

# Comparison of Geoprobe® PRT and AMS GVP Soil-Gas Sampling Systems with Dedicated Vapor Probes in Sandy Soils at the Raymark Superfund Site





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## Notice

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All data generated in this report were subjected to an analytical Quality Assurance Plan developed by EPA's New England Regional Laboratory. Also, a Quality Assurance Project Plan was implemented at the Ground Water and Ecosystems Restoration Division. Results of field-based studies and recommendations provided in this document have been subjected to external and internal peer and administrative reviews. This report provides technical recommendations, not policy guidance. It is not issued as an EPA Directive, and the recommendations of this report are not binding on enforcement actions carried out by the EPA or by the individual States of the United States of America. Neither the United States Government nor the authors accept any liability or responsibility resulting from the use of this document. Implementation of the recommendations of the document and the interpretation of the results provided through that implementation are the sole responsibility of the user.

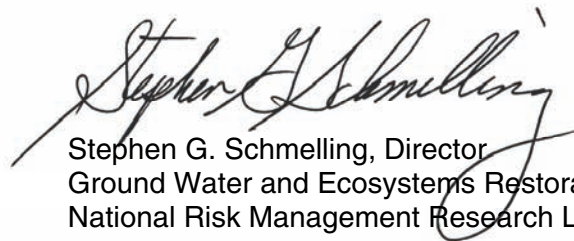
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## Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet these mandates, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This report describes the results of an investigation conducted to assist EPA's New England Regional Office in evaluating vapor intrusion in homes and a commercial building near the Raymark Superfund Site in Stratford, Connecticut. Specifically, a study was conducted to compare results of soil-gas sampling using dedicated vapor probes, a truck-mounted direct-push technique, Geoprobe® Post-Run-Tubing system, and a hand-held rotary hammer technique, AMS Gas Vapor Probe kit. Testing revealed some statistically significant differences. However, the magnitude of variation was similar to that due to spatial variability on the scale of testing (1 m). Hence for practical purposes, all three sample systems were considered approximately equivalent. This investigation should provide confidence that the PRT and GVP sample systems are satisfactory for collecting soil-gas samples in sandy soils, such as those present near the Raymark site, to evaluate the potential for vapor intrusion.



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## Abstract

A study was conducted near the Raymark Superfund Site in Stratford, Connecticut to compare results of soil-gas sampling using dedicated vapor probes, a truck-mounted direct-push technique - the Geoprobe Post-Run-Tubing (PRT) system, and a hand-held rotary hammer technique - the AMS Gas Vapor Probe (GVP) kit. A comparison of VOC concentrations using dedicated vapor probes and the GVP sampling kit indicated that the two methods provided similar results. However, at one location, VOC concentrations were significantly higher for dedicated vapor probes indicating potential leakage with the GVP system. VOC concentrations using the PRT system were higher than VOC concentrations using dedicated vapor probes by an average factor of 1.2. This is the same magnitude observed for spatial variability on a scale of 1 m (median of 1.2 and average of 1.3 for 90 sample pairs). However, this effect did not appear to be due to spatial variability which would result in random scatter not a consistent bias as observed. It is also unlikely that extraction volume or sampling sequence caused the observed bias given the results of extraction volume and sample sequence testing. VOC concentrations using the PRT system were also higher than VOC concentrations using the GVP kit by an average factor of 2.4. Similar to the comparison between probe and PRT sampling systems, the effect did not appear to be due to spatial variability, extraction volume, or sequence of sampling. Thus, utilization of the PRT system resulted in observation of higher concentrations of VOCs compared to the GVP kit and dedicated vapor probes. However, variation in concentration was relatively minor when compared to spatial variability on the scale used for comparison testing. Hence for practical purposes, all three sample systems can be considered approximately equivalent.

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## List of Abbreviations

1,1,1-TCA	1,1,1 – trichloroethane
1,1-DCE	1,1 – dichloroethylene
TCE	trichloroethylene
c-1,2-DCE	cis-1,2-dichloroethylene
O <sub>2</sub>	oxygen
CO <sub>2</sub>	carbon dioxide
CH <sub>4</sub>	methane
ID	inner diameter
VOC	volatile organic chemical
PRT	post-run tubing
GVP	gas vapor probe
PVC	polyvinylchloride
SLPM	standard liter per minute
GC	gas chromatography



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## Executive Summary

Soil-gas sampling is widely used as a reconnaissance tool to help delineate the areal extent of ground-water contamination and both the areal and vertical extent of vadose zone contamination by volatile organic compounds (VOCs). Soil-gas sampling is often followed by ground-water and/or soil sampling to quantify contamination in these media. Since soil-gas data is generally not used to evaluate the need for corrective action or attainment of remedial goals, quality assurance and control (QA/QC) considerations associated with soil-gas sampling are often less stringent compared to ground-water or soil sampling. However, EPA's recent draft guidance on vapor intrusion (EPA, 2002) allows the quantitative use of soil-gas data along with empirical attenuation factors or the Johnson-Ettinger Model (1991) to directly assess potential exposure from vapor intrusion. Thus, collection of representative soil-gas samples could be critical to this endeavor. Representative soil-gas data refers to collection of a sufficient number of properly located samples within an area and depth of concern subject to adequate QA/QC measures. Implementation of QA/QC measures ensures that observed concentrations reflect true soil-gas concentrations in the vicinity of a probe during sampling.

There are a number of important QA/QC issues relevant to soil-gas sample collection. One issue not addressed in the literature is the equivalence of direct-push/hammer soil-gas sampling techniques with dedicated vapor probes. Dedicated probes are generally considered a reliable method for soil-gas sampling because of the use of a layer of bentonite to isolate a sand-packed screened interval. However, direct-push/hammer soil-gas sampling techniques have become common to support vapor intrusion investigations because they are more convenient (ability to sample the same day as probing) and less expensive compared to installation of dedicated probes. Also, direct-push/hammer techniques allow collection of soil-gas samples close to a building minimizing concern regarding interpolation and extrapolation of soil-gas concentrations beneath a building.

In this investigation, concentrations from soil-gas samples collected using dedicated vapor probes were compared with samples using the Geoprobe Post-Run Tubing (PRT) system and AMS Gas Vapor Probe (GVP) kit. The PRT system is one of the most commonly used truck-mounted direct-push soil-gas sampling systems in the United States. The PRT system can be used to collect soil-gas samples to depths up to 20 m. The hand-held rotary hammer GVP kit is suitable for shallow soil-gas sampling (up to 4 m) but allows access within 1 m of a building. These two methods were selected for evaluation because of their common use.

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Soil-gas sampling was conducted at one to three depths at several locations near the Raymark Superfund site in Stratford, Connecticut. Surficial soils in the soil-gas sampling areas are very permeable consisting of sand or a mixture of sand and gravel. A peristaltic pump with Masterflex<sup>®</sup> tubing, variable-area PVC flowmeter, and landfill gas meter were used in line to extract air, measure flow rates, and measure gas (O<sub>2</sub>, CO<sub>2</sub>, and CH<sub>4</sub>) concentrations during purging. A peristaltic pump and one-liter Tedlar bags were used for sampling. Purging and sampling occurred at a flowrate of 0.5 standard liters per minute (SLPM). On-site gas chromatography (GC) analysis was conducted by EPA's New England Regional Laboratory using their standard operating procedure. Air samples from each Tedlar bag were injected into two portable GCs with results compared to ensure consistency. Tedlar bag sampling and on-site analysis provided near real-time data. Detection limits for on-site analysis were 2 – 5 ppbv for VOCs of concern. Container, field, probe, and travel blanks demonstrated that Tedlar bags used to collect samples, coolers used to transport samples, PRT and GVP sample systems used to extract samples, and atmospheric air were not a source of VOCs at detection limits of concern. Replicate samples indicated excellent sample precision.

A mass-balance equation was used to estimate internal volume exchanges necessary to purge dedicated probe, PRT, and GVP systems prior to sample collection. Simulations indicated that if air within a sample system had initially been reduced to zero concentration because of direct exposure to atmospheric air, extraction of 2.2 to 3.0 internal volumes prior to sampling would ensure that VOC concentrations of air entering a sample vessel would be 90 to 95% of VOC concentrations of soil-gas entering a sampling system. This would be the most conservative condition and representative of PRT and GVP sample systems. A zero concentration would not be expected for a dedicated vapor probe which had been sealed for months prior to sampling. Purge testing at a dedicated vapor probe indicated concentration stabilization after only one internal volume exchange. In this investigation, at least 2 internal volumes of air were removed from dedicated vapor probes prior to sample collection. At least 3 internal volumes of air were removed from PRT and GVP sample systems prior to sample collection.

To allow a comparison of dedicated probe, PRT, and GVP sampling systems, it had to be demonstrated that the act of sample collection did not affect sample results at the system being sampled or at other nearby sample locations. Increasing internal volume exchanges or pre-sample air extraction volume in excess of a purging requirement could increase the possibility of collecting a soil-gas sample not representative of some integrated volume of soil around a screened interval. If properly sampled, VOC concentrations should remain relatively constant unless air is drawn in from a nearby region of lower or higher vapor concentration. To evaluate the impact of pre-sample internal volume exchanges on sample results, ten soil-gas samples were collected after various (starting with zero) internal volume exchanges at

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one PRT and one dedicated vapor location sampling location. In the test using the PRT system, up to 9 liters of air and 74 internal volume exchanges were extracted with little impact on vapor concentration. In the test using the dedicated vapor probe, up to 103 liters or internal volume exchanges were extracted with little impact on vapor concentration (1 internal exchange equaled 1 liter). Thus, it is unlikely that pre-sample air extraction impacted sample results at the systems being sampled.

To evaluate the potential impact of air extraction at one location on sample results at a nearby location and depth, three samples were taken non-sequentially from each sampling system. For example, at one location, the PRT system was sampled first, followed by the GVP system, followed by sampling at the dedicated probe. The sequence was then changed to sampling at the GVP system, followed by sampling at the dedicated vapor probe, followed by sampling at the PRT system and so on until three samples had been obtained from each system at each depth. A comparison of first and third VOC concentrations for locations and depths where three samples were collected indicated that sample collection at a one location did not impact sample results at another location. Also, coefficients of variation for the three samples were generally below 10% again indicating little impact.

Another potentially complicating factor in comparing vapor concentrations from dedicated probe, PRT, and GVP sampling systems is spatial variability. PRT and GVP sampling locations were positioned relatively close (usually within 1 m) to dedicated vapor probes to minimize the effect of spatial variability on soil-gas concentration. To assess the presence and magnitude of spatial variability at this scale, soil-gas sampling was conducted at three depths at five locations separated by 0.46 m (1.5') in a cross-like pattern using the PRT sampling system. In general, variation in VOC concentration with location at each depth was present but relatively minor.

Sampling systems were compared using data from all locations and depths. A comparison of VOC concentrations using dedicated vapor probes and the GVP sampling kit indicated that the two methods provided similar results ( $p = 0.31$  for two-tailed paired t-Test,  $p > 0.2$  for two-tailed non-parametric Wilcoxon Signed Rank Test). However, at one location,  $O_2$ ,  $CO_2$ , and VOC concentrations were noticeably different for sampling systems indicating potential leakage with the GVP system.

VOC concentrations using the PRT system were not statistically equivalent to VOC concentrations using dedicated vapor probes ( $p = 0.009$  for two-tailed paired t-Test,  $p < 0.01$  for two-tailed non-parametric Wilcoxon Signed Rank Test). VOC concentrations using the PRT system were higher than VOC concentrations detected using dedicated vapor probes by an average factor of 1.2. This is the same

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magnitude observed for spatial variability on a scale of 1 m (median of 1.2 and average of 1.3 for 90 sample pairs). However, this effect did not appear to be due to spatial variability which would result in random scatter not a consistent bias as observed. It is also unlikely that extraction volume or sampling sequence caused the observed bias given results from extraction volume and sample sequence testing.

VOC concentrations using the PRT system were also not statistically equivalent to VOC concentrations using the GVP kit ( $p = 0.03$  for two-tailed paired t-Test,  $p < 0.01$  for two-tailed non-parametric Wilcoxon Signed Rank Test). VOC concentrations using the PRT system were higher than VOC concentrations detected using the GVP kit by an average factor of 2.4. Similar to the comparison between probe and PRT sampling systems, the effect does not appear to be due to spatial variability, extraction volume, or sequence of sampling.

Thus, utilization of the PRT system resulted in observation of higher concentrations of VOCs compared to the GVP sampling system and dedicated vapor probes. However, the magnitude of variation was relatively minor especially when compared to variation on a scale of 1 m due to spatial variability. Hence for practical purposes, all three sample systems can be considered approximately equivalent.

This testing was conducted in highly permeable soils where the potential for leakage from direct-push/hammer soil-gas sampling systems would be expected to be low compared to less permeable soils such as silt and clay. Thus, the results of this investigation should not be extrapolated to other soil textures where additional investigation is needed. Also, only one direct-push and one rotary hammer method was evaluated for comparison with dedicated vapor probes. Thus, the results of this investigation should not be extrapolated to other direct-push/hammer soil-gas sampling techniques.

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## 1.0 Introduction

Soil-gas sampling is widely used as a reconnaissance tool to help delineate the areal extent of ground-water contamination and both the areal and vertical extent of vadose zone contamination by volatile organic compounds (VOCs). Soil-gas sampling is often followed by ground-water and/or soil sampling to quantify contamination in these media. Since soil-gas data is generally not used to evaluate the need for corrective action or attainment of remedial goals, quality assurance considerations associated with soil-gas sampling are often less stringent compared to ground-water or soil sampling. However, EPA's recent draft guidance on vapor intrusion (EPA, 2002) allows the quantitative use of soil-gas data along with empirical attenuation factors or the Johnson-Ettinger Model (1991) to directly assess potential exposure from vapor intrusion. Thus, collection of representative soil-gas samples could be critical to this endeavor. Representative soil-gas data refers to collection of a sufficient number of properly located samples within an area and depth of concern subject to adequate quality assurance and control (QA/QC) measures. Implementation of QA/QC measures ensures that observed concentrations reflect true soil-gas concentrations in the vicinity of a probe during sampling.

There are a number of important QA/QC issues relevant to soil-gas sample collection. One issue not addressed in the literature is the equivalence of direct-push/hammer soil-gas sampling techniques with dedicated vapor probes. Dedicated probes are generally considered a reliable method for soil-gas sampling because of the use of a layer of bentonite to isolate a sand-packed screened interval. However, direct-push/hammer soil-gas sampling techniques have become common to support vapor intrusion investigations because they are more convenient (ability to sample the same day as probing) and less expensive compared to installation of dedicated probes. Also, direct-push/hammer techniques allow collection of soil-gas samples close to a building minimizing concern regarding interpolation and extrapolation of soil-gas concentrations beneath a building.

In this investigation, concentrations from soil-gas samples collected using dedicated vapor probes were compared with samples using the Geoprobe Post-Run Tubing (PRT) system and AMS Gas Vapor Probe (GVP) kit. The PRT system is one of the most commonly used truck-mounted direct-push soil-gas sampling systems in the United States. The PRT system can be used to collect soil-gas samples to depths up to 20 m. The hand-held rotary hammer GVP kit is suitable for shallow soil-gas sampling (up to 4 m) but allows access within 1 m of a building. These two methods were selected for evaluation because of their common use.

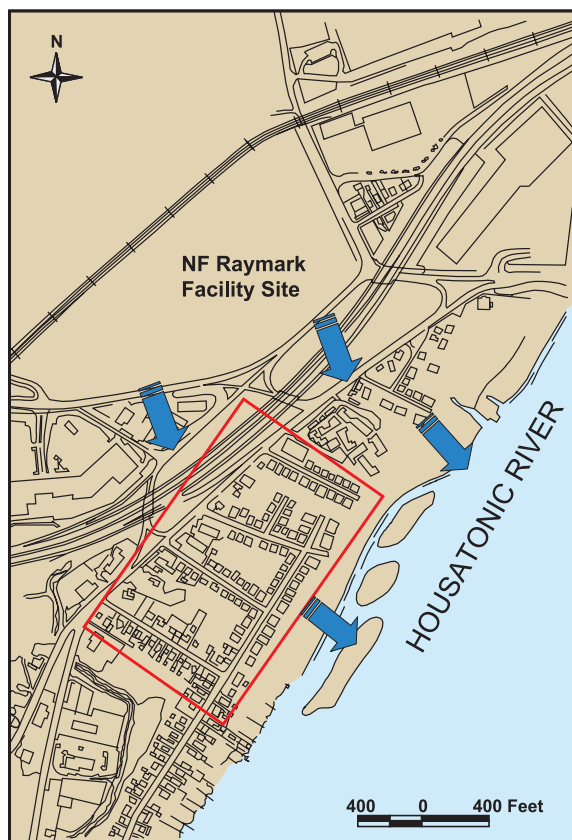
## 2.0 Site Description

The Raymark Superfund Site consists of 33.4 acres of land previously occupied by the Raybestos-Manhattan Company in Stratford, Connecticut, where the company disposed of solid-waste from settling lagoons during its operation. Between 1919 and 1989, the company produced asbestos and asbestos compounds, metals, phenol-formaldehyde resins, adhesives, gasket material, sheet packing, clutch facings, transmission plates, and brake linings. Between 1993 and 1996, EPA removed fill containing asbestos, lead, and PCBs from a number of residential properties and a middle school. EPA placed the fill back on the facility property and isolated the waste beneath a cap. In 1996 and 1997, EPA demolished the facility buildings and placed a cap over the area previously occupied by the buildings. The property is now occupied by commercial buildings (e.g., Wal-Mart, Home Depot).

As illustrated in **Figure 1**, ground water beneath the residential area of this investigation generally flows southeast from the former facility, underneath a large residential community, and discharges into the former facility is contaminated with a number of VOCs including 1,1,1-trichloroethane (1,1,1-TCA),

trichloroethene (TCE), cis-1,2-dichloroethene (c-1,2-DCE), 1,1-dichloroethene (1,1-DCE), and 1,1-dichloroethane (1,1-DCA).

**Figure 1.** Direction of ground-water flow (large arrows) and location of the residential area of investigation near the Raymark Superfund Site (modified from Tetra Tech 2000).

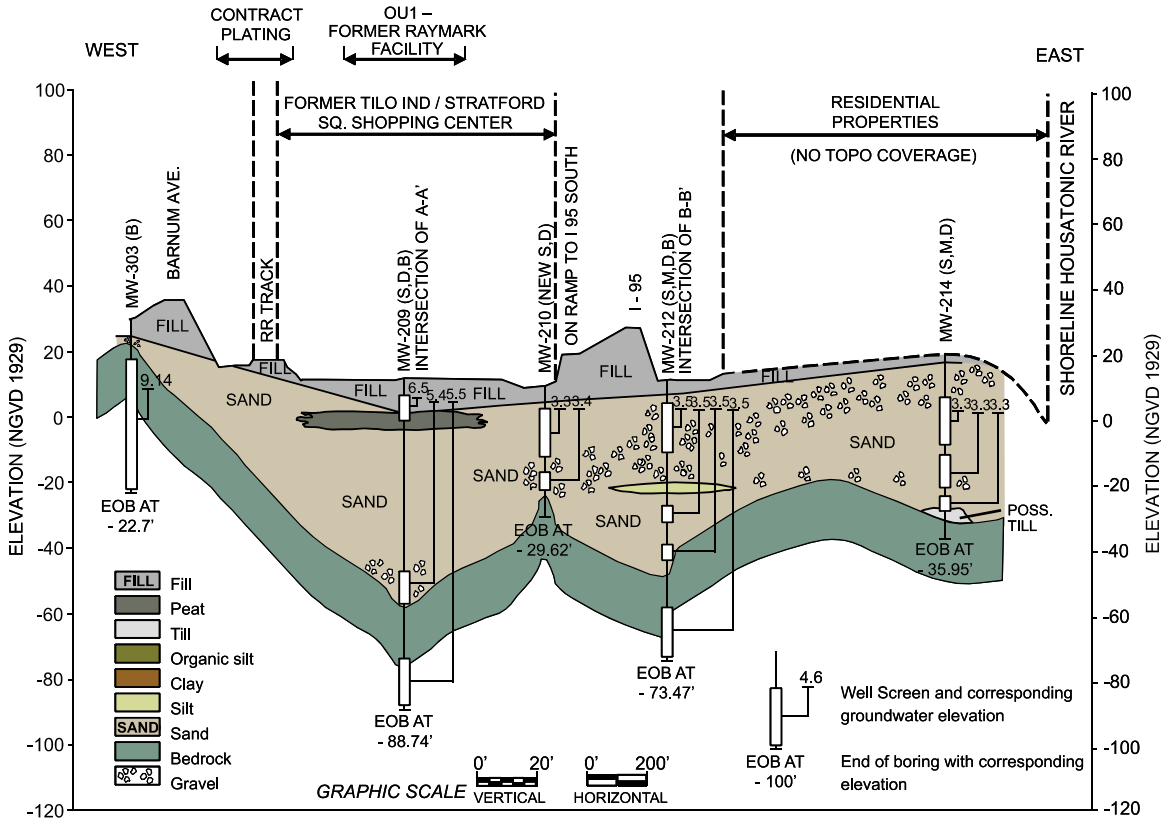


As illustrated in **Figures 2, 3, and 4**, glaciofluvial deposits and fractured granite bedrock valleys lie beneath the residential area of investigation. The remedial investigation (TetraTech NUS, 2000) and subsequent studies financed by EPA indicate that ground-water flow is heavily influenced by the location and orientation of bedrock valleys. This results in a fairly complex contaminant distribution profile making interpolation and extrapolation of ground-water and soil-gas contaminant profiles difficult.



**Figure 2.** Location of geologic cross-sections and the residential area of investigation near the Raymark Superfund Site (modified from Tetra Tech NUS, Inc., 2000).

Surficial soils in areas of soil-gas sampling consist of sand or a mixture of sand and gravel. The results of ten shallow single-well ground-water hydraulic conductivity tests taken from TetraTech NUS (2000) are illustrated in **Figure 5**. Bounds for sand and gravel are taken from Freeze and Cherry (1979). Values for hydraulic conductivity are typical of sand and vary from  $1.0 \times 10^{-03}$  to  $2.0 \times 10^{-02}$  cm/s. The results of a sub-slab air permeability test taken from a home (EPA, 2006) are illustrated in **Figure 6**. Air permeability values of sub-slab materials are representative of native soils since concrete was simply poured on sandy soils in basements. The range of radial permeability of soils tested,  $7.0 \times 10^{-07}$  –  $8.0 \times 10^{-07}$  cm<sup>2</sup> is typical of sandy soils.



