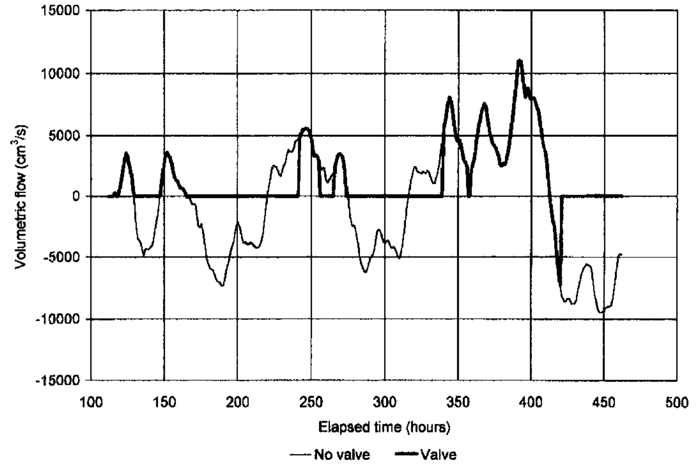

Figure 8b. Calculated volumetric flow with and without check valve based on average barometric pressure (positive flow is out of the well).

The same barometric pressure data used to calibrate the full-depth model were used for the check valve simulations. The results are shown in Figures 8a and 8b. The results in Figure 8a indicate that a check valve that functions according to pressure differentials effectively stops any net flow into the subsurface. However, the results in Figure 8b indicate that the check valve that functions according to the mean barometric pressure value is not only less effective at allowing subsurface gas to exit through the well, but also allows atmospheric gas to enter the subsurface. These results were quantified by calculating the cumulative flow out of the well for each check valve scenario. For the selected period of barometric pressure, check valves that are based on the annual mean pressure result in a net outflow of 1870 m^3. (Net flow is calculated by integrating the curves in Figure 8 and treating outflows as positive values and

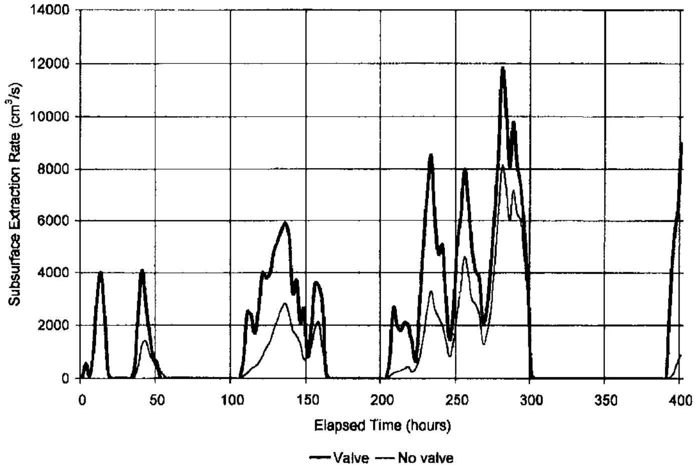

Figure 9. Subsurface gas extraction rates for the first 500 hours of barometric pressure data with and without a check valve based on pressure differentials.

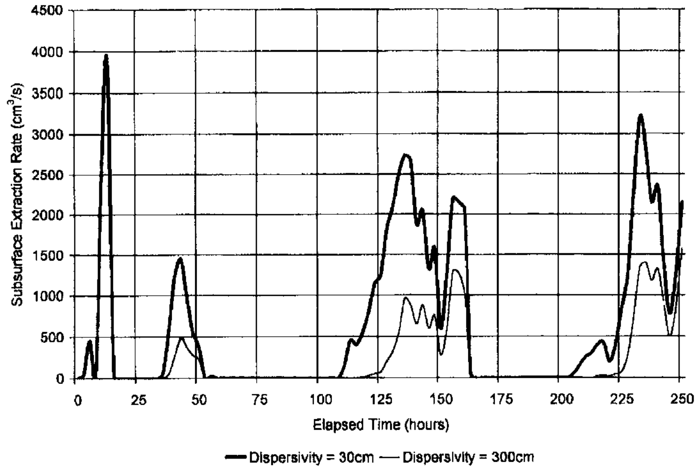

Figure 10. Subsurface gas extraction rates for longitudinal dispersivities of 30 and 300 cm for the first 250 hours of barometric head data with no check valve.

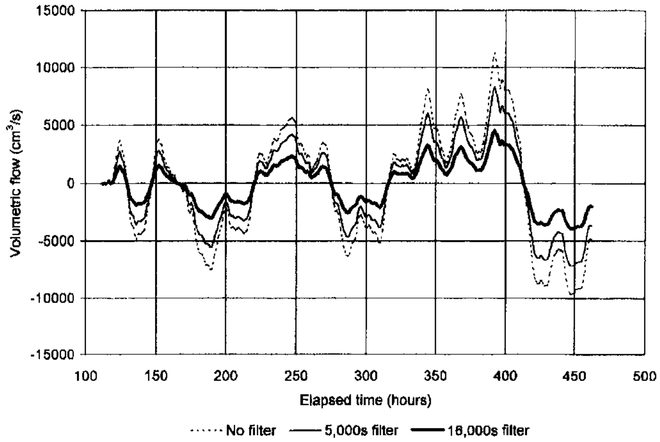

Figure 11. Calculated volumetric flow for no filters and for filter resistances of 5000 and 16,000 s.

inflows as negative values.) This compares to a net inflow of 354 m^3 in the absence of a valve. Check valves based on pressure differentials are even more effective and result in a net outflow of approximately 2400 m^3 during the 350 hours of the simulation.

The check valve flow volumes represent the net flow through the passive extraction well. These results do not indicate where this flow originated, and they do not provide information on mixing that may occur in the subsurface between atmospheric air and subsurface air. In the absence of a check valve, atmospheric gas enters the subsurface through the well screen during periods of high barometric pressure and mixes with subsurface gas. Because of the effects of this mixing, the gas that is extracted from the subsurface during a subsequent period of low barometric pressure is composed of both atmospheric and subsurface gas. With a check valve, no atmospheric gas is allowed to enter the subsurface through the well screen, and the effluent gas extracted during low barometric pressure events consists entirely of subsurface gas.

The gas transport model was used to incorporate the effects of this mixing. Two sets of simulations were conducted to evaluate the effects of check valves on gas transport. The first set assumed no check valve and the second set assumed a check valve that was activated based on pressure differentials between atmospheric and subsurface pressure. The results for the first 500 hours of simulation are presented in Figure 9. The vertical axis in Figure 9 gives the effluent flow rate for gases that originated in the subsurface. If the concentration at the well equals zero, then the subsurface extraction rate equals the volumetric flow rate. The portions of these curves with zero subsurface extraction correspond to periods of high barometric pressure when flow is into the well or to periods in which the concentration equals unity (i.e., pure atmospheric air). The relative concentrations of atmospheric and subsurface gas in the effluent gas stream are a function of the previous barometric pressure event. In the absence of a check valve, the longer the period of high barometric pressure and/or the greater the barometric pressure, the greater the mixing of atmospheric and subsurface gas. This results in lower relative concentrations of subsurface gas in the effluent gas stream. The cumulative volume of extracted subsurface gas can be obtained by integrating curves similar to what is shown in Figure 9. For a 1200-hour simulation period, the cumulative volumes with and without a check valve were 7730 and 2880 m^3, respectively. The extraction of subsurface gas increases approximately 270% with the implementation of a well check valve.

The transport model was also used to evaluate the effects of dispersivity on mixing. The first 250 hours of the barometric pressure data were used in this simulation, and the well was modeled without a check valve. Longitudinal and transverse dispersivities of 300 and 30 cm were used in the first simulation, and values of 30 and 3 cm were used in the second. Extraction rates for the two simulations are plotted in Figure 10. The time lag between the two cases is the result of less mixing with the lower dispersivities. Cumulative subsurface gas extraction volumes for longitudinal dispersivity values of 300 and 30 cm were 588 and 273 m^3, respectively, for the 250 hours of the simulation.

Contaminant Filters

Canister resistance values were assumed to range from 5000 and 16,000 s. These values are based on data for activated carbon provided by Calgon Carbon Corp. (1994). The same 350-hour interval of barometric pressure data used in the primary calibration was used for the filter simulations.

The cumulative volumes of flow for the three scenarios can be obtained by integrating the absolute values of the curves shown in

Figure 11. With no filter, the cumulative flow through the well is 5290 m^3 during the 350 hours of simulation. (It should be noted that the net flow through the well during this period is -354 m^3.) Including a canister with resistance of 5000 or 16,000 s results in a cumulative flow of 3940 and 2140 m^3, respectively. This suggests that carbon filters of the dimensions used in these simulations can reduce well flow from 25 to nearly 60%, depending on the activated carbon specifications.

Conclusions

The field data described in this study confirms that fluctuations in barometric pressure cause pressure gradients in the subsurface and that low-permeability layers accentuate these effects. Observed pressure differentials were on the order of 200 to 500 Pa for the shallow unit and on the order of 1000 to 1500 Pa for deeper probes located beneath the low-permeability caliche layer. These pressure differentials result in outflow during low barometric events. During a 38-hour period of low barometric pressure, approximately 500 m^3 of air were vented from the subsurface. Approximately 27 grams of carbon tetrachloride were removed from the subsurface during this same outflow event. Extraction rates on the order of 1 to 20 kilograms of carbon tetrachloride per year were observed in individual wells at the 200-West area.

The field data show that there is typically a lag between the time when air begins to flow out of the well and the time when the carbon tetrachloride concentration begins to increase. This lag is caused by relatively clean air that had entered the subsurface during the previous period of air inflow. The length of this lag is also a measure of the amount of subsurface mixing that occurs. Small values for dispersivity result in less mixing and larger lag times.

The results of the model calibration indicate that the match between calculated and observed flow rates depends on the estimated gas conductivity for the intermediate and the deep units. Simulations are relatively insensitive to the shallow unit conductivity provided the value is greater than approximately 3.0×10^{-4} cm/s. Computer simulations based on the field data collected at the site suggest that surface covers smaller than 30 m radius result in relatively small enhancements of flow for the 200-West area. With larger surface seals (i.e., up to 90 m radius), volumetric flow rates more than doubled. These simulations also show that check valves may increase the rate at which subsurface gases are extracted by a factor of nearly 3. For the 1200 hour period that was simulated in this study, the cumulative volume of extracted subsurface gas was 2880 m^3 without a check valve and was 7730 m^3 with a check valve. These estimates are sensitive to the value assumed for dispersivity. Decreasing the dispersivity by an order of magnitude (from 300 to 30 cm) results in a 50% reduction in extraction volume. Filters used to treat effluent gases from passive extraction systems can significantly reduce the effectiveness of these systems. Activated granular carbon filters of the dimensions used in these simulations can reduce well flow from 25 to nearly 60%, depending on the activated carbon specifications.

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REGENESIS 3-D Microemulsion® Factory Emulsified

Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion

PRODUCT APPLICATION INSTRUCTIONS

3-D Microemulsion® Factory Emulsified

As delivered, the 3-D Microemulsion factory emulsified product is a significant change compared to the physical state of standard 3-D Microemulsion. Whereas the standard 3-D Microemulsion is delivered in a concentrate form that requires an emulsification step prior to application, factory emulsified 3-D Microemulsion is delivered as a ready-to-apply, factory emulsion. It does not require shearing or any another other emulsion making steps. The only pre-application requirement is a quick stir and any required/recommended dilution of the factory emulsified 3-D Microemulsion with an appropriate volume of clear water.

