EVALUATION OF IMPACT RESULTING FROM HOME HEATING OIL TANK DISCHARGES

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1. Introduction and Scope

The Virginia Department of Environmental Quality (DEQ) oversees the investigation and characterization of discharges from home heating oil tanks. Remediation of home heating oil discharges is a defined activity of the DEQ Petroleum Program. The degree and extent of remediation required following a petroleum release in Virginia is based upon risks to human health and the environment posed by that release. The central question to address is under what circumstances do petroleum vapors from a subsurface heating oil discharge remediated under the DEQ Petroleum Program potentially pose an unacceptable risk to the residents?

The primary objective of the PVI Study is a scientifically-defensible answer to the question: To what degree do heating oil vapors emanating from a discharge from heating oil storage tank discharges remediated under the DEQ Petroleum Program pose an unacceptable risk to residents at the stated risk thresholds[1]? To achieve this objective, data was collected at a number of residences in the DEQ Home Heating Oil (HHO) program where investigation, characterization, remediation of home heating oil storage tank discharges were completed. The field study was designed to determine what constituent(s) are of significant concern for PVI due to the release of #2 diesel fuel and may be viewed as drivers of risk to human health (Secondary Objective 1). Further, various methods to assess the potential for human health risk were evaluated for applicability to the spill scenarios associated with home heating oil storage tank discharges.

An additional secondary objective of the PVI Study is to determine the site-specific variables that most strongly influence the advancement of vapor concentrations above potential risk threshold levels to residents (Secondary Objective 2). These variables were limited to easily-identifiable and previously documented characteristics of the HHO program cases including local geology or soil type and the severity of the spill. Physiographic region served as a reasonable variable for the former. Severity of the spill was addressed through the site category designation used in the DEQ HHO program. Each case receives one of four categories based severity and extent of contamination and risks from the discharge as a means to define the scope of work for a given case. The characteristics of the four categories defined in the 2014 DEQ guidance document are summarized below:

[1] Excess lifetime cancer risk of one in one million; Risk from exposure to non-carcinogens exceeds 1

- No Further Action (NFA): An *NFA* decision generally is appropriate at sites where the area is served by public water, the leaking tank has been out of service for an extended period and is not believed to be contributing product to the environment, and there is no reason to expect any impact(s) to receptor(s).
- Category 1: *Category 1* heating oil sites pose a low risk to receptors. If an impacted receptor has not been identified at the time the discharge is reported and if DEQ has decided that the *NFA* category is not appropriate, the heating oil tank discharge will start as a *Category 1* site. *Category 1* cases require limited field work and are typically involve an out-of-service heating oil tank that is still in place.
- Category 2: Discharges at *Category 2* heating oil tank sites are believed to present a threat to receptors such as drinking water supplies or a surface water body. Limited soil excavation, free product removal and vapor mitigation may be performed at *Category 2* sites. Remediation of *Category 2* cases typically involve excavation of the UST and soil surrounding the UST. Sites also may be placed into *Category 2* if petroleum vapors are present in non-living space structures (e.g. crawl spaces) and it is believed that the Category 2 scope of work guidelines for limited soil removal with ventilation of the crawl space will adequately protect human health.
- Category 3: Discharges at *Category 3* heating oil tank sites have impacted or present a high probability to impact a receptor including drinking water supplies, surface water bodies, or other receptors. The Case Manager may require initial abatement, an appropriate site characterization, and, if warranted, the development and implementation of a Corrective Action Plan. Sites requiring more than three monitoring wells or more than four quarters of ground water monitoring or free product removal should be placed in or moved to Category 3. Excavation of the UST and soil surrounding the discharge is typically one component of the remediation of a *Category 3* case.

As noted in the DEQ HHO program guidance document, *Category 1* cases may transition to *Category 2* if DEQ staff believe a receptor is at a moderate degree of risk. If an imminent threat or high probability to impact a receptor is found, *Category 1* or *2* cases may be moved to a *Category 3* heating oil discharge so that a more detailed characterization may occur.

The purpose of this final report is to address project objectives and to provide answers to these questions pertaining to the risk of PVI at sites within the HHO program administered by DEQ. The project began in early February 2017 with the first three months devoted to the sampling plan, evaluating reports, and developing field and laboratory PVI-related methods in support of the objectives. A pilot study was initiated in May 2017 with a focus on the sampling of local cases in the DEQ program located in Montgomery and Roanoke Counties and was completed in July 2017. The field investigation involved the collection of soil gas samples in the immediate vicinity of the former underground storage tank (UST) where heating oil was previously stored. Field activities continued during August 2017 through June 2018. The results of this soil gas sampling and analysis for petroleum-derived volatile organic compound (VOC) and semi-volatile organic compound (SVOC) concentrations are documented in this report. A summary of finding and recommendations are provided in the concluding section.

2. Approach and Methods

The primary objective of the field investigation was the collection of soil gas samples at each PVI study site. Laboratory analysis of samples enabled determination of soil gas composition and quantification of the concentrations of benzene, toluene, ethyl-benzene, m+p-xylene, o-xylene, and naphthalene (BTEXN) and TPH. Recently-published technical guidance produced by the U.S. EPA (2014) recommends soil gas sampling as an approach for screening petroleum-contaminated sites before proceeding with a VI investigation using sub-slab sampling or indoor air sampling. In addition, ITRC (2014) also identifies soil gas sampling as an initial investigative step at sites where petroleum VI is a potential concern. The Massachusetts Department of Environmental Protection (MADEP) which developed the *VPH/EPH Guidance* (MADEP 2002) recently modified VI guidance in favor of soil gas sampling and analysis of individual petroleum-derived VOC/SVOCs. Analysis of soil gas applies to any residual or mobile sources of VOC/SVOCs including soil, groundwater or product (e.g., LNAPL).

2.1. Site Selection and Sampling Plan

The initial primary task of the PVI Study was to devise and execute a sampling plan for the selection of sites for the field investigation. The DEQ program database was filtered to eliminate commercial and industrial cases as potential study sites. At the start of the project there were

5,936 residential heating oil UST release cases on record at DEQ since 2008 (**Table 1**). These cases represented that population from which a random sample was determined for the field investigation. Table 1 provides the distribution of all cases by DEQ Category within each DEQ regional office. Blue Ridge include both the previously split offices (Roanoke and Lynchburg). It is useful to note that some DEQ regional offices span more than one Physiographic Region in Virginia. The distribution of cases by Physiographic Region is addressed later in this section.

Within the population of residential cases, 4.6% of the total were listed as "No Further Action" (272 NFA Cases). The remaining subset of the population were grouped by DEQ Category (i.e., Categories 1, 2 and 3). Within this group of non-NFA cases, 5,316 cases were listed as "Closed" (5,664 or 93.7%) with the remaining cases listed as "Open" (348). Overall, Category 2 cases comprised 56% of all non-NFA cases and Categories 1 and 3 accounted for 34% and 10%, respectively. However, the distribution of categories varied by DEQ region. For example, the DEQ Tidewater Region oversees the most Category 3 cases, which comprise 34% of all cases in this regional office. As confirmed through this investigation, the number of Category 3 cases in the DEQ Tidewater Region reflects hydrogeological conditions (e.g., shallow water table) that are typical of the Hampton Roads area of Virginia.

A stratified sampling design plan was conducted to determine the test sites for this study. Previous studies that require homeowner's response and permission to conduct testing on their land suggest that over-sampling is required because only a fraction of homeowner return attempts at communication or agree to participate in this type of study. It was also determined after examining a sample of reports that not all home heating oil release sites would be amenable as study sites. For example, the placement of some tanks around homes, or under structures leaves some sites inaccessible for our testing methods. Based on an unknown amount of compliance with homeowners and the inaccessibility of some sites it was determined to generate a random sample of 400 with a target of between 40 and 48 sites.

Table 1. Number of Residential Heating Oil Sites by DEQ Region (2008 to February 2017)

DEQ Category	DEQ Region						
	Blue Ridge	Northern	Piedmont	Southwest	Tidewater	Valley	Total
Category 1	163	477	1,094	3	126	67	1,930
Category 2	1,310	179	1,146	24	252	252	3,163
Category 3	93	54	175	11	197	41	571
Subtotals	1,566	710	2,415	38	575	360	5,664
NFA	11	171	63	0	21	6	272
Totals	1,577	881	2,478	38	596	366	5,936
NFA = No Further Action							

An initial step was to determine a statistically-significant sample population that reflects the uneven geographic distribution of DEQ cases throughout the state. Given the potential variability in soil type and related conditions in the various regions, physiographic region was also considered to identify study sites. For the purpose of this investigation, cases were geographically designated by physiographic region (Valley and Ridge, Piedmont, and Coastal Plain). The Blue Ridge Mountain and Appalachian Plateau physiographic regions were included with the Valley and Ridge physiographic region. In addition, cases were categorized based on DEQ Category (i.e., Categories 1, 2 and 3). With the cases assigned to strata (i.e., physiographic regions), two possible sampling designs were proportionate and disproportionate stratified random sampling. The latter approach is thought to reduce the risk of falsely rejecting the null

hypothesis by oversampling sites with a higher potential for impact. In this case, the sample size of each stratum is not necessarily proportionate to the population size of the stratum.

A hybrid of the two approaches (i.e., proportionate and disproportionate) was used to create the random sample. A Neyman Allocation for a population weighted stratified random sampling plan was run using the statistical program R (www.r-project.org/). For 50% of the sample (*N*=200), proportional population weighting was given to each physiographic region for the random sample. For the other 50%, DEQ category was incorporated as a variable. To account for the potential higher impact at Category 3 cases, a sampling plan using *N*=200 was run assuming a higher variability for Category 3 cases with rankings of 1 assigned to Categories 1 and 2, 10 being assigned to Category 3 cases of each region. The two groups were combined to yield 400 total cases (**Table 2**).

Table 2. Random Sample of Heating Oil Cases by Region and Category (*N*=400).

Physiographic Region	**Category 1**	**Category 2**	**Category 3**	**Total**	**% of Total**
[a]Valley & Ridge	4	20	9	33	8%
Piedmont	76	130	25	231	58%
Coastal Plain	46	53	37	136	34%
Total	126	203	71	400	100%
% of Total	31%	51%	18%	100%	
[a]Cases located in the Blue Ridge Physiographic Region are included under Valley & Ridge					

Figure 1 is a map showing the distribution of the 400 cases selected by random sample (Table 2) and the five physiographic regions of Virginia. The randomly-sampled sites are clustered around urban and metropolitan areas in Virginia, reflecting the distribution of population. It is noted that the weighting of Category 3 sites in 50% of the sample did not result in a heavy skewing away from the proportional population weighting of sites. The 10:1 ratio noted above is log-based, approximately equivalent to a 3:1 weighting.

Homeowners were contacted by letter explaining the nature and scope of the PVI study and seeking their interest and permission to participate. Approximately 20% of the letters were not delivered by the U.S. Postal Service and returned for various reasons. Approximately 70 responses were received either through direct contact by telephone or by email correspondence. After examining the site investigation reports and determining suitability as a PVI study site, 15 cases were selected in Montgomery and Roanoke Counties for the pilot study and 46 cases were selected as suitable for the investigation following completion of the pilot phase. The number of pilot study cases by DEQ Category was 2 in Category 1, 9 in Category 2, and 4 in Category 3.

Cases in the NFA category were not included in the initial random sample of 400 cases but were considered in a separate random sample. Of the 272 cases listed in the NFA category, only 7 cases were located outside of the Coastal Plain and Piedmont Physiographic Regions. A random sample of 100 cases were selected from the remaining 265 NFA cases. The 100 cases were weighted 36:64 between the Coastal Plain and Piedmont Physiographic Regions, respectively, to reflect the distribution of the 265 cases. Approximately 14 responses were received from which 10 cases were evaluated through site investigation. Two the respondents called to indicated their unwillingness to participate in the study. The other two cases were not included as field study sites because the former UST area was not accessible to soil probes due to renovation or additions to the homes. The distribution of the ten NFA cases included in the PVI study by physiographic regions adequately reflected the distribution noted in the total population (40% Coastal Plain and 60% Piedmont Physiographic Regions). Eight of the ten NFA cases were located in Northern Virginia.

Table 3 lists the PVI study sites by DEQ Category which includes the NFA study sites and the distribution of Pilot Study sites by DEQ Category. **Figure 2** is a map showing the distribution of all study sites among the three major physiographic regions. The distribution of the 46 cases evaluated through field investigation by DEQ Category and by the three major physiographic regions honored the targeted distribution of the sample population. For the latter, the minimum required number of cases for each of the three physiographic region were satisfied based on 40 as the minimum total number of sites. The percentages of Category 1 and 2 sites were slightly lower than those found in the total population of residential cases while the number of Category 3 sites (14) exceeded the target range of 8 to 10 cases.

Table 3. PVI Study Sites by Region and Category.

Physiographic Region	Category 1	Category 2	Category 3	Subtotals	NFA
Valley & Ridge	1	3	4	8	0
Piedmont	7	11	5	23	6
Coastal Plain	2	6	7	15	4
Subtotals	10	20	16	46	10
Pilot	2	9	4	15	0
The Pilot study consisted of 15 cases in Montgomery and Roanoke Counties. The PVI study consisted of 10 cases listed as No Further Action (NFA) and 46 cases (non-NFA) listed by DEQ Category.					

One important factor influencing site selection is the reliance of volunteer participation. It is reasonable to surmise that the larger percentage of Category 3 sites investigated in the PVI study may reflect a higher response rate based on potential concerns and perceptions of the individual homeowners. Closed cases constituted 42 of the 46 PVI study sites or 91.3% of sites. This percentage of closes cases reasonably reflects the percentage of closes cases (93.7%) noted in the total population of the DEQ program.

2.2. Sampling Methodology

2.2.1. Field Methods

The primary method to evaluate the potential for PVI was the collection of soil gas samples outside of dwellings at each study site. Soil gas probes were installed in the vicinity of the documented location of the site USTs. Site Characterization Reports served as an invaluable resource in determining the location of soil gas sampling and specifically the former UST area at study site. In general, at least two soil gas probes were installed in the UST area in immediate proximity to the residential dwellings. However, an adaptive approach was employed for determining the number and location of soil gas samples based on site conditions (e.g.,

underground utilities). Although U.S. EPA (2014) recommends collecting soil gas samples from at least two discrete depths when investigating the potential for VI, the sample collection strategy was limited to one depth, typically 4 to 6 feet below ground surface, because of the relatively shallow depth of the USTs. In addition, a background soil gas sample was collected as a control at each site unless conditions prevented the installation of a soil gas probe.

Installation of temporary soil gas probes was initiated using AMS 5/8-in Tile Probe Extensions to create a small-diameter borehole depth. The tile probe was pushed into the ground by hand in soft soil or driven to depth using a slide hammer. The temporary soil gas probe consisted of an AMS GVP Retract-A-Tip connected to AMS GVP Extensions (5/8-inch x 3-ft stainless steel hollow threaded rods). Teflon tubing (OD: ¼ in.) was connected to the soil probe and extended to ground surface through the hollow probe shaft. Soil gas samples were collected using portable, battery-operated, hand-held SKC vacuum pumps (AirCheck XR5000). During the pilot study, flow rates were varied from 25 to 100 cm^3/min, but at the majority of sites, samples were collected using a flow rate of 35 cm^3/min. Sampling flow rates were measured using a Dwyer Variable Area 65 mm glass flowmeter.

Split-flow samples were collected at a minimum of one soil gas probe at each site (i.e., a split in the tubing above ground). Soil gas was passed through stainless steel gas sampling cartridges containing either Tenax™ TA adsorbing polymer or Carbopack™ adsorbing polymer. Carbopack™ sampling tubes were generally used at split-flow samples. Sampling duration ranged from 15 to 30 minutes depending on the flow. For the target flow rate of 35 cm^3/min, a standard sampling duration of 30 minutes was used to allow capture 1,000 cm^3 of air.

At each site, field notes were collected including information on the type of structure (basement, crawl space, etc.) and the location of the soil gas probes in relation to the building. Depth below ground surface and horizontal distances from the structure and contaminant source were carefully recorded. Lateral drains, vegetation, and other potential surface or subsurface conduits for vapors were identified and noted. At a limited number of sites, gas samples were collected in the crawl spaces below homes or in drains at sites where these features were identified as potential conduits of vapor migration. In these cases, ambient air samples were also collected as a control and as comparison to crawl space samples.

2.2.2. Laboratory Methods

Samples were collected in stainless steel cartridges containing Tenax® TA (purchased pre-packed and unconditioned from Sigma Aldrich), an adsorbent suitable for the analysis of C_7-C_{26} organic compounds with low to moderate polarity (generally spanning the range of BTEXN and diesel range organics) [EPA TO-17]. Prior to sample collection, cartridges were pre-conditioned at 300ºC for 4 hours under 100 cm^3/min of pure N_2. Sample analysis and quantification protocols were modeled off of EPA Method TO-17.

Samples were thermally desorbed from cartridges at 300ºC with 230 cm^3/min of helium for five minutes. Prior to heating, water was purged from samples for 10 seconds under the same flow; longer purge times were found to result in the loss of the more volatile BTEX components. During this time, a measured fraction (typically ~10%) of the desorbed organic compounds were cryogenically concentrated at -95 ºC on a short length of deactivated silica (0.53 mm ID). After desorption, the cryogenic trap was immediately heated to the starting temperature of the gas chromatograph for analysis by gas chromatography/mass spectrometry (GC/MS, 7890/5977; Agilent Technologies, Inc.). The analytes were separated by a non-polar capillary column (Rxi-5ms, 30m x 0.25µm x 0.25 mm; Restek Corporation) with starting temperature of 35ºC (4 min hold) and a ramped temperature profile up to 300ºC (15ºC/min, final hold of 5 min). Analytes were detected by electron impact MS (Agilent Technologies 5977B) scanning a mass range of 33 to 350 at a scan speed of 3.125 u/s (8.1 Hz). Only a fraction of desorbed sample was actually analyzed ("analyzed fraction"), while the remainder was purged from the system to avoid oversaturating the mass spectrometer detector. The analyzed fraction was passed through a liquid-nitrogen-cooled cryo-trap for pre-concentration, and ranged from 1% to 20% depending on sample volumes and concentrations; this fraction was measured (DryCal Definer 220 Low; Mesa Labs) and used to convert measured analyte mass into sampled (on-tube) analyte mass.

Mass spectrometer signal was converted into analyte mass using multi-point calibration of authentic standards for BTEXN. Calibrants were loaded onto tubes by injecting 1-3 µL liquid standards into a stainless steel tee upstream of an adsorbent cartridge and purging through the cartridge for 5 minutes with pure N_2. This approach was validated by injection of *n*-alkanes spanning C_7-C_{30}, analysis of which showed efficient transfer and collection of analytes across the full volatility range of interest. Multi-point calibrations consistent of analytes at 5 or more concentrations, spanning two orders of magnitude in mass and generally bracketing the range of

signal observed of collected samples. Any time the mass spectrometer was re-tuned (e.g., due to loss of sensitivity or instrument maintenance), a multi-point calibration was conducted to constrain the sensitivity of that tune period. Within a tune period, drifts in sensitivity were monitored and corrected for through the daily injection of a calibrant with known concentration; this "tracking standard" was found to correct for instrument drift to within 10% for most of the experiment (30% in pilot study). Analyte mass was calculated based on the response factor determined by calibration, corrected for drifts in instrument sensitivity, and converted to sampled concentrations based on sample volume and "analyzed fraction."

In addition to BTEXN components, which were calibrated by authentic standards, we report combined mass of constituents in several ranges, e.g., "diesel range organics" or "total petroleum hydrocarbons" (i.e., TPH). We report here: C_9 and C_{10} aromatics, which were quantified with ion m/z 120 and 134 (respectively) and calibrated using o-xylene (corrected for differences in mass spectrometric fragmentation patterns); C_5-C_8 vapor phase hydrocarbons, which were quantified as the total ion signal in the retention time window before octane (which likely underestimates C_5-C_6 contribution) calibrated using the total ion response factor for octane; C_9-C_{12} vapor phase hydrocarbons, which were quantified as the total ion signal in the retention time window between nonane and dodecane calibrated using the total ion response factor for decane; and C_9-C_{18} "extractable petroleum hydrocarbons" (EPH), which were quantified as the total ion signal in the retention time window between nonane and octadecane calibrated using the total ion response factor for tetradecane. Note that these binned species based on total ion signal do not distinguish between hydrocarbons and other present compounds (e.g., oxygenates formed through biological decomposition).

Instrument calibration and correction for drifts in sensitivity was conducted by the regular introduction of standards. A BTEX standard (Supelco, 200 µg/mL in methanol) and *n*-C_7 to *n*-C_{30} alkane standard (Supelco, 1,000 µg/mL in hexane) were diluted in methylene dichloride to produce a 5-point standard curve. Each standard was injected into Tenax® TA tube with a flow rate of around 70 ccm for 3 minutes. Analysis of standards followed the same GC/MS program used for samples. BTEXN were all calibrated using authentic standards (i.e., introduction of known concentrations of each analyte of interest). Total petroleum hydrocarbon (TPH) was calculated from the integrated total ion signal between the retention times of *n*-nonane (C_9 alkane) and *n*-tricosane (C_{23} alkane), which spans the approximate range of diesel fuel.

Calibration of TPH was conducted using the total ion signal of n-tetradecane (C_{14} alkane), which is roughly in the middle of the TPH range.

To track the change in sensitivity of the MS instruments, a standard with known concentration was analyzed approximately every 10 samples. The standard used for this purpose was a concentration of the calibrant approximately in the middle of the multi-point calibration curve. Dilute heating oil #2 (1% by volume in methylene chlorine) was also intermittently used to monitor instrument sensitivity. Drops in sensitivity over time were fitted with an exponential decay that corrected for instrument drifts to within 20% error on average; this uncertainty is somewhat higher (~25%) for the initial pilot period, and somewhat lower (~15%) for the non-pilot samples. For compounds calibrated by authentic standards (BTEXN), this source of uncertainty is expected to dominate other sources of error (e.g., scatter in the calibration curve, which is < 10%), so overall precision and accuracy uncertainties are roughly 20%. For TPH, the use of a surrogate standard (n-C_{14}) in this case is expected to introduce additional uncertainty, overall, uncertainty in precision remains dominated by drifts in instrument sensitivity (20%).

Intermittently, analyzed sampled were re-analyzed to measure carryover between samples, which was found to be negligible except in the case of naphthalene. Blanks and re-analyzed samples showed naphthalene concentrations on the order of 0.5 ug/m^3; the average background was subtracted from reported naphthalene concentrations, but concentrations below 1 ug/m^3 should nevertheless be considered to be near the level of detection.

3. Results

Summary statistics for TPH and BTEXN concentrations in soil gas samples collected in the UST areas of the PVI and NFA Study Sites are presented in **Table 4**. Individual characteristics of the 46 PVI Study Sites are documented in **Tables 5**, **6**, and **7** for cases located in Valley and Ridge, Piedmont, and Coastal Plain Physiographic Regions, respectively. **Table 8** lists individual characteristics of the ten NFA PVI Study Sites. Maximum TPH, benzene, and naphthalene soil vapor concentrations of soil gas samples collected in the UST area of each site are included in Tables 5 through 8. Also included in these tables are site characteristics including building type and details from the Site Characterization Reports such as UST size, time since tank removal, replacement, or clean out. The last column (NAPL) of the tables is designed to indicate if the residence was impacted by oil either penetrating the building or present as free product in monitoring wells located on the property. Site Characterization Reports were the source of this information.

Tables 5 through 8 are located at the end of this section. The Results and Discussion sections will refer to Figures 3 through 22 located at the end of this report. The sites are identified with a letter (V, P, or C) indicating the Valley and Ridge, Piedmont, and Coastal Plain Physiographic Regions, respectively, and a number (e.g., V1, V2, etc.). The sites were numbered in the order by date of the sampling event. No Further Action sites are also identified using a letter (N) and a number. Soil gas sampling was repeated at two sites; one Valley and Ridge (V4) and one Piedmont (P10) to address the question of reproducibility of data. For these cases, the first sampling event was labeled with the letter A and the second event with the letter B (e.g., V4A and V4B).

3.1. Summary of Pilot Study

The pilot study included 21 site visits involving collection of soil gas samples at 15 sites during April through July 2017. Some of the return visits were conducted as training for graduate students in August. Results of the pilot study were summarized in a preliminary project report submitted to DEQ in December 2017 and revised in January 2018. A summary of results of the pilot study were presented to DEQ at the meeting of the Petroleum Program in Richmond on September 19, 2017.

One outcome of the pilot study was the generation of data addressing Secondary Objective 1. TPH concentrations in soil gas ranged over four orders of magnitude. Benzene and ethylbezene were detected above target exterior soil gas concentrations noted in the VISL Calculator (EPA 2015a), 12 and 37 $\mu g/m^3$, respectively, in only a small fraction of samples. Naphthalene was detected more consistently above the target exterior soil gas concentration of 1.8 mg/m^3 (EPA 2015a) in soil gas samples. These results suggested that these constituents could be of significant concern for PVI and potential drivers of risk to human health.

In preparation for field sampling ahead of the pilot study, methods for investigating PVI were compared. Field guidance from a number of state regulatory agencies was reviewed including New Jersey, Hawaii, Arizona and California, and the USEPA. In every case, an exclusive focus was collection of VOC/SVOC soil gas concentrations. There were no requirements for the collection of additional data pertaining to characteristics of the impacted soil (e.g., TOC, soil pH and moisture content). Evaluation of numerous Site Characterization Reports for HHO cases contained no such data. Site-specific hydrogeology or soil profiles were contained in these reports. Results of TPH-DRO concentration of soil samples in the release area or excavation pit were included in all reports.

As a result, data collection at field sites focused on the collection of soil gas samples to address the primary and secondary objectives. The need for a defensible random sampling of HHO cases with a sufficient number of samples to reasonably represent all DEQ Categories within the three major Physiographic Regions of Virginia served as an additional driver for focusing on the collection of soil gas samples, This approach was summarized and presented at the DEQ Petroleum Program meeting in Richmond on September 19, 2017.

3.2. Soil Vapor Concentrations

Table 4 provides the mean, median, and maximum concentrations of TPH and BTEXN in soil gas samples collected in the UST areas. These data include all PVI study sites classified as either Category 1, 2, 3, or NFA cases located in the three major physiographic regions. Pilot study results are not included in Table 4 (see Preliminary Project Report, December 2017). These results do not incorporate the concentrations observed in background samples. A total of 218 soil gas samples were analyzed in the UST areas. The mean number of soil gas samples

collected at each site was 4.7 with a minimum of three samples per site including two samples in the UST area and one background.

TPH concentrations ranged from no detection to a maximum of 687,000 μg/m^3. Approximately 96% of the samples were above detection (100 μg/m^3). TPH concentrations exceeded 140,000 μg/m^3 in the UST areas with proximity to homes (3.3 ft or less) at 1 of 20 Category 2 study sites and 4 of 16 Category 3 study sites[2]. Benzene was the least frequently detected of the BTEXN compounds (38%) compared to the TEXN compounds which were detected in 86% to 93% of samples in the UST areas. Relative to the compound-specific human-health-based risk levels for indoor air, only the maximum concentrations of benzene, ethylbenzene, and naphthalene were significant. However, elevated concentrations of ethylbenzene were only observed at two sites.

Table 4. Summary Statistics for Soil Gas Concentrations of TPH and BTEXN in Soil Gas Samples Collected in UST Areas Across All Heating Oil Categories.

	Soil Gas Concentration (ug/m^3)						
	TPH	Benzene	Toluene	Ethylbenz.	m+p-Xylene	o-Xylene	Naphthalene
Mean	36,551	2.00	96.5	8.63	18.8	12.5	21.6
Median	2,958	0.00	1.57	0.73	1.72	0.87	1.28
Maximum	687,000	68.3	7,877	785	1,514	913	1,094

Overall, these results provided a more complete data set for addressing Secondary Objective 1. Given this outcome and for the purpose of this report, results and discussion will focus on TPH, naphthalene, and benzene. As previously stated, the random sampling of DEQ cases was stratified by incorporating physiographic region and DEQ Category (1 through 3).

[2] Subslab soil gas screening level TPH concentration (140,000 μg/m^3) in Brewer et al. (2013).

The random sampling of NFA cases was treated separately. Therefore, the results are presented in terms of physiographic region and DEQ Category with NFA sampling sites treated as a separate group. Other factors including building type, time between tank removal/clean out and soil gas sampling, documented presence of oil, and other factors will be presented and discussed in the next sections of the report.

3.3. Physiographic Region and DEQ Category

Figures 3, 4, and **5** are box and whisker plots using maximum concentrations of soil gas collected in the UST areas and background concentrations of TPH, naphthalene, and benzene, respectively. For each plot, data are sorted by the three physiographic regions. The aim of these plots is to depict the distribution of data along with the mean and median values. Mean background concentrations of TPH, naphthalene, and benzene were consistently less compared to mean concentrations in the UST area in all three physiographic regions. Median background concentrations of TPH, naphthalene, and benzene were consistently less compared to median concentrations in the UST area with one exception. Coastal Plain sites exhibited the largest background TPH concentrations such the median value was slightly greater than the median TPH concentration in the UST area. This result is thought to reflect several factors. One is the shallow depth to the water table in the Tidewater relative to other regions which necessitated a shallow sampling depth. At a number of sites, background TPH concentrations consisted of monoterpenes which are derived from plants and not a petroleum source. In addition, multiple background samples showed elevated TPH concentrations in soil gas collected at a single Coastal Plain site where monitoring wells indicated the presence of NAPL. Eliminating results from this site, the median background TPH concentration is well below the UST median at Coastal Plain sites.

In general, greater variation of TPH and naphthalene concentrations in the UST areas was observed in the Valley and Ridge and Coastal Plain Physiographic Regions compared to the Piedmont Physiographic Region. Mean TPH and naphthalene concentrations in the UST areas were also greater in the Valley and Ridge and Coastal Plain Physiographic Regions compared to mean TPH and naphthalene concentrations in the Piedmont Physiographic Region. In contrast, the mean benzene concentrations in the UST areas were less in the Valley and Ridge and Coastal Plain Physiographic Regions compared to mean benzene concentration in the Piedmont

Physiographic Region. Median benzene concentrations in the UST areas only showed minor variations between physiographic regions.

Figures 6, 7, and **8** show the range of TPH concentrations by rank in soil gas samples collected in the UST areas located in the Valley and Ridge, Piedmont, and Coastal Plain Physiographic Regions, respectively. The bar graphs are color-coded by DEQ Category. Repeat samples are designated with a pattern fill. The results show TPH concentrations above a threshold of 140,000 $\mu g/m^3$ are limited to four Category 3 sites and Category 2 site. Otherwise, TPH concentrations observed at all other Category 2 sites and all Category 1 sites in the three physiographic regions were relatively low.

Figures 9, 10 and **11** show the range of naphthalene concentrations by rank in soil gas samples collected in the UST areas located in the Valley and Ridge, Piedmont, and Coastal Plain Physiographic Regions, respectively. Soil gas concentrations of naphthalene exceeded the EPA screening level (2.8 $\mu g/m^3$) in the UST areas of every Category 3 site except one, in 6 of 20 Category 2 sites, and 4 of 10 Category 1 sites. Elevated naphthalene concentrations above a threshold of 10.4 $\mu g/m^3$ were observed at seven Category 3 sites, three Category 2 sites, and two Category 1 sites[3]. Brewer et al. (2013) describe the most scientifically-defensible subslab soil gas screening level for naphthalene (72 $\mu g/m^3$). Naphthalene concentrations above 72 $\mu g/m^3$ were observed at one Category 1 site (Piedmont Physiographic Region), two Category 2 sites (Valley and Ridge and Coastal Plain Physiographic Regions), and three Category 3 sites (two Coastal Plain sites and one Piedmont)[4].

Figures 12, 13, and **14** show the range of benzene concentrations by rank in soil gas samples collected in the UST areas located in the Valley and Ridge, Piedmont, and Coastal Plain Physiographic Regions, respectively. Elevated benzene soil gas concentrations above the EPA screening level of 12 $\mu g/m^3$ were only observed at two Category 3 sites; one site located in the Piedmont Physiographic Region and one site located in the Coastal Plain Physiographic Region. No samples exceed the screening level for benzene (310 $\mu g/m^3$) estimated in Brewer et al. (2013).

[3] Subslab soil gas screening level naphthalene concentration (10.4 $\mu g/m^3$) in Lahvis (2018).
[4] Subslab soil gas screening level naphthalene concentration (72 $\mu g/m^3$) in Brewer et al. (2013).

3.4. No Further Action Sites

Figures 15, 16, and **17** show the range of TPH, naphthalene, and benzene concentrations, respectively, by rank in soil gas samples collected in the UST areas measured at NFA sites. Although TPH concentrations were generally low (<16,000 $\mu g/m^3$) and at or below TPH concentrations observed at most Piedmont and Coastal Plain sites, two Piedmont sites exhibited TPH concentrations above a threshold of 140,000 $\mu g/m^3$. An elevated level of naphthalene above a concentration threshold of 2.8 $\mu g/m^3$ was observed at four NFA sites. An elevated naphthalene concentration above a threshold of 10.4 $\mu g/m^3$ was observed at two Piedmont NFA sites, one of which was above the screening level concentration of 72 $\mu g/m^3$. Benzene concentrations at all NFA sites were generally below values observed at other PVI study sites. Benzene and naphthalene were not detected in soil gas samples in the UST areas at seven and four sites, respectively.

Table 5. Valley and Ridge Physiographic Region PVI Study Sites.

Site Characteristics									Sample Adjacent to Dwelling					
											Soil Gas Concentration (ug/m^3)			
ID	Category	Closed? (Y/N)	Building Type[1]	Tank Size (gal)	Fluid Volume Removed (gal)	Tank Removed?	Excavation Depth (ft)	Time[2] (days)	Sample Depth (ft)	Distance from dwelling (ft)	TPH	Benzene	Naphthalene	NAPL[3] (Y/N)
20122308	2	Y	B	550	50	N	N/A	1913	5.5	0.5	311,000	8.3	475	N
20122231	2	Y	B	300	NR	Y	8	1948	5.5	1.0	57,000	2.4	1.4	N
20142338	3	Y	B	550	210	Y	9	1163	5.0	1.0	5,900	5.8	4.97	N
20162264A*	3	Y	B	550	65	Y	8	528	5.3	1.7	123,000	7.7	10.8	Y-B
20162264B*	3	Y	B	550	65	Y	8	549	5.3	1.7	22,000	0	4.08	Y-B
20112079	3	Y	B	550	125	Y	12	2506	5.7	0.8	31,000	1.45	8.04	N
20172038	3	Y	B	1,500	NR	Y	8	401	5.6	0.5	19,000	0	17	N
20122193	2	Y	CS	550	140	Y	9	2060	2.5	1.5	4,800	0	6.74	N
20152413	1	Y	B	550	75	N	N/A	827	6.0	2.0	490	0	0.12	N

NR = Not Reported; N/A = Not Applicable
[1]Building Type: B = Basement; CS = Crawl Space; S = Slab
[2]Time: Time since tank removal or pump out (days)
[3]NAPL: N = No; Y-B = Yes, oil present in building; Y-W = Yes, free product present in monitoring wells
*Indicates the same site (20162264) but two sampling events (A = July 26, 2017 and B = August 16, 2017)

Table 6. Piedmont Physiographic Region PVI Study Sites.

Site Characteristics									Sample Adjacent to Dwelling					
											Soil Gas Concentration (ug/m^3)			
ID	Category	Closed? (Y/N)	Building Type[1]	Tank Size (gal)	Fluid Volume Removed (gal)	Tank Removed?	Excavation Depth (ft)	Time[2] (days)	Sample Depth (ft)	Distance from dwelling (ft)	TPH	Benzene	Naphthalene	NAPL[3] (Y/N)
20152319	2	Y	B	1,000	750	Y	10	869	4.9	5.7	3,900	2.79	0.89	N
20142376	2	Y	B	550	300	Y	13	1190	4.2	1.3	1,600	7.76	0.96	N
20152435	2	Y	B	300	50	Y	10	511	4.9	1.0	1,100	0	1.2	N
20097124	3	Y	B	750	150	Y	10	3087	5.2	1.9	8,900	2.54	3.31	N
20142394	2	Y	B	500	275	Y	15	1227	4.0	5.2	32,000	6.68	2.47	N
20156135	2	Y	CS	550	NR	Y	10	848	0.9	4.1	29,000	4.82	10.0	N
20146061	2	Y	B	550	500	Y	10	1358	5.0	1.2	17,000	2.52	9	N
20156134	1	Y	B	550	28	Y	9	884	5.2	1.6	12,000	1.02	3.3	N
20156059	3	N	B	550	394	Y	10	1022	4.5	4.2	281,000	68.3	BD	Y-B
20163113A*	3	N	B	300	NR	Y	11	669	4.6	0.9	293000	34.8	24.8	Y-W
20163113B*	3	N	B	300	NR	Y	11	724	4.6	0.9	427000	0	77.6	Y-W
20124137	1	Y	B	280	16	N	N/A	2198	2.6	1.0	7300	3.75	1.29	N
20124212	2	Y	B	280	22	Y	8	2110	5.0	4.3	2200	3.45	1.28	N
20144275	2	Y	CS	NR	840	Y	NR	1347	6.0	0.8	252	6.83	0.32	N
20144415	1	Y	B	1,500	NR	N	N/A	1227	3.7	1.0	18000	1.09	1.78	N
20124030	2	Y	B	550	303	Y	9	2208	5.0	1.7	1.9	0.75	1.17	N
20094134	1	Y	B	550	35	N	N/A	3306	6.0	1.2	36000	1.75	104	N
20134061	3	Y	B	550	220	Y	13	1887	3.3	1.5	6700	3.12	14.1	N
20132080	2	Y	B	500	110	Y	12	1852	3.1	2.3	3900	0	1.12	N

20163176	1	Y	CS	1,000	1265	N	N/A	798	4.3	1.0	29000	0	10.8	N
20093071	1	Y	B	NR	NR	N	N/A	3433	3.8	2.2	3200	0	0.79	N
20134244	1	Y	B	550	388	N	N/A	2004	5.1	1.0	4100	0.74	2.08	N
20084740	2	Y	CS	300	50	Y	8	3610	3.7	1.0	23000	5.74	14.1	N
20164303	3	Y	CS	300	280	Y	10	819	4.5	1.5	90000	0	54.5	Y-B

NR = Not Reported; N/A = Not Applicable
[1]Building Type: B = Basement; CS = Crawl Space; S = Slab
[2]Time: Time since tank removal or pump out (days)
[3]NAPL: N = No; Y-B = Yes, oil present in building; Y-W = Yes, free product present in monitoring wells
*Indicates the same site (20163113) but two sampling events (A = October 6, 2017 and B = November 30, 2017)

Table 7. Coastal Plain Physiographic Region PVI Study Sites.

