

Clean Vapor, LLC

We appreciate the opportunity to review the Guidance document and provide technical comment. The document highlights the importance of an effective CSM and assessment. There remains opportunity to provide greater prescriptive direction in the areas of design, mitigation, monitoring and ongoing stewardship. As primary of author of the referenced NAVFAC document and contributor to many others referenced, I would be available for continued discussion.

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President and Board Chairman of Association of Vapor Intrusion Professionals (AVIP)



DRAFT Guidance for Evaluating Vapor Intrusion in Washington State

Investigation and Remedial Action

Toxics Cleanup Program
Washington State Department of Ecology
Olympia, Washington

Review Draft: October 2009

Revisions: February 2016 and April 2018

Draft for Public Comment: November 2021

Publication No. 09-09-047

Publication Information

This document is available on the Department of Ecology's website at <https://apps.ecology.wa.gov/publications/summarypages/0909047.html>

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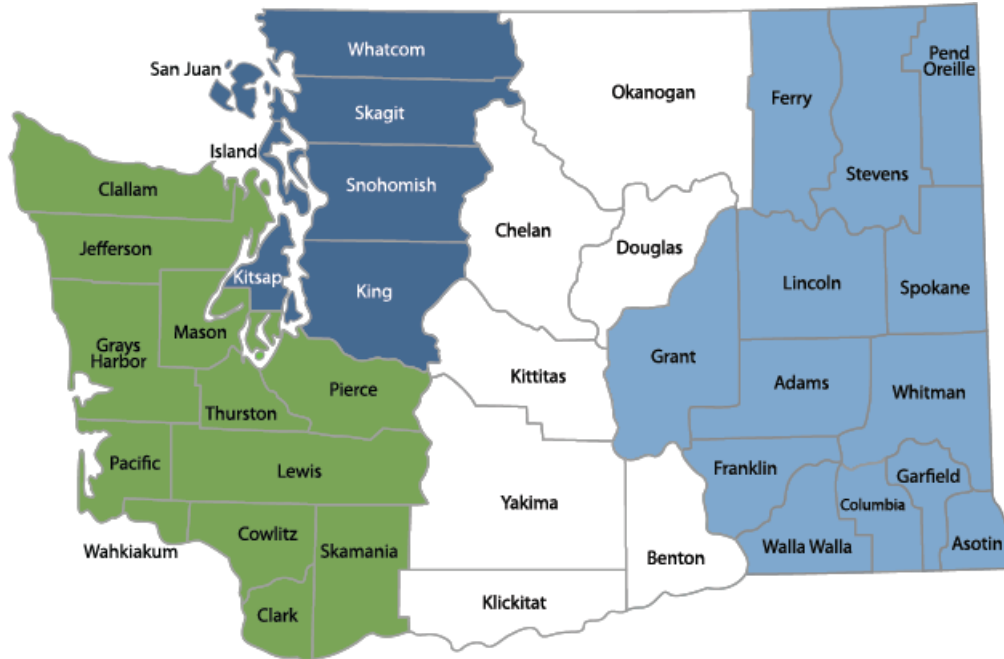
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Department of Ecology's Regional Offices

Map of Counties Served



| | | | |
|---|---|---------------------------------------|---------------------------------------|
| Southwest Region 360-407-6300 | Northwest Region 425-649-7000 | Central Region 509-575-2490 | Eastern Region 509-329-3400 |
|---|---|---------------------------------------|---------------------------------------|

| Region | Counties served | Mailing Address | Phone |
|---------------------|--|---|--------------|
| Southwest | Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum | PO Box 47775 Olympia, WA 98504 | 360-407-6300 |
| Northwest | Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom | 3190 160th Ave SE Bellevue, WA 98008 | 425-649-7000 |
| Central | Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima | 1250 W Alder St Union Gap, WA 98903 | 509-575-2490 |
| Eastern | Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman | 4601 N Monroe Spokane, WA 99205 | 509-329-3400 |
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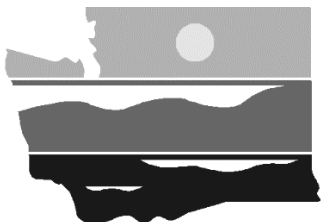
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DEPARTMENT OF
ECOLOGY
State of Washington

Table of Contents

| | |
|--|------------|
| Map of Counties Served | 3 |
| Figures, Equations, & Tables | v |
| Figures | v |
| Equations | v |
| Tables vi | |
| Acronyms & Abbreviations | vii |
| Chapter 1: Introduction..... | 1 |
| 1.0 Introduction..... | 1 |
| 1.1 Purpose | 2 |
| 1.2 Applicability..... | 3 |
| 1.2.1 Sites with elevated soil gas methane levels | 4 |
| 1.2.2 Workplace exposures to toxic, volatile substances | 4 |
| 1.3 The VI pathway..... | 5 |
| 1.4 How the VI guidance is structured..... | 6 |
| 1.5 Public involvement..... | 9 |
| 1.6 Responding to indoor air contamination caused by VI..... | 9 |
| 1.7 Updating the guidance | 10 |
| Chapter 2: Preliminary Assessments | 11 |
| 2.0 Introduction..... | 11 |
| 2.1 Is immediate action necessary? | 13 |
| 2.2 Are contaminants of concern volatile and toxic? | 14 |
| 2.3 Are buildings close enough to the contamination? | 14 |
| 2.4 Initial VI conceptual site model..... | 15 |
| 2.5 Assessing sites with only petroleum contamination..... | 17 |
| 2.6 Conclusions and next steps | 17 |
| 2.6.1 Situations not requiring further VI assessment..... | 17 |
| 2.6.2 Situations requiring further VI evaluation | 17 |
| 2.6.3 Next steps | 17 |
| Chapter 3: Tier 1 VI Evaluations..... | 19 |
| 3.0 Introduction..... | 19 |
| 3.1 Developing the framework for a Tier 1 evaluation | 21 |
| 3.1.1 Preferential pathways | 22 |
| 3.1.2 Evaluating conduits that connect site contamination directly to a building | 22 |
| 3.2 Applicability of Tier 1 evaluations to petroleum contamination..... | 23 |
| 3.3 Applicability of Tier 1 evaluations when TCE is present | 23 |
| 3.4 Groundwater is the only subsurface VOC source..... | 24 |
| 3.4.1 Calculating groundwater VI screening levels | 24 |
| 3.4.2 Situations where groundwater may not be impacting indoor air | 26 |
| 3.4.3 Limitations on using groundwater data for screening | 26 |
| 3.4.4 Shallow groundwater VOC concentrations exceed screening levels | 27 |
| 3.5 Contaminated vadose zone soil | 27 |
| 3.6 Using soil gas concentration data | 28 |
| 3.6.1 Advantages of near-source soil gas sampling..... | 28 |
| 3.6.2 Calculating soil gas screening levels | 29 |
| 3.6.3 Collecting representative soil gas data | 30 |

| | | |
|--|---|-----------|
| 3.6.4 | Soil gas may not be impacting indoor air | 31 |
| 3.6.5 | Limitations on using soil gas data | 31 |
| 3.6.6 | Soil gas VOC concentrations exceed screening levels | 32 |
| 3.7 | Factors affecting the number of samples and sampling events necessary | 33 |
| 3.7.1 | Spatial variability..... | 33 |
| 3.7.2 | Temporal variability..... | 33 |
| 3.8 | Multiple VOCs..... | 34 |
| 3.9 | Use of predictive modeling..... | 35 |
| 3.10 | Future building construction..... | 35 |
| 3.11 | Documenting the results of a Tier 1 evaluation | 35 |
| Chapter 4: Tier 2 VI Evaluations..... | | 39 |
| 4.0 | Introduction..... | 39 |
| 4.1 | Developing the framework for a Tier 2 evaluation | 40 |
| 4.2 | Applicability of Tier 2 evaluations to petroleum contamination..... | 43 |
| 4.3 | Applicability of Tier 2 evaluations when TCE is present | 43 |
| 4.4 | Indoor air VI cleanup and screening levels..... | 43 |
| 4.5 | Indoor air sampling events..... | 44 |
| 4.5.1 | Accounting for temporal variability | 47 |
| 4.5.2 | Accounting for spatial variability..... | 48 |
| 4.6 | Non VI sources of indoor air contamination..... | 49 |
| 4.6.1 | VOC sources inside the building..... | 49 |
| 4.6.2 | VOC contributions from ambient air | 50 |
| 4.7 | Measuring ambient air VOC concentrations..... | 51 |
| 4.8 | Sub-slab or crawl space sampling..... | 52 |
| 4.9 | Buildings covering large surficial areas | 54 |
| 4.10 | Factors affecting the number of sampling events | 55 |
| 4.11 | Factors affecting indoor air sample locations | 56 |
| 4.12 | Multiple VOCs..... | 57 |
| 4.13 | Decision making | 57 |
| 4.14 | Documenting and communicating the results of a Tier 2 evaluation..... | 58 |
| Chapter 5: Public Involvement | | 59 |
| 5.0 | Introduction..... | 59 |
| 5.1 | VI-related communication with the local community..... | 59 |
| 5.2 | Communications during the VI evaluation process..... | 60 |
| 5.2.1 | Pursue access agreements early..... | 60 |
| 5.2.2 | During and after the sampling process | 61 |
| 5.2.3 | When TCE is a VI contaminant of concern | 62 |
| 5.3 | Communications during building mitigation activities..... | 62 |
| 5.3.1 | Access agreements | 63 |
| 5.3.2 | Working with building owners and occupants | 63 |
| 5.3.3 | Notifying the public about the mitigation design | 63 |
| 5.3.4 | During construction and operation of the mitigation system | 64 |
| 5.3.5 | After installing a mitigation system..... | 64 |
| 5.3.6 | When a mitigation system is no longer needed..... | 64 |
| 5.3.7 | When TCE exceeds short-term action levels | 65 |
| 5.4 | Resources for communications with the public..... | 65 |
| Chapter 6: Mitigation..... | | 67 |
| 6.0 | Introduction..... | 67 |
| 6.1 | The purpose of VI mitigation | 68 |