Material Overview Handling and Safety

3-D Microemulsion factory emulsified is shipped and delivered as an emulsion of 2 part water to 3 parts active ingredient. Packaging is available in 275 gallon totes and/or 55 gallon drums.

- Each tote typically has a gross weight of 2,000 pounds
- Each drum has a weight of 400 pounds

At room temperature, 3-D Microemulsion factory emulsified is a liquid material with an appearance and viscosity roughly equivalent to milk. The microemulsion is not temperature sensitive above 50ºF (10ºC). If the user plans to apply the product in cold weather, consideration should be given to warming the material to above 50ºF so that it can be more easily handled. The material should be stored in a warm, dry place. It is common for stored factory emulsified 3-D Microemulsion to settle somewhat in the container while in transit, a quick pre-mix stir using a hand held drill, equipped with paint mixer attachment will rapidly re-homogenize the microemulsion. Factory emulsified 3-D Microemulsion is non-toxic, however field personnel should take precautions while handling and applying the material. Field personnel should use appropriate personal protection equipment (PPE) including eye protection. Gloves should be used as appropriate based on the exposure duration and field conditions. A Material Safety Data Sheet (MSDS) is provided with each shipment. Personnel who operate field equipment during the installation process should have appropriate training, supervision, and experience and should review the MSDS prior to site operations.

REGENESIS 3-D Microemulsion® Factory Emulsified

Factory Emulsified, pH Neutral, Staged Release, Electron Donor Emulsion

PRODUCT APPLICATION INSTRUCTIONS

3-D Microemulsion® Factory Emulsified Field Homogenization using a Cordless Drill Equipped with a Paint Mixing Attachment

Design and Specifications

Designs for 3-D Microemulsion factory emulsified remain unchanged from standard 3-D Microemulsion. An additional application method has been added with the use of a Dosatron® metering system.

Composition and associated physical properties of factory emulsified 3-D Microemulsion are as follows:

Density: is approximately 1 g/cc (8.34 lbs/gallon) at 20°C/68°F
Physical Form: liquid, composed of 2 part water to 3 parts Factory Emulsified 3-D Microemulsion (2:3)

The 3-D Microemulsion factory emulsion can be diluted water a (v/v) volume to volume basis to produce the desired diluted concentration. Most typical concentrations range from 1 to 10% (v:v); more dilute concentrations can be easily produced using the water volumes provided in the table below.

Higher dilution rates are governed by the following technical considerations:

- Factory emulsified 3-D Microemulsion required to treat the estimated contaminant mass
- Target pore volume in which the Factory Emulsified 3-D Microemulsion is applied
- Available application time (aquifer acceptance rate)

PRODUCT APPLICATION INSTRUCTIONS

Although using a more dilute microemulsion will produce a greater volume of the material, it will also lower the delivered concentration. Thus, the benefit of using a higher dilution rate (to affect a greater pore volume of the subsurface aquifer) is offset by the lower factory emulsified 3-D Microemulsion concentration. Another important consideration is the aquifer's capacity to accept the volume of material (i.e., the aquifer's hydraulic conductivity and effective/mobile porosity).

It is important that the user consider the 3-D Microemulsion factory emulsion dilution rate to be employed at a project site. The resulting emulsion volume will dictate the site water requirements and the time required for injection, etc. If the subsurface does not readily accept the volume as designed, the user can simply reduce the amount of water, thereby lowering the volume of subsequent batches. For more information on design and material dilution rates to meet specific site conditions, please contact Regenesis Technical Services.

The following table provides a quick reference to the dilution water necessary for some common application rates:

3-D Microemulsion Factory Emulsified (%)	3-D Microemulsion Factory Emulsified (mg/L)	3-D Microemulsion Factory Emulsified (gal)	Clear Water (gal)	Resulting Volume (gal)
10	100,000	1	9	10
5	50,000	1	19	20
3	30,000	1	32	33
2	20,000	1	49	50
1	10,000	1	99	100

EXAMPLE: Create a 50,000 mg/L factory emulsified 3-D Microemulsion material

- Dilute each gallon of material with 19 gallons of water resulting in a 20 gallon material volume

3-D Microemulsion® Factory Emulsified Dilution

There are two basic approaches for dilution of factory emulsified 3-D Microemulsion. These approaches are referred to as "on demand" and "batched" and are discussed below:

PRODUCT APPLICATION INSTRUCTIONS

On Demand – Dosatron® Metering System

This method consists of the dilution and application of factory emulsified 3-D Microemulsion in "real time". This is typically accomplished at the well head and is used almost exclusively via dedicated injection well applications. These systems are designed to dilute the material "in-line" and on an "as needed" basis. The most common metering system used for this purpose is the Dosatron® System. This is a volume-based metering system that is positioned at the surface and on individual well heads. These units create a targeted dilution of factory emulsified 3-D Microemulsion in water by metering a set volume of the material into a set volume of clear water passing through and powering the device. Thus, fluctuations in the water flow volume or pressure will not result in a change in the rate of factory emulsified 3-D Microemulsion delivered. This device will maintain consistent water to emulsion ratio regardless of water flow rate or pressure.

NOTE: prior to use, each drum or tote of factory emulsified 3-D Microemulsion should be stirred thoroughly using a paint mixer equipped drill.

In this method, each delivery point is manifold to a central clear water holding tank via a manifold system as shown below. Typically, a single pump is placed between the holding tank and the manifold, this pump is used to pressurize the system and to maintain the flow of clear water through the manifold and to the individual application points. A flow meter/totalizer, pressure gauge and ball check valve should be present between the manifold effluent and each Dosatron unit to allow the applier to regulate and monitor individual application rates. This will aid in determining each application point's optimal acceptance rate. Please refer to the User's Manual for your Dosatron. Additional information and specific set up information is available on the Dosatron® Website at http://www.dosatronusa.com/search-results.aspx?QueryExpr=manuals .

PRODUCT APPLICATION INSTRUCTIONS

Dilution of the Factory Emulsified 3-D Microemulsion® in a Batched Configuration

Batched

This method consists of preparing a pre-determined volume of dilute factory emulsified 3-D Microemulsion and storing it in a batch tank until applied. Delivery of the dilute microemulsion can be to a single delivery point (or well) or multiple delivery points via a manifold system, in either case the injection location must be plumbed to the factory emulsified 3-D Microemulsion holding tank and account for the issues outlined in the Application Methods introduction (below). The delivery of dilute microemulsion is typically via wells or direct push injection points that are connected to the central diluted microemulsion tank via a manifold system and include a dedicated inline flow meter/totalizer, pressure gauge and ball valve for each well or injection point. Often a single pump is placed between the dilute microemulsion tank and the manifold, this pump is used to pressurize the system and maintain flow of the dilute factory emulsified 3-D Microemulsion through the manifold and application points. The flow meter/totalizer and pressure gauge allow the applier to monitor application rates and back pressure for each well or injection point and thus the aquifer's acceptance rate. A simple manifold system with pressure gauges and flow meter/totalizer is shown below. NOTE: upon dilution the material should be stirred on a periodic and regular basis (as shown above).

PRODUCT APPLICATION INSTRUCTIONS

Factory Emulsified 3-D Microemulsion® Application

The application of the dilute factory emulsified 3-D Microemulsion is typically accomplished by injection via direct-push points (DPI) or dedicated injection wells. Regardless of which delivery option is used, dilution of the factory emulsion prior to application is most appropriate. Application can be performed using pressure or gravity feed.

At a minimum the applier should use the following instrumentation to monitor application:

- Pressure gauges
  - psi range should be selected based site specific conditions
    - aquifer conductivity (anticipated aquifer acceptance rate)
    - pump type (e.g. double diaphragm vs. positive displacement pumps)
    - application methods [Direct Push Injection vs. Injection Wells]
    - not-to-exceed pressures
- In-Line Flow Meters
  - range should be selected based on site specific requirements
- Pressure-Relief Valves for prevention of pressure buildup in various segments of the application tooling
  - positioning of pressure relief valves should be considered in the following locations
    - At or along product delivery lines or manifold
    - The injection well head or direct push injection rod → product delivery hose connection

For direct assistance or more information contact us at 1-949-366-8000 or send an e-mail to tech@regenesis.com

REGENESIS
Advanced Technologies for Groundwater Resources

Bio-Dechlor INOCULUM PLUS™

Bio-Dechlor INOCULUM PLUS (BDI PLUS™)

Application Instructions

(Direct-Push Injection)

General Information

Bio-Dechlor INOCULUM PLUS (BDI PLUS™) is an enriched natural microbial consortium containing species of *Dehalococcoides.* This microbial consortium has since been enriched to increase its ability to rapidly dechlorinate contaminants during *in situ* bioremediation processes. BDI PLUS has been shown to stimulate the rapid and complete dechlorination of compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). BDI PLUS also contains microorganisms capable of degrading chloromethanes (carbon tetrachloride and chloroform) as well as chloroethanes like trichloroethane (TCA).

Recent trends in engineered bioremediation indicate that the treatment of chlorinated solvent contamination sometimes results in slow or incomplete degradation of the intermediate compounds. When faced with this circumstance, bioaugmentation with a microbial consortium such as BDI PLUS offers a solution to accelerate or simply make possible the complete dechlorination of these otherwise recalcitrant compounds.

Regenesis believes that the best approach to install BDI PLUS into the subsurface is by direct-push methods. This allows for the BDI PLUS solution to be applied directly into the aquifer material and provides greater coverage/treatment over the life of the project. As a minimum, the following equipment will be needed to perform this type of installation:

- Direct-push drilling unit
- Grout pump (e.g. Geoprobe GS 2000)
- Appropriate hose assembly including a fitting that links a hose from the grout pump to the direct-push rods (provided by Regenesis with shipment)
- One or more 55+ gallon water drums, fitted with an appropriate lid that has at least one bung hole (number of drums depends on size of application)
- Rotary transfer pump (or equivalent) with appropriate amount of hose to connect from 55-gal drum to hopper of grout pump (similar to Grainger No. 1P893, Fill-Rite model #FR112GR))
- Compressed Nitrogen gas tank with appropriate regulator **(0 to 15 pounds per square inch (psi)).** A 300-ft^3 tank should be sufficient for discharge of concentrated or non-concentrated kegs and for nitrogen sparging to deoxygenate batch water.
- Pressure washer (or equivalent) for cleaning

Material Packaging and Safety

BDI PLUS is a mixture of living bacteria including members of the *Dehalococcoides* genus that are capable of anaerobically degrading chlorinated contaminants. The culture has been tested to ensure that it is free of the most common pathogenic bacteria, but like all living cultures it should be handled with due care to prevent contamination of work surfaces or field personnel.

During installation activities, Regenesis recommends that field personnel use at least level "D" personal protection equipment (PPE). A Materials Safety Data Sheet (MSDS) is sent with each shipment and should be reviewed before proceeding with installation activities.

WARNING

- The BDI PLUS container is pressurized to 10 to 15 psi with Nitrogen before shipping.
- Wear suitable eye protection, gloves, respirator and protective clothing.
- Gas cylinders used to dispense culture MUST be equipped with a proper pressure regulator.
- During operation DO NOT exceed the containers maximum working pressure of 15 psi.

UNPACKING

1. Carefully remove the container from shipping cooler and stand upright. DO NOT use the plastic sight tube as a handle.
2. Carefully check the container, connectors, valves and tubing for any damage or defects. If defects or damage is observed, do not use. Report any damage to Regenesis at 949-366-8000. A back up set of quick connects is provided in the packaging material.
3. Check and ensure that all valves are in the CLOSED position.

