Heating Oil Vapor Intrusion Study

Virginia Department of Environmental Quality
September 22, 2022

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Terms and Acronyms Used

Coefficient of determination (R2) – A statistical measure in a regression model that determines the proportion of variance. This essentially examines how the differences in one variable may be explained by differences in a second variable.

Mean – the mathematical average of all of the values

Median – the middle number in a set of numbers that are sorted in ascending or descending order.

Null hypothesis (H0) – a statistical hypothesis which suggests that two possibilities are the same (e.g. there is no difference in means between two sets of observations).

OSRR – Office of Spill Response and Remediation located in DEQ Central Office

Percentile – a measure used in statistics indicating the value below which a given percentage of observations in a group fall. For example, the 90^{th} percentile is the value below which 90% of the population will be found.

Standard deviation – a statistical measure of the amount of variation or dispersion of a set of values.

SCR – Site Characterization Report

VT – Virginia Tech. DEQ contracted with Virginia Tech in 2017 to collect soil vapor samples at home heating oil sites.

Wilcoxon-Mann-Whitney (WMW) test – A statistical test that may be used to compare population distributions and determine if they are identical without assuming that those populations follow a normal distribution.

Executive Summary

The Virginia Department of Environmental Quality (DEQ) is responsible for ensuring that actions needed to protect human health and the environment are taken following the release of petroleum into the environment. Vapor intrusion from petroleum release sites has been evaluated extensively by EPA and others, however, most of these studies and the resulting guidance focused upon vapor intrusion risks associated with gasoline released from regulated USTs. Vapor intrusion risks associated with releases from home heating oil USTs was identified by DEQ staff and stakeholders as an area where additional information was needed.

A previous study performed by Virginia Tech for DEQ assessed some of the risks of vapor intrusion after site work was performed. DEQ wanted to obtain more information about the potential for vapor intrusion risks at home heating oil release sites prior to any site work to ensure that current guidance is protective of human health. DEQ staff developed a study where consultants performing site work collected soil vapor samples as part of the site characterization process; participation was voluntary. This document describes the heating oil soil vapor study undertaken by DEQ, the procedures utilized in the study, and the findings and recommendations.

Soil vapor samples were collected at one hundred and six (106) home heating oil release sites. The data collected suggest that vapor intrusion risks at heating oil sites vary by category, structure type, and physiographic province within Virginia. In general, vapor intrusion risks associated with category 1 home heating oil cases were minimal. Risks associated with vapor intrusion at category 2 sites were more significant; especially prior to tank and soil removal which typically takes place at these sites. Houses with basements generally appeared to have greater potential risks associated with vapor intrusion than did houses with crawlspaces. Also, vapor intrusion risks were typically highest in the Piedmont Physiographic province and lowest in the Coastal Plain.

The findings of this study indicate that DEQ's present home heating oil procedures are protective against vapor intrusion risks if current heating oil tank cleanup guidance is followed. The study results pointed out the importance of tank and soil removal at Category 2 and Category 3 home heating oil sites, activities which are typically undertaken at these sites. Where tank and contaminated soil removal cannot be performed at a Category 2 or Category 3 case, staff and the tank owner/operator's consultant should evaluate the need to install a vapor abatement system. A vapor abatement system may be especially important where the Category 2 or Category 3 case has a basement and is located in the Piedmont Physiographic province.

1.0 Introduction

The DEQ Storage Tank Program is responsible for ensuring that petroleum releases are evaluated for their risk of impacting receptors and that the necessary cleanup actions are taken to protect human health and the environment. DEQ has had specific heating oil cleanup guidance in place since 2007, which can be found in the DEQ Tank Technical Manual. In accordance with guidance, staff assign each heating oil case to an initial cleanup Category (ranging 1-3) or No Further Action based on site criteria. This categorization system, using a variety of screening tools including TPH values, was intended to protect individuals and the environment from petroleum released from heating oil tanks. Although this categorization system had been implemented for a number of years, staff and the regulated and consulting communities identified vapor risks posed by home heating oil tank releases as an area needing further evaluation to determine if the current classification system was protective of human health.

Evaluating petroleum vapor intrusion risks from leaking underground storage tanks to structures presents unique challenges. Many petroleum constituents are ubiquitous in indoor air (regardless of nearby storage tanks/releases) as they are found in regular household products and building materials. Some of these constituents are often present in indoor at concentrations that exceed typical risk thresholds. Moreover, many constituents cannot be detected via olfactory senses at concentrations that may pose long-term risks via the indoor air exposure pathway (EPA 1992, American Industrial Hygiene Association 1989).

DEQ contracted with Virginia Tech in 2017 to collect soil vapor and other data at closed home heating oil release sites throughout the Commonwealth. The purpose of this study was to gain a better knowledge of potential vapor intrusion risks at home heating oil release sites. The Virginia Tech study, finalized in 2019 and summarized in Appendix E, provided useful information, but was limited in scope due to difficulties with gaining site access since the study targeted only closed cases. The length of time elapsed between the release report date and the follow-up vapor sampling performed by Virginia Tech ranged from 1 – 10 years.

Following the completion of the Virginia Tech study, DEQ staff believed that additional data was needed and that a more timely approach to data collection would help the agency to obtain the necessary data. DEQ staff developed a study where soil vapor samples would be collected as part of the site characterization process at active Category 1, 2, and 3 home heating oil release sites. The DEQ study utilized the tank owner's environmental consultants for collecting the soil vapor samples and these samples were collected before any site work such as product removal from the tank or soil excavation was performed. The study was set up this way so that DEQ could evaluate the Category system and determine if it adequately protected human health from petroleum vapor intrusion. This document describes the heating oil soil vapor study undertaken by DEQ, the procedures utilized in the study, and the findings and recommendations. Ultimately, the goal of this project is to provide the data which staff may use to develop vapor intrusion guidance for home heating oil release sites.

2.0 Study Procedures

DEQ organized a committee composed of Central Office and Regional staff to develop the home heating oil soil vapor study. A Charter was crafted describing the purpose of the committee (Appendix D). Staff evaluated the merits of using State Lead Contractors for collecting soil vapor samples or reimbursing the tank owner's contractor/consultant, since they would already have access to the property. DEQ decided that the most expeditious and least intrusive route for the tank owner was to use the tank owner's consultant, if they were interested in participating. These consultants would be responsible for gathering the pertinent site information as well as collecting soil vapor and ambient air samples. DEQ staff would analyze the data provided by the consultant.

DEQ reached out to multiple consultants across the Commonwealth with the goal of gaining comprehensive coverage for this study across the entire state. Fourteen (14) consultants agreed to collect samples and site data for this study with each DEQ region having at least 3 participating consultants. The workgroup members believed this was an appropriate number of participating consultants and would enable the collection of a sufficient amount of data.

2.1 Site selection

In order to minimize biases related to selecting sites included in the study, DEQ staff utilized a stratified random sample collection procedure. Staff generated tables with randomly highlighted rows (random table) for each DEQ region before the study was initiated. Case selection frequency varied per region based on historical numbers of home heating oil cases in the region. Once the study commenced, new cases were placed into the table with randomly highlighted rows in the order in which they were reported to the region. Cases that "fell" into a randomly selected, highlighted row were included in the study, provided that the consultant for that case had agreed to participate in the study. If the associated consultant chose not to participate in the PVI evaluation for a targeted project, the case would be handled as a normal heating oil case and no vapor sampling would occur. Staff would continue adding cases to the random table and proceed to the next randomly selected row.

The study included heating oil releases from underground storage tanks (USTs) initially assigned to Categories 1, 2 or 3. Releases assigned the Category of No Further Action (NFA) were not included in the study. Some of the cases included in this study were ultimately upgraded to the next category based on soil analytical data. Vapor sample data generated for this study was not used to upgrade cases. Rather, vapor sampling data was used to evaluate the current guidance to determine if that guidance protected persons from petroleum vapor intrusion at home heating oil release sites. The categories in the discussion and tables included in this report represent the FINAL category assigned to each case.

This study needed both sufficient numbers of cases statewide and within each of the physiographic provinces. Heating Oil PVI workgroup members evaluated the location of sites selected for this study to determine the physiographic province in which they were located. As the study progressed, DEQ reached sufficient numbers of cases in the Piedmont and Coastal Plain physiographic provinces while still needing additional cases in the Valley and Ridge province. DEQ, therefore, stopped collecting data from additional sites in the Piedmont and Coastal Plain areas while continuing for several more months to collect data from sites located in the Valley and Ridge.

2.2 Data Collection

Once a case was selected for the study, the DEQ case manager directed the environmental consultant to proceed with the collection of soil-gas samples. The participating environmental consultants were provided instructions and procedures for collecting the data as outlined in Appendix A – Sample Collection Procedures. The document described a procedure to collect near-slab soil gas samples at sites with leaking home heating oil underground storage tanks. The intent of the procedure was to collect quantitative soil-gas concentrations of petroleum constituents and fixed gases along with other site-specific data. The data would be used to support DEQ's study of the risk of vapor intrusion at leaking home heating oil UST sites.

The environmental consultants were not required to interpret the soil-gas data but were required to include the data in the Site Characterization Report (SCR). Once the SCR was submitted and uploaded to ECM, the case manager informed OSRR that the soil-gas data for the site was available for review. Workgroup staff then retrieved pertinent information from the SCR, placed that information into a summary spreadsheet (Appendix F), and evaluated the data.

2.3 Soil vapor screening levels

Volatile organic compounds (VOCs) including numerous petroleum constituents are ubiquitous in indoor air regardless of nearby petroleum storage tanks or releases from those tanks. These same constituents are present in many things found in the house and may be released from household furnishings, building materials, and consumer products. Some of these VOCs are also found in measurable concentrations in ambient, outdoor air even without the presence of heating oil tanks.

Given the ubiquitous nature of VOCs in indoor air and the great difficulty of determining the contributing source(s), DEQ staff determined that soil vapor samples would provide more reliable data for this study than would indoor air samples. DEQ staff developed subsurface soil vapor screening levels to determine if the petroleum vapors found in that area may have the potential to cause a vapor intrusion risk. These "soil vapor screening levels" are concentrations of constituents in soil vapor that are believed to have the potential to cause a vapor intrusion risk.

According to existing literature as well as the heating oil study performed for DEQ by Virginia Tech, the primary vapor intrusion risk drivers are likely to be TPH, benzene, and naphthalene. Ethylbenzene may pose risks in a few instances.

TPH often is defined by the method. Method 8015 TPH DRO typically "identifies" petroleum hydrocarbons in the C10 through C24 to C28 range depending upon the lab. Number 2 heating oil is primarily composed of constituents in the C11 through C20 range, but has constituents lighter than C11 and heavier than C20. Vapor risks are not typically assigned to the TPH fraction above C19 due to the extremely low vapor pressures exhibited by these heavier hydrocarbons. The lighter fractions of #2 heating oil will have a disproportionately larger representation in the vapor phase.

According to Brewer (2015), approximately 75% of diesel fuel vapors are C9 to C12 aliphatic compounds and 25% are C5 to C8 aliphatics. Less than 1% of the diesel fuel vapors are comprised of aromatic compounds. Number two heating oil is similar to diesel in its range of hydrocarbons.

Table 1 lists the soil vapor screening levels utilized in this study. Information about derivation of the soil vapor screening levels may be found in Appendix B.

Table 1. Soil Vapor Screening Levels

Constituent	Soil Vapor Screening Level, ug/m3
benzene	180
toluene	2600000
ethylbenzene	550
xylenes	50000
naphthalene	41.5
TPH	116250

3.0 Study Results

Soil vapor data were collected from 106 home heating oil cases as part of this study. Table 2 shows the case distribution by physiographic province and final category at the end of this study.