| | | |
|---|--|-----------|
| 6.2 | Types of mitigation..... | 69 |
| 6.3 | Mitigating contaminated vapors that enter a building via conduits | 71 |
| 6.4 | Mitigation design..... | 71 |
| | 6.4.1 Pre-design activities..... | 71 |
| | 6.4.2 Mitigation system work plan and checklist..... | 72 |
| | 6.4.3 Mitigation emissions | 74 |
| 6.5 | Integrating public participation with mitigation | 75 |
| 6.6 | Post-construction considerations | 75 |
| | 6.6.1 Construction Completion Report and checklist..... | 76 |
| | 6.6.2 System Performance Report and checklist | 76 |
| 6.7 | Terminating and decommissioning the system..... | 78 |
| Chapter 7: Completing VI Cleanup Actions..... | | 81 |
| 7.0 | Introduction..... | 81 |
| 7.1 | Establishing media cleanup standards for the VI pathway..... | 81 |
| | 7.1.1 Establishing groundwater cleanup standards..... | 82 |
| | 7.1.2 Establishing soil cleanup standards | 83 |
| | 7.1.3 Establishing cleanup standards when there are multiple VOCs or pathways of exposure | 84 |
| 7.2 | Other considerations when establishing media cleanup standards..... | 85 |
| | 7.2.1 Soil gas sampling to verify VI protectiveness | 85 |
| | 7.2.2 Indoor air sampling to verify VI protectiveness | 85 |
| | 7.2.3 Indoor air cleanup levels different than those in the CLARC data tables | 86 |
| 7.3 | Ensuring long-term protectiveness from VI..... | 87 |
| | 7.3.1 Institutional controls..... | 88 |
| | 7.3.2 Environmental covenants..... | 89 |
| | 7.3.3 Other controls..... | 89 |
| 7.4 | Addressing buildings with large volumes of indoor air | 90 |
| Glossary..... | | 91 |
| References..... | | 95 |
| Appendix A: Vapor Intrusion (VI) Investigations and Short-term Trichloroethene (TCE) | | |
| Toxicity | | 1 |
| A-1 | Introduction..... | 1 |
| A-2 | Background | 1 |
| A-3 | VI screening and action levels for TCE | 2 |
| | A-3.1 Indoor air action levels for TCE | 2 |
| | A-3.2 VI short-term screening levels for TCE in groundwater and soil gas | 5 |
| A-4 | VI Investigation | 7 |
| | A-4.1 Identify any buildings where VI may result in indoor TCE concentrations above the short-term action level | 7 |
| | A-4.2 Notify and involve Ecology | 9 |
| | A-4.3 Prepare for indoor air sampling | 10 |
| | A-4.4 Determine if 3-week average indoor air TCE concentrations exceed the short-term action level..... | 11 |
| A-5 | Responding to exceedances of the short-term TCE indoor air action level | 12 |
| | A-5.1 Systems for mitigating vapor intrusion | 12 |
| | A-5.2 EPA-recommended actions and MTCA cleanups..... | 13 |
| A-6 | Working with people who are affected by vapor intrusion | 15 |
| | A-6.1 Outreach before indoor air sampling | 16 |
| | A-6.2 Outreach after indoor air sampling | 17 |

| | |
|--|----------|
| Appendix B: Process for Initially Assessing the Potential for Petroleum Vapor Intrusion (PVI) | 1 |
| B-1 Introduction..... | 1 |
| B-2 Background..... | 1 |
| B-3 MTCA Cleanup Rule requirements regarding vapor intrusion..... | 2 |
| B-4 Assessing the vapor intrusion pathway for sites with petroleum contamination..... | 3 |
| Appendix C: Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) | 1 |
| C-1 Introduction..... | 1 |
| C-2 VI Sampling and Analysis Plan..... | 1 |
| C-2.1 Tier 1 Evaluations..... | 1 |
| C-2.2 Tier 2 Evaluations..... | 3 |
| C-3 Quality Assurance Project Plan..... | 4 |
| Appendix D: Soil Gas Sampling for VI Evaluations | 1 |
| D-1 Introduction..... | 1 |
| D-2 Sub-slab soil gas sampling..... | 1 |
| D-3 Soil gas sampling beyond the building footprint..... | 4 |
| D-4 Passive soil gas sampling..... | 7 |
| D-5 Sources of information for soil gas sampling..... | 8 |
| Appendix E: Updated Screening Levels, Cleanup Levels, and Assessing Petroleum Vapor Intrusion (PVI) Threats to Future Buildings | 1 |
| E-1 Introduction..... | 1 |
| E-2 General overview..... | 1 |
| E-3 Petroleum mixtures..... | 1 |
| E-3.1 Background..... | 1 |
| E-3.2 Accounting for the cumulative effects of petroleum mixtures..... | 2 |
| E-4 Indoor air contaminants from sources other than PVI..... | 3 |
| E-5 Assessing the potential threat of Petroleum VI on future buildings..... | 4 |
| E-5.1 Background..... | 4 |
| E-5.2 When Method A soil and groundwater cleanup levels are met..... | 5 |
| E-5.3 When Method B soil cleanup levels and Method A groundwater cleanup levels are met..... | 7 |
| E-5.4 When soil or groundwater contamination remains following cleanup..... | 8 |
| E-6 Considerations when developing a Tier 1 or Tier 2 sampling plan to evaluate the potential for petroleum vapor intrusion..... | 9 |
| E-7 Process to establish a generic TPH indoor air cleanup level..... | 10 |
| E-7.1 Evaluated data..... | 10 |
| E-7.2 Developed the generic TPH cleanup and screening levels..... | 11 |
| E-7.3 Evaluated Washington state’s vapor intrusion sampling data..... | 13 |
| E-7.4 Researched other states’ vapor intrusion sampling approaches and cleanup levels..... | 13 |
| E-7.5 Conclusion..... | 13 |
| E-8 Process for calculating a site-specific TPH indoor air cleanup level (with example) | 15 |
| E-8.1 Steps and equations for calculating a site-specific Method B air cleanup level for total petroleum hydrocarbons (TPH)..... | 15 |
| E-8.2 Parameter definitions, values, and cleanup levels..... | 17 |

Figures, Equations, & Tables

Figures

| | |
|---|----|
| Figure 1: A generic conceptual site model for the vapor intrusion exposure pathway..... | 5 |
| Figure 2: How the VI Guidance is structured | 7 |
| Figure 3: Basic steps for completing a Preliminary Assessment | 12 |
| Figure 4: Basic steps for performing a Tier 1 vapor intrusion evaluation. | 20 |
| Figure 5: Basic steps for the Tier 2 assessment process..... | 42 |
| Figure 7: Six-liter Summa canister..... | 47 |
| Figure 8: Cross-section of a sub-slab depressurization system. Source: Tri-Services Handbook for the Assessment of the Vapor Intrusion Pathway (February 2008). Note: Installing a mitigation fan in the attic is an option only if the attic is not—and will not be—occupied. | 79 |

| | |
|--|---|
| Figure D-1: Drilling through a concrete slab using a rotary hammer drill (Photo credit: EPA 2006) | 2 |
| Figure D-2: Tracer gas applications when collecting soil gas samples (Credit: NYDOH 2006)... | 3 |
| Figure D-3: Sub-slab soil gas probe schematic (Credit: NJDEP 2005)..... | 4 |
| Figure D-4: Soil gas probe construction diagram (Credit: Missouri Risk-based Corrective Action for Petroleum Storage Tanks, Soil Gas Sampling Protocol, April 21, 2005) | 6 |
| Figure D-5: Photograph of a multi-depth nested vapor well utilizing small diameter, inert tubing NOTE: Valves are turned off. (Credit: H&P Mobile GeoChemistry, Inc. website, “How to Collect Reliable Soil-Gas Data”)..... | 7 |

Equations

| | |
|--|----|
| Equation 1: Generic groundwater VI screening levels. The groundwater screening level protective of indoor air is equal to the indoor air cleanup level over the vapor attenuation factor times a unit conversion factor times the Henry’s Law constant..... | 25 |
| Equation 2: Generic soil gas VI screening levels. Soil gas screening level that is protective of indoor air is equal to the indoor air cleanup level over the vapor attenuation factor | 29 |
| Equation 3: Equation for Method B cleanup level for TPH. The TPH cleanup level is equal to the hazard index times the average body weight times the unit conversion factor times the averaging time over the breathing rate times the exposure duration times the exposure frequency times the sum of the fraction by weight of the petroleum components times the inhalation absorption fraction for the petroleum components over the inhalation reference dose for the petroleum components..... | 15 |
| Equation 4: Simplified form of Equation 3. In first equation, the individual petroleum component cleanup level is equal to the inhalation reference dose for the petroleum component times the average body weight times the unit conversion factor times the hazard quotient times the averaging time over the breathing rate times the inhalation absorption fraction for the petroleum component times the exposure duration times the exposure frequency. In second equation, the TPH cleanup level is equal to one over the sum of the fraction by weight of the petroleum components over the air cleanup level for the petroleum components..... | 16 |