Culture Keg in Cooler

STORAGE

If the schedule of bacteria application requires adding the bacteria over a period of more than one day, the keg(s) should be stored at a temperature 2-4 °C, but freezing must be avoided. This can normally be achieved by storing the kegs under ice in the provided coolers. Keg should be pressurized with Nitrogen to pressure 10- 15 psi. before storing to ensure a tight seal on the keg cap.

SHIPPING

After completion of operation, please, ship cooler with keg and all attachments back to the following address:

Shaw Environmental, Inc.
17 Princess Road, Lawrenceville, NJ 08648

Specific Installation Procedures

1. The BDI PLUS must be added to the previously prepared "oxygen-free" water before it is installed in the subsurface. The desired amount of BDI PLUS should be carefully discharged into the 55-gal drum containing the appropriate amount of "oxygen free" water. The tables provided below indicates the amount of water that a given amount of BDI PLUS should be mixed with.

   The BDI PLUS must be added to "oxygen-free" water before it is installed in the subsurface. To ensure that the water has reached the desired anoxic state prior to mixing with BDI PLUS an appropriate amount of nitrogen sparging into the 55-gal drum containing a given amount of water at least **one hour** prior to adding the BDI PLUS. To ensure that a sufficient quantity of "oxygen free" water is available throughout the day, a large trough of "nitrogen sparged" water can be prepared and additional 55-gal drums can be filled from this trough. The water in the trough can be transferred to the 55-gal drums where the BDI is mixed with the water using a primed transfer pump.

   Nitrogen sparging is accomplished by a gas sparging device equivalent to a fish tank aerator. Adjust the 300ft^3 nitrogen tank pressure regulator to 3-5 psi and immerse the gas sparger to the bottom of the drum or trough. By internal convection and oxygen stripping processes, the oxygen levels should diminish within an hour. Be careful to not consume too much gas and not have nitrogen to empty the kegs. Keeping an eye on tank pressure loss and dissolved oxygen level will indicate when one can trim down on the sparge pressure and conserve the nitrogen.

Volume of BDI PLUS™	**Volume of water**
5 liters	50 gal
1 liter	10 gal

Volume of BDI PLUS™ **concentrate**	**Volume of water**
0.5 liters	50 gal
0.1 liter	10 gal

BDI PLUS Dilution Chart

2. The drive rod assembly should be fitted with a disposable tip on the first drive rod and pushed down to the desired depth. This process should be done in accordance with the manufacturer's standard operating procedure (SOP).
3. A sub-assembly connecting the delivery hose to the drive rods and pump should be used. The sub-assembly should be constructed in a manner that allows for the drive rods to be withdrawn while the material is being pumped.
4. Prior to connecting the hose to the sub-assembly a volume check should be completed to determine the volume and weight of product displaced with each pump stroke.
5. After the drive rods have been pushed to the desired depth, the rod assembly should be withdrawn three to six inches so that the disposable tip has room to be dropped.
    a. If an injection tool is used instead of an expendable tip, the application of material can take place without any preliminary withdrawal of the rods.
6. Fill the annular space of the drive rods with water. This will minimize the amount of air introduced to the system.

7. Insert the telescoping suction pipe on the rotary transfer pump into a bung hole on the lid of the 55-gal drum and make sure that the pipe reaches the bottom of the drum. If possible, attach the suction pipe to the bung hole with the 2" bung adapter to ensure that the pump remains securely in place while pumping the Bio-Dechlor INOCULUM mixture from the drum to the pump hopper.
8. Attach the hose to the outlet of the rotary transfer pump making sure that the opposite end of the hose reaches the pump hopper. Open the opposite bung hole on the drum lid to prevent a vacuum then pump the desired amount of BDI PLUS solution into the hopper of the pump.
9. Connect the hose from the grout pump to the drive rod assembly.
10. Start pumping the BDI PLUS product solution.
11. The initial volume of BDI PLUS solution pumped should only be enough to displace the water within the drive rods. Once this is done the actual injection can start.
12. Begin withdrawing the drive rods, in accordance with the manufacturer's SOP, and start pumping the BDI PLUS solution simultaneously. The dosage should be 0.1 liter per vertical foot or 1 gallon per vertical foot if prepared using the BDI dilution chart. The withdrawal rate should be such that it allows the appropriate quantity of material to be injected into each vertical foot of aquifer being treated. The withdrawal rate should be slow to avoid creating a vacuum. This vacuum can potentially pull a small volume of material to the surface if the drive rods are withdrawn too quickly.
13. In less permeable soils such as clays and silts, there may be difficulty accepting the volume of estimated material. In this case Regenesis recommends using a "step-wise" application approach. For this approach we suggest withdrawing the drive rods in one-foot increments and then injecting the quantity of material required per vertical foot.
14. Look for any indications of aquifer refusal such as:
    - Excessive pump noise or application pressure spikes (e.g. squealing)
    - Surfacing of material through the injection point ("blow-by")

If acceptance appears to be an issue it is critical that the aquifer is given enough time to equilibrate before breaking down the drive rods and/or removing the hose. The failure to do this can lead to excessive back flow of the BDI PLUS material on personnel, equipment, and the ground surface.

15. If BDI PLUS solution continues to "surface" after the drive rods have been completely removed from the borehole a plug may be necessary. Large diameter disposable tips or wood stakes have been used successfully for this purpose.
16. Drive rods should be disconnected after one rod (typically 4 feet in length) has been withdrawn. The drive rods should be placed in a bucket (or equivalent) after they have been disconnected.
17. Complete the installation of the BDI PLUS solution at the designated application rate across the entire targeted vertical interval.
18. After the injection is completed, an appropriate seal should be installed above the vertical interval where the BDI PLUS solution has been placed to prevent contaminant migration. Typically, bentonite powder or chips are used to create this seal. However, consultants should review local regulations before beginning field installation activities to confirm that this approach can be used.
19. Complete the borehole at the surface as appropriate using concrete or asphalt.
20. Repeat steps 7 through 19 until the entire application has been completed. If additional drums of de-oxygenated water are required, prepare as suggested in Step 1.
21. Prior to the installation of BDI PLUS, all surface and overhead impediments should be identified as well as the location(s) of any underground structure(s). Underground structures include but are not limited to: utility lines (gas, electrical, sewer, etc), drain piping, and landscape irrigation systems.
22. The planned injection locations should be adjusted in the field to account for impediments and obstacles.
23. The actual injection locations should be marked prior to the start of installation activities to facilitate the application process.
24. Using an appropriate pump to install the BDI PLUS product is very critical to the success of the application as well as the overall success of the project. Based on our experience in the field, Regenesis strongly recommends using a pump that has a pressure rating of at least 1,000 psi and a delivery rate of at least 3 gallons per minute.

    If the application involves both HRC and BDI PLUS, two separate pumps may be required to facilitate the process. The pump used to deliver HRC to the subsurface should be in accordance with the specifications outlined in the General Guidelines section of the HRC Installation Instructions.

Additional Information

The internal workings of the grout pump can be cleaned easily by recirculating a solution of hot water and a biodegradable cleaner (e.g. Simple Green) through the pump and delivery hose(s). If additional cleaning and decontamination is required it should be conducted in accordance with the manufacturer's SOP and local regulatory requirements.

Note: Regenesis assumes that all of the material (microorganisms) sent to a site for installation purposes will be used for that particular project and that no material (microorganisms) will be left over at the conclusion of the installation activities.

REGENESIS
Advanced Technologies for Groundwater Resources

1011 Calle Sombra
San Clemente, CA 92673
949-366-8000

3-D MICROEMULSION® FACTORY EMULSIFIED

3-D MicroEmulsion®
FACTORY EMULSIFIED

STAGED RELEASE, pH NEUTRAL, FACTORY EMULSIFIED ELECTRON DONOR

DESCRIPTION

Factory emulsified 3-D Microemulsion is a unique electron donor material that offers an engineered, 3 stage electron donor release profile, pH neutral chemistry and is delivered on-site as a factory emulsified material. This new molecule also exhibits a novel hydrophile-lipophile balance (HLB) which provides maximum subsurface distribution well beyond that of emulsified vegetable oils.

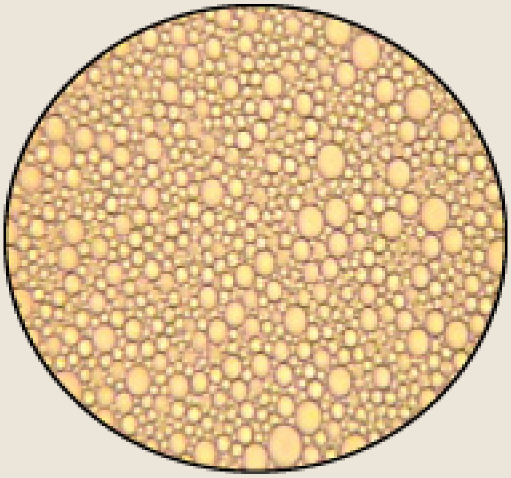

FIGURE 1: Microscopic view of factory emulsified 3-D Microemulsion.

FEATURES & BENEFITS

- **3 Stage Electron Donor Release Profile Avoids Multiple Re-applications Saving Time and Money**

  This feature optimizes start to finish timing of the enhanced reductive dechlorination process through an immediate, mid-range and long-term electron donor release. Without a 3 stage release profile, bioremediation efforts are inefficient, causing gaps in electron donor supply and requiring multiple injections. Factory emulsified 3-D Microemulsion offers a 3 stage electron donor release for optimal results (Figure 2).

Stage 1 - Immediately available free lactic acid (lactate) is fermented rapidly

Stage 2 - Controlled-release lactic acid (lactate esters and polylactate esters) are metabolized at a more controlled rate

Stage 3 - Free fatty acids and fatty acid esters are converted to hydrogen over a mid to long-range timeline giving factory emulsified 3-D Microemulsion an exceptionally long electron donor release profile

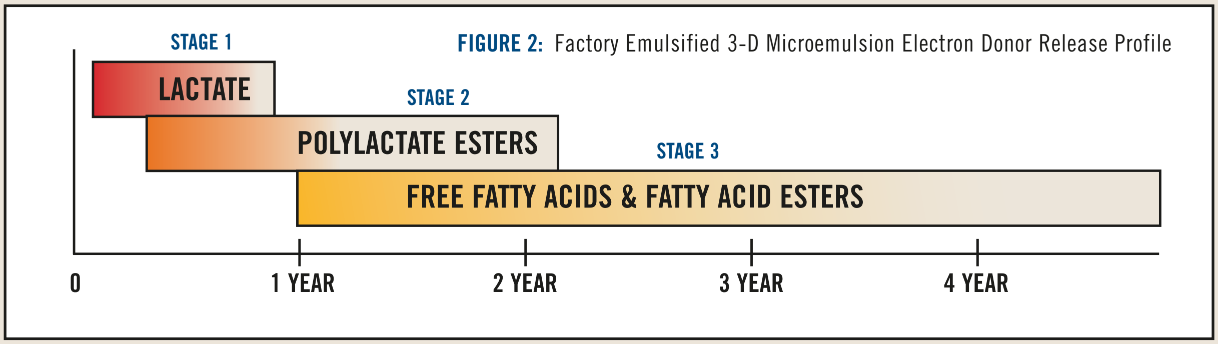

FIGURE 2: Factory Emulsified 3-D Microemulsion Electron Donor Release Profile

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REGENESIS
Advanced Technologies for Contaminated Site Remediation

3-D MicroEmulsion®
FACTORY EMULSIFIED

STAGED RELEASE, pH NEUTRAL, FACTORY EMULSIFIED ELECTRON DONOR

FEATURES & BENEFITS

- **A Unique Hydrophile/Lipophile Balance (HLB) Enhances Distribution and Limits Reduction in Hydraulic Conductivity**

  The HLB feature allows the product to distribute in the subsurface via micellar movement. During this process, microscopic colloidal aggregates (micelles) continuously propagate from areas of high concentration to those of lower concentration moving the factory emulsified 3-D Microemulsion electron donor material into areas beyond those affected by the initial injection. This enhanced distribution mechanism allows for greater spacing between injection points and less time required for material application. Additionally, due to its unique hydrophile-lipophile balance, applications of factory emulsified 3-D Microemulsion have not resulted in the significant aquifer blockage as seen with the use of emulsified oil products.