**Figure 3.** Geologic cross-section G – G' (modified from Tetra Tech NUS, Inc., 2000).

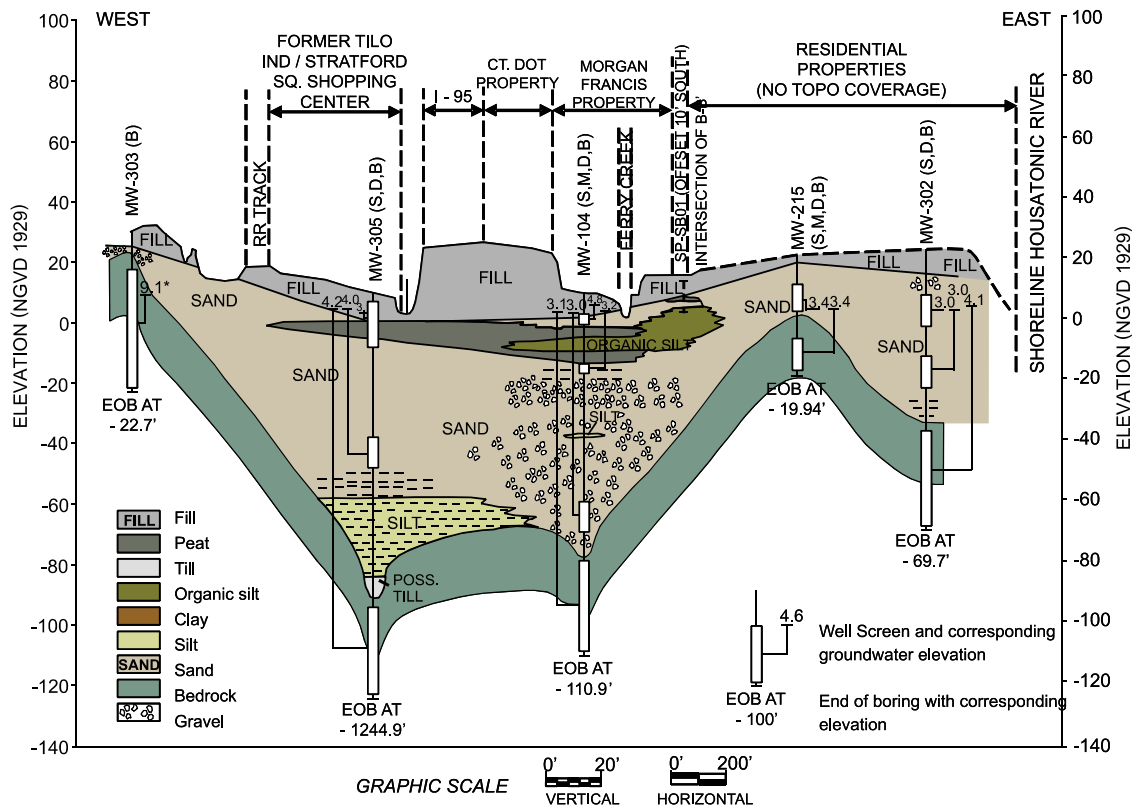


Figure 4. Geologic cross-section H – H' (modified from Tetra Tech NUS, Inc., 2000).

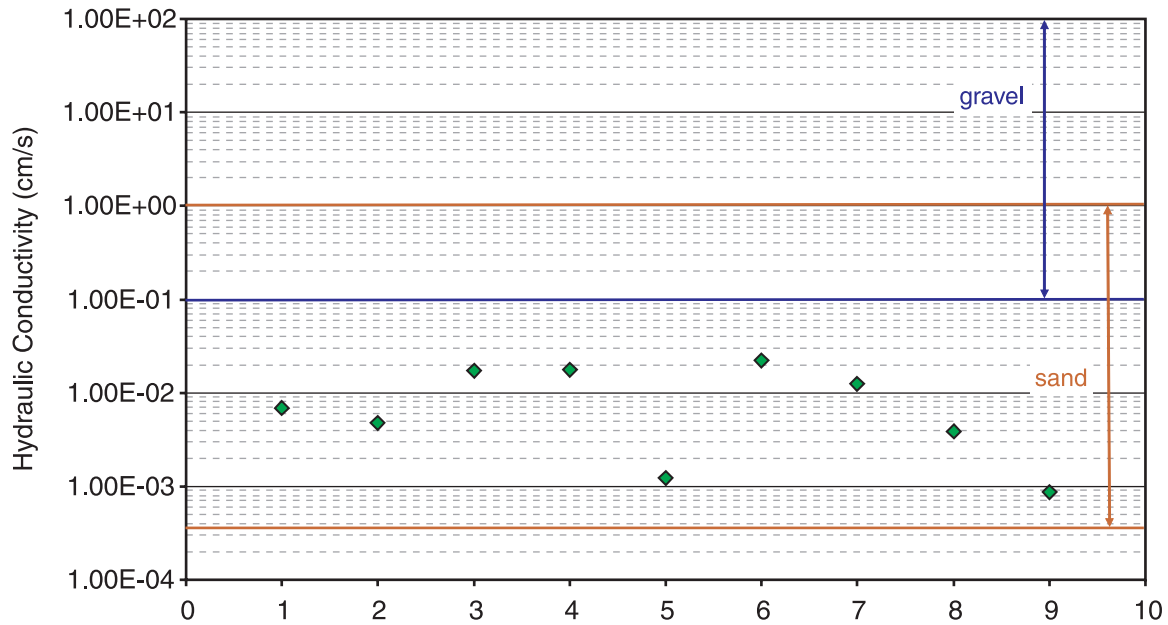
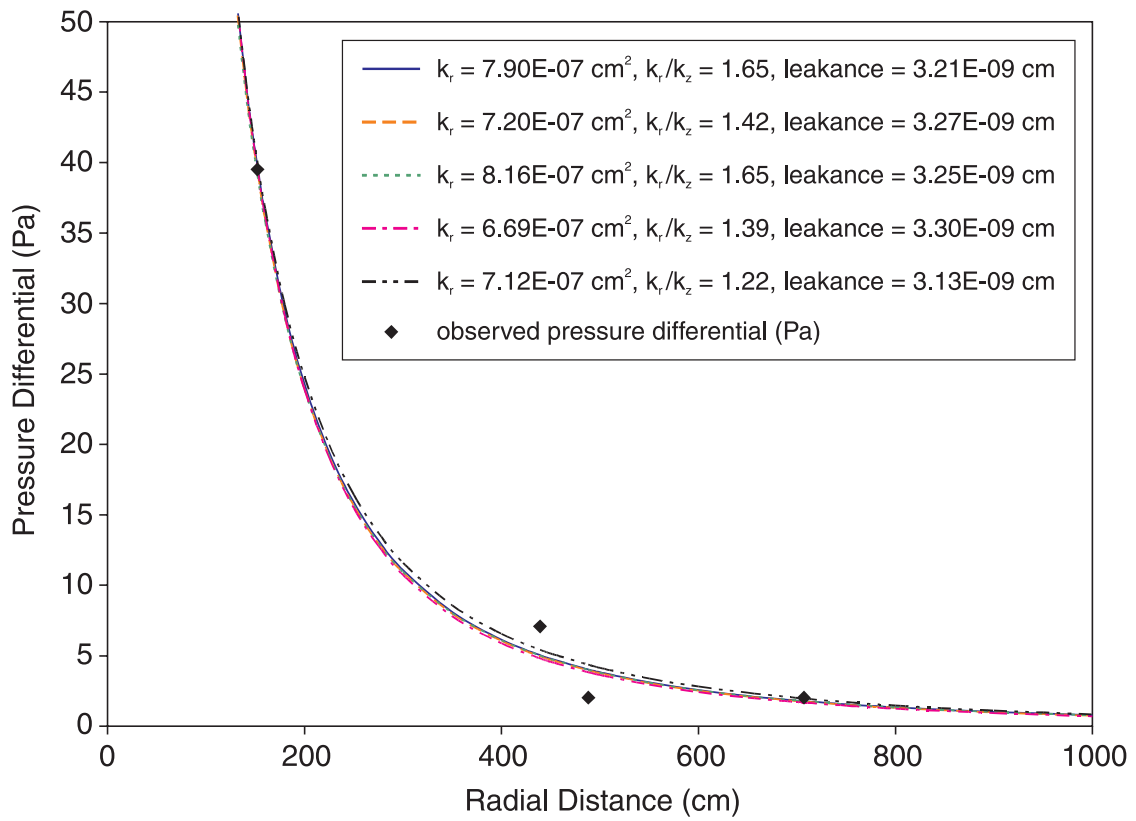


Figure 5. Results of ten shallow single-well hydraulic conductivity tests at the Raymark site (boundary values for sand and gravel taken from Freeze and Cherry, 1979).



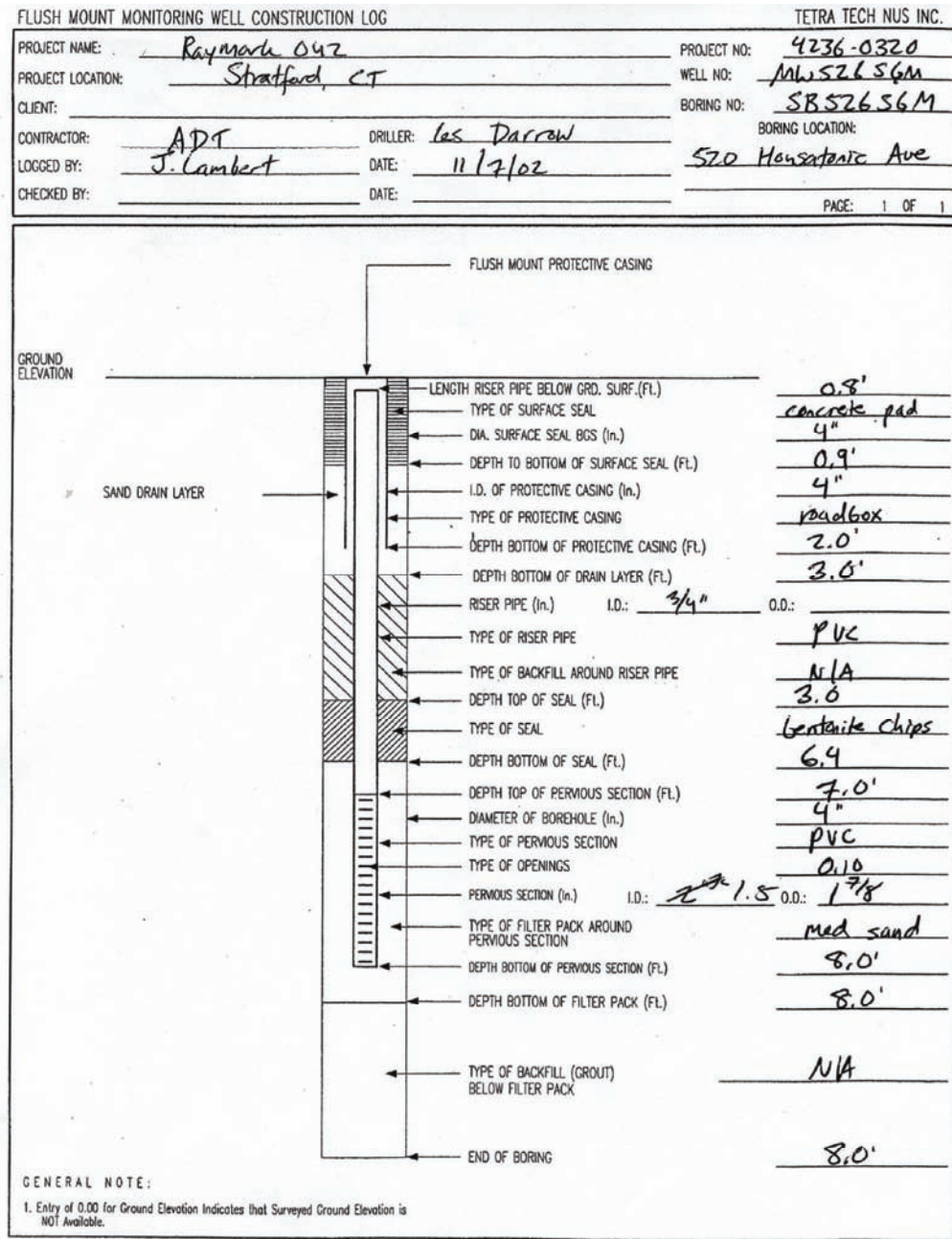


**Figure 6.** Results of a sub-slab air permeability test taken from EPA (2006).

### 3.0 Methods and Materials

#### 3.1 Soil-Gas Sampling from Dedicated Vapor Probes

Dedicated vapor probes used in the study were installed by Tetra-Tech for U.S. EPA, Region I. A typical construction log for a dedicated probe is illustrated in **Figure 7**.



**Figure 7.** Typical construction log for dedicated vapor probes installed at the Raymark Site.

Boreholes for dedicated vapor probes were installed using a drill rig equipped with a hollow-stem auger. The diameter of boreholes varied from 8 to 13 cm (3 to 5"). A 1.9 cm ( $\frac{3}{4}$ " ) inner diameter (ID) polyvinylchloride (PVC) riser pipe containing a metal valve at the upper end and a 30 cm (1') long 3.8 cm (1.5") ID PVC factory-slotted screen interval at the lower end was lowered into each borehole and set in place with a filter pack consisting of medium-grained sand. Dry bentonite chips were placed above each filter pack in small increments (e.g., 15 cm) and hydrated to create a seal above the sample interval. Medium-grained sand was placed above each bentonite seal to serve as a drainage layer. A flush-mounted iron casing was then set in place at each borehole and sealed in concrete.

Depths of fill materials and screened intervals in each borehole are summarized in **Table 1** in Appendix A. Concrete extending from the surface to sand drain layers varied in thickness from 0.2 to 0.3 m (0.5 to 0.8'). Bentonite layers extending from the base sand drain layers to the top of the sand filter packs were 0.2 m thick (0.5') for probes screened 0.61 – 0.91 m (2 to 3') below grade, 0.9 to 1.1 m thick (3.0 to 3.5') for probes screened 2.1 to 2.4 m (7 to 8') below grade, and 2.0 to 2.1 m thick (6.5 to 7.0') for probes screened 3.0 – 3.3 m (10 to 11') below grade.

**Figures 8, 9, and 10** illustrate purge and sample collection in dedicated vapor probes. Tetra Tech (2000) attached a valve with a metal barbed fitting to a riser pipe to seal all dedicated probes. A PVC barbed union and 0.95 cm ( $\frac{3}{8}$ " ) ID Teflon<sup>®</sup> tubing was attached to the barbed fitting during purging and sample collection.



**Figure 8.** Photograph of valve used to seal dedicated probes, PVC barbed fitting, and Teflon<sup>®</sup> tubing used for sampling.

During purging, a peristaltic pump with Masterflex<sup>®</sup> tubing, variable-area PVC flowmeter, and landfill gas meter were used in line to extract air, measure flow rate, and measure oxygen ( $O_2$ ), carbon dioxide ( $CO_2$ ), and methane ( $CH_4$ ) gas concentrations. Purge and sample collection occurred at a flow rate of 0.5 standard liters per minute (SLPM). To eliminate the potential of cross-contamination, flowrate was not measured during sampling but set during purging. Teflon<sup>®</sup> and Masterflex<sup>®</sup> were replaced after sampling at each depth and location.



**Figure 9.** Photograph of peristaltic pump, flowmeter, and landfill gas meter used during purging dedicated vapor probes.



**Figure 10.** Photograph of peristaltic pump and one-liter Tedlar bags (replicate sample) used for sampling dedicated vapor probes.

### 3.2 Soil-Gas Sampling with the GeoProbe PRT System

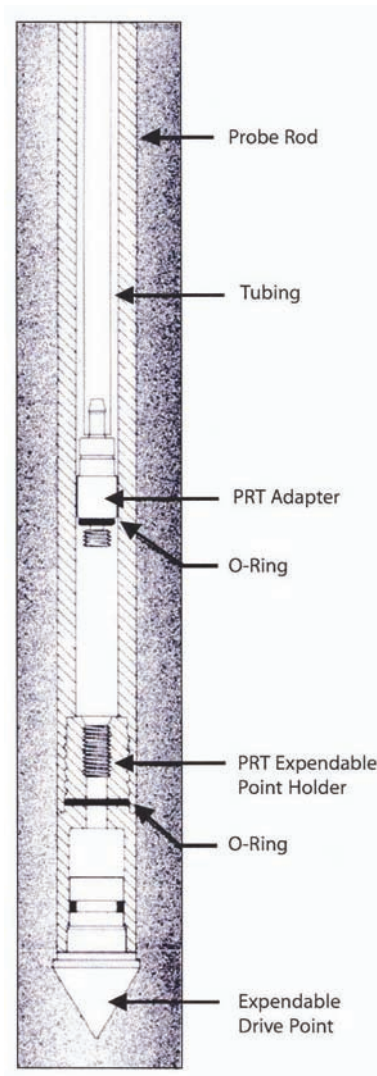
A photograph of a Geoprobe PRT system mounted on a flat-bed truck is illustrated in **Figure 11**. Each sample location was surveyed for the presence of underground utilities prior to probing. **Figures 12** through **16** illustrate components of the PRT system. Probe rods were pushed vertically into the ground until the desired depth was reached. The probe rods were then retracted approximately 5 cm for sampling. A metal rod was used to push out the expendable point. The Teflon® tubing containing the PRT and an adapter with an O-ring was then inserted into the probe rods and turned counterclockwise to engage the adapter threads with the expendable point holder.





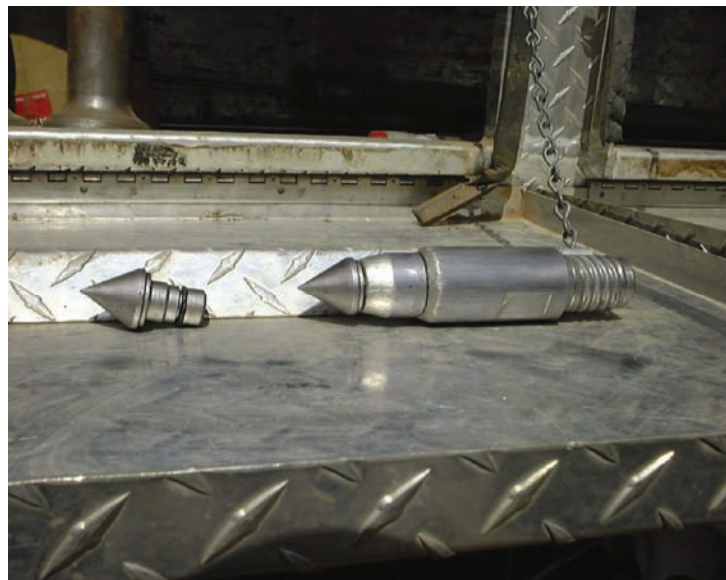
**Figure 11.** Photograph of truck-mounted PRT system.

The tubing was pulled up lightly to test engagement of the threads. After sampling was completed, the tubing was pulled up firmly until it released from the adapter. The probe rods were then retracted to recover the point holder and PRT adapter. Teflon<sup>®</sup> tubing was replaced at each sample depth to avoid potential cross-contamination.



**Figure 12.** Components of PRT sampling system.

Similar to sampling at dedicated vapor probes, a peristaltic pump, flowmeter, and landfill gas meter were used in line to extract air and measure flow rate and O<sub>2</sub>, CO<sub>2</sub>, and CH<sub>4</sub> concentrations during purging. A peristaltic pump and one-liter Tedlar bags were used for sampling. Flowrate during purging and sampling was 0.5 SLPM.



**Figure 13.** Photograph of an expendable point and expendable point holder.



**Figure 14.** Photograph of a PRT adapter with an O-ring and associated Teflon® tubing.



**Figure 15.** Photograph of metal rod used to push out the expendable point.



**Figure 16.** Photograph of connection of PRT adapter to expendable point holder.



### 3.3 Soil-Gas Sampling with the AMS GVP System

As illustrated in **Figure 17**, if asphalt was present at the probing location, a rotary hammer drill and concrete bit were used to cut a 3.8 cm (1½") hole prior to sampling.



**Figure 17.** Creation of hole in asphalt prior sampling with GVP kit.

A section (30 cm longer than target depth) of 0.48 cm (3/16") ID x 0.64 cm (1/4") OD Teflon® tubing was attached to the barbed end of an AMS Retract-A-Tip as illustrated in **Figure 18**. A disassembled view of the Retract-A-Tip is provided in **Figure 19**. The Retract-A-Tip consists of a stainless-steel tip, screen, and housing having a 1.6 cm (5/8") outside diameter. The tip was then connected to 0.91 meter (3') sections of threaded 1.6 cm OD stainless-steel pipe. The pipe was connected to an AMS extension drive adapter and hammered to a desired depth with a rotary hammer drill as illustrated in **Figure 20**.



**Figure 18.** Photograph of Retract-A-Tip and Teflon® tubing.



**Figure 19.** Disassembled view of Retract-A-Tip.



**Figure 20.** Photograph of hammering Retractable Tip and support pipe using a rotary hammer drill and the GVP extension drive adapter.

As illustrated in **Figure 21**, prior to sampling, the Retractable Tip and associated pipe was retracted 5 cm using a jack provided with the GVP kit. After sampling, the rods were removed from the ground using the AMS retrieval jack. The Retractable Tip was then cleaned prior to sampling at the next depth.

Again, similar to sampling at dedicated vapor probes, a peristaltic pump, flowmeter, and landfill gas meter were used in line to extract air and measure flow rate and  $O_2$ ,  $CO_2$ , and  $CH_4$  concentrations during purging. A peristaltic pump and one-liter Tedlar bags were used for sampling. Purging and sampling occurred at a flowrate of 0.5 SLPM.



**Figure 21.** Retraction of Retractable Tip prior to sampling.

As illustrated in **Figure 22**, dedicated vapor probe, PRT, and GVP sampling systems were generally located within 1 m of each other to minimize the effect of spatial variability on data interpretation.



**Figure 22.** Proximity of dedicated vapor probe (metal cover surrounded by white concrete at base of Geoprobe unit), PRT, and GVP sampling systems.



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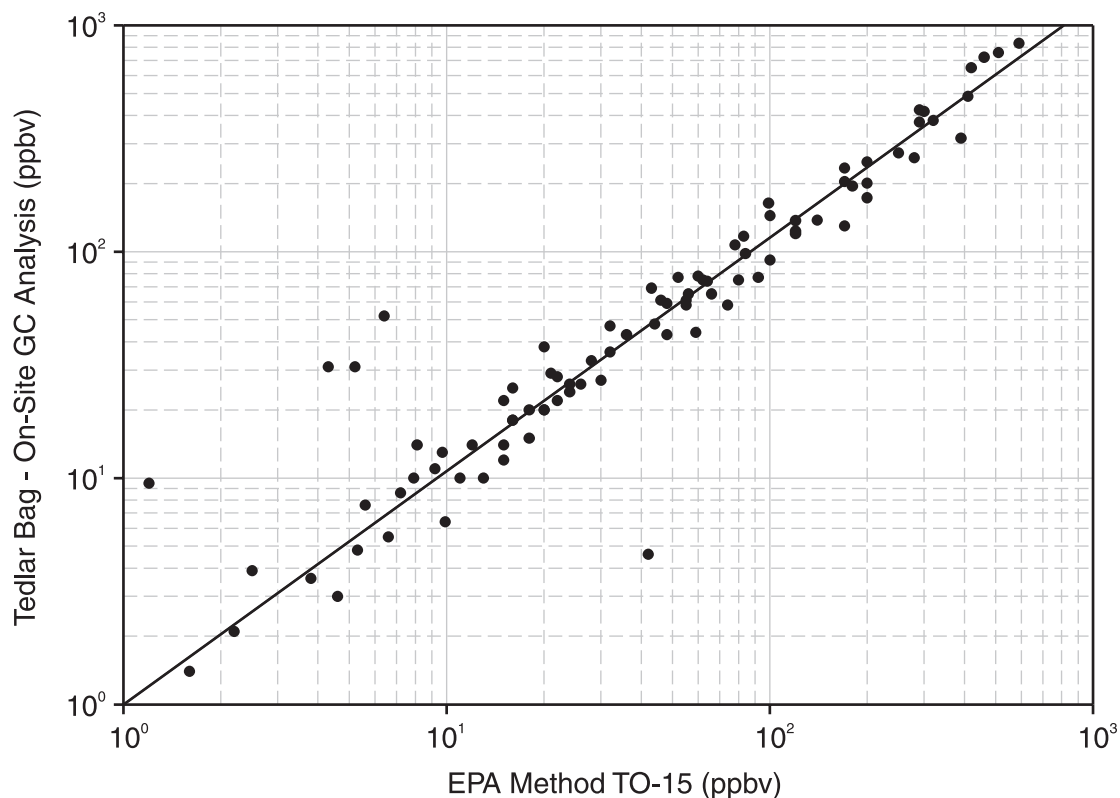
### 3.4 On-Site Soil-Gas Analysis and Data Quality

On-site gas chromatography (GC) analysis was conducted by EPA's New England Regional Laboratory using their standard operating procedure (USEPA, 2002b). Air samples from each Tedlar bag were injected into two portable GCs with results compared for consistency. The first GC was a Shimadzu 14A equipped with a 30 m, 0.53 mm megabore capillary column, a photoionization detector (PID), and an electron capture detector. The second GC was a Photovac 10A10 equipped with a 1.2 m (4'), 0.32 cm (1/8") SE-30 column and a PID. A Hamilton 250 µl steel barrel syringe with a 2.5 cm 25-gauge needle was used to directly inject 200 µl of sample into both GCs. Single concentration standards were prepared from readily available commercial methanol stock solutions and diluted in VOC-free water in Class A volumetric glassware to a concentration of 10 µg/l. After preparation, standards were immediately transferred into 40 ml VOA vials and stored in an ice bath (0 – 1°C). Prior to air sample analysis, 10 ml of standard was withdrawn from a 40 ml VOA vial to create a headspace above the liquid standard. Field GCs were calibrated for target compounds using the headspace above the 10 µg/l standard.