Table 2. Cases by Category and Physiographic Province

Heating Oil Category	Coastal Plain	Piedmont	Valley and Ridge	Total
Category 1	22	18	14	54
Category 2	11	24	8	43
Category 3	4	3	2	9
Total	37	45	24	106

Initially, a total of 77 sites were assigned as Category 1, 26 sites as Category 2, and 3 sites as Category 3. A total of 23 sites included in this study were elevated from Category 1 to Category 2 and 6 sites were elevated from Category 2 to Category 3. Multiple saturated soil samples were observed at 29 sites. A total of 62 sites contained a basement, 41 sites contained a crawlspace, and 3 sites were slab on grade. Table 3 provides additional site data.

Soil gas data was collected from the sites at depths ranging from 0.5' to 9.5' below grade. The soil gas sample points ranged from 0.25' to 12.1' lateral distance from the residential structures. TPH concentrations from the soil gas samples collected at the sites ranged from non-detect to 9,750,000 ug/m^3. Benzene, Toluene, Ethylbenzene, Xylenes, and Naphthalene concentrations from the soil gas samples collected at the sites ranged from non-detect to 26,200 ug/m^3, 389,000 ug/m^3, 78,000 ug/m^3, 242,600 ug/m^3, and 11,800 ug/m^3, respectively.

At five sites included in this DEQ soil vapor study, an additional round of soil gas data was collected after initial corrective actions were completed. A comparison of before and after vapor sampling produced notable results. Soil vapor concentrations were reduced at all five of these sites following the removal of the tank and soil. Soil vapor concentrations at four sites dropped to below the soil screening levels. The study performed by Virginia Tech for DEQ involved the collection of soil gas at home heating oil cases where various types of corrective actions, including tank and soil removal had already occurred. These post tank and soil removal results from DEQ's study correspond with those from the Virginia Tech study.

Maximum TPH concentrations from soil samples collected at the sites in this study ranged from 120 mg/kg to 77,400 mg/kg. Light non-aqueous phase liquid (LNAPL) was observed on shallow groundwater at 15 sites. LNAPL was also observed in a borehole at one site and in a potable water well at one other site. A sheen was observed on shallow groundwater at two sites.

Table 3. Summary Matrix for Heating Oil Cases in this Study

Physiographic Province	Initial HO Categorization			HO Category Elevated		Sites with Multiple Saturated Samples	Structure Type*		
	Cat 1	Cat 2	Cat 3	Cat 1 to Cat 2	Cat 2 to Cat 3		b	cs	s
Valley & Ridge	18	4	2	4	0	5	20	2	2
Piedmont	30	14	1	12	2	19	40	5	0
Coastal	29	8	0	7	4	5	2	34	1
Total:	**77**	**26**	**3**	**23**	**6**	**29**	**62**	**41**	**3**

*b-basement, cs-crawlspace, s-slab

3.1 Aggregate Data

3.1.1 Comparison of Cases with Screening Values by Physiographic Region

Soil vapor concentrations were compared to the soil vapor screening levels discussed in Section 2.3. Staff also calculated vapor attenuation shown at sites. Fifty four (54) category 1 heating oil cases were included in this study. Fifty (50) of the 54 Category 1 cases did not appear to exceed soil vapor screening levels. This number represents a 93% "passing" rate.

Forty three (43) Category 2 cases were evaluated in the study and 28 of them did not exceed soil vapor screening levels. This is a "passing" rate of 65% prior to any combination of investigation and remediation activities that typically involve soil excavation.

Nine (9) Category 3 heating oil cases were randomly selected for the study and 3 of those cases exceeded the soil vapor screening levels; a passing rate of 67%. Two of the heating oil cases included in this study were initially placed into Category 3 because they had documented petroleum vapors inside the residence. Appropriate vapor abatement actions were immediately undertaken at both of these residences.

Table 4. Heating Oil Category and Soil Vapor Screening Results.

	Coastal Plain	Piedmont	Valley & Ridge	totals
Category 1 cases not exceeding screening levels	27	16	13	50
Category 1 cases potentially exceeding screening levels	1	2	1	4
Category 2 cases not exceeding screening levels	9	14	5	28
Category 2 cases potentially exceeding screening levels	2	10	3	15
Category 3 cases not exceeding screening levels	3	2	1	6
Category 3 cases potentially exceeding screening levels	1	1	1	3

3.1.2 Frequencies of Different Constituents Exceeding Soil Vapor Screening Levels

Twenty two (22) cases had constituents in soil vapor that appeared to exceed soil vapor screening levels. TPH exceeded the soil vapor screening level in 21 of the 22 cases and appears to be the principal risk driver. Ethylbenzene and benzene were the constituents next most often exceeding soil vapor screening levels. Every case where they exceeded soil vapor screening levels, TPH also exceeded the soil vapor screening level. Naphthalene, despite having a very low soil vapor screening level, was only found to exceed that concentration at 7 sites. Interestingly, TPH, benzene, and ethylbenzene also exceeded soil vapor screening levels at 6 of these 7 sites. Toluene has a very large soil vapor screening concentration and this constituent never came close to exceeding that level.

3.2 Data Analysis

3.2.1 TPH in Soil vs Vapor Concentration

Some decisions are made by the petroleum program on the basis of TPH concentrations in soil. Can TPH concentrations in soil samples collected from a site be utilized to predict soil vapor concentrations?

Regression analysis is a statistical technique used to infer a relationship between a dependent variable and one or more independent variables. The coefficient of determination, R^2 is used to analyze how differences in one variable can be explained by a difference in a second variable. R^2 values can vary from 0 to 1. In general, the higher the R^2 value, the better the regression model fits the data.

Staff compared the maximum TPH concentration found in soil at each site with the soil vapor concentrations measured as part of this study. Regression analyses show that the maximum TPH concentration in soil found at individual sites was a poor predictor of soil vapor concentrations.

Table 5. Matrix for Constituents Exceeding Soil Vapor Screening Levels

Case	B	T	E	X	N	TPH
20202230					x	
20202231	x		x		x	x
20202248	x		x	x		x
20204325	x		x	x	x	x
20211007			x			x
20212019	x		x	x	x	x
20212021	x		x		x	x
20212055	x		x			x
20212062	x		x	x		x
20212071			x	x		x
20212078	x		x	x		x
20212099						x
20212108	x		x	x		x
20212146	x		x			x
20212170			x			x
20212174	x		x		x	x
20212184	x		x	x		x
20214218			x			x
20215016						x
20215061	x		x	x		x
20215131	x		x		x	x
20216090	x		x	x		x
Totals	15	0	19	10	7	21

Table 6. Regression Coefficients of Determination (R^2). TPH in soil versus constituent soil vapor Concentration

Constituent in soil vapor	R value
Benzene	.006
Toluene	.007
Ethylbenzene	.011
Xylenes	.008
Naphthalene	.006
TPH	.008

3.2.2 Soil Vapor Concentrations by Physiographic Province

Geologically, Virginia has five physiographic provinces: Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain. Cases randomly selected for the study as described above were assigned to the physiographic province where they were located. Because of geologic and cleanup similarities, heating oil cases from the Blue Ridge and Appalachian Plateau were placed into the Valley and Ridge category. Therefore this study groups cases by their location in the Valley and Ridge, Piedmont, or Coastal Plain physiographic provinces.

Statistical Analyses

Basic statistics such as mean, median, standard deviation and percentiles were compiled for soil vapor concentrations associated with the Coastal Plain, Piedmont, and Valley and Ridge provinces. See Tables 7a through 7f below.

The mean and median soil vapor concentrations for each constituent were noticeably higher in the Piedmont than they were in the Coastal Plain or Valley and Ridge. Median concentrations were much lower than the means, often by orders of magnitude suggesting that many of the reported soil vapor concentrations were relatively low, but a small number of extremely high soil vapor concentrations skewed the means.

Consistent with the mean and median data, percentiles show that many of the soil concentrations, regardless of constituent, were relatively low, but a small number of extremely high concentrations skewed the soil vapor data. The percentiles also showed that soil vapor concentrations were consistently higher in the Piedmont than they were in the Coastal Plain or Valley and Ridge.

DEQ staff also analyzed the data by performing a two-tailed Wilcoxon-Mann-Whitney test to determine if soil vapor concentrations were statistically different in one physiographic region than in another. For example, was the mean benzene soil vapor concentration found in the coastal plain statistically different than the mean in the Piedmont? One null hypothesis, for example, is that the mean benzene concentration in the Coastal Plain physiographic region is not statistically different than the mean in the other physiographic region. The alternative hypothesis is that the means are not the same. Statistical differences were found for the following:

Benzene:
The mean benzene concentration associated with sites in the Piedmont is statistically greater than the mean benzene concentration associated with sites in the Valley and Ridge.

Toluene:
The mean toluene concentration associated with sites in the Piedmont is statistically greater than the mean toluene concentration associated with sites in the Coastal Plain and in the Valley and Ridge.

The null hypothesis of statistically equal means could not be rejected for any of the other constituents and physiographic region combinations.

Table 7a. Benzene statistics by physiographic province. Values in ug/m3

	Coastal Plain	Piedmont	Valley & Ridge
mean	636	2060	270
median	1	2	0
Standard deviation	2959	5848	1043
90^{th} percentile	417	6680	301

Table 7b. Toluene statistics by physiographic province. Values in ug/m3

	Coastal Plain	Piedmont	Valley & Ridge
mean	1429	14054	2287
median	0	13	3
Standard deviation	8735	51072	11886
90^{th} percentile	269	23900	1825

Table 7c. Ethylbenzene statistics by physiographic province. Values in ug/m3

	Coastal Plain	Piedmont	Valley & Ridge
mean	2240	5338	2314
median	4	7	0
Standard deviation	10150	14333	8095
90^{th} percentile	1300	19200	4410

Table 7d. Xylenes statistics by physiographic province. Values in ug/m3

	Coastal Plain	Piedmont	Valley & Ridge
mean	6509	21644	11565
median	16	29	1
Standard deviation	30734	56162	37869
90^{th} percentile	6510	85500	29250

Table 7e. Naphthalene statistics by physiographic province. Values in ug/m3

	Coastal Plain	Piedmont	Valley & Ridge
mean	31	345	34
median	0	0	0
Standard deviation	114	1450	159
90^{th} percentile	45	454	13.2

Table 7f. TPH statistics by physiographic province. Values in ug/m3

	Coastal Plain	Piedmont	Valley & Ridge
mean	256978	823934	503748
median	9000	17200	14650
Standard deviation	707647	1975857	1071894
90^{th} percentile	659000	3315000	1805000

3.2.3 Soil Vapor Comparison: Houses with Basements versus Houses with a Crawlspace

Another element that staff evaluated was whether house type (i.e. houses with basement, slab-on grade, or crawlspace) might result in different soil vapor concentrations. Statistical data for houses having basements versus houses having crawlspaces is summarized in Tables 8a through 8f.

Across all regions, soil vapor concentrations were generally higher near houses having basements than they were near houses having crawlspaces. Few houses having slab-on-grade construction were included in this study thus no conclusions could be made about soil vapor concentrations associated with this type of structure.

To further evaluate the data, staff used a two-tailed Wilcoxon- Mann-Whitney (WMW) test to evaluate the mean concentration for each constituent associated with houses having basements against those associated with houses having crawlspaces. The null hypothesis is that the mean vapor concentration associated with one house type is not statistically different than the mean associated with another house type. A two-tailed WMW test indicated that the mean toluene concentrations associated with crawlspaces were less than the means for those constituents associated with basements. The null hypothesis was not rejected for the other constituents.