FIGURE 3: A 2000 lb. tote of factory emulsified 3-D Microemulsion. The material can be delivered in drums, totes or tanker trucks.

- **Highly Efficient Application Designs**

  When designing an *in situ* remediation project with factory emulsified 3-D Microemulsion, application designs are based on mass balance and stoichiometric demand from the contaminant, competing electron acceptors and a minimum total organic carbon (TOC) loading. This often results in a more efficient dosing requirement compared to design methods employed by other electron donor suppliers.

- **Neutral pH**

  Neutral pH minimizes potentially harmful impacts to beneficial biodegrading microorganisms required to metabolize chlorinated contaminants. This feature can be highly valuable when the microemulsion is used in conjunction with pH-sensitive commercial bioaugmentation cultures

- **Injection-Ready Formulation, Simple and Easy Application**

  3D Microemulsion is delivered on-site as a factory emulsified, injection-ready product. It can be applied as delivered or further diluted and mixed with additional site water to form a higher-volume ready-to-inject microemulsion. This material can be applied through a variety of application techniques including permanent or temporary injection wells and direct-push points.

- **Choose from a Range of Packaging Options**

  Factory emulsified 3-D Microemulsion can be delivered in 400 lb. drums, 2000 lb. totes and large volume tanker trucks making shipping, receiving and application on any site simple and convenient (Figure 3).

Accelerate the process of complete dechlorination

Bio-Dechlor INOCULUM® (Dechlorinating Microbes)

BIOAUGMENTATION TO ACCELERATE THE PROCESS OF COMPLETE DECHLORINATION

Bio-Dechlor INOCULUM® is an enriched natural microbial consortium containing species of *Dehalococcoides* sp. (DHC). This microbial consortium has since been enriched to increase its ability to rapidly dechlorinate contaminants during in situ bioremediation processes. Bio-Dechlor INOCULUM has been shown to stimulate the rapid and complete dechlorination of compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). The most current culture of Bio Dechlor INOCULUM PLUS(+) now contains microbes capable of dehalogenating halomethanes (e.g. carbon tetrachloride and chloroform) and haloethanes (e.g. 1,1,1 TCA and 1,1, DCA) as well as mixtures of these halogenated contaminants.

Bio-Dechlor INOCULUM PLUS(+) is provided in a liquid form and is designed to be injected directly into the contaminated subsurface. Once in place, this microbial consortium works to accelerate the extant rate of chlorinated ethene degradation. When faced with an insufficient quantity of critical dechlorinating microbes, Bio-Dechlor INOCULUM PLUS(+) supplies many beneficial chlorinated solvent degraders including the all important DHC required to achieve complete and rapid dechlorination.

This microbial consortium is compatible with most electron donors however it is often optimized with the addition of any of Regenesis' Hydrogen Release Compound (HRC®) products.

SPECIES OF *DEHALOCOCCOIDES* SP. (DHC)

DETECTION AND QUANTIFICATION OF *DEHALOCOCCOIDES* (DHC) IN THE SUBSURFACE

The advent of modern biotechnology has allowed the development of unique and rapid genetic assays for the detection of microorganisms. Bio-Dechlor CENSUS℠, an example of this advance, offers a state-of-the-art technique for the quantitative detection of *Dehalococcoides*, the microbe shown to be required for complete biodegradation of higher chlorinated compounds through to ethene.[1, 2]

Existing analytical technologies offer only a crude qualitative assessment (+/-) of the presence of the required *Dehalococcoides* species. These tests utilize a common technique known as the Polymerase Chain Reaction (PCR), whereby traces of DNA specific only to microbes of interest (their "fingerprint") are amplified from environmental samples such that they can be detected. This approach, unfortunately, does not allow for specific quantification of the existing and present microbial population, leaving the environmental professional with insufficient information for complete site assessment and management.

Regenesis now offers a solution to the quantification dilemma, Bio-Dechlor CENSUS. This census of critical microorganisms is a proprietary analysis and is provided by specialized laboratories in the environmental industry. Bio-Dechlor CENSUS utilizes a process termed "Real-Time PCR" in which the DNA amplification step is actually quantified with a fluorescent signal, indicating the number of target microbes in the sample (Figure 1). This valuable quantitative information allows environmental professionals to properly assess project sites for the potential for natural biodegradation of chlorinated contaminants and the degree of bioaugmentation that may be required.

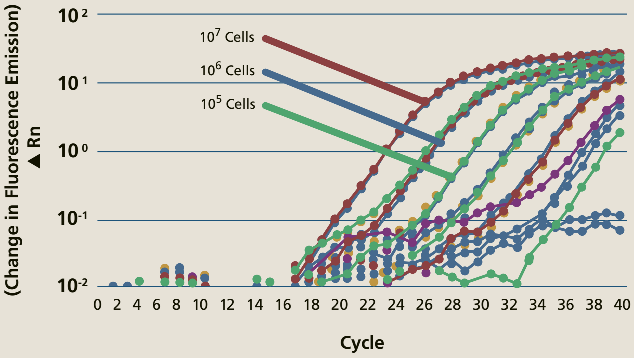

FIGURE 1: REAL-TIME PCR AMPLIFICATION OF 10-FOLD DILUTIONS OF GENOMIC DNA DERIVED FROM *DEHALOCOCCOIDES*

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1. Maymo-Gatell, X.; Y-T Chien; J.M Gossett; S.H. Zinder, Science 1997, 276, 1568-1571.
2. Löffler, F.E.; Q. Sun; J. Li; J.M. Tiedje; Applied Environmental Microbiology 2000, 66(4), 1369-1374.

3-D Microemulsion (3DMe)™
MATERIALS SAFETY DATA SHEET

Last Revised: March 26, 2007

Section 1 – Material Identification

Supplier:

REGENESIS

1011 Calle Sombra
San Clemente, CA 92673

Phone:	**949.366.8000**
Fax:	**949.366.8090**
E-mail:	**info@regenesis.com**

Chemical Name(s):	• Glycerides, di-, mono [2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxyl]-1-oxopropoxy]propanoates] • Propanoic acid, 2-[2-[2-(2-hydroxy-1-oxopropoxy)-1-oxopropoxy]-1-oxopropoxy]-1,2,3-propanetriyl ester • Glycerol
Chemical Family:	**Organic Chemical**
Trade Name:	**3-D Microemulsion (3DMe)™**
Synonyms:	**HRC Advanced™ HRC-PED (Hydrogen Release Compound – Partitioning Electron Donor)**
Product Use:	**Used to remediate contaminated groundwater (environmental applications)**

Section 2 – Chemical Identification

CAS#	**Chemical**
823190-10-9	**HRC-PED**
61790-12-3 or **112-80-1**	**Fatty Acids (neutralized)**
201167-72-8	**Glycerol Tripolylactate**
56-81-5	**Glycerol**

Section 3 – Physical Data

Melting Point:	**Not Available (NA)**
Boiling Point:	**Not determined (ND)**
Flash Point:	**> 200 ºF using the Closed Cup method**
Density:	**0.9 -1.1 g/cc**
Solubility:	**Slightly soluble in acetone. Insoluble in water.**
Appearance:	**Amber semi-solid.**
Odor:	**Not detectable**
Vapor Pressure:	**None**

Section 4 – Fire and Explosion Hazard Data

Extinguishing Media:	**Use water spray, carbon dioxide, dry chemical powder or appropriate foam to extinguish fires.**

Water May be used to keep exposed containers cool.

For large quantities involved in a fire, one should wear full protective clothing and a NIOSH approved self contained breathing apparatus with full face piece operated in the pressure demand or positive pressure mode as for a situation where lack of oxygen and excess heat are present.

Section 5 – Toxicological Information

Acute Effects:	**May be harmful by inhalation, ingestion, or skin absorption. May cause irritation. To the best of our knowledge, the chemical, physical, and toxicological properties of the 3-D Microemulsion have not been investigated. Listed below are the toxicological information for glycerol, lactic acid and fatty acid.**	
RTECS#	**MA8050000** **Glycerol**	
Irritation Data:	**SKN-RBT 500 MG/24H MLD**	**85JCAE-,207,1986**
	EYE-RBT 126 MG MLD	**BIOFX* 9-4/1970**
	EYE-RBT 500 MG/24H MLD	**85JCAE-,207,1986**

Section 5 – Toxicological Information (cont)

Toxicity Data:	**ORL-MUS LD50:4090 MG/KG**	**FRZKAP (6),56,1977**
	SCU-RBT LD50:100 MG/KG	**NIIRDN 6,215,1982**
	ORL-RAT LD50:12,600 MG/KG	**FEPRA7 4,142,1945**
	IHL-RAT LC50: >570 MG/M3/1H	**BIOFX* 9-4/1970**
	IPR-RAT LD50: 4,420 MG/KG	**RCOCB8 56,125,1987**
	IVN-RAT LD50:5,566 MG/KG	**ARZNAD 26,1581,1976**
	IPR-MUS LD50: 8,700 MG/KG	**ARZNAD 26,1579,1978**
	SCU-MUS LD50:91 MG/KG	**NIIRDN 6,215,1982**
	IVN-MUS LD50:4,250 MG/KG	**JAPMA8 39,583,1950**
	ORL-RBT LD50: 27 MG/KG	**DMDJAP 31,276,1959**
	SKN-RBT LD50: >10 MG/KG	**BIOFX* 9-4/1970**
	IVN-RBT LD50: 53 MG/KG	**NIIRDN 6,215,1982**
	ORL-GPG LD50: 7,750 MG/KG	**JIHTAB 23,259,1941**

Target Organ Data: **Behavioral (headache), gastrointestinal (nausea or vomiting), Paternal effects (spermatogenesis, testes, epididymis, sperm duct), effects of fertility (male fertility index, post-implantation mortality).**

Only selected registry of toxic effects of chemical substances (RTECS) data is presented here. See actual entry in RTECS for complete information on lactic acid and glycerol.

Fatty Acids

Acute oral (rat) LD50 value for fatty acids is 10000 mg/kg. Aspiration of liquid may cause pneumonitis. Repeated dermal contact may cause skin sensitization.

Section 6 – Health Hazard Data

One should anticipate the potential for eye irritation and skin irritation with large scale exposure or in sensitive individuals. Product is not considered to be combustible. However, after prolonged contact with highly porous materials in the presence of excess heat, this product may spontaneously combust.

Handling: **Avoid continued contact with skin. Avoid contact with eyes.**

In any case of any exposure which elicits a response, a physician should be consulted immediately.

