Petroleum Vapor Intrusion (PVI): Updated Screening Levels, Cleanup Levels, and Assessing PVI Threats to Future Buildings

Implementation Memorandum No. 18

Date:	January 10, 2018
To:	Interested Persons
From:	Jeff Johnston, Section Manager Information & Policy Section Toxics Cleanup Program
Contact:	Policy & Technical Support Unit, Headquarters
Attachments:	A – Ecology's process to establish a generic Method B TPH air cleanup level
	B – Process for calculating a site-specific TPH indoor air cleanup level (with example)
	C – Response to comments on the August 7, 2017, review draft of this memo

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Acronyms and Abbreviations

Acronym or Abbreviation	Definition
APH	air phase hydrocarbon
BTEXN	benzene, toluene, ethylbenzene, xylenes, and naphthalene
CLARC	Cleanup Levels and Risk Calculator
CPFi	inhalation cancer potency factor
CPOC	conditional point of compliance
CUL	cleanup levels
DRO	diesel range organics
EC	equivalent carbon
Ecology	Washington State Department of Ecology
EDB	ethylene dibromide
EDC	1,2 dichloroethane (also known as ethylene dichloride)
EPA	Environmental Protection Agency
ESA	Environmental Site Assessment
FS	Feasibility Study
GRO	gasoline range organics
HDOH	Hawaii Department of Health
HI	Hazard Index
ITRC	Interstate Technology Regulatory Council
JP-8	jet propellant 8
MDL	method detection limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MTBE	methyl tert-butyl ether
MTCA	Model Toxics Control Act
NFA	no further action
PCBs	polychlorinated biphenyls
PCE	tetrachloroethylene (also called perchloroethylene)
PQL	practical quantitation limit
PVI	petroleum vapor intrusion
RCW	Revised Code of Washington
RfDi	inhalation reference dose
RI	Remedial Investigation
SIM	Selective Ion Mode
TCP	Toxics Cleanup Program
TPH	total petroleum hydrocarbons
$\mu g/m^3$	micrograms per cubic meter
VCP	Voluntary Cleanup Program
VPH	volatile petroleum hydrocarbon
VOC	volatile organic compound
WAC	Washington Administrative Code

1.0 Summary

To ensure consistency with the Model Toxics Control Act (MTCA) and Washington Department of Ecology's (Ecology's) guidance on petroleum vapor intrusion, this memo makes the following changes. The first five are related to the vapor intrusion data tables in the Cleanup Levels and Risk Calculator (CLARC). The other two explain how to assess whether PVI represents a threat to future buildings and how to develop Tier I and Tier II sampling plans.

1. **Remove petroleum fraction levels and replace with a generic TPH level.**
The indoor air cleanup levels and soil gas screening levels for the air phase hydrocarbon (APH) petroleum fractions will be removed and replaced with a generic Method B total petroleum hydrocarbon (TPH) indoor air cleanup level of 140 $\mu g/m^3$. Corresponding TPH soil gas screening levels will be added. An Appendix will be added to both the Method B and Method C vapor intrusion data tables describing how to calculate a site-specific TPH indoor air cleanup level.

2. **Annotate when indoor air cleanup levels and soil gas screening levels apply.**
A footnote will be added to all of the individual non-carcinogenic petroleum compounds levels to indicate that the indoor air cleanup levels and corresponding soil gas screening levels only apply when the release is limited to that specific compound. For petroleum mixtures, the additive effects of the compounds present must be accounted for using the generic value or the process provided in Attachment B of this memo.

3. **Remove VPH groundwater screening levels**.
The volatile petroleum hydrocarbon (VPH) screening levels will be removed since they do not account for the additive effects of the petroleum mixture. A generic TPH groundwater vapor screening level will not be provided since a Henry's Law constant can't be accurately determined due to the variable makeup of petroleum mixtures.

4. **Remove *m* and *o* isomers of xylene and replace with total xylenes.**
Using total xylenes provides consistency with the soil and groundwater cleanup levels set forth in MTCA.

5. **Clarify the applicability of screening levels for several compounds.**
In CLARC, benzene, naphthalene, 1,2 dichloroethane (also known as ethylene dichloride, EDC), and xylenes have vapor intrusion groundwater screening levels below the Method A groundwater cleanup levels found in MTCA Table 720-1 (WAC 173-340-900). For each of these compounds, the screening level will be replaced with a link to Section 5.2 of this memo to help users understand how to apply the levels.

6. **Assessing potential PVI impacts to future buildings.** Several options are provided for ensuring future buildings will be protected for PVI, based on the amount of contamination remaining following cleanup.

7. **Tier I or Tier II sampling plans.** Chapter 6 identifies the factors that should be accounted for if a Tier I or Tier II sampling plan needs to be developed.

2.0 Purpose and Applicability

In the years following the release of Ecology's 2009 draft vapor intrusion guidance (*Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action*), a significant amount of new data has become available regarding the makeup and migration potential of petroleum vapors. This yielded a number of questions on how the petroleum provisions in the 2009 draft guidance were affected. After assessing the new information, Ecology released Implementation Memo No. 14 in March 2016 (*Updated Process for Initially Assessing the Potential for Petroleum Vapor Intrusion*, Ecology 2016c), which adopted EPA's PVI screening criteria and vertical separation distances for benzene and TPH. In addition, Ecology adopted ITRC's recommended horizontal screening distance of 30 feet for sites with a good site characterization.

Since the March 2016 memo was released, implementation-related questions have arisen and several inconsistencies were also identified. Ecology prepared this memo to address these issues and to:

1. Provide the basis for several modifications to the CLARC data tables to account for the additive effects of non-carcinogenic compounds present in petroleum mixtures. This includes establishing a generic TPH cleanup level of 140 $\mu g/m^3$ as well as corresponding sub-slab and deep soil gas screening levels.

2. Explain how to assess whether PVI represents a reasonably likely threat to future buildings.

3. Provide additional direction for developing Tier I or Tier II PVI sampling plans.[1]

This memo primarily applies to releases of petroleum-containing fuels from:
1) underground storage tanks, 2) spills, 3) home heating oil tanks, and 4) bulk tank farms.
This memo should be used when sites do not initially "screen out" using the process established in Implementation Memo No. 14, or when further vapor evaluation is necessary after implementing the selected cleanup action.

Ecology has begun evaluating the 2009 draft vapor intrusion guidance to determine which portions need updating to make the document consistent with current guidelines and practices. Since revising the guidance will be a time-consuming process, Ecology is developing several Implementation Memos to address some of the most pressing VI issues.

[1] To learn more about Tier I and II petroleum VI sampling plans, see Ecology's 2009 *Draft Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (pp. 1-14 and 1-15).

3.0 General Overview

Petroleum is made up of hundreds of different chemical compounds. Due to the large number of constituents present, default cleanup levels for total petroleum hydrocarbon (TPH) are provided in MTCA's Method A tables. MTCA also allows Method B or C TPH cleanup levels to be developed using analytical methods that divide the petroleum mixture into equivalent carbon (EC) fractions. The toxicity of each carbon fraction is determined using a) a specified compound within that range, or b) an assigned reference dose selected by Ecology that is intended to account for all petroleum constituents within that carbon range.

The CLARC data tables currently provide indoor air cleanup levels, as well as groundwater and soil gas screening levels, for a number of individual petroleum compounds and fractions. This includes groundwater screening levels for some of the volatile petroleum hydrocarbon (VPH) fractions. It also includes indoor air cleanup levels and soil gas screening levels for several air phase hydrocarbon (APH) fractions.

The following sections highlight those areas where changes to or clarification of the current approach are warranted. Ecology intends to incorporate these concepts into the updated vapor intrusion guidance document.