Site Characteristics									Sample Adjacent to Dwelling					
											Soil Gas Concentration (ug/m^3)			
ID	Category	Closed? (Y/N)	Building Type[1]	Tank Size (gal)	Fluid Volume Removed (gal)	Tank Removed?	Excavation Depth (ft)	Time[2] (days)	Sample Depth (ft)	Distance from dwelling (ft)	TPH	Benzene	Naphthalene	NAPL[3] (Y/N)
20153154	2	Y	B	NR	52	N	N/A	921	5.0	1.0	77,000	0	82.2	N
20124298	2	Y	CS	275	NR	Y	13	2146	5.6	1.0	4,000	4.76	2.19	N
20094442	1	Y	CS	550	150	N	N/A	3095	5.3	1.0	986	3.7	2.39	N
20124502	3	Y	CS	500	385	Y	8	2059	5.5	0.9	1,200	0	9.37	Y-W
20144156	2	Y	CS	300	25	Y	8	1588	4.4	1.0	341	0.09	2.76	N
20145107	3	Y	S	1,000	200	Y	7	1528	5.0	30	115,000	6.35	54.8	Y-W
20145049	3	N	S	500	156	Y	6	1623	5.0	3.3	688,000	67.76	1,094	Y-W
20145104	3	N	S	275	96	Y	12	1442	4.7	3.3	431,000	1.06	752	Y-W
20124391	3	Y	B	275	124	Y	6	2918	5.7	4.0	1,600	2.21	9.54	N
20165220	1	Y	CS	550	550	N	N/A	715	2.8	0.9	1,100	0	3.64	N
20135043	3	N	S	500	95	Y	6	1967	4.3	2.5	895	0	4.57	Y-W
20145110	3	N	CS	NR	NR	N	N/A	1590	3.9	1.3	1,400	0	7.47	N
20105157	2	Y	S	275	124	Y	6	2940	3.0	1.3	4,800	0	1.36	N
20145018	2	Y	S	1,000	622	Y	7	1760	5.0	1.0	7,900	0	2.38	N
20105161	2	Y	CS	NR	180	Y	6	2926	4.3	6.8	6,200	0	1.86	N

NR = Not Reported; N/A = Not Applicable
[1]Building Type: B = Basement; CS = Crawl Space; S = Slab
[2]Time = Time since tank removal or pump out (days)
[3]NAPL: N = No; Y-B = Yes, oil present in building; Y-W = Yes, free product present in monitoring wells

Table 8. PVI Study Sites in the No Further Action Category.

Site Characteristics									Sample Adjacent to Dwelling					
											Soil Gas Concentration (ug/m^3)			
ID	Category	Closed? (Y/N)	Building Type[1]	Tank Size (gal)	Fluid Volume Removed (gal)	Tank Removed?	Excavation Depth (ft)	Time[2] (days)	Sample Depth (ft)	Distance from dwelling (ft)	TPH	Benzene	Naphthalene	NAPL[3] (Y/N)
20103153	NFA	Y	B	NR	NR	NR	NR	3102	5.0	1.1	1,100	0	0.83	N
20143080	NFA	Y	CS	550	NR	Y	NR	1688	3.3	1.0	234,000	0	113	N
20123172	NFA	Y	B	550	NR	Y	NR	2260	3.8	0.6	6,400	1.53	13.8	N
20123084	NFA	Y	B	500	NR	NR	NR	2399	4.3	2.0	2,000	0	5.42	N
20175155	NFA	Y	S	NR	NR	N	N/A	556	2.5	7.0	1,500	0	0.77	N
20114435	NFA	Y	S	550	NR	N	N/A	2603	2.7	1.0	5,500	0	0.56	N
20153038	NFA	Y	B	550	NR	N	N/A	1408	3.0	1.6	4,400	1.34	2.36	N
20153028	NFA	Y	CS	550	NR	N	N/A	1415	1.5	1.3	205,000	3.55	0.4	N
20103300	NFA	Y	CS	NR	NR	NR	NR	2963	4.2	0.7	15,000	0	6.66	N
20113081	NFA	Y	B	550	NR	Y	NR	2791	4.0	0.7	9500	0	1.43	N

NR = Not Reported; N/A = Not Applicable
[1]Building Type: B = Basement; CS = Crawl Space; S = Slab
[2]Time = Time since soil sample was collected (days)
[3]NAPL: N = No; Y-B = Yes, oil present in building; Y-W = Yes, free product present in monitoring wells

4. Analysis of Results

4.1. TPH Concentrations and BTEXN Concentrations

Relationships between soil gas composition and key constituents of concern is a subject of on-going research. **Figure 18** is a plot of all TPH concentrations in soil gas collected in the UST areas at all Category 1, 2, 3, or NFA sites versus naphthalene concentrations. Overall, the plot suggests a positive correlation between TPH and naphthalene concentrations. The correlation is weak for naphthalene concentrations ≤ 10 $\mu g/m^3$ but improves from $R^2 = 0.56$ using all data to $R^2 = 0.76$ for naphthalene concentrations greater than 10 $\mu g/m^3$. Scatter plots of TPH and BTEX concentrations using the study data did not reveal any strong correlations. The positive correlation between TPH and naphthalene soil gas concentrations observed in the data is a useful finding for consideration of risk at other sites. For example, these results could be used to estimate naphthalene levels in soil gas after measuring the TPH concentration in a soil gas sample.

4.2. Attenuation Time and TPH Concentrations

For the purpose of this analysis, attenuation time is defined as time (days) between tank removal/clean out and soil gas sampling. The plot of TPH concentration as a function of attenuation time (**Figure 19)** reveals no discernable trend and suggests other factors are more relevant. Further, this operational definition for attenuation time used here may underestimate the duration of time at some sites where the UST was no longer in use and oil was not replenished in close time proximity to tank removal or clean out. Critical unavailable data are the volume or mass or residual oil remaining in the subsurface either in the soil phase (immobile) or present as free product.

4.3. Building Type and TPH Concentrations

Building types in the Valley and Ridge and Piedmont Physiographic Regions were either basements or crawl space (81% and 19%, respectively). Residences in the Coastal Plain Physiographic Region were primarily either slab or crawl space constructed (47% each). This skewed distribution between building type in the Commonwealth reflects a number of factors such as soil type and the year-round shallow water table observed in the Tidewater area of

coastal regions. Compiling data from all sites, there appears to be no relationship between TPH concentrations and building type (**Figure 20**). The concentration ranges and patterns seen in the data for each building type are nearly identical. Similar to attenuation time, there results suggest that other factors are more relevant.

4.4. Impacts of Separate Phase Oil and TPH Concentrations

To assess the relationship between the presence of a separate oil phase and TPH concentrations, plots of TPH concentrations are reconstituted in rank order for each DEQ Category in **Figures 21**, **22**, and **23** (Category 1, 2, and 3, respectively). As shown in **Figure 21**, a wide range of TPH concentrations were observed at Category 1 sites. Unfortunately, there was no clear trend between the TPH concentrations and site variables including TPH soil concentrations or volume of fluid removed from the tank. Only one tank was replaced at the 12 Category 1 sites investigated. Otherwise, the original tanks were decommissioned below ground. It may useful to reiterate that soil gas samples were typically collected between buildings and decommissioned USTs at Category 1 sites. The positioning of soil gas probes adjacent to residences was designed to identify the potential for PVI and was not necessarily designed to measure TPH and BTEXN concentrations in oil-contaminated soil that may be present below decommissioned USTs at these Category 1 sites.

A plot of TPH concentrations Category 2 sites (**Figures 22**) confirms previously-stated results that TPH levels at these sites are relatively low. In contrast to the Category 1 sites, all of the Category 2 sites had USTs removed. Unlike Category 3 sites, Category 2 should not be impacted by the presence of residual oil in the subsurface. The relatively low TPH concentrations confirms this assumption.

Figure 23 indicates that while elevated TPH concentrations were not observed at all Category 3 cases, the majority of sites that experienced impacts to groundwater or where oil directly penetrated into or below residences are associated with the largest TPH vapor concentrations. Three of the six sites impacted by a separate oil phase or free product on the water table showed TPH concentrations above 140,000 $\mu g/m^3$ including one Piedmont site. In all three cases the water table was relatively shallow placing the free product in proximity to the soil probes. Only one of four sites where oil had previously impacted either the basement or crawl space showed TPH concentrations at or above 140,000 $\mu g/m^3$.

4.5. Analysis of Risk and Primary Objective

Models for PVI risk, including the EPA VISL Calculator, are based on a back-calculated soil gas concentration that is the ratio of the indoor air goal and the attenuation factor (AF) (Brewer et al. 2013). The AF can differ between models, reflecting selection and estimated Indoor Air Exchange Rate and Contaminant Mass Flux Rate. The greater the AF, the larger the screening level concentration (i.e., less conservative). Brewer et al. (2013) utilized the AF value used by the state of Hawaii (0.001) which results in larger, less conservative soil gas screening levels compared to the EPA VISL method. As a result, the subslab soil gas screening level for the common model for PVI is indirectly proportional to the AF.

As previously noted, the VISL Calculator (EPA 2015a) provides target soil gas concentrations for BTEXN compounds based on a soil vapor-to-indoor air AF of 0.03. Brewer et al. (2013) published example subslab soil gas screening levels for BTEXN compounds and C5-C8 aliphatic, C9-C18 aliphatic, and C9-C16 aromatic carbon ranges based on a target excess cancer risk of 10^{-6} and a target Hazard Quotient of 1.0 and an AF of 0.001. Brewer et al. (2013) presented example indoor air and soil vapor screening levels for TPH based on default carbon range compositions for gasolines and middle distillates. Lahvis (2018) recently published a summary of soil gas data from petroleum sites with a particular focus on vertical screening distances for TPH and naphthalene.

Independent of the sensitivity of screening levels to the AF, a significant complicating factor is the applicability of the standard PVI conceptual model to the home heating oil problem. The standard PVI conceptual model assumes the subslab soil gas and subsequent flux is uniform and beneath the entire slab of the residence. In the case of home heating oil, only a small fraction of HHO cases have either a light non-aqueous phase liquid (LNAPL) of oil on the water table or dissolved petroleum hydrocarbon compounds in groundwater present beneath the slab. Instead, HHO cases are typified by residual soil contamination adjacent to the dwelling. In the vast majority of cases, even with measureable levels of TPH and BTEXN, the soil gas is predisposed to diffuse vertically upward to the atmosphere and less likely to penetrate the residence through lateral migration. In addition, the proximity of the spill to the atmosphere is beneficial to enhance aerobic biodegradation through a resupply of oxygen from the atmosphere.

As a result, current models for calculating PVI risk are applicable to only a few HHO cases. The one exception is sites where a residual LNAPL is confirmed to be present in monitoring well screened at the water table. For these cases, the vertical distance between the building slab and the LNAPL is a critical factor is assessing PVI risk. Based on the results of an extensive field study of soil gas concentrations at petroleum sites, Lahvis (2018) reported vertical screening distances for naphthalene are generally <3 ft compared to 15 ft for gasoline-derived LNAPL sources where BTEX is the risk driver. However, Lahvis (2018) also concluded that vertical screening distances for TPH generally exceed 15 ft. Although the sampling locations relative to building slab and depth of samples were not provided, this study lends support to PVI risk for LNAPL sites.

5. Summary of Findings and Recommendations

Secondary Objective 1. TPH and naphthalene appear as the only contaminants of concern for the potential for PVI. Results of this study suggest a positive correlation between TPH and naphthalene soil gas concentrations particularly when elevated concentrations of naphthalene are present (>10 $\mu g/m^3$). Overall, risk levels of benzene and ethylbenzene are a subject of concern at only a few sites. Detectable levels of toluene, m+p-xylene, and o-xylene were present in soil gas samples but not at concentrations that constitute a risk to human health when evaluating health-based risk by individual constituents. In terms of frequency of cases with elevated TPH concentrations in soil gas samples (>140,000 $\mu g/m^3$), just under 10% of the cases investigated showed evidence for potential for PVI based on the conventional model for vapor intrusion through the building slab.

Secondary Objective 2. No one single factor appears to be an indicator of elevated TPH and naphthalene in soil gas in the former UST area. Several factors have been identified and are summarized below. With the exception of Coastal Plain sites, particularly in the Tidewater area of Virginia, the influence of physiographic region was not clearly delineated in the results. Compared to physiographic region, DEQ Category appears to be a stronger indicator for the potential for elevated soil gas concentrations. In particular, Category 3 cases located in the Tidewater area of the Coastal Plain with LNAPL present are indicative of sites where potential PVI is the greatest concern.

Two of the ten NFA cases (20%) showed elevated TPH concentrations in soil gas samples (>140,000 μg/m^3). One of these two NFA cases, showed elevated naphthalene in soil gas in the former UST area (>72 μg/m^3). The two NFA cases were located in the Piedmont. One UST was removed by the owner (20143080) at a site with no indications of a release. For the other case (20153028) the UST had to be close in place due to site conditions. TPH and naphthalene concentrations in soil gas samples at the remaining eight sites were relatively low compared to results of the Category-based study sites. However, the low sample size is problematic to draw adequate conclusions. The low sample size was due to the low response rate from homeowners contacted at NFA sites. Another complicating factor was the limited documentation associated with NFA cases, resulting in considerable uncertainty about the location of the former UST area and any action taken to address the spill.

Primary Objective. Screening-level risk levels are ill-defined for target exterior soil gas concentrations. Although indoor air concentrations are available for the calculation of carcinogenic risk, the risk of exterior soil gas adjacent to the home is dependent on an assumed attenuation factor, which is operationally-defined as the ratio of indoor air concentration and soil gas concentration of any compound. For example, the VISL Calculator (EPA 2015a) employs an attenuation factor of 0.030. An attenuation factor of 0.030 implies an acceptable exterior soil gas concentration 33 times greater than the interior risk-based concentration. Because attenuation factors must be estimated or assumed, the findings in this report are not based on absolute concentration levels for TPH or BTEXN. Instead, we are focusing findings and recommendations relative to characteristics of sites where TPH and naphthalene concentrations are elevated and may pose a potential for PVI and subsequently the potential for risk to human health. However, we make no presumption on or calculation of risk in this report.

The following is a summary of key findings and recommendations:

5.1. **Free Product in Groundwater (Category 3).** Shallow water table conditions prevalent in the Tidewater area or elsewhere combined with free product present in monitoring wells are an indicator for the potential for PVI. Further, results suggest this combination is not limited to the Tidewater area as evidenced by high vapor phase TPH concentrations at a Piedmont site with impacted groundwater and a shallow water table.

Recommendation 1: Inventory Category 3 sites where monitoring wells have been installed and free product has been observed. Direct environmental consultants to confirm the absence or presence of free product. At sites where free product is present and within an unacceptable distance from the residence (<6 ft) conduct soil gas surveys to determine the potential for PVI including sub-slab sampling.

5.2. **Poor Correlation between Soil Vapor Concentrations with Reported TPH Concentrations in Soil Samples.** The presence of elevated soil gas concentrations indicated residual contamination remains in the former UST areas. However, there was no apparent correlation between soil vapor concentrations obtained in this investigations and the TPH concentrations in soil documented in Site Characterization Reports. For the latter this includes both TPH soil concentrations of pre-remediation samples and samples collected in conjunction with removal of USTs. This outcome likely reflects inherent heterogeneity in the distribution of released oil in soil in proximity to former USTs.

Recommendation 2: Consider a more consistent approach to collection of soil samples prior to and during UST removal and how TPH concentrations in soils are factored into decision-making at new cases. In particular, collecting samples to determine the level of petroleum (i.e., TPH) in potentially impacted soils during excavation and the removal of USTs and surrounding soil may be beneficial in assessing the potential for PVI and the effectiveness of remediation.

The following is recommended for further study:

5.3. **Potential Impacts to Indoor Air Quality.** Although the objectives of this study were achieved, the penetration of petroleum vapors into homes and the potential impact to indoor air quality should be further examined. While it is possible that attenuation of vapors is preventing such impacts, the results of this study demonstrate soil gas concentrations above TPH and naphthalene screening levels if site-specific attenuation factors are insufficient.

Recommendation 3: It would be prudent to collect and analyze sub-slab and side-slab samples combined with indoor air samples at a subset of study sites. Specifically, sub-slab and side-slab samples would be collected prior to removal of USTs of a Category 2

and 3 sites to evaluate potential impacts before and after remediation. Because indoor air studies are complicated by VOC sources inside homes, collection of sub-slab and side-slab samples would provide more compelling answers to the question of PVI risk.

Although this recommendation is likely beyond the scope of DEQ to consider for further study, advances in technology should be integrated where possible to address PVI potential. For example:

5.4. **Improved understanding of petroleum vapor attenuation.** A well-established attenuation mechanism at petroleum-contaminated sites is biodegradation. Resources and time are an inhibitor for a broad study, but the presence of an active and robust population of BTEXN-degrading bacteria may be the best indicator of protection of human health in the soil adjacent to homes.

Recommendation 4: Using novel but cost-effective microbial tools, evaluate microbial biomarkers in soil from a subset of sites evaluated in this study. This may prove to be the most important and useful moving forward to prevent potential PVI and for the protection of human health.

6. References

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7. Figures

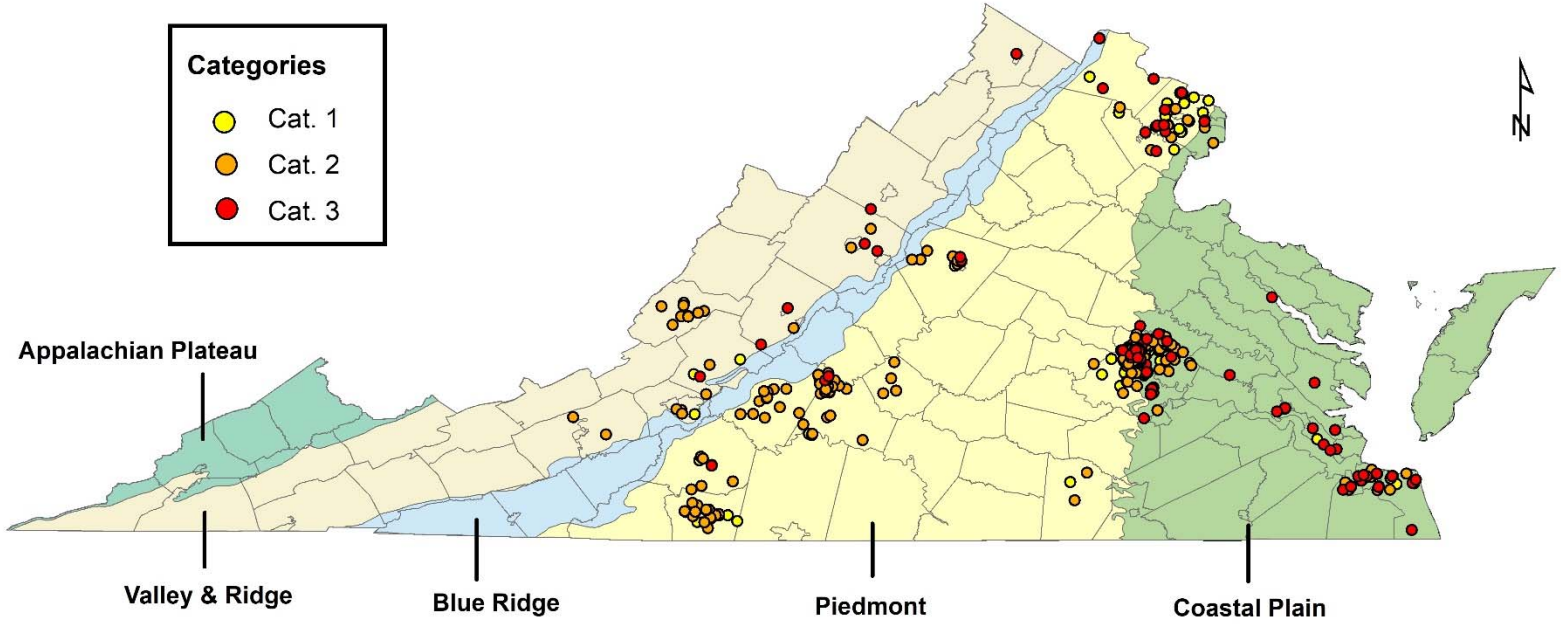


Figure 1. Distribution of Residential DEQ Home Heating Oil Cases Selected Through Random Sampling ($N = 400$).

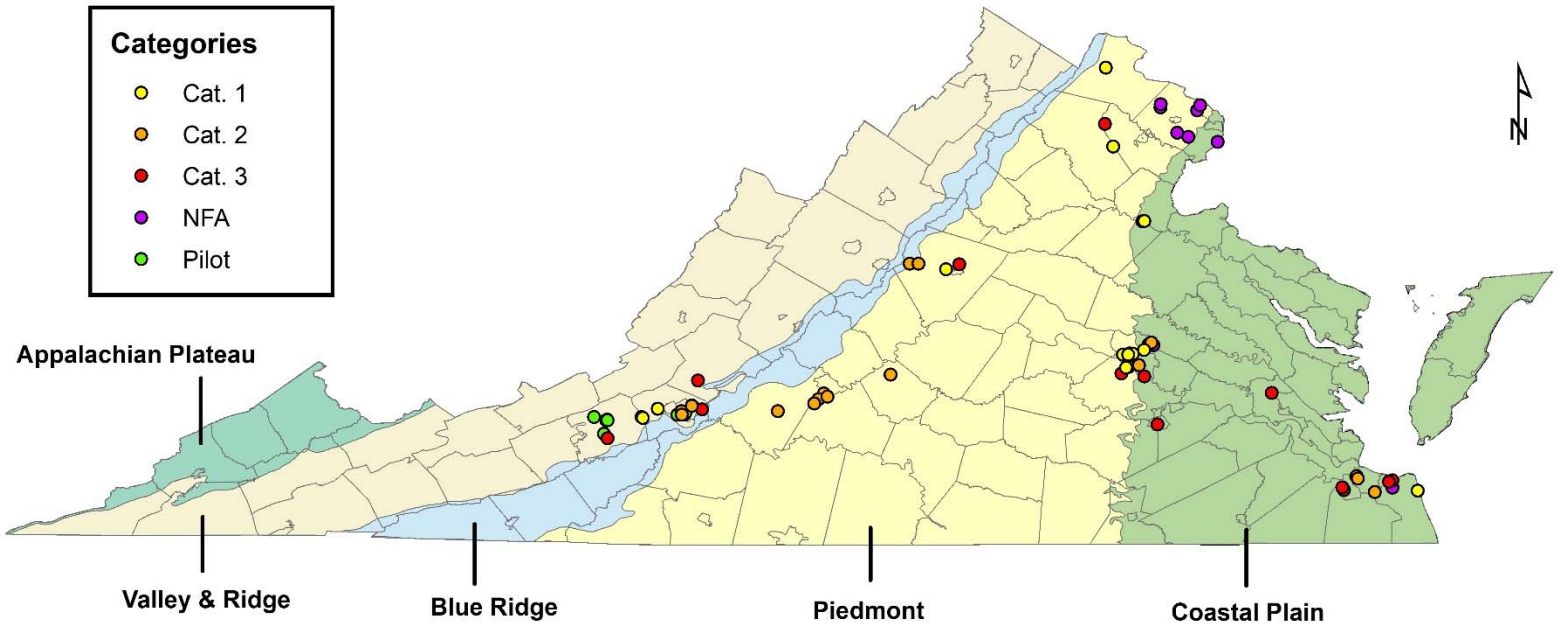


Figure 2. Distribution of Petroleum Vapor Intrusion Study Sites by DEQ Category. NFA refers to the category No Further Action. Pilot refers to the pilot study conducted at sites located in Montgomery and Roanoke Counties.

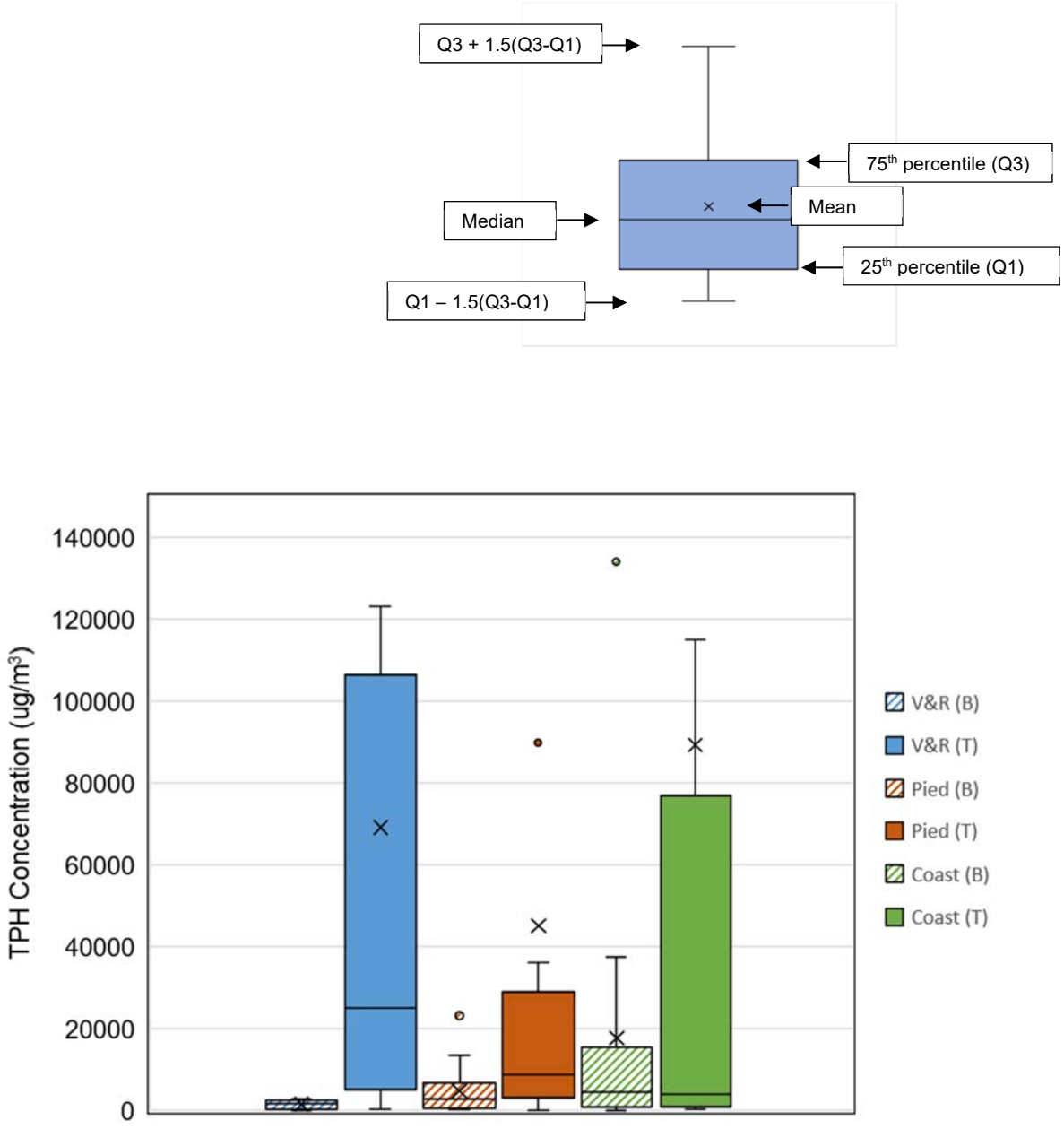


Figure 3. Box plots of soil gas TPH concentrations sorted by the three major physiographic regions of samples collected at soil gas probes located in UST areas and samples collected in background locations. V&R = Valley and Ridge. Pied = Piedmont. Coast = Coastal Plain. B = Background. T = UST area. Off-scale values are 311,000 (Valley and Ridge – Tank), 293,000 (Piedmont – Tank), 427,000 (Piedmont – Tank), 431,000 (Coastal – Tank), and 688,000 (Coastal – Tank).

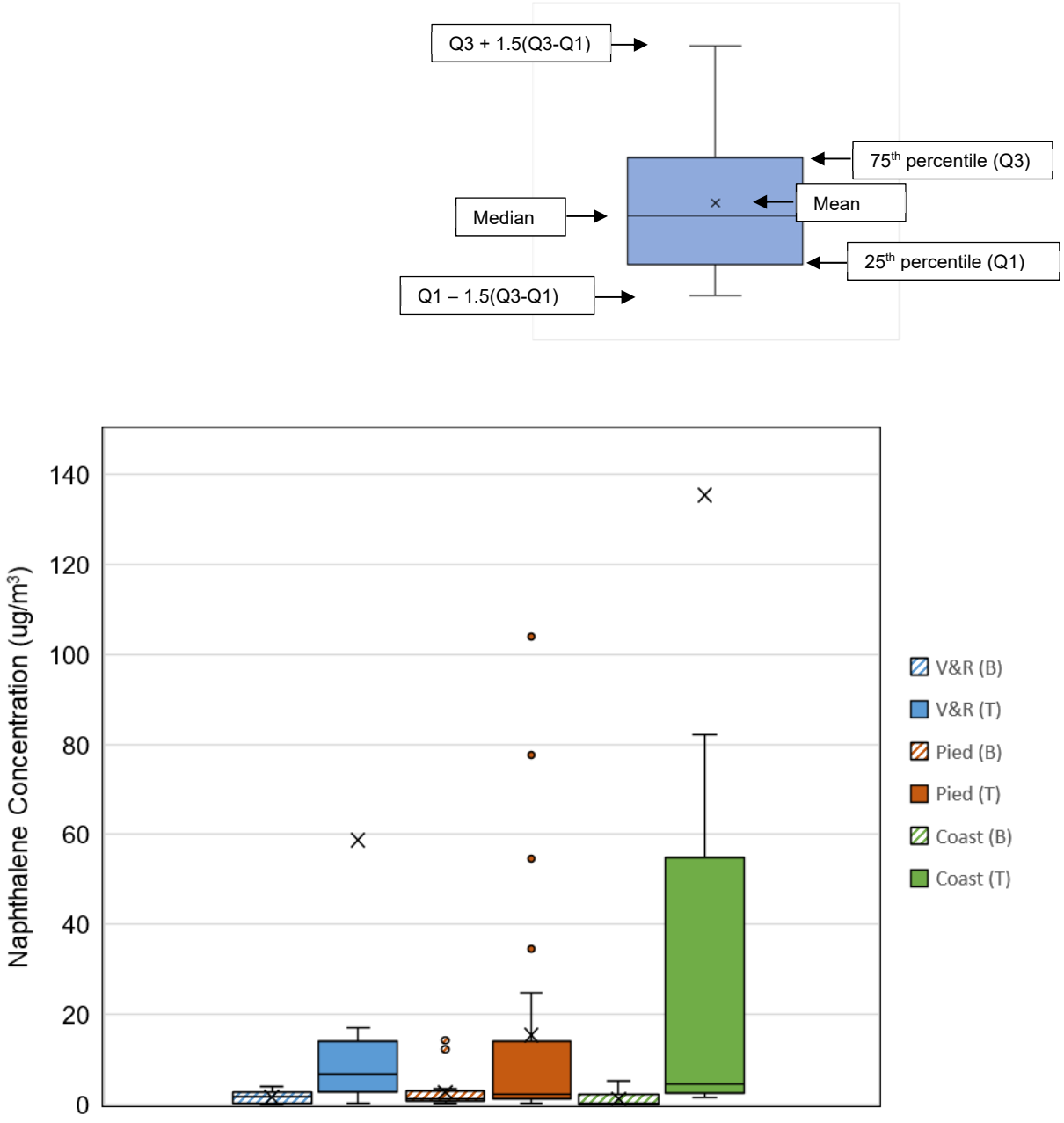


Figure 4. Box plots of soil gas naphthalene concentrations sorted by the three major physiographic regions of samples collected at soil gas probes located in UST areas and samples collected in background locations. V&R = Valley and Ridge. Pied = Piedmont. Coast = Coastal Plain. B = Background. T = UST area. Off-scale values are 475 (Valley and Ridge – Tank), 752 (Coastal – Tank), and 1,094 (Coastal – Tank).

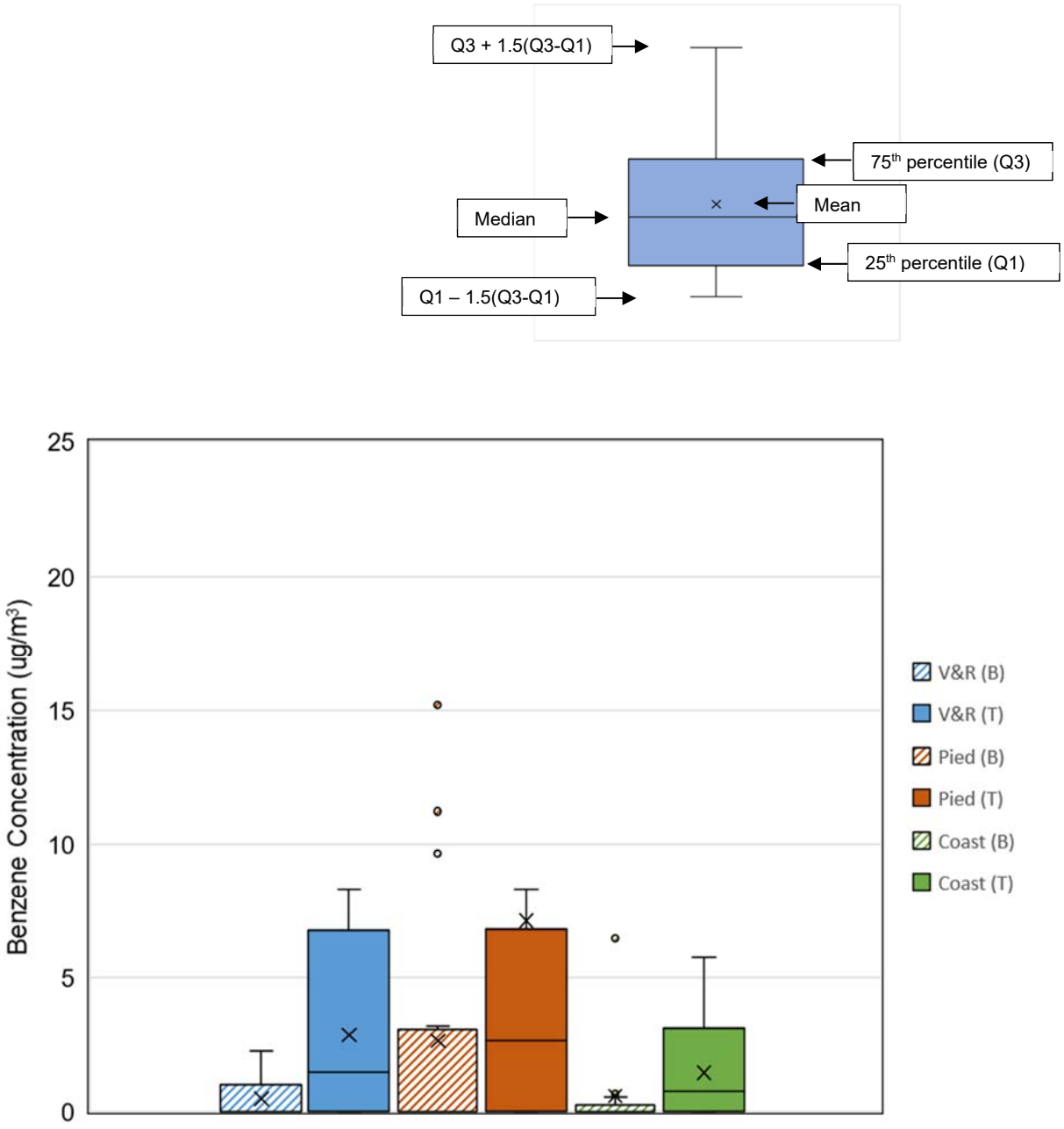


Figure 5. Box plots of soil gas benzene concentrations sorted by the three major physiographic regions of samples collected at soil gas probes located in UST areas and samples collected in background locations. V&R = Valley and Ridge. Pied = Piedmont. Coast = Coastal Plain. B = Background. T = UST area. Off-scale values are 34.8 (Piedmont – Tank) and 68.3 (Piedmont – Tank).

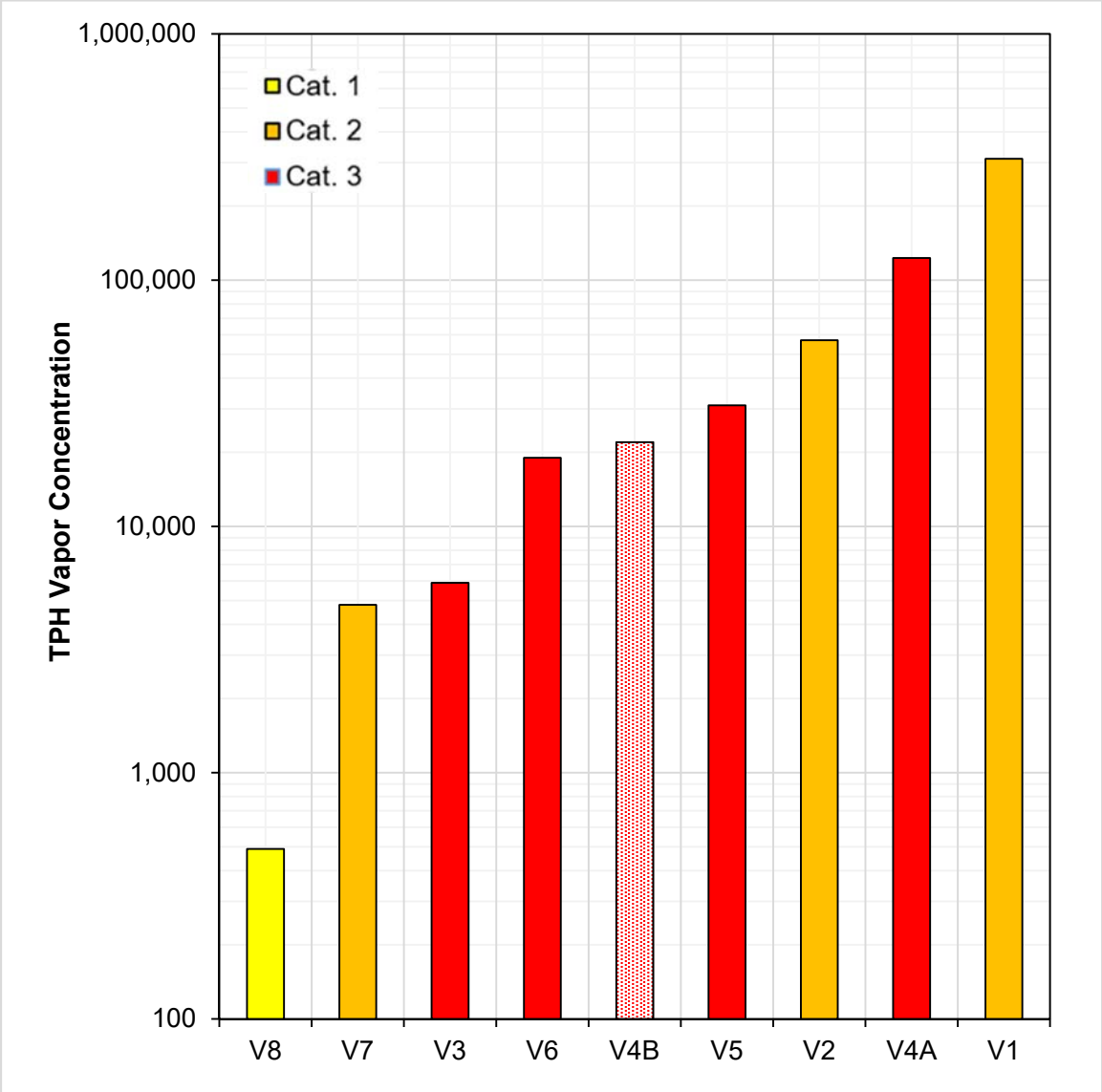


Figure 6. Range of TPH concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Valley & Ridge physiographic region. Repeat samples (V4A and V4B) were collected during two separate site trips at Site V4.