Tables

| | |
|--|----|
| Table 1: Recommended minimum number of sampling events for three sampling methods | 56 |
| Table A-1: Vapor intrusion TCE Indoor Air Cleanup Levels, chronic (mean long-term air concentration for RME receptor)* | 3 |
| Table A-2: Vapor intrusion TCE Indoor Air Action Levels, short-term (maximum 3-week mean concentration for women of childbearing age) | 3 |
| Table A-3: Vapor intrusion subsurface screening levels for soil gas for short-term exposures to TCE | 6 |
| Table E-1: Indoor air cleanup levels and background concentrations for three petroleum compounds | 3 |
| Table E-2: Groundwater screening and cleanup levels for four petroleum compounds | 6 |
| Table E-3: Inhalation reference doses for non-carcinogenic parameters | 14 |
| Table E-4: Inhalation cancer potency factors for carcinogenic parameters..... | 14 |
| Table E-5: Parameter definitions | 17 |
| Table E-6: Fraction or compound specific parameter values, and non-carcinogenic cleanup levels | 18 |
| Table E-7: Non-carcinogenic example measurements and calculations..... | 19 |
| Table E-8: Carcinogenic example measurements and evaluation. | 20 |

Acronyms & Abbreviations

| Acronym or Abbreviation | Definitions |
|-------------------------|--|
| 1E-5 | one in one hundred thousand (1×10^{-5} or 1x100,000) |
| 1E-6 | one in one million (1×10^{-6} or 1x1,000,000) |
| atm m ³ /mol | air to moles per cubic meter |
| AER | air exchange rate |
| APH | air phase hydrocarbon |
| APU | air purification units |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| BTEXN | benzene, toluene, ethylbenzene, xylenes, and naphthalene |
| CLARC | Ecology's Cleanup Levels and Risk Calculation data tables |
| COEES | Ecology's Community Outreach and Environmental Education Specialist |
| COPC | contaminant of potential concern |
| CPF | carcinogenic potency factor |
| CPF _i | inhalation cancer potency factor |
| CPOC | conditional point of compliance |
| CSIA | compound specific isotope analysis |
| CSM | (vapor intrusion) Conceptual Site Model |
| CUL | cleanup levels |
| 1,2-DCE | 1,2-dichloroethylene |
| DoD | United States Department of Defense |
| DOSH | Division of Occupational Safety and Health (part of Washington Department of Labor & Industries) |
| DRO | diesel range organics |
| DTSC | California Department of Toxic Substances Control |
| EC | equivalent carbon |
| Ecology | Washington State Department of Ecology |
| EDB | ethylene dibromide |
| EDC | 1,2 dichloroethane (also known as ethylene dichloride) |
| EPA | United States Environmental Protection Agency |

| Acronym or Abbreviation | Definitions |
|--------------------------------|--|
| ESA | Environmental Site Assessment |
| FS | Feasibility Study |
| GC/MS | gas chromatography/mass spectrometry |
| GRO | gasoline range organics |
| Hcc or HLC | Henry's Law Constant (Hcc is the unitless form) |
| HDOH | Hawai'i Department of Health |
| HI | non-carcinogenic Hazard Index |
| HQ | non-carcinogenic Hazard Quotient |
| HVAC | heating, ventilation, and air conditioning |
| IRIS | EPA's Integrated Risk Information System |
| ITRC | Interstate Technology Regulatory Council |
| JP-8 | jet propellant 8 |
| LNAPL | light non-aqueous phase liquid |
| L&I | Washington State Department of Labor & Industries |
| MDL | method detection limit |
| µg/L | micrograms per liter |
| µg/m ³ | micrograms per cubic meter |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| mmHg | millimeters of mercury |
| MTBE | methyl tert-butyl ether |
| MTCA | Model Toxics Control Act, Chapter 70A.305 RCW |
| NAPL | non-aqueous phase liquids |
| NFA | no further action |
| OSHA | Occupational Safety and Health Administration (federal agency) |
| PCBs | polychlorinated biphenyls |
| PCE | tetrachloroethylene (also called perchloroethylene) |
| PELs | permissible exposure limits |
| PLP | potentially liable person or party |
| PQL | practical quantitation limit |

| Acronym or Abbreviation | Definitions |
|-------------------------|---|
| PVI | petroleum vapor intrusion |
| PVOC | petroleum volatile organic compounds |
| QA | quality assurance |
| RCRA | Resource Conservation and Recovery Act |
| RCW | Revised Code of Washington |
| RfD | reference dose |
| RfDi | inhalation reference dose |
| RI | Remedial Investigation |
| RME | reasonable maximum exposure (RME) means the highest exposure that can be reasonably expected to occur for a human or other living organisms at a site under current and potential future site use |
| SAP | Sampling and Analysis Plan |
| SIM | Selective Ion Mode |
| SL | screening level |
| SMDS | sub-membrane depressurization systems |
| SOP | standard operating procedures (SOPs) |
| SSDS | sub-slab depressurization systems |
| SVE | soil vapor extraction |
| SVOC | semi-volatile organic compound |
| TCE | trichloroethene or trichloroethylene |
| TCP | Toxics Cleanup Program |
| Tier 1 | term used by Ecology to describe VI assessments that use subsurface (groundwater and soil gas) VOC measurements |
| Tier 2 | term used by Ecology to describe VI assessments that use indoor air VOC measurements |
| TPH | total petroleum hydrocarbons |
| VAF | vapor attenuation factors |
| VCP | Ecology's Voluntary Cleanup Program |
| VI | vapor intrusion |
| VISL | EPA's Vapor Intrusion Screening Level calculator database |
| VOC | volatile organic compound |

| Acronym or Abbreviation | Definitions |
|--------------------------------|--|
| VPH | volatile petroleum hydrocarbon |
| WAC | Washington Administrative Code |
| WISHA | Washington Industrial Safety and Health Act, Chapter 49.17 RCW |

Chapter 1: Introduction

Vapor intrusion can pose a threat to people's health. This guidance is intended to help consultants, potentially liable persons, and Ecology staff address these situations.

1.0 Introduction

When volatile hazardous substances such as gasoline or solvents are released into the environment, they can contaminate soil and groundwater. This contamination can also result in the formation of chemical vapors. The concentrations of these chemical vapors decrease as distance from the contamination increases and are influenced by the chemicals' properties, the soil characteristics, and the potential for biological and chemical transformations. The process by which these chemical vapors migrate through the soil and into indoor air is called *vapor intrusion* (VI). When it occurs, there is the potential for humans to be exposed if occupied buildings are in the vicinity of the contamination, or if buildings are constructed in the area in the future.²

Washington's environmental cleanup law—the Model Toxics Control Act (MTCA)—is the primary statute governing the cleanup of hazardous substances in Washington state. At sites where there has been a confirmed release of a hazardous substance, the potentially liable person or party (PLP) must investigate, and if necessary, remediate the contamination in accordance with the MTCA cleanup regulations (Chapter 173-340 of the Washington Administrative Code). Investigation and remediation must address all potential exposure pathways including VI. As a result, the Washington State Department of Ecology (Ecology) expects that all site investigations include an assessment of the VI pathway whenever volatile hazardous substances are present in the subsurface.³

To provide a comprehensive document for addressing VI, Ecology converted three previous Implementation Memos into Appendices for this guidance.

1. **Implementation Memo No. 22 is now Appendix A:** Vapor intrusion (VI) investigations and short-term trichloroethene (TCE) toxicity. (formerly Ecology publication no. 18-09-047, now obsolete)

² Contamination of air from soil gas entering enclosed belowground structures such as manholes or utility vaults (which are commonly unoccupied) could be considered VI. That is a much different scenario than intrusion into occupied buildings and is not the focus of this document.

³ See: [WAC 173-340-357\(3\)\(f\)\(i\)](#); [WAC 173-340-450\(2\)\(c\) & \(3\)\(a\)\(i\)](#); [WAC 173-340-720\(1\)\(c\) & \(1\)\(d\)\(iv\)](#); [WAC 173-340-740\(3\)\(b\)\(iii\)\(C\) & \(3\)\(c\)\(iv\)](#); [WAC 173-340-745\(2\)\(c\) & \(5\)\(b\)\(iii\)\(C\)](#); and [WAC 173-340-750](#).

2. **Implementation Memo No. 14 is now Appendix B:** Updated process for initially assessing the potential for petroleum vapor intrusion (formerly Ecology publication no. 16-09-046, now obsolete)
3. **Implementation Memo No. 18 is now Appendix E:** Petroleum vapor intrusion (PVI): Updated screening levels, cleanup levels, and assessing PVI threats to future buildings (formerly Ecology publication no. 17-09-043, now obsolete)

We incorporated two other documents into the text of this guidance:

1. **Implementation Memo No. 21:** Frequently asked questions (FAQs) regarding vapor intrusion (VI) (formerly Ecology publication no. 18-09-046, now obsolete)
2. **Ecology's 2009 Draft VI Guidance**, an earlier version of this guidance, Ecology publication no. 09-09-047.