4.0 Accounting for the Cumulative Effects of Petroleum Mixtures

4.1 Background

WAC 173-340-750(3)(b)(ii)(C) specifies that for petroleum mixtures, a TPH air cleanup level shall be calculated using Equation 750-1 and shall take into account the additive effects of the petroleum fractions and volatile organic compounds present in the petroleum mixture. Establishing a total TPH cleanup level requires measuring the indoor air concentration of three petroleum fractions (Aliphatics EC5-8, Aliphatics EC9-12, and Aromatics EC9-10) as well as any non-carcinogenic petroleum VOC's and determining the proportion of each in the mixture. Each individual proportion is then divided by its air cleanup level and the resulting ratios are summed. The inverse of the total is the TPH air cleanup level. This process is parallel to MTCA Equations 720-3, 740-3, and 745-3. See Attachment B in this memo for more details on how to calculate a site-specific TPH air cleanup level.

The concentration of any carcinogenic component of the mixture should be evaluated against its air cleanup level. Additive cancer risks should also be considered, which is separate from the process described above for non-carcinogenic components.

CLARC provides Method B air cleanup levels for individual petroleum compounds and certain fractions based on a target hazard quotient of 1 for each compound or fraction. CLARC does not provide a Method B air cleanup level for TPH because the TPH cleanup level is a site-specific calculation that depends on the composition of the mixture. In practice, the concentrations of individual compounds and fractions have been compared to their individual air cleanup levels and the additive hazards of the mixtures have not been considered.

4.2 New approach

To ensure that the additive effects of the non-carcinogenic petroleum constituents are properly addressed, Ecology has developed a Method B generic indoor air TPH cleanup level of 140 $\mu g/m^3$ that can be used when assessing the potential for petroleum vapor intrusion. Ecology established this generic cleanup level using information from Ecology's site files, as well as laboratory and site-specific data on the typical makeup of petroleum vapors collected by the Hawaii Department of Health (HDOH). See Attachment A for the specific assumptions that were used, along with the supporting data.

Ecology will be replacing the APH levels currently in CLARC with the generic TPH indoor air cleanup level of 140 $\mu g/m^3$ and corresponding TPH soil vapor screening levels. Along with these changes, a footnote will be added to the individual petroleum constituents in CLARC that have non-carcinogenic indoor air cleanup levels. The footnote will indicate that the additive effects of these compounds must be accounted for when addressing releases of petroleum mixtures.

> **NOTE:** See Attachment A for a discussion on why a higher Method C generic indoor air TPH cleanup level was not developed.

While the generic Method B TPH cleanup level can be used at any site, conducting sampling to establish a site-specific TPH cleanup level is also an option. Determining a site-specific cleanup level may be worthwhile if the anticipated makeup of the petroleum vapors would primarily consist of the lower weight aliphatic compounds in the EC5-8 range. This is because the toxicity of this carbon range is lower than the other fractions that need to be evaluated. As a result, the calculated TPH indoor air cleanup level may be much higher than the generic level of 140 $\mu g/m^3$.

4.3 Indoor air contaminants from sources other than PVI

There are a number of sources that can affect the measured concentrations of petroleum constituents in indoor air. In addition to ambient sources, common household products such as gasoline, lighter fluids, automotive chemicals, miscellaneous paint products, natural gas, and many others can contribute to the measured TPH levels. Table 1 below compares Ecology's indoor air cleanup levels with a range of potential "background" concentrations for indoor air developed by EPA and the Massachusetts Department of Environmental Protection. The table shows that cleanup levels for benzene, naphthalene, and TPH can be within or even below the range of typical background indoor air concentrations. This can present challenges when assessing the potential for vapor intrusion, especially when the measured concentrations are low.

Indoor sources unrelated to PVI can contribute the same chemicals as those being assessed as part of the PVI evaluation. Therefore, it is important to inventory all products or other PVOC-emitting materials and remove those from the building several days to a week prior to sampling. If measured concentrations of contaminants are within the range of anticipated background values, then multiple lines of evidence should be evaluated to determine the likely cause of the exceedances.

Table 1: Indoor air cleanup levels and background concentrations for three petroleum compounds.

Compound	Ecology Indoor Air Cleanup Levels (μg/m^3)	Range of Potential Background Concentrations[2] (μg/m^3)
Benzene	0.32	<Reporting Limit – 4.7
Naphthalene	0.074	0.18 – 1.7
TPH	140 or a site-specific determination	116 – 594

[2] The benzene and naphthalene ranges were compiled by the Environmental Protection Agency (EPA) and represent the 50th percentile of the data evaluated. The TPH values were compiled by the Massachusetts Department of Environmental Protection and represents the 50th to 80th percentile.

5.0 Assessing the Potential Threat of Petroleum Vapor Intrusion on Future Buildings

5.1 Background

Future site use

WAC 173-340-702(4) specifies that: "Cleanup standards and cleanup actions shall be established that protect human health and the environment for current and **potential future site and resource uses**" (emphasis added). A well-established process exists for addressing future use issues for pathways other than vapor intrusion. If the applicable cleanup levels can't be met, institutional controls (which often include an environmental covenant) are required to ensure the site remains protective of human health and the environment.

However, ensuring that the vapor pathway is protected in the future can be difficult, especially under the following scenarios:

- A building is not currently present in the area of contamination but could be constructed within it;
- The building that is currently located in the area of contamination could be replaced or significantly modified; or
- The building located in the area of contamination may currently be used commercially, but could change to residential use.

Since property use can change over time, the cleanup action needs to account for plausible future land use scenarios. This can occur by achieving soil and groundwater cleanup levels that will be protective in the most likely situations, or by requiring that the necessary institutional controls be established.

PVI screening levels

Ecology's CLARC database contains generic soil gas and groundwater PVI screening levels that were calculated based on the attenuation factors provided in the Environmental Protection Agency's March 2012 report, *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings*. The attenuation factors assume no biodegradation because the data analyzed by EPA were exclusively from chlorinated solvent sites.

Most chlorinated compounds do not readily degrade under aerobic conditions in the vadose zone. A much greater reduction in concentrations typically occurs when petroleum hydrocarbons are the contaminants of concern. For example, Abreu, Ettinger, and McAlary (2009) modeled various source vapor concentrations and separation distances when biodegradation was accounted for. The modeling predicted that groundwater sources without free-phase petroleum had nearly 100 times more attenuation than the generic value of 1000 that was used to establish the groundwater screening values, if at least one meter of separation was present between the source and the basement.

Determining whether a future building could be impacted by PVI can be difficult, since the location, configuration, and use of that structure is often unknown. The remainder of this section focuses on future building protection based on the cleanup levels achieved during remedial action. Depending on the cleanup levels chosen for the site, additional PVI evaluation or institutional controls such as property restrictions may be necessary to ensure protection of indoor receptors.

5.2 When Method A soil and groundwater cleanup levels are met

In general, the vast majority of sites that meet the Method A soil and groundwater cleanup levels will be protective of the PVI pathway both now and if a building is constructed in the future. However, there are four petroleum compounds that have groundwater PVI screening levels below the Method A groundwater cleanup levels. The compounds and their respective groundwater screening and cleanup levels are found in Table 2.

Table 2: Groundwater screening and cleanup levels for four petroleum compounds.[3]

Compound	Method A Groundwater Cleanup Level (µg/L)	Groundwater PVI Screening Level (µg/L)
Benzene	5.0	2.4
1,2 dichloroethane or EDC	5.0	4.2
Naphthalene	160	8.9
Xylene[4]	1000	333

[3] Based on the discussion that follows, the Method A groundwater cleanup levels can typically be used when evaluating the potential for PVI. Two situations where additional evaluation may be necessary are provided at the end of this section.

[4] The xylene groundwater screening level was calculated using an estimated Henry's Law constant at 13^0 C of 0.138 that was determined by taking the mean of the 3 individual isomers.