First Aid Procedures

Inhalation: **Remove to fresh air. If not breathing give artificial respiration. In case of labored breathing give oxygen. Call a physician.**

Ingestion: **No effects expected. Do not give anything to an unconscious person. Call a**

physician immediately. DO NOT induce vomiting.

Section 6 – Health Hazard Data (cont)

Skin Contact:	**Flush with plenty of water. Contaminated clothing may be washed or dry cleaned normally.**
Eye Contact:	**Wash eyes with plenty of water for at least 15 minutes lifting both upper and lower lids. Call a physician.**

Section 7 – Reactivity Data

Conditions to Avoid:	**Strong oxidizing agents, bases and acids**
Hazardous Polymerization:	**Will not occur.**
Further Information:	**Hydrolyses in water to form lactic acid, glycerol and fatty acids.**
Hazardous Decomposition Products:	**Thermal decomposition or combustion may produce carbon monoxide and/or carbon dioxide.**

Section 8 – Spill, Leak or Accident Procedures

After Spillage or Leakage:	**Neutralization is not required. The material is very slippery. Spills should be covered with an inert absorbent and then be placed in a container. Wash area thoroughly with water. Repeat these steps if slipperiness remains.**
Disposal:	**Laws and regulations for disposal vary widely by locality. Observe all applicable regulations and laws. This material may be disposed of in solid waste. Material is readily degradable and hydrolyses in several hours.**

No requirement for a reportable quantity (CERCLA) of a spill is known.

Section 9 – Special Protection or Handling

Should be stored in plastic lined steel, plastic, glass, aluminum, stainless steel, or reinforced fiberglass containers.

Protective Gloves:	**Vinyl or Rubber**
Eyes:	**Splash Goggles or Full Face Shield. Area should have approved means of washing eyes.**
Ventilation:	**General exhaust.**
Storage:	**Store in cool, dry, ventilated area. Protect from incompatible materials.**

Section 10 – Other Information

This material will degrade in the environment by hydrolysis to lactic acid, glycerol and fatty acids. Materials containing reactive chemicals should be used only by personnel with appropriate chemical training.

The information contained in this document is the best available to the supplier as of the time of writing. Some possible hazards have been determined by analogy to similar classes of material. No separate tests have been performed on the toxicity of this material. The items in this document are subject to change and clarification as more information becomes available.

REGENESIS
Advanced Technologies for Groundwater Resources

Material Safety Data Sheet (MSDS)

Bio-Dechlor INOCULUM PLUS (BDI PLUS™)

SECTION 1 - MATERIAL IDENTIFICATION AND INFORMATION

Material Name: DHC microbial consortium (SDC-9) MSDS #: ENV 1033

Date Prepared: 1/05/2006 CAS #: N/A (Not Applicable)

Prepared By: Simon Vainberg Formula #: N/A

Material Description: Non-hazardous, naturally occurring non-altered anaerobic microbes and enzymes in a water-based medium.

SECTION 2 - INGREDIENTS

Components	%	OSHA PEL	ACGIH TLV	OTHER LIMITS
Non-Hazardous Ingredients	100	N/A	N/A	N/A

SECTION 3 - PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point: 100°C (water)

Specific Gravity (H_2O = 1): 0.9 - 1.1

Vapor Pressure @ 25°C: 24 mm Hg (water)

Melting Point: 0°C (water)

Vapor Density: N/A

Evaporation Rate (H_2O = 1): 0.9 - 1.1

Solubility in Water: Soluble

Water Reactive: No

pH: 6.0 - 8.0

Appearance and Odor: Murky, yellow to grey water. Musty odor.

SECTION 4 - FIRE AND EXPLOSION HAZARD DATA

Flash Point: N/A

Flammable Limits: N/A

Extinguishing Media: Foam, carbon dioxide, water

Special Fire Fighting Procedures: None

Unusual Fire and Explosion Hazards: None

SECTION 5 - REACTIVITY DATA

Stability: Stable

Conditions to Avoid: None

Incompatibility (Materials to Avoid): Water-reactive materials

Hazardous Decomposition Byproducts: None

SECTION 6 - HEALTH HAZARD DATA

HEALTH EFFECTS

The effects of exposure to this material have not been determined. Safe handling of this material on a long-term basis will avoid any possible effect from repetitive acute exposures. Below are possible health effects based on information from similar materials. Individuals hyper allergic to enzymes or other related proteins should not handle.

Ingestion: Ingestion of large quantities may result in abdominal discomfort including nausea, vomiting, cramps, diarrhea, and fever.

Inhalation: Hypersensitive individuals may experience breathing difficulties after inhalation of aerosols.

Skin Absorption: N/A

Skin Contact: May cause skin irritation. Hypersensitive individuals may experience allergic reactions to enzymes.

Eye Contact: May cause eye irritation.

FIRST AID

Ingestion: Get medical attention if allergic symptoms develop (observe for 48 hours). Never give anything by mouth to an unconscious or convulsing person.

Inhalation: Get medical attention if allergic symptoms develop.

Skin Absorption: N/A

Skin Contact: Wash affected area with soap and water. Get medical attention if allergic symptoms develop.

Eye Contact: Flush eyes with plenty of water for at least 15 minutes using an eyewash fountain, if available. Get medical attention if irritation occurs.

NOTE TO PHYSICIANS: All treatments should be based on observed signs and symptoms of distress in the patient. Consideration should be given to the possibility that overexposure to materials other than this material may have occurred.

SECTION 7 - SPILL AND LEAK PROCEDURES

Reportable quantities (in lbs of EPA Hazardous Substances): N/A

Steps to be taken in case of spill or release: No emergency results from spillage. However, spills should be cleaned up promptly. All personnel involved in the cleanup must wear protective clothing and avoid skin contact. Absorb spilled material or vacuum into a container. After clean-up, disinfect all cleaning materials and storage containers that come in contact with the spilled liquid.

Waste Disposal Method: No special disposal methods are required. The material may be sewered, and is compatible with all known biological treatment methods. To reduce odors and permanently inactivate microorganisms, mix 100 parts (by volume) of SDC-9 consortium with 1 part (by volume) of bleach. Dispose of in accordance with local, state and federal regulations.

SECTION 8 - HANDLING AND STORAGE

Hand Protection: Rubber gloves.

Eye Protection: Safety goggles with side splash shields.

Protective Clothing: Use adequate clothing to prevent skin contact.

Respiratory Protection: Surgical mask.

Ventilation: Provide adequate ventilation to remove odors.

Storage & Handling:
Material may be stored for up to 3 weeks at 2-4°C without aeration.

Other Precautions: An eyewash station in the work area is recommended.

For Interim Remedial Measure, On-site: Soil Sampling, Groundwater Sampling, Slug Testing, Vapor Extraction System Installation at
New York State Department of Environmental Conservation,
Hazardous Waste Voluntary Cleanup Site No. V-00601-3
American Cleaners Store, 734 Ulster Ave, Kingston, NY 12401; Town & County of Ulster

A. SITE DESCRIPTION

Site: **American Cleaners Store, Dry Cleaning and Customer Service**
Date of Plan: May 1, 2011
Location: East Side of Ulster Avenue (aka Albany Ave), in free-standing building With parking area in front, back, north and south sides. Active Conrail tracks are located about 100 feet behind (east of) the American Cleaners building.
Hazards: Tetrachloroethene (PCE or Perc) was used in the dry cleaning process. A spill occurred in the parking area behind (south) of the building and waste PCE was placed in the dumpsters behind the building prior to hazardous waste control. PCE has migrated downward into the unconsolidated overburden sediments beneath the parking lot and under the building. PCE vapors have been detected next to the building and beneath the pavement in downgradient locations. Dissolved PCE has been detected in groundwater sampled from monitoring wells around the building and downgradient toward Ulster Avenue. Ambient air gas sampling with SUMMA canisters has shown no indoor air, outdoor air or subslab vapors contaminated with PCE above NYS DOH standards in Pauline’s Restaurant and two other buildings across Albany Avenue. Oil and gasoline spills were reported at nearby gas station along Ulster Avenue. A Meineke Car Care store is located next door on the south side of American Cleaners.
Topography: The building lies at an elevation of approximately 175 feet above sea level. The area is generally flat along Ulster Avenue for a half mile or more to the south and north. The land slopes moderately downhill from Route 9W to the railroad tracks behind the AC Building. On the west side of Ulster Avenue, the land slopes gently toward the north-flowing Esopus Creek approximately a half mile to the west. The direction of groundwater flow is approximately North 65° West.
Additional Information: American Cleaners continues to function as a dry cleaning operation with standard use of regulated solvents and standard operating procedures, which reduce human exposure and spillage of materials.

B. **CLEANUP OBJECTIVES** – The objective of this investigation is to define the extent and nature of tetrachloroethene contamination in soils and groundwater in the subsurface overburden materials surrounding the building.

C. **ONSITE ORGANIZATION AND COORDINATION** – The following personnel are designated to carry out the stated job functions on site. (Note: One person may carry out more than one job function.)

Health and Safety Officer …………………. Katherine J Beinkafner, PhD, CPG
Driller …………………………………………Todd Syska
American Cleaners Owner …………………. Erez Halevah
AC Site Manager ……………………………..Jay Scanlon
NYSDEC Oversight & Project Manager …. Parag B. Amin

All site visitors will also be given an introduction to the Health and Safety plan and relevant site procedures.
All personnel arriving or departing the site should log in and out with Katherine Beinkafner or Jay Scanlon. All activities on site must be cleared through Katherine or Jay.

D. ONSITE CONTROL

The Health & Safety Officer has been designated to coordinate access control and security on site. Because hazardous or toxic waste is beneath the ground surface, the work zone will be defined by traffic cones, which define a safe perimeter. No one should enter the work zone without the acknowledgement of the driller or project manager. A hot zone will be defined if a need arises. The decontamination zone will be a special area where drilling equipment is cleaned or safety gear is changed. If hazardous or toxic waste is detected through monitoring, the safety zones will immediately be established by the Health & Safety Officer.

A safe perimeter will be established with orange traffic cones and yellow or orange caution tape and will move with the drill rig from drilling location to drillkng location.
No unauthorized person should be within this area.
The onsite Command Post will be at the American Cleaner's front door if an emergency arises or at the back of the Credit Union if the front door is unsafe.
The staging area for drilling or other site operations will be on the north side of the building near the front so that people inside can see the equipment and workers outside.
The prevailing wind conditions are from the north and northwest, so the command post is upwind from the Work Zone.

E. HAZARD EVALUATION

The following substance(s) are known or suspected to be on site. The primary hazards of each are identified.

Substances Involved	Concentrations (If Known)	Primary Hazards
Tetrachloroethene	ND to 7800 ug/L in groundwater ND to 580,000 ug/m^3 in Soil Gas	

The following additional hazards are expected on site: uneven parking lot and paved areas, pot holes, weeds and overgrowth off the pavement.

Hazardous Substance Fact Sheet for tetrachloroethene is attached.