1.1 Purpose

The purpose of this guidance is to provide PLPs,⁴ site managers, and consultants a practical approach for assessing VI at sites in Washington where volatile chemicals in the subsurface might pose a threat to indoor air quality. The guidance contains information about:

- A process for evaluating the VI pathway during a remedial investigation and feasibility study (see [WAC 173-340-350](#)⁵) or as part of an independent cleanup action.
- Methods, techniques, and references for VI-related soil gas, indoor air, crawl space and ambient air sampling.
- References to soil, groundwater, and soil gas VI screening levels as well as indoor air cleanup levels.
- Options for communicating with the public when VI is impacting, or has the potential to impact, indoor air quality.
- Mitigation measures and techniques to protect receptors from VI.

Section 1.4 describes how the guidance is structured around these topics.

⁴ For purposes of this guidance, "PLP" broadly refers to the individual or party responsible for cleaning up the site. It is not intended to limit responsibility to only those who are designated as PLPs per RCW [70A.305.040](#). Instead, it is a general reference to the *responsible party*.

⁵ <https://apps.leg.wa.gov/waC/default.aspx?cite=173-340-350>

This guidance discusses types of equipment and sampling methods in general, but does not provide specific recommendations on which equipment or sampling methods to use since many factors will determine those choices. Instead, references are provided throughout this document to help select specific equipment and sampling methods most appropriate for site-specific conditions.

For purposes of this guidance:

- “Site” refers to contaminated site, which is also known as a cleanup site.
- Actions identified by “must” or “required” are generally used for immediate tasks that protect human health, or for following requirements in rule or law (the Washington Administration Code, WAC, or the Revised Code of Washington, RCW).
- Remedial actions are any action or expenditure consistent with the purposes of MTCA to identify, eliminate, or minimize any threat posed by hazardous substances to human health or the environment (WAC [173-322A-100\(45\)](#)). For example, every step in the [MTCA cleanup process](#)⁶ is a “remedial action.”
- Cleanup actions are a subset of remedial actions. Any remedial action, except interim actions, taken at a site to eliminate, render less toxic, stabilize, contain, immobilize, isolate, treat, destroy, or remove a hazardous substance that complies with WAC 173-340-350 through 173-340-390.

1.2 Applicability

This guidance can be applied to most sites in Washington state when there is the potential for vapor intrusion to impact existing or future buildings. Ecology developed it to be consistent with MTCA, and it is also generally consistent with VI guidance documents from the Environmental Protection Agency (EPA), the Interstate Technology Regulatory Council (ITRC) and other state programs.⁷ Nevertheless, Ecology recognize that VI evaluation and mitigation techniques are constantly changing, and as a result, it may be appropriate to use approaches and methodologies not specifically addressed here.

The following discussion provides several examples of when this guidance’s applicability may be limited, or may need to be supplemented with additional guidance.

⁶ <https://ecology.wa.gov/Spills-Cleanup/Contamination-cleanup/Cleanup-process>

⁷ In June 2015, EPA published two guidance documents for evaluating the vapor intrusion pathway. In 2014, ITRC released a comprehensive petroleum VI document. Since 2015, several states have finalized updated VI guidance documents.

1.2.1 Sites with elevated soil gas methane levels

Some of the recommendations in this guidance could apply when evaluating and responding to elevated methane levels present in soil gas near an occupied building, or when landfill-generated methane gas is (or may be) migrating into buildings or other structures.

However, there are unique vapor transport, health, and safety aspects to these situations that merit separate treatment. For that reason, the guidance does not address scenarios such as these in detail. When methane is identified as a potential concern, consider using ASTM E2993-16, “Standard Guide for Evaluating Potential Hazard as a Result of Methane in the Vadose Zone.”

1.2.2 Workplace exposures to toxic, volatile substances

Certain industrial and commercial operations require toxic, volatile substances and workers in such settings may be exposed to vapors from these chemicals. Workplace safety is regulated by both the Washington State Department of Labor & Industries (L&I) Division of Occupational Safety and Health (DOSH) and the federal Occupational Safety and Health Administration (OSHA). This guidance does not alter or affect the concentrations for worker protection established by these agencies.⁸ It does apply to any building where subsurface contamination poses a potential threat to indoor air quality from VI, including buildings where the primary receptors of concern are workers.

Vapor intrusion evaluations are challenging if a building with persistently elevated levels of indoor air contamination (caused by the business use of volatile chemicals inside or adjacent to the building) has the same chemicals in the soil gas beneath the building. Therefore, Ecology does not recommend conducting indoor air sampling as part of the VI evaluation when the following scenario occurs:

- The chemicals used in the workplace are the same substances found in soil gas beneath the building,
- The chemicals are routinely used, so it is not feasible to schedule indoor air sampling during a period when there are not significant measurable impacts from these compounds, and
- Employees who occupy the workplace are routinely exposed to much higher concentrations from facility operations than the potential contributions from VI.

⁸ The Washington Industrial Safety and Health Act (WISHA), provides for the state’s occupational safety and health rules (Chapter 296-800 WAC). OSHA and WISHA establish permissible exposure limits (PELs) for workplace chemicals. PELs are based on both risk and economic feasibility. For most VOCs, the human health-based indoor air cleanup levels required under MTCA are much lower than the PELs.

Instead, Ecology recommends deferring a VI evaluation for such spaces until a time when these conditions no longer apply. Note: This does not affect the need to expeditiously clean up subsurface contamination in accordance with WAC [173-340-360](https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-360).⁹

1.3 The VI pathway

Volatile contaminants in the subsurface typically partition into the gas phase and migrate into the soil pore space that isn't occupied by water. Within the deeper portions of the vadose zone, gas-phase chemicals move primarily via molecular diffusion. However, nearer the surface and approaching buildings, pressure gradients can play a significant role, with advection of soil gas generally being the dominant transport mechanism influencing vapor intrusion.¹⁰ Gas-phase chemicals can enter buildings through cracks, seams, or utility penetrations in subsurface (that is, basement) walls and floors, or through openings in floors that are in direct contact with the ground surface. Figure 1 illustrates a generic VI conceptual model.

In this guidance, vapor intrusion (VI) refers to the migration of hazardous volatile chemicals from the subsurface into the indoor air of nearby buildings. Subsurface contamination in this context refers to soils, groundwater, soil gas, or vapors contaminated by hazardous substance releases, including non-aqueous phase liquids (NAPLs).

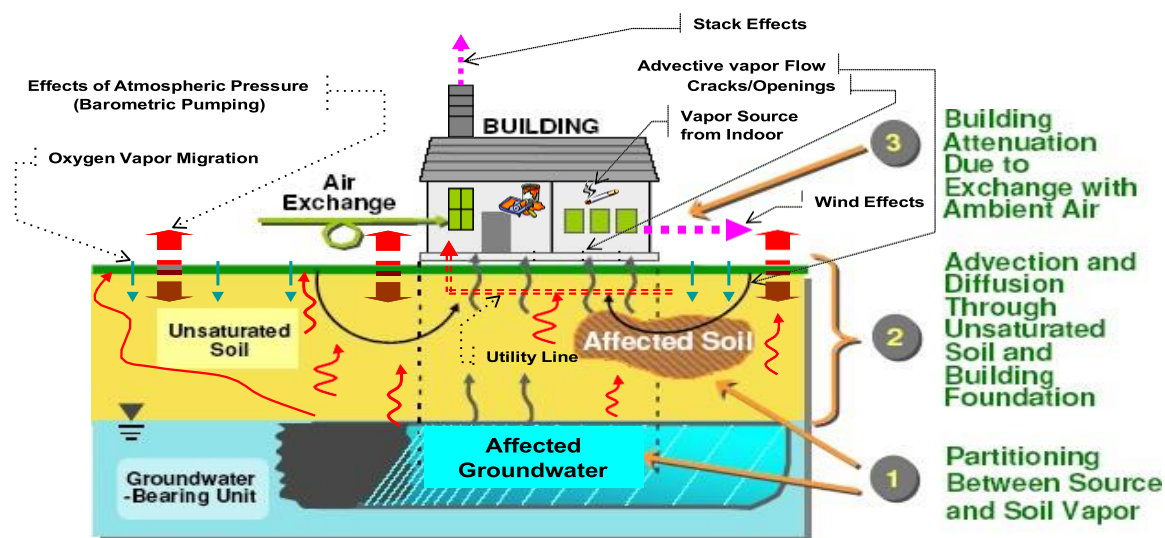


Figure 1: A generic conceptual site model for the vapor intrusion exposure pathway.

⁹ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-360>

¹⁰ Pressure differences can occur for various reasons, and the air pressure inside an occupied building is often lower than both ambient air and the subsurface. This creates the potential for both ambient air contaminants and contaminants present in shallow soil gas to move indoors.

Subsurface contamination may coincide with areas where belowground conduits such as piping are present. Conduits above the water table can preferentially transport contaminated soil gas, primarily when the conduit is very close or in direct contact with highly contaminated soils or NAPL. When conduits intercept contaminated groundwater, the contamination can enter the conduit and be transported in both the liquid and vapor phases. Conduit terminations can be located near the foundation or inside the building through the plumbing network. In either case, building-specific VI conceptual models must account for potential vapor migration through these preferential pathways. This scenario is discussed in more detail in Chapter 3.

In rare cases, vapors that accumulate in enclosed spaces can pose immediate safety hazards such as explosions and acute health effects, or aesthetic problems such as odors. Section 2.1 in Chapter 2 provides more information about vapor scenarios that require an immediate response, including short-term health effects from trichloroethene (TCE). Typically, chemical concentrations in indoor air due to VI are relatively low and the primary concern is the potential for non-acute health effects associated with longer term exposures, as well as risks from short-term exposures to TCE. This guidance was developed to address such scenarios.