Accurately developing generic groundwater PVI screening levels for gasoline range organics (GRO) and diesel range organics (DRO) is not possible because the Henry's Law constant will vary depending on which petroleum constituents are present. Ecology's Method A GRO and DRO groundwater cleanup levels are 800/1000 µg/L[5] and 500 µg/L, respectively. EPA's *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (USEPA 2015a) allows for a TPH screening level of up to 30,000 µg/L as long as six (6) feet of clean, biologically active soil is present between the source and the lowest point of the building. However, no specific separation distances are provided for low level TPH groundwater concentrations.

Ecology evaluated available technical information and reference materials to help determine the significance of these screening/cleanup levels. The results are summarized as follows:

1. EPA's PVI guidance indicates that "the potential for petroleum vapor intrusion from dissolved petroleum hydrocarbon contaminant plumes is typically limited to sites where there are high concentrations of dissolved contaminants or the plume is in direct contact with a building foundation, basement or slab." (p. 61, USEPA 2015a)

2. The Interstate Technology Regulatory Council (ITRC) PVI guidance has similar language on the potential effects of dissolved phase sources, and also has an evaluation of the empirical studies used to establish vertical separation distances. ITRC reported that over 94% of the measured benzene concentrations in soil gas are less than 30 – 50 µg/m^3 at vertical separation distances as small as zero (0) feet. ITRC indicated that benzene requires the greatest distance to biodegrade and that vertical screening distances derived from soil gas data for benzene are greater than other petroleum compounds, including xylene, ethylbenzene, hexane, C5-8 aliphatics, C9-12 aliphatics, C9-18 aromatics, and naphthalene. (ITRC 2014)

3. Research by Roger Brewer and Josh Nagashima of HDOH and several other authors, concluded that soil gas screening levels do not take into account an expected decrease in vapor concentrations over time due to biodegradation and source area depletion. The screening levels can be overly conservative for sites with limited contamination. The document is available on HDOH's website: *Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors: Implications for Potential Vapor Intrusion Hazards* (HDOH 2012).

4. Washington's Method A petroleum groundwater cleanup levels are less than the groundwater PVI screening levels used by other states, including Hawaii, Massachusetts, New Jersey, and Oregon.

[5] The higher value is allowed if there is no detectable benzene in groundwater.

This information supports a conclusion that, under most conditions, future buildings are unlikely to be impacted by PVI if the Method A soil and groundwater cleanup levels have been met. However, either of the following situations may warrant additional PVI evaluation, even if Method A soil and groundwater cleanup levels have been met.

> *Situation No. 1.* If a residential development is planned after cleanup is completed, or
>
> *Situation No. 2.* If multiple petroleum compounds (including GRO and/or DRO) are present in shallow groundwater just below the Method A groundwater cleanup levels.

In either of these situations, soil gas sampling coupled with the use of a predictive model such as PVI Screen or BioVapor that account for aerobic biodegradation can be used to evaluate whether PVI could represent a potential concern.

5.3 When Method B soil cleanup levels and Method A groundwater cleanup levels are met

WAC 173-340-740(3) outlines the requirements for establishing unrestricted Method B soil cleanup levels using either the standard or modified approach. When standard Method B soil cleanup levels are used, MTCA generally requires that the soil-to-vapor pathway be evaluated whenever petroleum constituents are significantly higher than a concentration derived for protection of groundwater for drinking water use. If modified Method B cleanup levels are used, the vapor intrusion pathway needs to be evaluated whenever the calculated cleanup levels are significantly higher than would be calculated without the proposed changes.

MTCA does not define the term “significantly higher,” so for these situations, the established Method B soil concentrations need to be evaluated on a case-by-case basis. When an empirical demonstration is used to address the soil-to-groundwater pathway for any petroleum constituent, the resulting Method B soil concentration will be higher than the Method A soil cleanup level in MTCA’s Table 740-1, which was developed based on protection of groundwater for drinking water use. However, the extent to which the Method A levels are exceeded could vary substantially. For example, a site that meets the benzene groundwater cleanup level could potentially use the Method B direct contact cancer cleanup level (18.2 mg/kg) that is up to 600 times higher than the Method A soil cleanup level for benzene (0.03 mg/kg) that is protective of the soil to groundwater pathway.

In some cases when Method B soil cleanup levels are used, the remaining volatile organic compound (VOC) concentrations could pose a VI threat to future building construction. In such situations, one of the following approaches would need to be used to ensure the VI pathway is protected:

1) Use the PVI screening concentrations and vertical separation distances in Implementation Memo No. 14 to help evaluate whether restrictions on future building locations are necessary;

2) Provide justification that the remaining soil concentrations are not significantly higher than a concentration derived for the protection of groundwater in accordance with WAC 173-340-747;

3) Show that the mass of remaining contamination is not significant enough to adversely affect future buildings with PVI. Soil gas sampling, coupled with the use of a predictive model such as PVI Screen or BioVapor that accounts for aerobic biodegradation, can be used to justify this conclusion; or

4) Implement institutional controls. For example, the property owner may be required to file a deed restriction indicating Ecology must be contacted before any future building construction takes place.

5.4 When soil or groundwater contamination remains following cleanup

For most situations where the Method A cleanup levels are exceeded, an environmental covenant will be necessary. This includes situations where contaminated soil remains following cleanup due to the presence of structural impediments or where a conditional groundwater point of compliance (CPOC) was approved. Ecology has developed a guidance document on environmental covenants titled, *Toxics Cleanup Procedure 440A: Establishing Environmental Covenants under the Model Toxics Control Act* (Ecology 2016b). Appendix 1 contains example provisions when vapor migration is a potential concern, including language that prohibits future building construction unless approved by Ecology.

6.0 Considerations When Developing a Tier I or Tier II Sampling Plan to Evaluate the Potential for Petroleum Vapor Intrusion

As discussed earlier, this memo applies to sites that do not initially screen out of the PVI assessment process using the procedures established in Implementation Memo No. 14 (Ecology 2016c). It also applies when further PVI sampling is necessary after the selected cleanup action is completed. In these situations, it will be necessary to implement either a Tier I or Tier II vapor intrusion evaluation. Developing a Tier I or II petroleum vapor intrusion sampling plan should take into account the following:

1. It is generally not necessary to use both Method TO-15 (Summa Canisters) and Method TO-17 (Sorbent Tubes) for determining compliance with established PVI cleanup or screening levels. Other analytical methods may be appropriate depending on the site-specific situation. For example, Method 8260 Modified could be used for screening purposes to help define areas of higher concentrations. In addition, analysis of oxygen, carbon dioxide and methane will require using alternative methods such as ASTM D1946.

2. Indoor air samples should generally be analyzed for:

    a. *Petroleum equivalent carbon (EC) fractions*[6]
        - EC5-8 (aliphatics),
        - EC9-12 (aliphatics), and
        - EC9-10 (aromatics)

    b. *Petroleum VOC's*[7]
        - benzene
        - ethylbenzene
        - toluene
        - xylenes
        - naphthalene

    c. *Other petroleum compounds*[8]

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[6] The three carbon fractions listed should be analyzed using the Massachusetts DEP APH Test Methods WSC-CAM-IX, July 2010 rather than a bulk analysis of TPHg and TPHd. This is because diesel range organics can contain a significant amount of lighter end compounds, especially EC5-8 aliphatics.

[7] It may be necessary to use the selective ion mode (SIM) for TO-15 analysis to obtain the necessary indoor air cleanup levels.

[8] Analyze for petroleum compounds such as EDB, EDC, and MTBE when soil, groundwater, or product analysis confirms their presence at the site.