F. PERSONAL PROTECTIVE EQUIPMENT

Based on evaluation of potential hazards, the following levels of personal protection have been designated for the applicable work areas or tasks:

Location	Job Function	Level of Protection
Work Zone	Drilling, Sampling	D until higher levels needed.
Contamination	N/A	A B C D Other
Reduction Zone	N/A	A B C D Other

Specific protective equipment for each level of protection is as follows:

Level A	Fully encapsulating suit, SCBA (disposable coveralls)
Level B	Splash gear (type), SCBA
Level C	Splash gear (type), Full-face canister respirator
Level D	**Hard Hats, Gloves, Safety Steel-toe Boots, Safety Glasses, Long sleeve shirts, long work pants.**

The following protective clothing materials are required for the involved substance(s):

Substance	Material
(Chemical Name)	(material name, e.g. Viton)
none at this time	none at this time

If air-purifying respirators are authorized, (filtering medium) is the appropriate canister for use with the involved substances and concentrations. A competent individual has determined that all criteria for using this type of respiratory protection have been met. Appropriate canister type will be filled in if dust, hazardous gas or vapors are detected on site.

No changes to the specified levels of protection shall be made without the approval of the site safety officer and the project team leader.

G. ONSITE WORK PLANS

The work party and any substitutes will be listed on the Signature Page of this Health and Safety Plan.

H. COMMUNICATION PROCEDURES

All other onsite communications will use voice commands.
Personnel in the Work Zone should remain in constant contact with or within sight of the Project Team Leader. Any failure of communication or accident or emergency requires an evaluation of whether personnel should leave the Work Zone.
Continuing Intermittent Horn BEEPING is the emergency signal to indicate that all personnel should leave the Work Zone and meet at the Command Post.

The following standard hand signals will be used in case of failure of voice communications:

Hand gripping throat	Out of air, can't breathe
Grip partner's wrist or both hands around waist	Leave area immediately
Hands on top of head	Need assistance
Thumbs up	OK, I am all right, I understand
Thumbs down	No, negative

I. DECONTAMINATION PROCEDURES

Personnel and equipment in contact with contaminated soil or groundwater upon leaving the Work Zone shall be thoroughly decontaminated. The standard level "C" decontamination protocol shall be used with the following decontamination stations (if needed):

Emergency decontamination will include the following stations (if needed):

- Equipment Drop
- Outer Garment, Boots, and Gloves Wash and Rinse
- Outer Boot and Glove Removal
- Canister or Mask Change
- Boot, Gloves and Outer Garment Removal
- Face Plate Removal
- Field Wash

The following decontamination equipment is required:

- Buckets with Brushes
- Gallons of Distilled or Bottled Water
- Detergent
- Benches
- Plastic on Ground & Plastic Bags for Disposable items
- Spare Canisters for Respirators

Detergent and water will be used as the decontamination solution.

J. SITE-SPECIFIC SAFETY AND HEALTH PLAN

1. The Site Safety Officer and is directly responsible to the Project Team Leader for safety recommendations on site.
2. Emergency Medical Care

Emergency Medical Service: Hurley Avenue Medical
211 Hurley Avenue
Kingston, NY 12401
845 339-2804

Hospital with Emergency Room:	Kingston Hospital 396 Broadway
See map to Hospital	Kingston, NY 12401 (845) 331-3131

Ambulance Service: no listing in area, call Ulster Fire or 911

The following First-aid equipment is on site:

- First-aid kit
- Emergency eyewash
- Emergency shower spray

List of emergency phone numbers:

Agency/Facility	Phone #	Contact
Police	845 331-1671	City of Kingston Police
	845 382-1111	Town of Ulster Police
Fire	845 331-1211	City of Kingston Fire Dept
	845 339-1280	Ulster Hose Company #5 830 Ulster Avenue
Hospital	845 331-3131	Kingston Hospital
Ambulance	no local listings, call 911 or other services	

3. Environmental Monitoring (see attached Contingency Plan)

The following environmental monitoring instruments shall be used on site (cross out if not applicable) at the specified intervals.

Meter		Monitoring Frequency
Combustible Gas Indicator	-	excavation and fresh exposures
HNU/Microtip (VOCs)	-	excavation and fresh exposures

The following will be monitored if a relevant contingency plan is invoked:

Oxygen Monitor	-	continuous / hourly / daily / other
Colorimetric Tubes	-	continuous / hourly / daily / other
Air Temperature/Thermometer	-	continuous / hourly / daily / other
Radioactivity Meter	-	continuous / hourly / daily / other

4. Emergency Procedures (should be modified as required for incident)
The following standard emergency procedures will be used by onsite personnel. The Site Safety Officer shall be notified of any onsite emergencies and be responsible for ensuring that the appropriate procedures are followed.

Personnel Injury in the Work Zone: Upon notification of an injury in the Exclusion Zone, the designated emergency signal, continuing horn beeping shall be sounded. All site personnel shall assemble at the Command Post. The rescue team will enter the Work Zone (if required) to remove the injured person to safety. The Site Safety Officer and Project Team Leader should evaluate the nature of the injury, and the affected person should be decontaminated to the extent possible prior to movement. The onsite EMT shall initiate the appropriate first aid, and contact should be made for an ambulance and with the designated medical facility (if required). No persons shall reenter the Work Zone until the cause of the injury is determined.

Personnel Injury in the Support Zone: Upon notification of any injury in the Support Zone, the Project Team Leader and Site Safety Officer will assess the nature of the injury. If the cause of the injury or loss of the injured person does not affect the performance of site personnel, operations may continue, with the onsite EMT initiating the appropriate first aid and necessary follow-up as stated above. If the injury increases the risk to others, the designated emergency signal, continuing intermittent horn beeping shall be sounded and all site personnel shall move to the decontamination line for further instructions. Activities on site will stop until the added risk is removed or minimized.

Fire/Explosion: Upon notification of a fire or explosion on site, the designated emergency signal continuing intermittent horn beeping shall be sounded and all site personnel assembled at the Command Post. The fire department shall be alerted and all personnel moved to a safe distance from the involved area.

Personal Protective Equipment Failure: If any site worker experiences a failure or alteration or protective equipment that affects the protection factor, that person and his/her buddy shall immediately leave the Work Zone. Reentry shall not be permitted until the equipment has been repaired or replaced.

Other Equipment Failure: If any other equipment on site fails to operate properly, the Project Team Leader and Site Safety Officer shall be notified and then determine the effect of this failure on continuing operation on site. If the failure affects the safety of personnel or prevents completion of the Work Plan tasks, all personnel shall leave the Work Zone until the situation is evaluated and appropriate actions taken.

5. PERSONAL MONITORING

The following personal monitoring will be in effect on site.

Personal exposure sampling: Total VOCs will be measured with an hnu DL-101 or photovac microtip HL-2000 or HL-3000 at the well bore or monitoring wells or soil sampling locations to assess the safety of the breathing zone.

Medical monitoring: The expected air temperature will be (50°F). If it is determined that heat stress monitoring is required (mandatory if over 70°F) the following procedures shall be followed: monitoring body temperature, respiration rate, pulse rate. If a level of personal Protection higher than C is required, continuous outdoor temperature monitoring will be a standard operating procedure and will be described in the revision of this Plan.

Health and Safety Plan Acknowledgement and Agreement Page

I acknowledge I have reviewed a copy of this Health and Safety Plan for
American Cleaners Middletown Site, understand it, and agree to comply with its provisions.

►Health and Safety Officer ____
Name Company
______________/____/_____________________
Date Signature EMT? CPR? FirstAid?FirstResponder?

► ____
Position Name Company
______________/____/_____________________
Date Signature EMT? CPR? FirstAid?FirstResponder?

► ____
Position Name Company
______________/____/_____________________
Date Signature EMT? CPR? irstAid?FirstResponder?

► ____
Position Name Company
______________/____/_____________________
Date Signature EMT? CPR? FirstAid?FirstResponder?

► ____
Position Name Company
______________/____/_____________________
Date Signature EMT? CPR? FirstAid?FirstResponder?

List of emergency phone numbers:

Agency/Facility	Phone #	Contact
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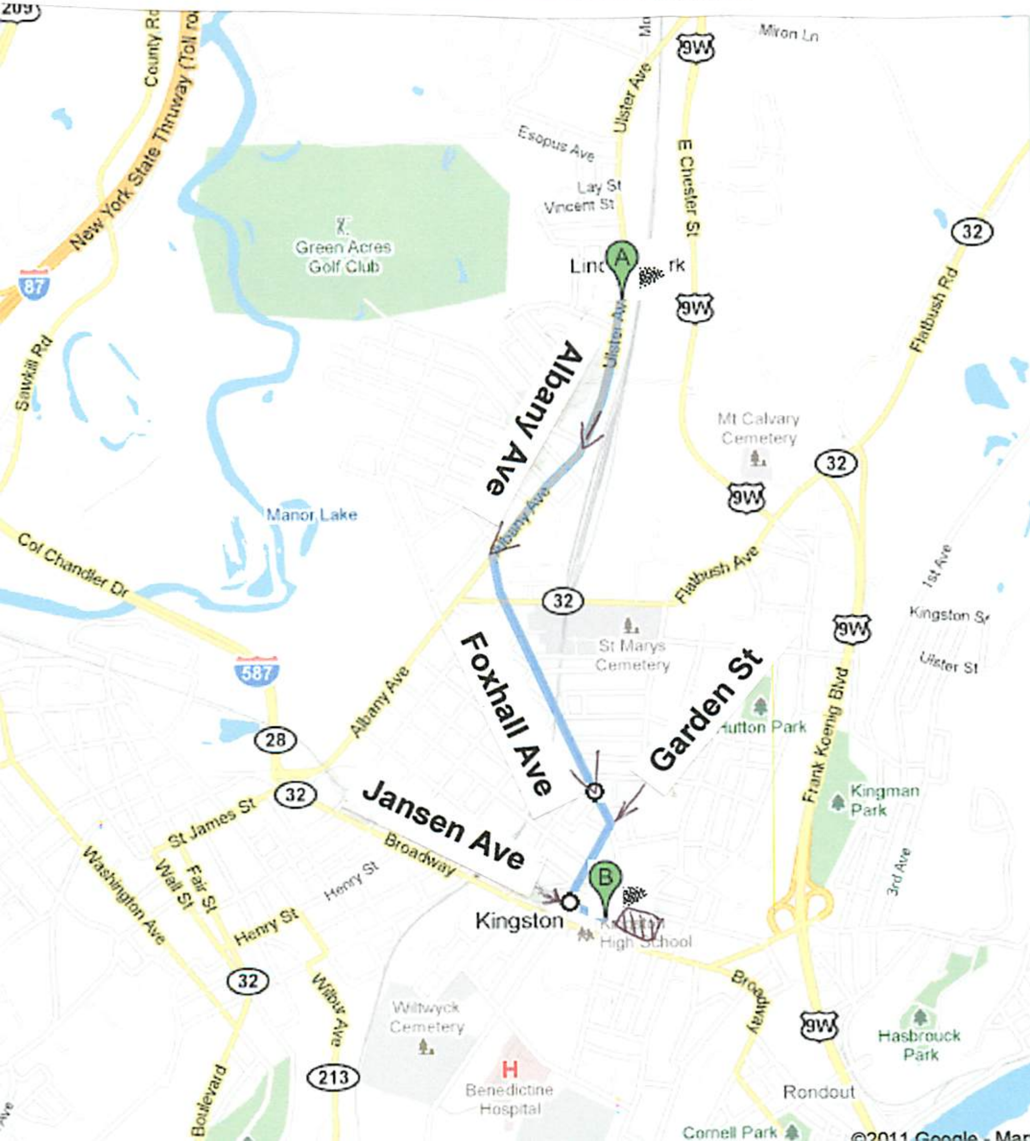
	845 339-1280	Ulster Hose Company #5 830 Ulster Avenue
Hospital	845 331-3131	Kingston Hospital
Ambulance	no local listings, call 911 or other services	