Only 3 of the heating oil cases randomly selected for this study were associated with slab-on-grade houses. Given the small number of these houses, staff were not able to evaluate potential risks to this type of structure.

Table 8a. Summary statistics for vapor phase benzene concentrations associated with basements and crawlspaces. Values in ug/m3

	Basement	Crawlspace
mean	1587	591
median	1	1
Standard deviation	5062	2832
90^{th} percentile	4334	450

Table 8b. Summary statistics for vapor phase toluene concentrations associated with basements and crawlspaces. Values in ug/m3

	Basement	Crawlspace
mean	11024	1309
median	6	0
Standard deviation	44229	8354
90^{th} percentile	10148	145

Table 8c. Summary statistics for vapor phase ethylbenzene concentrations associated with basements and crawlspaces. Values in ug/m3

	Basement	Crawlspace
mean	4632	2044
median	0	3
Standard deviation	13132	9717
90^{th} percentile	14320	1300

Table 8d. Summary statistics for vapor phase xylene concentrations associated with basements and crawlspaces. Values in ug/m3

	Basement	Crawlspace
mean	19502	5920
median	6	15
Standard deviation	52743	29420
90^{th} percentile	59000	5600

Table 8e. Summary statistics for vapor phase naphthalene concentrations associated with basements and crawlspaces. Values in ug/m3

	Basement	Crawlspace
mean	264	27
median	0	0
Standard deviation	1252	109
90th percentile	145	13

Table 8f. Summary statistics for vapor phase TPH concentrations associated with basements and crawlspaces. Values in ug/m3

	Basement	Crawlspace
mean	764682	232260
median	20000	7900
Standard deviation	1778840	679614
90th percentile	3168000	470000

Soil vapor concentrations associated with basements versus crawlspaces were further evaluated by sorting cases by heating oil category and physiographic province. The findings are summarized below and the statistics are provided in Table 9a through 9r.

Coastal Plain, Category 1, Houses having Crawlspaces

This study included 38 Category 1 heating oil cases that were in the coastal plain and had crawlspaces. When staff considered soil vapor attenuation at these sites, it appeared that one of the 38 cases might exceed the soil vapor screening levels depending upon the amount of attenuation and biodegradation taking place at the site. Possible exceedance for one case out of 38 amounts to 3% of the sites in this class (Coastal Plain, Category 1, houses with crawlspaces). It appears that risks for this group of sites in general is minimal.

Piedmont, Category 1, Houses having Crawlspaces

This study included 4 category 1 heating oil cases that were in the Piedmont and had crawlspaces. When staff considered soil vapor attenuation at these sites, none of them appeared to exceed soil vapor screening levels. Vapor intrusion risks for this group of cases appears to be minimal.

Valley and Ridge, Category 1, Basement

This study included ten (10) Category 1 heating oil cases that were in the Valley and Ridge and had basements. Staff considered soil vapor attenuation at these sites. It appeared that one of these cases may exceed the soil vapor screening levels after factoring in vapor attenuation away from the source. This amounts to possible exceedance 10% of the time. Overall, the vapor intrusion risk associated with this group of cases appeared to be minimal.

Piedmont, Category 1, Basement

This study included 14 Category 1 cases in the Piedmont that had basements. Staff considered soil vapor attenuation away from the source at these sites. Two of the 14 cases in this group may exceed soil vapor screening levels after factoring in attenuation which is an exceedance rate of 14%. Vapor intrusion risk from these cases appears to be minimal.

Coastal Plain, Category 2, Crawlspace

This study included 9 Category 2 cases in the coastal Plain that had crawlspaces. Staff considered attenuation away from the source. Two of the nine cases exceeded the soil vapor screening levels which corresponds to18% of the cases in this group. Vapor intrusion risk from these cases appears to be minimal.

Piedmont, Category 2, Basement

This study included 23 Category 2 cases in the Piedmont that had basements. Even after considering attenuation by distance away from the source, 11 of the 23 cases in this group may exceed soil vapor screening levels; amounting to 48% of the cases. Category 2 cases in the Piedmont where the house has a basement may be at increased risk of vapor intrusion if contaminated soil is not removed.

Valley and Ridge, Category 2, Basement

This study included 8 Category 2 sites from the Valley and Ridge that had basements. Even after considering attenuation away from the source at these sites, 3 of the 8 cases may pose some risk of vapor intrusion which amounts to 38% of the cases in this group. Category 2 cases in the Valley and Ridge where the house has a basement may be at increased risk of vapor intrusion if contaminated soil is not removed.

Table 9a. Benzene, Category 1: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, crawlspace	Piedmont, basement	V&R, basement
50^{th} percentile	1	3	1	0
90^{th} percentile	49	307	724	20
95^{th} percentile	65	532	11108	30

Table 9b. Benzene, Category 2: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, basement	Valley and Ridge, basement
50^{th} percentile	1	4	0
90^{th} percentile	717	6940	1680
95^{th} percentile	1958	9100	3682

Table 9c. Benzene, Category 3: Percentiles by House Type and Physiographic Province

	Coastal Plain, Crawlspace
50th percentile	299
90th percentile	13600
95th percentile	17800

Table 9d. Toluene, Category 1: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, crawlspace	Piedmont, basement	V&R, basement
50th percentile	0	11	5	0
90th percentile	97	78	715	58
95th percentile	300	111	69920	112

Table 9e. Toluene, Category 2: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, basement	Valley and Ridge, basement
50th percentile	2	28	0
90th percentile	3468	51700	4260
95th percentile	19260	112000	27290

Table 9f. Toluene, Category 3: Percentiles by House Type and Physiographic Province

	Coastal Plain, Crawlspace
50th percentile	11
90th percentile	6990
95th percentile	8495

Table 9g. Ethylbenzene, Category 1: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, crawlspace	Piedmont, basement	V&R, basement
50th percentile	2	3	0	0
90th percentile	712	44	636	553
95th percentile	1285	50	28408	1589

Table 9h. Ethylbenzene Category 2: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, basement	Valley and Ridge, basement
50th percentile	12	29	0
90th percentile	2122	20800	4620
95th percentile	8084	33800	18670

Table 9i. Ethylbenzene, Category 3: Percentiles by House Type and Physiographic Province

	Coastal Plain, Crawlspace
50th percentile	503
90th percentile	42300
95th percentile	60150

Table 9j. Xylenes, Category 1: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, crawlspace	Piedmont, basement	V&R, basement
50th percentile	10	16	0	0
90th percentile	1389	122	3576	1539
95th percentile	6288	189	109515	7096

Table 9k. Xylenes, Category 2: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, basement	Valley and Ridge, basement
50th percentile	53	117	0
90th percentile	22071	95600	36280
95th percentile	39400	161000	95800

Table 9l. Xylenes, Category 3: Percentiles by House Type and Physiographic Province

	Coastal Plain, Crawlspace
50th percentile	1005
90th percentile	89790
95th percentile	166195

Table 9m. Naphthalene, Category 1: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, crawlspace	Piedmont, basement	V&R, basement
50th percentile	0	0	0	0
90th percentile	13	0	38	0
95th percentile	102	0	81	1

Table 9n. Naphthalene, Category 2: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, basement	Valley and Ridge, basement
50th percentile	0	0	0
90th percentile	87	718	12
95th percentile	151	1760	86

Table 9o. Naphthalene, Category 3: Percentiles by House Type and Physiographic Province

	Coastal Plain, Crawlspace
50th percentile	0
90th percentile	84
95th percentile	182

Table 9p. TPH Category 1: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, crawlspace	Piedmont, basement	V&R, basement
50th percentile	8450	1210	3575	14700
90th percentile	221000	60900	254200	489600
95th percentile	384000	87480	3206350	1311000

Table 9q. TPH, Category 2: Percentiles by House Type and Physiographic Province

	Coastal plain, crawlspace	Piedmont, basement	Valley and Ridge, basement
50th percentile	20000	40800	5160
90th percentile	1294000	3360000	2211200
95th percentile	2043000	4250000	3130000

Table 9r. TPH, Category 3: Percentiles by House Type and Physiographic Province

	Coastal Plain, Crawlspace
50th percentile	48135
90th percentile	3350000
95th percentile	3875000

Staff evaluated the combination of heating oil category, physiographic province, and house type on soil vapor concentrations and potential vapor intrusion risks. This study included 41 cases where the houses had crawlspaces. After considering the soil vapor concentrations as well as their distribution and probable attenuation at individual sites, it appeared that only four of the 41 cases involving houses with crawlspaces may pose some type of vapor intrusion risk. This is a "passing rate" of 90% for houses with crawlspaces. Moreover, this does <u>not</u> take into account vapor reduction that is achieved by soil removal that is routinely conducted at Category 2 and Category 3 heating oil cases. Overall, the vapor intrusion risk associated with houses having crawlspaces appears to be low.

This study included 62 heating oil cases that were associated with houses having basements. Eighteen of those cases may pose a vapor intrusion risk. This is a passing rate of 71% before taking soil removal associated with Category 2 and 3 cases into account. The Category 1 cases associated with houses having basements, however, appeared to have much lower vapor risks with a passing rate of 88%. These results suggest that vapor risks at Category 1 sites are relatively low while risks at Category 2 and 3 sites are more substantial. The results support the importance of removing contaminated soil at Category 2 and Category 3 sites where the associated house has a basement. At Category 2 or Category 3 cases in the Piedmont or Valley and Ridge where the house has a basement, other corrective actions such as the installation of a subsurface ventilation system may be appropriate if soil cannot be removed. The study included very few Coastal Plain sites where the house had a basement. As with the Category 2 and Category 3 cases in the other physiographic provinces where the house has a basement, it may be advisable to install a subsurface ventilation system or take other corrective actions if soil cannot be removed.

Only 3 sites having slab on grade construction were included in this study. While none of these cases appeared to have a significant vapor intrusion risk, this is an insufficient sample size with which to draw conclusions about this type of structure.

Table 10. Summary Matrix, Heating Oil Category – Physiographic Province- House Type

Category, Physiographic Province, and House Type	Crawlspace	Basement	Slab on Grade	Totals
Category 1, Coastal Plain, did not exceed RML	21	2		23
Category 1, Coastal Plain, exceed RML	1	0		1
Category 1, Piedmont, did not exceed RML	4	12		16
Category 1, Piedmont, exceed RML	0	2		2
Category 1, Valley and Ridge, did not exceed RML	2	9	2	13
Category 1, Valley and Ridge, exceed RML	0	1		1
Category 2, Coastal Plain, did not exceed RML	7		1	8
Category 2, Coastal Plain, exceed RML	2			2
Category 2, Piedmont, did not exceed RML		13		13
Category 2, Piedmont, exceed RML		10		10
Category 2, Valley and Ridge, did not exceed RML		5		5
Category 2, Valley and Ridge, exceed RML		3		3
Category 3, Coastal Plain, did not exceed RML	3			3
Category 3, Coastal Plain, exceed RML	1			1
Category 3, Piedmont, did not exceed RML		2		2
Category 3, Piedmont, exceed RML		1		1
Category 3, Valley and Ridge, did not exceed RML		1		1
Category 3, Valley and Ridge, exceed RML		1		1
Totals	41	62	3	106

3.2.4 Soil Vapor Concentrations by Heating Oil Category

Soil vapor concentrations were evaluated for Category 1, Category 2, and Category 3 heating oil sites. As shown in Table 11 below, soil vapor concentrations generally were much higher at Category 2 and Category 3 heating oil tank sites than they were at Category 1 sites.