ID Case	#
V1	20122308
V2	20122231
V3	20142338
V4	20162264

ID Case	#
V5	20112079
V6	20172038
V7	20122193
V8	20152413

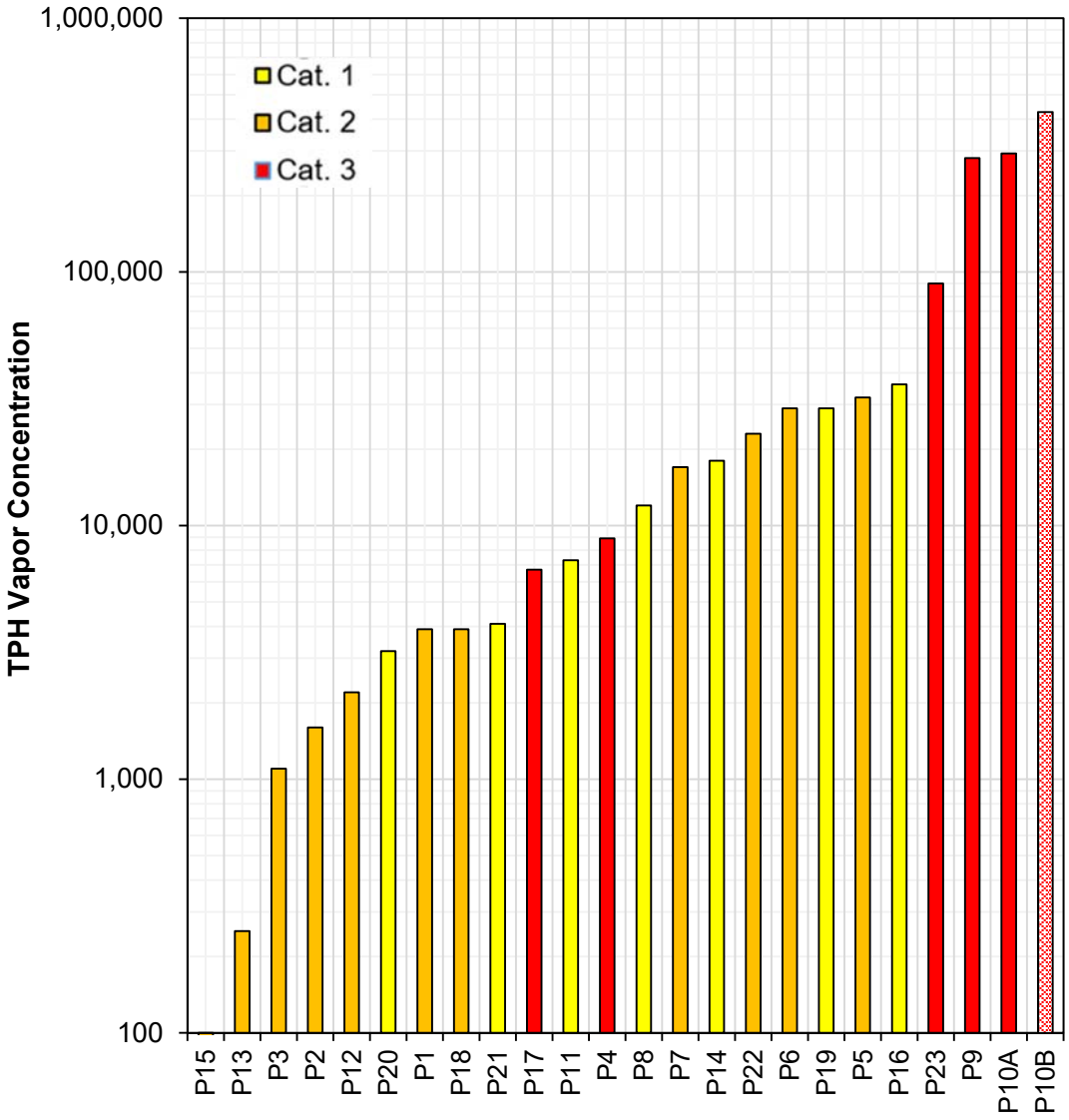


Figure 7. Range of TPH concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Piedmont physiographic region. Repeat samples (P10A and P10B) were collected during two separate site trips at Site P10.

ID Case	#
P1	20152319
P2	20142376
P3	20152435
P4	20097124
P5	20142394
P6	20156135

ID Case	#
P7	20146061
P8	20156134
P9	20156059
P10	20163113
P11	20124137
P12	20124212

ID	Case #
P13	20144275
P14	20144415
P15	20124030
P16	20094134
P17	20134061
P18	20132080

ID	Case #
P19	20163176
P20	20093071
P21	20134244
P22	20084740
P23	20164303

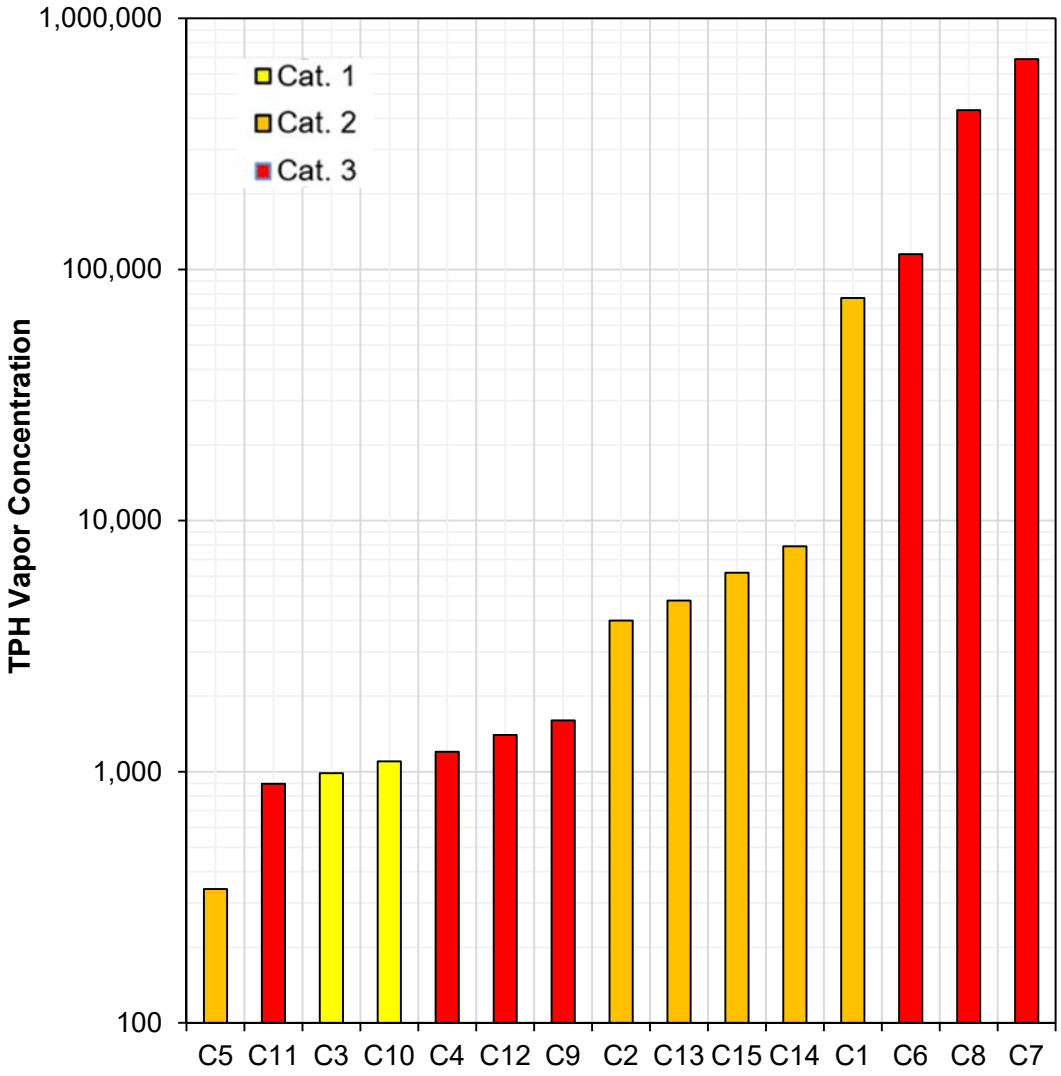


Figure 8. Range of TPH concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Coastal Plain physiographic region.

ID Case	#
C1	20153154
C2	20124298
C3	20094442
C4	20124502
C5	20144156

ID Case	#
C6	20145107
C7	20145049
C8	20145104
C9	20124391
C10	20165220

ID	Case #
C11	20135043
C12	20145110
C13	20105157
C14	20145018
C15	20105161

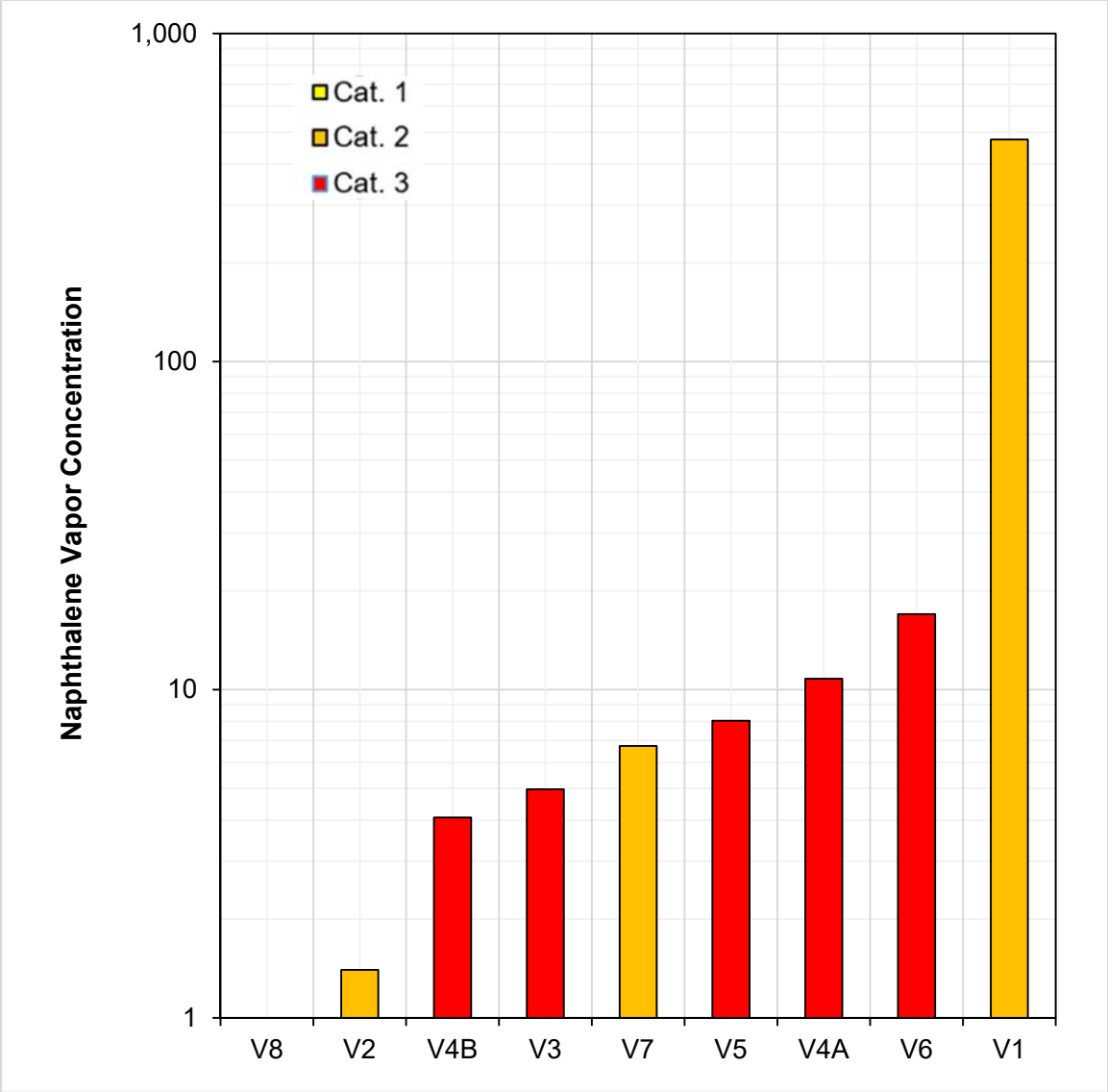


Figure 9. Range of naphthalene concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Valley & Ridge physiographic region. Repeat samples (V4A and V4B) were collected during two separate site trips at Site V4.

ID Case	#
V1	20122308
V2	20122231
V3	20142338
V4	20162264

ID Case	#
V5	20112079
V6	20172038
V7	20122193
V8	20152413

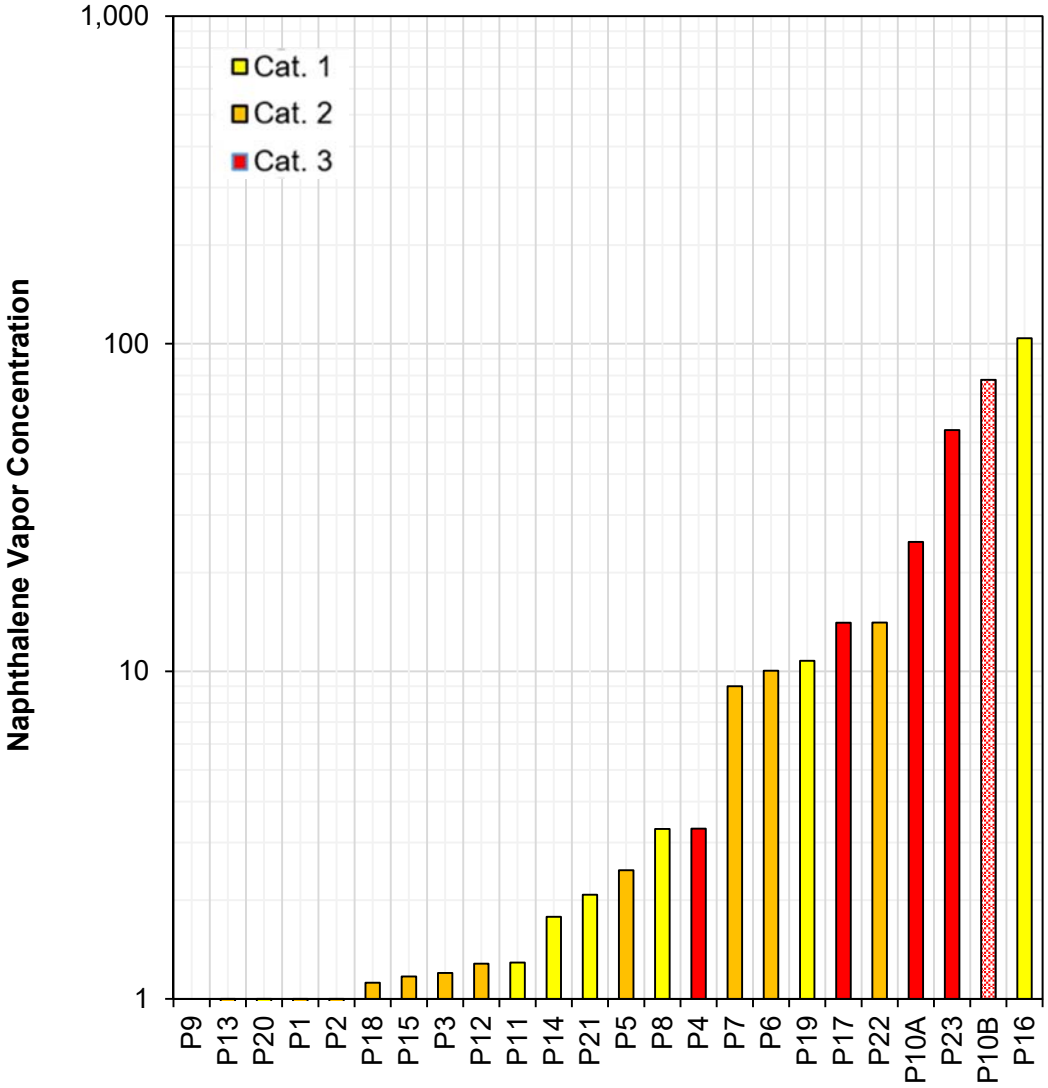


Figure 10. Range of naphthalene concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Piedmont physiographic region. Repeat samples (P10A and P10B) were collected during two separate site trips at Site P10.

ID Case	#
P1	20152319
P2	20142376
P3	20152435
P4	20097124
P5	20142394
P6	20156135

ID Case	#
P7	20146061
P8	20156134
P9	20156059
P10	20163113
P11	20124137
P12	20124212

ID	Case #
P13	20144275
P14	20144415
P15	20124030
P16	20094134
P17	20134061
P18	20132080

ID	Case #
P19	20163176
P20	20093071
P21	20134244
P22	20084740
P23	20164303

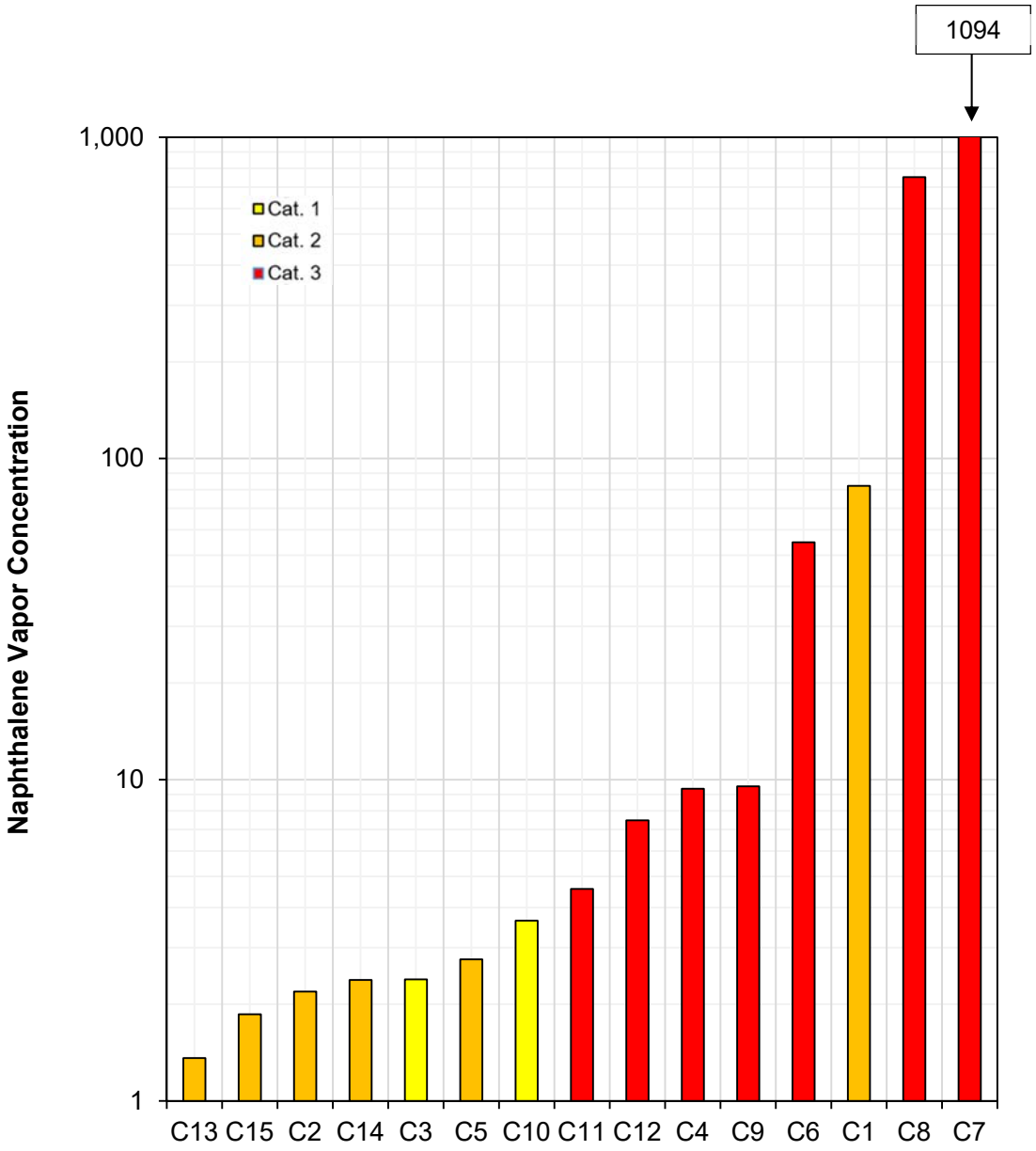


Figure 11. Range of naphthalene concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Coastal Plain physiographic region.

ID Case	#
C1	20153154
C2	20124298
C3	20094442
C4	20124502
C5	20144156

ID Case	#
C6	20145107
C7	20145049
C8	20145104
C9	20124391
C10	20165220

ID	Case #
C11	20135043
C12	20145110
C13	20105157
C14	20145018
C15	20105161

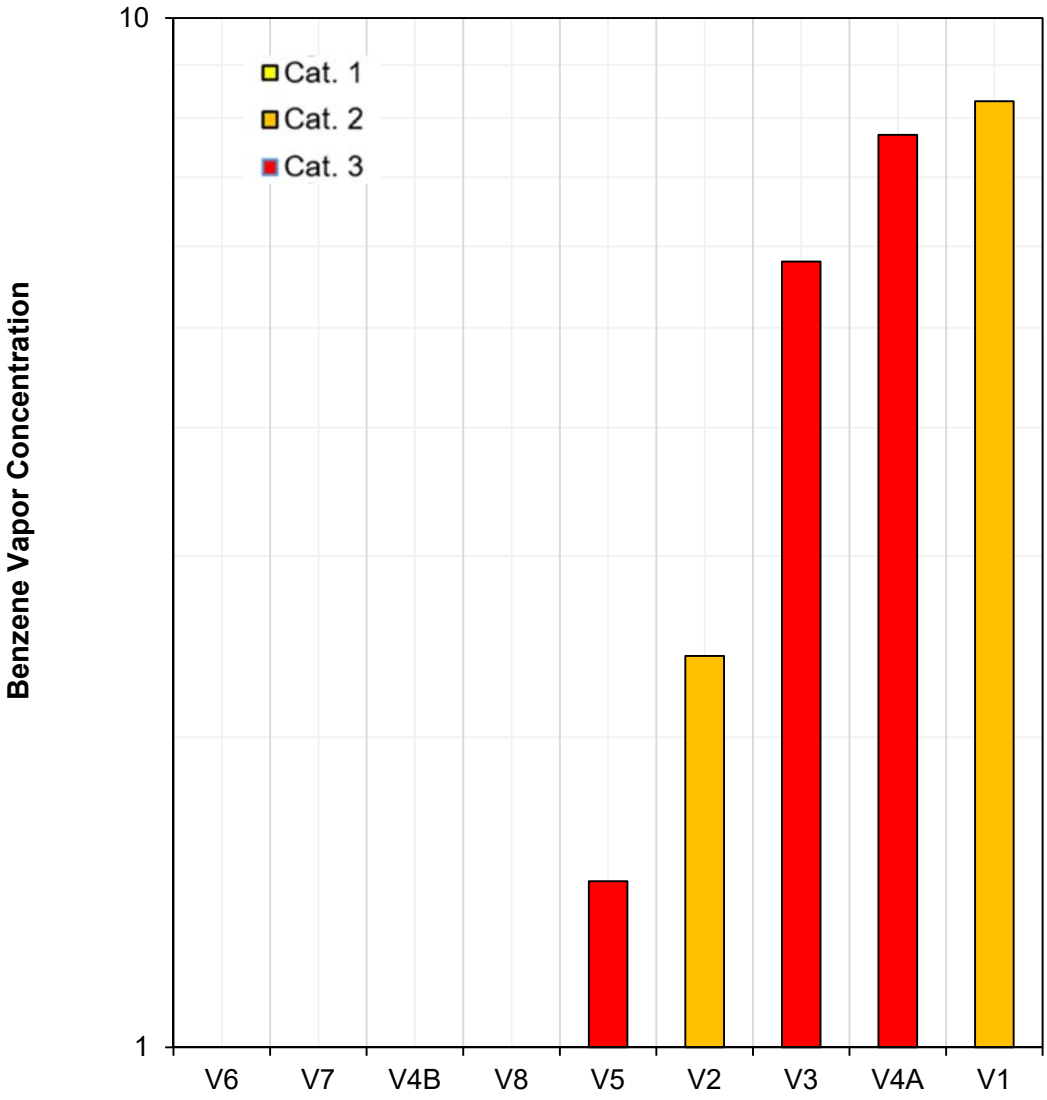


Figure 12. Range of benzene concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Valley & Ridge physiographic region. Repeat samples (V4A and V4B) were collected during two separate site trips at Site V4.

ID Case	#
V1	20122308
V2	20122231
V3	20142338
V4	20162264

ID Case	#
V5	20112079
V6	20172038
V7	20122193
V8	20152413

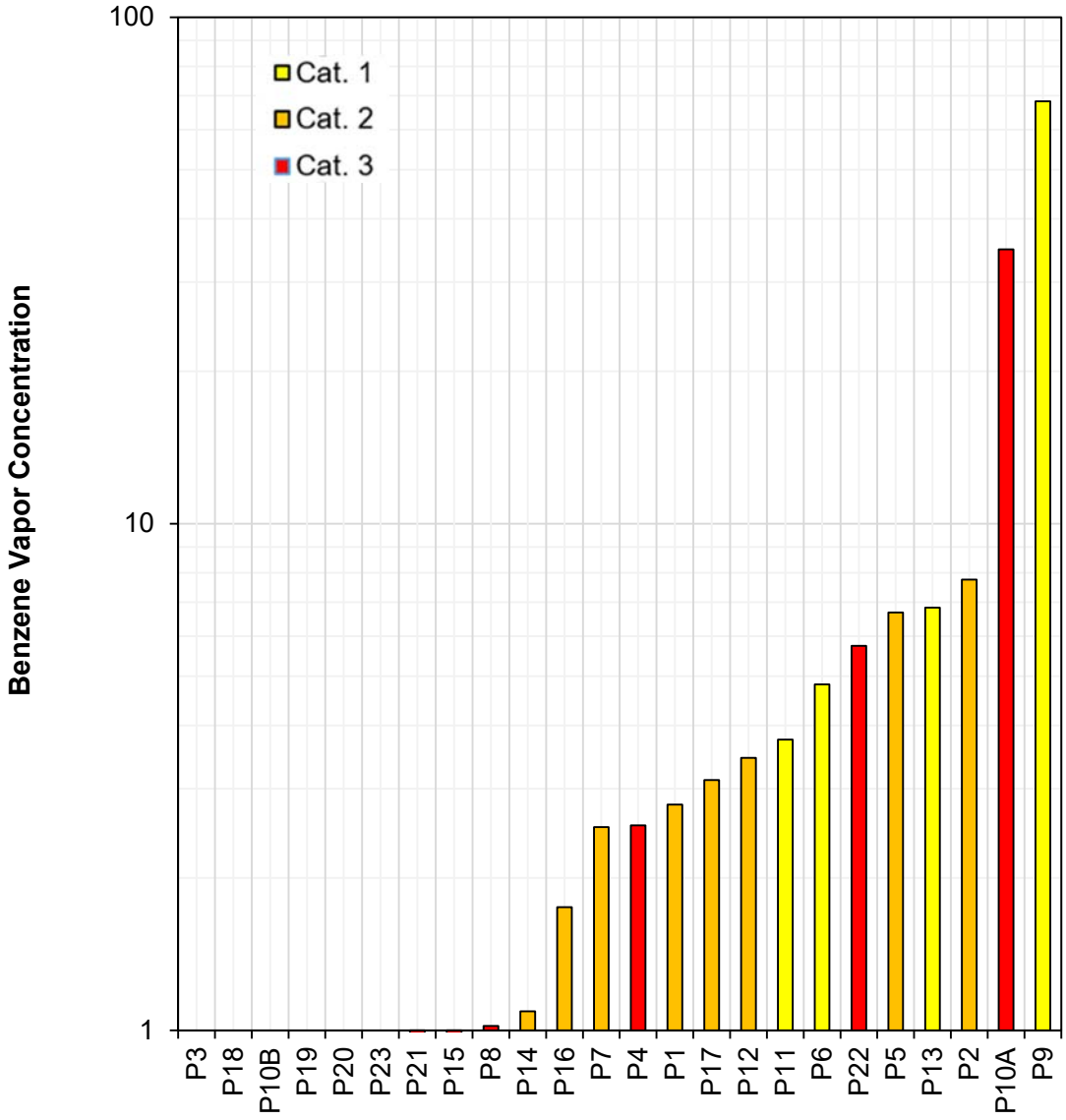


Figure 13. Range of benzene concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Piedmont physiographic region. Repeat samples (P10A and P10B) were collected during two separate site trips at Site P10.

ID Case	#
P1	20152319
P2	20142376
P3	20152435
P4	20097124
P5	20142394
P6	20156135

ID Case	#
P7	20146061
P8	20156134
P9	20156059
P10	20163113
P11	20124137
P12	20124212

ID	Case #
P13	20144275
P14	20144415
P15	20124030
P16	20094134
P17	20134061
P18	20132080

ID	Case #
P19	20163176
P20	20093071
P21	20134244
P22	20084740
P23	20164303

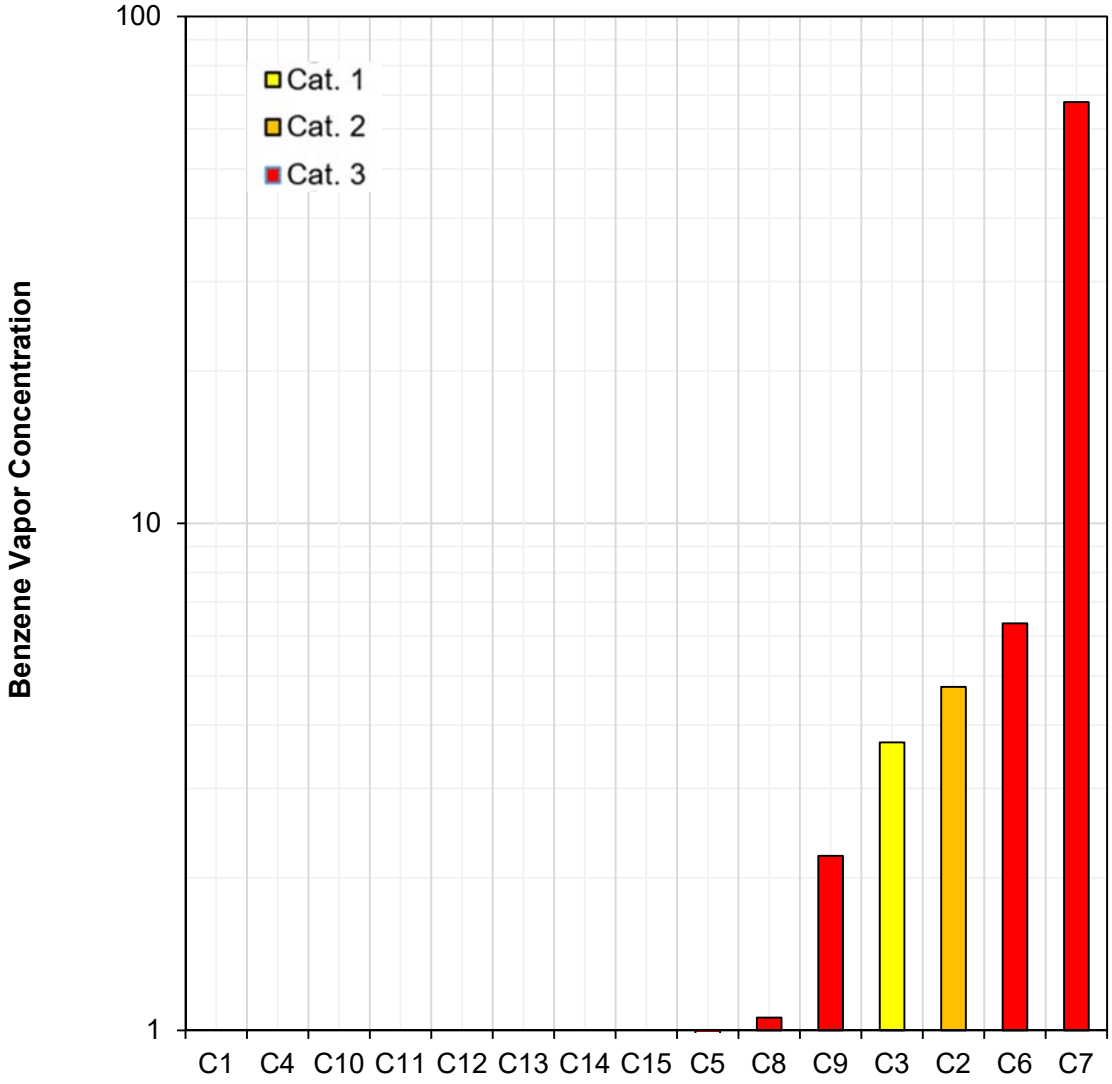


Figure 14. Range of benzene concentrations (µg/m^3) in soil gas collected in the UST Area at sites located in the Coastal Plain physiographic region.

ID Case	#
C1	20153154
C2	20124298
C3	20094442
C4	20124502
C5	20144156

ID Case	#
C6	20145107
C7	20145049
C8	20145104
C9	20124391
C10	20165220

ID	Case #
C11	20135043
C12	20145110
C13	20105157
C14	20145018
C15	20105161

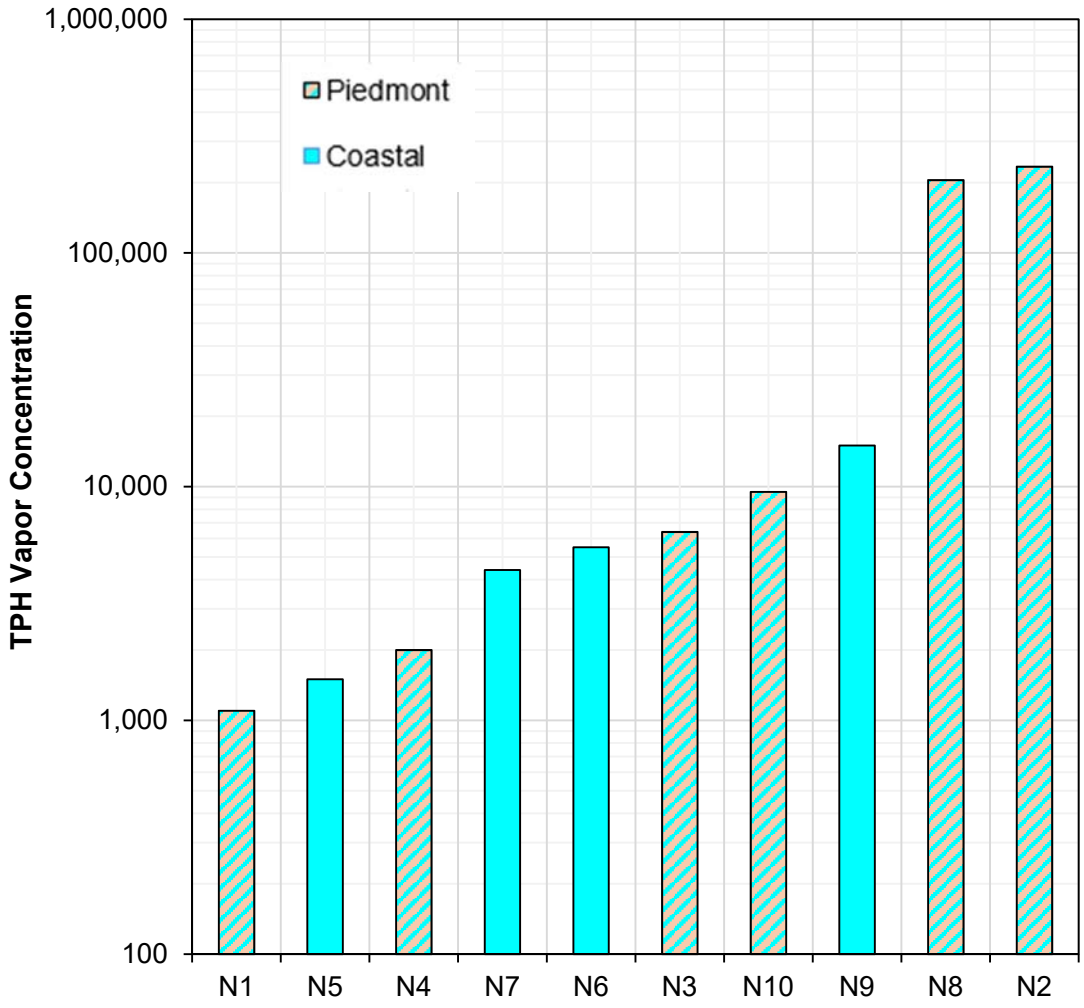


Figure 15. Range of TPH concentrations (µg/m^3) in soil gas collected in the UST Area at No Further Action sites sorted by physiographic region.

ID Case	#
N1	20103153
N2	20143080
N3	20123172
N4	20123084
N5	20175155

ID Case	#
N6	20114435
N7	20153038
N8	20153028
N9	20103300
N10	20113081

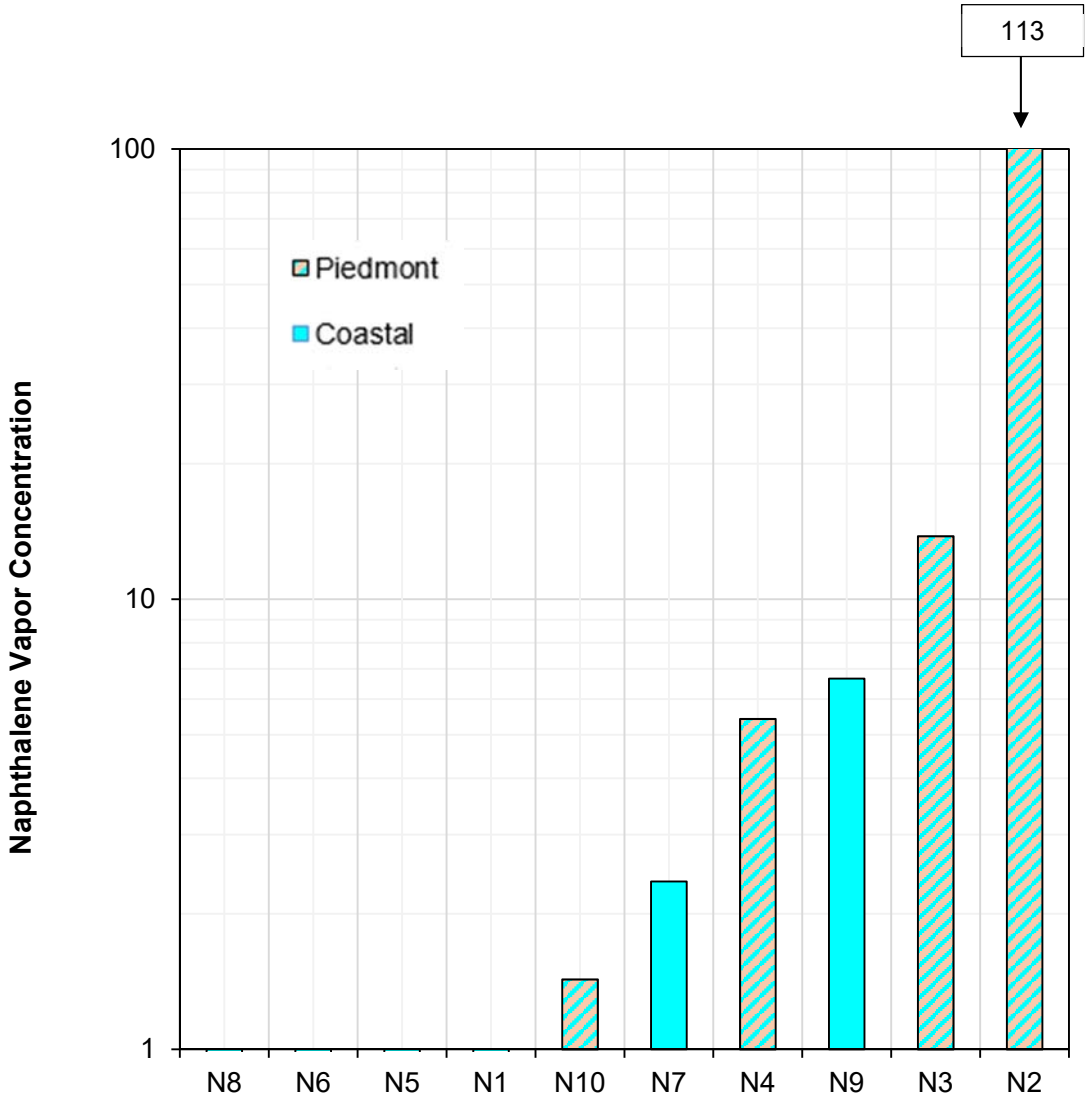


Figure 16. Range of naphthalene concentrations (µg/m^3) in soil gas collected in the UST Area at No Further Action sites sorted by physiographic region.