1.4 How the VI guidance is structured

This guidance establishes a tiered process for evaluating the VI pathway that is generally consistent with other guidance documents from state and federal agencies. The process is a series of steps to gather the data needed to determine if VI is impacting indoor air. All of these steps will typically occur at the site characterization stage, although it is often necessary to gather supplemental data when moving from one step to the next.

This section and Figure 2 briefly summarize the major steps of the process, while three chapters discuss them in detail:

- Chapter 2: Preliminary Assessments
- Chapter 3: Tier 1 Evaluations
- Chapter 4: Tier 2 Evaluations

Since this guidance does not provide detailed discussion on all VI-related issues, refer to other state documents such as those developed by California, Massachusetts, Michigan, and New Jersey; Interstate Technology Regulatory Council's (ITRC's) guidance; and two EPA guidance documents. See References for citations.

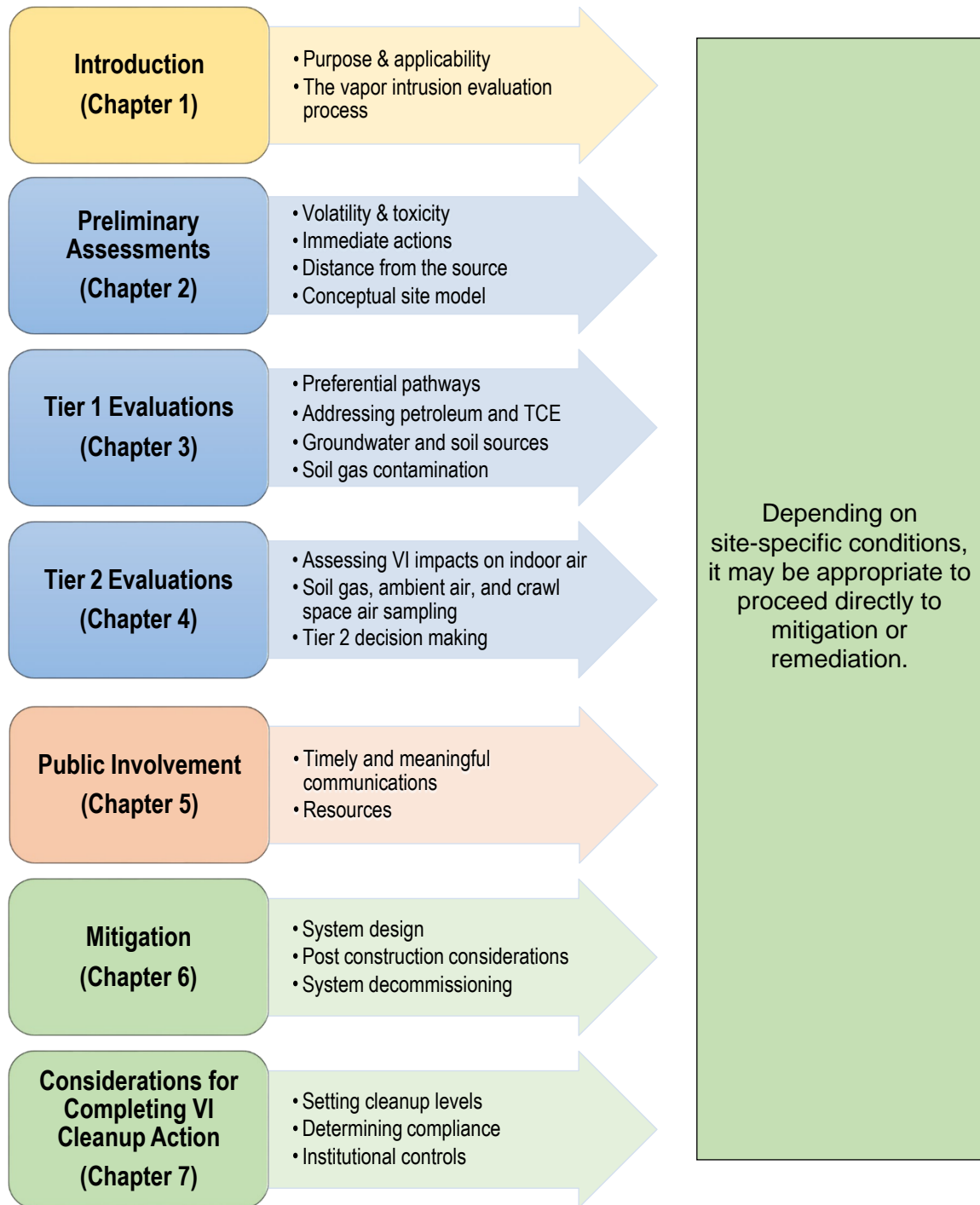


Figure 2: How the VI Guidance is structured.

Preliminary Assessments

The goal of a Preliminary Assessment is to identify whether the potential for VI exists at a specific site and if it does, which buildings could be affected. Preliminary Assessments are typically completed early in the site investigation process.

The first step is to determine whether the chemicals that are known or reasonably suspected of being present at the site are sufficiently toxic and volatile. If the chemicals present at the site do not meet these criteria, there is no need to further assess the VI pathway. If the chemicals are determined to be both toxic and volatile, but the contamination is at a sufficient distance from any occupied building, then VI is unlikely to pose a threat to indoor receptors. As long as subsequent site characterization information does not invalidate this conclusion, existing site buildings do not require further VI assessment.

If the Preliminary Assessment concludes that there are toxic and volatile hazardous substances at the site and the contamination is close to one or more currently occupied buildings, the next step will typically be a Tier 1 evaluation.

If the impacted area is undeveloped, but buildings could be constructed in the future, a Tier 1 evaluation should be completed to determine potential VI concerns.

Tier 1 Evaluations

A Tier 1 evaluation is completed during the site investigation to evaluate whether the concentrations of volatile contaminants in the subsurface are high enough to potentially result in unacceptable indoor air levels. Tier 1 evaluations can be conducted for existing buildings or buildings that could be constructed in the future. This evaluation typically uses generic soil gas and/or groundwater screening levels found in Ecology's [Cleanup Levels and Risk Based Calculator \(CLARC\) Data Tables](#).¹¹ If the Tier 1 evaluation concludes that subsurface contamination is significant enough to pose a threat to the indoor air quality of one or more occupied buildings, the next step is typically a Tier 2 evaluation.

¹¹ <https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC/Data-tables>

Tier 2 Evaluations

The goal of a Tier 2 evaluation is to determine whether concentrations of VOCs in indoor air from VI are at unacceptable levels. Tier 2 evaluations also typically include measurements of ambient air and sub-slab soil gas or crawl space air. If the measured indoor air concentrations exceed the applicable cleanup levels and are not due to ambient air or indoor air sources such as household cleaners, paints, gasoline or other VOCs, quickly implement VI mitigation and/or other measures to protect indoor receptors.

1.5 Public involvement

Once it becomes apparent that VI has the potential to impact indoor air quality, consider community involvement even if access to properties and buildings to collect samples has not yet been obtained. **Chapter 5** focuses primarily on interactions with owners and occupants of buildings that are undergoing a VI evaluation. **Section 5.4** lists resources that can help when talking to members of the public about vapor intrusion.

1.6 Responding to indoor air contamination caused by VI

In most cases, if VI is unacceptably impacting indoor air, mitigation measures should be implemented to protect receptors until the subsurface source has been effectively cleaned up. **Chapter 6** discusses VI mitigation and lists guidance and resources about types of mitigation technologies available.

If subsurface levels of toxic, volatile substances are elevated and pose a potential VI threat, the *source* of the problem must be addressed as part of the cleanup action for the site.¹² **Chapter 7** focuses on the VI source and discusses approaches for establishing subsurface cleanup standards protective of indoor air quality. It also discusses other VI-related cleanup issues, such as the need for institutional controls.

¹² The goal of a site cleanup action is to remediate subsurface contamination such that indoor air cleanup levels are not exceeded within existing or future buildings. VI mitigation, by definition, does not remediate the subsurface VI source.

1.7 Updating the guidance

This VI Guidance is a living document and Ecology expects to revise it in the future.

VI is an evolving science. Over time, as sites continue to be evaluated nationwide, our understanding of the relationship between subsurface contamination and indoor air impacts will improve. This may allow people to better predict the degree of VI impacts at any given building, and estimate the concentration of indoor air contaminants due only to VI. In addition, Ecology anticipates that the MTCA cleanup regulations related to VI will be modified in the future.¹³

Regulatory changes and advances in the science of VI evaluation and mitigation will likely require revisions to portions of this guidance.

¹³ In December 2018, Ecology launched the first of several planned rulemakings to update the MTCA Cleanup Rule, Chapter 173-340 WAC. Learn more at <https://ecology.wa.gov/Regulations-Permits/Laws-rules-rulemaking/Rulemaking/WAC-173-340>

Chapter 2: Preliminary Assessments

Preliminary Assessments are completed early in the investigation so you can identify if the potential for VI exists and if so, which buildings could be affected.

2.0 Introduction

The goal of a Preliminary Assessment is to determine whether chemicals of sufficient toxicity and volatility are known (or reasonably suspected) to be present in the subsurface and could migrate into nearby buildings. Performing a Preliminary Assessment requires the nature and extent of soil and groundwater contamination be defined well enough to:

- Identify the hazardous substances present, and
- Conservatively estimate the lateral and vertical extent of the contamination.¹⁴

Figure 3 shows the basic steps involved in a Preliminary Assessment of the VI pathway.