3. In addition to the compounds identified in item No. 2 above, soil gas samples should also be analyzed for oxygen, carbon dioxide, and methane. Sampling for these constituents are important because they provide another line of evidence to help determine if an active biodegradation zone is present. Methane can also cause an explosion hazard in enclosed spaces at concentrations in air between 5% (lower explosive limit) and 15% (upper explosive limit) by volume. Methane above 15% continues to present a concern because concentrations have the potential to drop into the explosive range. Ecology recommends using ASTM procedure E2993-16 (*Standard Guide for Evaluating the Potential Hazard as a result of Methane in the Vadose Zone)* if methane concentrations are determined to be a concern.

4. Laboratories typically do not subtract out the concentrations of those constituents that have compound specific cleanup levels when reporting a total TPH concentration. As a result, an adjustment to some of the fractions may be necessary to avoid double counting. The process outlined in Chapter 8 of *Guidance for Remediation of Petroleum Contaminated Sites* (Ecology 2016a) provides several examples of when an adjustment would be necessary.

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Attachment A:

Ecology's Process to Establish a Generic TPH Indoor Air Cleanup Level

Implementation Memo No. 18 establishes a generic TPH indoor air cleanup level of 140 µg/m^3. This appendix provides details on how Ecology established this number.

A.1 Evaluated the data

Since 2009 when Ecology originally developed indoor air cleanup levels and soil vapor screening levels, a significant amount of additional data on petroleum vapor intrusion has become available. Much of the work on the makeup of petroleum vapors has been conducted by the Hawaii Department of Health (HDOH 2012). In 2011 and 2012, HDOH sampled three fresh petroleum products (gasoline, diesel, and JP-8) and five sites with various types of petroleum releases. Their major findings and conclusions are summarized below.

- Petroleum vapors from gasoline consisted primarily of aliphatic compounds in the C5-8 range.
- There was an increased proportion of aliphatic compounds in the C9-12 range when middle distillates (such as diesel) were evaluated.
- Aromatics, including BTEXN, make up a small portion of the overall mixture—especially for older sites.
- Samples analyzed using both summa canisters (method TO-15) and sorbent tubes (method TO-17) showed similar results for VOCs at the C-12 level or below.
- Samples analyzed using sorbent tubes indicated that there were minimal petroleum VOCs above C-12 in petroleum vapors.
- Toluene, ethylbenzene, xylene, and naphthalene were not significant risk drivers for the evaluated sites.
- Benzene typically drives risk for fresh releases, while TPH typically drives risk for older releases and releases from middle distillates.
- Of the sites evaluated, TPH alone would have been adequate to screen the sites for potential vapor intrusion hazards.

A.2 Developed the generic TPH cleanup and screening levels

Given the availability of more detailed information on petroleum vapors, Ecology concluded that developing a sufficiently protective generic indoor air TPH cleanup level was possible. The first step was to determine which non-carcinogenic petroleum constituents should be used for calculating the generic TPH cleanup level.

There are five petroleum compounds (benzene, EDB, EDC, MTBE, and naphthalene) that have both a cancer and non-cancer cleanup level. To estimate the non-carcinogenic contribution of these compounds, a concentration of just below the cancer cleanup level was selected for each constituent and then divided by the non-carcinogenic cleanup level.

For MTBE, 9.5 $\mu g/m^3$ was used (which is just below the cancer cleanup level of 9.62 $\mu g/m^3$). This level would represent a hazard quotient of 0.007 (9.5 $\mu g/m^3$/1,370 $\mu g/m^3$). Using the same methodology and a concentration of 0.3 $\mu g/m^3$ for benzene, its contribution would be 0.022 (0.3 $\mu g/m^3$/13.7 $\mu g/m^3$). The maximum these compounds could contribute to the Hazard Index (HI) is 0.029 or approximately 3%. The remaining three compounds (EDB, EDC, and naphthalene) have cancer cleanup levels less than the method detection limit (MDL) and therefore their contribution to the overall HI calculation can't be accurately quantified using the approach described above.

Ecology concluded that it was not necessary to account for the non-carcinogenic contributions of benzene, EDB, EDC, MTBE, or naphthalene when establishing a generic Method B indoor air TPH cleanup level, given their limited potential to affect the HI calculation.

The next step was to evaluate the non-carcinogenic risk of the various petroleum fractions along with the most toxic individual compound remaining (xylene). The EC 10-12 aromatic fraction has the lowest cleanup level for all of the non-carcinogens (see Table A-1). However, the toxicity of this fraction is based on naphthalene which will be accounted for individually using the carcinogenic cleanup level. The next lowest non-carcinogenic cleanup levels are for xylene, followed by the EC 12-16 aromatic fraction. Work done by the Hawaii DOH found that xylene makes up a small percentage of the overall petroleum vapor mixture and that there are minimal petroleum VOCs above EC 12. Hawaii DOH also found that the EC 5-8 aliphatic fraction typically represents a very large percentage of the composition in petroleum vapors from gasoline releases. For diesel releases, the EC 8-12 aliphatic fraction can make up a significant portion of the petroleum vapors.

Since the toxicity of the EC 8-12 aliphatic fraction is relatively close to the toxicity of both xylene and the EC 12-16 aromatic fraction, but typically makes up significantly more of the petroleum vapors, it was concluded that the generic Method B indoor air TPH cleanup level could be determined by assuming the petroleum vapors are made up entirely of the EC 8-12 aliphatic fraction. This should provide a sufficiently protective approach since petroleum vapors often contain a large percentage of the EC 5-8 aliphatic fraction—which is significantly less toxic than either xylene or the EC 8-12 aliphatic fraction.

If the reference dose for EC 8-12 aliphatic fraction is used, MTCA's Equation 750-1 results in a generic Method B TPH indoor air cleanup level of 140 $\mu g/m^3$. When the currently accepted attenuation factors of 0.03 and 0.01 are applied, they result in a sub-slab TPH screening level of 4,700 $\mu g/m^3$ and a deep soil gas screening level of 14,000 $\mu g/m^3$.

> **NOTE:** The same process was evaluated for establishing a generic Method C indoor air TPH cleanup level. However, with the exception of EDB, the cancer cleanup levels for benzene, EDC, MTBE, and naphthalene are at or above the PQLs and in some cases, are relatively close to the non-cancer cleanup level. For example, the Method C indoor air cancer cleanup level for benzene is 3.21 $\mu g/m^3$, while the non-cancer cleanup level is 30 $\mu g/m^3$. If benzene was measured just below the cancer cleanup level (e.g. 3 $\mu g/m^3$) this concentration would represent 10% of the HI. When the other carcinogenic compounds are also considered, they collectively have the potential to account for more than 50% of the HI. Given this relatively large amount, it was concluded that using a similar approach to establish a generic Method C indoor air TPH cleanup level was not appropriate. For sites that qualify under WAC 173-340-706 to use Method C cleanup levels, either the Method B level of 140 $\mu g/m^3$ or a site-specific approach can be used.

The generic Method B cleanup level is intended for those situations where the site does not initially screen out using the process established in Implementation Memo No. 14 (Ecology 2016c). While this Attachment focuses on establishing a generic TPH cleanup level, it does not preclude analyzing indoor air for each of the individual petroleum fractions in order to calculate a site-specific TPH air cleanup level.

A.3 Evaluated Washington state's vapor intrusion sampling data

To assess the degree of protection afforded by the generic TPH cleanup level, actual site-specific vapor intrusion sampling data from Washington state were evaluated. The purpose of this effort was to determine if any situations could be found where total TPH was less than the generic Method B indoor air cleanup level of 140 μg/m^3 but where the Hazard Index exceeded 1.

A limited number of sites were identified where a Tier I or Tier II PVI assessment had been completed, but lacked sampling results for total TPH. With no total TPH data available, it became necessary to rely on APH sampling results as a surrogate for a total TPH analysis.