ID Case	#
N1	20103153
N2	20143080
N3	20123172
N4	20123084
N5	20175155

ID	Case #
N6	20114435
N7	20153038
N8	20153028
N9	20103300
N10	20113081

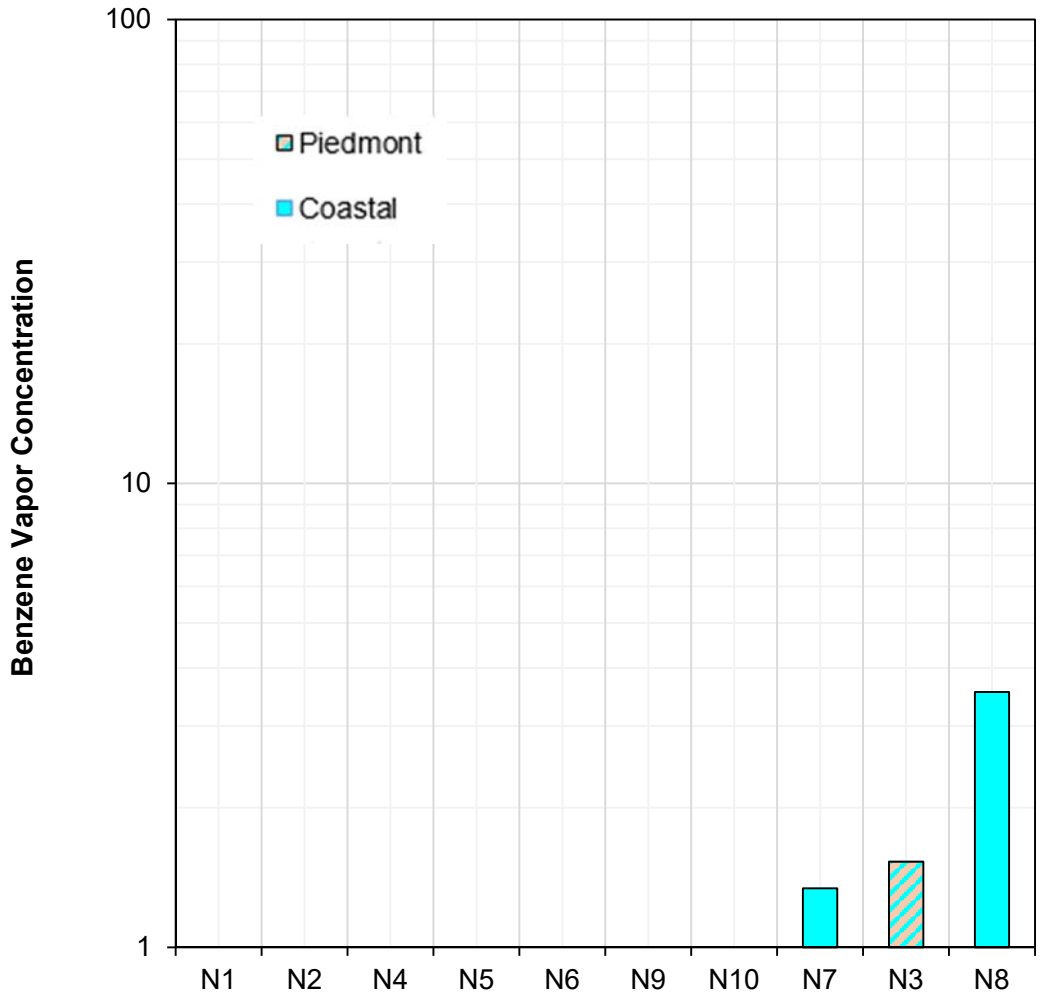


Figure 17. Range of benzene concentrations (µg/m^3) in soil gas collected in the UST Area at No Further Action sites sorted by physiographic region.

ID Case	#
N1	20103153
N2	20143080
N3	20123172
N4	20123084
N5	20175155

ID	Case #
N6	20114435
N7	20153038
N8	20153028
N9	20103300
N10	20113081

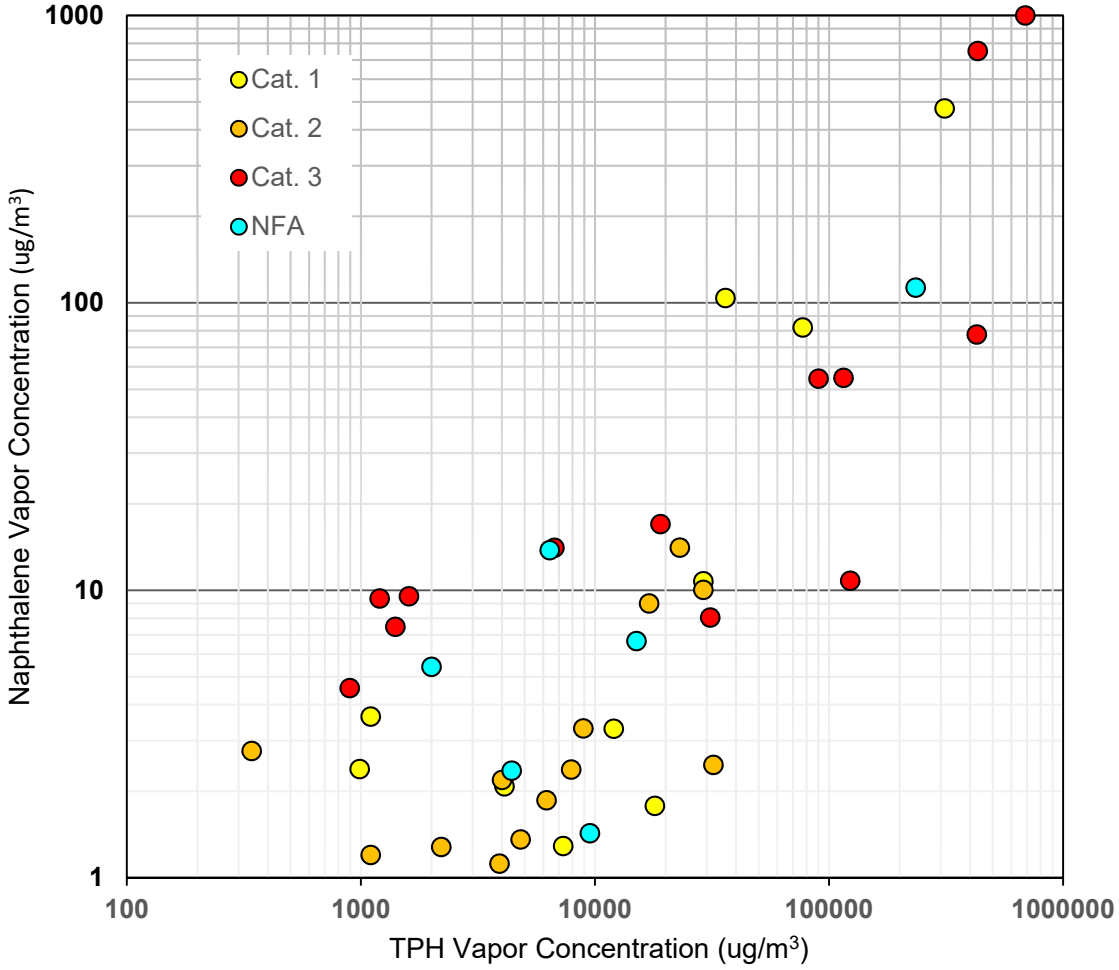


Figure 18. Comparison of TPH and naphthalene concentrations in soil gas collected in the UST Area sorted by DEQ category.

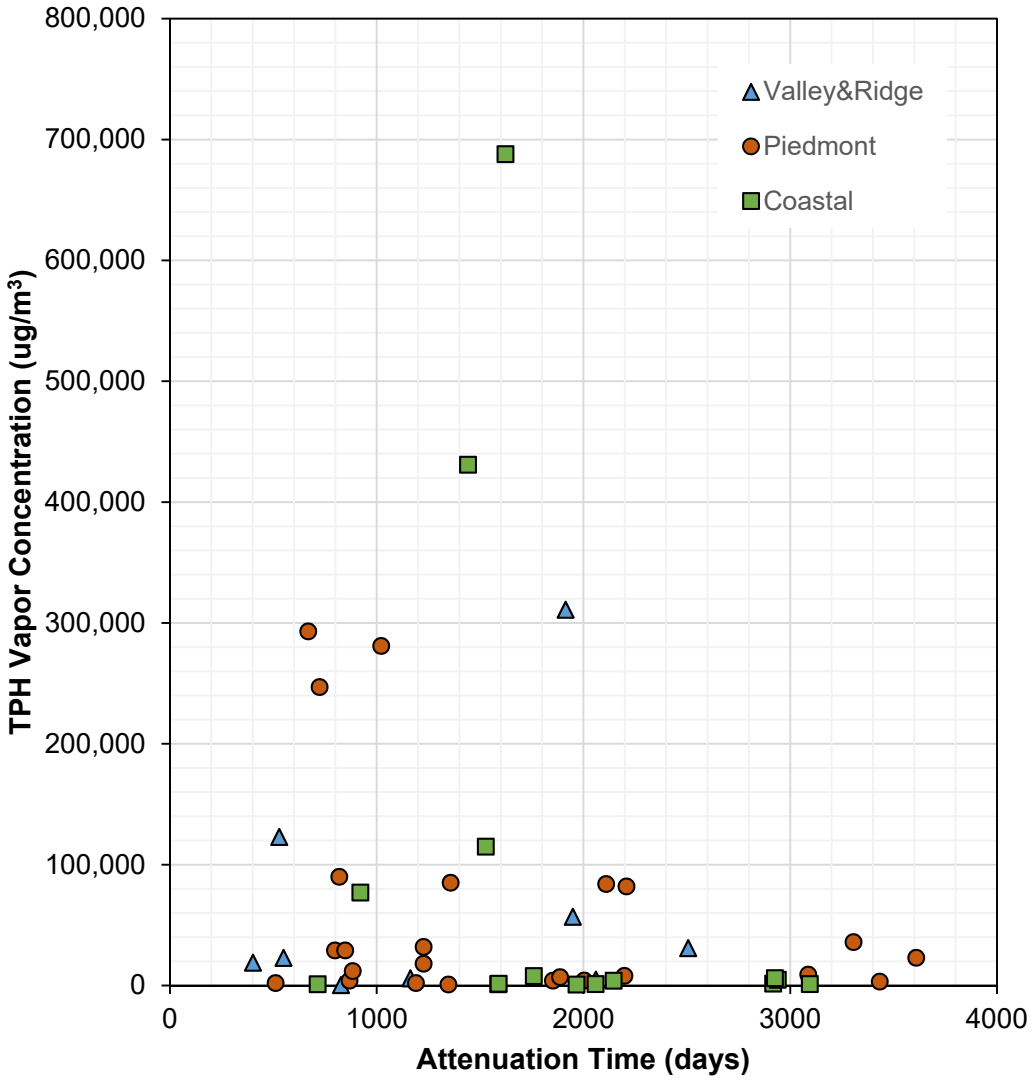


Figure 19. TPH concentrations in soil gas collected in the UST Area sorted by the three major physiographic regions as function of attenuation time, defined as the time (days) between when the UST was either removed, replaced, or cleaned out and when soil gas samples were collected.

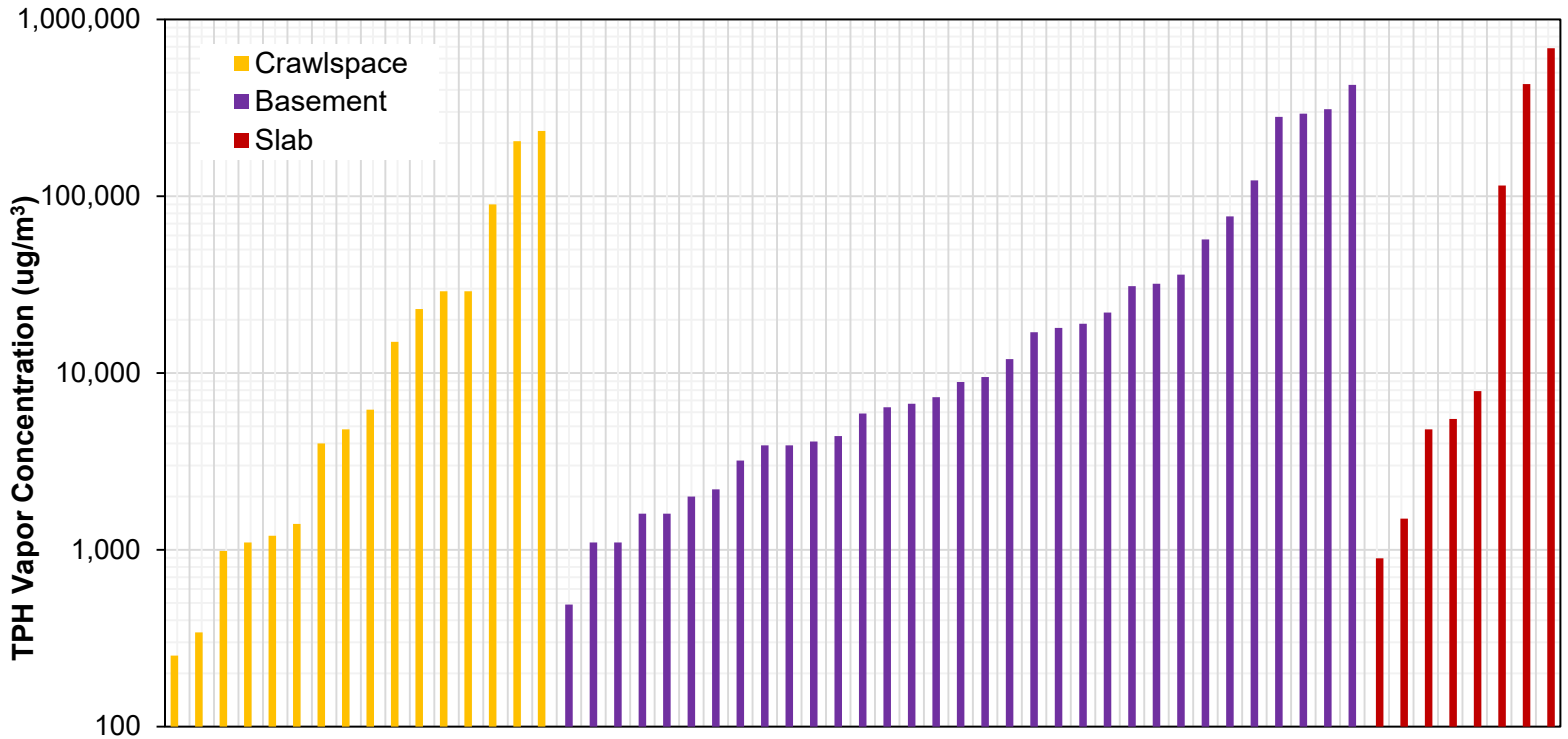


Figure 20. TPH concentrations (µg/m^3) in soil gas collected in the UST Area sorted by building type.

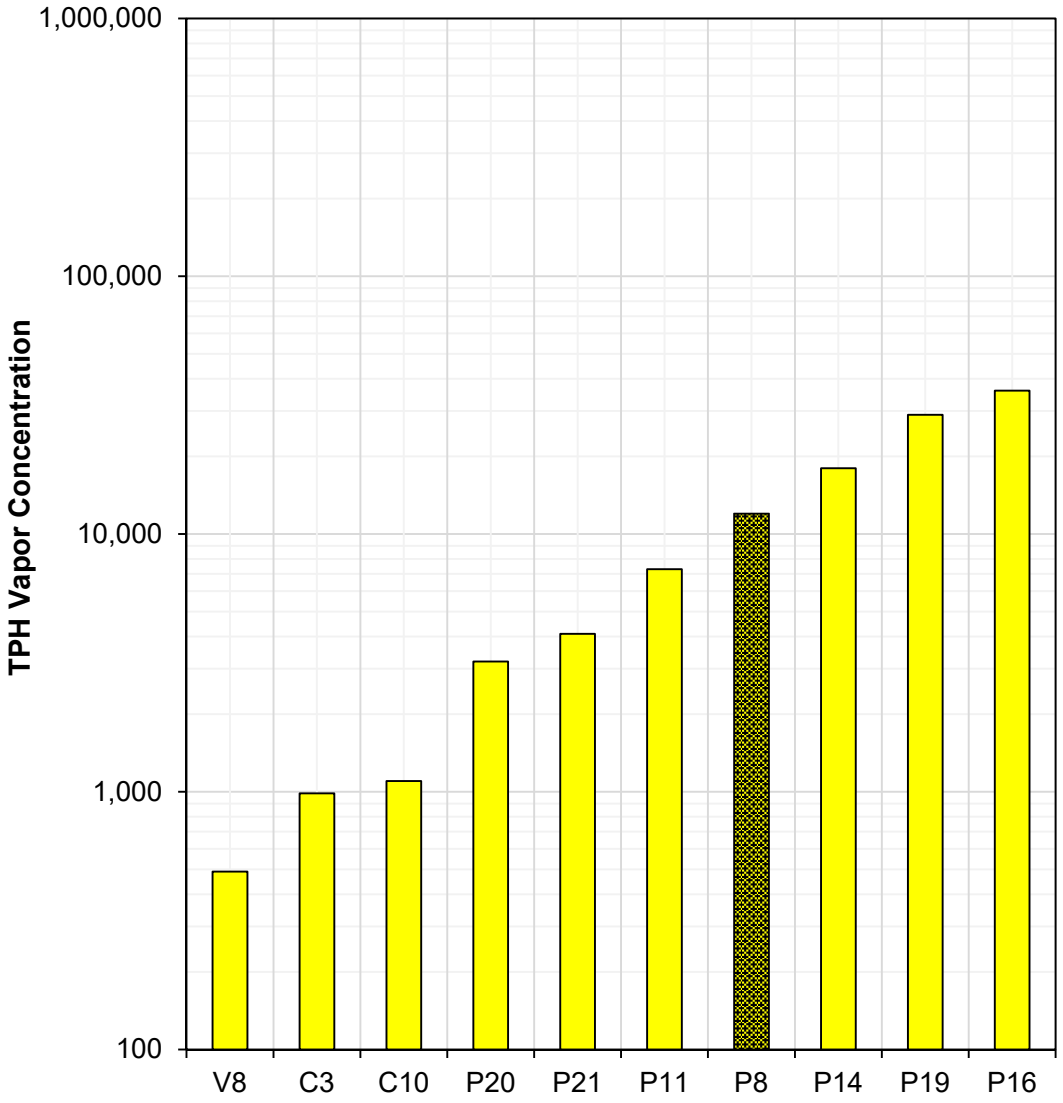


Figure 21. TPH concentrations (µg/m^3) in soil gas collected in the UST Area at Category 1 sites. The UST at Site P8 was replaced. Otherwise, USTs were not removed and were cleaned out at each of the remaining sites.

ID Case	#
V8	20152413
C3	20094442
C10	20165220
P20	20093071
P21	20134244

ID Case	#
P11	20124137
P8	20156134
P14	20144415
P19	20163176
P16	20094134

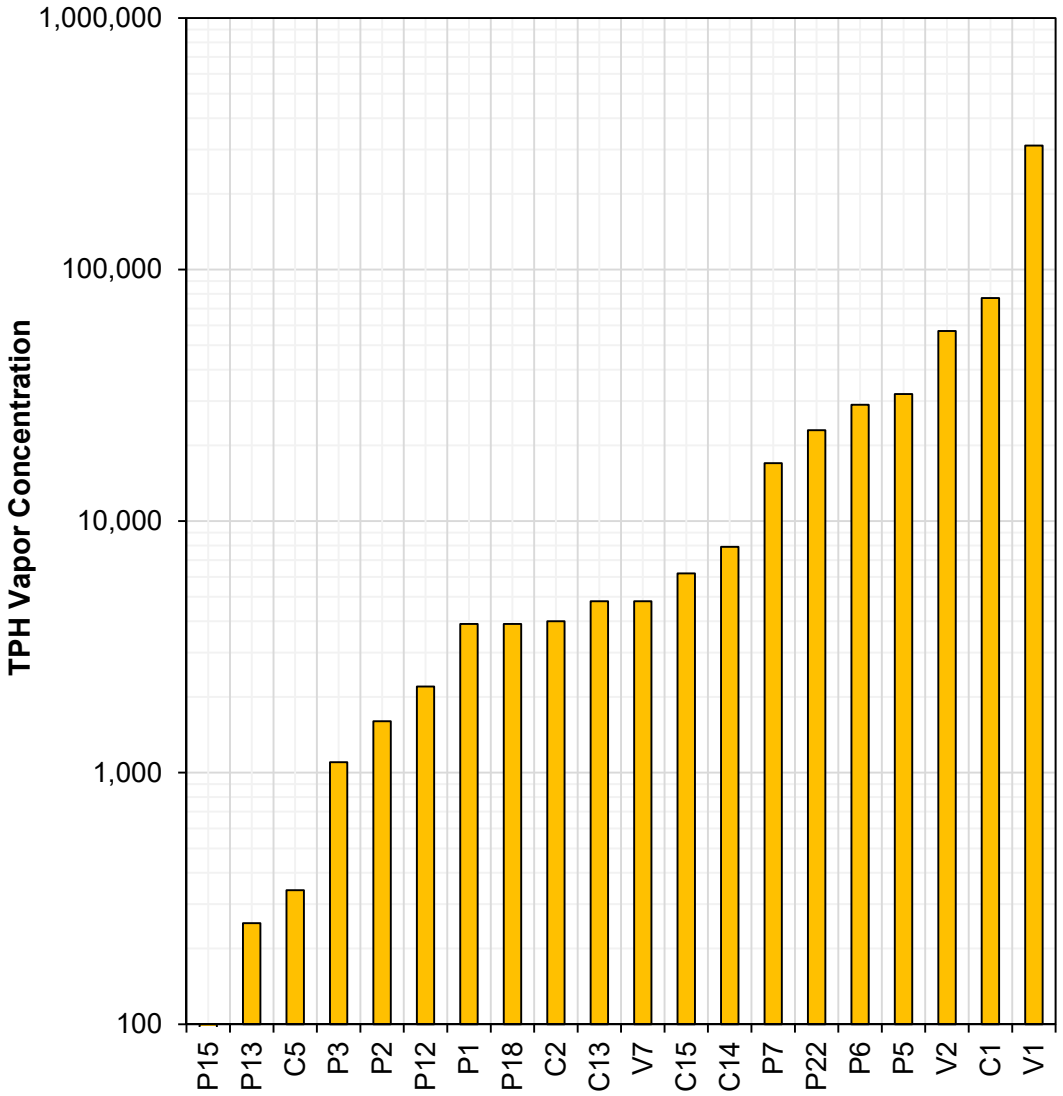


Figure 22. TPH concentrations (µg/m^3) in soil gas collected in the UST Area at Category 2 sites. USTs were removed at each site.

ID Case	#
P15	20124030
P13	20144275
C5	20144156
P3	20152435
P2	20142376
P12	20124212
P1	20152319

ID Case	#
P18	20132080
C2	20124298
C13	20105157
V7	20122193
C15	20105161
C14	20145018
P7	20146061

ID	Case #
P22	20084740
P6	20156135
P5	20142394
V2	20122231
C1	20153154
V1	20122308

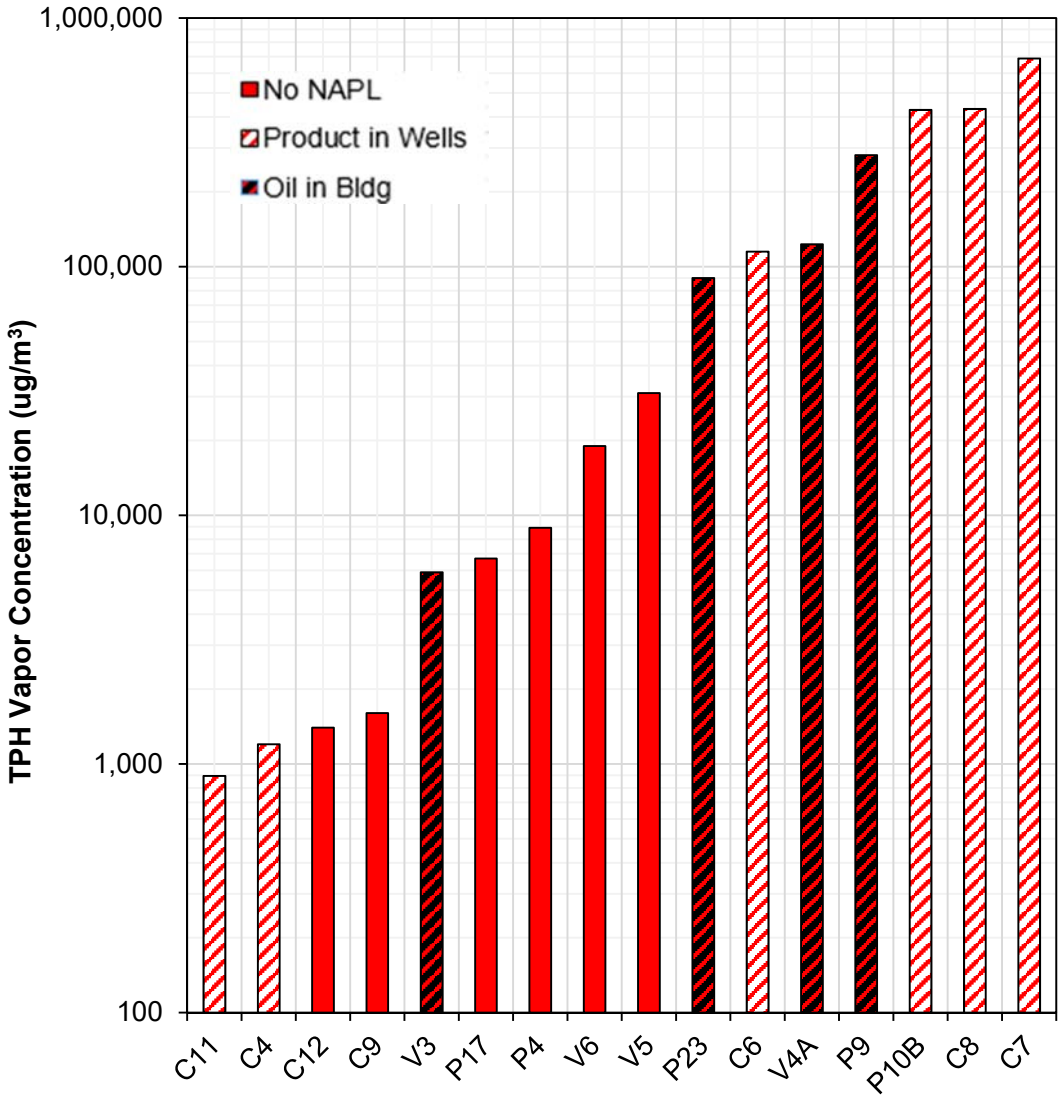


Figure 23. TPH concentrations (µg/m^3) in soil gas collected in the UST Area at Category 3 sites. USTs were removed at each site.

ID Case	#
C11	20135043
C4	20124502
C12	20145110
C9	20124391
V3	20142338
P17	20134061
P4	20097124
V6	20172038

ID Case	#
V5	20112079
P23	20164303
C6	20145107
V4	20162264
P9	20156059
P10	20163113
C8	20145104
C7	20145049

Appendix

6'-9.5"
3'-12"

Soil Vapor Site Log

Case #	2012-2308
Address	3542 Evelyn Drive Salem
Category	1
Date	8/16/2017
Time	3:30 pm
Weather	~~8888~~, 90°F, 45%H

Max TPH-DRO	
ID	
Concentration	
Depth	

Site Sketch

Sample ID	Tube ID	Depth (ft)	Q (cc/min)		Start Time	End Time	Pump #	Tube #	
3542-3-6	B28278	5'5"	100		4:29	4:44	4	4	*
(2) 3542-4-6	B25322	5'5"		7.5	3:53	4:23	4	4	*
(1) 3542-5-6	B25334	5'2"		7.8	4:01	4:33	5	7	
3542-6-6	B284165	"	100		4:01	4:33	3	3	

People present	MAW AW ERW
Additional Notes	*Sampled single stream- 4th pump died Andrew ran into something while drilling- may have been tank. Equipment now coated.

Soil Vapor Site Log

Case #	2012-2231
Address	2527 Memorial Ave Roanoke, VA
Category	2
Date	8/16/2017
Time	1:30 pm
Weather	88°, 48%, cloudy

Site Sketch

Max TPH-DRO	
ID	
Concentration	
Depth	

Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time	Pump #	Tube #
(2) 2527-1-6	B28426	5'4"	37 / 7.3	1:43	2:13	3	3
2527-5-6	B25311	5'4"	~100 / 7.3	1:43	"	5	7
(3) 2527-6-6	B28455	4'6"	42 / 7.9	1:55	1:25	7	7
2527-7-6	B28411	4'6"	100	1:55	"	4	4
(1) 2527-8-6	B29705	out 2'4"	44 / 7.4	2:24	2:54	5	7
2527-9-6	B25358		100	2:24	2:54	3	3

People present	
Additional Notes	HOW LONG IS SS RODS? 2'4's are 6'8"

* Pump cut off @ unknown time. Pumped an extra 10 min.

Soil Vapor Site Log

Case #	2014-2338
Address	2720 Mansfield Roanoke
Category	2
Date	8/16/2017
Time	11:15 am
Weather	87°F, 55% Humid, Clr Sky

Site Sketch

Max TPH-DRO	
ID	
Concentration	
Depth	

	Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time	Pump #	Tube #
①	2720-3-6	B29631	5'1"	40 | B,S 7.4	11:22	11:52	3	3
①	2720-4-6	B28457	"	100	"	"	5	7
②	2720-5-6	B29820	4'10"	| 7.5	11:40	12:10	4	4
②	2720-6-6	B29709*	4'10"	100	"	"	7	7

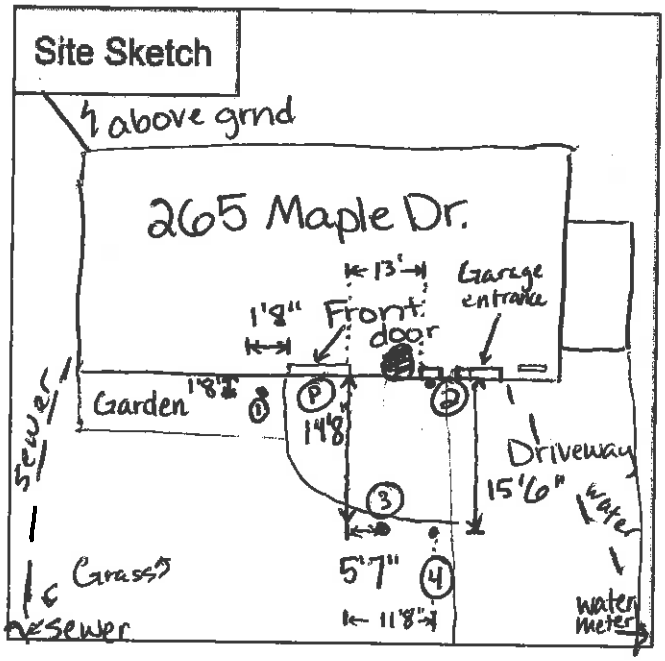
People present	MAW AW ERW
Additional Notes	* Had to tap to initiate flow. B Found both previous pilot holes.

Soil Vapor Site Log

Case #	2016-2264
Address	265 Maple Dr Christiansburg
Category	3
Date	8/17/2017
Time	9:00 am
Weather	74°F, 88% H, clr sky

Max TPH-DRO	
ID	~~10,300~~ 37116GW5
Concentration	10,300
Depth	7.5'

Site Sketch



Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time	Pump #	Tube #	
~~265-4~~	~~B28472~~ B28415		☆ Low flow meter broke ☆			~~5~~	~~7~~	
(1) 265-1	B25320	5'4"	H 100	10:15	10:35	3	3	
(2) 265-2	B29831	1'6"	L 37 7.5	9:50	10:20	4	4	*
(P) 265-P	B28334	–	L 37 7.5	10:01	10:31	7	7'	**
(3) 265-3	B29698	4'10"	100	10:28	10:48	4	4	
(4) 265-4	B28389	5'6"	100	10:50	11:10	4	4	

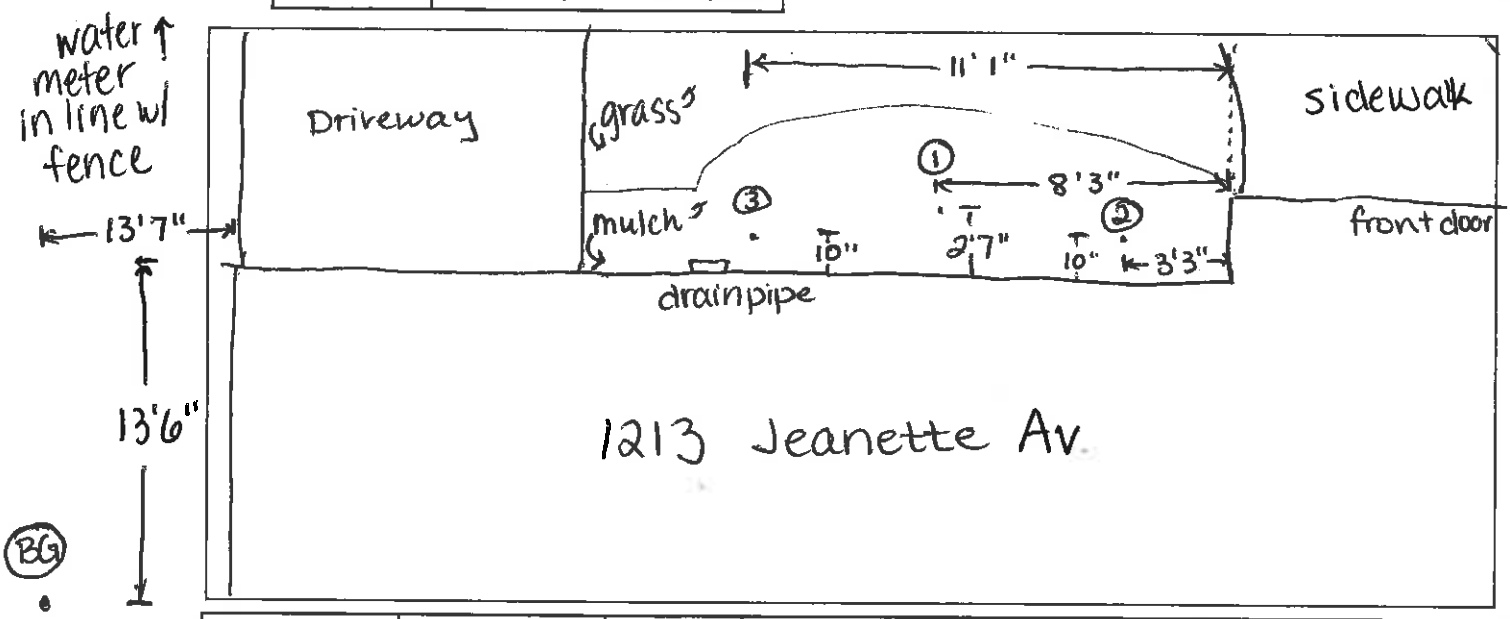
People present	MAW, AW, ERW
Additional Notes	Concrete slab over site. Potential water study site - owner OK Tips still smell after cleanup.

*Drain pipe
*Testing probe tip

Soil Vapor Site Log

Case #	2011-2079
Address	1213 Jeanette Av Vinton
Category	3
Date	8/23/2017
Time	10:45 am
Weather	overcast, light rain 78°F, 71% Hum.

Max TPH-DRO	
ID	S-7
Concentration	36,000
Depth	11'



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
Split ①	1213-1-AT	B28433	~6'8"	102	10:58	11:28	5	7
	1213-2-AT	B28411	~6'8"	53	10:58	11:28	4	4
②	1213-3-AT	B28457	5'8"	53	11:10	11:40	2	8
	1213-4-AT	B29820	5'8"	100	11:10	11:40	7	7'
③	1213-5-NT	B28432	5'5"	53	11:42	12:12	4	4
	1213-6-NT	B28294	5'5"	102	11:42	12:12	5	7
	1213— BG	B25117	5'6"	100	11:33	12:03	3	3

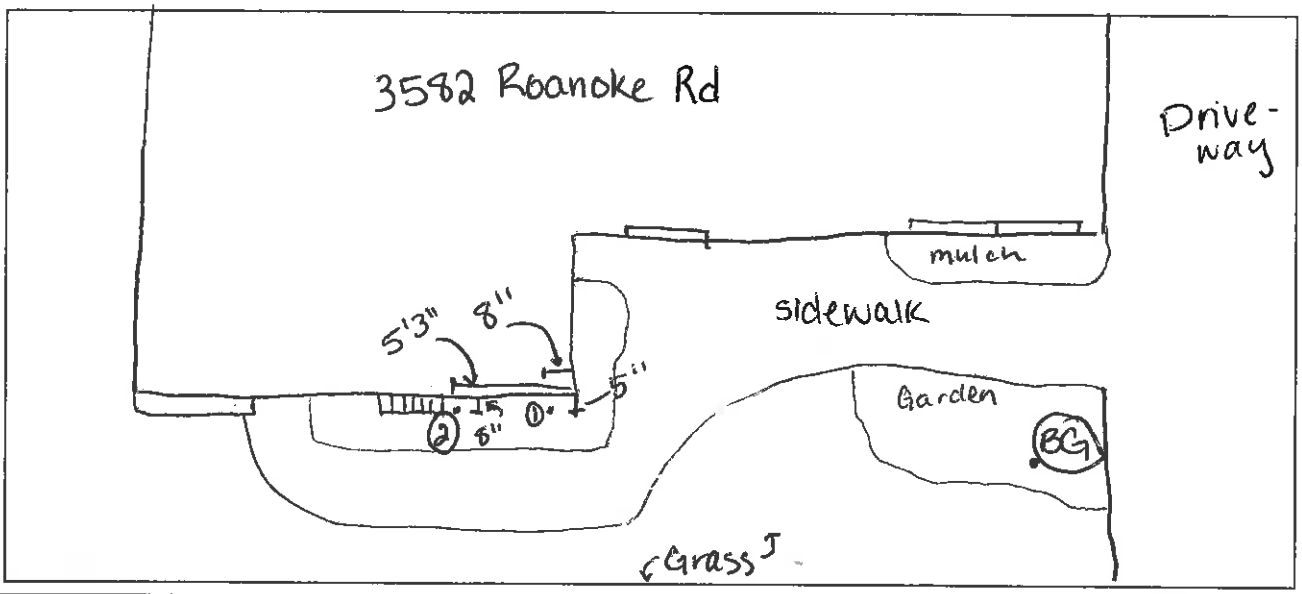
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: 1213-1-AT, 1213-2-AT. Use PVC soil remediation tube instead of a hole we drilled. ② smelled of diesel. Relatively easy probe installation.