A two-tailed Wilcoxon Mann Whitney test was utilized to compare the mean concentration of individual constituents in one category of heating oil cases against those in another category of heating oil cases. The null hypothesis was that the mean concentration of the constituent in the higher category was equal to the mean in the lower category. The WMW test indicated that the benzene, toluene, ethylbenzene, xylene, and TPH concentrations at Category 2 sites in this study were significantly greater than they were at Category 1 cases. Likewise, benzene and ethylbenzene at Category 3 cases were found to be significantly greater than they were at Category 2 cases.

Table 11. Soil Vapor Concentration Distribution at Category 1 Sites and Category 2 Sites. Concentrations in ug/m3

	Cat 1 50th percentile	Cat 2 50th percentile	Cat 1 90th percentile	Cat 2 90th percentile
Benzene	1	1	36	5949
Toluene	3	6	135	18540
Ethylbenzene	1	10	608	13910
Xylenes	6	44	1269	56950
Naphthalene	0	0	12	225
TPH	7850	25950	251600	2924000

Table 12. Soil Vapor Concentration Distribution at Category 3 Sites.

	Cat 3 50th percentile	Cat 3 90th percentile
Benzene	23	19200
Toluene	21	10750
Ethylbenzene	147	61700
Xylenes	949	194670
Naphthalene	0	1377
TPH	56500	5630000

3.2.5 Soil Vapor Concentrations, Shallow Versus Deep Groundwater

Results from the study performed by Virginia Tech suggested that subsurface vapor concentrations may be greater in areas having shallow groundwater.

This study evaluated the potential effects of groundwater depth on soil vapor concentrations. Cases where groundwater was encountered during site activities (soil boring, excavation) were considered to have shallow groundwater. Sites where groundwater was not encountered during site activities were considered to have deep groundwater. Although there is some variability, shallow groundwater as defined in this study generally is within approximately eight feet of grade.

Tables 13a through 13f below summarize basic statistics for soil vapor constituents at sites with shallow versus deep groundwater. Unlike the study performed by Virginia Tech, this study showed that soil vapor concentrations were generally higher at sites having deep groundwater. When statistical tests of the means were compared using a two-tailed Wilcoxon Mann Whitney test, only one parameter, TPH, was statistically higher at sites having deep groundwater than at sites having shallow groundwater.

Table 13a. Benzene Soil Vapor Concentrations, Shallow vs. Deep Groundwater

	Shallow GW	Deep GW
mean	701	981
median	1	1
Standard deviation	3105	3664

Table 13b. Toluene Soil Vapor Concentrations, Shallow vs. Deep Groundwater

	Shallow GW	Deep GW
mean	1552	8618
median	0	10
Standard deviation	9108	40794

Table 13c. Ethylbenzene Soil Vapor Concentrations, Shallow vs. Deep Groundwater

	Shallow GW	Deep GW
mean	2377	3198
median	4	2
Standard deviation	10574	9819

Table 13d. Xylene Soil Vapor Concentrations, Shallow vs. Deep Groundwater

	Shallow GW	Deep GW
mean	6789	14864
median	15	20
Standard deviation	31991	44128

Table 13e. Naphthalene Soil Vapor Concentrations, Shallow vs. Deep Groundwater

	Shallow GW	Deep GW
mean	21	213
median	0	0
Standard deviation	100	1190

Table 13f. TPH Soil Vapor Concentrations, Shallow vs. Deep Groundwater

	Shallow GW	Deep GW
mean	250399	579829
median	10750	14500
Standard deviation	704552	1472288

3.2.6 Soil Vapor Concentrations at Sites Having Free Product Versus Sites Without Free Product

DEQ staff compared soil vapor concentrations at sites where free product was detected versus sites where free product was not detected (Tables 14a through 14f). Sites where free product was found generally had higher soil vapor concentrations than at sites where free product was not found. The data set of sites not having free product included Category 1 cases. Since sites where free product is found are placed in at least Category 2, a more representative evaluation may be to compare the concentrations of soil gas at sites having free product versus the concentrations at the Category 2 cases where free product was not found. Upon performing this comparison, cases having free product generally had higher concentrations of benzene, ethylbenzene, and naphthalene, but little difference was found in toluene, xylene, and TPH concentrations.

Table 14a. Benzene Soil Vapor Concentrations, Sites with Free Product versus Sites Not Having Free Product. Concentrations in ug/m3

	Benzene at sites w. FP	Benzene at all sites not having FP	Benzene at Category 2 sites not having FP
mean	2241	557	828
median	4	1	1
Standard deviation	6144	2057	2117

Table 14b. Toluene Soil Vapor Concentrations, Sites with Free Product versus Sites Not Having Free Product. Concentrations in ug/m3

	Toluene at sites w. FP	Toluene at all sites not having FP	Toluene at Category 2 sites not having FP
mean	8111	5701	11942
median	1	5	13
Standard deviation	24210	34998	54844

Table 14c. Ethylbenzene Soil Vapor Concentrations, Sites with Free Product versus Sites Not Having Free Product. Concentrations in ug/m3

	ethylbenzene at sites w. FP	ethylbenzene at all sites not having FP	ethybenzene at Category 2 sites not having FP
mean	6712	2118	3408
median	25	2	5
Standard deviation	16052	8174	9211

Table 14d. Xylene Soil Vapor Concentrations, Sites with Free Product versus Sites Not Having Free Product. Concentrations in ug/m3

	Xylenes at sites w. FP	Xylenes at all sites not having FP	Xylenes at Category 2 sites not having FP
mean	20931	10121	17498
median	233	15	20
Standard deviation	50259	37855	46582

Table 14e. Naphthalene Soil Vapor Concentrations, Sites with Free Product versus Sites Not Having Free Product. Concentrations in ug/m3

	Naphthalene at sites w. FP	Naphthalene at all sites not having FP	Naphthalene at Category 2 sites not having FP
mean	278	120	100
median	0	0	0
Standard deviation	1001	954	322

Table 14f. TPH Soil Vapor Concentrations, Sites with Free Product versus Sites Not Having Free Product. Concentrations in ug/m3

	TPH at sites w. FP	TPH at all sites not having FP	TPH at Category 2 sites not having FP
mean	674649	433299	678750
median	54000	9000	20000
Standard deviation	1170435	1282178	1314074

3.2.7 Soil Vapor Concentration Distributions by Soil type

Staff evaluated soil vapor concentrations associated with different types of soil. In general, soil vapor concentrations were highest in sand. Sandy clay and clay loam generally were associated with lower soil vapor concentrations. Soil vapor concentration distributions by soil type are summarized in Tables 15a through 15e below.

Table 15a. Soil Vapor Concentration Distribution by Soil Type, Benzene

	50^{th} percentile	75^{th} percentile	80^{th} percentile	90^{th} percentile	95^{th} percentile
Clay	0	3.8	15.7	402.3	2299
Clay loam	1.0	2.6	4.3	8.0	139.5
sand	17.7	531.8	726	6254	13290
Sandy clay	1.7	9.7	16.7	60.2	384
Silty clay	2.7	23.5	76.2	321.8	2826

Table 15b. Soil Vapor Concentration Distribution by Soil Type Ethylbenzene

	50^{th} percentile	75^{th} percentile	80^{th} percentile	90^{th} percentile	95^{th} percentile
Clay	.9	101.8	310.2	3253	5370
Clay loam	1	25.5	32.0	109.2	1265
sand	79.2	1250	1300	22090	47450
Sandy clay	.7	36	62.2	492	1662
Silty clay	14.5	447.5	767.6	6400	19460

Table 15c. Soil Vapor Concentration Distribution by Soil Type, Xylenes

	50^{th} percentile	75^{th} percentile	80^{th} percentile	90^{th} percentile	95^{th} percentile
Clay	16.8	516.4	1554	16747	27387
Clay loam	5.9	128.6	168.3	1371	6578
sand	295	6575	15340	81200	152510
Sandy clay	6.1	60	170.8	1591	3573
Silty clay	75.9	2020	3540	36860	71860

Table 15d. Soil Vapor Concentration Distribution by Soil Type, Naphthalene

	50^{th} percentile	75^{th} percentile	80^{th} percentile	90^{th} percentile	95^{th} percentile
Clay	0	0	0	13	260.4
Clay loam	0	0	0	8.0	23.1
sand	0	0	23.2	87.4	219
Sandy clay	0	0	0	11.78	92.6
Silty clay	0	43.5	194	633.8	1107

Table 15e. Soil Vapor Concentration Distribution by Soil Type, TPH

	50th percentile	75th percentile	80th percentile	90th percentile	95th percentile
Clay	31950	225750	494800	1921000	2958500
Clay loam	660	4060	7152	34680	253640
sand	135000	440000	634000	1944000	3100000
Sandy clay	4500	33000	65760	224000	378000
Silty clay	14000	171200	576800	1237800	2652800

3.3 Results of soil vapor sampling following tank and soil removal

Soil vapor samples at all sites in this study were collected prior to tank removal and soil excavation. At 5 cases, DEQ decided to have the consultant return to the site and collect soil vapor samples following tank removal and soil excavation. Soil vapor concentrations at all 5 of these cases exceeded the soil vapor screening levels during the first round of sampling. Following excavation activities, soil vapor concentrations at 4 of these 5 cases dropped to below the soil vapor screening levels. Concentrations of individual constituents in soil vapor typically dropped by approximately one order of magnitude following soil excavation. Soil vapor data from the Virginia Tech study was entirely taken at sites where various investigation and remediation activities had already occurred including tank and soil removal at most Category 2 and Category 3 sites. Soil vapor data from the second round of samples in the DEQ study corresponds to what was found by Virginia Tech.

Table 16. Soil Vapor Concentrations pre and post Excavation

Constituent	Average concentration pre excavation	Average concentration post excavation
Benzene	5142	872
Toluene	15571	685
Ethylbenzene	21724	2156
Xylenes	85034	14915
Naphthalene	1072	48
TPH	2613840	529915

3.4 Summary of DEQ's Soil Vapor Study

One hundred six (106) cases were evaluated as part of the DEQ study. The primary findings of the study are:

- Risk Drivers
  - TPH appears to be the principal vapor intrusion risk driver. Of the 22 cases that exceeded soil vapor screening thresholds, TPH exceeded its screening level in 21 of them.
  - Toluene in soil vapor never exceeded its soil vapor screening threshold
- The maximum TPH concentration in soil measured at a site is a poor predictor soil vapor concentrations.
- There were 54 Category 1 cases included in this study. Only 4 of them had soil vapor concentrations exceeding soil vapor screening levels. This means that 93% of the Category 1 cases had soil vapor concentrations that were below the screening levels. It appears, therefore, that vapor intrusion risks at most Category 1 cases is minimal.