There were 12 sites that had sampling results for both APH fractions and individual petroleum compounds (typically BETX), representing a total of 66 individual vapor samples. None of the sample results had total TPH concentrations (as measured by a sum of the APH values) less than the generic TPH cleanup level but with a corresponding HI greater than 1. Ecology intends to continue evaluating new information while this approach is being implemented to determine if any modifications are warranted.

A.4 Evaluated other states' vapor intrusion sampling approaches and cleanup levels

Ecology also attempted to determine if programs in other states have established a generic total TPH indoor air cleanup level for assessing the potential for petroleum vapor intrusion. States were identified that were known to use non-compound specific soil or groundwater petroleum indicators (e.g. TPH, GRO, DRO, and carbon fractions), and states known to have comprehensive vapor intrusion programs. This resulted in 17 states being formally evaluated, of which only one (Hawaii) uses total TPH screening levels for assessing the petroleum vapor pathway. Specifically, Hawaii uses a screening level is 600 μg/m^3 for a gasoline release and 130 μg/m^3 for a diesel release. There were 6 states where cumulative risk for the non-carcinogenic petroleum constituents must be accounted for, while several others indicated that cumulative risk would be addressed on a case-by-case basis.

A.5 Conclusion

Based on the evaluations described above, Ecology believes that the process for establishing a generic Method B indoor air TPH cleanup level provides a sufficiently protective approach and meets the requirements of MTCA.

Table A- 1: Inhalation reference doses for non-carcinogenic parameters and inhalation cancer potency factors for carcinogenic parameters

Non-Carcinogenic Parameters	**Inhalation Reference Dose (RfDi) (mg/Kg-day)**
EC 5-8 Aliphatics	1.7
EC >8-12 Aliphatics	0.085
EC >12-18 Aliphatics	0.085
EC 9-10 Aromatics	0.114
EC >10-12 Aromatics	0.00086
EC >12-16 Aromatics	0.05
Benzene	0.00857
Ethylbenzene	0.286
Toluene	1.4
Total Xylenes (m, o, p)	0.029
Naphthalene	0.00086
Carcinogenic Parameters	**Inhalation Cancer Potency Factor (CPFi) (Kg-day/mg)**
Benzene	0.0273
EDB	2.10
EDC	0.091
MTBE	.00091
Naphthalene	0.119

Attachment B:

Process for Calculating a Site-Specific TPH Indoor Air Cleanup Level (with Example)

B.1 Steps and equations for calculating a site-specific Method B air cleanup level for total petroleum hydrocarbons (TPH)

Step 1. Select an air sample with high TPH concentrations for fractionation.

Step 2. Use the fractionated results in the equation below to calculate a Method B air CUL.

Step 3. Compare the TPH concentrations in compliance air samples with the Method B air CUL.

Equation for Method B CUL for TPH:

$$CUL_{TPH} = \frac{HI \ x \ ABW \ x \ UCF \ x \ AT}{BR \ x \ ED \ x \ EF \ \left[\sum_{i=1}^{i=n} \frac{F_i \ x \ ABS_i}{RfDi_i}\right]}$$

Simplified Form of the Equation:

Individual petroleum component: $CUL_i = \frac{RfDi_i \ x \ ABW \ x \ UCF \ x \ HQ \ x \ AT}{BR \ x \ ABS_i \ x \ ED \ x \ EF}$

(WAC 173-340-750, Equation 750-1)

TPH cleanup level: $CUL_{TPH} = \frac{1}{\sum_{i=1}^{i=n} \frac{F_i}{CUL_i}}$

B.2 Parameter definitions, values, and cleanup levels

Table B-1: Parameter definitions.

Abbrev.	Name	Value	Units
ABS_i	Inhalation absorption fraction for petroleum component $_i$	fraction-specific	unitless
ABW	Average body weight	16	kg
AT	Averaging time	6	yr
BR	Breathing rate	10	m^3/day
CUL_i	Air cleanup level for petroleum component $_i$	calculated	µg/m^3
ED	Exposure duration	6	yr
EF	Exposure frequency	1.0	unitless
F_i	Fraction by weight of petroleum component $_i$	fraction-specific sample-specific	unitless
HQ	Target hazard quotient	1.0	unitless
$RfDi_i$	Inhalation reference dose for petroleum component $_i$	fraction-specific	mg/kg-day
UCF	Unit conversion factor	1,000	µg/mg
IF	Intermediate calculation factor: ABW x UCF x HQ x AT / (BR x ED x EF)	1,600	kg-µg-day/ mg-m^3

Note: The Intermediate Factor (IF) of 1,600 was calculated using the default values listed in Table B-1. The result was used with the specific parameter values in Table B-2 to calculate the individual cleanup levels.

Table B-2: Fraction or compound specific parameter values, and non-carcinogenic cleanup levels.

Petroleum Fraction or Compound	ABS_i (unitless)	$RfDi_i$ (mg/kg-day)	Non-carcinogenic CUL_i (µg/m^3)
Aliphatics EC>5-8	1	1.7	2.72E+03
Aliphatics EC>9-12	1	0.085	1.36E+02
Aromatics EC>9-10	1	0.114	1.82E+02
Benzene	1	0.00855	1.37E+01
Toluene	1	1.4	2.24E+03
Ethylbenzene	1	0.286	4.58E+02
Xylenes	1	0.029	4.64E+01
Naphthalene	1	0.00086	1.38E+00

Note: $CUL_i = RfD_i \times IF/ABS_i$

Table B-3: Non-carcinogenic example measurements and calculations.

Petroleum Fraction or Compound	Measured Conc. Site-Specific Sample (μg/m^3)	Fraction of Total Concentration (F_i)	Total TPH Non-carcinogenic CUL_i (μg/m^3)	F_i / CUL_i
Aliphatics EC>5-8	319	0.91	2.72E+03	3.35E-04
Aliphatics EC>9-12	12	0.03	1.36E+02	2.52E-04
Aromatics EC>9-10	6	0.02	1.82E+02	9.43E-05
Benzene	0.2	0.0006	1.37E+01	4.17E-05
Toluene	8	0.02	2.24E+03	1.02E-05
Ethylbenzene	1.8	0.01	4.58E+02	1.12E-05
Xylenes	2.7	0.01	4.64E+01	1.66E-04
Naphthalene	<0.07	0.00	1.38E+00	---
Total TPH	349.7	1.00	**1,098**	---

Note: The Total TPH Non-carcinogenic CUL = 1 / ∑ (F_i / CUL_i)

Based on the composition of the sample shown in Column 2 in Table B-3, the measured total TPH concentration of 349.7 μg/m^3 does not exceed the calculated site-specific TPH air cleanup level of 1,098 μg/m^3. However, this example only accounts for the non-carcinogenic effects of the petroleum mixture. An evaluation of the carcinogenic compounds also needs to be completed. As shown in the table below, benzene is below the indoor air carcinogenic cleanup level of 0.321 μg/m^3 and naphthalene is below the method detection limit. For this example, EDB, EDC and MTBE were not constituents of concern for air because they were not detected is soil, water or product samples.

Table B-4: Carcinogenic example measurements and evaluation.

Carcinogenic Compound	Measured Conc. Site-Specific Sample (μg/m^3)	Carcinogenic CUL (μg/m^3)	Carcinogenic CUL Exceeded? (Yes/No)
Benzene	0.2	0.321	No
Naphthalene	<0.07	0.074	No

Attachment C:

Response to comments on the August 7, 2017, review draft of this memo

Response to Comments: Petroleum Vapor Intrusion (PVI): Updated Screening Levels, Cleanup Levels, and Sampling Considerations

A public comment period was held from August 7 through September 22, 2017, for the review draft of this document dated August 7, 2017. The following comments were received during that period and helped inform updates to this final version dated January 2018.