On-site GC analysis for 1,1,1-TCA, 1,1-DCE, TCE, and c-1,2-DCE was identical to that used for sub-slab sampling at the Raymark site (EPA, 2006). Sub-slab air samples collected using EPA Method TO-15 (EPA, 1999) were compared with sub-slab air samples collected using a peristaltic pump and one-liter Tedlar bags. As illustrated in **Figure 23**, there was good agreement between this sampling and analytical method and EPA Method TO-15.

Sample container blanks were collected to ensure that VOCs of concern were not present in Tedlar bags prior to sample collection. Four one-liter Tedlar bags (one from each batch received) were filled with laboratory-grade nitrogen gas and analyzed. The results of testing are summarized in **Table 2** in Appendix A. Analysis of container blanks indicated that Tedlar bags used for sampling were not a source of VOCs of concern above detection limits of 2 to 4 ppbv.

Field blanks were collected to assess potential breakthrough of VOCs of concern from atmospheric air into Tedlar bags during sampling. Outdoor air samples were collected each of the three days of soil-gas sampling. The results of testing are summarized in **Table 3** in Appendix A. Analysis of field blanks indicated that there was little potential for atmospheric air to impact soil-gas sample results of VOCs of concern above detection limits of 2 to 4 ppbv.



**Figure 23.** Comparison of EPA Method TO-15 with sample collection using a peristaltic pump and Tedlar bags with on-site GC analysis of 1,1,1-TCA, 1,1-DCE, TCE, and c-1,2-DCE ( $n = 91$ ,  $r^2 = 0.88$ ).

Probe blanks were collected to ensure that components of the PRT and GVP sample systems and associated tubing were not the source of VOCs of concern. Atmospheric air was passed through the probe and tubing of GVP and PRT sampling systems several times and collected into one-liter Tedlar bags. The results of testing are summarized in **Table 4** in Appendix A. Analysis of probe blanks indicated that neither GVP nor PRT sample systems and associated tubing were sources of VOCs of concern above detection limits of 2 to 5 ppbv. Tubing for both systems was discarded after sampling at each location and depth to avoid potential cross-contamination.

Travel blanks were collected to ensure that storage of Tedlar bags in a cooler (not chilled) prior to analysis did not impart an analytical bias (e.g., VOC transport from one Tedlar bag to another or presence of VOCs in the cooler). A one-liter Tedlar bag was filled with laboratory-grade nitrogen and placed in a cooler used to transport (hand carry to mobile laboratory) samples each day. The results of travel blanks are summarized in **Table 5** in Appendix A. Analysis of travel blanks for VOCs of concern indicated that transport of the Tedlar bags did not impact sample results at detection limits above 2 to 4 ppbv.

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Replicate samples, which consisted of two samples from the same air stream, were collected to assess the precision of the entire sample and analysis procedure. **Figure 10** illustrates collection of replicate samples from a dedicated vapor probe. The results of replicate sampling are summarized in **Table 6** in Appendix A. The relative percent difference (RPD) of 15 replicate analytical pairs (from 5 samples) with detectable concentrations varied from 0.0 to 9.1% (9 out of 15 sample pairs were 0.0%). By comparison, EPA Method TO-15 (EPA, 1999) requires replicate precision less than or equal to 25%. RPD is defined as:

$$\text{RPD} = 100 \frac{|X_1 - X_2|}{\bar{X}}$$

where:  $\bar{X}$  = sample mean and  $X_1$  and  $X_2$  are values for samples 1 and 2, respectively.

### 3.5 Computation of Pre-Sample Internal Volume Exchange Requirements

The internal volume of dedicated vapor probes consisted of a 3.8 cm (1.5") ID, 30.5 cm (1') long slotted PVC pipe used as a screened interval, a 1.9 cm (0.75") ID PVC riser pipe to the surface, and 0.95 cm (3/8") ID Teflon® tubing used between valves and one-liter Tedlar sample bags. The internal volume of the valve at the top of the riser pipe was insignificant compared to other internal volume components. The internal volume of the PRT sample system consisted of an open 2.5 cm (1") diameter by 5 cm (2") long cylindrical hole created during riser pipe retraction and tubing used for connection to one-liter Tedlar bags. The internal volume of the retractable point holder and PRT adapter were similar to the Teflon® tubing and were incorporated into the computation of the internal volume of tubing. The internal volume of the GVP sample system consisted of a 0.64 cm (1/4") ID 5 cm (2") long stainless-steel screen and 0.48 cm (3/16") ID Teflon® tubing.

Tubing used to sample dedicated vapor probes and direct-push/hammer soil-gas sampling systems should be purged prior to sampling. Air inside tubing will initially have direct contact with and be representative of outdoor air. The relatively small screened interval of PRT and GVP sample systems should also be purged prior to sampling because outside air may be drawn into the screened interval during riser pipe retraction. However, the screened interval and riser pipe of a sealed dedicated vapor probe should be more reflective, although not necessarily the same, as nearby soil-gas concentrations if the probe was installed some time (e.g., days or weeks) prior to sampling. Thus, less internal volume exchanges or purge volumes may be necessary prior to sampling dedicated vapor probes compared to PRT and GVP sample systems. Internal volumes and pre-sample internal volume exchanges were calculated for each sample system at each depth and location and are presented in tables throughout Appendix A.

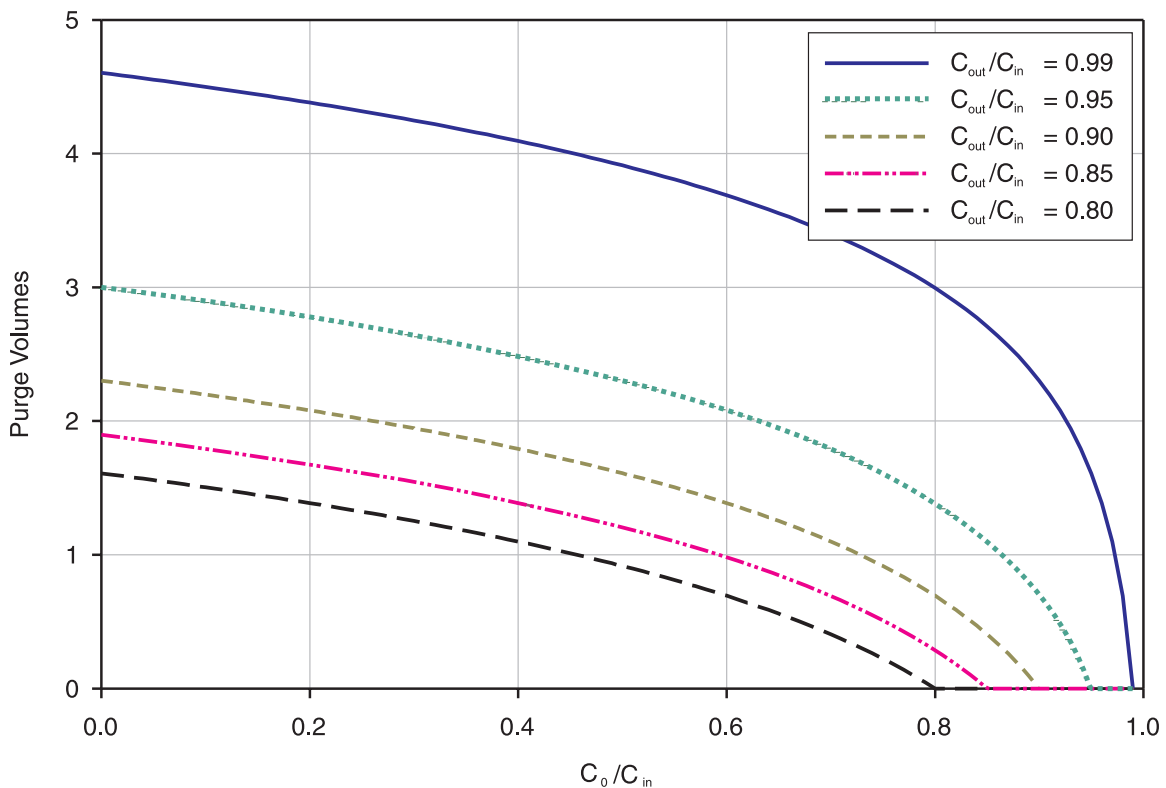
Calculation of a minimum purge volume prior to sampling can be estimated using a mass balance equation:

$$\frac{dC_{out}}{dt} = \frac{Q}{V}(C_{in} - C_{out})$$

where  $C_{out}$  is a well-mixed vapor concentration within and exiting the sample system,  $C_{in}$  = constant concentration entering the system from surrounding soil-gas,  $Q$  = flow rate entering and exiting sample system,  $t$  = time, and  $V$  = internal volume of sampled system. When subject to an initial condition,  $C_0$  (vapor concentration at time zero), purge volume ( $tQ/V$ ) can be expressed as a function of  $C_{in}$  and  $C_{out}$  by:

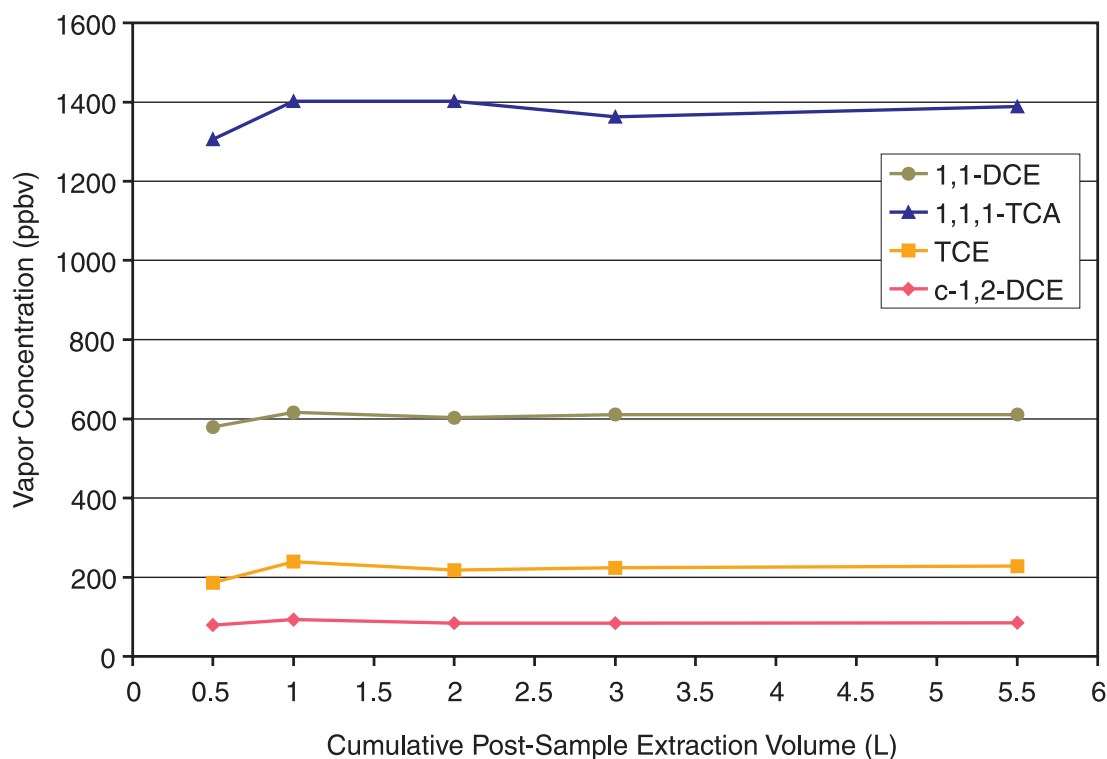
$$\frac{tQ}{V} = \ln \left| \frac{C_{in} - C_0}{C_{in} - C_{out}} \right|$$

Purge volumes as a function of  $C_0/C_{in}$  and  $C_{out}/C_{in}$  are illustrated in **Figure 24**.



**Figure 24.** Purge volume as a function of  $C_0/C_{in}$  and  $C_{out}/C_{in}$ .

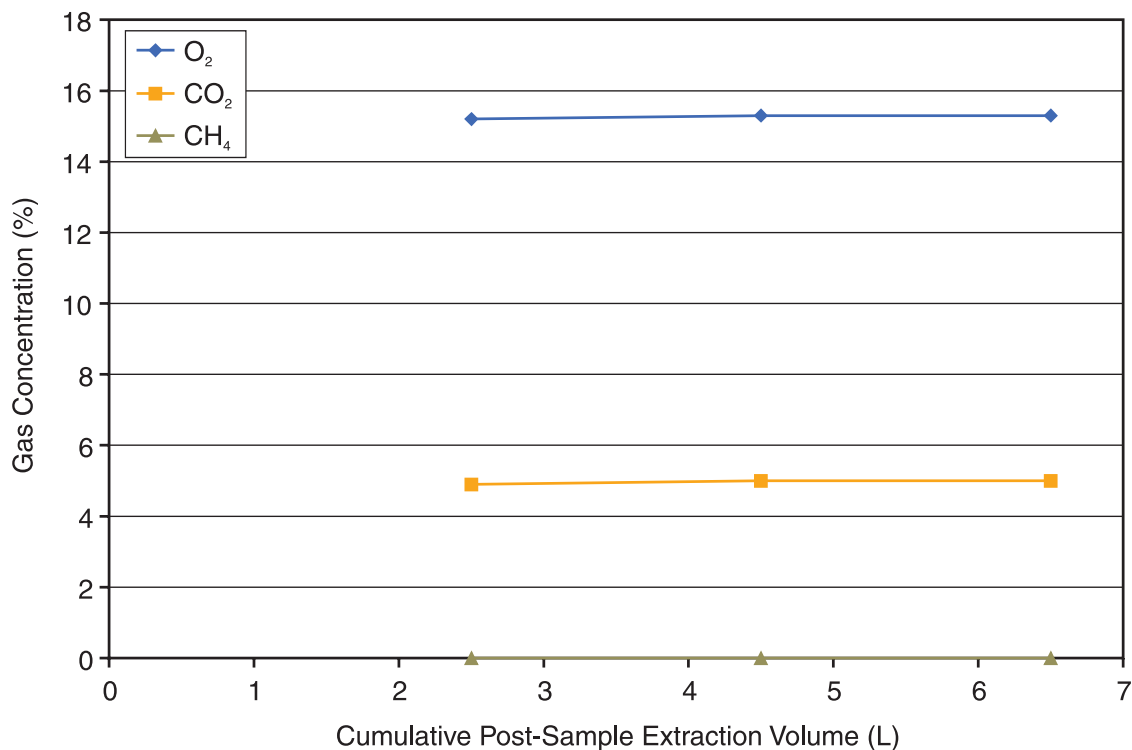
The ideal condition is that  $C_{out}/C_{in} = 1$ . However, extraction of 2.2 to 3 purge volumes ensures that the exiting vapor concentration is approximately 90 to 95% of the entering concentration even when vapor concentration inside the sample system has been reduced to  $C_{out}/C_{in} = 0$ . This would be the condition most representative of PRT and GVP sample systems. However, as previously discussed, it is unlikely that  $C_o/C_{in}$  would equal zero for dedicated vapor probes. If for instance  $C_o/C_{in} = 0.4$ , then extraction of 1.8 to 2.5 purge volumes results in the exiting concentration being approximately 90 to 95% of the entering concentration. **Figure 25** illustrates vapor concentration as a function of cumulative post-sample extraction volume at dedicated vapor probe MW513SG. Sample volume was 0.5 liters.



**Figure 25.** Vapor concentration as a function of cumulative post-sample extraction volume up to 5.5 liters at dedicated vapor probe MW513SG.

One internal exchange or purge volume was calculated to be one liter. Cumulative post-sample extraction volume represents the summation of air extracted during and prior to sample collection. Thus, air extraction did not occur prior to the first sample and five liters of air were extracted prior to the fifth sample. Only the first 5 samples are shown in **Figure 25**. To evaluate the effect of extraction volume on sample concentration, a total of 10 samples were collected at MW513SG up to a cumulative post-sample volume of 103 liters. These results will be discussed in Section 3.6. There appears to be a slight increase in concentration for all four VOCs analyzed after the first sample. Thus, at least in this case, a purge volume of one liter or 1 internal air exchange would have been sufficient to stabilize concentrations in dedicated

vapor probes. Stabilization of O<sub>2</sub>, CO<sub>2</sub>, and CH<sub>4</sub> concentrations is sometimes used as an indicator of sufficient purging. Sequential sampling indicated stable O<sub>2</sub>, CO<sub>2</sub>, and CH<sub>4</sub> concentrations at virtually all locations as evidenced in Appendix A. For example, **Figure 26** illustrates a stable gas concentration after extraction of two liters of air at dedicated vapor probe MW514SG. Similar to MW513SG, sample volume was 0.5 liters while one internal exchange volume was calculated to be one liter.



**Figure 26.** O<sub>2</sub>, CO<sub>2</sub>, and CH<sub>4</sub> concentration as a function of cumulative post-sample extraction at dedicated vapor probe MW514SG.

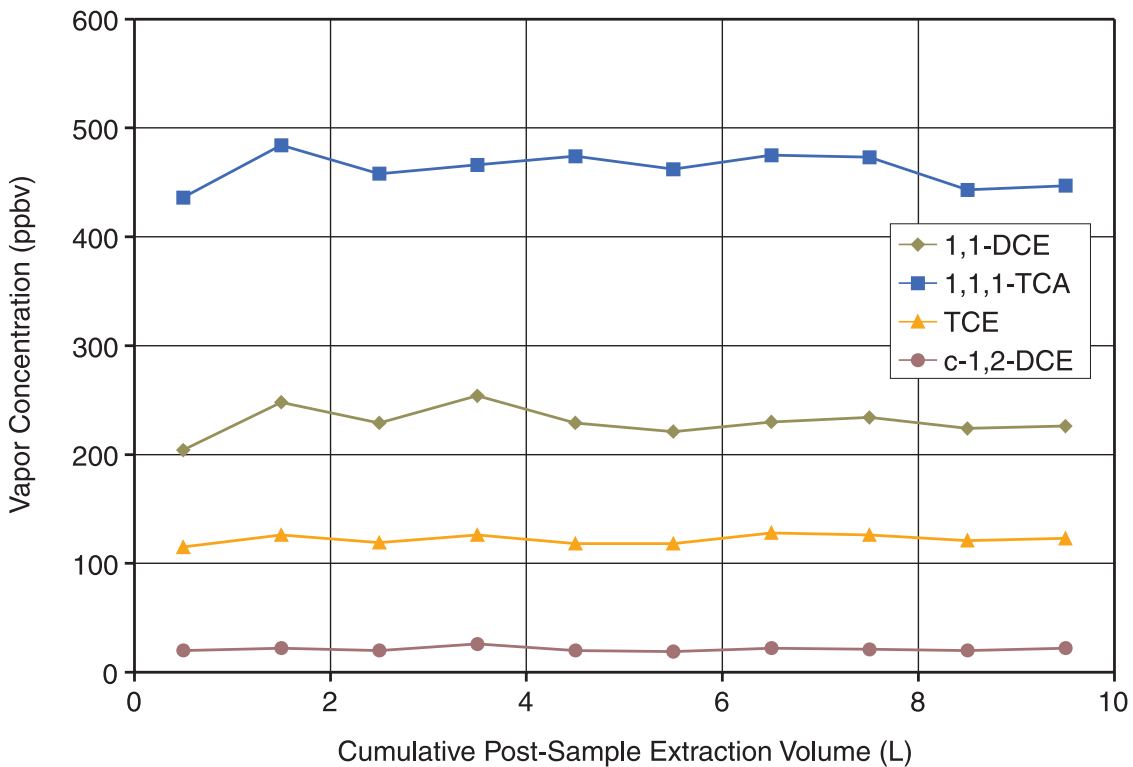
In this investigation, at least 2 internal volumes were exchanged prior to sampling dedicated vapor probes. Because of the relatively small internal volumes of PRT and GVP soil-gas systems, at least 3 internal volumes were exchanged prior to sampling.

### 3.6 Assessment of Extraction Volume on Sample Results

To allow a comparison of dedicated probe, PRT, and GVP sampling systems, the act of sample collection should neither affect sample results from the system being sampled nor at other sample systems nearby. The potential for sample collection affecting sampling results from the system being sampled is discussed in this section. The potential for sample collection affecting sampling results at other sample systems nearby is discussed in Section 3.7. Increasing pre-sample air extraction volume in excess of a purging requirement could increase the possibility of collecting a soil-gas sample which is not representative of

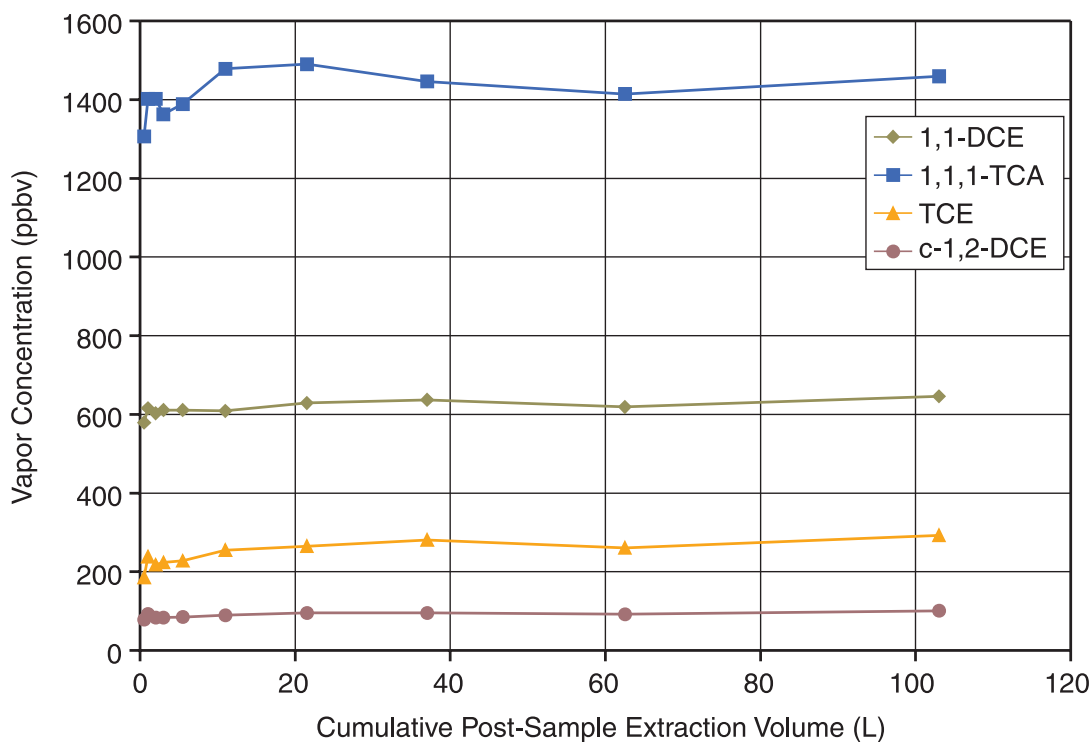
some integrated volume of soil around a screened interval. The most direct way to evaluate the impact of a pre-sample air extraction volume on sample results is to collect a number of soil-gas samples sequentially and observe vapor concentration as a function of extraction volume. During sample collection, VOC concentrations should remain relatively constant unless air is drawn in from a nearby region of lower or higher vapor concentration. Extraction volume testing was performed at one location using the PRT sampling system and at another location using a dedicated vapor probe.