- There were 43 Category 2 cases included in the study and 28 of them had soil vapor concentrations below the screening levels prior to soil excavation. This means that 65% of the cases had soil vapor concentrations that were below the screening levels. DEQ took a second round of samples at 5 sites (Category 2) following soil excavation. All 5 of those cases had high soil vapor concentrations prior to excavation and the concentrations dropped noticeably after excavation. Following excavation, soil vapor at 4 of the 5 sites had dropped to below the screening level.
- There were 9 Category 3 cases included in the study; soil vapor concentrations at 3 of these sites exceeded screening levels. The releases at two of these cases were reported to DEQ and immediately placed into Category 3 because the homeowners noticed petroleum vapors in their residences.
- This study compared cases in the physiographic regions. In general, soil vapor concentrations were higher in the Piedmont than they were in the Valley and Ridge or the Coastal Plain.
- This study compared cases where the house had a basement versus those cases where the house had a crawlspace. In general, soil vapor concentrations were lower around houses that had crawlspaces than around houses that had basements.
    - Less than 3% of the Category 1 cases associated with houses that had crawlspaces exceeded screening levels. Risk from this type of structure and category combination appears to be minimal.
    - Category 1 cases where the house had a basement appear to be associated with a small level of risk. Twelve percent of these cases exceeded soil vapor screening levels.
    - Category 2 and Category 3 cases from the Coastal Plain where the house had a crawlspace appear to be associated with a moderate level of risk. Twenty three (23) percent of these cases exceeded soil vapor screening levels prior to tank and soil excavation. Results of this study as well as those from the Virginia Tech study show that soil vapor concentrations are significantly reduced following soil excavation which is performed at most Category 2 and Category 3 heating oil sites.
    - Category 2 and Category 3 cases from the Piedmont and Valley and Ridge where the house had a basement appear to be associated with a significant level of risk as over 40% of these cases exceeded the screening levels prior to tank removal and soil excavation. These potential pre-excavation risks show the importance of subsequent tank and soil removal which is typically performed at Category 2 and Category 3 heating oil sites. If the tank and soil cannot be removed, it may be advisable to take other abatement measures such as the installation of a vapor removal system at these sites.
- This study compared soil vapor concentrations at sites having shallow groundwater versus those at sites having deeper groundwater. In general, soil vapor concentrations were higher at sites having deeper groundwater, but the difference was not statistically significant in the DEQ Study. The Virginia Tech Study, however, showed markedly higher soil vapor concentrations at sites having shallow groundwater.
- This study compared soil vapor concentrations at sites having free product versus those where free product was not encountered. In general, sites having free product were associated with higher soil vapor concentrations that at sites where free product was not encountered, but the differences were not statistically significant.

3.5 Summary of 2017 Soil Vapor Study Performed by Virginia Tech

In 2017, DEQ contracted with Virginia Tech to perform a soil vapor study at cases where oil had been released from a residential heating oil UST. DEQ staff provided Virginia Tech with a list of all cases, starting in FY2008, where heating oil had been discharged from a residential heating oil UST. At sites where access was granted by the homeowner, Virginia Tech staff collected site data and subsurface soil vapor samples.

Primary findings of the soil vapor study performed by Virginia Tech are summarized below:

- Soil vapor samples were collected at 56 sites
- TPH and naphthalene appeared to be the principal contaminants of concern (COC) with regards to petroleum vapor intrusion (PVI) risks. A study by Brewer used 72 ug/m3 as the risk-based threshold for naphthalene and 140,000 ug/m3 as the screening level for TPH in soil gas.
- Physiographic region within the state had some influence on higher vapor concentrations as it related to shallow groundwater. Sites with a combination of shallow water table (within 6' of ground surface) and free product were associated with higher TPH and naphthalene concentrations in soil vapor.
- Cases where there were documented impacts of oil in crawl spaces or in basements generally had higher observed TPH and/or naphthalene concentrations in soil vapor.
- There is poor correlation between soil vapor concentrations and the maximum reported TPH concentration in soil documented in Site Characterization Reports.
- Soil vapor concentrations by DEQ Category
  - Samples were collected at ten (10) NFA cases. TPH concentrations in soil vapor exceeded the screening level of 140,000 ug/m3 at two of these sites.
  - Samples were collected at ten (10) Category 1 cases. One Category 1 site had a naphthalene soil gas concentration that exceeded the screening level of 72 ug/m3. None of the Category 1 sites had TPH concentrations that exceeding the screening level.
  - Samples were collected at twenty (20) Category 2 cases. Two of the cases had vapor concentrations that exceeded screening levels. One of these sites exceeded the screening levels for both TPH and naphthalene while the other exceeded the screening level for naphthalene.
  - Samples were collected at sixteen (16) Category 3 sites. Four of the sites had TPH vapor concentrations that exceeded the screening concentration of 140,000 ug/m3 while three of these same sites also had naphthalene concentrations that exceeded screening levels for that constituent. Three of these cases have free product on shallow groundwater. The fourth case had free product that entered a basement. All four of these cases are still open.

3.6 Discussion and Comparison of the DEQ and the Virginia Tech findings

DEQ contracted with Virginia Tech in 2017 to collect soil vapor samples at home heating oil sites. Subsequently, DEQ worked with remediation contractors to collect additional soil vapor samples at home heating oil sites. Measured soil gas concentrations at the sites evaluated by Virginia Tech (VT in tables below) were noticeably lower than the soil gas concentrations at sites included in the DEQ study (Table 17).

Table 17. Soil gas concentrations across all heating oil categories in the respective studies

	TPH VT Study	TPH DEQ Study	Ethylbenzene VT Study	Ethylbenzene DEQ study	Naphthalene VT study	Naphthalene DEQ Study
Mean	36551	550,439	9	3518	22	160
Median	2958	14200	1	2	1	0
maximum	687,000	9,750,000	7,877	7800	913	11800

The study performed by Virginia Tech evaluated a mix of open and closed heating oil cases. More than three years had elapsed since tank removal or pump out in 42 of the 56 cases evaluated by Virginia Tech. In all instances, more than a year had elapsed since the case had been initiated and the tank had been pumped out and/or removed. The soil vapor study performed by RP lead contractors for DEQ, by contrast, involved collecting samples at new home heating oil cases prior to any tank work or excavation. It is possible that the much lower soil vapor concentrations measured in the Virginia Tech study were due to the time elapsed since tank pump out and/or soil excavation (i.e. source removal).

The principal risk drivers identified in the study performed by Virginia Tech were TPH and naphthalene. TPH, also appears to be the primary risk driver identified by DEQ.

Both studies looked at the relationship between the maximum measured TPH concentration in soil at a site and the soil vapor concentrations at the site. The conclusion in both cases was that the maximum measured TPH concentration in soil is a poor predictor of vapor phase concentrations.

Both studies evaluated soil vapor by DEQ heating oil category. Soil vapor measured in the DEQ and Virginia Tech studies exceeded screening levels in 8% and 10% of the Category 1 cases, respectively. At Category 2 cases, 32% of the cases in the DEQ study initially exceeded subsurface screening levels while 10% of the cases in the Virginia Tech study exceeded subsurface screening levels. Soil vapor samples were collected in the DEQ study prior to tank pump out and/or soil excavation while soil vapor samples collected in the Virginia Tech study were collected post tank pump out and/or soil excavation. DEQ subsequently asked consultants to return to several of the sites and collect soil vapor samples after tanks and soil had been removed. In all cases where this type of resampling occurred, the soil vapor concentrations decreased noticeably after the tank and contaminated soil were removed.

Analysis of data from the study performed by Virginia Tech suggest that soil vapor concentrations were greater at cases having shallow groundwater. Data from the DEQ study, however, showed slightly higher soil vapor concentrations associated with sites having deeper groundwater.

Persons analyzing data from the Virginia Tech study noticed that cases where free product had been found typically had greater soil vapor concentrations than at sites where free product had not been found. Data from the DEQ study showed some difference here as well, but it was not as pronounced as in the Virginia Tech study.

4.0 Conclusions and recommendations

The soil vapor studies performed by Virginia Tech and by DEQ suggest that current heating oil procedures are generally protective with regards to soil vapor risks to indoor air quality. Risk from petroleum constituents in soil vapor appears to be relatively low at most Category 1 sites.

The data from the DEQ study suggest that vapor risks associated with houses having crawl spaces is considerably lower than the risks associated with houses having basements.

Soil vapor concentrations typically are higher at Category 2 cases prior to tank and soil removal. Data from the studies indicate that soil vapor concentrations drop noticeably following tank and soil removal. The data also suggest that, perhaps, a third of these Category 2 cases may exceed vapor risks if the tank and soil are not removed. Sometimes, the tank and soil cannot be removed at cases due to site constraints. In those Category 2 cases where the tank and soil cannot be removed, it is recommended that staff and consultants consider installing a vapor abatement system. This is especially true for Category 2 sites where the house has a basement.

The DEQ study only had a small number of Category 3 cases. One of the primary reasons for placing a heating oil case into Category 3 is a documented impact to a receptor. Two of the Category 3 cases in the DEQ study had documented vapor impacts to the structure and were remediated accordingly. Where Category 3 cases do not have a documented vapor impact, staff and consultants may consider the benefits of removing the tank and contaminated soil. If the tank and contaminated soil cannot be removed, consideration should be given to installing a vapor abatement system.

REFERENCES

EPA. 1992. Reference Guide to Odor Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990. EPA 600/R-92/047.

American Industrial Hygiene Association. 1989. Odor Thresholds for Chemicals with Established Occupational Health Standards

Brewer, Roger. 2015. Petroleum Vapor Intrusion Facts, Fallacies and Implications. Hawaii Dept. of Health, HEER.

Appendix A. Sample Collection Procedures Provided to Consultants

The data will be collected at most sites by hand- or power-tool driven stainless steel soil-gas probe points, with samples collected by SUMMA® canister and analysis by USEPA Method TO-15. For sites with very shallow groundwater where using driven probes is not practicable (i.e., at some Coastal Plain and Tidewater sites) soil gas samples may be collected directly from properly screened and sealed groundwater monitoring wells.

1. PRE-SAMPLING SITE ASSESSMENT

1. Contractor is responsible for clearing utilities at the locations to be sampled.
2. Contractor is responsible for obtaining site access.
3. Contractor will inspect the site before collecting samples.
4. On the field note sheet provided by DEQ, the contractor will record:
   a. Whether the home has a basement, crawl space, or is slab on grade.
   b. Location of any potential preferential pathways for vapor migration, such as drains or utilities.
   c. Type of groundcover present in the area to be sampled.
   d. Duration and amount of most recent precipitation: If possible, samples should not be collected within 24 hours of a precipitation event, or if the area has been irrigated.
   e. Provide a site sketch showing the location of the UST, house, sample locations, and other pertinent site features.

2. NUMBER AND LOCATION OF SAMPLES

1. Collect two soil vapor samples at each site and one ambient air QA/QC sample (discussed in section 6 below):
   (1) DEPTH SELECTION: The first sample should be collected near the lowest level of the structure. If the house has a basement, the sample should be collected about one foot below the level of the basement floor. If the house is slab on grade, collect the sample one foot below the grade elevation. If the house has a crawl space, collect the sample as close as possible to the ground surface.
   (2) The second sample should be collected at a depth that corresponds with the bottom depth of the UST.
2. LOCATION SELECTION: Samples should be collected between the UST and house and as close to the house as possible. If a location between the tank and house is not feasible, the contractor will contact the DEQ case manager to discuss other possible sample locations.

3. SAMPLING POINT CONSTRUCTION

3A. Locations with Groundwater Below the Depth of the UST.

1. Samples will be collected using a stainless steel probe point driven into the soil by drive-rod or other method.

2. The sampling interval (analogous to a well screen length) on the probe will be no more than 6 inches.
3. All materials connected to the probe should be non-reactive with petroleum, i.e., stainless steel, Teflon or Nylon. Polyethylene tubing should not be used.
4. Seal the probe point at the surface with bentonite in order to prevent leakage of air into the sample;
5. Connect the probe with a minimum amount of tubing, but sufficient for gas-tight fittings needed for purging, leak testing, and measurement of fixed gases (see below).

3B. Locations with Submerged USTs and/or Shallow Groundwater

NOTE: Every effort should be made to collect samples by the method described in 4A. However, if that method is not possible due to very shallow groundwater, then the following method may be used:

1. Samples will be collected from a temporary PVC monitoring well installed by hand-auger or direct push.
2. The screened interval of the well must cross the water table, such that at least one foot of screen is above the water table.
3. The well will be sealed at the surface with bentonite.
4. The contractor will provide an air-tight seal of the well cap with appropriate tubing for air sample collection (see below).