***Comment No. 1* –** The title is good in that it provides a separate document for petroleum vapor intrusion. Although it is titled Petroleum Vapor Intrusion they use the acronym VI and should use PVI to be consistent with other such documents in use by states and the EPA

***Response* –** The document has been modified to use the acronym PVI throughout.

***Comment No. 2* –** Section 1.0. The use of 140 µg/m3 does not have scientific basis as TPH is not a valid way to evaluate what, if any, is the true risk from PVI. To be consistent with the vast majority of other state and federal guidance documents listing the risk drivers such as benzene or naphthalene levels for evaluating PVI risk in indoor air. TPH screening levels will not be useful to evaluate PVI risk. There are many contributors to TPH in soil gas that have nothing to do with PVI risk such as natural organic material, methane which can be a safety risk, but not a health risk.

***Response* –** There is rule language in Washington Administrative Code (WAC) 173-340-750(3)(b)(ii)(C) that specifies for petroleum mixtures, a total TPH air cleanup level shall be calculated using equation 750-1 and shall take into account the additive effects of the petroleum fractions and volatile organic compounds present in the petroleum mixture. The guidance indicates that this would typically require sampling of 3 petroleum fractions (C5-8 aliphatics), (C9-12 aliphatics) and (C9-10 aromatics) along with those specific petroleum compounds that have a non-carcinogenic cleanup level. Appendix B provides an example of how these results are used to calculate a site specific TPH cleanup level.

The purpose of developing the generic 140 µg/m3 indoor air TPH cleanup level was two-fold. First, if the sum of the measured concentrations is less than 140 µg/m3, then there would be no need to calculate a site specific value. Second, having a generic indoor air cleanup level allowed for the calculation of shallow and deep soil gas screening levels.

Comment No. 3 **–** Section 2.0. Although the document acknowledges that there has been a significant amount of new data regarding migration of petroleum vapors which is true. The document does not include the vast majority of this work including that used to develop the EPA OUST PVI guidance document and have chosen to focus on a very small subset of work that mentions TPH as an issue to be factored into PVI investigations. The broader work identifies specific compounds as risk drivers rather than TPH.

Response **–** Ecology adopted EPA's PVI screening concentrations and vertical separation distances for benzene and TPH in March, 2016. In addition, ITRC's recommended horizontal screening distance of 30 feet was adopted for sites with a good site characterization. This is detailed in Implementation Memorandum No. 14 titled: "*Updated Process for Initially Assessing the Potential for Petroleum Vapor Intrusion"* which is available at: https://fortress.wa.gov/ecy/publications/SummaryPages/1609046.html.

The document was expanded to more clearly indicate that Ecology has adopted EPA's PVI screening criteria.

Comment No. 4 **–** Section 3.0. Although petroleum is made up of a mixture of compounds the risk drivers are a small subset and for the most common spilled hydrocarbon mixture (gasoline) the primary risk driver is just one compound - benzene. So unlike the EPA OUST document which tries to simplify the process of evaluating PVI risk from spilled UST's (primarily gasoline) this guidance adds unneeded complexity which will result in unneeded work and expense to evaluate and not be reliable indicators of risk to human health.

Response **–** As mentioned in the response to Comment No. 3, Ecology has adopted EPA's PVI screening criteria and anticipates that many sites will screen out because either the contamination is not high enough or occupied buildings are too far away. In most instances, the next step for sites that don't initially screen out will be to gather soil gas data. Indoor air sampling would typically only occur when soil gas results exceed the appropriate soil gas screening levels.

Comment No. 5 **–** Section 4.1. "CLARC does not provide…..because the TPH cleanup level is a site-specific calculation that depends on the composition of the mixture". Why not just use a known risk driver for releases of gasoline (benzene) rather than complicating things with a TPH level that is not a risk level indicator?

Response **–** As discussed in the response to Comment No. 2, Washington Administrative Code requires that a TPH indoor air cleanup level be calculated. This would not be a bulk analysis, but instead determined by summing the results of the three individual petroleum fractions along with those specific petroleum compounds that are likely to be present and have non-carcinogenic cleanup levels. However, this step is only necessary when a site cannot screen out using the process described in Implementation Memo No. 14.

Comment No. 6 **–** Section 4.2. Now it is clear that the reference used for used for the emphasis on TPH is the work done in Hawaii by Roger Brewer. This work was reviewed and not accepted by the US EPA OUST PVI guidance document and not accepted by the ITRC PVI guidance document. Both of these guidance documents include technical input for a broad range of experts in the field along with a balance of input from state regulators who did consider carefully the TPH issue. Prior to including any TPH screening levels it is appropriate to document why Washington Department of Ecology diverges from these documents.

Response **–** Ecology could find no documentation that the work by Roger Brewer was not accepted by either EPA or ITRC. In fact, both documents included several references to his work. Regardless, Ecology only used the information from Brewer to help document the makeup of petroleum vapors and the information he presented is consistent with the work of others including both EPA and ITRC.

Comment No. 7 **–** Section 5.1. This is a PVI document; however, in this section the document references an EPA document on attenuation factors for chlorinated vapor intrusion. This certainly adds to another level of confusion and uncertainty in how this document can or should be used. The inherent differences in degradation behavior identify the need for a separate approach.

Response **–**The reason Ecology referenced the March 2012 EPA document was because EPA's 2015 PVI guidance does not contain recommended generic attenuation factors. We realize that in most cases the March 2012 document will provide conservative screening levels for PVI, but they will only come into play if a site can't screen out using the process set out in Implementation Memo No. 14. In addition, the potential exists to develop alternative attenuation factors based on site specific data.

Comment No. 8 **–** Section 5.2. Why are the PVI screening levels different than the Method A groundwater cleanup levels? No explanation is given and no mention of depth to groundwater as a factor.

Response **–** The Method A groundwater cleanup levels are typically based on EPA's drinking water standards (e.g. benzene at 5 ug/l), while the groundwater VI screening levels are calculated using Equation 1 in Ecology's 2009 draft Vapor Intrusion Guidance. Regardless, as discussed in Section 5.2 of the guidance, sites that meet the Method A groundwater cleanup levels will almost always be protective of any future building construction.

Comment No. 9 **–** Section 5.2. Further in this section the EPA and ITRC efforts are acknowledged, however, it was not widely applied besides this section (future use of a property). The topic of future use is probably best addressed using a model that is designed for PVI such as EPA bioscreen or API biovapor which can accommodate different future scenarios to evaluate risk.

Response **–** As discussed earlier, Implementation Memo No. 18 only applies to sites that do not initially screen out using the procedures established in Implementation Memo No. 14. For those sites that don't screen out and need to consider potential impacts on future buildings, Ecology has expanded Sections 5.2 and 5.3 to discuss the potential for using modeling that accounts for aerobic biodegradation when evaluating potential impacts.

Comment No. 10 **–** The basis for including total (bulk) TPH is the Brewer et al. (2013) study, which was conducted at 5 non-motor gasoline (pipeline) sites with "large" releases of AVGAS, JP-4, JP-8, and diesel. These were NOT petroleum UST sites. Soil-gas samples were collected "within the immediate vicinity of the source" with very elevated TPH concentrations indicative of residual LNAPL. No data is reported in Brewer et al. (2013) on measured ambient air or measured indoor concentrations, nor is any data reported on vapor migration, such as soil-gas concentration profiles (i.e., attenuation with distance from the source). All the estimates relating source-zone soil gas concentrations to inhaled air concentrations in Brewer et al. (2013) are extrapolated; they are not supported by measurements. In addition, from the Brewer et al. (2013) report: "[the] study was not intended to evaluate actual vapor intrusion risks at the study sites where soil vapor samples were collected" and "significant vapor intrusion impacts have not been identified at any of the sites.".

Response **–** Ecology is not proposing that bulk TPH analysis be used to evaluate indoor air quality. See the response to Comment No. 2 for more details on the proposed process for determining total TPH. The information developed by Brewer et al. was only used to help determine the potential makeup of petroleum vapors. See the response to Comment No. 6 for more discussion on this issue.