The computation of the internal volume of a PRT sampling system when sampling at a depth of 0.76 m (2.5') near MW 525SG is summarized in **Table 7a** in Appendix A. The computation of cumulative post-sample extraction volumes and pre-sample internal exchanges is summarized in **Table 7b** in Appendix A. Since the internal volume of the PRT sampling system was only 0.122 liters, pre-sample internal volume exchanges were relatively high during testing at this location (up to 73.6). Vapor concentration as a function of cumulative post-sample extraction volume is presented in **Figure 27** which demonstrates little or no effect of extraction volume on sample concentration of 1,1,1-TCA, 1,1-DCE, TCE, and c-1,2-DCE.



**Figure 27.** Vapor concentration as a function of cumulative pre-sample extraction volume using the PRT sampling system at a depth of 0.76 m near MW525SG.

Vapor concentration as a function of cumulative post-sample extraction volume at dedicated vapor probe MW513SG is illustrated in **Figure 28**. The internal volume of MW513SG having a screened interval 2.1 m (6.9') to 2.4 m (7.9') below grade was 1 liter. The computation is summarized in **Table 8a** in Appendix A. The computation of cumulative post-sample extraction volumes and pre-sample internal exchanges is summarized in **Table 8b** in Appendix A. A total of 10 samples and 103 liters of air were extracted during this test. Since the internal volume of MW513SG was one liter, pre-sample internal exchanges were equivalent to pre-sample air extraction volumes. Thus, 102.5 liters of air or 102.5 internal exchanges occurred prior to collecting the tenth sample. With the exception of sample results for 1,1,1-TCA which are somewhat erratic, it is apparent after the first one or two internal volume exchanges, sample concentration remained relatively constant even after extraction of over 100 liters air. With the exception of explicit extraction testing, the most air extracted during any sampling event was 8 liters (for deep dedicated vapor probes). This indicates that it is unlikely that the act of sample collection impacted sample results at any sample system at any depth in this study.

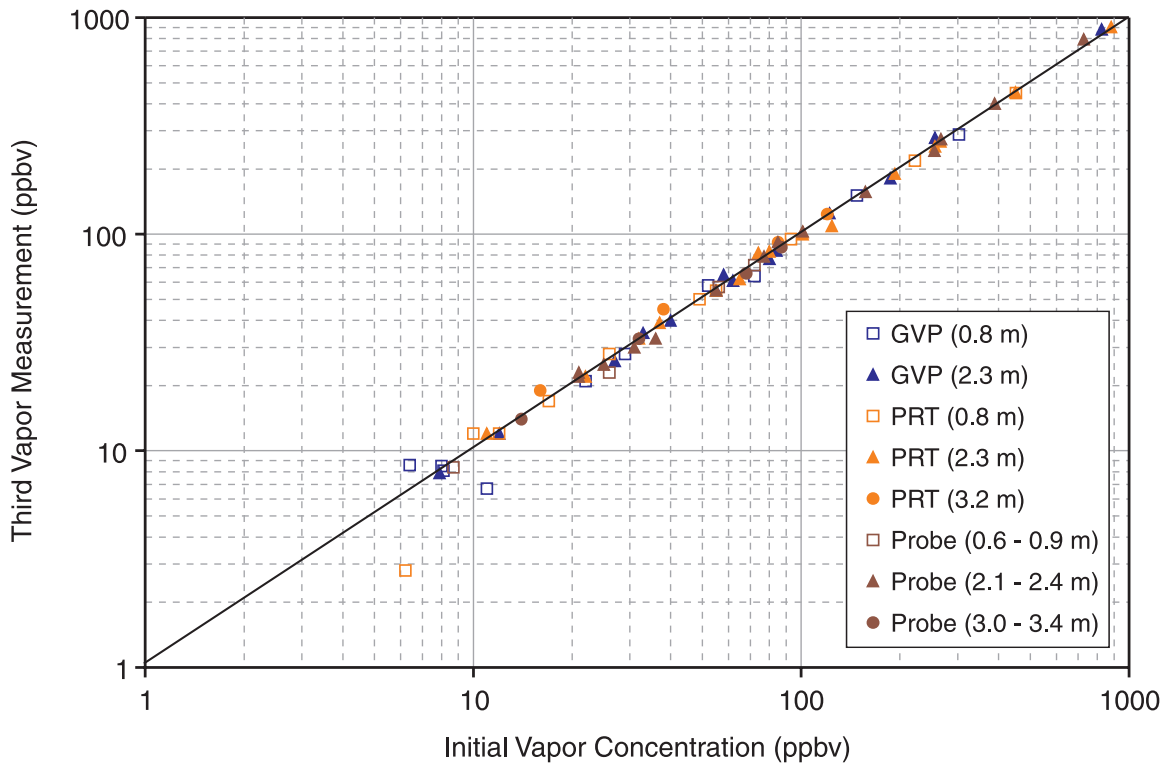


**Figure 28.** Vapor concentration as a function of cumulative post-sample extraction volume at dedicated vapor probe MW513SG at a depth interval of 2.1 to 2.4 m.



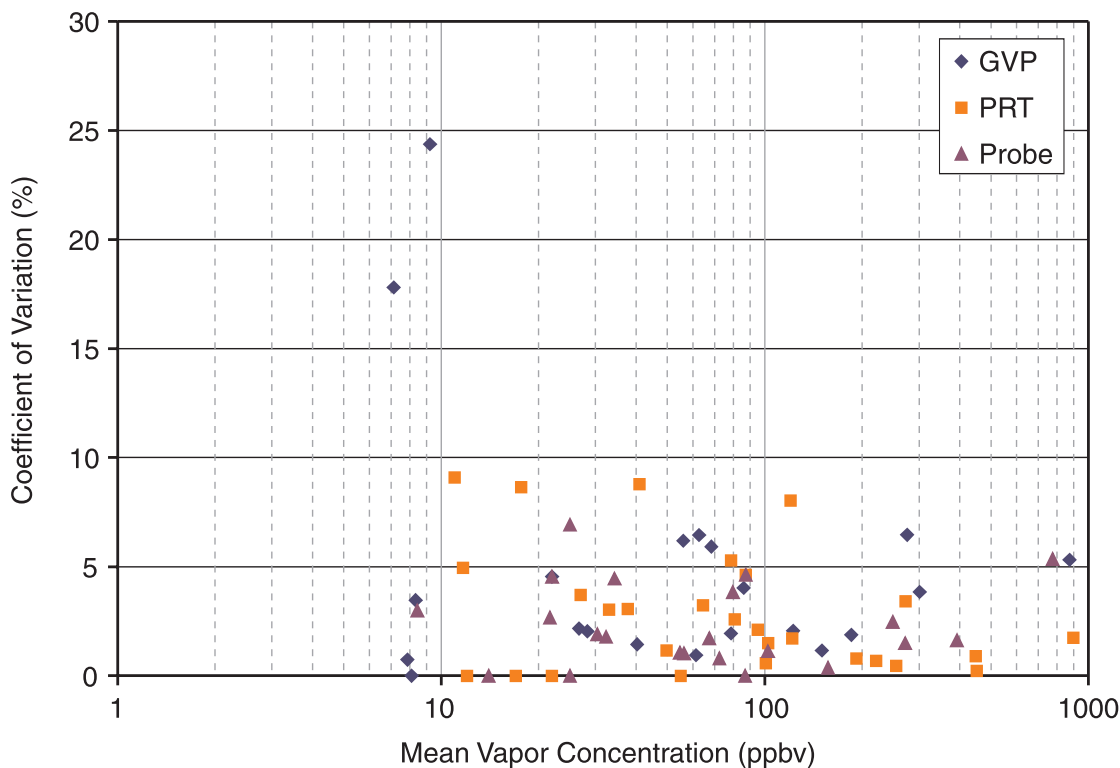
### 3.7 Assessment of Impact of Air Extraction at One Location on Another Location

At least conceivably, excessive air extraction volume at one probe could impact vapor concentration at a nearby probe. To evaluate the potential impact of pre-sample extraction volume at one location on sample results at a nearby location and depth, three samples were taken from each sampling system at most test locations. For example, at MW523SGS, the PRT system was sampled first followed by the GVP system followed by sampling at the dedicated probe. The sequence was then changed to sampling at the GVP system followed by sampling at the dedicated vapor probe followed by sampling at the PRT system and so on. A comparison of first and third vapor concentrations for locations and depths where three samples were collected is presented in **Figure 29**. A 1:1 correlation between samples indicates that sample collection at one location did not impact sample results at another location.



**Figure 29.** Comparison of first and third samples at dedicated probe, PRT, and GVP sample locations.

**Figure 30** illustrates coefficients of variation ( $100 \times \text{standard deviation}/\text{mean}$ ) for all locations where three samples were collected for each sample system at each depth. Coefficients of variation were low except when approaching detection limits around 5 - 10 ppbv again indicating that sample collection at one location did not impact sample results at another location.



**Figure 30.** Coefficient of variation (%) as a function of mean vapor concentration for first, second, and third samples at dedicated probe, PRT, and GVP sample locations.

### 3.8 Consideration of Spatial Variability on Comparison of Sampling Techniques

PRT and GVP sampling locations were positioned relatively close (usually within 1 m) to dedicated vapor probes to minimize the effect of spatial variability in comparing soil-gas sampling techniques. To assess the presence and magnitude of spatial variability on this scale, soil-gas sampling was conducted at five locations and three depths near MW213 using the PRT sampling system. **Figures 31** and **32** illustrate the scale and locations of testing.

The computation of internal volumes using the PRT sampling system at five locations at depths of 0.76 m (2.5'), 2.3 m (7.5'), and 3.2 m (10.5') are summarized in **Tables 9a** through **9c** in Appendix A. Sample results and computation of pre-sample internal exchanges at these depths are summarized in **Tables 9d** through **9f** in Appendix A. As these tables indicate, there were 2 to 3 internal exchanges prior to sampling. Pre-sample O<sub>2</sub> and CO<sub>2</sub> concentrations were similar with depth and location. **Figures 33a**, **33b**, and **33c** illustrate variation in concentration with depth and location. Concentration varied by a factor of 1.0 to 2.8. However, variation in most measurements was relatively minor as evidenced by a median of 1.2 and average of 1.3 for 90 sample pairs.

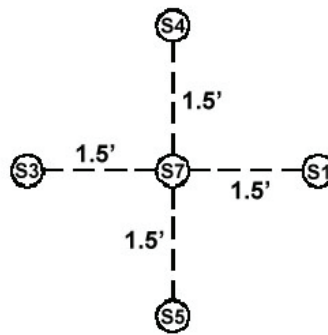


**Figure 31.** Photograph illustrating five PRT sample locations (orange flags) near MW213.

**SIDEWALK**

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GRASS

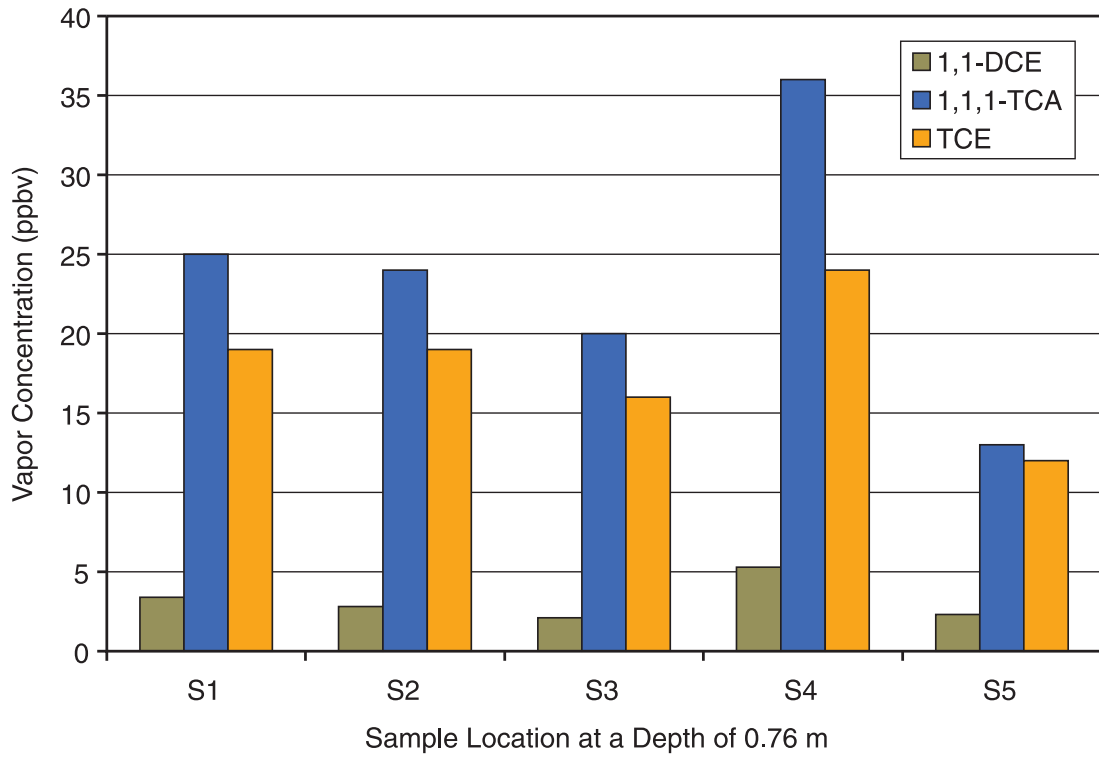


ASPHALT (street)

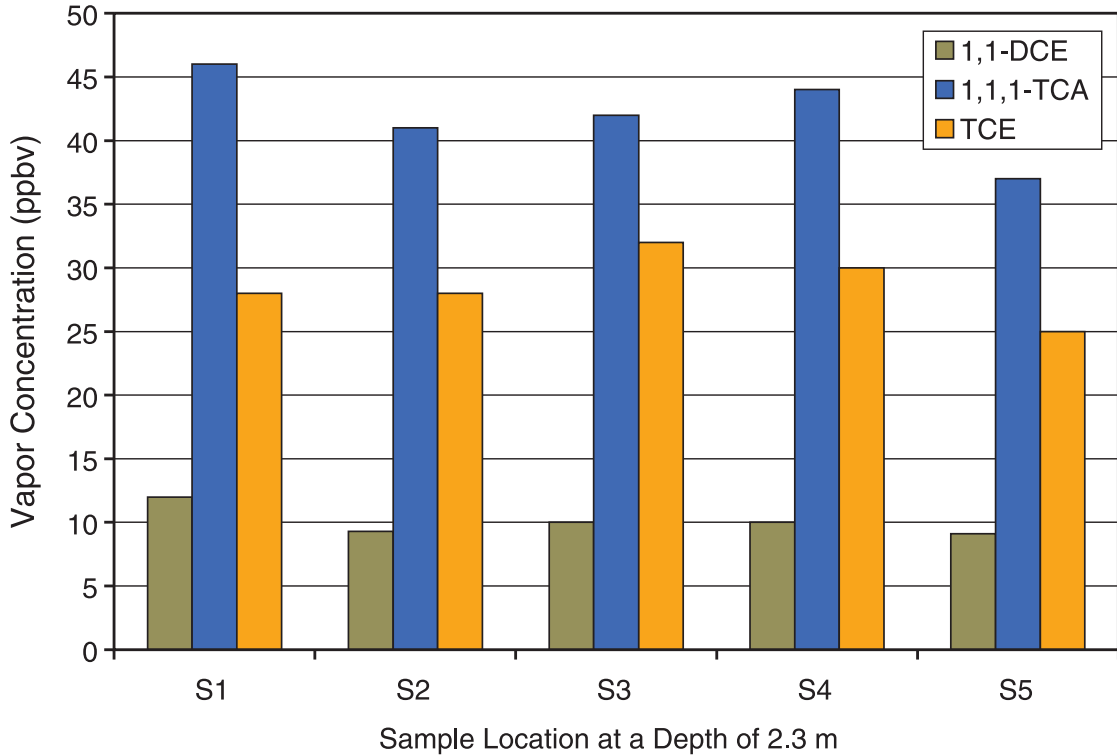
MW213



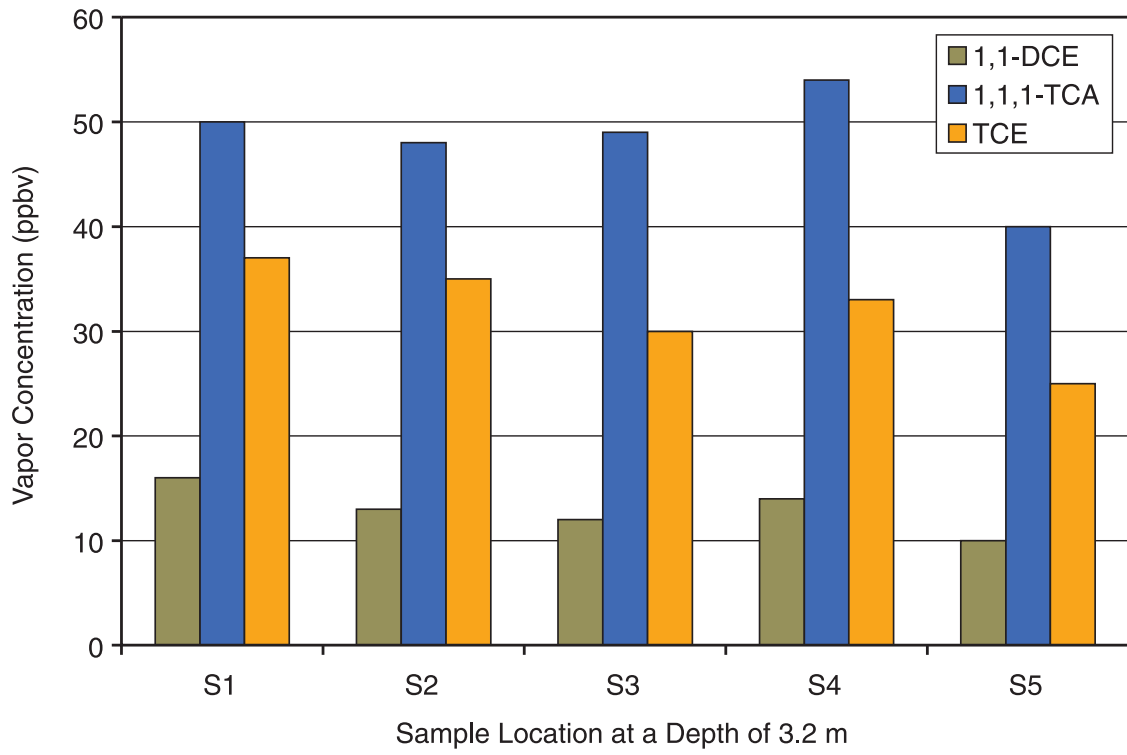
**Figure 32.** Schematic illustrating five PRT sample locations near MW213 in plan view.



**Figure 33a.** Vapor concentration at S1 through S5 (one sample at each location) at a depth of 0.76 m.



**Figure 33b.** Vapor concentration at S1 through S5 (one sample at each location) at a depth of 2.3 m.



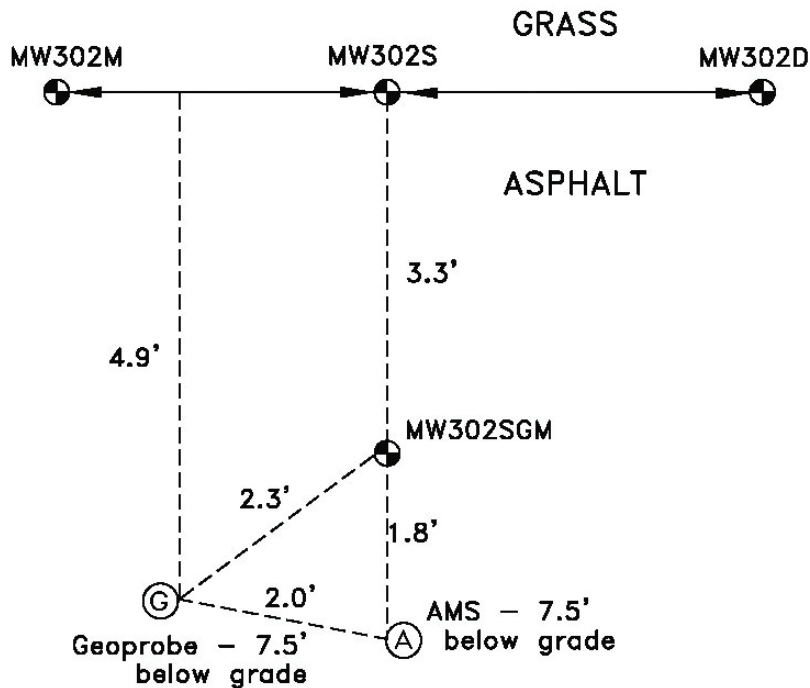
**Figure 33c.** Vapor concentration at S1 through S5 (one sample at each location) at a depth of 3.2 m.

## 4.0 Results

The results of testing at and near each dedicated vapor probe are summarized in this section. These results will be combined and discussed in further detail in Section 5.

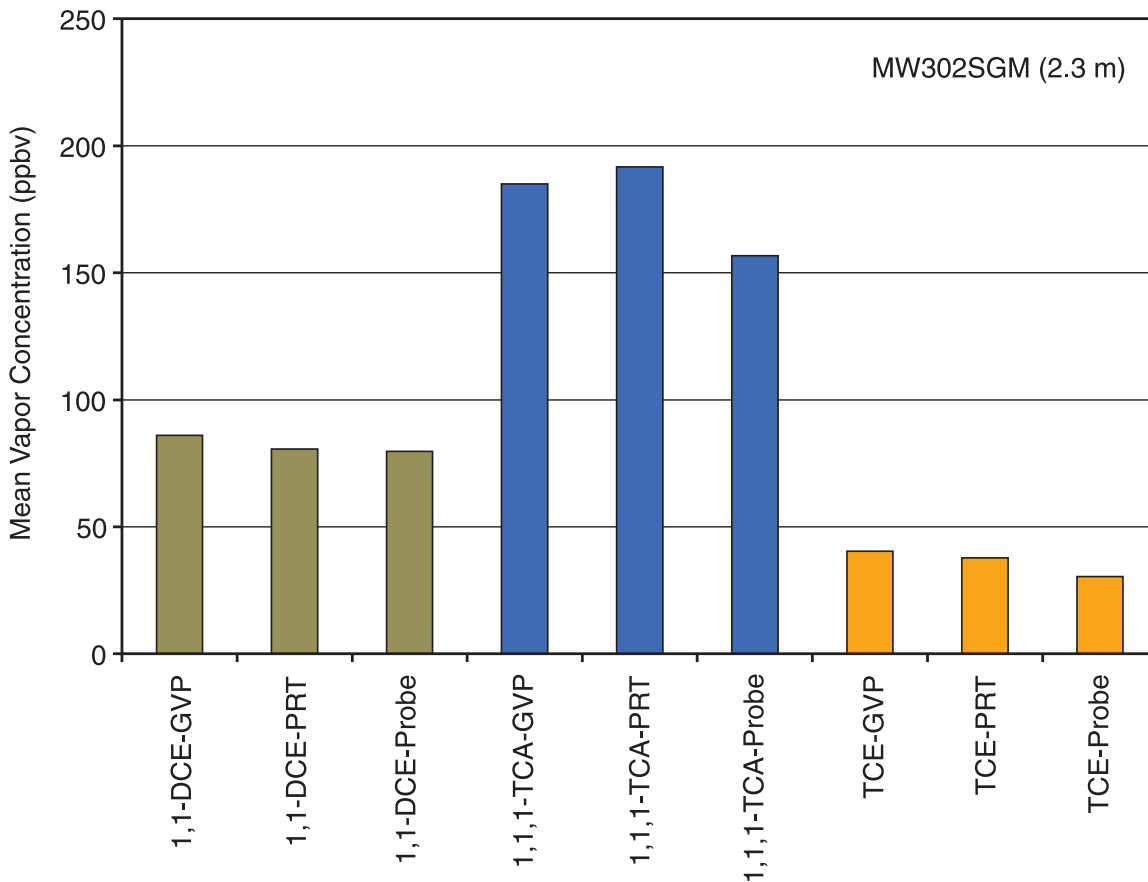
### 4.1 Results of Testing at MW302SGM

A schematic illustrating the location of the dedicated probe MW302SGM and nearby PRT and GVP sampling locations systems is illustrated in **Figure 34**. The screened interval of MW302SGM is 2.1 – 2.4 m (7 – 8') below ground surface. Soil-gas samples were collected using the PRT and GVP systems at 2.3 m (7.5') below ground surface. Samples were collected from each system three times.