4. SAMPLE COLLECTION

1. Allow the probe point to equilibrate at least one hour after installation before the sample is collected.
2. Purge the system of at least one volume of air before sampling.
3. Flow rates of between 100 to 200 ml/min and vacuums of less than 100 inches of water should be maintained during purging and sampling
4. Perform a "shut-in" test, i.e., place the system under vacuum and monitor for any leakage.
5. Sample for fixed gases: O2, CO2, methane using a landfill gas meter or similar field instrument and record the percentages of each on the field note sheet.
6. Collect the vapor samples in a SUMMA canister using a collection time of no more than 30 minutes.

5. SAMPLE ANALYSIS

Analyze samples by USEPA Method TO-15 for BTEX, naphthalene and Total Petroleum Hydrocarbons (TPH) in the C5 to C12 range. The contractor must verify with the lab that they are capable of detecting naphthalene at a low detection limit (10 ug/m3) with Method TO-15**. Also, the contactor must instruct the lab to report TPH as the sum of all compounds falling within the carbon range of C5 to C12.**

6. QUALITY CONTROL

1. Collect one ambient air sample by SUMMA canister/TO-15 at each site. The sample location should be away from any obvious petroleum source, such as tank, cars, or outdoor power

equipment. The ambient sample should be collected 3-5 feet above the ground surface and 5 to 15 feet away from any buildings.

2. The DEQ case manager will advise if equipment blanks or duplicate samples should be collected.
3. If probe points or tubing are to be re-used, follow USEPA protocols for decontamination between locations.

REFERENCE

This procedure is based on the technical guidance provided by the Interstate Technology and Regulatory Council (ITRC), specifically Appendix G of the on-line guidance document: Petroleum Vapor Intrusion, Fundamentals of Screening, Investigation and Management, 2014. For detailed instructions, including links to videos on the installation of vapor sampling points and the collection of samples by Summa canister, use the following link to the ITRC website.

https://www.itrcweb.org/PetroleumVI-Guidance/#Appendix%20G.%20Investigation%20Methods%20and%20Analysis%20Toolbox.htm#Investigation_Methods_and_Analysis_Toolbox%3FTocPath%3DInvestigation%2520Methods%2520and%2520Analysis%2520Toolbox%7C_____0

Appendix B. Derivation of Soil Vapor Screening Levels

Soil vapor concentrations are often utilized as a screening mechanism to identify whether vapor intrusion may be an issue at a site and, perhaps, warrant further investigation. Two primary factors involved in deriving soil vapor screening levels are inhalation risk concentrations and subslab soil gas attenuation factors.

Resident indoor air screening levels for petroleum fractions and constituents of concern are shown in Tables B-1 and B-2. According to EPA (2021), the petroleum hydrocarbon fractions shown in Table B-2 are as follows:

- Low aliphatic, C5 – C8, risk based on hexane
- Medium aliphatic, c9 – c18, risk based on nonane
- High aliphatic, C19 – C32, risk based on white mineral oil

Table B-1. Residential Indoor Air Screening levels for Select Petroleum Constituents

Constituent	Residential Indoor Air Screening Level (ug/m3)
Benzene	.36
Toluene	5200
Ethylbenzene	1.1
Xylenes	100
Naphthalene	.083

Screening levels from EPA 2021

Table B-2. Residential Indoor Air Screening Levels for Petroleum Hydrocarbon Fractions

Petroleum Hydrocarbon Fraction	Residential Indoor Air Screening Level (ug/m3)
Aliphatic high	Not given (extremely low volatility)
Aliphatic low	630
Aliphatic medium	100

Screening levels from EPA 2021

Vapor screening levels are not provided for the higher petroleum fractions as aliphatic compounds above approximately C13 have very low volatility. A site involving a diesel release evaluated by Brewer et al (2013) had aliphatic vapor fractions of approximately 25% c5 – C9 and 74% c9 – c12. Data from Geosphere (2006), however, suggest that the c5 – c9 aliphatic fraction may contribute almost 50% of the aliphatic vapors at a fresh diesel release. Reference concentrations for the medium aliphatic fraction are lower than that of the low aliphatic fraction thus indicating a greater risk from hydrocarbons in this range. DEQ decided to utilize the aliphatic fraction breakdown corresponding to the study performed by Brewer and associates (2013) as it would result in more conservative risk screening values.

DEQ derived the TPH risk fraction as follows:
RBC aliphatic low = 630 ug/m3. This fraction makes up 25% of the aliphatic vapors.
Weighted RBC for aliphatic low: 630 ug/m3 * .25 = 157.5 ug/m3
RBC aliphatic medium = 100 ug/m3. This fraction makes up 75% of the aliphatic vapors.
Weighted RBC for aliphatic medium: 100 ug/m3 * .75 = 75 ug/m3

A weighted RBC for TPH using these aliphatic fractions is 232.5 ug/m3

DEQ applied an attenuation factor of .002 (Brewer et al 2014) in order to derive subslab screening levels for various petroleum constituents and the aliphatic TPH fraction at heating oil tank sites (Table B-3).

Table B-3. Subslab screening levels at home heating oil tank sites.

	Indoor air RBC, ug/m3	Subslab screening levellevel, ug/m3
benzene	0.36	180
toluene	52000	2600000
ethylbenzene	1.1	550
xylenes	100	50000
naphthalene	0.083	41.5
TPH	232.5	116250

REFERENCES

Brewer, Roger, Josh Nagashima, Mark Rigby, Martin Schmidt, and Harry O'Neil. 2014. Estimation of Generic Subslab Attenuation Factors for Vapor Intrusion Investigations. *Groundwater Monitoring and Remediation*.

Brewer, Roger, Josh Nagashima, Michael Kelley, Marvin Heskett, and Mark Rigby. 2013. Risk-Based Evaluation of Total Petroleum Hydrocarbons in Vapor Intrusion Studies. International Journal of Environmental Research and Public Health. 10: p 2441 – 2467.

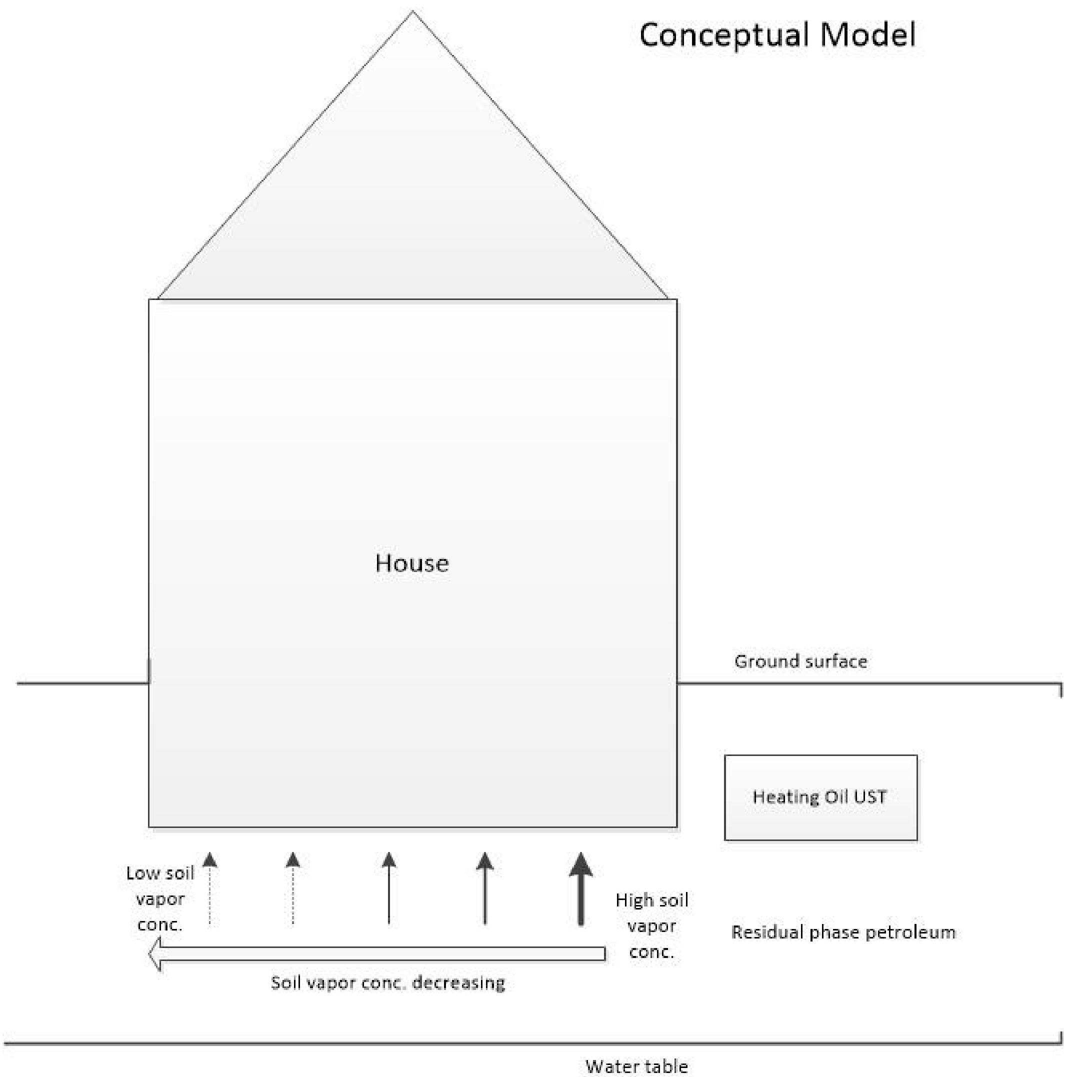
Correction: Brewer, Roger, Josh Nagashima, Michael Kelley, Marvin Heskett, and Mark Rigby. 2013. Risk-Based Evaluation of Total Petroleum Hydrocarbons in Vapor Intrusion Studies. International Journal of Environmental Research and Public Health. 10: p 2441 – 2467. (published in 2014).

U.S. EPA Region III. 2021. Regional Screening Levels (RSLs) – Generic Tables.

Geosphere, Inc. 2006. Hydrocarbon Characterization for Use in Hydrocarbon Risk Calculator and Example Characterizations of Selected Alaska Fuels.

Appendix C. Soil Vapor Conceptual Site Model at Home Heating Oil Tank Sites

This study evaluated soil vapor concentrations following documented discharges from home heating oil USTs. The conceptual model for most of these heating oil releases is that the bulk of contamination at the site is in the soil immediately adjacent to and underneath of the UST. Soil vapor concentrations are, thus highest in proximity to the tank and will decrease with distance from the tank.



Staff estimated soil vapor concentrations by distance from a source using models developed by EPA and API. The EPA model assumes no biodegradation by distance and the API model assumes biodegradation provided that oxygen is present in the subsurface. Samples collected by consultants as part of this study showed subsurface oxygen contents were usually in the vicinity of atmospheric levels (approximately

21%). This suggests that conditions under which biodegradation can occur probably are present at most home heating oil release sites.

Staff modeled vapor concentration by distance from the soil vapor sample location. It was assumed that the formation was homogeneous and isotropic. The graph below shows results of a model run using the Biovapor model (API 2010) as well as the EPA model (EPA 2015). It appears that soil vapor concentrations decrease by distance from the source and this decrease appears to follow a negative exponential function. Staff thus developed an estimated vapor decay function that provides values between those derived by the EPA and API models. The DEQ vapor decay function is:

$$\text{Estimated vapor concentration at distance (d)} \approx C_0 * e^{\sqrt{(-d\ /\ 5)}}$$

C_0 = measured vapor concentration (ug/m3)
d = distance in feet from the measured soil vapor location

Example
The concentration of a soil vapor sample in the source area is 200,000 ug/m3 TPH. What is the estimated concentration at 5 feet from this location? What is the concentration at 10 feet from this location?