***Comment No. 11* –** Potential risks of PVI at petroleum UST sites are better defined by the empirical studies of US EPA (2013), Lahvis et al. (2013), and most recently, Lahvis (in press), involving soil-gas measurements from hundreds of petroleum UST sites. These studies demonstrate that PVI risks at petroleum release sites are bounded by benzene and relatively negligible for TPH (expressed as fractions) at vertical source (LNAPL)-to-building separation distances > 3 ft. Application of indoor TPH in PVI risk assessments at petroleum UST sites that "fail" site screening has the potential to trigger significant unnecessary data collection given the high likelihood of encountering buildings separated from LNAPL sources by < 15 ft.

Alternatively, Washington Ecology may want to consider a conservative, constituent-specific screening distance for TPH (e.g., 5 ft instead of 15 ft) which would serve as a trigger for additional TPH-specific risk assessment. The target here would be **non-petroleum UST PVI sites** (e.g., petroleum industrial sites, such as refinery, pipeline, aviation, terminal) with LNAPL sources, and assessments based on TPH fractions rather than bulk TPH given the technical justifications provided in this memo.

***Response* –** Implementation Memo No. 18 only applies to those sites that do not screen out using the process set for in Implementation Memo No. 14 which uses the same soil/groundwater concentrations and separation distances as EPA's 2015 PVI guidance. Additional language has been added to the document to more clearly indicate that the EPA process is the first step in evaluating whether PVI represents a potential concern. For those sites that don't screen out using Implementation Memo No. 14, it is anticipated that the next step would typically be soil gas sampling with the results being compared to the generic soil gas screening levels. Ecology anticipates that a large percentage of petroleum sites will have adequately addressed the VI pathway by this point in the process.

***Comment No. 12* –** The role of total (bulk) TPH measurements in PVI risk assessment is currently not well understood. As noted in Lahvis (in press), there is disparity in vertical screening distances derived for TPH fractions (generally < 3 ft) versus total (bulk) TPH (generally > 15 ft). The reason for this ambiguity is uncertain, but may be related to the analysis of bulk air-phase samples. Positive bias resulting from contributions of background sources of non-petroleum hydrocarbons cannot be eliminated from total TPH analyses either, which could be a widespread issue inherent to virtually all indoor-air samples.

***Response* –** See responses to Comment Nos. 10 and 11.

Comment No. 13 **–** Empirical studies of background “TPH” concentrations in indoor air or studies to support the use of an indoor-air screening level of 140 µg/m^3 are currently limited. A potential therefore exists for numerous false positives. Fitzgerald (2002) in reporting on measurements for the Massachusetts DEP, suggests a conservative upper limit of 200 µg/m^3 in indoor residential air for total TPH background, based on TPH fraction analysis results. This nominal background level would not include the effect of potential indoor sources of chemicals detected as TPH: use of home heating oil and burners; attached garages; stored gasoline; natural gas stoves, water heaters, and other natural gas-fired appliances; fresh paint, carpet and construction materials; smoking, candles, or other partial-combustion sources; and a variety of consumer products and cleaners. The background level of 200 µg/m^3 also neglects differences between summed TPH fraction analyses and a potentially higher direct total TPH measurement.

Response **–** The generic indoor air TPH cleanup level was primarily developed to allow for the calculation of shallow and deep soil gas screening levels. Ecology acknowledges that factors such as indoor air sources can present challenges for determining compliance using the 140 µg/m3 generic TPH indoor air cleanup level. The guidance also allows for calculating a site-specific TPH cleanup level using the process set forth in Attachment B. This approach will almost always result in a higher cleanup level and in some cases above the typical background range for TPH. Ecology has added a discussion to the guidance on factors to consider and options available for addressing those compounds where background contributions can often exceed the indoor air cleanup levels (i.e. benzene, naphthalene and TPH).

Comment No. 14 **–** Documented cases of PVI at petroleum UST sites with predominantly gasoline sources are a relatively rare occurrence in comparison to the thousands of leaky underground storage tank cases. The probability of diesel or middle distillate PVI occurrences are even more rare, given diesel-range constituents have a lower volatility than gasoline-range constituents. In particular, diesel contains only a very small percentage of sufficiently volatile and toxic constituents that could pose a human-health risk for petroleum vapor intrusion. Several studies, including Anderson et al. (2008), DeHate et al. (2011), USEPA (2013), Lahvis et al. (2013), Lahvis (in press), have shown that the volatile component (namely < C12 compounds) do not migrate more than a few feet from LNAPL sources before concentrations in soil gas fall below typical (median) risk-based screening levels or are no longer a concern for PVI. TPH, other than BTEX (e.g., C_5 – C_8 aliphatics, C_9 – C_{12} aliphatics, C_9 – C_{10} aromatics), will also have very low aqueous solubility. Hence any consideration of TPH in PVI risk assessment should be restricted to LNAPL sources with volatile constituents (such as gasoline).

Response **–** As discussed in the response to Comment No. 2, Ecology is proposing to use fractions (along with those specific petroleum compounds that have non-carcinogenic cleanup levels) for determining the total amount of TPH present. Ecology anticipates that the PVI pathway at most sites will be addressed before indoor air sampling is necessary.

Comment No. 15 **–** The use of generic TPH screening levels as an alternative to TPH fractions is not recommended because of uncertainties in estimating soil-gas RBSLs and quantifying vapor concentrations for fuel mixtures composed of hydrocarbons with highly disparate fate and transport characteristics and toxicity (TPHCWG, 1997). As noted in TPHCWG (1997) and Lahvis (in press), risks for total (bulk) TPH are better defined and bounded using TPH fractions. This position is further supported by the Washington Ecology's own use of TPH fractions in the derivation of the generic TPH screening levels (as described in the Appendix to the VI guidance).

Response – See response to Comment No. 2.

Comment No. 16 **–** Soil-gas samples collected prior to future development and building construction may not be representative of the PVI risk post construction given the potential for a building foundation to affect hydrocarbon vapor transport. The effect of the building foundation on hydrocarbon vapor concentrations can either be positive (decrease) or negative (increase) depending on whether the flow of atmospheric air and potential for aerobic biodegradation below the slab is enhanced or reduced, respectively. Modeling, using tools such as BioVapor (www.api.org/pvi) that account for biodegradation, can be extremely helpful in predicting risks for future development. In particular, these models can be used to predict the depth below the slab of the aerobic/anaerobic interface (i.e., location where hydrocarbon vapor concentrations decrease by several orders of magnitude within a short vertical distance and the PVI risk becomes greatly diminished), which is arguably more informative in PVI risk-based decision making than predicting indoor-air or sub-slab vapor concentrations. With this predictive capability, one could then decide on the need for additional soil-gas, sub-slab, or indoor-air sampling or some engineering control. For example, in California, additional data PVI risk assessment is greatly reduced if aerobic conditions can be demonstrated at a depth of 5 or more feet from a building foundation[9]. A model such as BioVapor could also be used to establish soil-gas screening levels and attenuation factors based on conservative assumptions regarding biodegradation. Brewer et al. (2013) present modeling results which would support an attenuation factor of 100,000 in some cases. BioVapor could also be used to develop a relevant, site-specific TPH attenuation factor.

[9] The California Low Threat Tank Closure Policy (http://www.swrcb.ca.gov/ust/lt_cls_plcy.shtml) allows for a 1000x increase in screening levels if aerobic conditions (> 4% oxygen) can be demonstrated in soil gas sample collected within 5 ft (depth) of a building foundation.

***Response* –** Ecology has expanded the options for evaluating future building construction to include the use of modeling that accounts for aerobic biodegradation.