**Figure 34.** Schematic illustrating the location of sampling systems at MW302SGM in plan view.

The computation of internal volumes and cumulative pre-sample internal exchanges is summarized in **Tables 10a** and **10b** in Appendix A. Pre-sample internal exchanges for GVP, PRT, and probe systems varied from 6.7 – 33.6, 2.9 – 14.3, and 2.5 – 6.5 respectively. VOC and gas concentrations detected from sample systems at MW514SG are illustrated in **Figure 35** and summarized in **Table 10c** in Appendix A. VOC concentrations of 1,1-DCE, 1,1,1-TCA, and TCE were slightly lower at the dedicated probe compared to PRT and GVP sample systems by a factor up to 1.3.

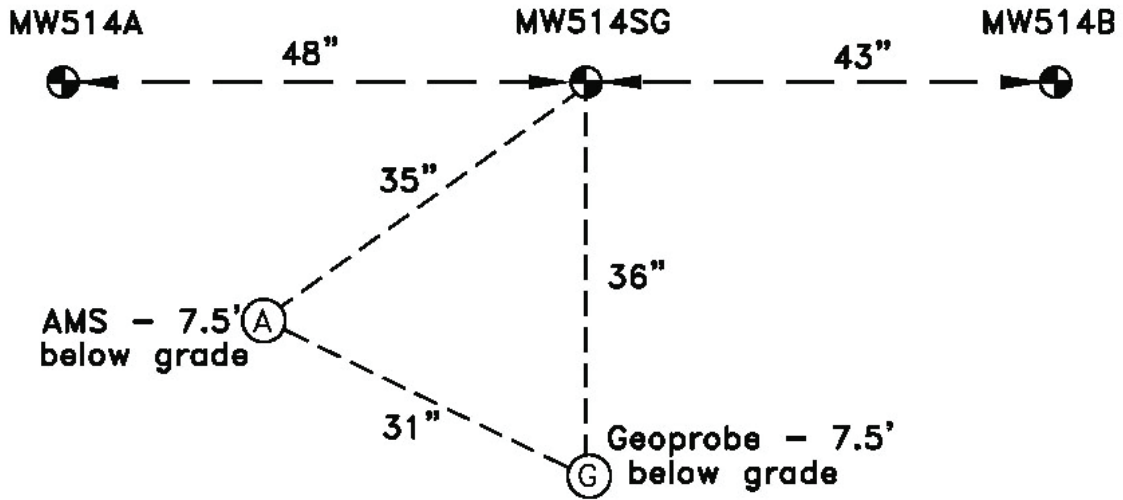


**Figure 35.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW302SGM at a depth of 2.3 m.

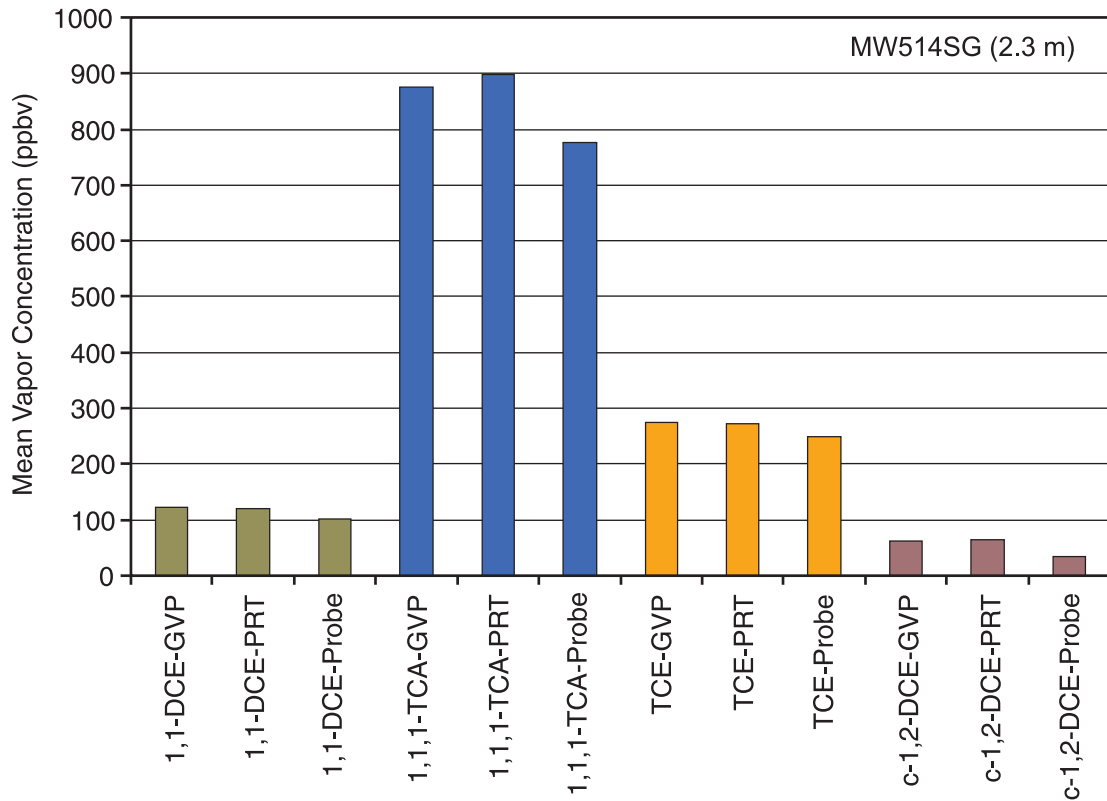
#### 4.2 Results of Testing at MW514SG

A schematic of the location of dedicated probe MW514SG and nearby PRT and GVP sampling systems is illustrated in **Figure 36**. The screened interval of MW514SG is 2.1 – 2.4 m (6.9 – 7.9') below ground surface. PRT and GVP were sampled at 2.3 m (7.5') below ground surface. Samples were collected from each system three times.

The computation of internal volumes and cumulative pre-sample internal exchanges is summarized in **Tables 11a** and **11b** in Appendix A. Pre-sample internal exchanges for GVP, PRT, and probe systems varied from 8.1 – 40.4, 2.8 – 13.9, and 2.5 – 6.5 respectively. VOC and gas concentrations detected from sample systems at MW514SG are illustrated in **Figure 37** and summarized in **Table 11c** in Appendix A. O<sub>2</sub> and CO<sub>2</sub> concentrations were very similar in all three sample systems. VOC concentrations of 1,1-DCE, 1,1,1-TCA, TCE, and c-1,2-DCE were similar for the GVP and PRT sample systems but higher than VOC concentrations detected using the dedicated vapor probe by a factor of up to 1.9.



**Figure 36.** Schematic illustrating the location of sampling systems at MW514SG in plan view.

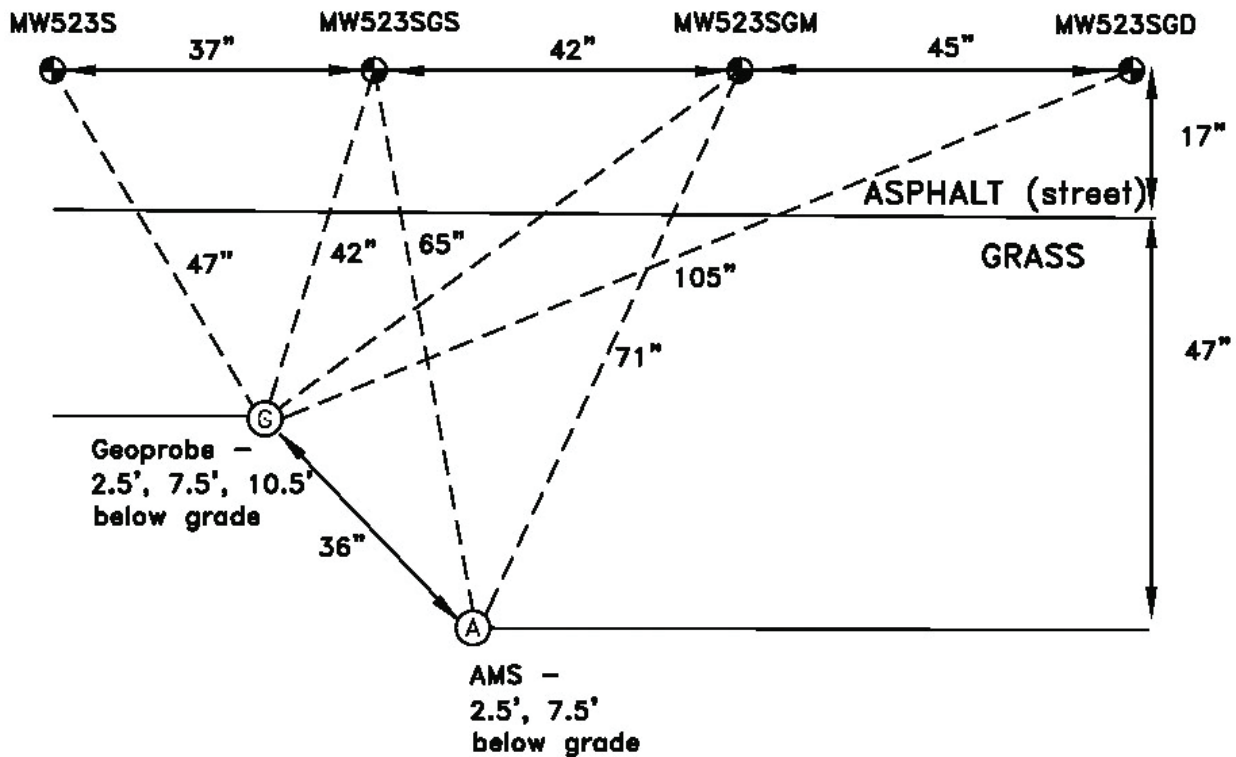


**Figure 37.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW514SG at a depth of 2.3 m.



### 4.3 Results of Testing at MW523SGS, MW523SGM, and MW523SGD

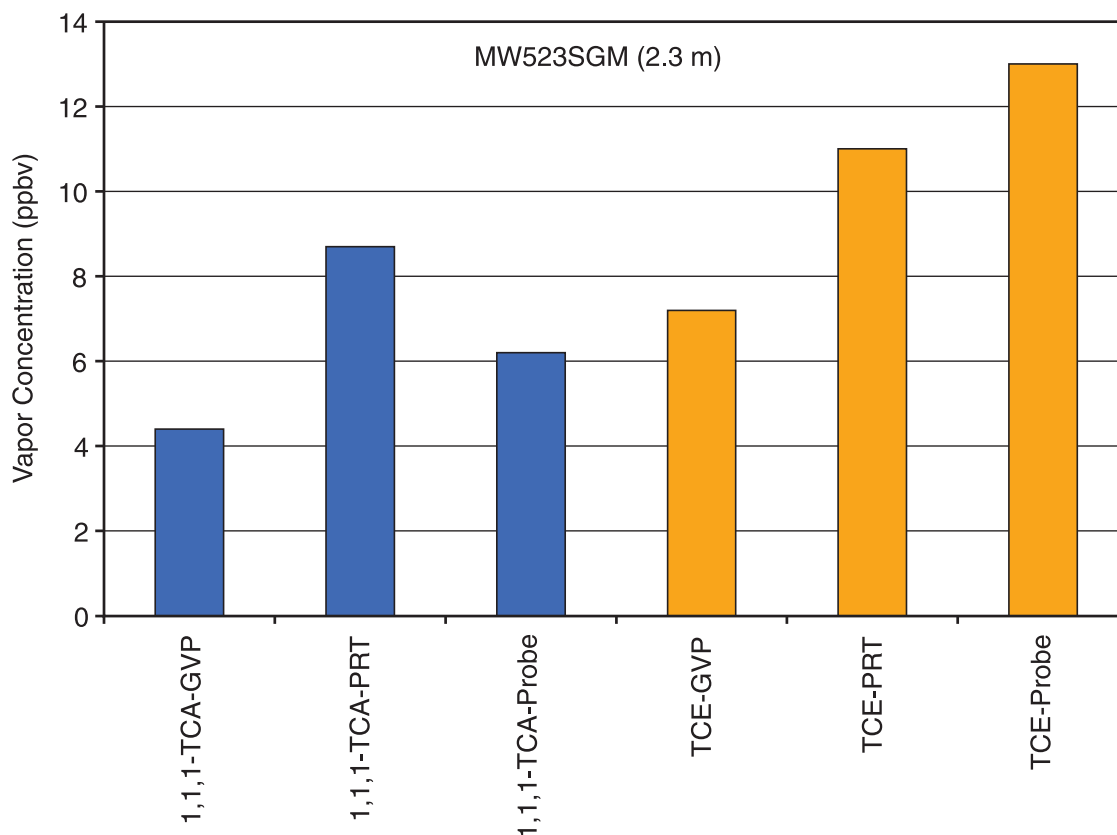
A schematic of the location of dedicated probes MW523SGS, MW523SGM, and MW523SGD and nearby PRT and GVP sampling locations is illustrated in **Figure 38**. The separation of shallow, medium, and deep dedicated vapor probes made it difficult to locate associated PRT and GVP sample systems nearby. While PRT and GVP systems are within 0.91 m (3') of each other, both sample systems were more than 1 m away from dedicated vapor probes used for comparison.



**Figure 38.** Schematic illustrating the location of sampling systems at MW523SGS, MW523SGM, and MW523SGD in plan view.

The screened interval of MW523SGS is 0.6 – 0.9 m (2 – 3') below ground surface. PRT and GVP were sampled at 0.8 meters (2.5 feet) below ground surface. Computation of internal volumes at MW523SGS is summarized in **Table 12a** in Appendix A. Computation of pre-sample internal exchanges and VOC and gas concentrations detected from sample systems at MW523SGS is summarized in **Table 12b** in Appendix A. Pre-sample internal exchanges for GVP, PRT, and probe systems were 4.1, 1.8, and 3.5 respectively. The high CH<sub>4</sub> concentration detected in MW523SGS was caused by a natural gas leak in the area. Interference by CH<sub>4</sub> caused an increase in detection limits for 1,1-DCE and c-1,2-DCE. VOC concentrations were too low to discern any differences between sampling systems.

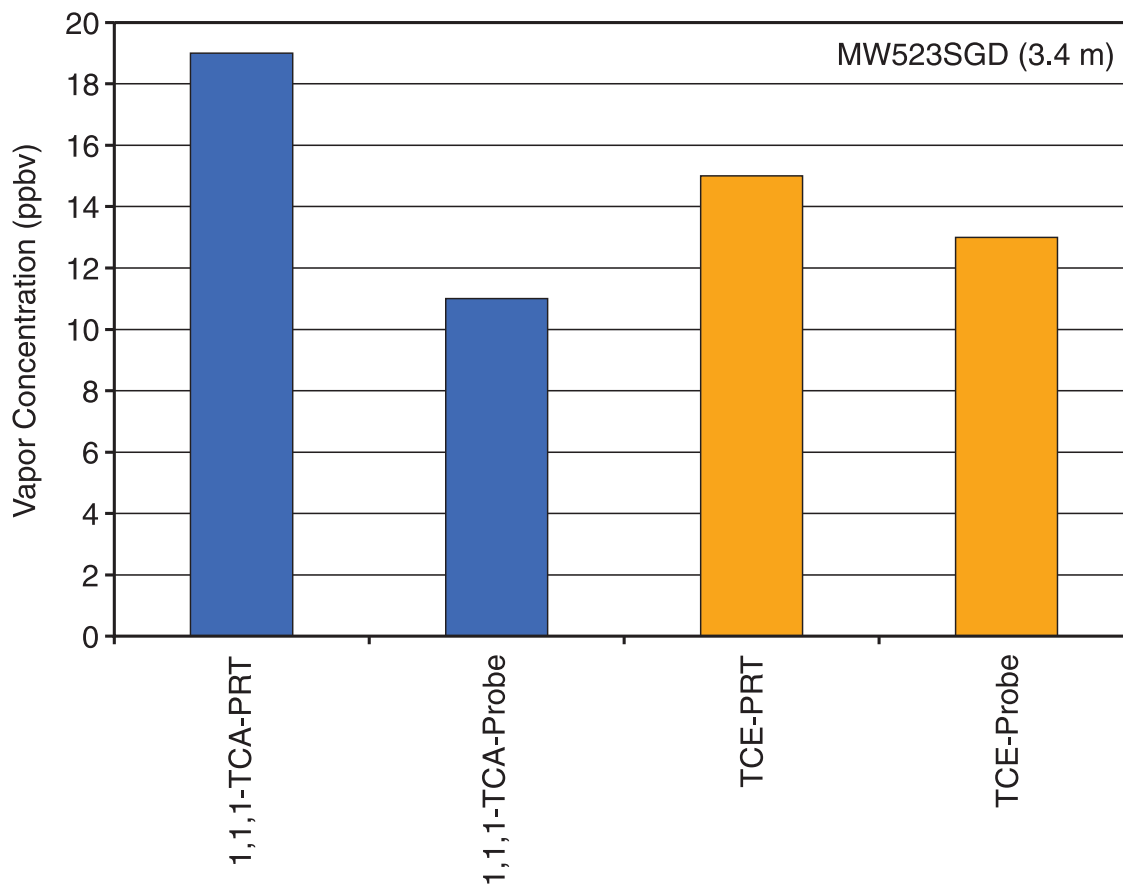
The screened interval of MW523SGM is 2.1 – 2.4 m (7 – 8') below ground surface. PRT and GVP were sampled at 2.3 m (7.5') below ground surface. Computation of internal volumes at MW523SGM is summarized in **Table 13a** in Appendix A. Computation of pre-sample internal exchanges and VOC and gas concentrations detected from sample systems at MW523SGM is summarized in **Table 13b** in Appendix A. VOC concentrations are illustrated in **Figure 39**. Pre-sample internal exchanges for GVP, PRT, and probe systems were 5.8, 2.5, and 2.5 respectively. Again, interference by CH<sub>4</sub> caused an increase in detection limits for 1,1-DCE and c-1,2-DCE. VOC concentrations of 1,1,1-TCA and TCE were slightly higher for the dedicated probe and PRT system compared to the GVP system (by a factor of up to 1.9).



**Figure 39.** Comparison of vapor concentrations (1 sample from each sample system) at MW523SGM at a depth of 2.3 m.

The screened interval of MW523SGD is 3.2 – 3.5 m (10.5 – 11.5') below ground surface. The PRT system was sampled at 3.4 m (11') below ground surface. Sampling at this depth with the GVP system proved difficult (resistance to penetration with rotary hammer drill). Computation of internal volumes at MW523SGD is summarized in **Table 14a** in Appendix A. Computation of pre-sample internal exchanges and VOC and gas concentrations detected from sample systems at MW523SGM is summarized in **Table 14b** in Appendix A. Vapor concentrations are illustrated in **Figure 40**. Pre-sample internal exchanges for

PRT and probe systems were 1.8 and 2.0 respectively. The CH<sub>4</sub> gas concentration was not as high as the shallower depths but still interfered with detection of 1,1-DCE and c-1,2-DCE. VOC concentrations for 1,1,1-TCA and TCE were slightly higher for the PRT system compared to the dedicated vapor probe (factor up to 1.7).

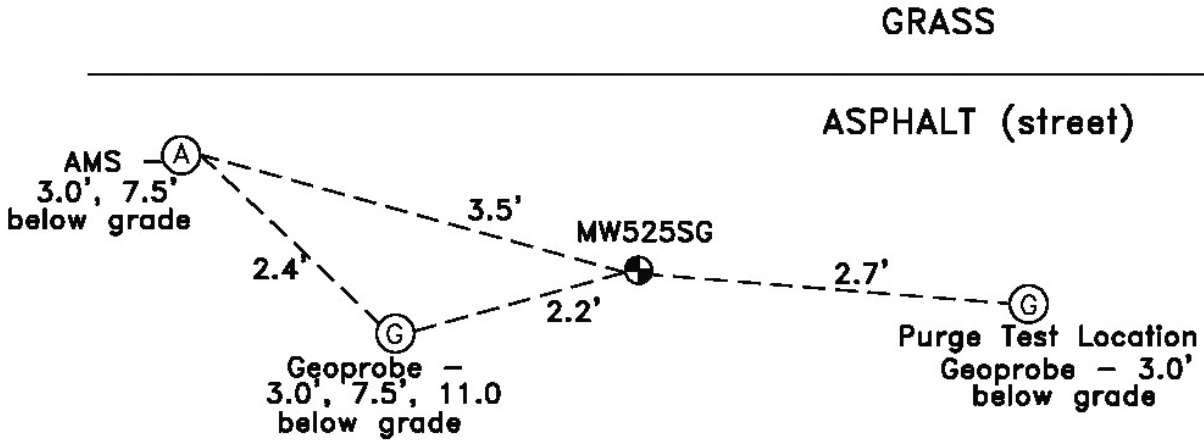


**Figure 40.** Comparison of vapor concentrations (1 sample from each sample system) at MW523SGD at a depth of 3.4 m.

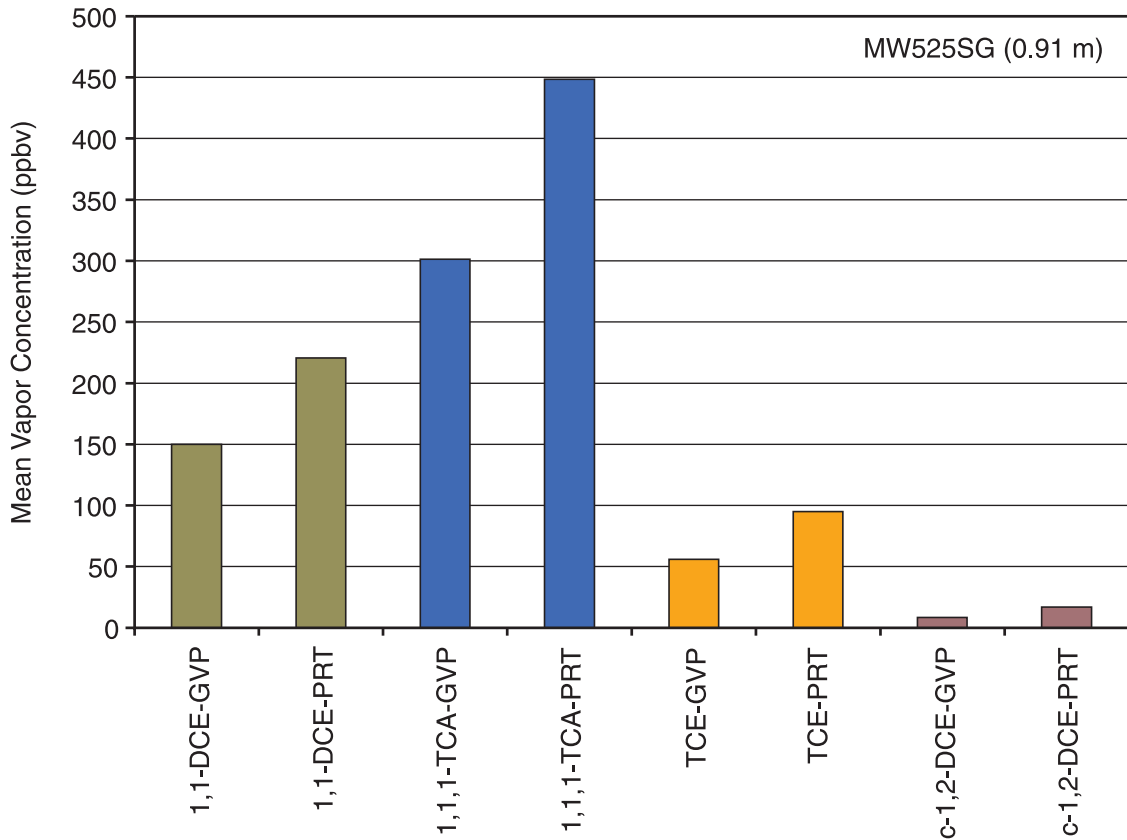
#### 4.4 Results of Testing at MW525SG

A schematic illustrating the location of the dedicated probe MW525SG and nearby PRT and GVP sampling locations systems is illustrated in **Figure 41**. The screened interval of MW523SGS is 2.1 – 2.4 m (7 – 8’) below ground surface. In addition to collecting soil-gas samples at 2.3 m (7.5’), samples were collected at 0.91 m (3’) using PRT and GVP sample systems. Soil-gas samples were also collected at 3.4 m (11’) using the PRT system but not used or presented here for comparison purposes. The location of purge or extraction volume testing near MW525SG using the PRT sampling system at a depth of 0.76 m is also illustrated in **Figure 41**. The results of this test were previously discussed in Section 3.6. The computation of internal volumes of PRT system and GVP kit at 0.91 m is summarized in **Table 15a** in Appendix A. The

computation of pre-sample internal exchanges is summarized in **Table 15b** in Appendix A while VOC and gas concentrations are summarized in **Table 15c** in Appendix A. Pre-sample internal exchanges for GVP and PRT systems were 8.7 – 60.9 and 1.9 – 13.4 respectively. Vapor concentrations are illustrated in **Figure 42**. Mean VOC concentrations of 1,1-DCE, 1,1,1-TCA, and TCE using the PRT system appear to be slightly higher (up to a factor of 1.7) compared to sampling with the GVP kit.