¹⁴ When estimating the extent of groundwater impacts, it isn't necessary to include dissolved VOC's deeper in the aquifer as these contaminants will not volatilize and contaminate soil gas. If NAPL overlies the water table, you should estimate its lateral boundaries during the Preliminary Assessment.

Determining if further VI evaluation is needed

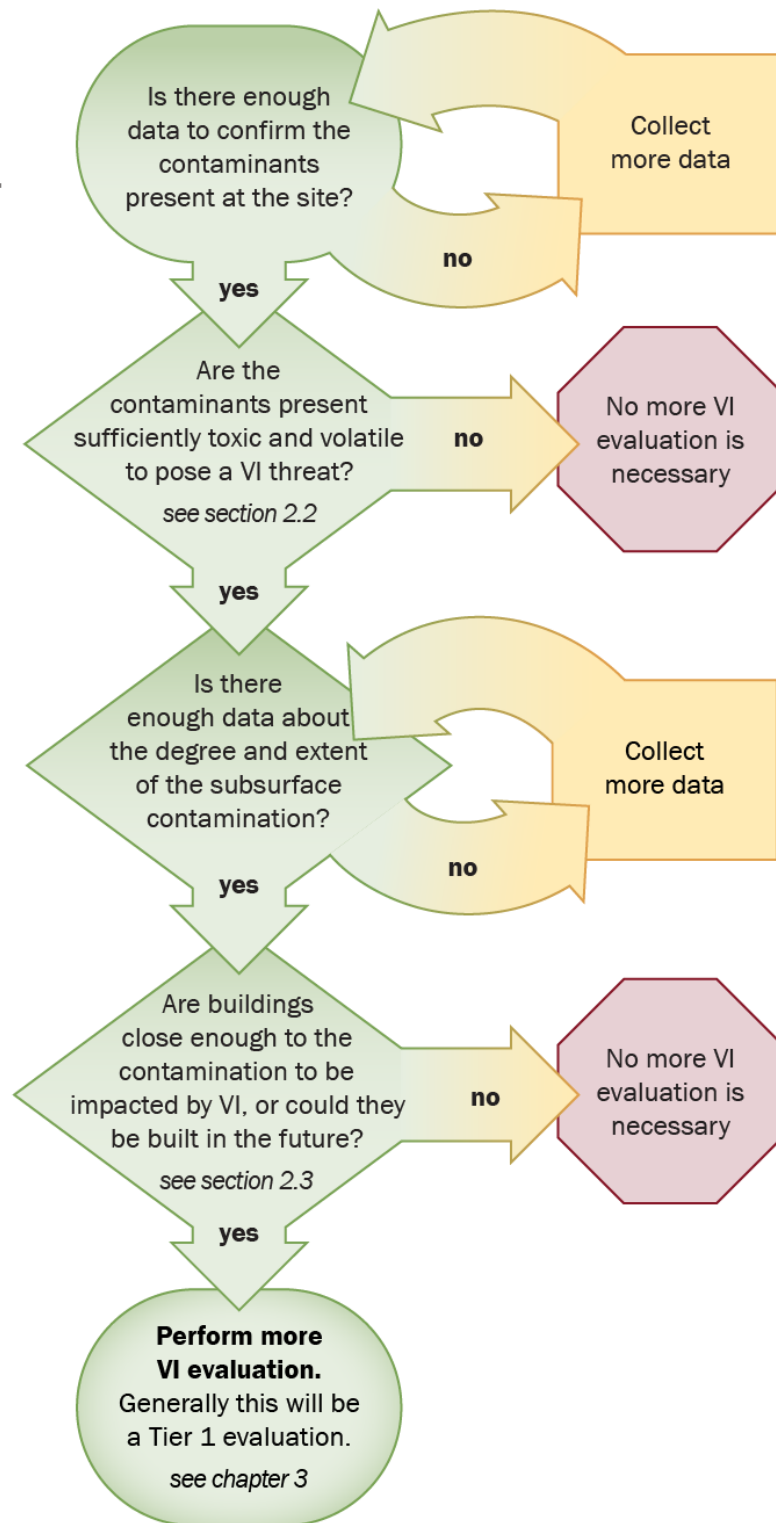


Figure 3: Basic steps for completing a Preliminary Assessment

2.1 Is immediate action necessary?

Most VI scenarios are not associated with safety concerns or indoor air concentrations that pose acute hazards. The following examples identify when immediate action may be necessary. With the exception of the last bulleted item, this guidance was not developed to address these relatively rare situations.

- When vapors are known or suspected to be flammable, combustible, corrosive or chemically reactive. Investigators should immediately assess and respond to the situation. Under MTCA, cleanup levels protective of air quality cannot exceed ten percent (10%) of the lower explosive limit for any hazardous substance or mixture of hazardous substances.¹⁵

Note: Ecology advises that you immediately evacuate buildings with potential fire or explosive conditions and contact the local fire department.

- When odors are detected and there is a known or suspected subsurface VOC contaminant source nearby. Odors can reduce the quality of life for occupants and in certain cases may result in more serious health effects. For some chemicals like benzene and naphthalene, the odor detection threshold exceeds the indoor air concentrations that are acceptable under MTCA.
- When building occupants report health problems and occupants and/or health agencies believe the problems may be linked to inhaling contaminants because a known or suspected source of site-related VOC contamination is nearby.
- When site-related volatile non-aqueous phase liquid (free product) is in contact with the building.
- When trichloroethene (TCE) contamination in soil or groundwater is in close proximity to buildings where occupants include women of childbearing age. Based on memoranda issued by EPA (see References), short-term exposures to relatively low levels of TCE vapors have the potential to cause heart defects in developing fetuses. Ecology has developed specific recommendations for rapidly evaluating and mitigating the potential impacts from TCE when the conditions described above are present: see Appendix A.

Scenarios such as these are relatively rare. More typically, VI-related health concerns are associated with long-term chronic exposures to relatively low levels of VOCs in indoor air. Nevertheless, if indoor air quality in an occupied building is being impacted by VI, the source-to-receptor pathway is complete and actions should be taken to quickly investigate the impact and respond appropriately. When VI mitigation is deemed necessary, the system should be installed as soon as possible—well before choosing and implementing the comprehensive site cleanup action.

¹⁵ See WAC 173-340-750(3)(b)(iii) and (4)(b)(iii).

2.2 Are contaminants of concern volatile and toxic?

Ecology's CLARC VI Data Tables provide Method B and C indoor air cleanup levels. They also provide groundwater and soil gas screening levels for a number of substances that are sufficiently volatile and toxic to pose a potential threat to indoor air quality from the VI pathway. If these substances are present in the subsurface, determine the proximity of the contamination to existing buildings, as explained in Section 2.3 below.

CLARC's VI Data Tables contain most of the substances that are volatile and toxic enough to contaminate indoor air from VI and are consistent with the chemicals listed in EPA's [Vapor Intrusion Screening Level \(VISL\) calculator database](#)¹⁶. The major difference between Ecology's and EPA's resources is that if a reliable analytical method is not available for a particular substance, that compound is not included in the CLARC VI Data Tables.

VISL screening levels are only provided for those chemicals that have inhalation toxicity data and meet volatility criteria (i.e., a Henry's Law Constant greater than 10^{-5} atm m³/mol or a vapor pressure greater than 1 mmHg). The calculator uses the same database as EPA's [Regional Screening Levels](#)¹⁷ for toxicity values and physiochemical parameters. If chemicals with EPA VI screening levels are present in the subsurface, but are not included in the CLARC VI Data Tables, we recommend contacting us at Ecology to discuss next steps.

Note: We update the CLARC Data Tables about every six months, usually in the spring and fall. We may modify the list of compounds as new analytical methods or toxicity information becomes available.

2.3 Are buildings close enough to the contamination?

Sufficient lateral distance between the contamination and a building can limit the potential for VI. Generally, buildings located more than 30 feet horizontally from the edge of volatile subsurface petroleum contamination¹⁸ or 100 feet horizontally from the edge of any other type of volatile subsurface contamination¹⁹ are unlikely to experience unacceptable VI impacts.

Relying solely on these distance criteria, however, could exclude buildings where unacceptable VI impacts are possible, such as when either of these conditions are present:

¹⁶ <https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator>

¹⁷ <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables>

¹⁸ Petroleum Vapor Intrusion: Fundamentals of Screening, Investigating and Management. Washington, D.C. Interstate Technology and Regulatory Council (October 2014).

¹⁹ See EPA's Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (June 2015).

- The vadose zone geology has a very high soil gas permeability (e.g., Karst deposits, fractured bedrock conditions, or clay soils with continuous fissuring). Soil gas contaminants can follow these preferential flow paths without substantial attenuation. If these geologic features have a significant horizontal component to their alignment, elevated VOC concentrations in soil gas may extend beyond the distances specified above.
- Subsurface sewer lines or other utility corridors are present at the site and capable of transporting site-related VOCs over extended distances. This scenario is a primary concern when the conduit is very close to or directly intersects contaminated groundwater or non-aqueous phase liquids (NAPL), or when the conduit is located in the vadose zone and is in contact with or very close to highly contaminated soils or NAPL.