Concentration at 5 feet $\approx 200{,}000 \text{ ug/m3} * e^{\sqrt{(-5\ /\ 5)}}$

$\approx 200{,}000 * e^{\sqrt{-1}}$

$\approx 200{,}000 * .368$

$\approx 73{,}600$ ug/m3

Concentration at 10 feet $\approx 200{,}000 \text{ ug/m3} * e^{\sqrt{(-10\ /\ 5)}}$

$\approx 200{,}000 * e^{\sqrt{-2}}$

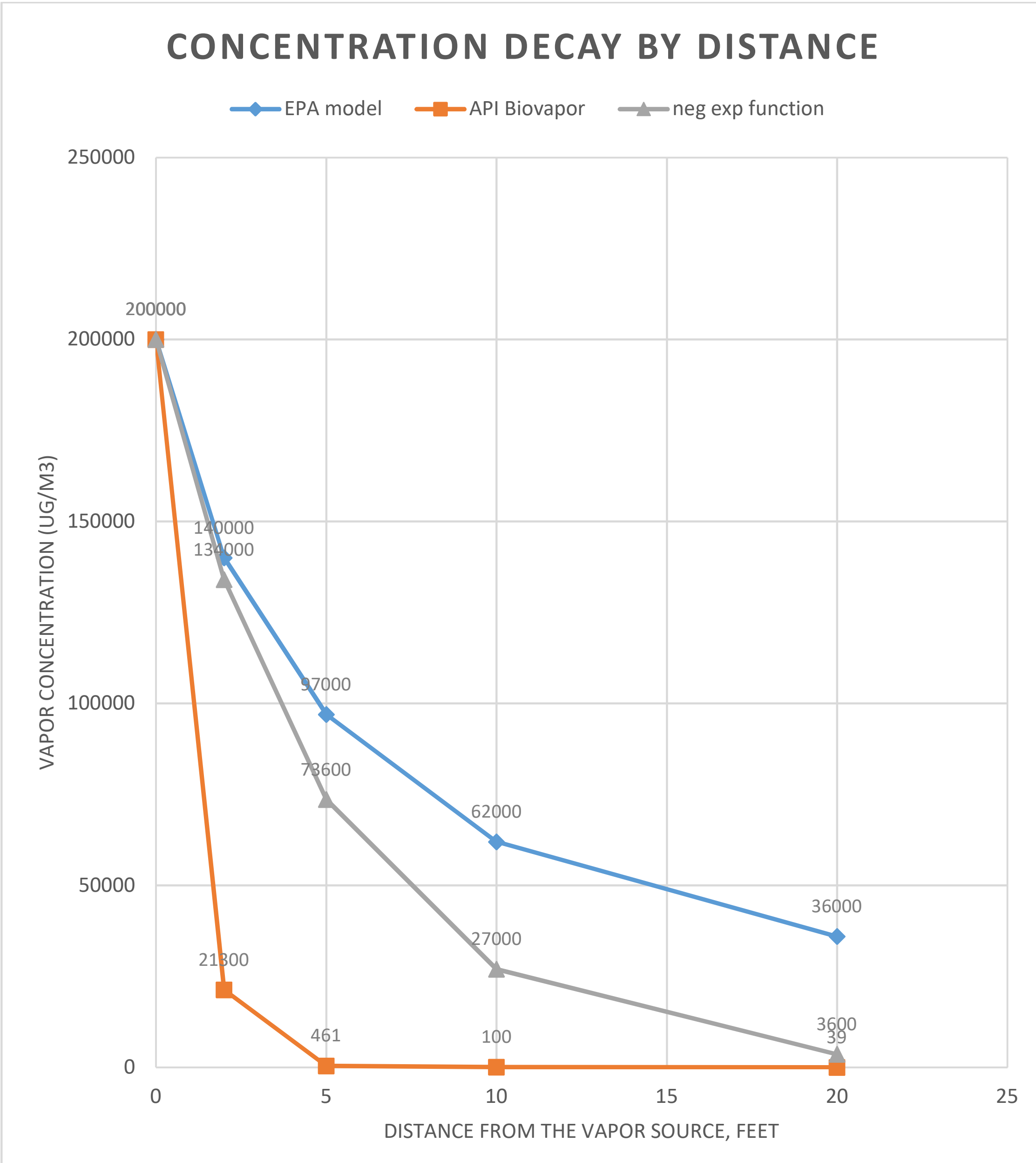
$\approx 200{,}000 * .135$

$\approx 27{,}000$ ug/m3

American Petroleum Institute (API). 2010. BioVapor version 2.1

EPA. 2015. Vapor Intrusion Screening Level Calculator.

Graph corresponding to Example above: DEQ Soil Vapor Attenuation Estimates by Distance from the Source and Model



Appendix D. Home Heating Oil Vapor Intrusion Charter Statement

Project Name:	**Petroleum Vapor Intrusion**
Project Start Date:	August 2, 2019

Team Members (when applicable)

James Barnett, OSRR

Chad Quesenberry, OSRR

Joe Glassman, NRO

Kris McCandless, NRO

Amy Webster, TRO

Shon Pritchard, SWRO

Opportunity Statement:

An opportunity exists to improve the technical basis for Petroleum Program procedures as related to evaluating risks posed by petroleum vapor intrusion. Petroleum vapor intrusion presents unique challenges as many petroleum constituents are ubiquitous in indoor air (regardless of nearby storage tanks/releases) and often present at concentrations that exceed typical risk thresholds. Moreover, many constituents cannot be detected via olfactory senses at concentrations that may pose long-term risks via the indoor air exposure pathway. This effort should improve employee knowledge of petroleum vapor intrusion and lead to the development of program guidance which will update program procedures to better reflect current scientific knowledge.

Project Goal(s):

The DEQ Petroleum Program has a need for vapor intrusion guidance. The **primary** goal of this project is to develop technically sound and defensible draft PVI guidance that is protective of human health and the environment. Interim project goals that need to be reached in order to attain the primary project goal include:

1. Identify petroleum vapor knowledge gaps related to PVI from home heating oil (HHO) tanks
2. Design the research framework for a study which addresses deficiencies in PVI knowledge as it relates to HHO tanks
3. Carry out study to evaluate PVI from HHO tanks; and
4. Develop draft petroleum vapor intrusion guidance that is technically sound, defensible, and protective of human health and the environment.

Stakeholder Analysis

Stakeholder	Why are they interested in the project?
LT members/ Managers	Improve consistency in program implementation.
Petroleum Program Staff	Petroleum program staff members spend time evaluating risks posed by petroleum releases. This effort will increase staff understanding of vapor intrusion and lead to improved consistency and decision-making within the program.
Storage Tank Owners and Operators	Storage tank owners/operators have a vested interest in the requirements for investigating and cleaning up petroleum releases.
Environmental Consulting Community	Environmental consultants perform most of the site characterization and clean-up work at petroleum release sites. They will benefit from any technical support documents provided by this project and they will need to understand DEQ guidance and procedures as they pertain to investigating and cleaning up petroleum releases.

Project Scope:

In Scope:	Out of Scope:
Petroleum products with a primary focus on motor fuels and heating oils. Design HO PVI study Carry out HO PVI study Develop draft petroleum vapor intrusion guidance to address both HO and non-home heating oil tanks	Volatile organic constituents that are not associated with petroleum motor fuels or heating oils Review and comment by all Petroleum Program Case Managers Public review and comment Training Program Development Issuance of any documents as DEQ guidance

Deliverables:

1) Home Heating Oil PVI Study Design
   a) Define questions to be answered by study
   b) Study Procedures
      1) Sampling design (which sites to include in study)
      2) Data collection
      3) Data analysis
2) Heating Oil PVI Study Results
3) Develop draft petroleum vapor intrusion guidance
   a) PVI associated w. regulated USTs
   b) PVI associated with home heating oil tanks

Completion Milestones and Target Dates:

Define the Project

1) Develop draft project charter – August 2, 2019
2) Define Project Goals – August 9, 2019
3) Define Project Scope – August 9, 2019

Set up Project Workgroup

1) Discuss project with GW managers – PPM call in August 20, 2019
2) Request volunteers to serve on workgroup – within 1 week post PPM call
3) Establish PVI workgroup – by Sept 27, 2019
4) First workgroup conference call – by Oct. 11, 2019

HHO PVI Study Design

1) Define questions to be answered by HHO study – by Oct. 3, 2019
2) Develop site sampling design – by Oct. 8, 2019
3) Develop data collection methodology – Oct. 30, 2019
4) Develop data analysis strategy and tools – Oct. 30, 2019
5) Draft HHO PVI study design, estimated project schedule – by Nov. 29, 2019
6) Final HHO PVI study design, estimated project schedule – by January 7, 2020

Conduct HHO PVI study fieldwork

1) Start Jan. 15, 2020
2) End??? (target date specified in HHO PVI study design)

HHO PVI Study Results

Project deliverables and target dates specified in HHO PVI Study Design

Workgroup will propose a schedule to develop draft guidance following completion of fieldwork

Develop Draft PVI Guidance

Schedule to be determined

Team Guidelines

- Ensure that everyone on the team has the opportunity for input
- Share the workload
- identify and utilize group members strengths to maximize efficiency
- Complete action items on time
- Maintain project momentum
- Reach consensus on recommendations

Project Background

The DEQ needs to establish program guidance related to dealing with petroleum vapor intrusion.

EPA and ITRC have issued PVI guidance, but the data upon which those guidance documents are based primarily is related to gasoline from regulated USTs. Many other states also have issued PVI guidance. Technical information provided within these documents is expected to be of value and the workgroup may consider the merits of guidance issued by EPA, ITRC, and others for its potential usefulness in Virginia.

Relatively little data exists related to PVI from home heating oil tanks. The DEQ needs additional technical information in order to develop program procedures related to PVI from home heating oil tanks.

Appendix E. White Paper for Virginia Tech Study (the Virginia Tech Study report is available upon request)

MEMORANDUM

DEPARTMENT OF ENVIRONMENTAL QUALITY

DIVISION OF LAND PROTECTION AND REVITALIZATION
OFFICE OF SPILL RESPONSE AND REMEDIATION

Mail Address:
P.O. Box 1105
Richmond, VA 23218

Location:
1111 East Main St., Suite 1400
Richmond, VA 23219

SUBJECT: Petroleum Vapor Intrusion at Home Heating Oil Tank Sites

TO: Betty Lamp, Director, Office of Spill Response and Remediation

FROM: James Barnett, State Lead Program Manager, Office of Spill Response and Remediation

DATE: February 8, 2019

The Virginia Department of Environmental Quality (DEQ) oversees the investigation and corrective action of petroleum releases including discharges from home heating oil tanks. DEQ has developed programmatic procedures to streamline the release response and corrective action process for most home heating oil tank discharges. DEQ contracted with Virginia Tech to evaluate risks from petroleum vapor intrusion at home heating oil tank discharge sites. This memo summarizes the findings of the study, discusses potential implications related to existing program guidance and procedures, and provides recommendations based upon the results of the study.

Issue Statement

Discharges from home heating oil tanks are the most common type of oil discharge dealt with by DEQ staff. DEQ's policies and procedures must protect human health and the environment while, at the same time, not requiring those activities that provide minimal additional protection.