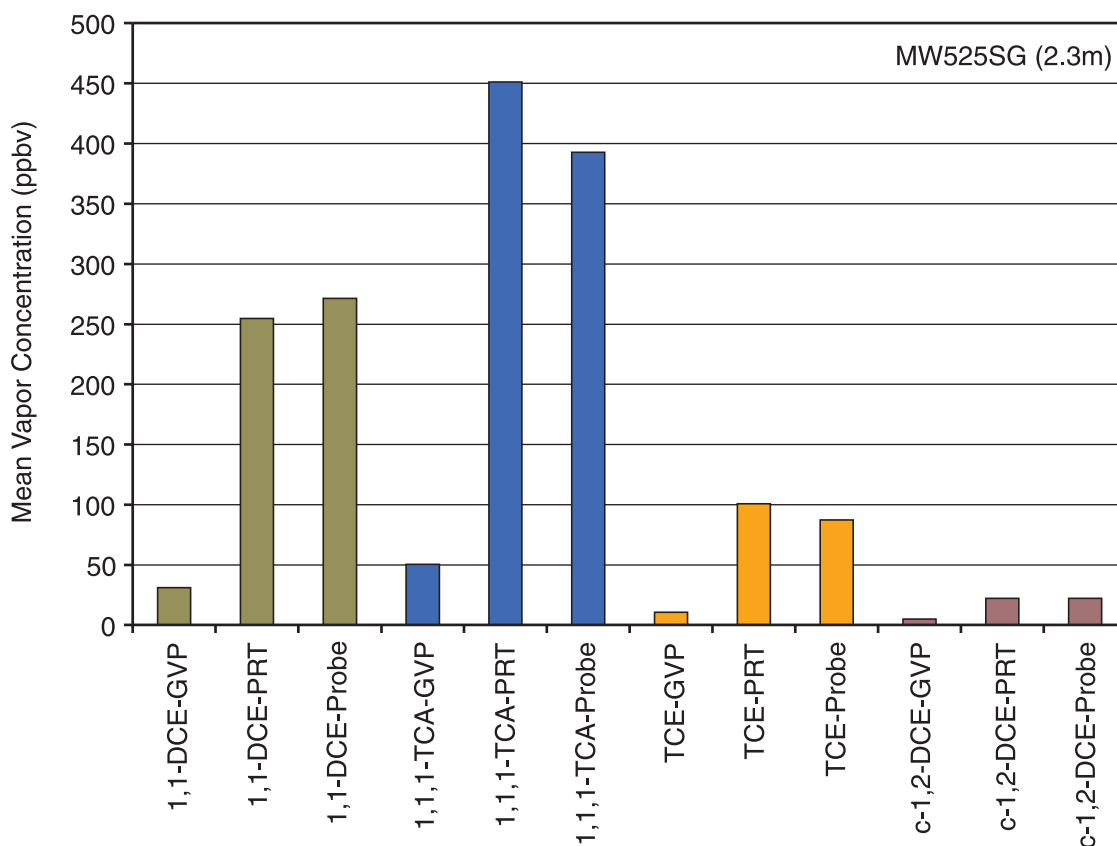


**Figure 41.** Schematic illustrating the location of sampling systems at MW525SG in plan view.



**Figure 42.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW525SG at a depth of 0.91 m.

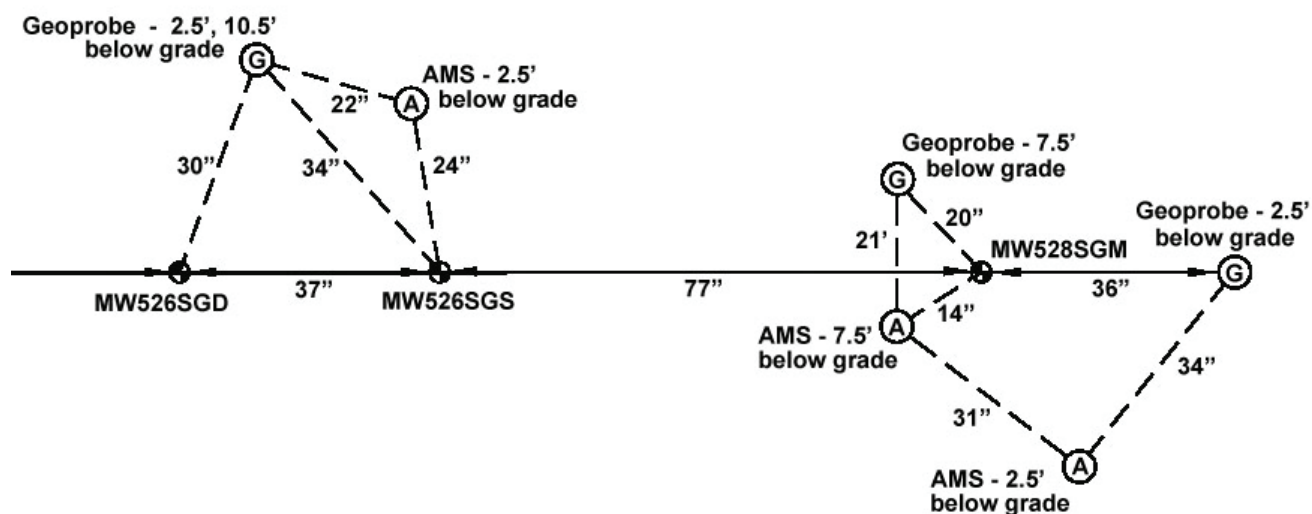
Soil-gas samples were also collected at a depth of 2.3 m (7.5') at nearby PRT and GVP locations. The computation of internal volumes and pre-sample internal exchanges is summarized in **Tables 16a** and **16b** in Appendix A. Pre-sample internal exchanges for GVP, PRT, and dedicated probe sample systems were 6.0 – 30.1, 2.9 – 14.7, and 2.6 – 6.8 respectively. VOC concentrations are illustrated in **Figure 43** and summarized in **Table 16c** in Appendix A. O<sub>2</sub> concentration appeared higher and CO<sub>2</sub> concentration lower using the GVP kit compared to PRT and dedicated probe sample systems. Mean CO<sub>2</sub> concentrations in the PRT and dedicated vapor probe sample systems were approximately six times higher than the mean CO<sub>2</sub> concentration detected using the GVP kit. Mean VOC concentrations of 1,1-DCE, 1,1,1-TCA, and TCE using the GVP kit appeared lower by a factor of 8 to 9 compared to mean VOC concentrations detected using the PRT and dedicated probe sample systems. Given the relatively small distance between the GVP kit and PRT (0.73 m) and dedicated probe sample systems (1.1 m), it is unlikely that these differences in concentration were due entirely to spatial variability. It appears likely that recharge from atmospheric air or leakage occurred during sampling with the GVP kit at this location.



**Figure 43.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW525SG at a depth of 2.3 m.

#### 4.5 Results of Testing at MW526SGS, MW526SGM, and MW526SGD

A schematic illustrating the location of the dedicated vapor probes MW526SGS, MW526SGM, and MW526SGD and nearby PRT and GVP sampling locations systems is illustrated in **Figure 44**. The relatively large distance between shallow, medium, and deep dedicated vapor probes necessitated the use of multiple PRT and GVP sampling locations.

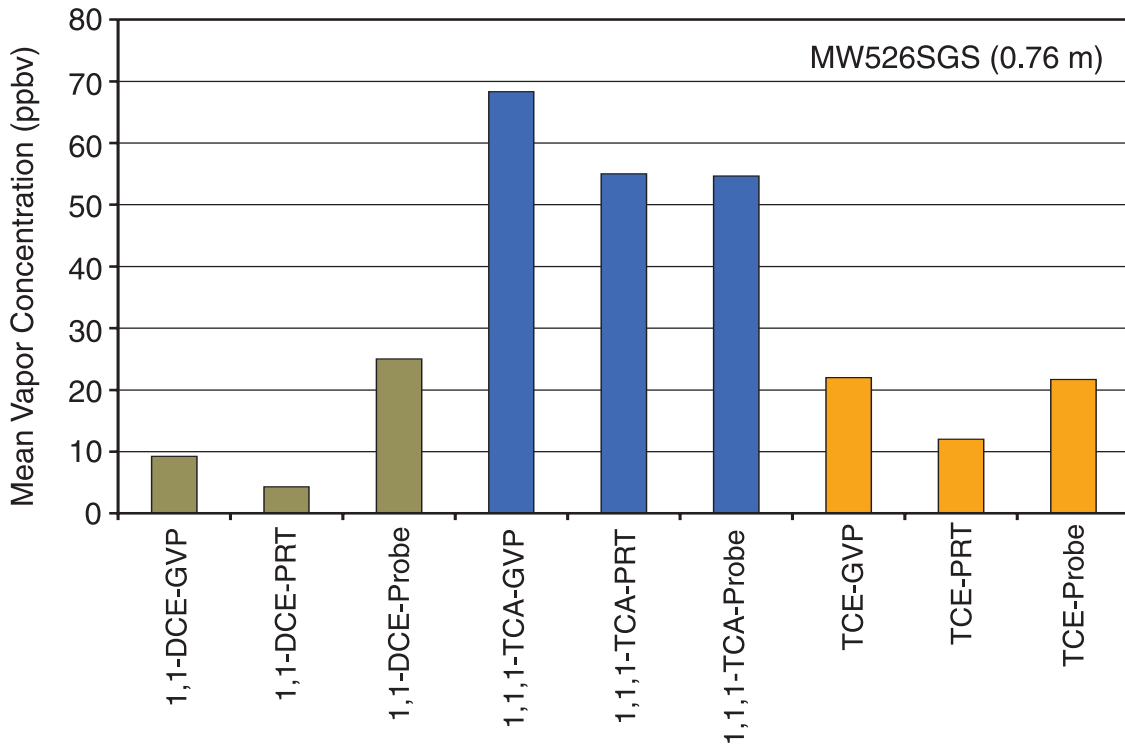


**Figure 44.** Schematic illustrating the location of sampling systems at MW526SGS, MW526SGM, and MW526SGD in plan view.

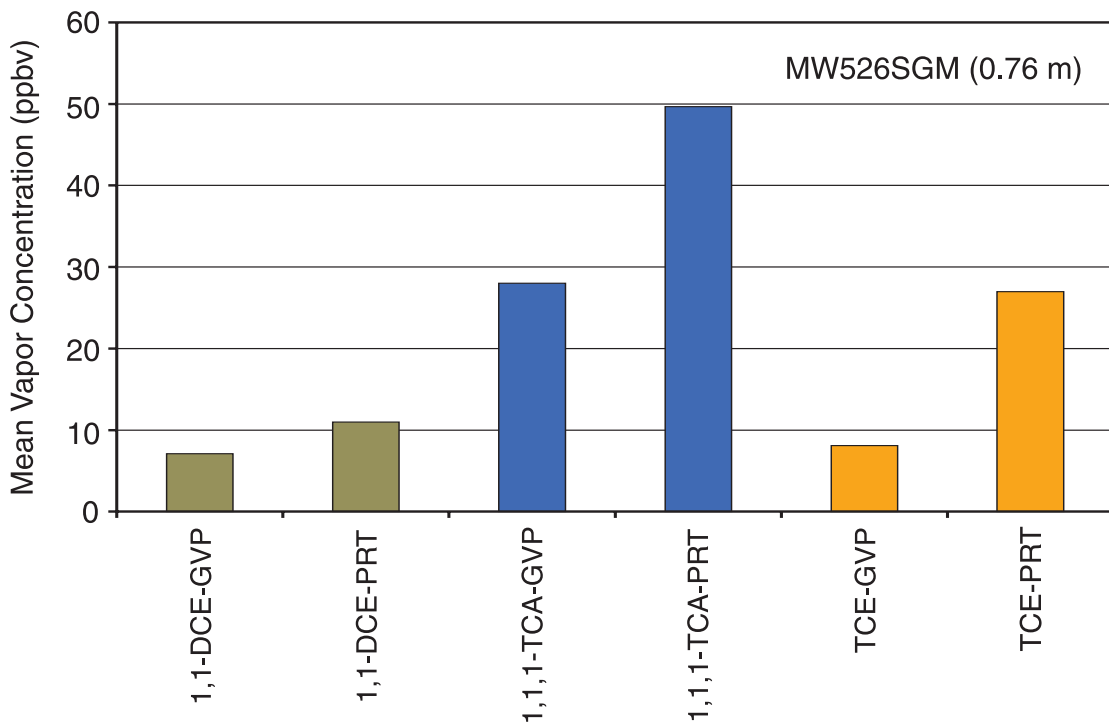
MW526SGS is screened over a depth of 0.61 to 0.91 m (2 to 3') while soil-gas samples were collected at a depth of 0.76 m (2.5 ft) at nearby PRT and GVP locations. The computation of internal volumes and pre-sample internal exchanges is summarized in **Tables 17a** and **17b** in Appendix A. Pre-sample internal exchanges for GVP, PRT, and dedicated probe sample systems were 8.7 – 60.9, 2.0 – 13.8, and 3.5 – 9.6 respectively. VOC concentrations are illustrated in **Figure 45** and summarized in **Table 17c** in Appendix A. Mean O<sub>2</sub> and CO<sub>2</sub> concentrations were similar for all three sample systems. There did not appear to be any clear trends in 1,1-DCE, 1,1,1-TCA, and TCE concentrations with the three sample systems. However, the concentration of 1,1-DCE in the dedicated probe was 5.8 times greater than that in the PRT system whereas concentrations of 1,1,1-TCA were nearly equivalent.

Soil-gas samples were also collected at a depth of 0.76 m (2.5') using PRT and GVP sampling systems near MW526SGM. The computation of internal volumes and pre-sample internal exchanges for these sampling systems is summarized in **Tables 18a** and **18b** in Appendix A. Pre-sample internal exchanges for GVP and PRT sample systems were 4.5 – 31.3 and 2.0 – 14.2 respectively. VOC concentrations are illustrated in **Figure 46** and summarized in **Table 18c** in Appendix A. Mean VOC concentrations for 1,1-

DCE, 1,1,1-TCA, and TCE using the PRT system appeared to be slightly higher than those using the GVP system by a factor up to 3.3.

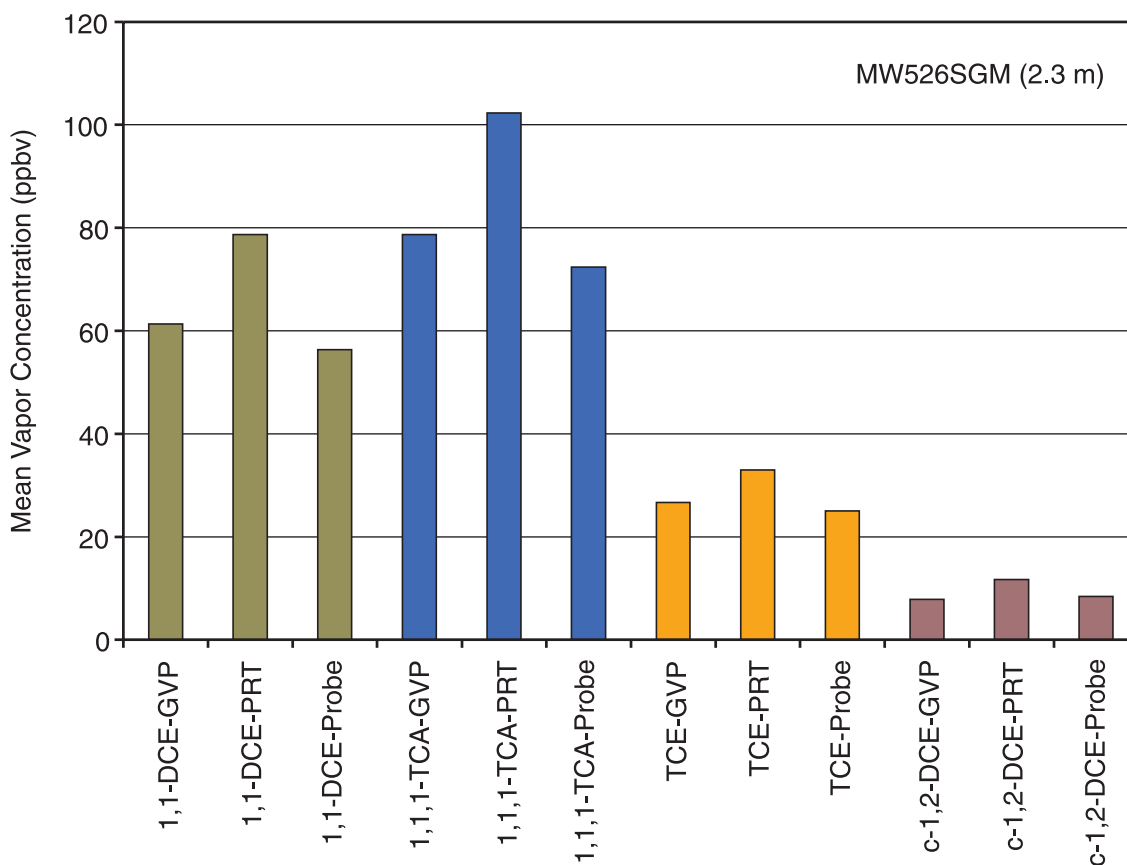


**Figure 45.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW526SGS at a depth of 0.76 m.



**Figure 46.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW526SGM at a depth of 0.76 m.

MW526SGM is screened over a depth of 2.1 to 2.4 m (7 to 8'). Soil-gas samples were collected at a depth of 2.3 m (7.5') at nearby PRT and GVP locations. The computation of internal volumes and pre-sample internal exchanges is summarized in **Tables 19a** and **19b** in Appendix A. Pre-sample internal exchanges for GVP, PRT, and dedicated vapor probe sample systems were 7.4 – 37.2, 3.0 – 14.9, and 2.5 – 6.5 respectively. VOC concentrations are summarized in **Figure 47** and in **Table 19c** in Appendix A. VOC concentrations of 1,1-DCE, 1,1,1-TCA, TCE, and c-1,2-DCE using GVP and dedicated vapor systems appeared similar but lower than VOC concentrations detected using the PRT sampling system by a factor of up to 1.4 which is within the range expected for spatial variability on the scale of 1 m.

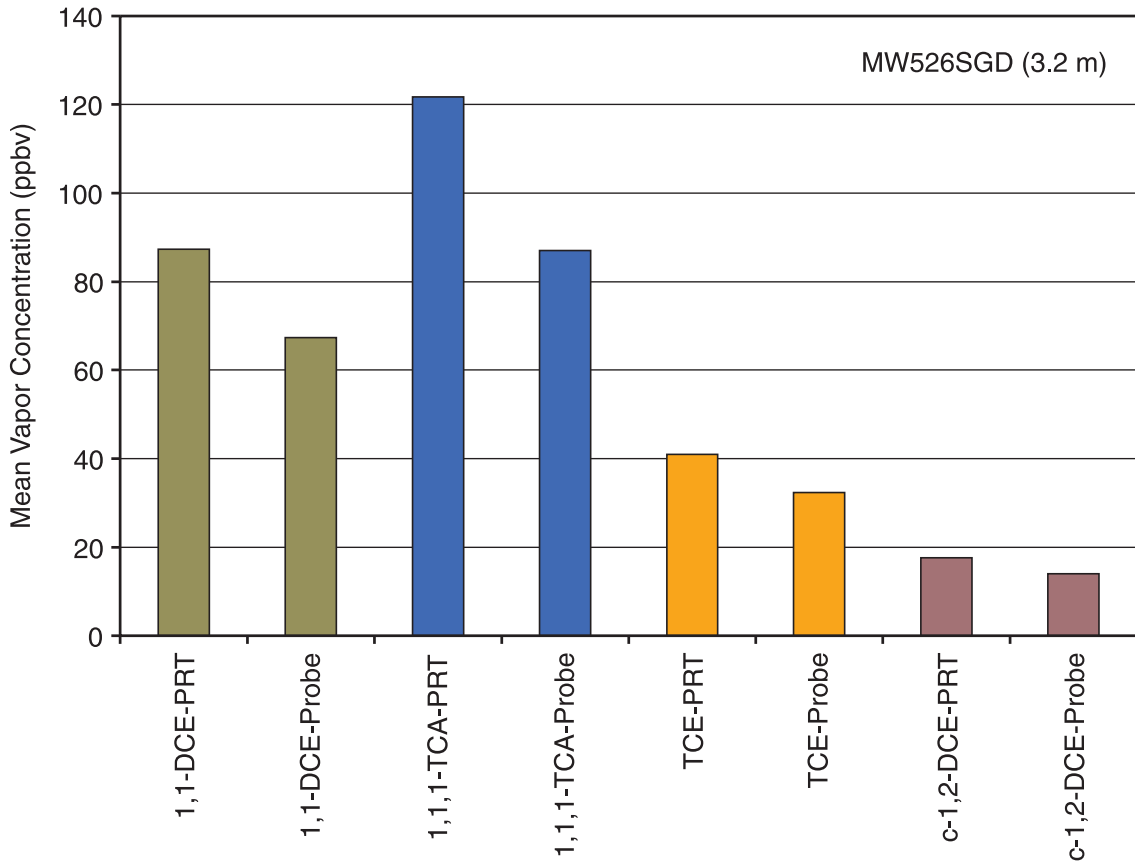


**Figure 47.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW526SGM at a depth of 2.3 m.

MW526SGD is screened over a depth of 3.0 to 3.4 m (10 to 11'). Soil-gas samples were collected at a depth of 3.2 m (10.5') at a nearby PRT location. The computation of internal volumes and pre-sample internal exchanges for these sampling systems is summarized in **Tables 20a** and **20b** in Appendix A. Pre-sample internal exchanges for PRT and dedicated vapor probe sample systems were 3.4 – 12.6 and 2.4 – 6.0 respectively. Gas and VOC concentrations are summarized in **Table 20c** in Appendix A. VOC



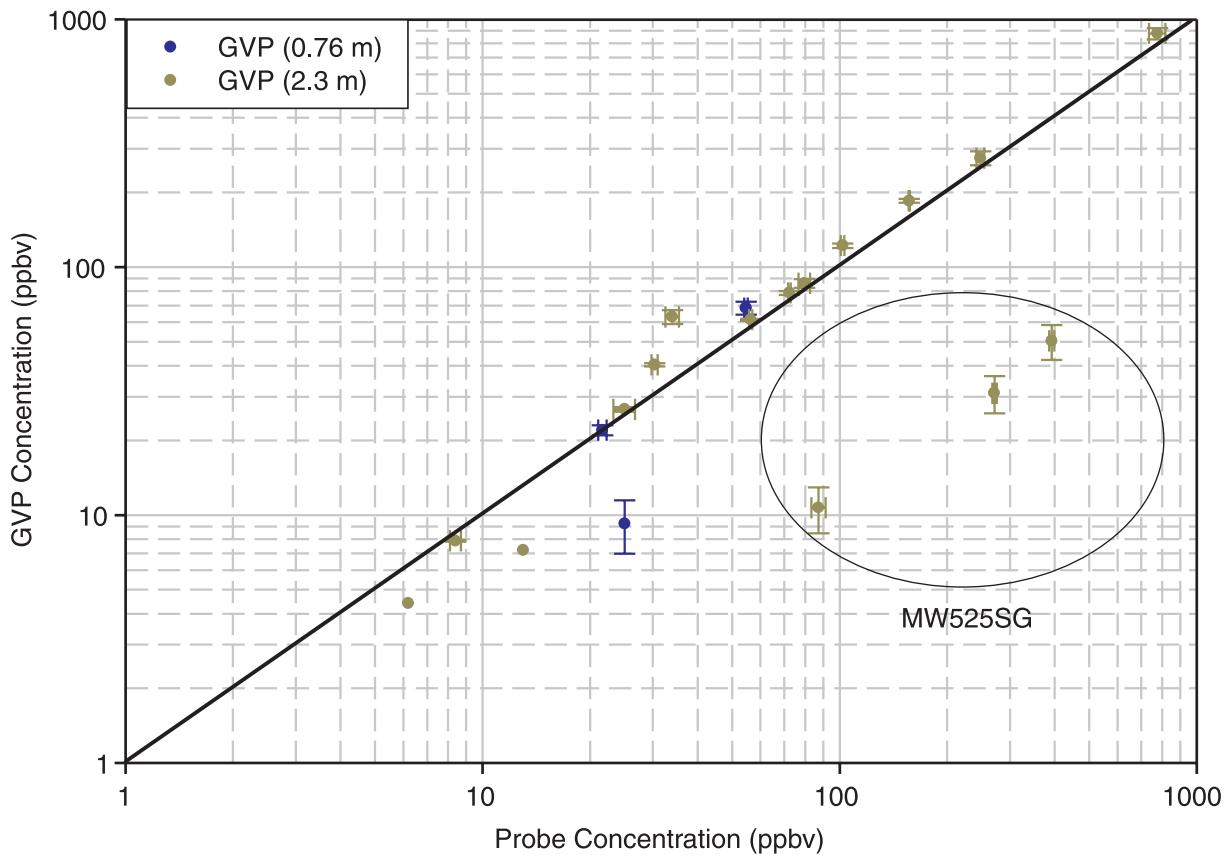
concentrations are illustrated in **Figure 48**. Mean O<sub>2</sub> and CO<sub>2</sub> concentrations were similar for both sampling systems. Mean VOC concentrations of 1,1-DCE, 1,1,1-TCA, TCE, and c-1,2-DCE were higher using the PRT system compared to dedicated vapor probes by a factor up to 1.4 which is within the range expected for spatial variability on the scale of 1 m.