- **Note:** In the two examples above, neither the 30-foot horizontal screening distance for petroleum nor the 100-foot distance for non-petroleum compounds (such as chlorinated contaminants) should be used for screening purposes.
- **Note:** If sewer lines or utility corridors intersect contaminated groundwater or NAPL, the potential contaminant transport distance should be estimated. Depending on the anticipated range of influence, the number of buildings requiring evaluation may need to be expanded.²⁰
- **Note:** When soil gas is subject to pressure gradients, its contents can be transported through advection. A special case of this phenomena can occur at landfills where subsurface methane gas and other VOCs can migrate considerable distances. As discussed in Chapter 1, this guidance document is not intended for most methane intrusion situations and the “100-foot rule” often won’t be sufficiently conservative for soil gas contaminated by landfills.

Applying the lateral VI screening distances not only requires adequate information about the extent of subsurface contamination, but often necessitates continued monitoring to ensure site conditions do not change over time. For example, an expanding groundwater plume could potentially threaten buildings that initially appeared to far away to be impacted.

2.4 Initial VI conceptual site model

An initial conceptual site model (CSM) should be developed during the Preliminary Assessment stage and include the following information:

1. **Cross-sectional views** depicting the water table, any perched saturated zones, vadose zone strata, and the location of all potential VI sources, including any NAPL or residual NAPL known to be present.

²⁰ Identifying buildings potentially impacted by conduit transport is typically performed as part of a Tier 1 evaluation (Chapter 3).

2. **A series of plan-view figures** depicting the extent of soil, groundwater, and NAPL contamination overlaid with the footprints of all occupied buildings above or within 100 feet of the contaminated boundaries (or 30 feet for sites where only petroleum contamination constitutes the VI source).²¹
3. The location and depths of sewer lines and utility tunnels present within the source area and/or impacted groundwater.²² This includes lateral lines that extend from the street into or near buildings.

Some of the information recommended above may not be available at the Preliminary Assessment stage, so supplement and update the CSM as additional information becomes available. The specific elements that should comprise the CSM for Tier 1 and Tier 2 evaluations are provided in Chapters 3 and 4, respectively.

Buildings identified during the preparation of the Initial VI Conceptual Site Model should be differentiated based on the primary receptors present, which include:

- Indoor workers
- Residents
- Individuals less exposed than residents but are not adult workers (e.g., students).
- Sensitive receptors, such as the elderly; women of child-bearing age; infants and children; people suffering from chronic illness; and disadvantaged populations.

Note: WAC [173-340-702\(4\)](#)²³ requires that cleanup standards and actions must be protective of current **and potential future site and resource uses**. This means that all developable areas within the appropriate lateral screening distance will need a VI evaluation whether a building currently exists or not.

²¹ If several VOCs are present with different lateral extents, consider using multiple figures to clearly identify the information.

²² McHugh and Beckley (2019) developed a conceptual site model along with an investigation protocol for evaluating VOC flux through the interior of a sewer or utility tunnel. A utility tunnel is a conduit for carrying electrical, water, and sewer pipes as well as fiber optics, cable TV, and phone lines. Utility tunnels are not typically installed in residential areas and lines that are directly buried are not considered utility tunnels.

²³ <https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-702> (General policies.)

2.5 Assessing sites with only petroleum contamination

Appendix B provides screening criteria to initially assess whether VI is a potential concern at sites with only petroleum contamination. If this initial assessment indicates the screening criteria are met, then site conditions do not pose a VI threat to existing buildings. However, if the screening criteria are not met, the current site conditions may pose a potential for petroleum VI and further evaluation consisting of a Tier 1 and possibly a Tier 2 evaluation would be necessary. If the site has contamination remaining at the completion of the cleanup, further vapor assessment will be necessary to determine if future property restrictions are necessary.

2.6 Conclusions and next steps

Scenarios in the next two sections can apply to the entire site or just portions of the site.

2.6.1 Situations not requiring further VI assessment

If the site characterization is sufficient to conclude that chemicals of sufficient volatility and toxicity are either a) not present or b) are present but no occupied buildings are located above or near the contamination and couldn't be constructed in this area in the future, then further assessment of the VI pathway isn't necessary. The results of the VI assessment should be documented and provided to Ecology as part of the site investigation results.

2.6.2 Situations requiring further VI evaluation

If chemicals of sufficient volatility and toxicity are known or reasonably suspected to be present, evaluate further when:

- Buildings could be constructed in areas above or near the contamination in the future, or
- Occupied buildings are present above or near the contamination.

While the first scenario currently has no VI concern, WAC 173-340-702(4) requires that cleanup standards and cleanup actions be protective of both current and potential future site and resource uses. This will necessitate a Tier 1 evaluation (Chapter 3) prior to development, which can often take place after the cleanup action has been completed. For the second scenario, the Tier 1 evaluation should begin without delay.

2.6.3 Next steps

This guidance is structured with the assumption that Tier 1 evaluations follow Preliminary Assessments. While this will often be the case, some site- or building-specific situations may warrant moving directly to a Tier 2 evaluation, such as:

- If the Preliminary Assessment results in one or more building needing further evaluation due to the presence of preferential flow paths, an appropriate course of action would likely be moving directly to Tier 2 and gathering sub-slab and indoor air samples. This is

because the Tier 1 groundwater and soil gas screening levels were developed under an assumption that conditions were conducive for significant attenuation to occur. When vapors are migrating through highly permeable zones, however, this assumption may no longer be valid and if not, the Tier 1 process would no longer apply.

- **TCE contamination in soil or groundwater is in close proximity to buildings where occupants include woman of childbearing age.** In these cases, Tier 2 indoor air sampling should not be delayed although it may be appropriate to conduct Tier 1 sampling concurrently.

Certain site- or building-specific situations may indicate that VI mitigation should be implemented even though indoor air sampling hasn't been performed. This is referred to as *preemptive* mitigation and can be deemed necessary at any point in the VI evaluation process. Chapter 6 is devoted to discussing VI mitigation.

Chapter 3: Tier 1 VI Evaluations

Tier 1 evaluations take place outside a building and help you determine whether the concentrations of volatile contaminants in the subsurface are high enough to potentially result in unacceptable indoor air levels

3.0 Introduction

If the Preliminary Assessment determines that the potential exists for subsurface volatile contaminants to affect indoor air quality in occupied buildings, then additional VI work is necessary. A Tier 1 evaluation is often the next course of action in the VI evaluation process.

This guidance is structured so that Tier 1 evaluations generally don't collect VI information from inside buildings and instead are based on the presumption that it may be possible to "screen out" VI concerns without building-specific information. By comparison, VI investigations designed to gather indoor samples are referred to as Tier 2 evaluations. See "Distinguishing between Tier 1 and Tier 2 evaluations" below.

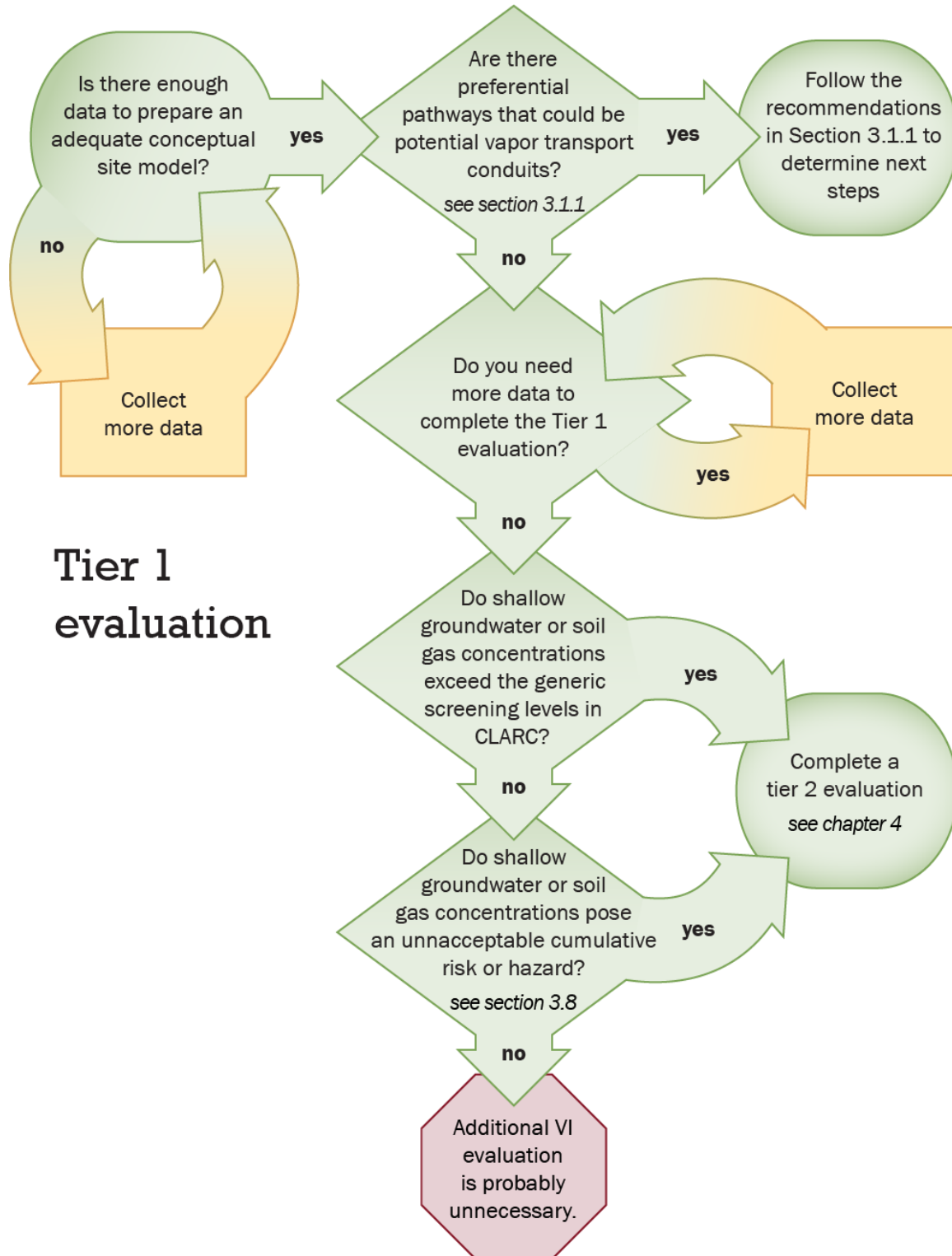
Since Tier 1 evaluations rely on subsurface data, you can use them to assess the potential for VI in existing buildings as well as future structures. This chapter focuses on determining if VI is causing unacceptable indoor air impacts. While many of these recommendations will also apply to a future building's Tier 1 evaluation, Section 3.10 specifically discusses the unique challenges posed by this scenario.