DIRECTIONS
FROM AMERICAN CLEANERS KINGSTON
734 Ulster Avenue
TO KINGSTON HOSPITAL
EMERGENCY ROOM ENTRANCE
At eastern end of Jensen Avenue



DIRECTIONS
FROM AMERICAN CLEANERS KINGSTON
734 Ulster Avenue
TO KINGSTON HOSPITAL
EMERGENCY ROOM ENTRANCE
At eastern end of Jensen Avenue

(A) 734 Ulster Ave, Kingston, NY 12401

	1. Head **south** on **Ulster Ave** toward **Stahlman Pl**	go 0.4 mi	total 0.4 mi
	2. Continue onto **Albany Ave**	go 0.4 mi	total 0.7 mi
↰	3. Turn left onto **Foxhall Ave** About 4 mins	go 0.7 mi	total 1.5 mi
↱	4. Turn right onto **Garden St** About 1 min	go 0.2 mi	total 1.7 mi
	5. Continue onto **E O'Reilly St**	go 253 ft	total 1.7 mi
↰	6. Turn left onto **Jansen Ave**	go 0.1 mi	total 1.8 mi

(B) Jansen Ave Kingston Hospital ER Entrance

Appendix 13:
Community Air Monitoring Plan, June 5, 2014, page 1 of 3
For Interim Remedial Measure, On-site: Soil Sampling, Groundwater Sampling, Slug Testing, Vapor Extraction System Installation at
New York State Department of Environmental Conservation,
Hazardous Waste Voluntary Cleanup Site No. V-00601-3
American Cleaners Store, 734 Ulster Av, Kingston, NY 12401; Town & County of Ulster

Community air monitoring consists of two types of monitoring: continuous and periodic. Specific meters are required to monitor air. A photo-ionization detector (PID) is used to measure VOCs in air and a particulate meter is used to monitor dust. NYSDOH and NYSDEC provide specific guidelines to respond to monitoring measurements.

Continuous Monitoring will be conducted for the ground intrusive activities identified in the RIWP such as advancement of soil borings and installation of monitoring wells. Since these tasks will be performed outdoors in a public parking lot, continuous monitoring will be conducted 5 to 150 feet downwind of the boring / well locations avoiding any exhaust from machinery. A data recording Hnu (photo-ionization) meter will be used to monitor the VOCs in the air. Particulate dust will be monitored with a DataRAM™. The equipment will be calibrated at least once each day or in accordance with manufacturers' recommendations.

Periodic monitoring for VOCs will be conducted during the non-intrusive tasks of well development and collection of groundwater samples from monitoring wells. Readings will be taken with the Hnu meter when the cap of the monitoring well is first opened to determine if VOCs have accumulated above the water table inside the well casing. Readings will be obtained while the purge water is accumulating in the graduated cylinder to ascertain if VOCs are degassing from the pump discharge water.

The following two sections are from the generic CAMP in Appendix 1A in the back of the DER-10 manual (November 2009). They describe what actions to take based on monitoring results reaching specific measurement levels.

VOC Monitoring, Response Levels, and Actions

Volatile organic compounds (VOCs) must be monitored at the downwind perimeter of the immediate work area (i.e., the exclusion zone) on a continuous basis or as otherwise specified. Upwind concentrations should be measured at the start of each workday and periodically thereafter to establish background conditions. The monitoring work should be performed using equipment appropriate to measure the types of contaminants known or suspected to be present. The equipment should be calibrated at least daily for the contaminant(s) of concern or for an appropriate surrogate. The equipment should be capable of calculating 15-minute running average concentrations, which will be compared to the levels specified below.

1. If the ambient air concentration of total organic vapors at the downwind perimeter of the work area or exclusion zone exceeds 5 parts per million (ppm) above background for the 15-minute average, work activities must be temporarily halted and monitoring continued. If the total organic vapor level readily decreases (per instantaneous

readings) below 5 ppm over background, work activities can resume with continued monitoring.

2. If total organic vapor levels at the downwind perimeter of the work area or exclusion zone persist at levels in excess of 5 ppm over background but less than 25 ppm, work activities must be halted, the source of vapors identified, corrective actions taken to abate emissions, and monitoring continued. After these steps, work activities can resume provided that the total organic vapor level 200 feet downwind of the exclusion zone or half the distance to the nearest potential receptor or residential/commercial structure, whichever is less - but in no case less than 20 feet, is below 5 ppm over background for the 15-minute average.

3. If the organic vapor level is above 25 ppm at the perimeter of the work area, activities must be shutdown.

4. All 15-minute readings must be recorded and be available for State (DEC and DOH) personnel to review. Instantaneous readings, if any, used for decision purposes should also be recorded.

Particulate Monitoring, Response Levels, and Actions

Particulate concentrations should be monitored continuously at the upwind and downwind perimeters of the exclusion zone at temporary particulate monitoring stations. The particulate monitoring should be performed using real-time monitoring equipment capable of measuring particulate matter less than 10 micrometers in size (PM-10) and capable of integrating over a period of 15 minutes (or less) for comparison to the airborne particulate action level. The equipment must be equipped with an audible alarm to indicate exceedance of the action level. In addition, fugitive dust migration should be visually assessed during all work activities.

1. If the downwind PM-10 particulate level is 100 micrograms per cubic meter (mcg/m^3) greater than background (upwind perimeter) for the 15-minute period or if airborne dust is observed leaving work area, then dust suppression techniques must be employed. Work may continue with dust suppression techniques provided that downwind PM-10 particulate levels do not exceed 150 mcg/m^3 above the upwind level and provided that no visible dust is migrating from the work area.

2. If, after implementation of dust suppression techniques, downwind PM-10 particulate levels are greater than 150 mcg/m^3 above the upwind level, work must be stopped and a re-evaluation of activities initiated. Work can resume provided that dust suppression measures and other controls are successful in reducing the downwind PM-10

particulate concentration to within 150 mcg/m^3 of the upwind level and in preventing visible dust migration.

3. All readings must be recorded and be available for State (DEC and DOH) personnel to review.

Appendix 14 Investigation Personnel revised June 5, 2014 page 1

For Interim Remedial Measure, On-site: Soil Sampling, Groundwater Sampling, Slug Testing, Vapor Extraction System Installation at
New York State Department of Environmental Conservation,
Hazardous Waste Voluntary Cleanup Site No. V-00601-3
American Cleaners Store, 734 Ulster Av, Kingston, NY 12401; Town & County of Ulster

Field Inspection and Engineering Report by

- Project Engineer Jolanda G. Jansen, P.E.

Field Work Identified in the RIWP will be conducted by

- Consulting Hydrogeologist & Health and Safety Officer Katherine J. Beinkafner, Ph.D. CPG
- Geoprobe Driller & Geologist Todd J. Syska

Their qualifications are provided in the resumes following this cover page.

Other Personnel& Contact Information

American Cleaners Site Owner …………………	Erez Halevah Cell (845) 551-1133 Office (845) 343-0111
AC Site Manager …………………………………	Jay Scanlon Phone (845) 338-6164
NYSDEC Oversight & Project Manager …. ….	Parag B. Amin Phone (518) 402-9662

RESUME

Jolanda G. Jansen, P.E. 72 Colburn Drive, Poughkeepsie, NY 12603

Education

Bachelor of Civil Engineering, University of Canterbury, Christchurch, New Zealand, 1975
Juris Doctor, Pace University School of Law, 2010

Engineering Liscense

New York State #068972-1, 1992

Professional Experience

Owner, 2009 – present, **Jansen Engineering, PLLC**
Key Projects: Sustainability Master Plan, Camphill Village, Columbia County
Project Manager, 2007 – 2008, **Hudson Valley Development Group, LLC**
Key Projects: 26 Home Cluster Subdivision with Central Sewer
4-story School to Condo Conversion
Project Manager, 2001 – 2007, **Spectra Engineering, P.C.**
Key Projects: Vassar College Student Housing, Site Plan
150 unit townhouse complex, WWTF and Site Plan
Bright Horizons Children's Center, Site Plan
Subdivisions throughout Dutchess and Ulster County
Project Manager, 1996 – 2001, **Hayward and Pakan Associates**
Key Projects: Buddhist Monastery Master Plan
Seventh Day Adventist Camp, WWTF
Staff Engineer, 1994 – 1996, **Morris Associates**
Assistant Engineer, 1987 – 1994, **Hayward and Pakan Associates**
Assistant Surveyor, 1986 – 1987, **Kemble Surveying**

Special Skills & Training

40-hour Safety at Hazardous Materials Sites
Annual 8-hour Refresher Courses
AutoCAD, bilingual Dutch

Community Service

Coordinator, 2002 – 2009, **Hudson Valley Smart Growth Alliance**

Coordinated conferences on the following topics: SEQRA & Green Building, Sustainable Energy Infrastructure, Magnetizing Downtowns, Planning for Biodiversity; Building Green; Smart Growth – Smart Jobs; Transit Oriented Development; Wind Power; Transfer of Development Rights; Cost of Sprawl; Decentralized Wastewater Systems; Strengthening our Hamlets, Villages and Cities; Affordable Housing and Smart Growth Successes.

Public Speaking

Sustainability Knowledge Exchange with the Netherlands, 2009

Carbon Neutral Community Planning in the Netherlands, 2008

Reducing the Carbon Footprint of Used-Water Treatment, 2008

Innovative Wastewater Treatment in Dutchess County, 2007

References

Available upon request

RESUME

KATHERINE J. BEINKAFNER, Ph.D., CPG

Geologist/Hydrogeologist

Mid-Hudson Geosciences
1003 Route 44/55; P.O.Box 332
Clintondale, NY 12515-0332

rockdoctor@optonline.net
Telephone and FAX (845) 883-5866
Cell: (845) 464-3622

EXPERTISE:
Investigation & Remediation of Subsurface Contaminants
Groundwater, Hydrology, Karst, and Wetland Studies
Environmental Regulatory Compliance, HazMat
QA, Senior Review, Expert Testimony
Surface and Borehole Geophysics
Computer Modeling of Groundwater Systems
Risk Assessment of Subsurface Contaminants

EMPLOYMENT EXPERIENCE:

1998-Present	Owner, Consultant	Mid-Hudson Geosciences
1997-1998	Sr. Hydrogeologist	Ballard Engineering, PC, New City, NY
Fall 1996	Adjunct Professor	Ramapo College, Mahwah, NJ
1991-1993	Sr. Hydrogeologist	EA Engineering, Newburgh, NY
1989-1991	Sr. Hydrogeologist	Dames & Moore, Pearl River, NY
Fall 1987	Adjunct Professor Groundwater-Hydrology	Rutgers, The State University of New Jersey, Newark Newark, NJ
1986-1987	Senior Consulting Hydrogeologist	Milton Chazen Engineering Associates Poughkeepsie, NY
1984-1986	Senior Reservoir Geologist	Lawrence-Allison West, Operations Contractor for Naval Petroleum Reserve #3, Casper, WY
1985	Dipmeter Consultant	Terrasciences, Inc., Lakewood, CO
1980-1984	Senior Development Geologist	Sohio Petroleum Company San Francisco, CA
1979	Summer Geologist	ARCO Oil and Gas Company Midland, TX
1979	Consulting Petroleum Geologist	Kirby Exploration Co. Houston, TX
1975	Adjunct Teaching Geologist	College of St. Rose Albany, NY
1972-1979	Scientist (Oil & Gas Geology)	Geological Survey, New York State Museum & Science Service, State Education Dept. Albany, NY 12234
1969-1972	Junior Scientist (Oil & Gas Geology)	Geological Survey (same as above)
1966-1968	Physics Teacher	F. D. Roosevelt H. S., Hyde Park, NY

EDUCATION:

1961-1965	S.U.N.Y. at New Paltz New Paltz, NY 12560	B.A. (Geology) M.A. (Geology)
1965-1966	Rensselaer Polytechnic Institute Troy, NY 12180	Geophysics
1968-1969	University of Pennsylvania Philadelphia, PA 19104	M.S. (Physics)
1977-1980	Syracuse University Syracuse, NY 13210	Ph.D. (Geology)

PUBLICATIONS:

Beinkafner, K.J., 2000, Increasing Water Resources with a Horizontal Well, Illinois Mountain, Highland Water District, Highland, NY: National Groundwater Association Eastern Focus Conference, Newburgh, NY October 5, 2000, 10:40 AM

UNPUBLISHED REPORTS:

Geologic Interpretation of Dipmeter Logs," joint author with Andy Bengtson, SOHIO Petroleum Company, San Francisco, 1984.