**Figure 48.** Comparison of mean (3 samples from each sample system) vapor concentrations at MW526SGD at a depth of 3.2 m.

## 5.0 Discussion of Comparison Testing

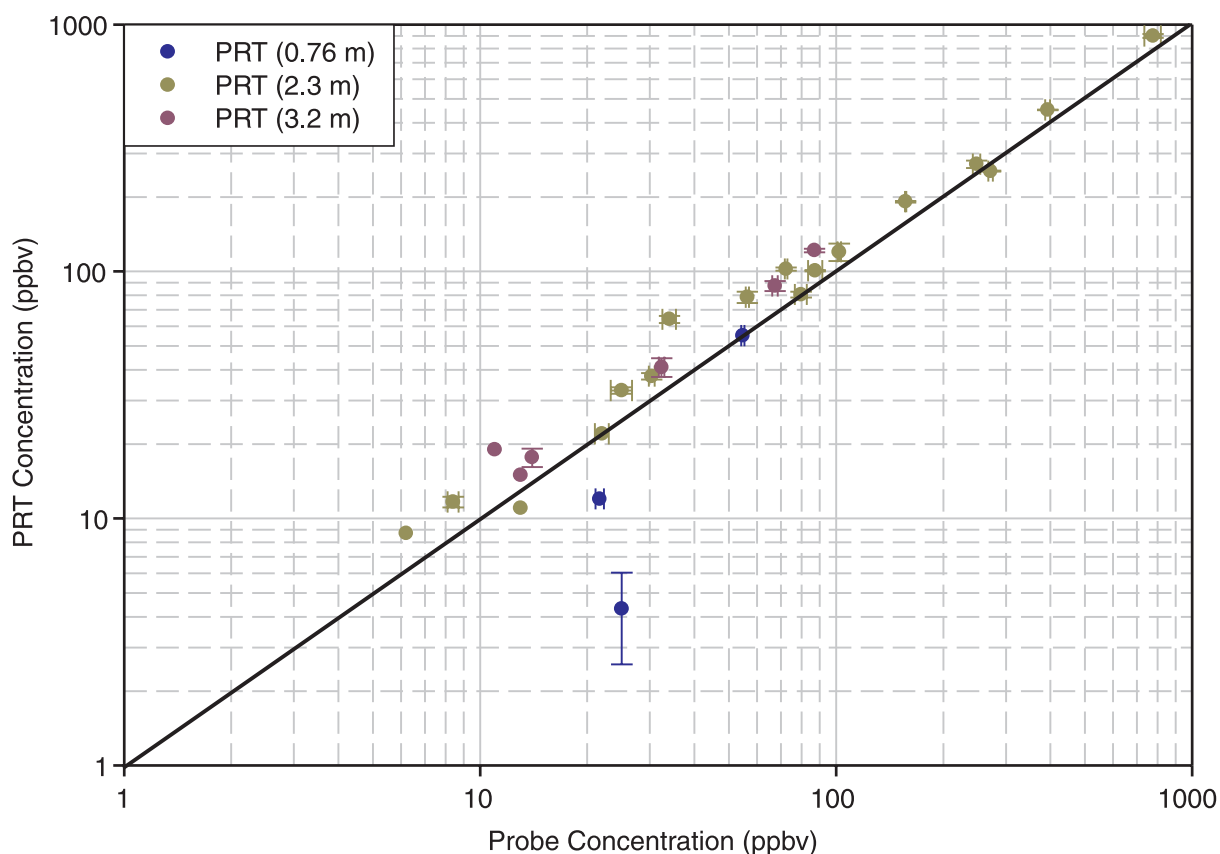
A comparison of dedicated vapor probes and the GVP sampling kit is illustrated in **Figure 49**. The vapor probes were screened at depths of 0.61 – 0.91 and 2.1 – 2.4 m while soil-gas samples were collected at depths of 0.76 and 2.3 m. With the exception of sampling at MW525SG at a depth of 2.3 m, there was no apparent bias in sample collection method. As previously discussed, at this location and depth, O<sub>2</sub> concentration was higher and CO<sub>2</sub> concentration lower (by a factor of 6) using the GVP kit compared to the PRT system and dedicated vapor probe indicating likely leakage with the GVP kit. However, use of all sample data reveals no statistical difference in sampling methods ( $p = 0.31$  for two-tailed t-Test,  $p > 0.2$  for two-tailed Wilcoxon Signed Rank Test). Random scatter about the 1:1 line is likely due at least in part to spatial variability.



**Figure 49.** Comparison of probe and GVP VOC concentrations – error bars represent one standard deviation from three samples.

A comparison of dedicated vapor probes and PRT sampling systems is illustrated in **Figure 50**. The vapor probes were screened at depths of 0.61 – 0.91, 2.1 – 2.4, and 3.0 – 3.4 m while soil-gas samples were

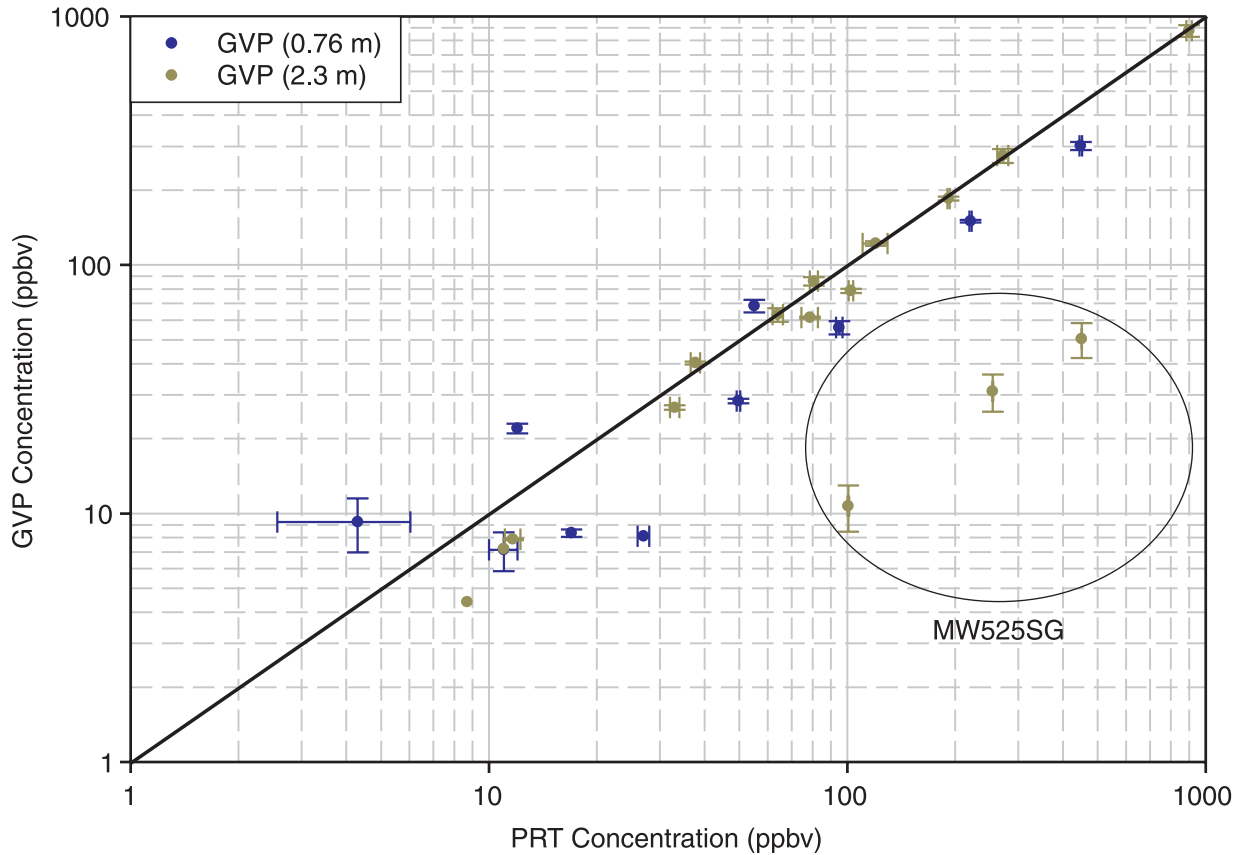
collected at depths of 0.76, 2.3, and 3.2 m using the Geoprobe® PRT system. Both visually and statistically ( $p = 0.009$  for two-tailed t-Test,  $p < 0.01$  for two-tailed Wilcoxon Signed Rank Test), VOC concentrations in the PRT system were higher than corresponding VOC concentrations in dedicated vapor probes. VOC concentrations using the PRT system were higher than VOC concentrations detected using dedicated vapor probes by an average factor of 1.2. The effect does not appear to be due to spatial variability which would result in random scatter of data. It is unlikely that extraction volume or sampling sequence caused the observed bias given results discussed in Sections 3.6 and 3.7. Also, it is unlikely that a difference in screen length (5 cm for PRT and GVP system and 30 cm for dedicated vapor probes) resulted in elevated PRT concentrations relative to dedicated vapor probes since concentrations should be equivalent for vapor concentration increasing uniformly with depth. A non-uniform increase in concentration with depth (e.g., exponential function) would result in lower PRT concentrations relative to dedicated vapor probes.



**Figure 50.** Comparison of dedicated vapor probe and GVP VOC concentrations – error bars represent one standard deviation from three samples.

A comparison of PRT and GVP sampling systems is illustrated in **Figure 51**. Both systems were sampled at depths of 0.76 and 2.3 m. Again, bias at location MW525SG at a depth of 2.3 m indicated leakage during sampling with the GVP system. Both visually and statistically ( $p = 0.03$  for two-tailed t-Test,  $p <$

0.01 for two-tailed Wilcoxon Signed Rank Test), VOC concentrations in the PRT system were higher than corresponding VOC concentrations using the GVP system. VOC concentrations using the PRT system were higher than VOC concentrations detected using the GVP kit by an average factor of 2.4. Similar to the comparison between probe and PRT sampling systems, the effect does not appear to be due to spatial variability, extraction volume, or sequence of sampling.



**Figure 51.** Comparison of PRT and GVP VOC concentrations – error bars represent one standard deviation from three samples.

Thus, utilization of the PRT system resulted in observation of higher concentrations of VOCs compared to the GVP sampling system and dedicated vapor probes. However, the magnitude of variation was relatively minor when compared to variation on a scale of 1 m due to spatial variability (median of 1.2 and average of 1.3 for 90 sample pairs).

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## 6.0 Summary

A study was conducted near the Raymark Superfund Site in Stratford, Connecticut to compare results of soil-gas sampling using dedicated vapor probes, a truck-mounted direct-push technique – Geoprobe® Post-Run-Tubing (PRT) system, and a hand-held rotary hammer technique - AMS Gas Vapor Probe (GVP) kit.

A comparison of VOC concentrations using dedicated vapor probes and the GVP sampling kit indicated that the two methods provided similar results. However, at one location, O<sub>2</sub>, CO<sub>2</sub>, and VOC concentrations were noticeably different for sampling systems indicating potential leakage with the GVP system.

VOC concentrations using the PRT system were not statistically equivalent to VOC concentrations using dedicated vapor probes. VOC concentrations using the PRT system were higher than VOC concentrations detected using dedicated vapor probes by an average factor of 1.2. This is the same magnitude observed for spatial variability on a scale of 1 m (median of 1.2 and average of 1.3 for 90 sample pairs). However, this effect did not appear to be due to spatial variability which would result in random scatter not a consistent bias as observed. It is also unlikely that extraction volume or sampling sequence caused the observed bias given results from extraction volume and sample sequence testing.

VOC concentrations using the PRT system were also not statistically equivalent to VOC concentrations using the GVP kit. VOC concentrations using the PRT system were higher than VOC concentrations detected using the GVP kit by an average factor of 2.4. Similar to the comparison between probe and PRT sampling systems, the effect does not appear to be due to spatial variability, extraction volume, or sequence of sampling.

Thus, utilization of the PRT system resulted in observation of higher concentrations of VOCs compared to the GVP sampling system and dedicated vapor probes. However, the magnitude of variation was relatively minor when compared to variation on a scale of 1 m due to spatial variability. Hence for practical purposes, all three sample systems can be considered approximately equivalent.

This testing was conducted in highly permeable soils where the potential for leakage from direct-push/hammer soil-gas sampling systems would be expected to be low compared to less permeable soils such as silt and clay. Thus, the results of this investigation should not be extrapolated to other soil textures where additional investigation is needed. Also, only one direct-push and one rotary hammer method was

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evaluated for comparison with dedicated vapor probes. Thus, the results of this investigation should not be extrapolated to other direct-push/hammer soil-gas sampling techniques.

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## Appendix A

**Table 1.** Depth of Fill Materials and Screened Intervals in Boreholes Containing Dedicated Vapor Probes

Depth (m)	302SG	513SG	514SG	523SGS	523SGM	523SGD	525SG	526SGS	526SGM	526SGD
Bottom of concrete seal	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.2
Bottom of sand drain layer	0.8	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.9	0.9
Bottom of bentonite	1.8	1.8	2.0	0.5	2.0	3.0	2.0	0.5	2.0	2.9
Top of screen	2.1	2.1	2.1	0.6	2.1	3.2	2.1	0.6	2.1	3.0
Bottom of screen	2.4	2.4	2.4	0.9	2.4	3.5	2.4	0.9	2.4	3.4
Bottom of sand filter	2.4	2.4	2.4	1.0	2.4	3.5	2.4	1.0	2.4	3.4

**Table 2.** Results of Container Blanks

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
SSEB-01	ND(4.0)	ND(3.0)	ND(3.0)	ND(4.0)
SSEB-02	ND(4.0)	ND(3.0)	ND(3.0)	ND(4.0)
SSEB-03	ND(4.0)	ND(3.0)	ND(3.0)	ND(4.0)
SSEB-04	ND(4.0)	ND(3.0)	ND(3.0)	ND(4.0)

ND() = not detected (detection limit)

**Table 3.** Results of Field Blanks

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
Ambient 1	ND(2.0)	ND(3.0)	ND(3.0)	ND(2.0)
Ambient 2	ND(2.0)	ND(3.0)	ND(2.0)	ND(2.0)
Ambient 3	ND(3.0)	ND(3.0)	ND(2.0)	ND(4.0)

ND() = not detected (detection limit)

**Table 4.** Results of Probe Blanks

Sample System	Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
GVP	SM-A-525	ND(2.0)	ND(3.0)	ND(3.0)	ND(2.0)
PRT	SM-G-525	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)
PRT	SM-526-G	ND(2.0)	ND(3.0)	ND(2.0)	ND(2.0)
GVP	SM-526-A	ND(3.0)	ND(3.0)	ND(2.0)	ND(4.0)
PRT	SM-526-G2	ND(3.0)	ND(3.0)	ND(5.0)	ND(4.0)

ND() = not detected (detection limit)

**Table 5.** Results of Travel Blanks

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
ST-5-5-03	ND(2.0)	ND(3.0)	ND(3.0)	ND(2.0)
ST-5-6-03	ND(2.0)	ND(3.0)	ND(2.0)	ND(2.0)
ST-5-7-03	ND(3.0)	ND(3.0)	ND(2.0)	ND(4.0)

ND() = not detected (detection limit)

**Table 6.** Results of Replicate Samples

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
523-8-G1	ND(30)	8.7	11	ND(25)
523-8-G1(rep)	ND(30)	8.9	11	ND(25)
526-3-A2R	6.4	28	8.1	ND(3.0)
526-3-A2R(rep)	6.4	26	8.1	ND(3.0)
526-3-A3	6.7	64	21	ND(4.0)
526-3-A3(rep)	6.7	65	23	ND(4.0)
526-8-G3	82	102	33	12
526-8-G3(rep)	82	105	33	12
302SG-1	77	157	31	ND(6.0)
302SG-1(rep)	77	157	30	ND(6.0)

ND() = not detected (detection limit)

**Table 7a.** Computation of Internal Volume of PRT Sampling System When Sampling at 0.76 m Near MW 525SG

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
PRT	2.54	5.1	26	NR	NR	NR	0.64	305	96.5	0.122

NR = not relevant

**Table 7b.** Computation of Pre-Sample Extraction and Internal Exchange Volumes of PRT Sample System When Sampling at 0.76 m Near MW525SG

Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
525-3-PRT1	0.0	0.0	0.0	0.50	0.5	204	436	115	20
525-3-PRT2	0.5	1.0	8.2	0.50	1.5	248	484	126	22
525-3-PRT3	0.5	2.0	16.4	0.50	2.5	229	458	119	20
525-3-PRT4	0.5	3.0	24.5	0.50	3.5	254	466	126	26
525-3-PRT5	0.5	4.0	32.7	0.50	4.5	229	474	118	20
525-3-PRT6	0.5	5.0	40.9	0.50	5.5	221	462	118	19
525-3-PRT7	0.5	6.0	49.1	0.50	6.5	230	475	128	22
525-3-PRT8	0.5	7.0	57.3	0.50	7.5	234	473	126	21
525-3-PRT9	0.5	8.0	65.5	0.50	8.5	224	443	121	20
525-3-PRT10	0.5	9.0	73.6	0.50	9.5	226	447	123	22

**Table 8a.** Computation of Internal Volume Dedicated Vapor Probe MW513SG When Sampling at a Depth Interval of 2.1 to 2.4 m

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
Probe	3.81	30.5	347	1.9	213	608	0.95	61	43.4	0.999

**Table 8b.** Computation of Pre-Sample Extraction and Internal Exchange Volumes of Dedicated Vapor Probe MW513SG When Sampling at a Depth Interval of 2.1 to 2.4 m

Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)
513SG-1	0.0	0.0	0.0	0.50	0.5	579	1306	186	79
513SG-2	0.0	0.5	0.5	0.50	1.0	616	1402	239	93
513SG-3	0.5	1.5	1.5	0.50	2.0	603	1402	218	84
513SG-4	0.5	2.5	2.5	0.50	3.0	611	1363	224	84
513SG-5	2.0	5.0	5.0	0.50	5.5	611	1389	228	85
513SG-6	5.0	10.5	10.5	0.50	11.0	609	1478	255	90
513SG-7	10.0	21.0	21.0	0.50	21.5	629	1490	265	96
513SG-8	15.0	36.5	36.5	0.50	37.0	637	1446	281	96
513SG-9	25.0	62.0	62.0	0.50	62.5	619	1414	261	92
513SG-10	40.0	102.5	102.5	0.50	103.0	646	1459	293	101

**Table 9a.** Computation of Internal Volumes Using the PRT Sampling System at Five Sample Locations at a Depth of 0.76 m Near MW213

Sample Identification	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
213-3-S1	2.54	5.1	26	NR	152	NR	0.64	332	105.2	0.131
213-3-S2	2.54	5.1	26	NR	152	NR	0.64	335	106.1	0.132
213-3-S3	2.54	5.1	26	NR	152	NR	0.64	293	92.6	0.118
213-3-S4	2.54	5.1	26	NR	152	NR	0.64	274	86.8	0.113
213-3-S5	2.54	5.1	26	NR	152	NR	0.64	305	96.5	0.122

NR = not relevant

**Table 9b.** Computation of Internal Volumes Using the PRT Sampling System at Five Sample Locations at a Depth of 2.3 m Near MW213

Sample Identification	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
213-8-S1	2.54	5.1	26	NR	152	NR	0.64	418	132.2	0.158
213-8-S2	2.54	5.1	26	NR	152	NR	0.64	439	138.9	0.165
213-8-S3	2.54	5.1	26	NR	152	NR	0.64	457	144.7	0.170
213-8-S4	2.54	5.1	26	NR	152	NR	0.64	497	157.3	0.183
213-8-S5	2.54	5.1	26	NR	152	NR	0.64	430	136.0	0.162

NR = not relevant

**Table 9c.** Computation of Internal Volumes Using the PRT Sampling System at Five Sample Locations at a Depth of 3.2 m Near MW213

Sample Identification	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
213-11-S1	2.54	5.1	26	NR	152	NR	0.64	671	212.3	0.238
213-11-S2	2.54	5.1	26	NR	152	NR	0.64	610	193.0	0.219
213-11-S3	2.54	5.1	26	NR	152	NR	0.64	616	194.9	0.221
213-11-S4	2.54	5.1	26	NR	152	NR	0.64	655	207.4	0.233
213-11-S5	2.54	5.1	26	NR	152	NR	0.64	622	196.8	0.223

NR = not relevant

**Table 9d.** Computation of Pre-Sample Extraction and Internal Exchange Volumes and Sample Results Using the PRT Sampling System at a Depth of 0.76 m Near MW213