***Comment No. 17* –** Indoor air (i.e., petroleum hydrocarbon vapor) has also been shown to migrate below building foundations and affect vapor concentrations sub-slab (McHugh et al., 2006).

***Response* –** Ecology acknowledges that contaminants can migrate downward through the foundation of a building and into the vadose zone.

***Comment No. 18* –** Total (bulk) TPH concentration measurements can be useful primarily in helping identify LNAPL sources (see ITRC, 2014), in evaluating possible acute health and safety (flammability) risks, and in discerning petroleum vapour source type (dissolved versus LNAPL). Bulk soil gas TPH measurements in three of the five cases evaluated in Brewer et al., 2013, for example, would identify LNAPL within 1 to 5 feet of ground surface.

***Response* –** See response to Comment No. 2.

***Comment No. 19* –** The draft guidance specifies that soil gas samples should be analyzed for oxygen, carbon dioxide and methane. Provide additional direction in the guidance on when these constituents should be sampled for.

***Response* –** Ecology has included more details on why these parameters would be most useful.

***Comment No. 20* –** Section 5.1, page 5. Quite a few states are recognizing that using attenuation factors that don't consider biodegradation of petroleum VOC's is too conservative.

***Response* –** See response to Comment No. 7.

***Comment No. 21* –** It's not clear whether the groundwater VI screening levels included in Table 1 are expected to be used instead of Method A groundwater cleanup levels.

***Response* –** The document has been clarified to indicate that the Method A groundwater cleanup levels can be used for evaluating whether PVI may be a potential issue in most situations.

***Comment No. 22* –** The phrase “presents a challenge” in Section 5.2 is vague and could be interpreted multiple ways.

***Response* –** This sentence was revised to better explain the intent.

***Comment No. 23* –** Under item No. 4 on page 7, it’s not clear if “cleanup levels” is referring to VI cleanup levels or all cleanup levels.

***Response* –** This item was clarified to explain that the phrase “cleanup levels” is referring to all cleanup levels.

***Comment No. 24* –** On the top of Page 8, consider removing “Ecology believes”.

***Response* –** The requested change was made to the document.

***Comment No. 25* –** Under Situation No. 1 on page 8, change “it may be prudent” to “soil gas sampling could assist when evaluating residential exposure conditions”.

***Response* –** The requested change was made to the document.

***Comment No. 26* –** Under Situation No. 2 on page 8, change “may be warranted” to “would be recommended”.

***Response* –** The requested change was made to the document.

***Comment No. 27* –** On the bottom of page 8, clarify what pathway the benzene cleanup value of 0.03 mg/kg applies to.

***Response* –** The document was modified to clarify that the benzene cleanup level of 0.03 mg/kg applies to the soil to groundwater pathway.

Comment No. 28 **–** Under item No. 1 on page 10, consider allowing other Methods, such as Modified 8260 under certain conditions.

Response **–** This provision was expanded to account for situations where PVI screening is being used to help assess where to sample.

Comment No. 29 **–** Under item No. 2 on page 10, the first sentence says "at a minimum" but then the second sentence adds more. Consider clarifying what the minimum requirements are.

Response **–** This provision has been modified to better clarify the intent.

Comment No. 30 **–** Under item No. 2 on page 10, the Department should also consider allowing oxygen readings to be used to screen out a site for PVI, if they are high enough within the vadose zone as this is indicative that aerobic biodegradation is occurring. Some states allow for a real time screening of oxygen versus lab results.

Response **–** While the presence of oxygen is typically a good indication that biodegradation is occurring, Ecology relies on multiple lines of evidence when determining whether the PVI pathway has been adequately addressed.

Comment No. 31 **–** Clarify that the reference to 5% and 15% is the lower explosive limit and upper explosive limit for methane. Also mention that even if methane is above 15%, it can still be a concern because it can rapidly drop and then pose a risk for explosion.

Response **–** The requested change was made to the document.

Comment No. 32 **–** Under item No. 3 on page 10 define what "EC" stands for.

Response **–** The requested change was made to the document.

Comment No. 33 **–** Under item No. 3 on page 10, the last sentence is not clear on how the samples should be analyzed or the format that should be used for reporting the results.

Response **–** This provision was expanded to better explain how the samples should be analyzed and how the results should be reported.

Comment No. 34 **–** The third paragraph under A.2 on page is difficult to follow. Consider revising to clarify the intent of the paragraph.

Response **–** The discussion was revised to better explain the process that was used.

Comment No. 35 **–** Under item No. 1 on page 10, it should be noted that proposed requirements for PVI analysis include additional analysis beyond TO-15 and TO-17. Analysis of fixed gases (aka natural gases) must be performed using either ASTM D-1945/D-1946 or EPA Method TO-3.

Response **–** Item No. 1 was expanded to clarify that because petroleum vapors consist primarily of hydrocarbons that do not exceed C12, it isn't necessary to use both TO-15 and TO-17 to capture the entire range. A note was added to indicate that other analytical methods may also be appropriate depending on the goals of the sampling.

Comment No. 36 **–** The required reporting of nC5-8 aliphatics, nC9-12 aliphatics and nC9-10 aromatics may not be possible for TO-15 without adjustment because laboratories report these ranges and compositions based on a standard VPH analyte list (APH screening levels have been removed from CLARC). For example, Eurofins Air Toxics of Folsom, California reports nC8-C12 (not nC9), a portion of which is referenced to decane and a portion is referenced to dodecane. Ecology does not address if the nC8-12 aliphatics (the basis of the proposed Method B TPH CUL) can be obtained by simple addition of the various ranges of aliphatics reported using the APH Method.

Response **–** Section 6.0 of the guidance was expanded to indicate that the 3 petroleum fractions should be analyzed using the Massachusetts DEP APH Test Method: WSL-CAM-IX-A, July 2010.

Comment No. 37 **–** Perhaps some note regarding the use of Method TO-3 is warranted since this GC/FID method is commonly used elsewhere for identifying carbon range makeup of petroleum vapor and indoor air samples. However, this method does not provide quantification of aliphatic and aromatic composition and is subject to interference by non-petroleum compounds such as PCE, TCE, acetone, etc.

Response **–** See response to Comment No. 28.

Comment No. 38 **–** Although not mentioned due to very low screening levels (what Ecology references as Cleanup Levels), indoor air sampling should be performed using TO-15 in the selective ion mode (SIM) not in full scan mode; however, the number of target compounds is generally reduced for SIM.

Response **–** A note was added to Section 6.0 indicating that it may be necessary to use Selective Ion Mode (SIM) in order to achieve the specified cleanup levels for certain compounds (e.g. naphthalene).

Comment No. 39 **–** Ecology mentions use of the "generally accepted" attenuation factors of 0.03 for sub-slab and 0.01 for deep soil gas. It is acknowledged that these attenuation factors were developed for chlorinated compounds based on EPA's 2012 Vapor Intrusion Database, and are the default values used in the EPA VISL. However, numerous studies by Stantec utilizing tracer gas indicate that both factors are at least one to two orders of magnitude underestimates of attenuation. This is particularly true for dense, lower permeability northwest soils with higher moisture contents. Setting soil gas screening levels based on the proposed 140 ug/m3 TPH indoor air screening level and application of these factors results in overly conservative soil gas screening levels (CUL's) which would likely result in unnecessary investigation and unwarranted vapor mitigation.

Response **–** See responses to comment No 7.

Comment No. 40 **–** The proposed use of Table B-1 is unclear and not described in the document. Moreover, the exposure assumptions (particularly the body weight, exposure duration and averaging time appear to indicate use of these assumptions for evaluating early life exposure not included in the equations.

Response **–** A note was added following Table B-1 that explains how the parameters are used to calculate compound specific cleanup levels. The exposure assumptions are the default values contained in Washington Administrative Code (WAC) 173-340-750(3)(b)(ii)(A).