Soil Vapor Site Log

Case #	2017-2038
Address	3582 Roanoke Rd Daleville
Category	3
Date	9/7/2017
Time	11:00 am
Weather	62°F 66%H Partial Clouds

Max TPH-DRO	
ID	SS-2
Concentration	3,440
Depth	8'



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
①	3582-1-H-AT	B284604	5'7"	~~35~~ 100	11:26	11:56	1	4
①	3582-2-L-AT	B285278	5'7"	35	11:26	11:56	2	8
	3582-BG-	B285339	1'10"	100	11:33	12:03	4	3
②	3582-3-H-AT	B29698	5'7"	100	11:45	12:15	5	7
②	3582-4-L-AT	B28433	5'7"	35	11:45	12:15	7	7'

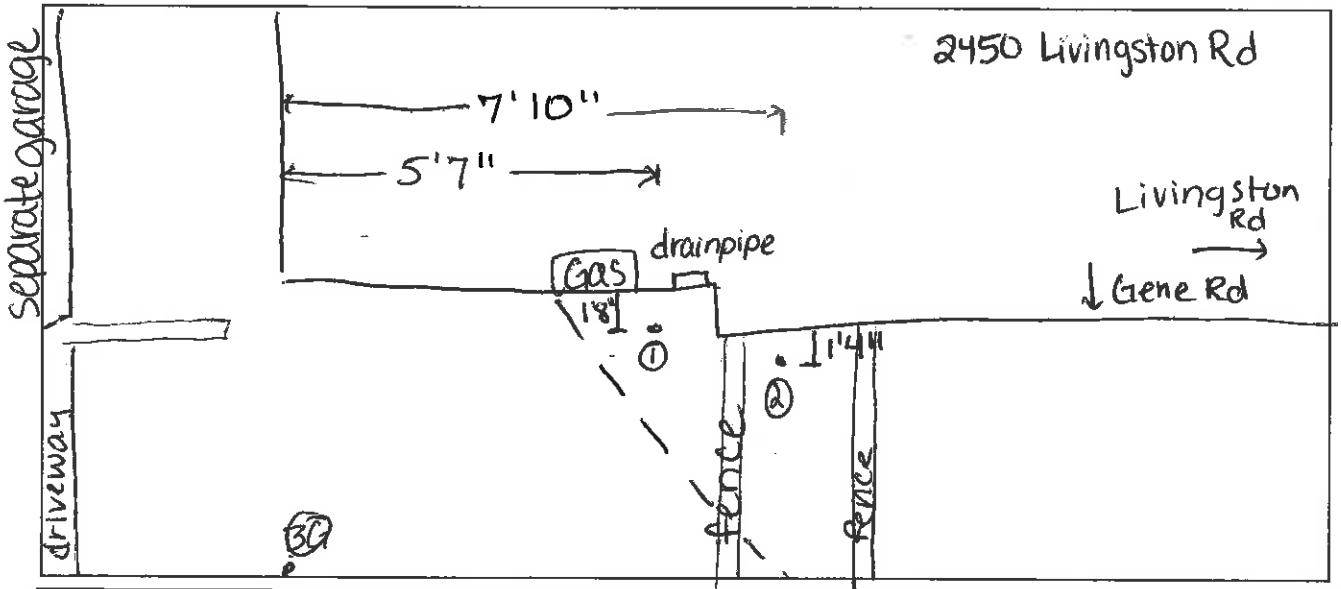
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: SS Probe tip was in lab, did BG w/out tip.

Soil Vapor Site Log

Case #	2012-2193
Address	2450 Livingston Rd Roanoke
Category	2
Date	9/7/2017
Time	1:45 pm
Weather	71°F 41%H Mostly Cloudy

Max TPH-DRO	
ID	HA-2
Concentration	32,000
Depth	6.5'



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
①	2450-1-H-AT	B28334	2'4"	100	2:10	2:40	1	3
①	2450-2-L-AT	B28424	2'4"	35	2:10	2:40	2	8
	2450-BG	B28455	2'1"	100	2:19	2:49	7	7'
②	2450-3-H-AT	B25320	5'2"	100	2:30	3:00	4	4
②	2450-4-L-AT	B29705	5'2"	35	2:30	3:00	5	7

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Probe installation difficult

Soil Vapor Site Log

Case #	2016 - 2264
Address	265 Maple Ave Christiansburg
Category	
Date	9/7/17
Time	4:00 pm
Weather	73°F

Max TPH-DRO	
ID	
Concentration	
Depth	

Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
265-DS	B28426	~2'	50	4:14	4:34	1	7
265-H	B25334	~6'	100	4:22	4:52	2	7
265-L	B28415	~6'	35	4:22	4:52	4	4

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

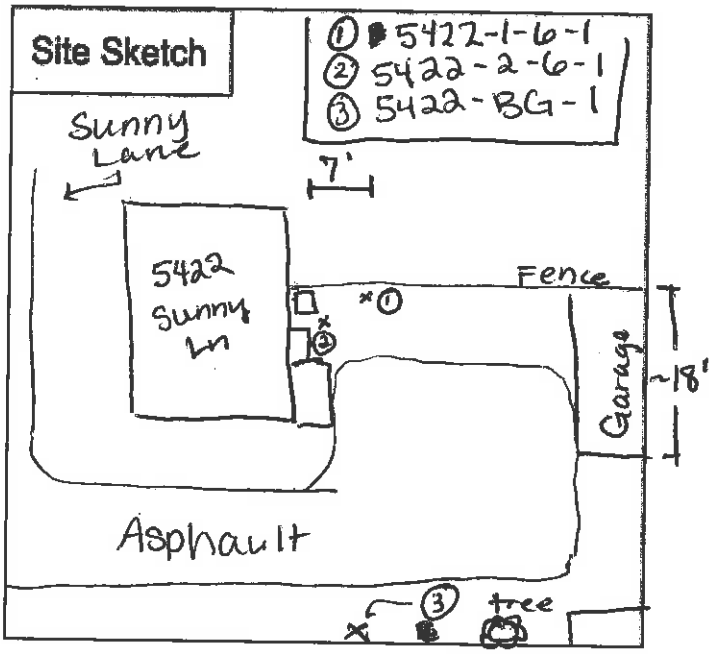
Notes:

Soil Vapor Site Log

Case #	2015-2413
Address	5422 Sunny Ln Elliston
Category	1
Date	7/13/2017
Time	10:30
Weather	mid 80's, above 50% humidity

Max TPH-DRO	
ID	
Concentration	
Depth	

Site Sketch



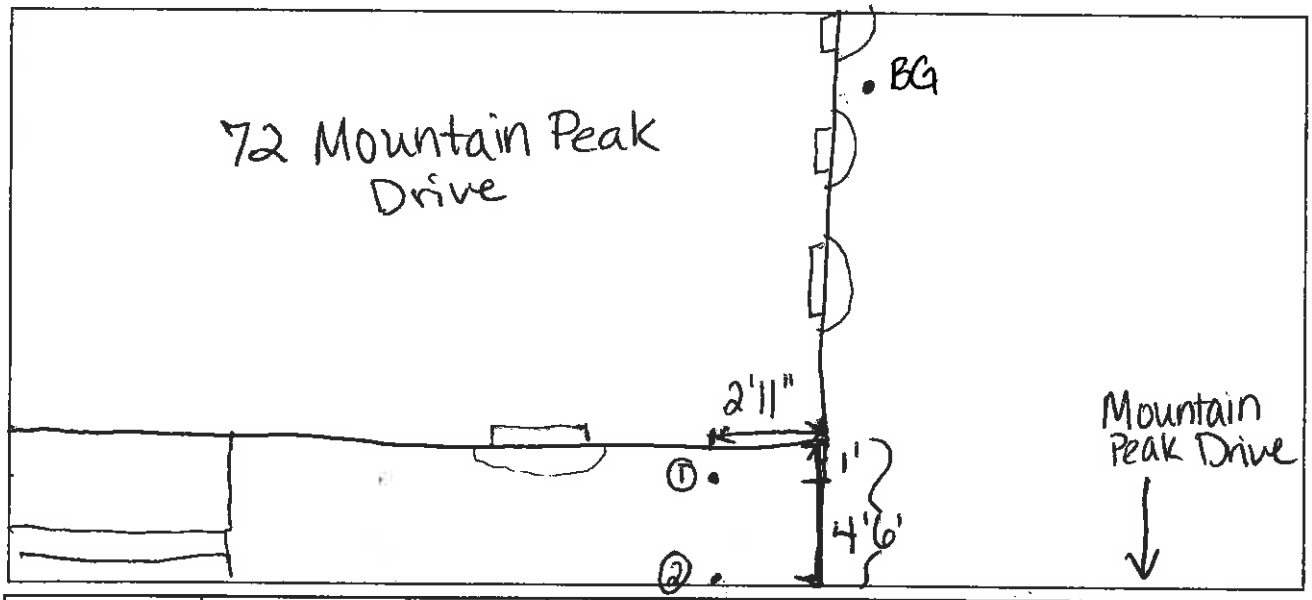
Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time	Pump #	Tube #	Out
5422-2-6-1	B28413	6	100	10:50 ~~10:44~~	11:20 ~~11:14~~	3	3	–
5422-1-6-1	B29853	6	100	~~11:06~~	11:36	5	7	1'4"
5422-BG-1	B28470	~~4'~~	100	11:28	11:58	~~3~~	~~3~~	3'

People present	
Additional Notes	

Soil Vapor Site Log

Case #	2015-2345
Address	72 Mountain PkDr Lynchburg
Category	2
Date	9/14/2017
Time	11:30 am
Weather	75°F 58% H 30inHg

Max TPH-DRO	
ID	B01-2
Concentration	47,300
Depth	5'



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
①	72-1-H-AT	B28410	4'10"	100	11:50	12:20	4	4
①	72-2-L-AT	B28334	4'10"	35	11:50	12:20	1	3
	72-BG	B28454	4'8"	100	11:56	12:26	7	7'
②	72-3-H-AT	B25334	4'7"	100	12:05	12:35	2	8
②	72-4-L-AT	B28455	4'7"	35	12:05	12:35	5	7

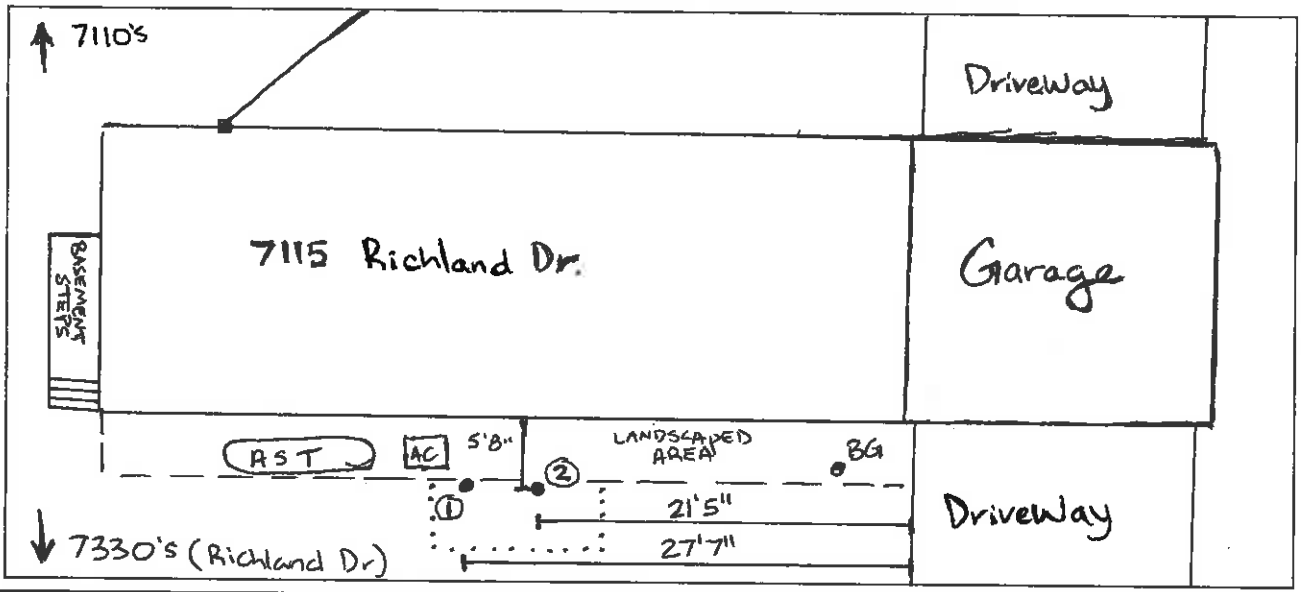
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Easy probe installation

Soil Vapor Site Log

Case #	2015-2319
Address	7115 Richland Dr. Lynchburg
Category	2
Date	9/14/2017
Time	13:00
Weather	76°F 56% H 30 inHg

Max TPH-DRO	
ID	B01-3
Concentration	72,000
Depth	6'



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
(1)	7115-1-H-AT	B29631	4'10"	100	13:23	13:53	1	7
	7115-2-L-AT	B29705	4'10"	35	13:23	13:53	2	3
(2)	7115-3-H-AT	B28424	4'11"	100	13:30	14:00	4	4
	7115-4-L-AT	B28465	4'11"	35	13:30	14:00	5	8
(BG)	7115-BG	B29698	3'11"	100	13:37	14:07	7	7'

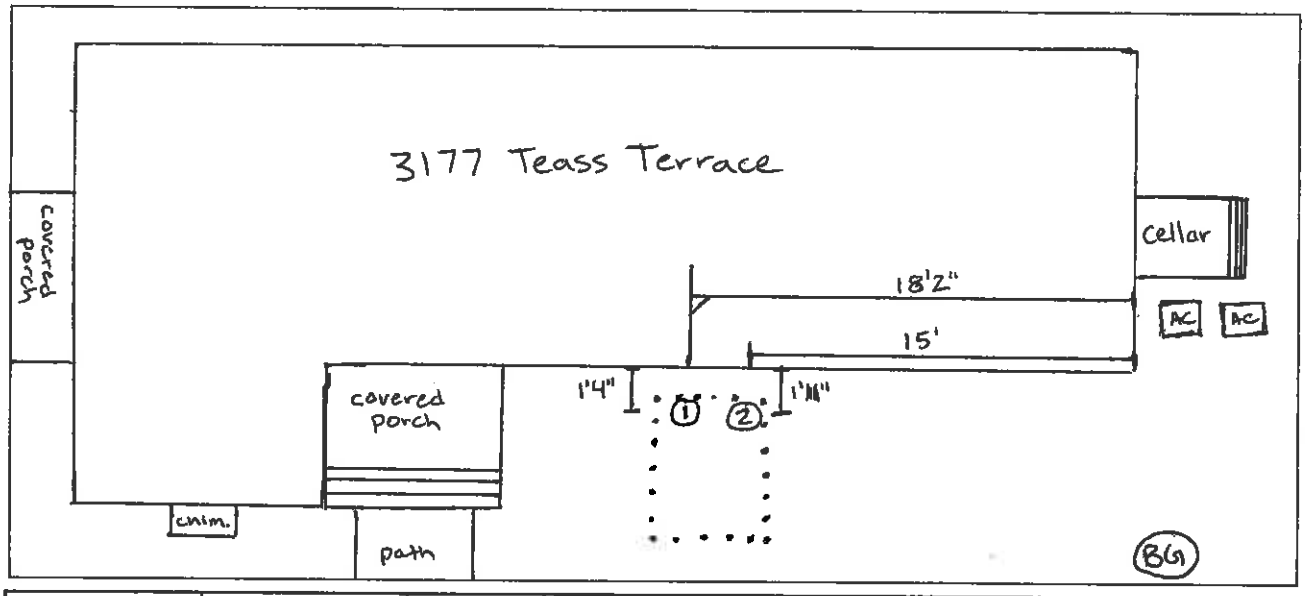
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2014-2376
Address	3177 Teass Terrace Bedford
Category	2
Date	9/14/2017
Time	15:30
Weather	Partly Cloudy 72°F 55%H

Max TPH-DRO	
ID	SW04
Concentration	42,900
Depth	8'



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
①	3177-1-H	B25339	4'2"	100	15:48	16:18	1	7'
①	3177-2-L	B28411	4'2"	35	15:48	16:18	2	8
BG	3177-BG	B28450	2'8"	100	15:55	16:25	4	7
②	3177-3-H-AT	B28293	4'3"	80	16:10	16:40	5	4
②	3177-4-L-AT	B25322	4'3"	100	16:43	16:53	1	7'
	3177-Ambient	B29680	—	100	16:25	16:45	—	—

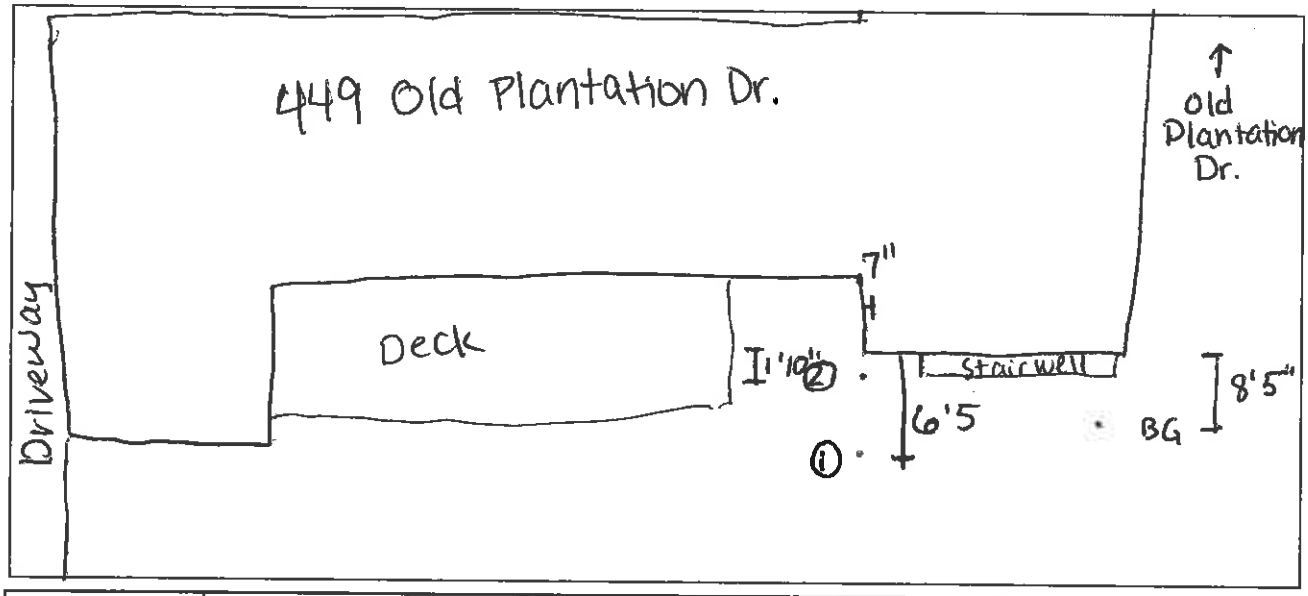
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: ① is 1'4" away from foundation
② is 1'11" away from foundation
② Was not getting 100 Q(ccm) OR behaving normally in Split Flow.

Soil Vapor Site Log

Case #	2009-7124
Address	449 Old Plantation Dr. Lynchburg, VA
Category	2
Date	12:17
Time	11:30 am
Weather	82°F 49% H 30 inHg Sunny

Max TPH-DRO	
ID	SS-4/117
Concentration	39,100
Depth	117"



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
449-1-H	B28389	5'2"	100	11:53	12:22	1	4
449-1-L	B25103	5'2"	35	11:53	12:22	2	3
449-2-H	B28426	3'11"	100	12:03	12:33	4	7
449-2-L	B28432	3'11"	35	12:03	12:33	5	8
449-BG	B28415	4'9"	35	12:15	12:45	7	7

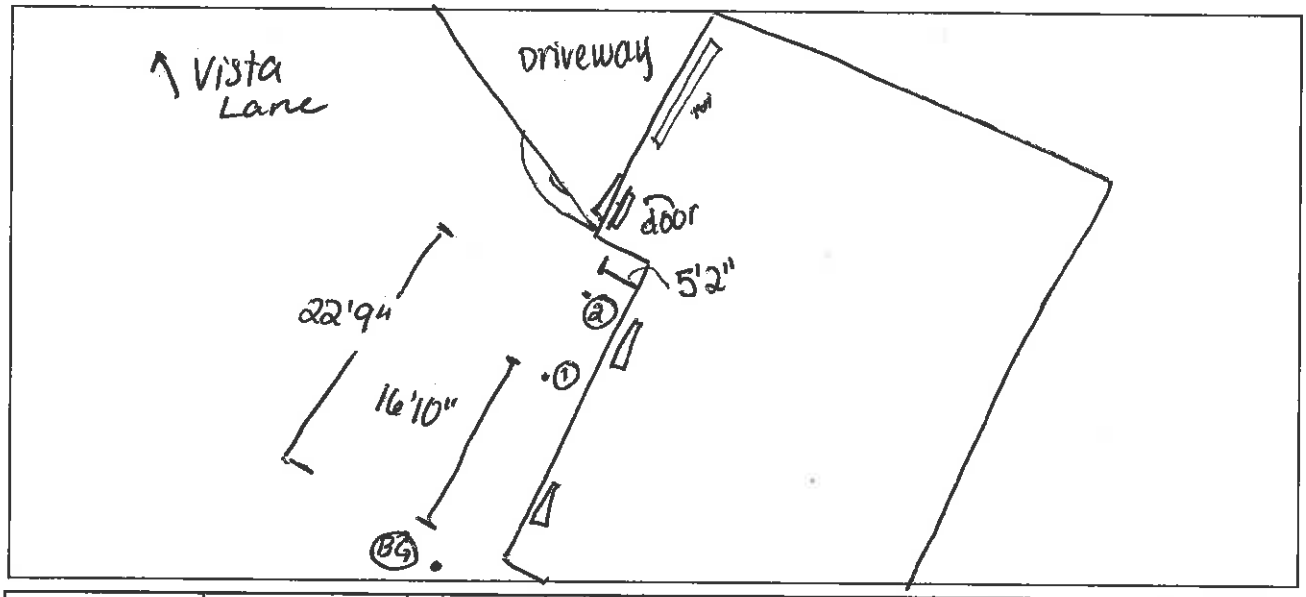
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Fill soil - easy installation
Natural Soil - difficult installation

Soil Vapor Site Log

Case #	2014-2394
Address	111 Vista Lane Lynchburg
Category	2
Date	9/21/17
Time	1:30 pm
Weather	

Max TPH-DRO	
ID	SS-1/6
Concentration	32,000
Depth	6'



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
111-1-H	B25117	4'6"	100	1:58	2:28	1	4
111-1-L	B28375	4'6"	35	1:58	2:28	2	3
111-2-H	B29831	4'	100	2:09	2:39	4	7'
111-2-L	B28278	4'	100	2:09	2:39	5	8
111-BG	B28378	2'3"	35	2:20	2:59	7	7

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	
Address	5422 Sunny Ln
Category	
Date	9/21/2017
Time	4:30 pm
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	

Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
5422- -H	B28457		100	4:37	5:07		
5422- -L L	B28442		35				

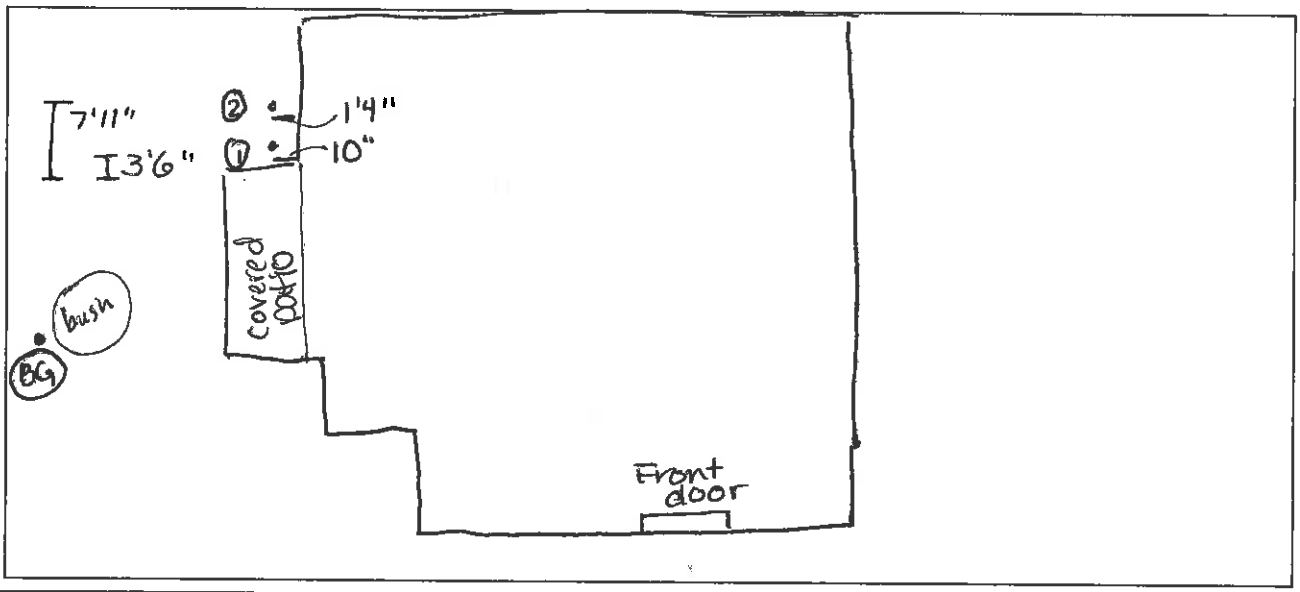
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2015-6135
Address	6818 Jarmans Gap Rd Crozet (Piedmont)
Category	2
Date	10/5/2017
Time	11:15
Weather	partial clouds

Max TPH-DRO	
ID	S-3-10
Concentration	1430
Depth	10'



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
6818-1-H-AT	B28278	4'1"	H 100	11:24	11:54	4	4
6818-1-L-AT	B28294	4'1"	L 35	11:24	11:54	5	8
6818-2-H-AT	B25334	4'4"	H 100	11:35	12:05	7	7
6818-2-L-AT	B28414	4'4"	L 35	11:35	12:05	2	3
6818-BG	B28455	2'8"	H 100	11:39	12:09	1	7'

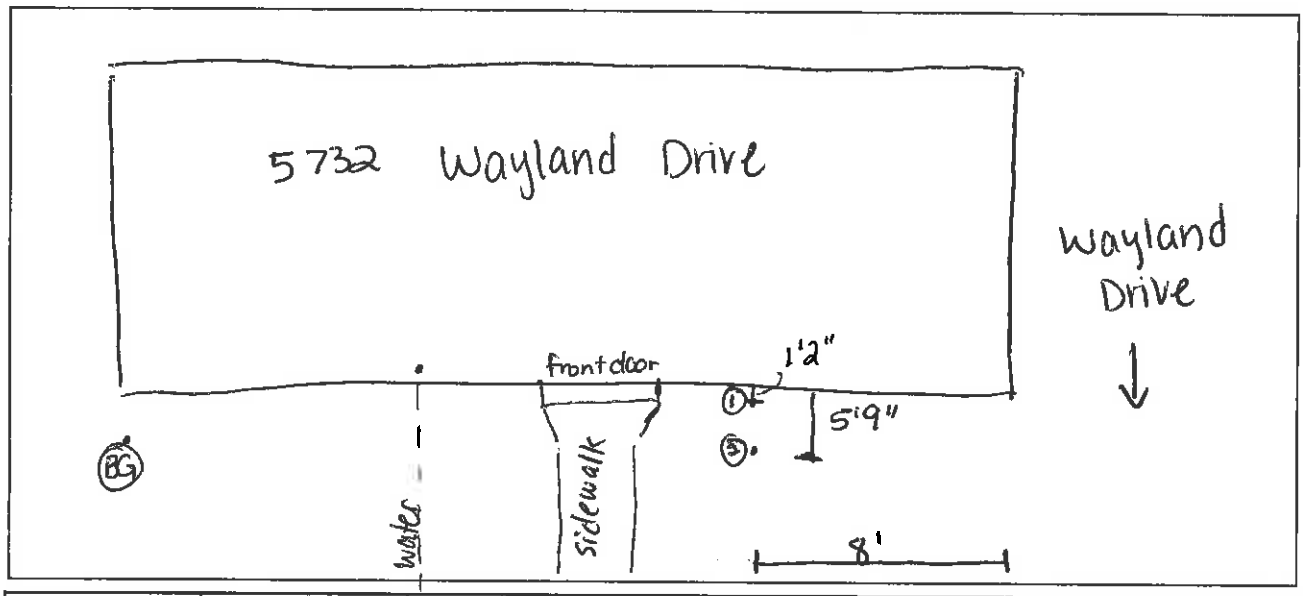
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: difficult probe installation

Soil Vapor Site Log

Case #	2014-60061
Address	5732 Wayland Dr. Crozet (Piedmont)
Category	2
Date	10/5/2017
Time	12:45 pm
Weather	partly cloudy

Max TPH-DRO	
ID	S-1-6.5
Concentration	56800
Depth	6.5'



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
5732-1-H	B28424	5'	H 100	12:52	1:22	5	7
5732-1-L	B28442	5'	L 35	12:52	1:22	4	3
5732-2-H	B28410	4'8"	H 100	1:00	1:30	7	7'
5732-2-L	B28432	4'8"	L 35	1:00	1:30	2	8
5332-BG	B28457	2'3"	100	1:05	1:35	1	4

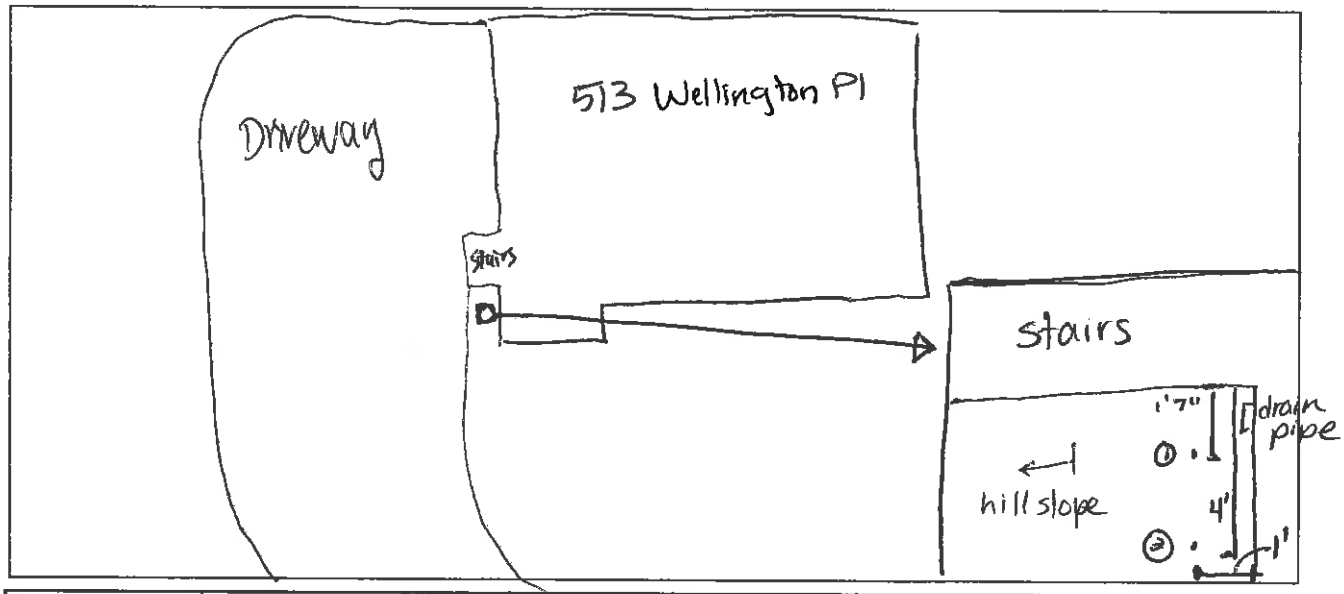
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Easy probe installation

Soil Vapor Site Log

Case #	2015-6134
Address	513 Wellington Place Charlottesville (P)
Category	1
Date	10/3/17
Time	2:45 PM
Weather	

Max TPH-DRO	
ID	SS-01
Concentration	16,000
Depth	7'



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
513-1-H	B28411	5'2"	H 100	2:50 pm	3:20	1	7
513-1-L	B28465	5'2"	L 35	2:50 pm	3:20	2	8
513-2-H	B28464	2'	H 100	2:57 pm	3:27	5	4
513-2-L	B25339	2'	L 35	2:57	3:27	4	3

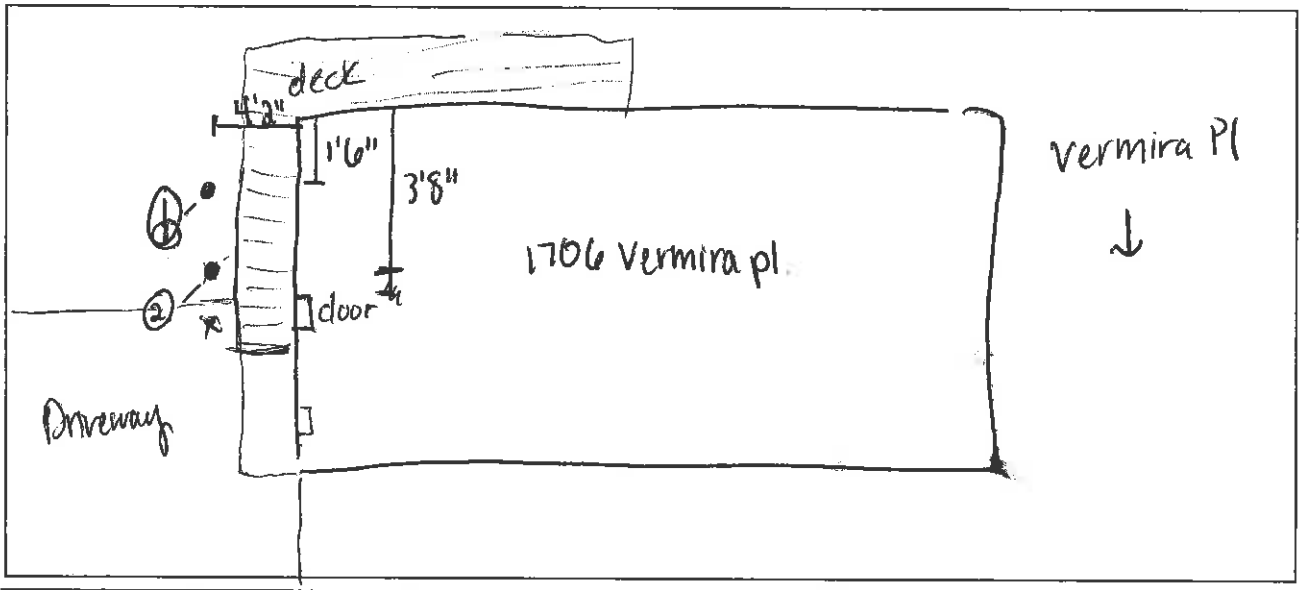
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: tank still in ground, awkward access

Soil Vapor Site Log

Case #	2015-6059
Address	1706 Vermira Pl. Charlottesville, VA
Category	3
Date	10/5/17
Time	4:40 pm
Weather	

Max TPH-DRO	
ID	S-1-6
Concentration	25,400
Depth	6 ft



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
1706-1-H	B29853	4'6"	H 100	4:50	5:20	2	4
1706-1-L	B25358	4'6"	L 35	4:50	5:20	1	8
1706-2-H	B29698	4'8"	100	4:56	5:26	4	7
1706-2-L	B28334	4'8"	35	4:56	5:26	5	3
1706-BG	B25363	1'10"	100	5:00	5:30	7	7

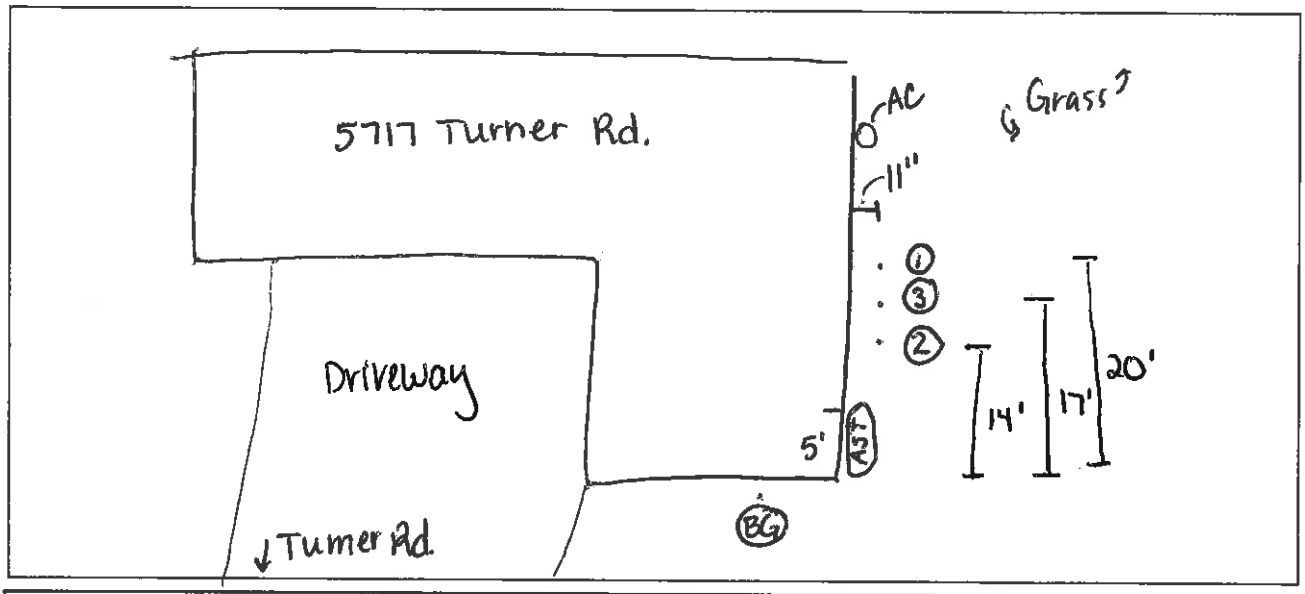
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: AROMATICS (1)

Soil Vapor Site Log

Case #	2016-3113
Address	5717 Turner Road Broad Run (Piedmont)
Category	3
Date	10/16/2017
Time	8:30 am
Weather	65°F, low Humidity clear

Max TPH-DRO	
ID	[redacted]
Concentration	~~520~~ 1,300 – 4,700
Depth	@ 11 – 14'



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
5717-1-H	B28378	4'7"	H 100	8:50	9:20	1	7'
5717-1-L	B28433	4'7"	L 35	8:50	9:20	2	8
5717-2-H	B29831	4'4"	H 100	8:59	9:29	4	7
5717-2-L	B28470	4'4"	L 35	8:59	9:29	5	3
5717-BG	B25320	5'	H 100	9:05	9:35	7	4
5717-3-H	B28426	4'7"	H ~~100~~ 100	9:27	~~9:57~~ 9:57	1	7'
5717-3-L	B28369	4'7"	L 35	9:27	9:57	2	8

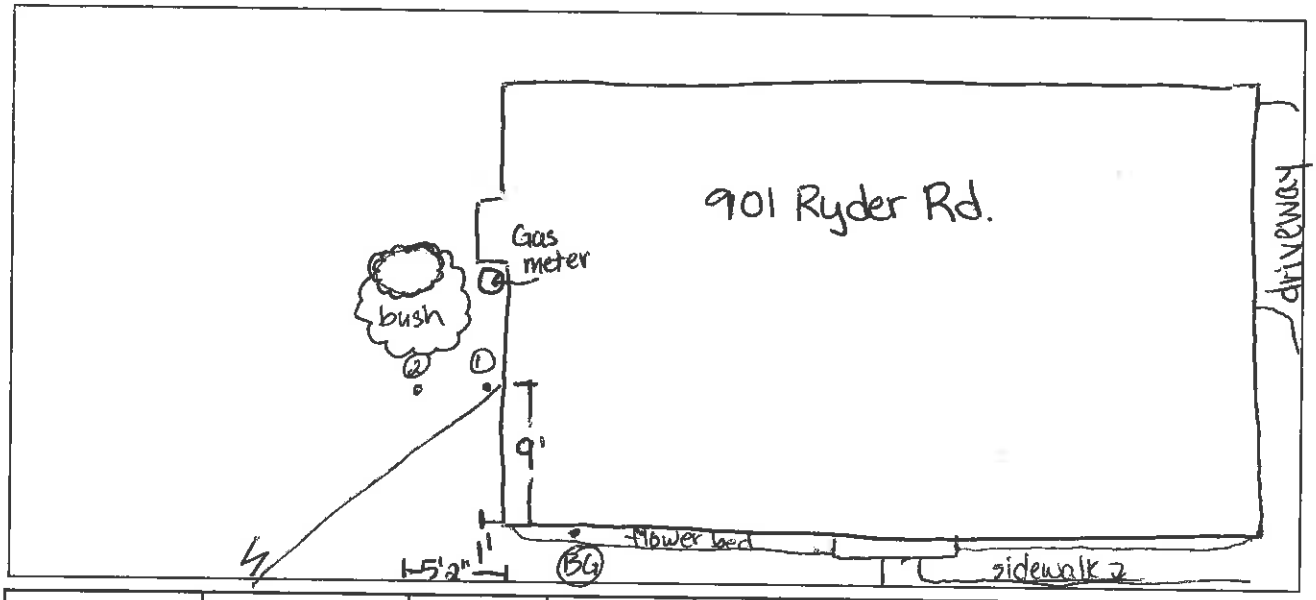
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Diesel olefactory-AST still operational. Layer of gravel encountered.