"Log Analysis for (Petroleum) Wells Using Computer Hardware and Software, based on Terra Sciences log analysis and mapping software, Lawrence Allison West, 1985.

UNPUBLISHED REPORTS (continued):

"Quantitative Geologic Model, Northern Second Wall Creek Reservoir," Lawrence Allison West, Casper, Wyoming, 1986.

"Radionuclide Transport to Human Access Locations, Transport Mechanism – groundwater and surface water (for Illionis LLRWSF License Application)," Dames and Moore, 1991.

"Subsurface Investigation Report, Town of New Paltz Landfill, Ulster County, New York," 1991.

"Sharkey Landfill Remedial Design, Groundwater Flow Model," Burns and Roe Industrial Services Co., 1991.

"Hydrogeologic Study of Wallkill Public Water Supply Watershed and Aquifer (Critical Environmental Area)," Mid-Hudson Geosciences, 1992.

"Ecological Risk Assessment of Benzene and Barium, Liquid Disposal Inc. Site, Michigan." EA Engineering, 1993.

"Complying with Hazardous Waste Laws and Requirements in New York State" notes for two-day short course sponsored by NYS DOT Bureau of Environmental Analysis and Mid-Hudson Geosciences, 1993&4.

"Hydrogeologic Investigation: Van Etten Mobil Station, Liberty, New York." Mid-Hudson Geosciences, 1994.

"Closure Investigation Report for Youmans Flats Landfill in Harriman State Park: Geologic, Hydrogeologic, Gas Venting, and Vector Study," 2 Volumes. Mid-Hudson Geosciences, 1995.

"Groundwater Resources in the Town of Gardiner, Ulster County,New York." Mid-Hudson Geosciences, 1995.

“Designing, Conducting and Analyzing Aquifer Tests Applicable to New York State’s Hydro-Geologic Conditions” Mid-Hudson Geosciences in conjunction with Hydrogeologic, Inc. and HKS Environmental, Inc. 1997, 4-day NYS DEC training course.

“Hydrogeologic Investigation of Underground Fuel Oil Tank at Highland High School, 320 Pancake Hollow Road, Highland, NY, NYSDEC Spill No. 97-06013”, 1998.

“Hydrogeology of Leipold Field, Ellenville Central School District, Edwards Place, Ellenville,” 1998.

“Investigation Summary and Remedial Plan Site No. 18 NYCDOT Nott Avenue Garage, Addendum No. 1” for NYC Dept. of Design & Construction, Ballard Engineering PC, March 20, 1998.

“Investigation Summary and Remedial Plan Site No. 13 NYCDOT Brookville Yard,” for NYC Dept. of Design and Construction, Ballard Engineering PC, April 12, 1998.

“Investigation Summary and Remedial Plan Site No. 11 NYCDOT Flatlands Garage Addendum No. 1” for NYC Dept. of Design & Construction, Ballard Engineering PC, February 4, 1998.

“Final Site Investigation Report for Irvington Waterfront Park …Village of Irvington, Westchester County, NY” (NYS DEC Brownfields Program)Chapters on Physical Characteristics of the Site, Nature and Extent of Contamination, Contaminant Fate and Transport, and Exposure Assessment, Ecosystems Strategies, Inc. March 18, 1998.

“Report: Phase I: Exploration and Assessment for Development of Groundwater Resources on Illinois Mountain Watershed Property, Highland Water District, Highland, NY” Mid-Hudson Geosciences, December 1, 1999.

“Report: 72-Hour Pumping Test, Sunset Ridge Subdivision, Phillipsburg Road, Town of Goshen, Orange County”, NY for Clients of Lanc & Tully Engineers by Mid-Hudson Geosciences, July 29, 2002.

“Shawangunk Recharge Area and Groundwater Management Plan” for New York-New Jersey Trail Conference by Mid-Hudson Geosciences, September 2002.

“Report: Aquifer Protection Study, Town of Hurley, Ulster County, NY” for Environmental Conservation Commission, Town of Hurley, Ulster County, December 2003, revised June 2004.

“Pumping Test Report for High Meadow School, Stone Ridge, NY” prepared for James L. Reynolds, Architect and Barry Medenbach, PE, Stone Ridge, NY October 28, 2004.

Letter Reports: “Hydrogeologic Analysis of Operation of Proposed Septic System Project,” “Hydrogeologic Analysis of Rainstorm and Operation of Proposed Septic System Project,” “Hydrogeologic Analysis of Water Table Variation During Monitoring Period, “ and “Method of Calculating Hydraulic Conductivity from Slug Testing, Addendum to Hydrogeologic Analysis of Operation of Proposed Septic System, Project: Plaza South, Newtown,” CT for PW Scott, PE of Brewster,NY, April through October 2005.

Several Papers RE: “Calculations and Actions for Pesticide Remediation in Former Orchards, now Residential Subdivisions in Orange County:” Greiner and Wildflower Vista Subdivisions, BCM Development in Town of Newburgh, Palladino and Double R Subdivisions, as a subcontractor to William L. Going & Associates, Pine Bush, NY, 2004-2005.

“Review of FEIS (November 18, 2004) and DEIS (July 28, 2004) for Proposed Mushroom Production and Processing Facility by Yukiguni Maitake Manufacturing Corporation of America in the Town of Mamakating” and “Review of DEIS (July 28, 2004) for Proposed Mushroom …” and associated testimony at Planning Board Hearings for Bashakill Area Assocation (BKAA), Wurtsboro, NY, April through October 2005.

UNPUBLISHED REPORTS (continued):

Additional Reports prepared for BKAA RE; Yukiguni Maitake Mushroom Plant:
- "Evaluation and Assessment of Design of a Process Wastewater Infiltration System" May 009
- "Groundwater Mounding Analysis beneath the Process Wastewater Infiltration Basin" August 2009.
- "Special Conditions Associated with NYSDEC Issuance of Yukiguni Maitake Permits" Sept. 2009.

"Report: Aquifer Protection Study, Town of Marbletown, Ulster County, NY," for Environmental Conservation Commission, Town of Marbletown, Stone Ridge, NY, September 2005.

Report: "Geologic Assessment of Hudson Landing Site, Kingston, NY", Recommending stormwater management practices to protect groundwater from potential contamination by flow into karst pathways, Ecosystems Strategies, Inc. November 2007.

Reports concerning proposed Ulster Manor Project in Town of Ulster: "Comments for the Ulster Manor FEIS RE: Soils and Geology including evidence of Karst Features on site, Surface water, Wetlands and Groundwater Resources, July 2008. "Comments on 'Dworkin's Letter 11/8/08" RE: Ulster Manor indicating confirmation of Karst Features on site and needed mitigation measures, Ecosystems Strategies, Inc. December 2008.

Reports submitted to US EPA for Industrial Hazardous Waste Site: Former General Switch, Middletown, NY (as subcontractor to Ecosystems Strategies, Inc.): "Well Installation and Remedial Selection Report" (October 2007). "Evaluation of Cone of Depression and Capture Zone for Bedrock Well" July 2010. Short Term Pumping Test to Evaluate Use of Overburden Well" March 2011.

Report: "Review of Draft Environmental Impact Statement (DEIS) for Warwick Views Subdivision, submitted by Warwick Views, LLC to Town of Warwick Planning Board" March 2010.

Additional Reports Prepared in conjunction with Paul A. Rubin dba HydroQuest: "Karst Hydrology #1" June 2010, "Karst Hydrology #2" August 2010, "Revision of DEIS and Public Review Recommended" January 2010.

PROFESSIONAL AFFILIATIONS:
- American Association of Petroleum Geologists
- American Institute of Professional Geologists
- Geological Society of America
- National Ground Water Association
- Hudson Mohawk Professional Geologists Association

PROFESSIONAL HONORS:
- Fellow of Geological Society of America

PROFESSIONAL CERTIFICATION:

Petroleum Geologist Number 2683 by American Association of Petroleum Geologists
Professional Geological Scientist Number 6611 by American Institute of Professional Geologists

HAZARDOUS WASTE TRAINING

29CFR 1910.120(e)(2)	40-hour Safety at Hazardous Materials Sites- Hands-On Workshop
29CFR 1910.120(e)(8)	OSHA 8-Hour Hazardous Materials Site Safety – Refresher Course
29CFR 1910.120(e)(4)	Supervisors of Hazardous Waste Operations – 8 Hours

Todd J. Syska

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PROFESSIONAL HISTORY

More than thirty years of progressively increasing responsibilities and diversified experience in project management, community and government relations, environmental remediation, and water system development.

EDUCATION

BA Magna Cum Laude, Geology/ Geography, State University of New York at New Paltz

PROFESSIONAL CERTIFICATIONS

NYS Water Well Contractor

NYS Pump Installer, Large and Small

Connecticut non-potable water well contractor

FAA Certified Airline Transport Pilot

FAA Certified Flight Instructor, Instruments and Airplanes

NYS Certification in Secondary Education: Science, Mathematics, and Computer Science

29CFR 1910.12-8 General Safety Training

29CFR 1910.120 Supervisor Training

29CFR1910.132 PPE Training

29CFR1910.132 Chain Saw Safety Training

29CFR1910.134 Respiratory Protection Training

29 CFR 1910.146 Confined Space Training

29CFR 1926 Subpart I, Powder Actuated Tools

29CFR 1926.502 Fall Protection

Advanced Landfill Design and Closure

Landfill Liner and Cover Systems Construction and Related Quality Assurance and Quality Control Specialty Training, NYSDEC/EPA

Sherwin Williams Advanced Coatings Application and Quality Assurance, Polyurea

ADDITIONAL TRAINING

EMPLOYMENT HISTORY

June 1994 to Present: Self Employed, President Todd J. Syska Inc.
Consultant to Engineers and professionals in the fields of environmental remediation and water system development.

June 1986 - June 1994: The Chazen Companies, Poughkeepsie, NY
Perform environmental site assessments. Responsible for the development of water, wastewater, and industrial waste treatment facilities. Design and permit landfills and municipal waste transfer and recycling centers. Provide computer support to the company and the scientific community.

July 1984 - June 1986: West Park Union Free School District
Established an instructional computer program where none had existed previously. Wrote and designed high school level curriculum. Taught computer application and programming to high school level students. Analyzed the computer needs of the administration and bookkeeping departments, specified hardware and software for use, and provided training and technical support to administrative and secretarial personnel.