The DEQ contracted with Virginia Tech to evaluate risks posed by petroleum vapor intrusion at home heating oil tank sites. The primary objective of the study was a scientifically defensible answer to the question: To what degree do heating oil vapors from a home heating oil discharge pose unacceptable risks to residents? A secondary objective was to determine the site-specific variables that most strongly influence the potential risk for petroleum vapor intrusion.

Discussion

DEQ's present home heating oil procedures were issued as guidance during the 2007 Fiscal Year. DEQ staff performed a database query and provided Virginia Tech with a list of all cases, starting in FY2008, where heating oil had been discharged from a residential heating oil UST. Virginia Tech randomly selected sites to include in the study and then requested that DEQ provide copies of the site characterization reports for the sites. Sites were grouped and then evaluated by:

- DEQ heating oil discharge category: NFA, Category 1, Category 2, Category 3.
- Physiographic region of state: Blue Ridge/Valley and Ridge, Piedmont, Coastal Plain

At sites where access was granted by the homeowner, Virginia Tech staff collected site data and subsurface soil vapor samples. Most samples were collected from within a couple of feet of the foundation of the house and from between the tank or former tank and the house. Soil vapor samples were analyzed for TPH, benzene, toluene, ethylbenzene, xylenes, naphthalene, and MTBE. TPH vapor concentrations represent a combined or total mass of hydrocarbon constituents ranging from C5 to C18.

Soil vapor survey sites were dependent on responses from current property owners. The lower the heating oil category, the fewer property owners responded for a variety of reasons. Category 3 sites represented the most responsive homeowners.

Report Findings:

- TPH and naphthalene appear to be the principal contaminants of concern (COC) with regards to petroleum vapor intrusion (PVI) risks. Moreover, the study data suggests a positive correlation between TPH and naphthalene in soil gas; especially when naphthalene is > 10 ug/m3. A study by Brewer uses 72 ug/m3 as the risk-based threshold for naphthalene and 140,000 ug/m3 as the screening level for TPH in soil gas.
- Fewer than 10% exceeded a risk-based threshold for either TPH soil gas or naphthalene soil gas. When a site did exhibit an exceedance of TPH or naphthalene soil vapor, a correlation between naphthalene and TPH concentrations was not consistent (see Appendix 1).
- The study indicated relatively poor correlation between measured TPH and BTEX concentrations in soil gas.
- Physiographic region within the state had some influence on higher vapor concentrations as it related to shallow groundwater. Sites with a combination of shallow water table (within 6' of ground surface) and free product were associated with higher TPH and naphthalene concentrations in soil vapor.
- Cases where there were documented impacts of oil in crawl spaces or in basements generally had higher observed TPH and/or naphthalene concentrations in soil vapor outside the residence.
- Time between tank removal or the collection of the initial soil sample (essentially the assumed release date) and the time that the soil gas samples were taken did not indicate any significant relationship between time of the release and observed soil gas concentrations.
- There is poor correlation between soil vapor concentrations and the maximum reported TPH concentration in soil documented in Site Characterization Reports.
- Soil vapor concentrations by DEQ Category
    - Samples were collected at ten (10) NFA cases. TPH concentrations in soil vapor exceeded the screening level of 140,000 ug/m3 at two of these sites.
      Note: Upon further file review by DEQ, soil samples for each site were not obtained in traditional fashion (hand auger at the end of the tank). One site was assigned NFA as a result of low TPH after a tank removal. The sample was taken at the bottom of the tank pit. The other site was assigned NFA as a result of a single sample collected during a tank closure in place under a deck were the sample was taken through the bottom of the tank. Both residences have crawl spaces which should induce air flow that would dissipate soil vapor before it would enter the home.
    - Samples were collected at ten (10) category 1 cases. One category 1 site had a naphthalene soil gas concentration that exceeded the screening level of 72 ug/m3. None of the category 1 sites had TPH concentrations that exceeding the screening level. Note: Upon further file review, the one site with elevated naphthalene soil vapor had a sump in the basement of the residence and no evidence of an impact was detected in the sump.
    - Samples were collected at twenty (20) category 2 cases. Two of the cases had vapor concentrations that exceeded screening levels. One of these sites exceeded the screening

levels for both TPH and naphthalene while the other exceeded the screening level for naphthalene.
Note: Upon further file review, at the site with elevated TPH and naphthalene soil gas vapors, free product was observed in the tank pit following tank removal. Soils were excavated and the case closed. The other site (naphthalene only) had a sheen on water in the basement sump and technically should have been elevated to a Category 3 due to the impact; proper remediation measures were taken to abate the impact. The sump discharge water had been redirected from the storm drain to a reinfiltration pit; the location of the soil vapor gas result may be elevated as a result of the proximity to the reinfiltration point.

- Samples were collected at sixteen (16) category 3 sites. Four of the sites had TPH vapor concentrations that exceeded the screening concentration of 140,000 ug/m3 while three of these same sites also had naphthalene concentrations that exceeded screening levels for that constituent. Three of these cases have free product on shallow groundwater. The fourth case had free product that entered a basement. All four of these cases are still open.
- Summary:
  - Soil vapor samples were collected at 56 sites.
  - 7 cases exceeded the naphthalene screening threshold of 72 ug/m3 (13%)
  - 7 cases exceeded the TPH screening threshold of 140,000 ug/m3
  - 4 of these cases had documented free product present and 3 of them are still open cases
  - Of the cases without documented free product present, 3 exceeded the naphthalene screening threshold (5%) and 2 exceeded the TPH screening threshold (4%). One of these 3 cases having elevated naphthalene had documented impacts to a basement sump (sheen and dissolved constituents).

Summary and Recommendations

Indoor Air Quality and Storage Tank Program Risk Thresholds
Many petroleum constituents found in residences are the result of various sources. Naphthalene is widely found in indoor air due to emissions from wood burning, gasoline and oil combustion, tobacco smoking, cooking, the use of mothballs, fumigants, and deodorizers, and many other sources (Chunrong and Batterman, 2010)[1]. This same source noted that maximum "background" indoor air concentrations of naphthalene range from 1.4 to 144 ug/m3 with medians ranging from .3 to 4 ug/m3.

Petroleum Soil Vapor Data and Free Product
The PVI study shows that most of the cases having elevated soil vapor concentrations are associated with free product and, often, shallow groundwater. In accordance with the program's procedures, these sites are managed as either Category 2 or Category 3 home heating oil cases. The results of the study suggest that vapor abatement via a vapor removal system or other type of vapor barrier in the vicinity of the heating oil UST may be appropriate at many sites where free product has been encountered.

1 Chunrong, Jia and Stuart Batterman. 2010. **International Journal of Environmental Research and Public Health**. July 7(7): 2903 - 2939

Petroleum Soil Vapor Data and PVI Risk Uncertainty

The PVI study only collected soil gas samples in the immediate vicinity of the UST and usually between the tank and the residence. Screening concentrations for petroleum in subsurface are based on an assumption of equal vapor concentrations under the entire building. This type of subsurface vapor concentration profile may not fit the typical home heating oil UST discharge situation where most contamination is likely present on one side of the structure and, perhaps, under one portion of the structure rather than under all of it. The researchers suggested that a follow-up study where soil gas data is collected from multiple points around the structure may be useful in order to better evaluate the potential for PVI at home heating oil discharge cases. DEQ believes that based on the now-established relationship between the presence of free product and shallow groundwater as a source of the majority of the TPH and naphthalene soil vapor gas results above the risk threshold, implementing an abatement strategy is more productive and proactive than additional studies.

The Storage Tank Program has utilized an excess lifetime cancer risk of 1 x 10-6 for carcinogenic constituents and a hazard quotient of unity (1) for establishing numeric risk thresholds for various petroleum constituents. The EPA Region III risk based concentration table lists an indoor air screening level of .083 ug/m3 for naphthalene. This corresponds with an estimated excess lifetime cancer risk of 1 x 10-6. Chunrong and Batterman noted that typical or background concentrations of naphthalene in most residences would correspond with risks in the range of 10-4. The Storage Tank Program may consider utilizing “background” concentrations of petroleum constituents in indoor air when establishing remedial endpoints related to PVI and petroleum vapors in indoor air.

DEQ recognizes that the sources of the contaminants in question (TPH and naphthalene) are abundant in a typical household, therefore trying to isolate the origin of specific COCs in indoor air would be extremely difficult. Therefore indoor air sampling may not be a reliable tool to evaluate the impact on indoor air from an outdoor release of petroleum.

Based on the Virginia Tech heating oil vapor intrusion study results, DEQ believes that the current categorization system for heating oil tank releases adequately protects individuals from vapor intrusion. Of the sites selected by the study for the vapor gas assessment, sites with exceedances above the risk threshold are mostly open cases and have free product associated with them. At sites where free product is present either in the tank pit or at shallow groundwater sites, DEQ might consider authorizing additional protective actions such as the installation of a passive vapor removal (radon-type) system along the structure in the vicinity of the free product if the structure is on a slab or has a basement. A crawl space with adequate ventilation and air circulation should provide adequate protection from any soil vapor TPH and/or naphthalene contaminants in the area due to free product.

DEQ’s current practice has been to proactively address potential vapor impacts from heating oil releases. It’s generally more cost effective to implement a solution than quantify the degree of risk to the receptor. This approach eliminates the need to collect soil gas vapor samples. DEQ’s technical guidance will be evaluated for modification based on the new information provided by this study.

Appendix 1: DEQ Summation of Vapor Intrusion Data

Category	TPH Vapor Level	Naphthalene vapor level	DEQ Comments
NFA	1100	0.83	
NFA	234000	113	tank was already removed
NFA	6400	13.8	
NFA	2000	5.42	
NFA	1500	0.77	
NFA	5500	0.56	
NFA	4400	2.36	
NFA	205000	0.4	tank had to be closed in place, sampled through bottom of tank
NFA	15000	6.66	
NFA	9500	1.43	
1	490	0.12	
1	12,000	3.3	
1	7300	1.29	
1	18000	1.78	
1	36000	104	site had basement w. sump, no evidence of impact
1	29000	10.8	tank could not be removed due to utilities
1	3200	0.79	
1	4100	2.08	
1	986	2.39	
1	1100	3.64	
2	311000	475	had FP in pit
2	57000	1.4	
2	4800	6.74	
2	3,900	0.89	
2	1,600	0.96	
2	1,100	1.2	
2	32,000	2.47	
2	29,000	10	
2	17,000	9	
2	2200	1.28	
2	252	0.32	
2	1.9	1.17	
2	3900	1.12	
2	23000	14.1	
2	77,000	82.2	Petroleum sheen on water in basement sump
2	4,000	2.19	
2	341	2.76	
2	4,800	1.36	
2	7,900	2.38	
2	6,200	1.86	

(Continued next page)

Category	TPH Vapor Level	Naphthalene vapor level	DEQ Comments
3	5900	4.97	
3	123000	10.8	FP to basement
3	22000	4.08	
3	31000	8.04	
3	19000	17	1500 gal ust
3	8900	2.54	
3	281000	0	FP in basement, case open
3	293000	24.8	FP in monitoring wells, shallow gw, case open
3	427000	77.6	FP in monitoring wells, shallow gw, case open
3	6700	14.1	FP in monitoring wells
3	90000	54.5	case initiated due to vapors in residence
3	1200	9.37	
3	115,000	54.8	oil in excavation and MWs. Shallow GW
3	688,000	1,094	FP in monitoring wells, oil in excavation, shallow Gw, case open
3	431,000	752	FP in monitoring wells, shallow gw, case open
3	1,600	9.54	
3	895	4.57	
3	1,400	7.47	