Soil Vapor Site Log

Case #	2012-~~[illegible]~~ 4137
Address	901 Ryder Rd. Richmond (P)
Category	1
Date	10/19/2017
Time	3:00 pm
Weather	clear sky 75°F

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
901-1-H	B29831	2'7"	100	3:25	3:55	1	4
901-1-L	B25103	2'7"	35	3:25	3:55	2	3
901-2-H	B28433	2'11"	100	3:35	4:05	4	7'
901-2-L	B28426	2'11"	35	3:35	4:05	7	8
901-BG	B28414	1'9"	100	3:40	4:10	5	7

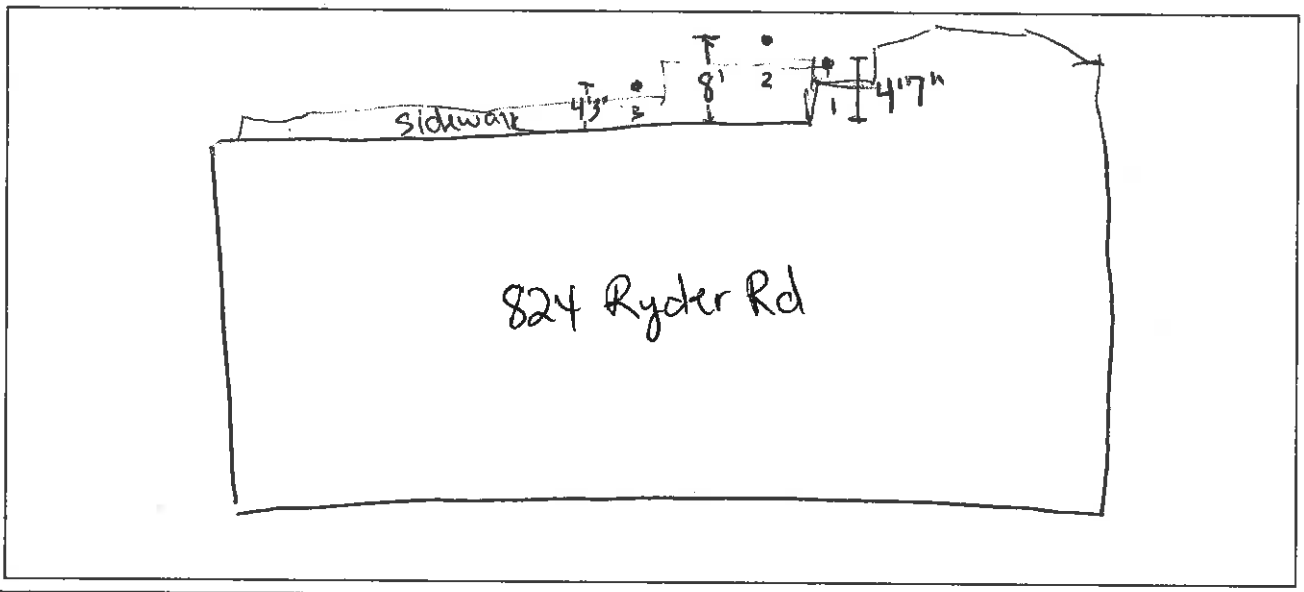
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: very tough to install

Soil Vapor Site Log

Case #	2012-4212
Address	824 Ryder Rd. Richmond (P)
Category	2
Date	10/19/2017
Time	
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
824-1-H	B25320	5'	100	4:40	5:10	1	7
824-1-L	B25334	5'	35	4:40	5:10	2	8
824-2-L	B28456	5'	35	4:44	5:14	4	4
824-3-H	B25117	5'	100	4:52	5:22	5	7'
824-3-L	B29680	5'	35	4:52	5:22	7	3

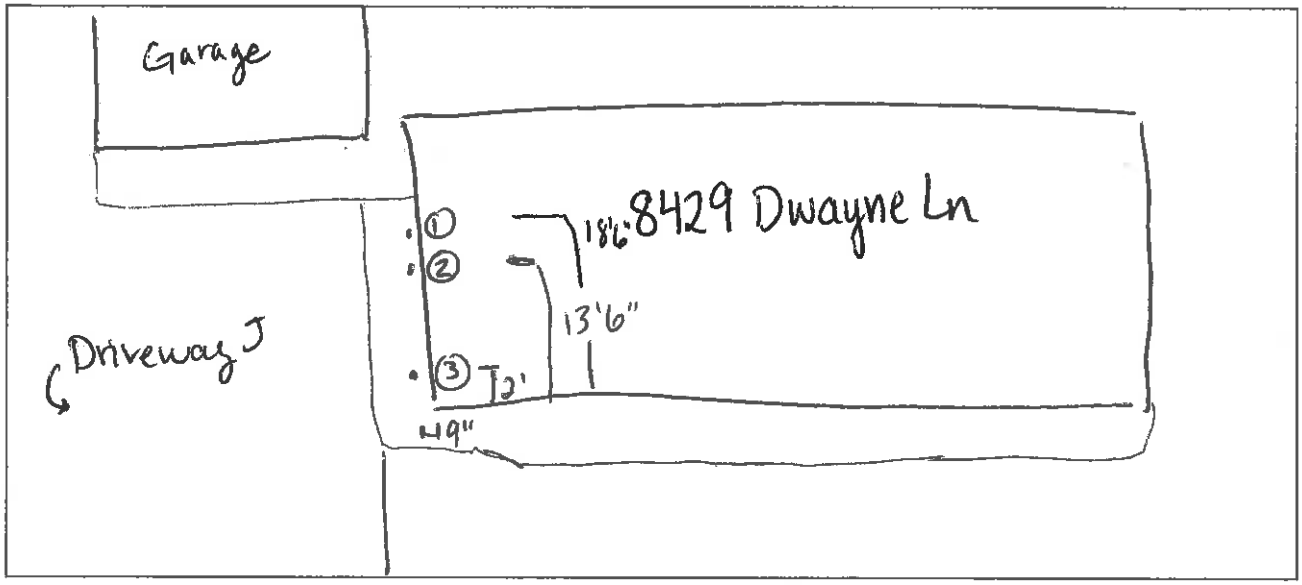
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2014-2475
Address	8429 Dwayne Ln. Richmond (P)
Category	
Date	10/19/2017
Time	6:00 pm
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
8429-1-H	B28389	6'	100			1	7'
8429-1-L	B28378	6'	35			2	3
8429-2-H	B28375	6'	100			4	7
8429-2-L	B28293	6'	35			5	8
NT 8429-3-L	B28415	6'	35			7	4

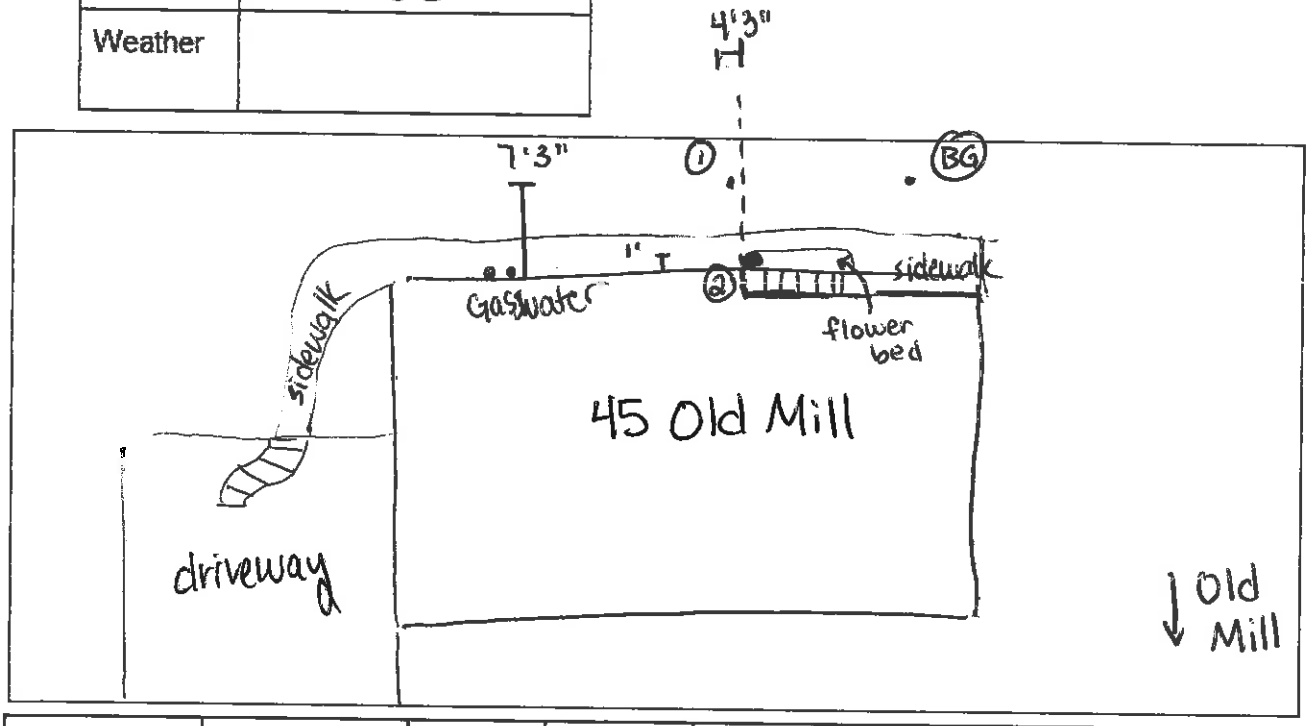
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: ③ was just awful

Soil Vapor Site Log

Case #	2014-4415
Address	45 Old Mill Richmond (P)
Category	1
Date	10/20/2017
Time	10:00
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
45-1-H	B25339	4'11"	100	10:21	10:51	1	7
45-1-L	B28470	4'11"	35	10:21	10:51	2	3
NT 45-2-H	B25322	3'8"	100	10:29	10:59	4	7'
45-2-L	B28465	3'8"	35	10:29	10:59	5	8
45-BG	B28432	2'6"	100	10:32	11:02	7	4

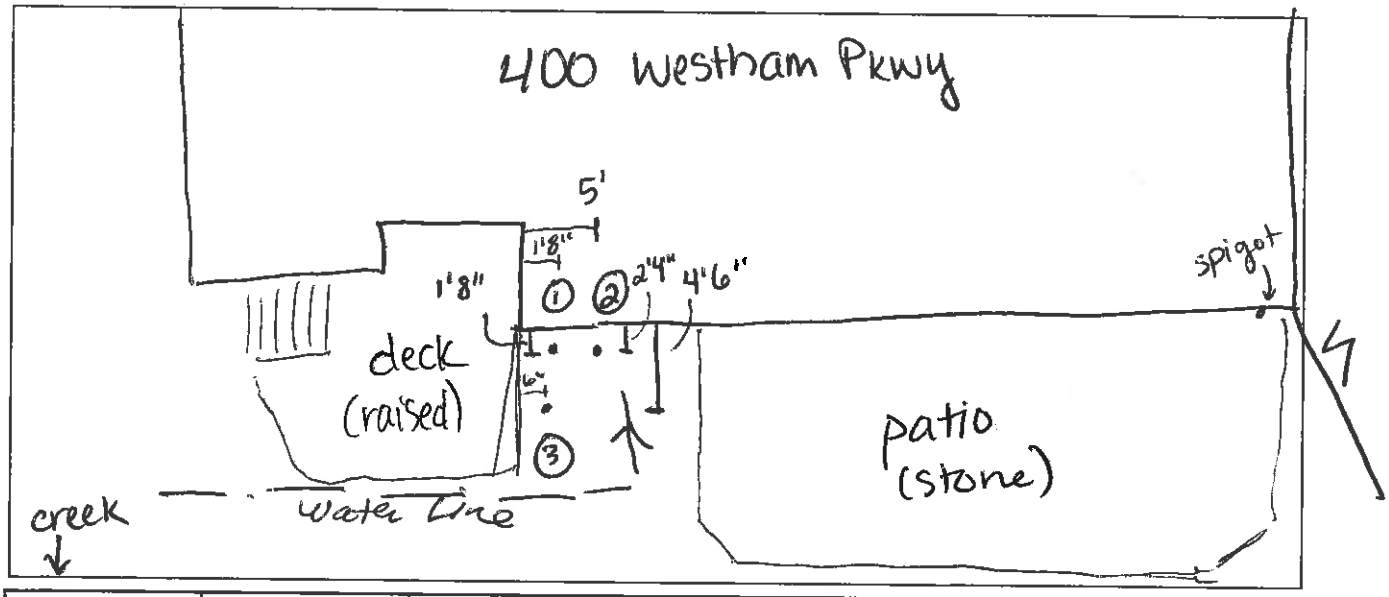
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2012-4030
Address	400 Westham PKWY Richmond (P)
Category	2
Date	10/20/2017
Time	11:52
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
400-1-H	B28424	5'	100	-	30 min	1	4
400-1-L	B29853	5'	35			2	3
400-2-H	B28450	4'8"	35			4	7'
* 400-2-L	B28442	4'8"	35		↓	5	8
400-3-L	B25358	4'10"	35	-	20 min	7	7

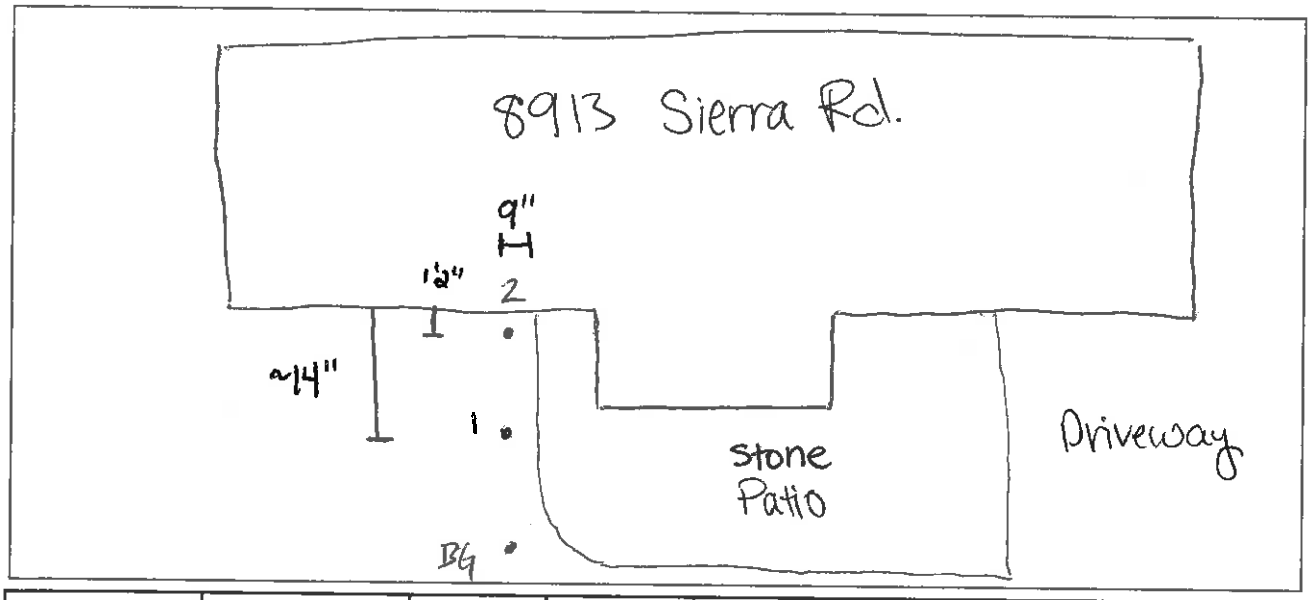
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: * Would not get high flow
Aromatics (3)

Soil Vapor Site Log

Case #	2009-4134
Address	8913 Sierra Rd. Richmond (P)
Category	1
Date	10/20/2017
Time	2:45
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
8913-1-H	B28457	6'	100		30	1	7
8913-1-L	B28410		35			2	3
8913-2-H	B25363		100			4	71
8913-2-L	B28294		35			5	8
8913-BG	B28334	↓	35		↓	7	4

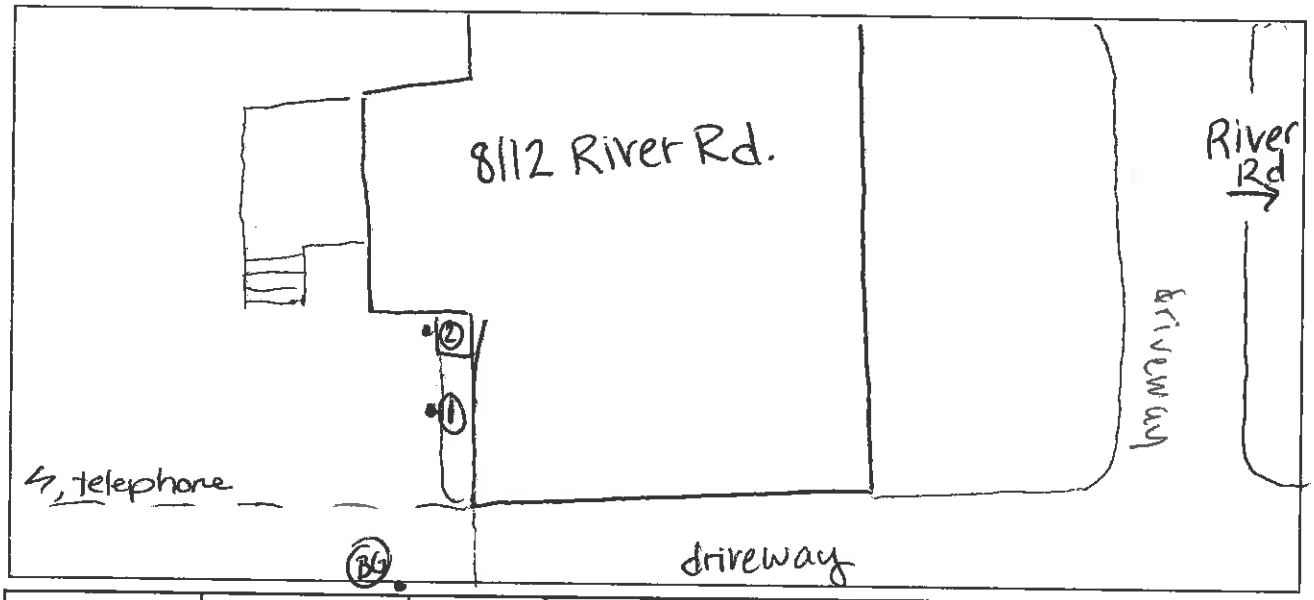
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: ① had water droplets in teflon tubing

Soil Vapor Site Log

Case #	2013-4061
Address	8112 River Rd Richmond (P)
Category	3
Date	10/20/2017
Time	4:00
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
8112-1-H	B29698	3'4"	100	–	30	1	7'
8112-1-L	B28369	3'4"	35	↓	↓	2	8
8112-2-H	B29709	3'4"	100	↓	↓	4	4
8112-2-L	B28455	3'4"	35	↓	↓	5	3
8112-3	B28464	3'3"	35	–	↓	7	7

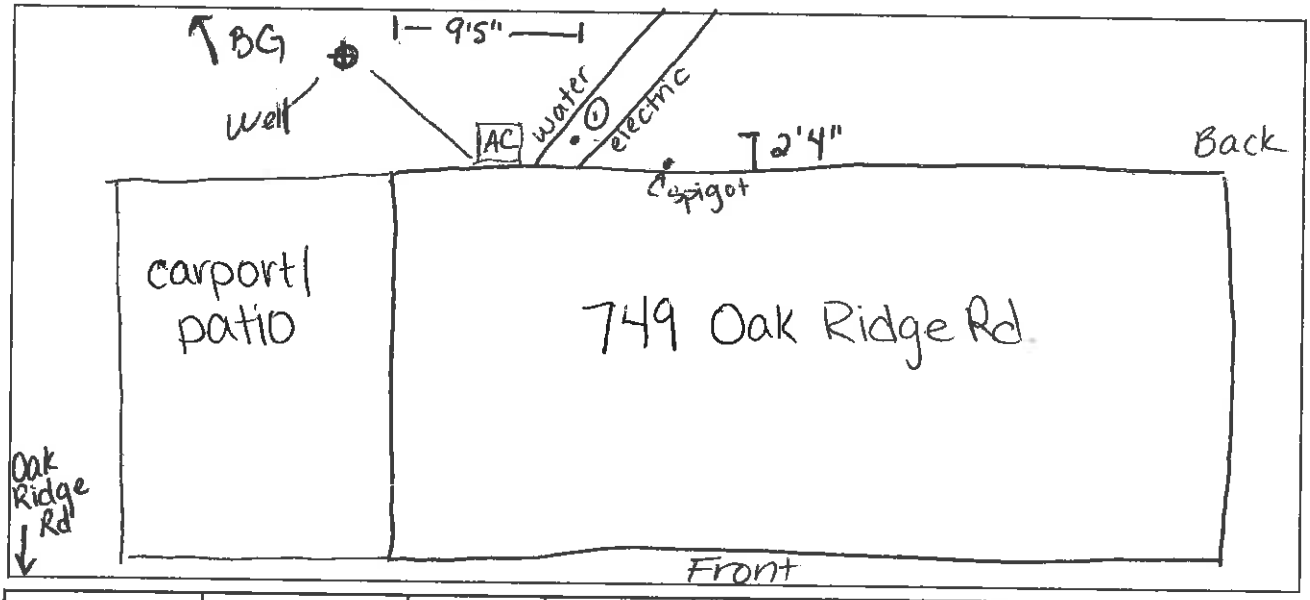
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: water table especially high at this site

Soil Vapor Site Log 2013-2080

Case #	~~2014-2376~~
Address	749 Oak Ridge Rd. Appomattox (P)
Category	2
Date	10/21/2017
Time	12:00
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
749-1-H	B28278	3'1"	100	—	30 min	1	7
749-1-L	B29844	3'1"	35	—	30 min	2	3
~~749-2-H~~	~~B29705~~						
~~749-2-L~~	~~B25311~~						
749-~~BGH~~ BG	B29631	3"	35	—	30 min	4	8
749-Blank	B28454	on table	0	12:50	1:41		

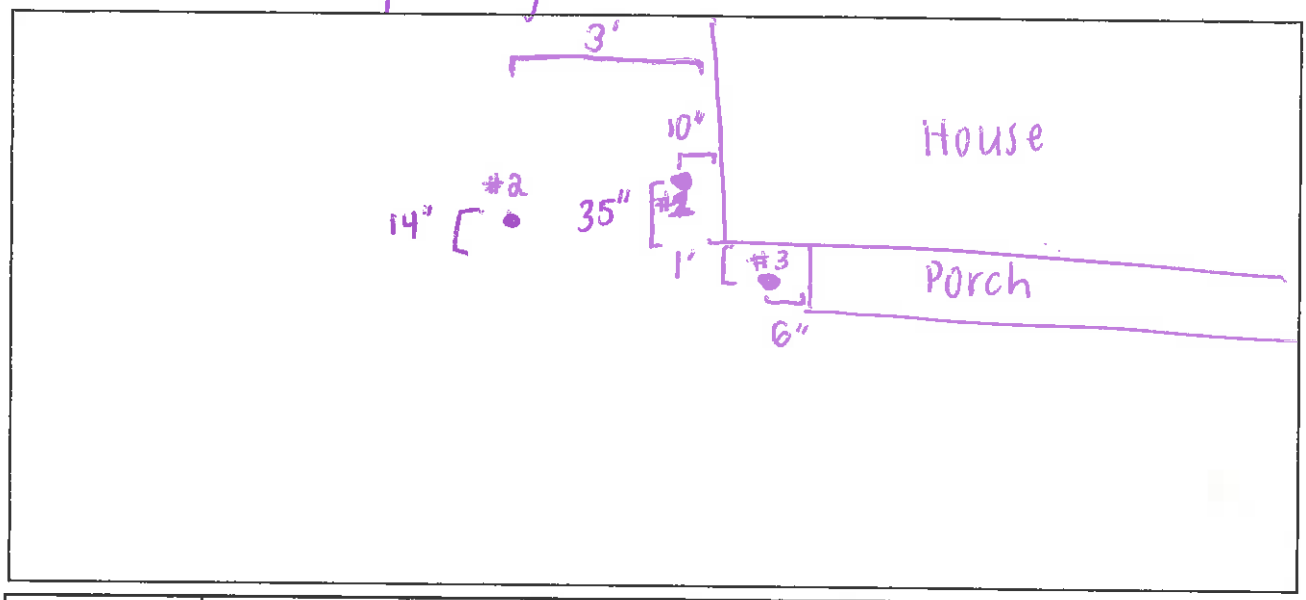
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: ~~St~~ Case # wrong in spreadsht
Basement sits on bedrock.

Soil Vapor Site Log

Case #	2015-3154
Address	804 Mortimer Ave F'burg, VA
Category	2
Date	11/05/17
Time	10:30
Weather	55°, cloudy sprinkling

Max TPH-DRO	
ID	
Concentration	14,000
Depth	70"



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
Tenax	1A	B25311	70"	33	00:00	15:00	2	10
carbo	1B	CARBO	70"	33	00:00	15:00	4	3
Tenax	2A	B28334	70"	33	00:00	15:00	5	7
carbo	2B	CARBO	70"	33	00:00	15:00	1	8
back-ground	3	B28455	5'	33	00:00	15:00	7	9

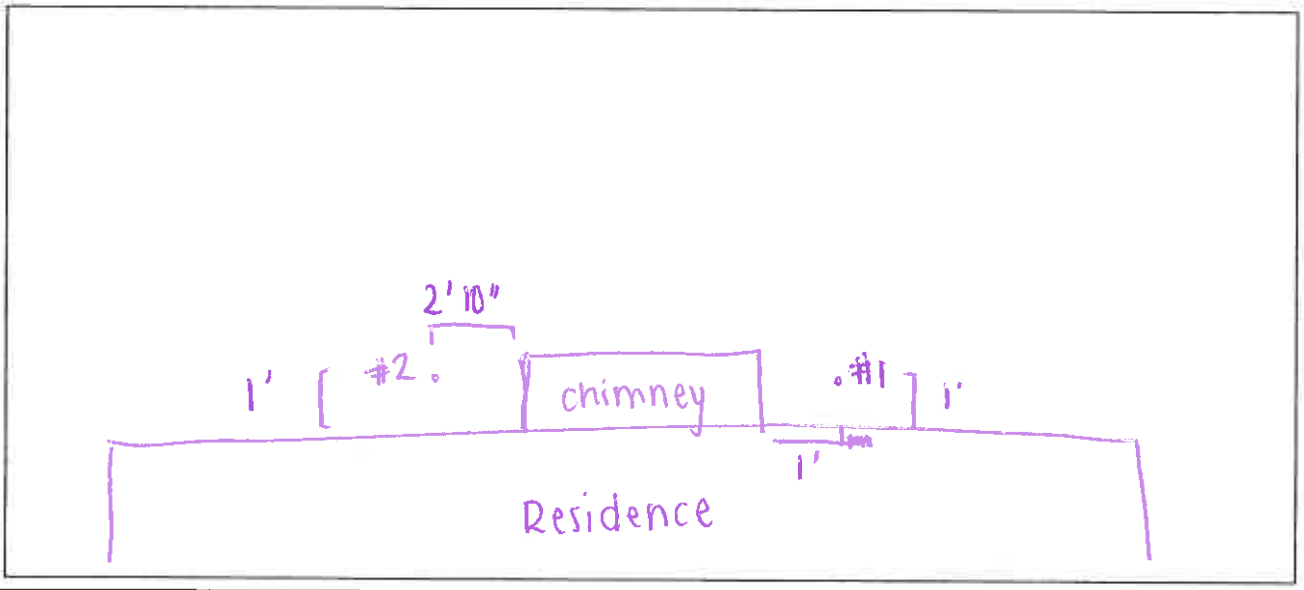
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2012-4298
Address	8204 Tarkington Dr Richmond, VA
Category	2
Date	11/04/17
Time	10:00
Weather	55° cloudy

Max TPH-DRO	
ID	
Concentration	23,506
Depth	13 ft



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
1A	B28378	5'7"	33	00:00	15:00	5	7
1B	B25334	5'7"	33	00:00	30:00	1	3
2A	B29853	5'9"	33	00:00	15:00	4	8
2B	B25358	5'9"	33	00:06	30:00	7	10
~~3~~ utilities	—	—	—	—	—	~~2~~	~~9~~

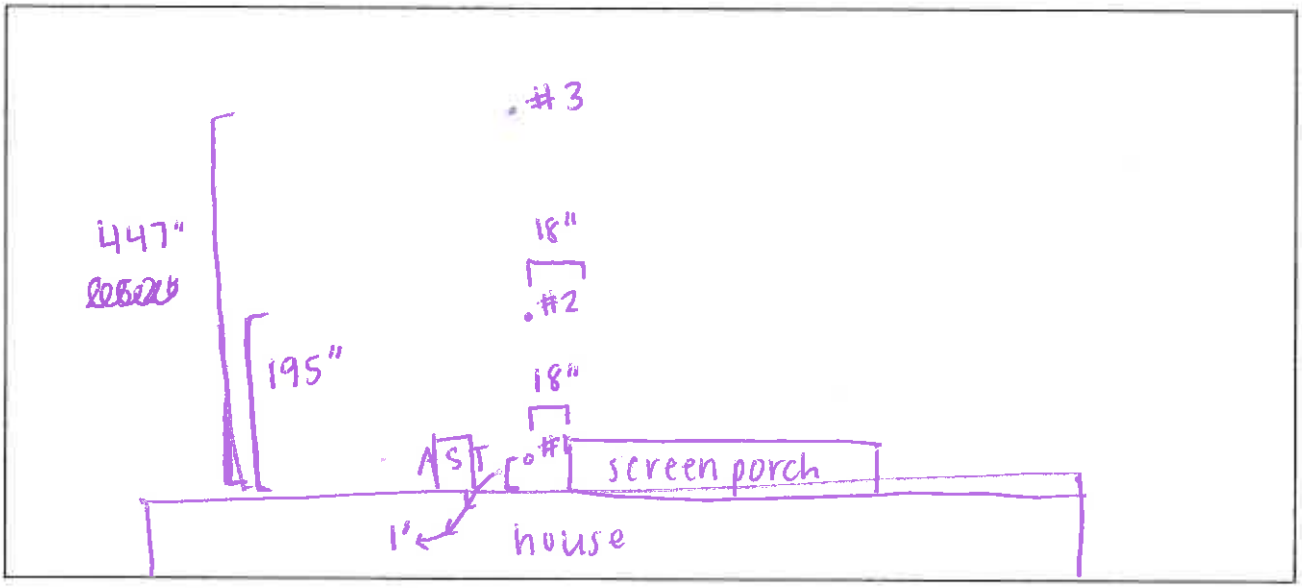
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2009-4442
Address	2208 Essex Rd Richmond, VA
Category	1
Date	11/04/17
Time	2:00
Weather	55°, cloudy

Max TPH-DRO	
ID	
Concentration	5,587
Depth	6'6"



Sample ID	Tube # Tenax	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube # Tubing
1A	B 25103	5'4"	33	00:00	15:00	5	7
1B	B 29680	5'4"	33	00:00	30:00	1	3
2A	B 29709	5'6"	33	00:00	15:00	4	8
2B	B 28375	5'6"	33	00:00	30:00	7	10
3	B 28293	3'	33	00:00	30:00	2	9

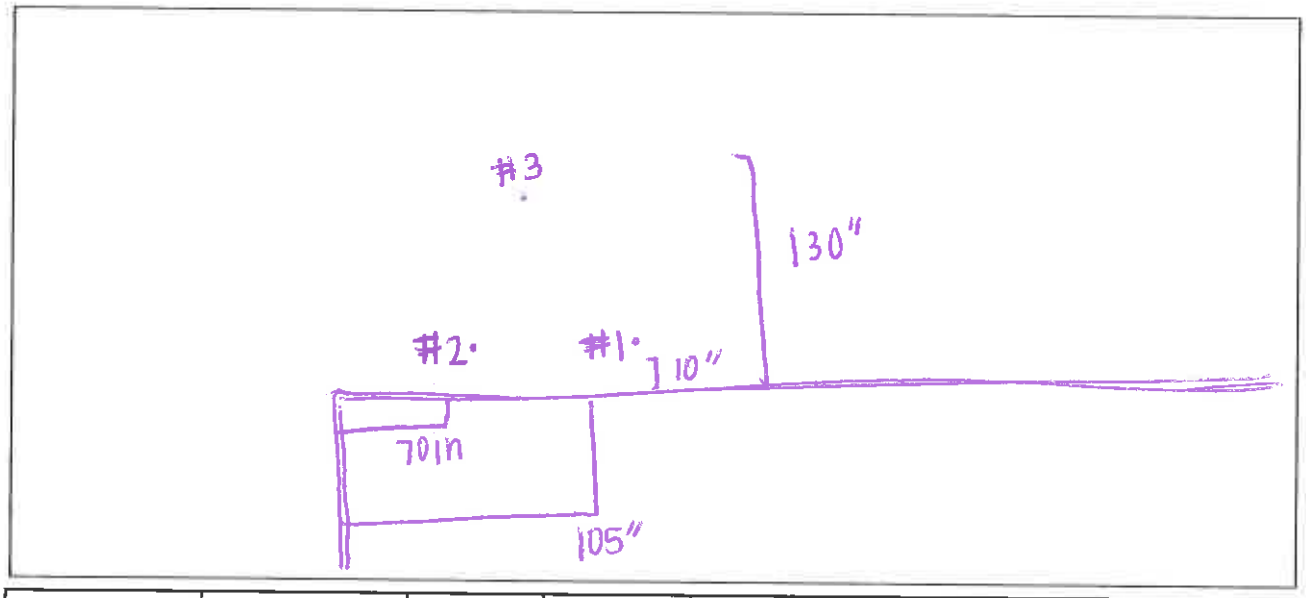
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2012-4502
Address	4733 Hopkins Rd Richmond, VA
Category	3
Date	~~11/03/17~~ 11/03/17
Time	3:45
Weather	Fair, 72°

Max TPH-DRO	
ID	
Concentration	16,820
Depth	6' 6"



	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube # Tubing
1	1A	B25322	5'8"	32	00:00	15:00	5	7
1	1B	B28415	5'8"	32	00:00	30:00	1	3
2	2A	B28426	5'6"	33	00:00	15:00	4	8
2	2B	B28389	5'6"	33	00:00	30:00	7	10
	~~	~~~~	~~~~	~~~~	~~~~	~~~~	~~~~	~~~~
3	3	B28442	5'	32	00:00	30:00	2	9

back-ground

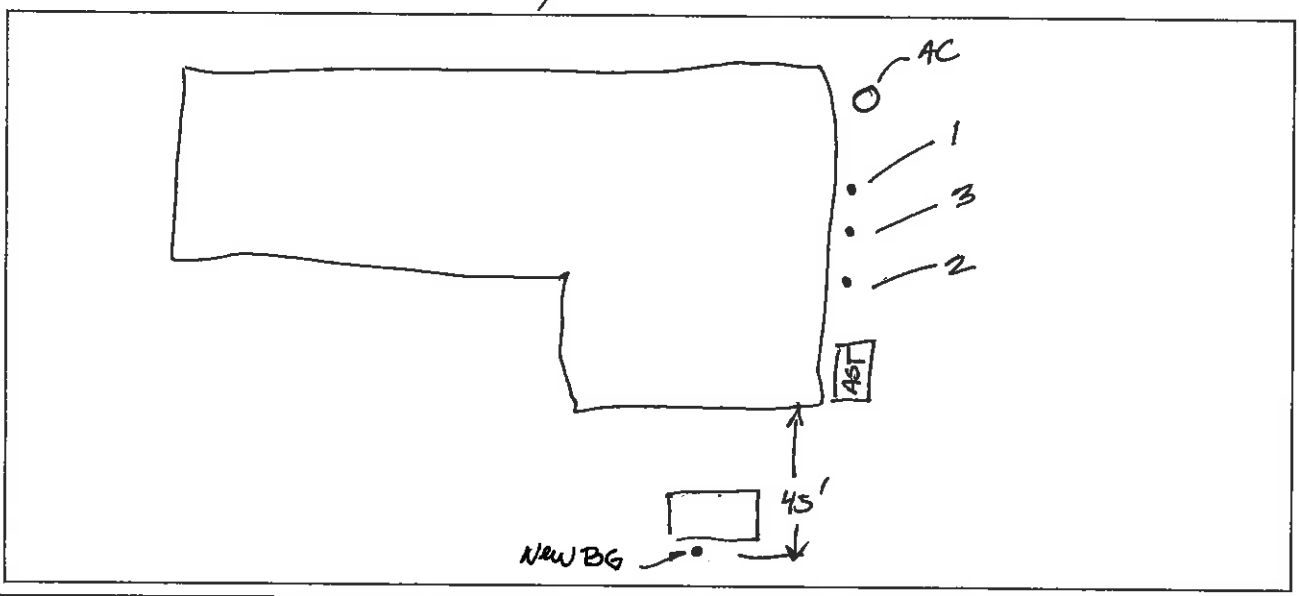
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2016-3113
Address	5717 Turner Rd. Broad Run, VA
Category	3 - Piedmont
Date	11/30/17
Time	11:30 AM
Weather	60°F - Light Clouds Partly Sunny

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
5717-New BG	B28424	3	33	12:06	12:36	5	7
5717-3C-30	B24560	5	33	12:27	12:57	4	8
5717-3T-30	B28465	5	33	12:27	12:57	3	7
5717-2C	B24581	5	33	12:44	1:14	1	4
5717-2T	B25117	5	33	12:44	1:14	2	3
5717-1T	B28411	3	33	1:02	1:32	3	7
5717-1C	B24570	3	33	1:02	1:32	4	8

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2016-3113
Address	5717 Turner Rd. Broad Run, VA
Category	3 - Piedmont
Date	11/30/17
Time	
Weather	

Max TPH-DRO	
ID	
Concentration	
Depth	

See Sheet 2

Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
5717-3R-15-T	B25339	5	33	1:16		5	7
5717-3R-15-C	B24592	5	33	1:16		7	9
5717-3R30							
5717-3R30							
5717-3T-15	B25339	5	33	1:16	1:31	5	7
5717-3C-15	B24592	5	33	1:16	1:31	7	9