Sample Sequence	Pre-Sample Purge Volume (L)	Pre-Sample Internal Exchange (-)	Sample Volume (L)	Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
213-3-S1	0.25	1.9	0.50	0.75	3.4	25	19	ND(4.0)	20.5	0.3	0.0
213-3-S2	0.25	1.9	0.50	0.75	2.8	24	19	ND(4.0)	20	0.4	0.0
213-3-S3	0.25	2.1	0.50	0.75	2.1	20	16	ND(4.0)	20.2	0.3	0.0
213-3-S4	0.25	2.2	0.50	0.75	5.3	36	24	ND(4.0)	20.2	0.3	0.0
213-3-S5	0.25	2.0	0.50	0.75	2.3	13	12	ND(4.0)	NA	NA	NA

NA = not analyzed

ND() = not detected

**Table 9e.** Computation of Pre-Sample Extraction and Internal Exchange Volumes and Sample Results Using the PRT Sampling System at a Depth of 2.3 m Near MW213

Sample Identification	Pre-Sample Purge Volume (L)	Pre-Sample Internal Exchange (-)	Sample Volume (L)	Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
213-8-S1	0.50	3.2	0.50	1.00	12	46	28	ND(4.0)	20.4	0.3	0.0
213-8-S2	0.50	3.0	0.50	1.00	9.3	41	28	ND(4.0)	20.3	0.3	0.0
213-8-S3	0.50	2.9	0.50	1.00	10	42	32	ND(4.0)	20.0	0.4	0.0
213-8-S4	0.50	2.7	0.50	1.00	10	44	30	ND(4.0)	20.3	0.3	0.0
213-8-S5	0.50	3.1	0.50	1.00	9.1	37	25	ND(4.0)	NA	NA	NA

NA = not analyzed

ND() = not detected

**Table 9f.** Computation of Pre-Sample Extraction and Internal Exchange Volumes and Sample Results Using the PRT Sampling System at a Depth of 3.2 m Near MW213

Sample Identification	Pre-Sample Purge Volume (L)	Pre-Sample Internal Exchange (-)	Sample Volume (L)	Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
213-11-S1	0.50	2.1	0.50	1.00	16	50	37	ND(4.0)	20.3	0.4	0.0
213-11-S2	0.50	2.3	0.50	1.00	13	48	35	ND(4.0)	20.2	0.3	0.0
213-11-S3	0.50	2.3	0.50	1.00	12	49	30	ND(4.0)	20.0	0.4	0.0
213-11-S4	0.50	2.1	0.50	1.00	14	54	33	ND(4.0)	19.9	0.4	0.0
213-11-S5	0.50	2.2	0.50	1.00	10	40	25	ND(4.0)	NA	NA	NA

NA = not analyzed

ND() = not detected

**Table 10a.** Internal Volumes of Probe, PRT, and GVP Systems at 2.3 m Near MW302SGM

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NR	274	NR	0.48	408	72.7	0.074
PRT	2.54	5.1	26	NR	305	NR	0.64	469	149	0.174
Probe	3.81	30.5	347	1.9	213	608	0.95	61	43.4	0.999

NR = not relevant

**Table 10b.** Cumulative Pre-Sample Internal Exchanges of Probe, PRT, and GVP Systems at 2.3 m Near MW302SGM

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	302-8-G1	0.5	0.5	2.9	0.50	1.0
GVP	302-8-A1	0.5	0.5	6.7	0.50	1.0
Probe	302SG-1	2.5	2.5	2.5	0.50	3.0
GVP	302-8-A2	0.5	1.5	20.2	0.50	2.0
Probe	302SG-2	1.5	4.5	4.5	0.50	5.0
PRT	302-8-G2	0.5	1.5	8.6	0.50	2.0
Probe	302SG-3	1.5	6.5	6.5	0.50	7.0
PRT	302-8-G3	0.5	2.5	14.3	0.50	3.0
GVP	302-8-A3	0.5	2.5	33.6	0.50	3.0

**Table 10c.** VOC and Gas Concentrations in Probe, PRT, and GVP Systems at 2.3 m Near MW302SGM

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
302-8-A1	84	187	40	ND(6.0)	19.7	1.3	0.0
302-8-A2	90	187	41	ND(6.0)	19.6	1.3	0.0
302-8-A3	84	181	40	ND(6.0)	NA	NA	NA
mean 302-8-A	86	185	40	ND(6.0)	19.7	1.3	0.0
stdev 302-8-A	3.5	3.5	0.6	IND	0.1	0.0	0.0
PRT							
302-8-G1	80	193	37	ND(6.0)	19.1	1.2	0.0
302-8-G2	79	192	37	ND(6.0)	NA	NA	NA
302-8-G3	83	190	39	ND(6.0)	NA	NA	NA
mean 302-8-G	80.7	192	38	ND(6.0)	IND	IND	IND
stdev 302-8-G	2.1	1.5	1.2	IND	IND	IND	IND
Probe							
302SG-1	77	157	31	ND(6.0)	20.1	1.3	0.0
302SG-2	83	156	30	ND(6.0)	NA	NA	NA
302SG-3	79	157	30	ND(6.0)	NA	NA	NA
mean 302SG	80	157	30	ND(3.0)	IND	IND	IND
stdev 302SG	3.1	0.6	0.6	IND	IND	IND	IND

ND( )-not detected

IND = indeterminate

**Table 11a.** Internal Volumes of Probe, PRT, and GVP Systems at 2.3 m Near MW514SG

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NR	274	NR	0.48	338	60.2	0.062
PRT	2.54	5.1	26	NR	305	NR	0.64	488	154	0.180
Probe	3.81	30.5	347	1.9	213	608	0.95	61	43.4	0.999

NR = not relevant

**Table 11b.** Cumulative Pre-Sample Internal Exchanges of Probe, PRT, and GVP Systems at 2.3 m Near MW514SG

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	514-8-G1	0.5	0.5	2.8	0.50	1.0
GVP	514-8-A1	0.5	0.5	8.1	0.50	1.0
Probe	514SG-1	2.5	2.5	2.5	0.50	3.0
GVP	514-8-A2	0.5	1.5	24.3	0.50	2.0
Probe	514SG-2	1.5	4.5	4.5	0.50	5.0
PRT	514-8-G2	0.5	1.5	8.3	0.50	2.0
Probe	514SG-3	1.5	6.5	6.5	0.50	7.0
PRT	514-8-G3	0.5	2.5	13.9	0.50	3.0
GVP	514-8-A3	0.5	2.5	40.4	0.50	3.0

**Table 11c.** VOC and Gas Concentrations of Probe, PRT, and GVP Systems at 2.3 m Near MW514SG

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
514-8-A1	122	825	256	58	15.6	4.7	0.0
514-8-A2	120	917	291	65	15.6	4.8	0.0
514-8-A3	125	883	279	65	15.6	4.6	0.0
mean 514-8-A	122	875	275	63	15.6	4.7	0.0
stdev 514-8-A	2.5	46.5	17.8	4.0	0.0	0.1	0.0
PRT							
514-8-G1	124	881	266	65	15.5	4.7	0.0
514-8-G2	127	911	283	66	15.4	4.8	0.0
514-8-G3	109	904	268	62	15.5	4.8	0.0
mean 514-8-G	120	899	272	64	15.5	4.8	0.0
stdev 514-8-G	9.6	15.7	9.3	2.1	0.1	0.1	0.0
Probe							
514SG-1	101	728	255	36	15.2	4.9	0.0
514SG-2	103	804	247	34	15.3	5.0	0.0
514SG-3	103	795	243	33	15.3	5.0	0.0
mean 514SG	102	776	248	34	15.3	5.0	0.0
stdev 514SG	1.2	41.5	6.1	1.5	0.1	0.1	0.0

**Table 12a.** Computation of Internal Volumes of Sample Systems at 0.8 m Near MW523SGS

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NR	91	NR	0.48	335	59.7	0.061
PRT	2.54	5.1	26	NR	152	NR	0.64	351	111.0	0.137
Probe	3.81	30.5	347	1.9	61	174	0.95	61	43.4	0.564

NR = not relevant

**Table 12b.** Computation of Pre-Sample Internal Exchanges and VOC Concentrations of Sample Systems at 0.8 m Near MW523SGS

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Pre-Sample Internal Exchange (-)	Sample Volume (L)	Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
PRT	523-3-G1	0.25	1.8	0.50	0.75	ND(30)	ND(2.0)	ND(4.0)	ND(25)	NA	NA	NA
GVP	523-3-A1	0.25	4.1	0.50	0.75	ND(30)	7.0	ND(5.0)	ND(25)	NA	NA	NA
Probe	523SGS-1	2.0	3.5	0.50	2.5	ND(15)	ND(3.0)	5.8	ND(25)	0.0	10.8	55.5

NA = not analyzed

**Table 13a.** Computation of Internal Volumes of Sample Systems at 2.3 m Near MW523SGM

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NR	274	NR	0.48	479	85.2	0.087
PRT	2.54	5.1	26	NR	305	NR	0.64	561	177.5	0.203
Probe	3.81	30.5	347	1.9	213	608	0.95	61	43.4	0.999

NR = not relevant

**Table 13b.** Computation of Pre-Sample Internal Exchanges and VOC Concentrations of Sample Systems at 2.3 m Near MW523SGM

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Pre-Sample Internal Exchange (-)	Sample Volume (L)	Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
PRT	523-8-G1	0.5	2.5	0.50	1.0	ND(30)	8.7	11	ND(25)	NA	NA	NA
GVP	523-8-A1	0.5	5.8	0.50	1.0	ND(30)	4.4	7.2	ND(25)	NA	NA	NA
Probe	523SGM-1	2.5	2.5	0.50	3.0	ND(30)	6.2	13	ND(25)	0.0	11.2	26.4

ND() = not detected

NA = not analyzed

**Table 14a.** Computation of Internal Volumes of Sample Systems at 3.4 m Near MW523SGD

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
PRT	2.54	5.1	26	NR	457	NR	0.64	796	252	0.278
Probe	3.81	30.5	347	1.9	305	868	0.95	61	43.4	1.259

**Table 14b.** Computation of Pre-Sample Internal Exchanges and VOC Concentrations of Sample Systems at 3.4 m Near MW523SGD

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Pre-Sample Internal Exchange (-)	Sample Volume (L)	Post-Sample Extraction Volume (L)	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
PRT	523-11-G1	0.5	1.8	0.5	1.0	ND(30)	19	15	ND(25)	NA	NA	NA
Probe	523SGD-1	2.5	2.0	0.5	3.0	ND(30)	11	13	ND(25)	0.0	12.2	9.6

ND() = non-detect

NA = not analyzed

**Table 15a.** Computation of Internal Volumes of Sample Systems at 0.91 m Near MW525SG

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NA	91	NR	0.48	152	27.1	0.029
PRT	2.54	5.1	26	NA	152	NR	0.64	332	105.2	0.131

NR = not relevant

**Table 15b.** Computation of Pre-Sample Internal Exchanges of Sample Systems at 0.91 m Near MW525SG

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	526-3-G1	0.25	0.25	1.9	0.50	0.75
GVP	525-3-A1	0.25	0.25	8.7	0.50	0.75
PRT	525-3-G2	0.25	1.00	7.6	0.50	1.50
GVP	525-3-A2	0.25	1.00	34.8	0.50	1.50
PRT	525-3-G3	0.25	1.75	13.4	0.50	2.25
GVP	525-3-A3	0.25	1.75	60.9	0.50	2.25

**Table 15c.** Summary of VOC Concentrations in PRT and GVP Systems at 0.91 m near MW525SG

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
525-3-A1	148	303	52	8.0	NA	NA	NA
525-3-A2	151	312	58	8.5	NA	NA	NA
525-3-A3	151	289	58	8.5	NA	NA	NA
mean 525-3-A	150	301	56	8.3	NA	NA	NA
stdev 525-3-A	1.7	11.6	3.5	0.3	NA	NA	NA
PRT							
525-3-G1	222	452	93	17	18.2	2.0	0.0
525-3-G2	221	444	97	17	NA	NA	NA
525-3-G3	219	449	95	17	18.2	1.8	0.0
mean 525-3-G	221	448	95	17	18.2	1.9	0.0
stdev 525-3-G	1.5	4.0	2.0	0.0	0.0	0.1	0.0

NA = not analyzed

**Table 16a.** Computation of Internal Volumes of Sample Systems at 2.3 m Near MW525SG

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NA	274	NR	0.48	457	81.4	0.083
PRT	2.54	5.1	26	NA	305	NR	0.64	457	145	0.170
Probe	3.81	30.5	347	1.9	213	608	0.95	61	0.0	0.955

NR = not relevant

**Table 16b.** Computation of Pre-Sample Internal Exchanges of Sample Systems at 2.3 m Near MW525SG

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	525-8-G1	0.5	0.5	2.9	0.5	1.0
GVP	525-8-A1	0.5	0.5	6.0	0.5	1.0
Probe	525SG-1	2.5	2.5	2.6	0.5	3.0
GVP	525-8-A2	0.5	1.5	18.1	0.5	2.0
Probe	525SG-2	1.5	4.5	4.7	0.5	5.0
PRT	525-8-G2	0.5	1.5	8.8	0.5	2.0
Probe	525SG-3	1.5	6.5	6.8	0.5	7.0
PRT	525-8-G3	0.5	2.5	14.7	0.5	3.0
GVP	525-8-A3	0.5	2.5	30.1	0.5	3.0



**Table 16c.** Summary of VOC and Gas Concentrations in PRT and GVP Systems at 2.3 m Near MW525SG

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
525-8-A1	33	55	12	ND(5.0)	19.9	0.3	0.0
525-8-A2	25	41	8.1	ND(5.0)	20.1	0.2	0.0
525-8-A3	35	55	12	ND(5.0)	20.0	0.3	0.0
mean 525-8-A	31	50	11	ND(5.0)	20.0	0.3	0.0
stdev 525-8-A	5.3	8.1	2.3	IND	0.1	0.1	0.0
PRT							
525-8-G1	256	450	101	22	18.2	1.9	0.0
525-8-G2	254	451	101	22	18.2	1.9	0.0
525-8-G3	254	452	100	22	18.4	2.0	0.0
mean 525-8-G	255	451	101	22	18.3	1.9	0.0
stdev 525-8-G	1.2	1.0	0.6	0.0	0.1	0.1	0.0
Probe							
525SG-1	267	389	85	21	18.4	1.8	0.0
525SG-2	272	389	85	22	18.4	1.8	0.0
525SG-3	275	400	92	23	18.4	1.8	0.0
mean 525SG	271	393	87	22	18.4	1.8	0.0
stdev 525SG	4.0	6.4	4.0	1.0	0.0	0.0	0.0

**Table 17a.** Computation of Internal Volumes of Sample Systems at 0.91 m Near MW526SGS

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NA	91	NA	0.48	152	27.1	0.029
PRT	2.54	5.1	26	NA	152	NA	0.64	320	101.3	0.127
Probe	3.81	30.5	347	1.9	61	174	0.95	61	43.4	0.564

NR = not relevant

**Table 17b.** Computation of Pre-Sample Internal Exchanges of Sample Systems at 0.91 m Near MW526SGS

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	526-3-G1	0.25	0.25	2.0	0.50	0.75
GVP	526-3-A1	0.25	0.25	8.7	0.50	0.75
Probe	526SGS-1	2.0	2.0	3.5	0.50	2.5
GVP	526-3-A2	0.25	1.00	34.8	0.50	1.50
Probe	526SGS-2	1.2	3.7	6.6	0.50	4.2
PRT	526-3-G2	0.25	1.00	7.9	0.50	1.50
Probe	526SGS-3	1.2	5.4	9.6	0.50	5.9
PRT	526-3-G3	0.25	1.75	13.8	0.50	2.25
GVP	526-3-A3	0.25	1.75	60.9	0.50	2.25

**Table 17c.** Summary of VOC and Gas Concentrations in PRT and GVP Systems at 0.91 m Near MW526SG

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
526-3-A1	11	72	22	ND(4.0)	18.2	1.3	0.0
526-3-A2	10	69	23	ND(4.0)	18.5	1.2	0.0
526-3-A3	6.7	64	21	ND(4.0)	18.4	1.2	0.0
mean 526-3-A	9.2	68	22	ND(4.0)	18.4	1.2	0.0
stdev 526-3-A	2.3	4.0	1.0	IND	0.2	0.1	0.0
PRT							
526-3-G1	6.2	55	12	ND(4.0)	18.7	1.1	0.0
526-3-G2	3.9	55	12	ND(4.0)	18.7	1.1	0.0
526-3-G3	2.8	55	12	ND(4.0)	18.9	1.1	0.0
mean 526-3-G	4.3	55	12	ND(4.0)	18.8	1.1	0.0
stdev 526-3-G	1.7	0.0	0.0	IND	0.1	0.0	0.0
Probe							
526SGS-1	25	55	21	ND(3.0)	19.0	1.0	0.0
526SGS-2	25	54	22	ND(3.0)	18.8	1.0	0.0
526SGS-3	25	55	22	ND(3.0)	18.8	1.0	0.0
mean 526SGS	25	55	22	ND(3.0)	18.9	1.0	0.0
stdev 526SGS	0.0	0.6	0.6	IND	0.1	0.0	0.0

ND() =not detected

IND = indeterminate

**Table 18a.** Computation of Internal Volumes of Sample Systems at 0.91 m Near MW526SGM

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NR	91	NA	0.48	305	54.3	0.056
PRT	2.54	5.1	26	NR	152	NA	0.64	308	97.4	0.123

NR = not relevant

**Table 18b.** Computation of Pre-Sample Internal Exchanges of Sample Systems at 0.91 m Near MW526SGM

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
GVP	526-3-A1R	0.25	0.25	4.5	0.5	0.75
PRT	526-3-G1R	0.25	0.25	2.0	0.5	0.75
GVP	526-3-A2R	0.25	1.00	17.9	0.5	1.50
PRT	526-3-G2R	0.25	1.00	8.1	0.5	1.50
GVP	526-3-A3R	0.25	1.75	31.3	0.5	2.25
PRT	526-3-G3R	0.25	1.75	14.2	0.5	2.25

**Table 18c.** Summary of VOC and Gas Concentrations in PRT and GVP Systems at 0.91 m Near MW526SGM

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
526-3-A1R	6.4	29	8.1	ND(3.0)	NM	NM	NM
526-3-A2R	6.4	28	8.1	ND(3.0)	NM	NM	NM
526-3-A3R	8.6	28	8.1	ND(3.0)	NM	NM	NM
mean 525-3-AR	7.1	28	8.1	ND(4.0)	NM	NM	NM
stdev 525-3-AR	1.3	0.6	0.0	IND	NM	NM	NM
PRT							
526-3-G1R	10	49	26	ND(4.0)	NM	NM	NM
526-3-G2R	11	50	27	ND(4.0)	NM	NM	NM
526-3-G3R	12	50	28	ND(4.0)	NM	NM	NM
mean 526-3-GR	11	50	27	ND(4.0)	NM	NM	NM
stdev 526-3-GR	1.0	0.6	1.0	IND	NM	NM	NM

ND( )-not detected

NM - not measured

IND - indeterminate

**Table 19a.** Computation of Internal Volumes of Sample Systems at 2.3 m Near MW526SGM

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
GVP	0.64	5.1	1.6	NR	274	NA	0.48	369	65.7	0.067
PRT	2.54	5.1	26	NR	305	NA	0.64	448	142	0.168
Probe	3.81	30.5	347	1.9	213	608	0.95	61	43.4	0.999

NR = not relevant

**Table 19b.** Computation of Pre-Sample Internal Exchanges of Sample Systems at 2.3 m Near MW526SGM

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	526-8-G1	0.5	0.5	3.0	0.5	1.0
GVP	526-8-A1	0.5	0.5	7.4	0.5	1.0
Probe	526SGM-1	2.5	2.5	2.5	0.5	3.0
GVP	526-8-A2	0.5	1.5	22.3	0.5	2.0
Probe	526SGM-2	1.5	4.5	4.5	0.5	5.0
PRT	526-8-G2	0.5	1.5	9.0	0.5	2.0
Probe	526SGM-3	1.5	6.5	6.5	0.5	7.0
PRT	526-8-G3	0.5	2.5	14.9	0.5	3.0
GVP	526-8-A3	0.5	2.5	37.2	0.5	3.0

**Table 19c.** Summary of VOC and Gas Concentrations in Sample Systems at 2.3 m Near MW526SGM

Sample Identification	1,1-DCE (ppbv)	1,1,1-TCA (ppbv)	TCE (ppbv)	c-1,2-DCE (ppbv)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)
GVP							
526-8-A1	62	80	27	7.9	19.3	0.8	0.0
526-8-A2	61	79	27	7.8	19.2	0.8	0.0
526-8-A3	61	77	26	7.9	19.3	0.8	0.0
mean 526-8-A	61	79	27	7.9	19.3	0.8	0.0
stdev 526-8-A	0.6	1.5	0.6	0.1	0.1	0.0	0.0
PRT							
526-8-G1	74	101	32	11	19.3	0.7	0.0
526-8-G2	80	104	34	12	19.2	0.7	0.0
526-8-G3	82	102	33	12	19.3	0.7	0.0
mean 526-8-G	79	102	33	12	19.3	0.7	0.0
stdev 526-8-G	4.2	1.5	1.0	0.6	0.1	0.0	0.0
Probe							
526SGM-1	56	72	26	8.7	19.3	0.9	0.0
526SGM-2	56	73	26	8.2	19.3	0.9	0.0
526SGM-3	57	72	23	8.4	19.3	0.9	0.0
mean 526SGM	56	72	25	8.4	19.3	0.9	0.0
stdev 526SGM	0.6	0.6	1.7	0.3	0.0	0.0	0.0

**Table 20a.** Computation of Internal Volumes of Sample Systems at 3.2 m Near MW526SGD

Sample Method	Screen ID (cm)	Screen Length (cm)	Screen Volume (cm <sup>3</sup> )	Riser ID (cm)	Riser Length (cm)	Riser Volume (cm <sup>3</sup> )	Tubing ID (cm)	Tubing Length (cm)	Tubing Volume (cm <sup>3</sup> )	Internal Volume (L)
PRT	2.54	5.1	26	NR	457	NR	0.64	610	193	0.219
Probe	3.81	30.5	347	1.9	305	868	0.95	61	43.4	1.259

NR = not relevant

**Table 20b.** Computation of Pre-Sample Internal Exchanges of Sample Systems at 3.2 m Near MW526SGD

Sample Method	Sample Identification	Pre-Sample Purge Volume (L)	Cumulative Pre-Sample Extraction Volume (L)	Cumulative Pre-Sample Internal Exchanges (-)	Sample Volume (L)	Cumulative Post-Sample Extraction Volume (L)
PRT	526-11-G1	0.75	0.75	3.4	0.5	1.3
Probe	526SGD-1	3.0	3.0	2.4	0.5	3.5
PRT	526-11-G2	0.5	1.75	8.0	0.5	2.3
Probe	526SGD-2	1.8	5.3	4.2	0.5	5.8
PRT	526D-11-G3	0.5	2.8	12.6	0.5	3.3
Probe	526SGD-3	1.8	7.6	6.0	0.5	8.1

**Table 20c.** Summary of VOC and Gas Concentrations in Sample Systems at 3.2 m Near MW526SGD

<b>Sample Identification</b>	<b>1,1-DCE (ppbv)</b>	<b>1,1,1-TCA (ppbv)</b>	<b>TCE (ppbv)</b>	<b>c-1,2-DCE (ppbv)</b>	<b>O<sub>2</sub> (%)</b>	<b>CO<sub>2</sub> (%)</b>	<b>CH<sub>4</sub> (%)</b>
PRT							
526-11-G1	85	120	38	16	18.9	0.8	0.0
526-11-G2	85	121	40	18	19.0	0.8	0.0
526-11-G3	92	124	45	19	19.1	0.9	0.0
mean 526-11-G	87	122	41	18	19.0	0.8	0.0
stdev 526-11-G	4.0	2.1	3.6	1.5	0.1	0.1	0.0
Probe							
526SGD-1	68	87	32	14	19.2	0.9	0.0
526SGD-2	68	87	32	14	19.2	0.9	0.0
526SGD-3	66	87	33	14	19.2	0.9	0.0
mean 526SGD	67	87	32	14	19.2	0.9	0.0
stdev 526SGD	1.2	0.0	0.6	0.0	0.0	0.0	0.0





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