15 minutes

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #: 2014-4156

Address: COASTAL
8402 Spring Hollow Drive, Richmond

Category #: 2

Date: 03/28/2018

Time: 4:00

Weather:
Sunny, ~60's°F

Max TPH-DRO	
ID =	
Concentration =	
Depth =	

Tank Removed? = Y
Excavation Dimensions =

Stone Backfill? =
Depth (ft) Rock Encountered? =

Site Sketch

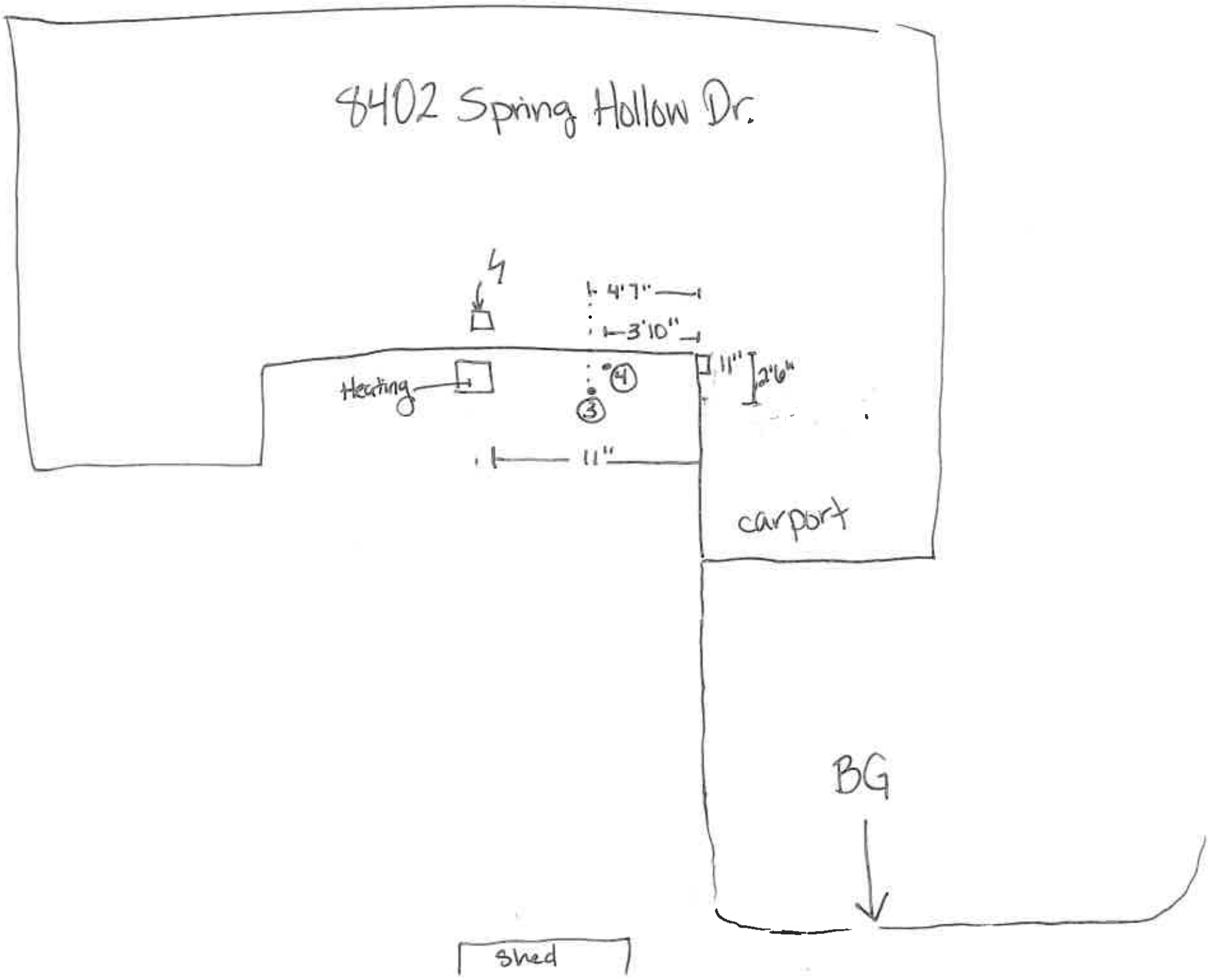
see back →

Additional Notes

used hand auger on 1 BG hole
1 split flow, 3 BG, no ambient
no olefactory

Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time	
8402-1-C -BG auger	CB24562	2'8"	28 on meter	4:29	4:59	5;9
8402-1-T-BG auger	B 29680	2' 8"	28.	4:29	4:59	2, 8
8402-2-T BG	B28455	2' 5"	28 on meter	4:35	5:05	3, 7
8402-3-T over tank	B25339	4'7"	"	4:50	5:20	7, 7
8402-4-T	B284 11	4'5"	"	4:53	5:25	4, 4

split flow


8402 Spring Hollow Dr.
4
4'7"
3'10"
Heating
4
3
11"
11"
2'6"
carport
BG
shed

Soil Vapor Site Log

Case #: 2014-5107

Address: COASTAL
1 Sterling Point Island

Category #: 3, initial report says 2

Date: 3/29/2018

Time: 10:00 am

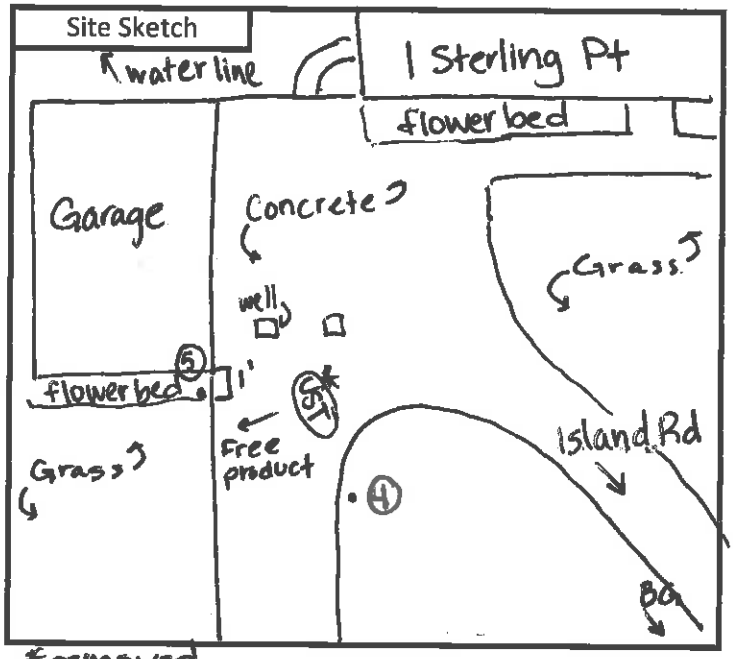
Weather:
sunny. 70-75°F (25°C)

Max TPH-DRO	
ID =	
Concentration =	
Depth =	

Tank Removed? = Y
Excavation Dimensions =

Stone Backfill? =
Depth (ft) Rock Encountered? =

Site Sketch



*removed

Additional Notes

Ambient air sample taken.
2BG's 1 Amb

1 BG w/ hand auger, split w/ Carbopack
electricity above ground. hit water table on (4)
olefactory on (4)

Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time
1-1-T 1-1-C BG	B29378 B24598	1' 8"	28 on m 30 on m	10:20	10:50
1-2-T Ambient	B25320	0	28 on m	10:21	10:51
1-3-T BG	B28433	1'8"	28 on m	10:30	11:00
1-4-T ☆ 1-4-C	B28426 B24570	5'	28 on m	10:43	11:13
1-5-T	B25358	4'7"	28 on m	10:49	11:19

near tank

Soil Vapor Site Log

Case #: 2014-[redacted]5049 Coastal

Address: 3000 Oakley Hall Road, Portsmouth.

Category #: 2

Date: 3/29/2018

Time: 12:24 pm.

Weather: Sunny. 25° slightly windy

Max TPH-DRO	
ID =	
Concentration =	
Depth =	

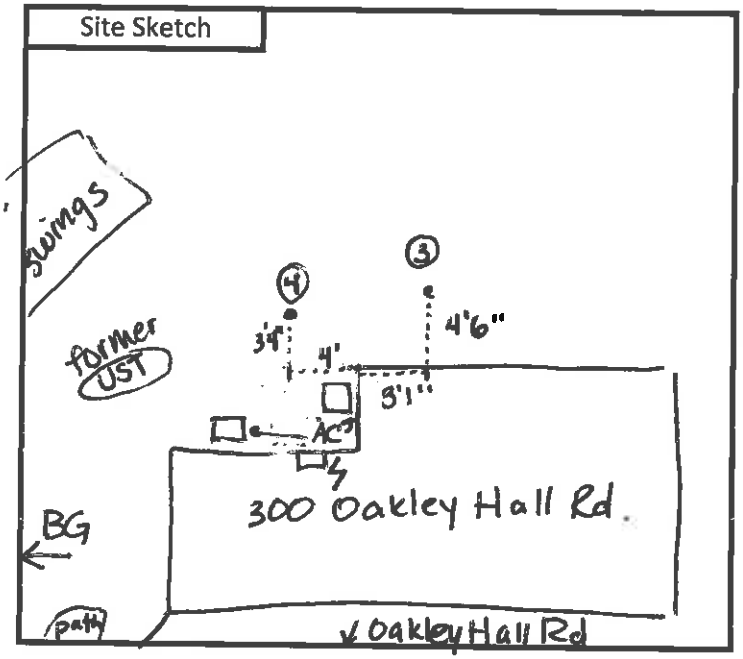
Tank Removed? =

Excavation Dimensions =

Stone Backfill? =

Depth (ft) Rock Encountered? =

Site Sketch



Additional Notes

2 BG, 1 hand augered, 0 amb (too windy)
known free product migration towards ③
olefactory ③

	Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time
BG	3000-1-T	B28464	2'4"	28 on m	12:30	1:00
	3000-1-C	B24524		28 on m		
BG	3000-2-T	B25103	2'9"	28 on m	12:35	1:05
	3000-3-C	B24242	4'4"	28 on m	12:47	1:17
	3000-3-T	B25117				
	3000-4-T	B28278	5'1"	"	12:56	1:26

Soil Vapor Site Log

Case #: 2014-5104

Address: COASTAL
120 Oslo Ct, Williamsburg

Category #: 3, marked in report as 2

Date: 3/29/2018

Time: 3:20 pm

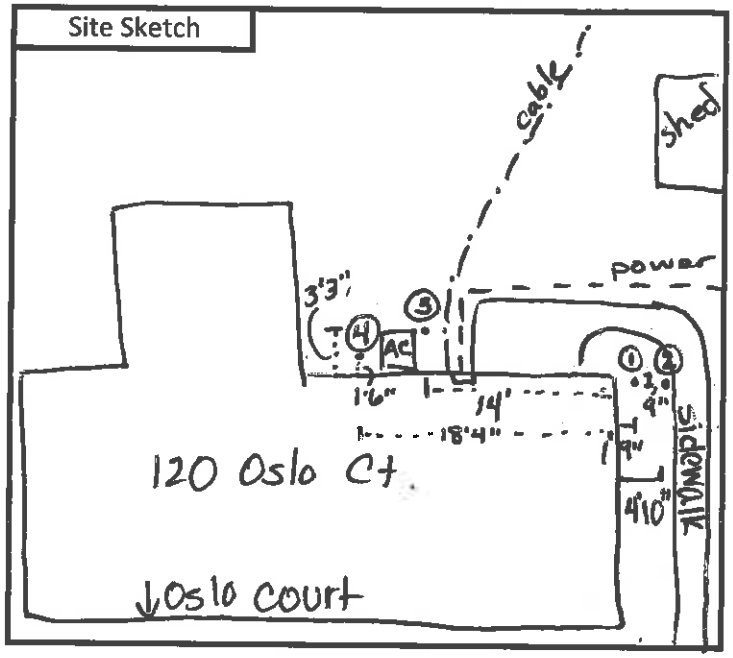
Weather:
upper 70°F's, sunny, windy

Max TPH-DRO	
ID =	
Concentration =	
Depth =	

Tank Removed? = Y
Excavation Dimensions =

Stone Backfill? =
Depth (ft) Rock Encountered? =

Site Sketch



Additional Notes
2 BG, ① Augered. 1 ambient
③ olefactory (bit connected to tubing may be from previous site)

Sample ID	Tube ID	Depth (ft)	Q (cc/min)	Start Time	End Time
auger 120-1-T	B28413	2'7"	28 on m	3:35	4:05
120-1-C BG	B24581				
120-2-T BG	B28432	1'8"	28 on m	3:40	4:10
over tank 120-3-T	B29705	4'8"	28 on m	3:47	4:17
120-3-C	B24548				
120-4-T	B28456	4'6"	28 on m	3:53	4:23
120-5-T Ambient	B25311	0'	28 on m	4:07	4:37

Soil Vapor Site Log

Case #	2012-4391
Address	2014 Woodland Rd Petersburg P/C → fall line?
Category	3
Date	5/23/2018
Time	6 pm
Weather	29°C, very humid, post rain

Max TPH-DRO	
ID	
Concentration	
Depth	

see back →

Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
flush → 2014-BG-1	B28389	2'3"	35	6:11		2	3
2014-BG-2	B28414	2'3"	↓	6:44		~~3~~	~~7~~
① 2014-1-1	B28378 ~~2'8"~~	11"		6:25		3	7
2014-1-2	B29844 ~~2'8"~~	11"		6:25		7	7
② 2014-2-1	B24524C	5'8"		6:33		5	8
2014-2-2	B28416T	5'8"		6:33		1	9
ambient → 2014-A	B28375	NA		6:58			

O2% 20.3

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

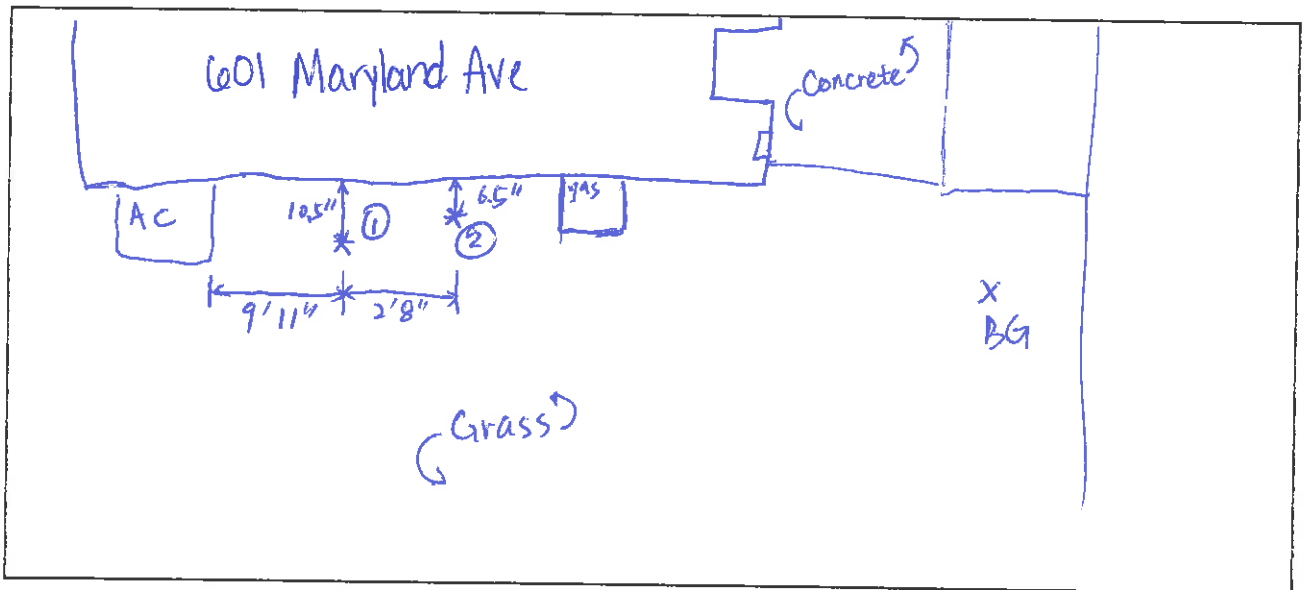
Notes: clay is very dry. will buy more
concerns about naphthalene generation on bag: running 2 tubes in a row to test directly after drilling

Soil Vapor Site Log

Case #	2016-5220
Address	601 Maryland Ave Virginia Beach C
Category	1
Date	5/24/2018
Time	8:54
Weather	mid 70°F (23°C) mid humidity

crawlspace

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
20.9%O_2 ~~601 Duplicate-BG~~	B28465T	2'6"	35	9:18	9:48	2	3
20.9%O_2 601-1-1	B24242C	2'10"	35	9:28	9:58	3	4
601-1-2	B25117T	2'10"	35	9:28	9:58	5	7
601-2	B28433T	3'2"	35	9:25	10:05		
601-A	B28369T	—	35	9:39		7	9

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

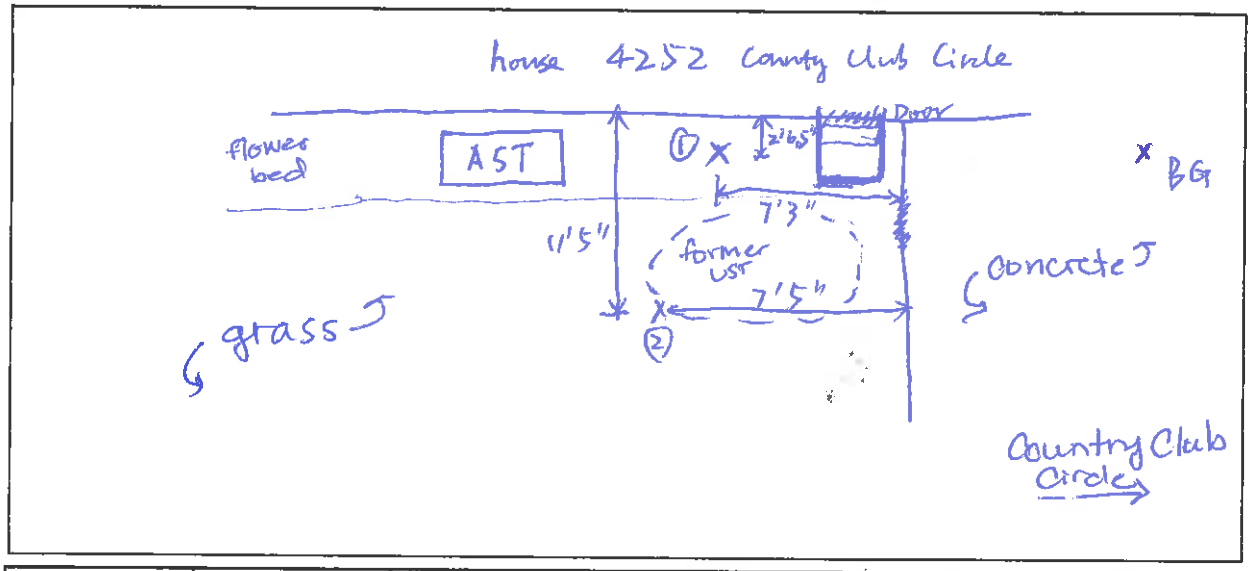
Notes: ~~BG- refreshed air w/out Tenax, then sampled~~ for ① & ②, refreshed air for 1 min before sampling

clay is very dry- some pathways may be open. WT is high

Soil Vapor Site Log

Case #	2018-5093
Address	4252 County Club Circle
Category	3
Date	05/24/2018
Time	11:55
Weather	Sunny, 26°C

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
4252-BG-1	B25320	1'10"	35	12:00	12:30	1	8
4252-1-C	B24560C	4'4"	1	12:13	12:43		
4252-1-T	B28457T	4'4"	1	12:13	12:43		
4252-2-T	B28413T	3'6"	1	12:13	12:43		
4252-BG-2	B28234	1'10"	↓	12:34			
4252-A	B28456T	—		30 min	—	3	71

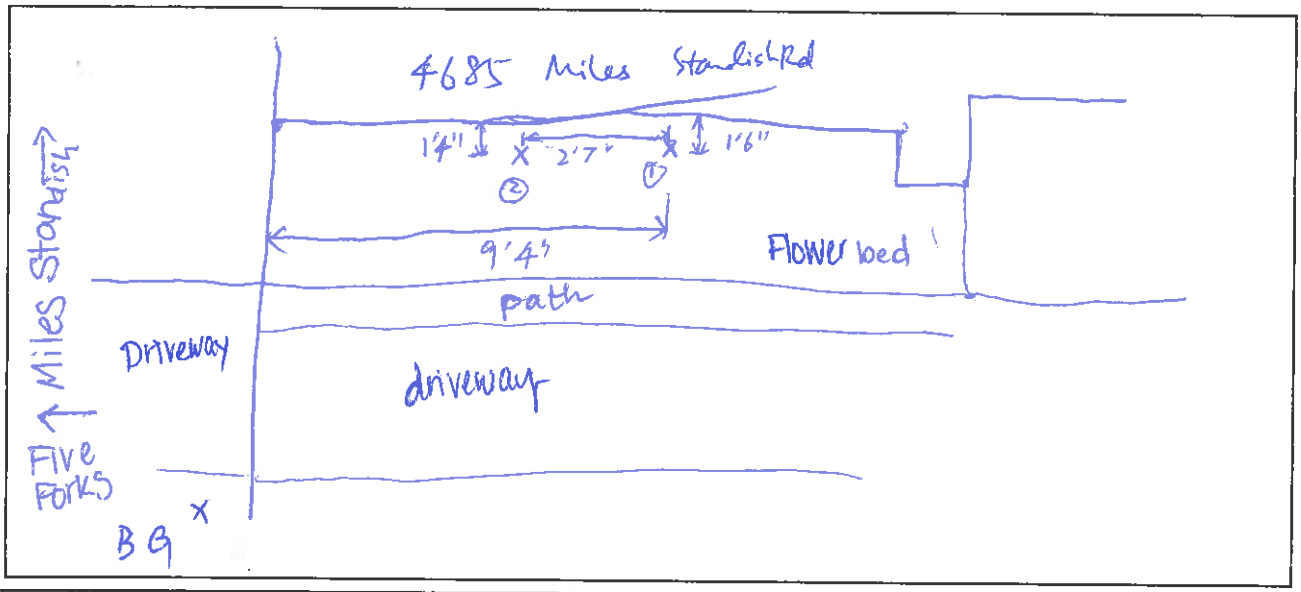
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: refreshed all probes by pulling air for 1 min before sampling
Clay is very dry.
A= ambient

Soil Vapor Site Log

Case #	2014-5110
Address	4685 Miles Standish Rd VA Beach C
Category	3
Date	5/24/2018
Time	2:26 pm
Weather	sunny low 80°F's

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
4685-BG-1	B28415T	1'3"	35	2:35	3:05	7	8
4685-1-1	B29705T	4'5"		2:42	3:12	3	9
4685-1-2	B24581C	4'5"		2:48	3:12	2	4
4685-2	B29831T	3'11"		2:49	3:19	1	3
4685-A	B28278T	—		2:52	3:32		

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

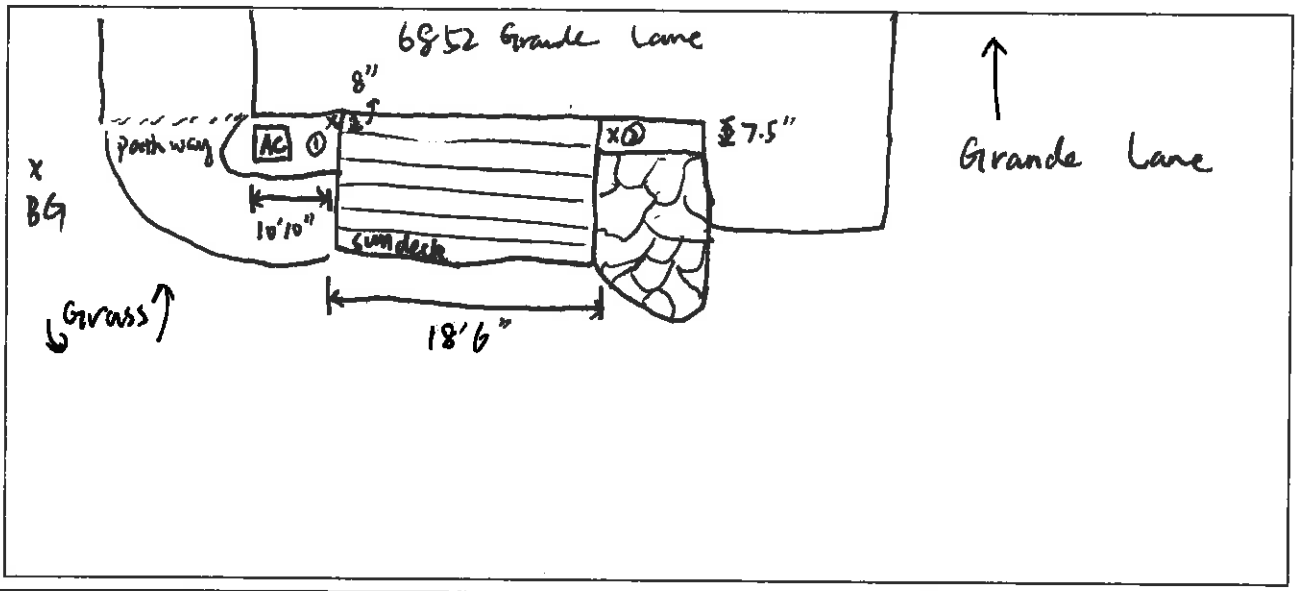
Notes: refreshed all except ①

Soil Vapor Site Log

Case #	2012-3172
Address	6852 Grande Lane Falls Church, VA
Category	– NFA
Date	6/6/2018
Time	2:19 pm
Weather	Mostly cloudy, 21°C

Max TPH-DRO	
ID	
Concentration	
Depth	

Basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	% O_2
6852-1-1T	B25117	4'6"	~~35~~ 9	2:39	3:09	5	4	15.5 R
6852-1-2C	B24524	4'6"	↓	2:39	3:09	7	7	
6852-BG	B25311	1'9"	↓	2:43	3:13	2	9	20.3%
6852-2	B29631	3'9"		2:47	3:17	1	10	20.9 A

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Don's know the location of UST.

R Rebounded to background (20.9%)

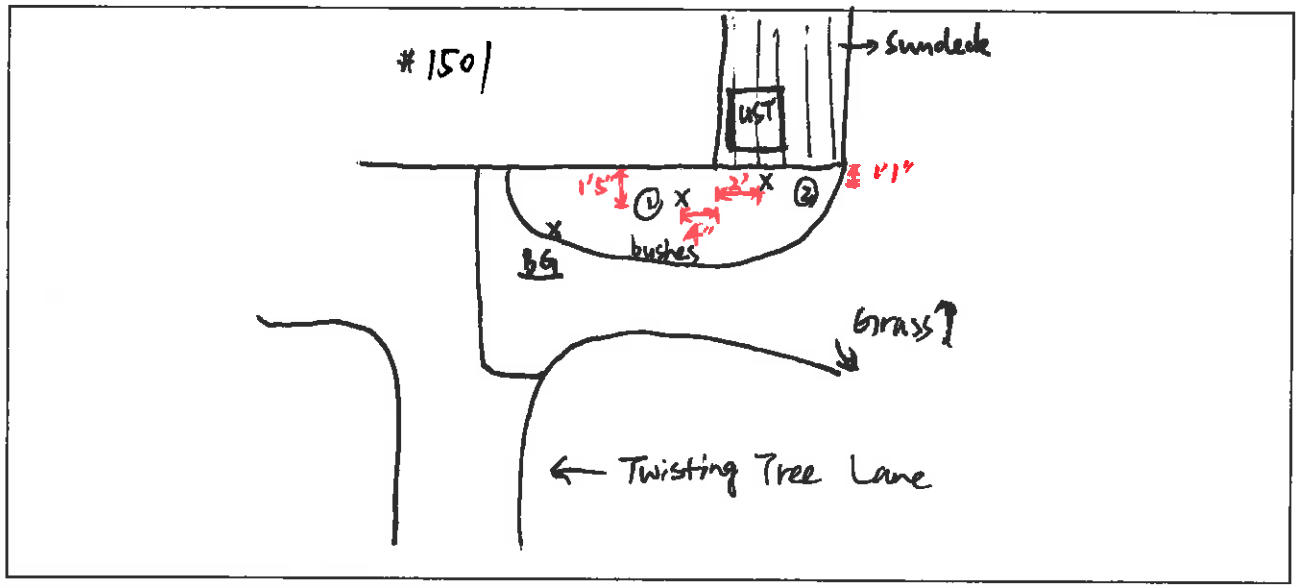
A Alarm sounded - repeated

Soil Vapor Site Log

Case #	2012-3084
Address	1501 Twisting Tree Lane, McLean, VA
Category	- NFA
Date	6/6/2018
Time	4:06 pm
Weather	Mostly Cloudy 21°C

Max TPH-DRO	
ID	
Concentration	
Depth	

Basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	
1501-1	B28432	3'11"	35	4:17	4:47	7	9	19.8
1501-2-1C	B24242	4'4"	↓	4:19	4:49	2	10	18.4 A
1501-2-2T	B28375	4'4"	↓	4:15	4:49	1	7	-18.9
1501-BG	B29698		↓	4:26	4:56	5	4	18.8-A
1501-A	B29831	-	↓	4:25	4:55	4	8	

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

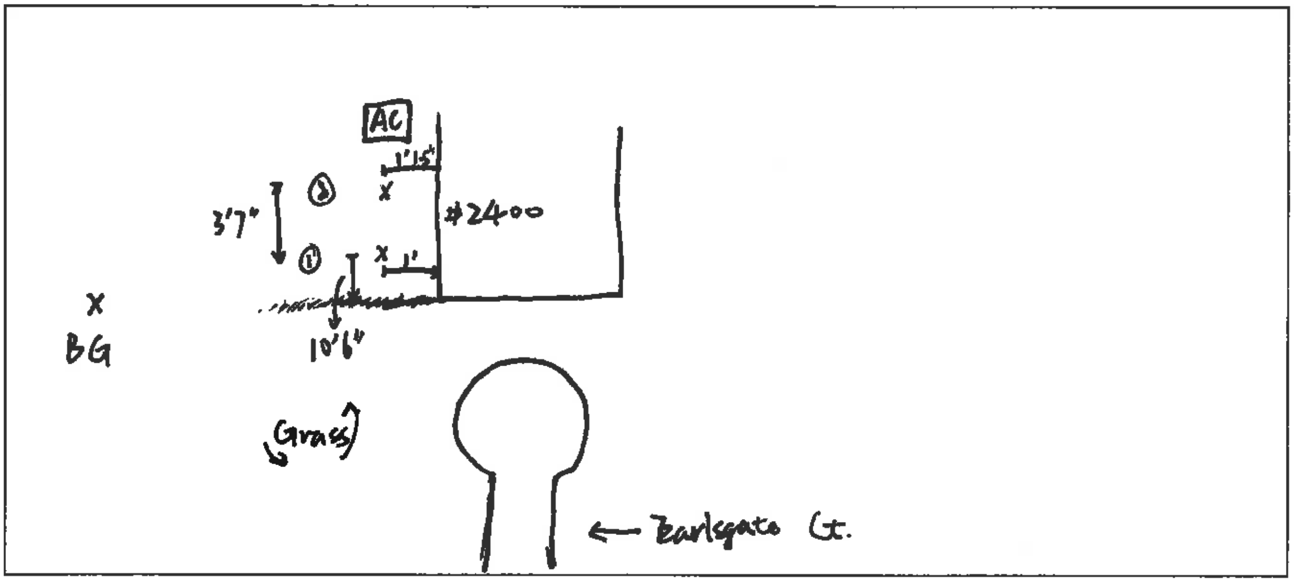
A Alarm

Soil Vapor Site Log

Case #	2014-3080
Address	2400 Earlsgate Ct. Reston.
Category	– NFA
Date	06/07/2018
Time	9:17 am.
Weather	Mostly cloudy 18°C.

Max TPH-DRO	
ID	
Concentration	
Depth	

Basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
2400-BG	B28389	2'	35	9:35	10:05	1	8
2400-1-1T	B28457	3'4"	↓	9:40	10:10	2	7
2400-1-2C	B24562	3'4"		9:40	10:10	~~4~~ 7	~~8~~ 4
2400-2	B28294	3'11"	↓	9:44	10:14	4	9

Margin notes: 10 = 10 ppm (beside 2400-1-1T / 2400-1-2C); 31 (beside 2400-2); 0.% ; 20.7 ~~19.9~~ (beside 2400-BG); 17.1 A, 17.5 (beside 2400-1-1T / 2400-1-2C); 16.1 (beside 2400-2)

Useful information: Stainless steel probe ~~7'3"~~ 4'3". 214 probe + retractable tip is 6'8".

Notes:

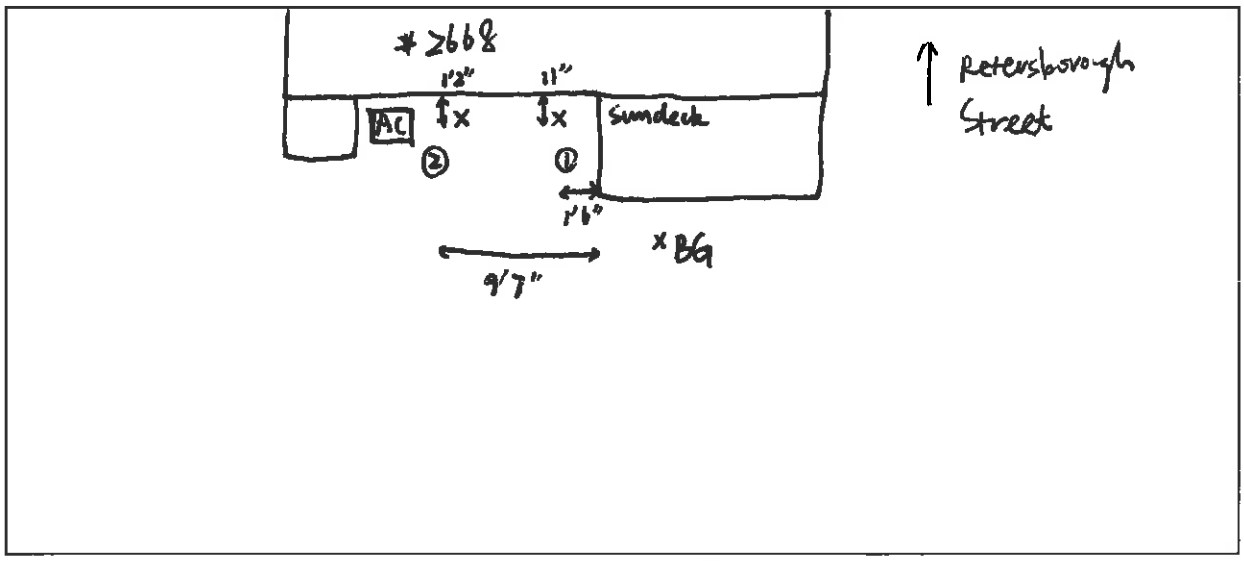
A Alarm

Soil Vapor Site Log

Case #	2010-3153
Address	2668 Petersborough Street, Herdon.
Category	– NFA
Date	06/07/2018
Time	10:49 am
Weather	~~Sunny~~ Partly Cloudy. 21°C

Max TPH-DRO	
ID	
Concentration	
Depth	

Basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
2668-BG	B25363	2'5"	35	11:01	11:31	1	4
2668-1-1T	B25322	5'	↓	11:07	11:37		
2668-1-2C	B24598	5"		11:07	11:37		
2668-2	B28414	4'3"		11:12	11:42	5	10

O_2%

20.9%

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

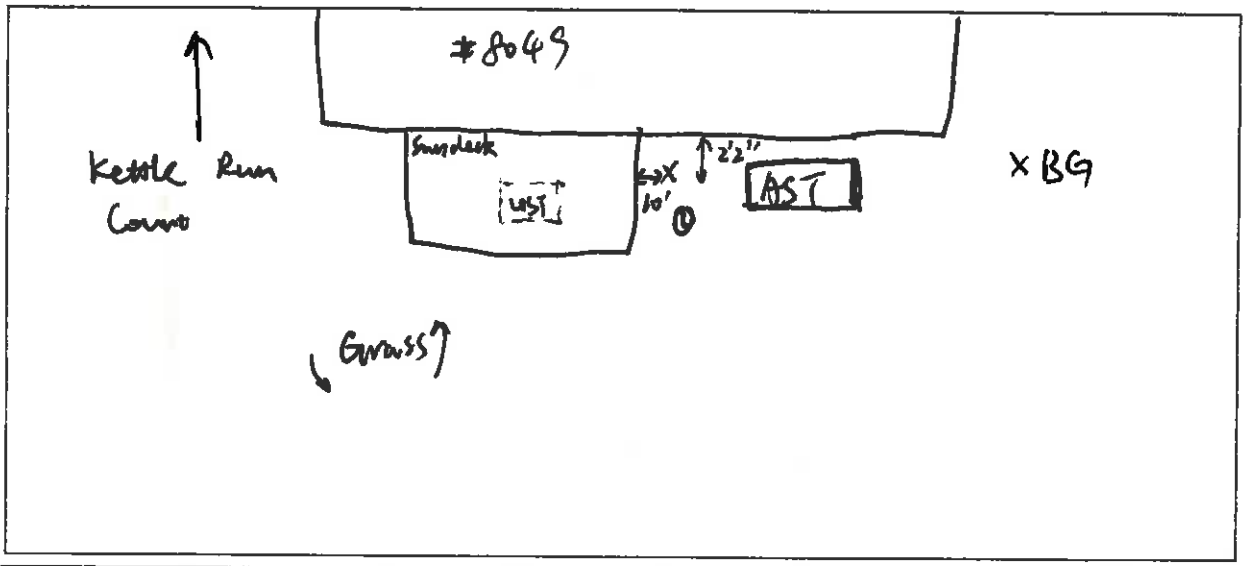
Notes: 4'3"

Soil Vapor Site Log

Case #	2009-3071
Address	8049 Kettle Run Lorton, Carlton, VA
Category	1
Date	06/07/2018
Time	1:52 pm
Weather	Sunny, 24°C

Max TPH-DRO	
ID	
Concentration	
Depth	

Basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
8049-BG	B28433	3'2"	35	2:01	2:31	1	3
8049-1-1T	B28465	3'10"	↓	2:09	2:39	2	8
8049-1-2C	B24560	3'10"	↓	2:09	2:39	7	10
8049-1A	B28378	~	↓	2:08	2:38	5	7

%O2
A 16.5-16.7%
20.9 A

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

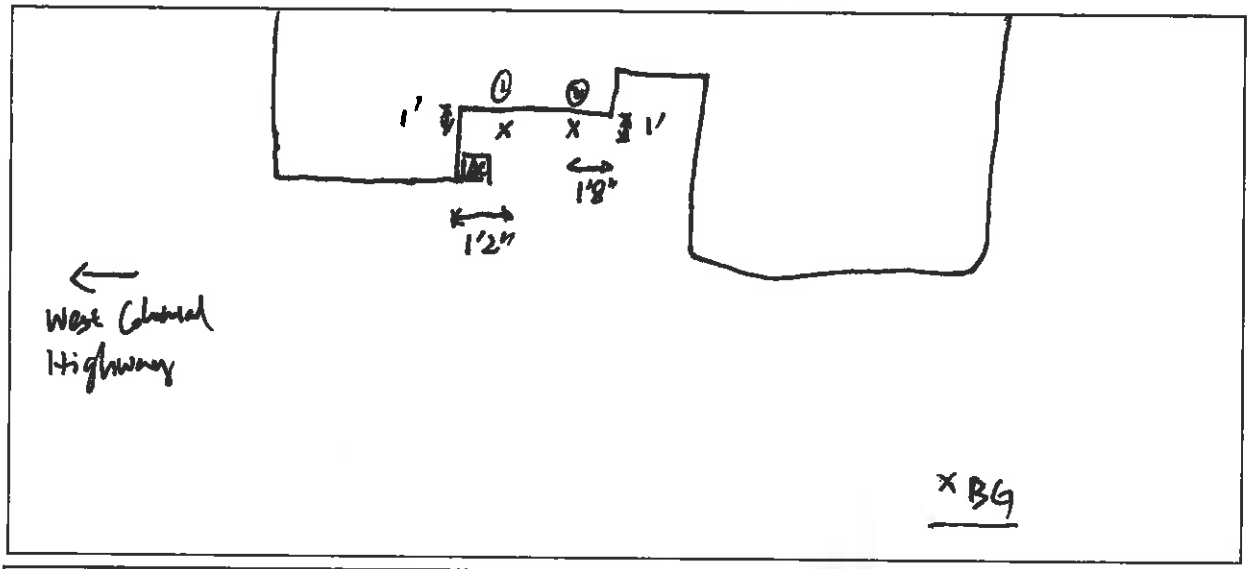
A Alarm

Soil Vapor Site Log

Case #	2016-3176
Address	38293 West Colonial Highway Hamilton.
Category	1
Date	06/07/2018
Time	4:06 pm
Weather	Sunny. 26°C

Max TPH-DRO	
ID	
Concentration	
Depth	

crawlspace



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	%O2
38293-A-in	B25320	–	35	4:17	4:47	2	8	
38293-BG	B28413	2'4"	|	4:17	4:47			17.7A
38293-1-1T	B28470	4'4"	|	4:26	4:56	4	10	19.6
38293-1-2C	B24570	4'4"	|	4:26	4:56	5	3	
38293-2	B28410	4'1"	↓	4:30	5:00	1	7	20.9
	[redacted]							
38293-A-out	B28369	–		4:49	4:19	2	8	

20 min

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

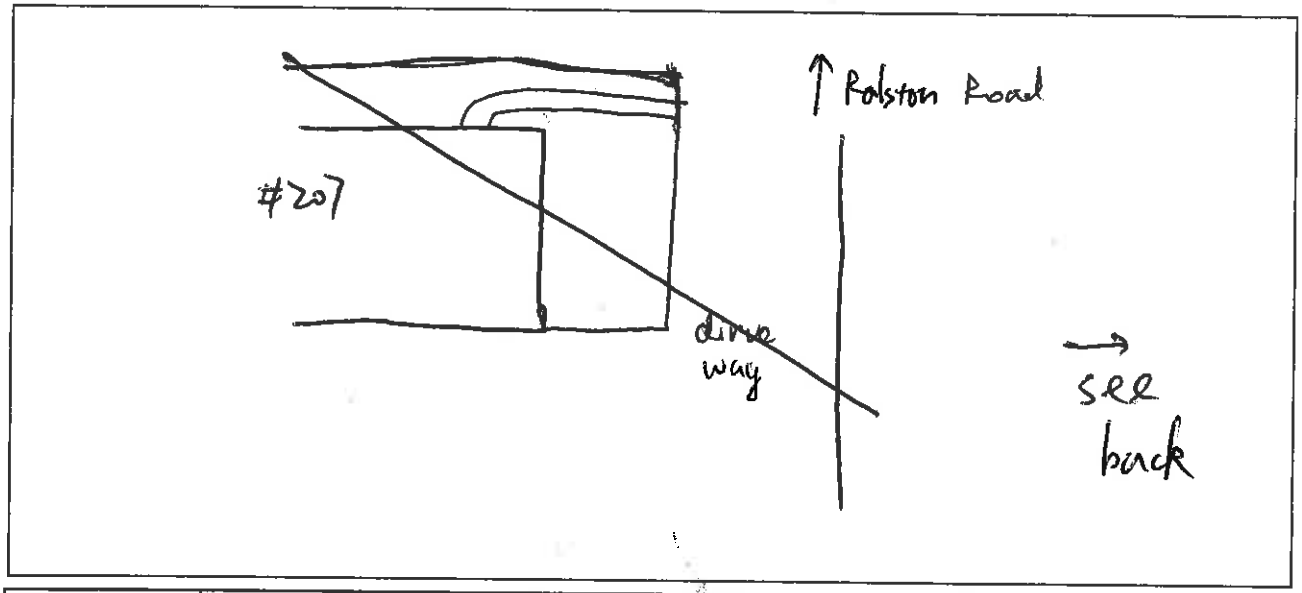
Notes:

A = Alarm

Soil Vapor Site Log

Case #	2018-4244
Address	207 Ralston Road, Richmond
Category	1
Date	06/13/2018
Time	11:57
Weather	Mostly cloudy. 25°C

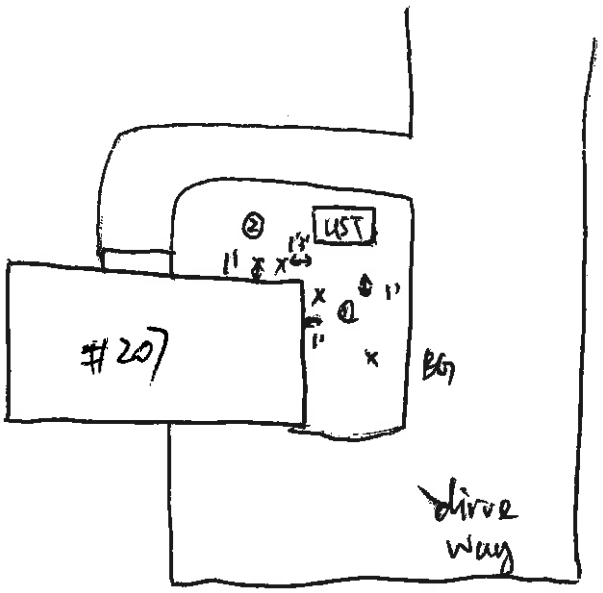
Max TPH-DRO	
ID	
Concentration	
Depth	



CO	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	O2
0	207-BG-a	B28413	2'1"	35	12:03	12:33	5	7	20.9%
0	207-1-1C	B24522	4'1"	↓	12:09	12:39	2	3	10.1%
	207-1-2T	B25358	4'1"		12:09	12:39	4	8	
8 ppm	207-2	B28454	5'1"		12:13	12:43	7	9	18.5

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

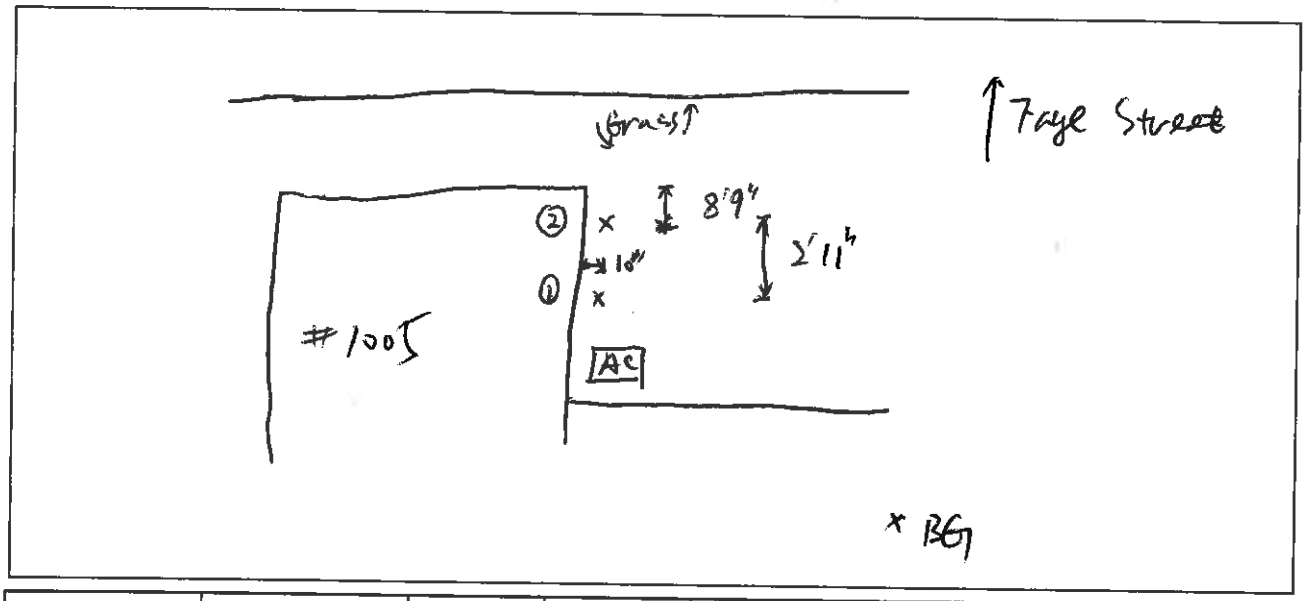
Notes: 4 Alarm


UST
#207
EG
driveway

Soil Vapor Site Log

Case #	2008-4740
Address	1005 Faye Street. Richmond
Category	2
Date	06/12/2018
Time	2:19
Weather	Sunny, 25°C

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	O_2 %
1005-BG-a	B25117	2'9"	35	2:29	2:59	7	9	14.3
1005-1-1C	B24562	3'6"	↓	2:39	3:09	2	8	20.9
1005-1-2T	B28415	3'1"	↓	2:39	3:09	4	3	
1005-2	B28432	3'8"	↓	2:40	3:10	5	7	20.9

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: Alarm

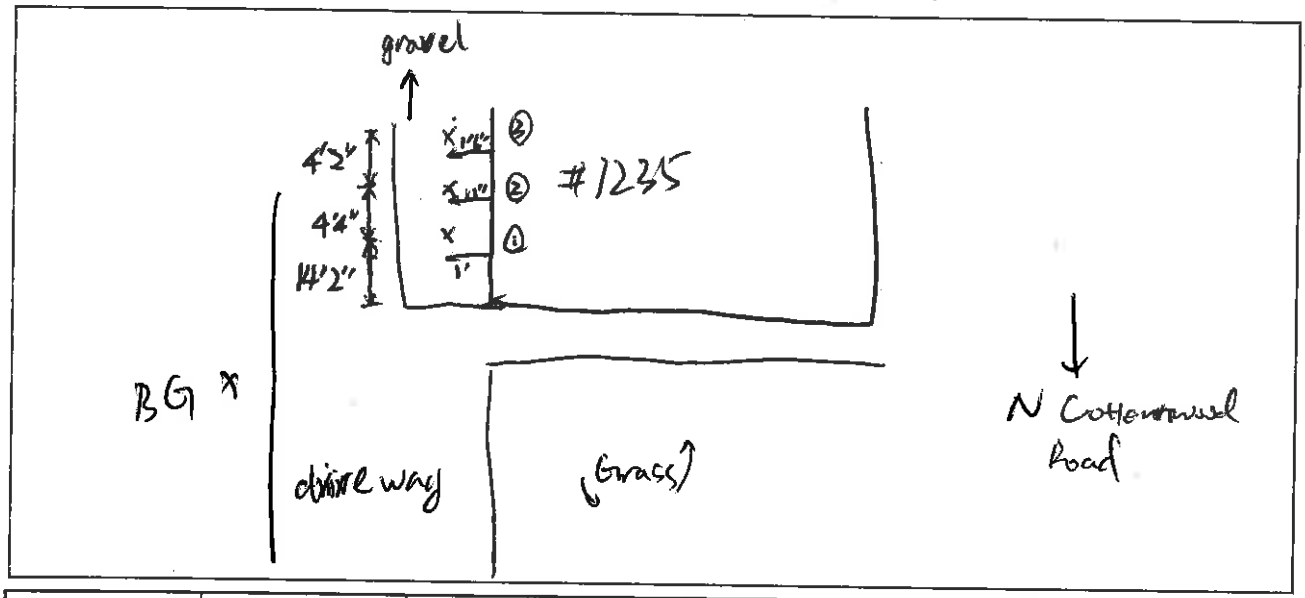
4'3"
1'8

Soil Vapor Site Log

Case #	2016-4303
Address	1235 N Cottonwood Road, North Chesterfield
Category	3
Date	06/13/2018
Time	3:47
Weather	Sunny, 29°C

Max TPH-DRO	
ID	
Concentration	
Depth	

Crawlspace



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
1235-BG	B29831	2'4"	35	3:50	4:20	5	3
1235-1-1C	B24560	3'8"		4:00	4:30	4	7
1235-1-2T	B25311	3'8"		4:00	4:30	2	10
1235-2	B25103	4'5"		4:00	4:30		
1235-3A	B29631	0		4:05	4:35	1	9
1235-3B	B29844	1'11"		4:12	4:42		
1235-C	B28433	-		4:23	4:53	5	3

CO ppm: — / — / 7 / 13 → | O2%: 19.6 / 20.3 / 20.3 / 20.9

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

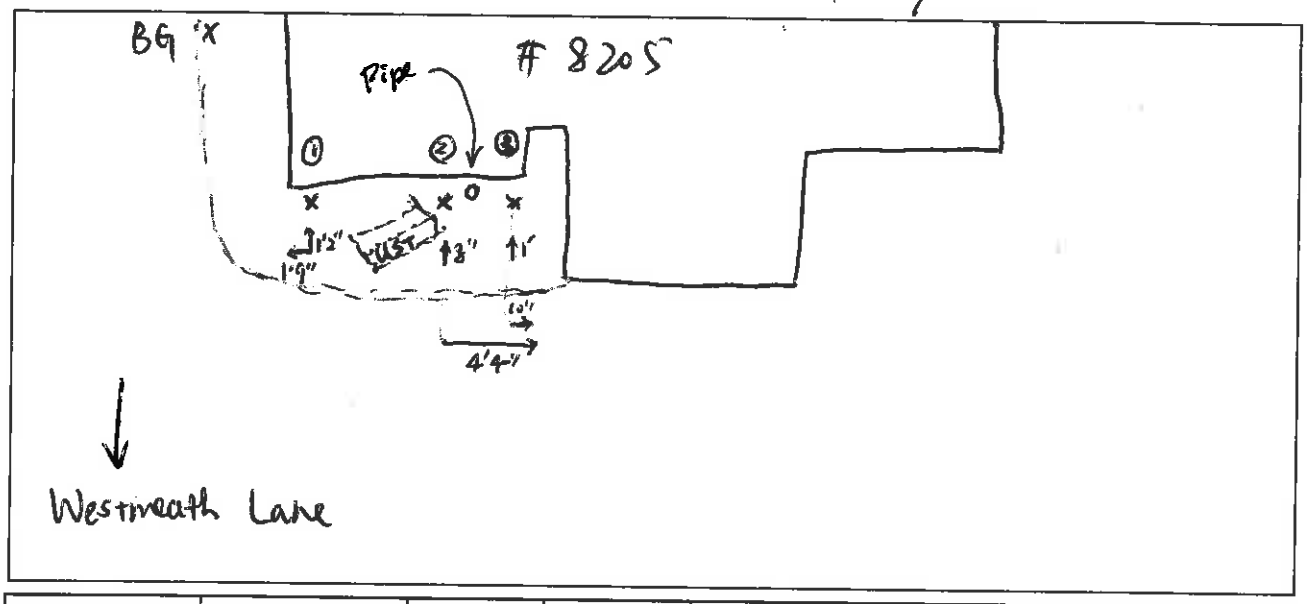
Notes: A - Ambient air
C - Crawspace

Soil Vapor Site Log

Case #	2011-4435
Address	8205 Westmeath Lane, Richmond
Category	⑤ – NFA
Date	06/14/2018
Time	8:48
Weather	Sunny. 26°C

Max TPH-DRO	
ID	
Concentration	
Depth	

~~tank location unknown~~
Crawlspace



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
8205-BG	B25322	1'3"	35	9:02	9:32	1	4
8205-1-1C	B24598	3'3"	↓	9:11	9:41	5	9
8205-1-2T	B28414	3'3"	↓	9:11	9:41	3	10
8205-2	B28465	2'10"	↓	9:26	9:56	4	3
8205-3	B28455	2'8"		9:20	9:50	2	7

200z
198
20-8

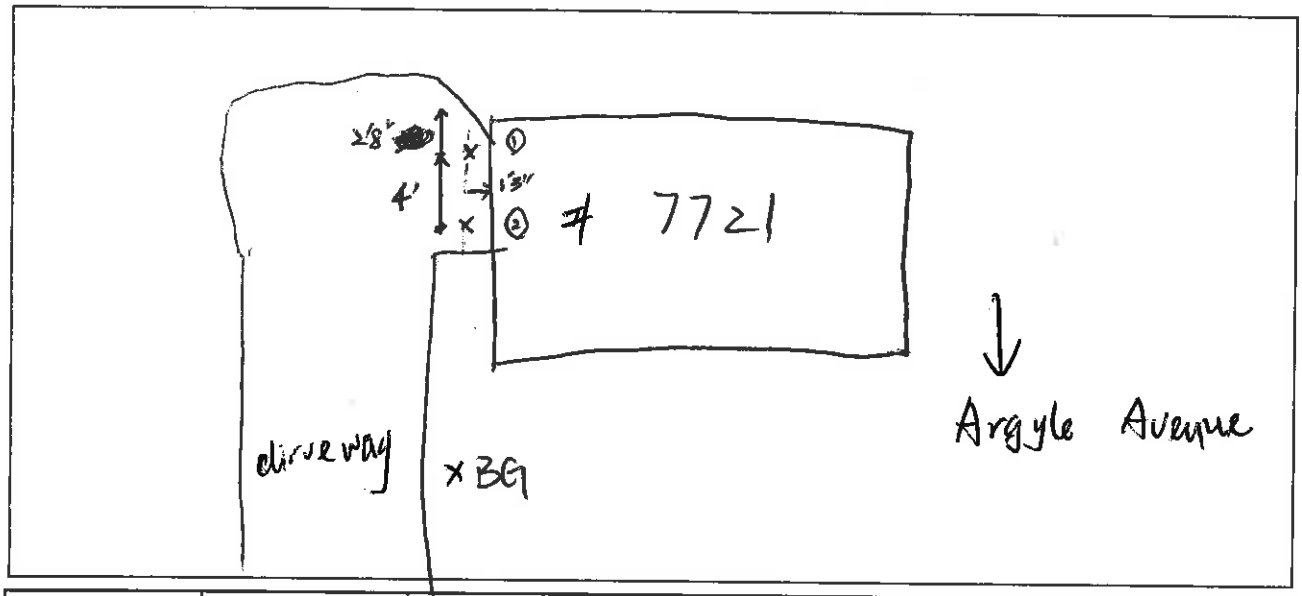
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: duct tape used to reenforce area where teflon comes out of probe.

Soil Vapor Site Log

Case #	2010-5157
Address	7721 Argyle Avenue. Norfolk.
Category	2
Date	06/14/2018
Time	12:17
Weather	Sunny, 28°C

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	
								O_2%
7721-BG	B28369	3'1"	35	12:24	12:54	1	3	20.9
7721-1-1C	B24570	6'	↓	12:29	12:59	5	9	>20.9
7721-1-2T	B28414	3'		12:29	12:59	3	10	>20.9
7721-2	B25339	2'4"	↓	12:32	12:02	2	4	20.9

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

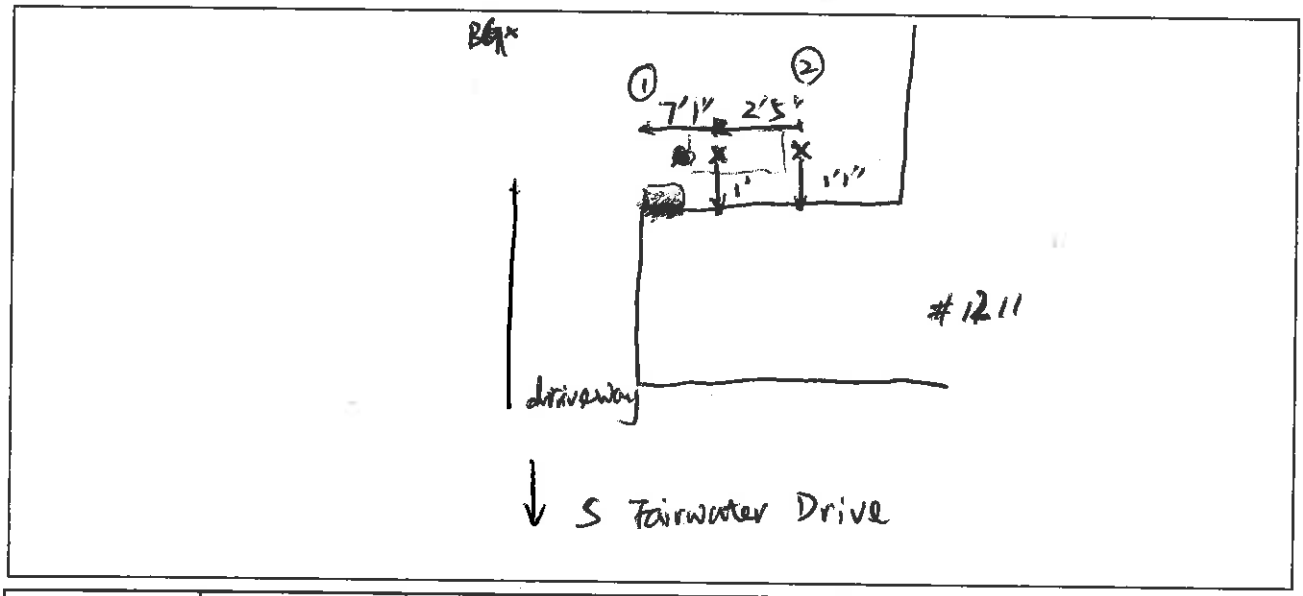
Notes: Alarm

Soil Vapor Site Log

Case #	2014-5018
Address	1211 S Fairwater Drive Norfolk
Category	2
Date	06/14/2018
Time	2:12
Weather	Sunny, 28°C

Max TPH-DRO	
ID	
Concentration	
Depth	

slab



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	O_2
1211-BG	B28450	1'8"	35	2:25	2:55	2	7	19.8 A
1211-1-1C	B24548	5'	↓	2:32	3:02	3	3	20.9
1211-1-2T	B28334	5'	↓	2:32	3:02	4	9	20.9
* 1211-2	B25363	4'9"	↓	2:44	3:14	1	4	20.9 A

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

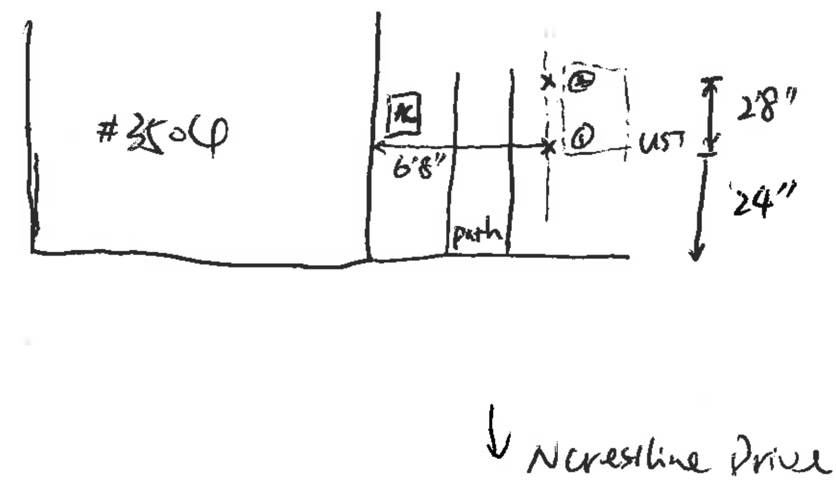
Notes: Sample 2 - Retractable tip appeared closed when removed

Soil Vapor Site Log

Case #	2010-5161
Address	3504 N Crestline Drive, Virginia beach
Category	2
Date	06/14/2018
Time	
Weather	Sunny, 29°C

Max TPH-DRO	
ID	
Concentration	
Depth	

Crawlspace



CO ppm	Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	% O_2
0	3504-BG	B29680	1'	35	4:20	4:50	3	7	18.2
0	3504-1-1C	B24524	2'8"	↓	4:24	4:54	7	10	20.9 A
	3504-1-2T	B28375	2'8"		4:28	4:54	5	3	
7	3504-2	B25320	4'4"		4:31	5:01	1	9	20.9
	3504-CS	B28456	—	35	4:36	5:06			—
	3504-A	B28470	—		4:37	5:07	4	8	—

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

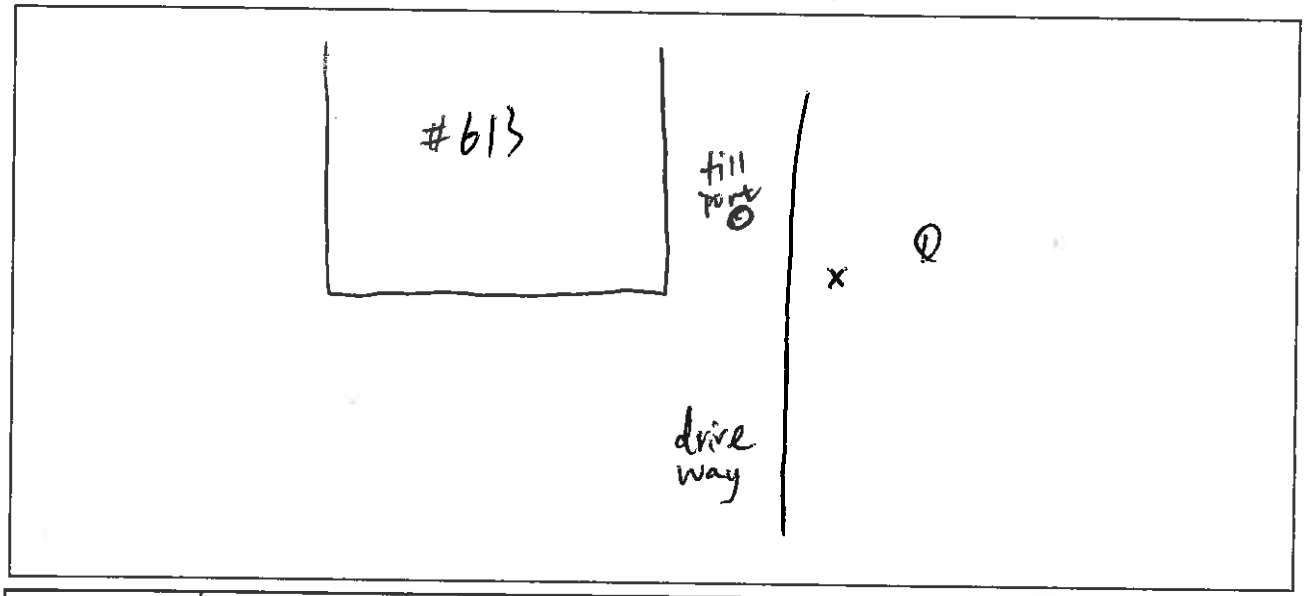
2'4'

Notes: Alarm

Soil Vapor Site Log

Case #	2017 - 5155
Address	~~4121 Indigo Drive Virginia Beach~~ 613 Greentree Drive, VB.
Category	N7A
Date	06/14/2018
Time	5:51
Weather	Sunny, @ 29°C

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
~~2017~~ 613-1-1C	B24242	2'4"	35	6:02	6:32		
613-1-2T	B28278	2'6"	↓	6:02	6:32		

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

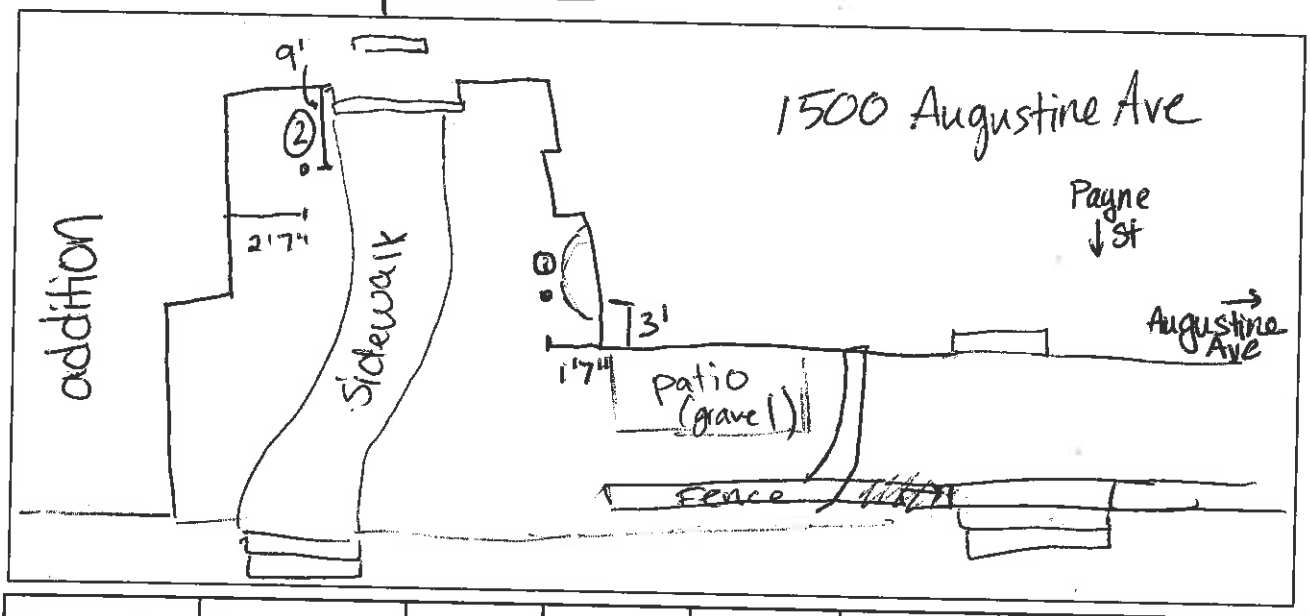
Notes: Oil is wet

Soil Vapor Site Log

Case #	2015-3038
Address	1500 Augustino Ave Fredericksburg (P)
Category	NFA
Date	6/20/2018
Time	9:00 am
Weather	81°F 63%H sunny

Max TPH-DRO	
ID	
Concentration	
Depth	

basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
20.9%O 1500-1-1 T	B25358 T	3'	35	30 min	—	2	4
1500-1-2 C	B24570 C	3'	↓	↓	↓	5	7
20.2%O 1500-2 T	B25320 T	2'6"	↓	↓		7	7
1500-A	B28457 T	—	—			3	8

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

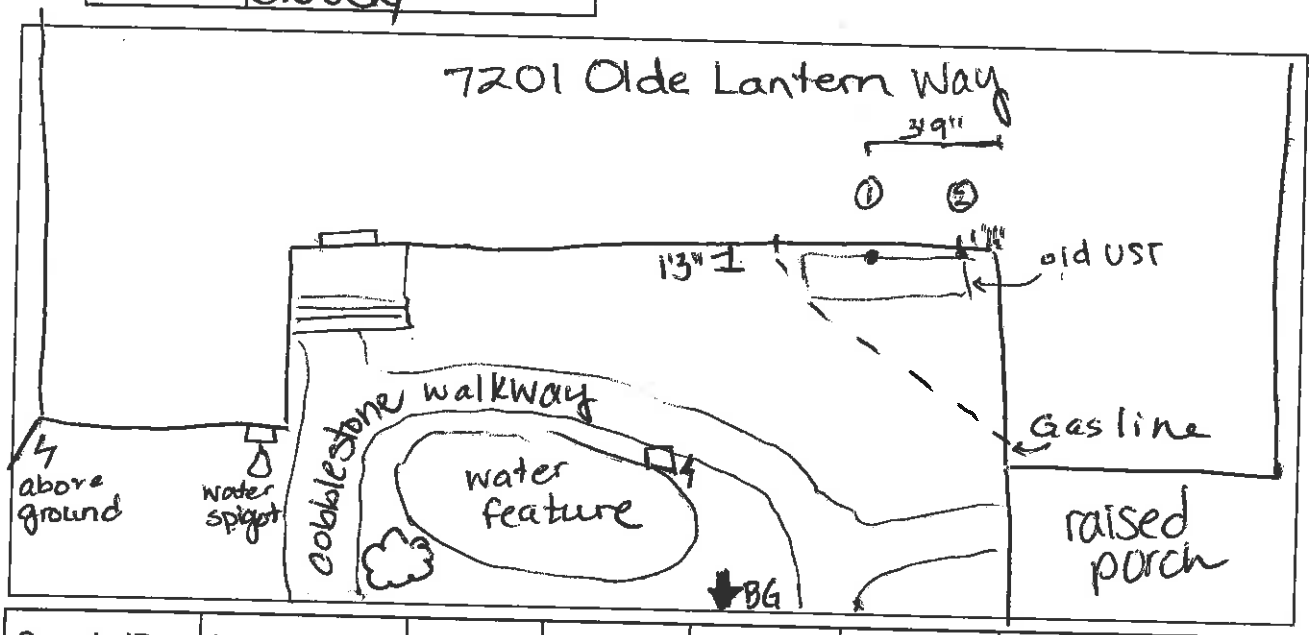
Notes: no bg's. homeowner warned us about high water table

Soil Vapor Site Log

Case #	2015-3028
Address	7201 Olde Lantern Way (P) Springfield
Category	NFA
Date	6/20/2018
Time	11:30am
Weather	80°F 87% H cloudy

Max TPH-DRO	
ID	
Concentration	
Depth	

basement



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #	% O2
[redacted]								
7201-BG	B25311 T	2'9"	35	11:41		7	7	13.3
7201-1-1	B28375 T	1'5"		30 min		5	7	20.2
7201-1-2	B24242 C	1'5"				2	4	
7201-2	B29698 T	1'4"				1	9	20.9

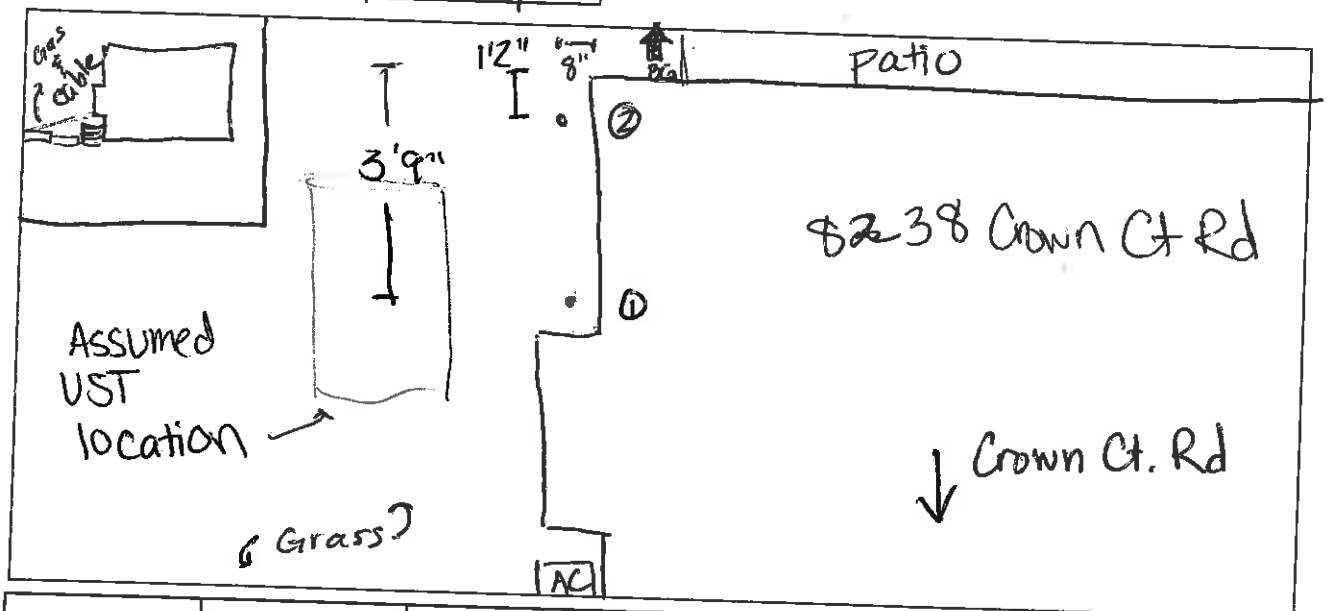
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: ① odor

Soil Vapor Site Log

Case #	
Address	8238 Crown Ct Rd Alexandria ("C")
Category	NFA
Date	6/20/2018
Time	2:00 pm
Weather	81°F 62% H partly cloudy

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
8238-BG	B25103 T	2'6"	35	30 min			
8238-1-1	B28294 T	4'2"	↓	↓			
8238-1-2	B24560 C	4'2"	↓	↓			
8238-2	B28432 T	4'8"	↓	↓			

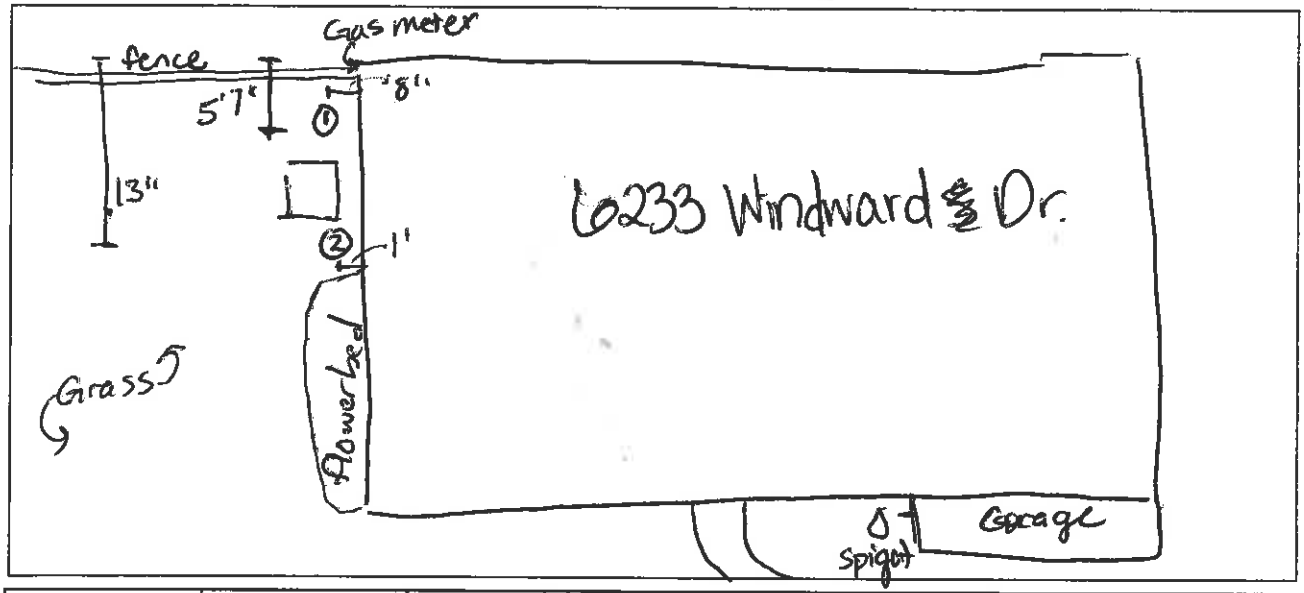
Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes:

Soil Vapor Site Log

Case #	2011-3081
Address	6233 Windward Dr Burke P
Category	NFA
Date	6/20/2018
Time	4:30 pm
Weather	light rain 79°F 71% H

Max TPH-DRO	
ID	
Concentration	
Depth	



Sample ID	Tube #	Depth (ft)	Q (ccm)	Start Time	End Time	Pump #	Tube #
6233-1-1	B28413 T	4'1"	35	30 min			
6233-1-2	B24522 C	4'1"					
6233-2-1	B28413T	4'					
6233-2-2	B24562 C	4'					

Useful information: Stainless steel probe 7'3". 214 probe + retractable tip is 6'8".

Notes: ② wet clay pulled up when probe removed