Distinguishing between Tier 1 and Tier 2 evaluations.

Tier 1 evaluations are investigations that take place outside of buildings. Tier 2 are investigations inside of buildings. We make this distinction because when sampling needs to occur inside a building, "Tier 2" signals a more comprehensive approach that includes indoor air, sub-slab, and ambient air sampling. It's also more straightforward to define the scope of effort this way when we're identifying (for example) information that needs to be part of a Sampling and Analysis Plan.

However, there may be situations where a Tier 1 evaluation results in the need to gather Tier 2 related information such as concurrent sub-slab and identifies the need for concurrent sub-slab sampling inside one or more buildings. You can take this approach on a case-specific basis, but additional actions beyond Tier 1 will be needed, including obtaining building access, expanding public involvement, and gathering building-specific information.

Figure 4 summarizes the Tier 1 process. Figure 5 in Chapter 4 summarizes the Tier 2 process.



Tier 1 evaluation

Figure 4: Basic steps for performing a Tier 1 vapor intrusion evaluation.

3.1 Developing the framework for a Tier 1 evaluation

The first step in the Tier 1 process should be to evaluate whether preferential pathways are present that could be potential vapor transport conduits to nearby buildings. These pathways include man-made structures such as sewers, land drains, and utility lines, as well as naturally occurring formations such as Karst or fractured bedrock conditions, or clay deposits with significant vertical fissuring. Evaluate preferential pathways first since they can provide opportunities for vapors to quickly migrate from the subsurface toward or into nearby buildings.

If additional information is needed to complete this evaluation, that should be the primary focus of the data gathering effort. Once this information has been collected, update the Conceptual Site Model since the type of preferential pathway, as well as the associated subsurface conditions, will affect the necessary follow-up actions. The following two sections discuss how preferential pathways should be evaluated.

If vapor migration through preferential pathways is not likely, then the emphasis should be on gathering data that will help determine what further actions (if any) are necessary.

The rest of this section discusses the steps and information typically needed to complete a Tier 1 evaluation.

Step 1: Update the VI conceptual site model. If additional data have been gathered since the Preliminary Assessment was completed, the VI CSM should be revised to account for this information. Review the CSM to identify any critical data gaps that must be addressed.

Step 2: If data gaps exist, prepare a Sampling and Analysis Plan (SAP)/Quality Assurance Project Plan (QAPP). In most cases, this will include collecting additional soil, groundwater, and soil gas samples. Appendix C has a list of items that should generally be part of a SAP and QAPP.

Step 3: Implement the SAP. Collect the specified information and incorporate the results into an updated VI CSM. If data gaps still exist, prepare and implement a second SAP/QAPP to gather missing information.

Step 4: Evaluate the data. Use Sections 3.4 through 3.6 to help evaluate the results from the site investigation. **Note:** While Sections 3.4 (et al.) focus on the primary line of evidence that should be evaluated, Ecology recommends a weight of evidence approach to help ensure a high level of confidence for determining the appropriate next steps.

Step 5: Document the results. Use Section 3.11 to help identify how to compile and present the Tier 1 data.

3.1.1 Preferential pathways

Below are the most frequently encountered preferential pathways and the recommended approach for addressing them:

- Land drains that terminate in close proximity but do not directly connect to a building, or geologic formations with high gas permeability that directly intersect contaminated groundwater or NAPL. When either of these conditions are present, the next step should typically be a Tier 2 evaluation that (at a minimum) includes sub-slab soil gas sampling. Ecology recommends this approach since its unlikely that standard soil gas sampling could quantify the magnitude of the impacts.
- Sewers, utility tunnels or land drains are in close proximity but do not directly intersect the seasonal high water table or vadose zone contamination. In most situations, the next step should be a Tier 1 evaluation to determine if soil gas concentrations are high enough to warrant a Tier 2 evaluation.
- Sewers or utility tunnels intersect contaminated groundwater or NAPL and connect directly to the indoor plumbing of a building. See Section 3.1.2 below for a recommended approach to evaluate this scenario.

3.1.2 Evaluating conduits that connect site contamination directly to a building

If conduits such as sewer lines or utility tunnels directly intersect contaminated groundwater or NAPL, Ecology strongly recommends implementing an alternative approach to the standard VI investigation to evaluate potential indoor air impacts. One option is to use the sampling strategy recommended by McHugh and Beckley²⁴ briefly summarized below. More detailed information along with the supporting references are available on the [U.S. Department of Defense's SERDP-ESTCP website](#).²⁵

McHugh and Beckley recommend beginning the evaluation by collecting vapor samples from the three high risk access points (typically manholes) located within or immediately downstream of the area where the conduit is in contact with the contaminated groundwater or NAPL. Samples should typically collected using a nylon or Teflon tube that can be inserted into the manhole to a point approximately one foot above the bottom of the manhole or one foot above the liquid level, whichever is shallower. Leak testing should be conducted to ensure a representative sample is collected.

The sampling results should be compared to CLARC's VI sub-slab screening levels. If the maximum measured concentrations are below the applicable screening levels, it is unlikely that vapor contributions from the sampled conduit are unacceptably impacting indoor air quality in nearby or downstream buildings.

²⁴ Protocol for Sewer/Utility Tunnel VI Investigations. ESTCP Project ER-201505 (Version 2). November 2018.

²⁵ Strategic Environmental Research and Development Program (SRDP) – Environmental Security Technology Certification Program (ESTCP): <https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201505/ER-201505>

If concentrations are higher than the applicable screening levels, additional samples should be collected at access points both upstream and downstream of the exceedance locations. Sampling should continue until all exceedance locations are bounded by two consecutive locations where the VOC concentrations are less than the screening levels. Tier 2 testing should be performed within all buildings that have lateral connections to the conduit at points where screening levels are exceeded.²⁶

3.2 Applicability of Tier 1 evaluations to petroleum contamination

As discussed in Section 2.5, buildings at petroleum sites that do not screen out using the criteria in Appendix B should generally proceed to a Tier 1 evaluation and follow the provisions in this section (3.2) and Sections 3.4 through 3.6.

While the horizontal and vertical screening distances specified in Appendix B will apply to many petroleum sites, certain conditions—such as vapor migration of volatile petroleum compounds through preferential flow paths or the presence of other precluding factors—may result in higher than expected VOC concentrations in soil gas immediately below a building and/or in indoor air. When these conditions are suspected, the Preliminary Assessment should be directly followed by a Tier 2 evaluation. These conditions often become apparent when developing the VI conceptual site model.

3.3 Applicability of Tier 1 evaluations when TCE is present

Relatively brief exposures to TCE may cause serious health problems to a developing fetus early in pregnancy.²⁷ When VI may be contributing TCE to indoor air and building occupants include women of childbearing age, use Appendix A in conjunction with Chapters 3 and 4. Appendix A addresses Short-term Trichloroethene (TCE) Toxicity and provides indoor air action levels, as well as soil gas and groundwater screening levels that are protective of short-term exposures to TCE.²⁸ Appendix A also provides options for effectively and rapidly responding to those situations where TCE concentrations from VI are above the recommended action levels.

For those buildings where it is very likely that the TCE short-term screening levels are not exceeded in nearby soil gas and/or groundwater, it would be appropriate to complete a Tier 1 evaluation. **However, when TCE may be present in indoor air due to VI and occupants**

²⁶ In those buildings where indoor air sampling is performed, the evaluation strategy must also account for the variability of VI impacts over time.

²⁷ USEPA (2014) Office of Solid Waste and Emergency Response memorandum: Compilation of information relating to early/interim actions at superfund sites and the TCE IRIS assessment.

²⁸ The short-term TCE indoor air action levels, along with the corresponding TCE short-term groundwater and soil gas screening levels, are higher than the long-term cleanup levels in CLARC.

include women of childbearing age, in most cases initiating a Tier 2 evaluation for these buildings should not be delayed.

3.4 Groundwater is the only subsurface VOC source

The following section covers how groundwater VI screening levels were calculated, and how to use the screening levels to determine if VI may pose a potential concern. This discussion assumes that preferential pathways have not been identified as a potential for vapor transport into or in close proximity to existing buildings.

3.4.1 Calculating groundwater VI screening levels

Ecology has established groundwater VI screening levels for approximately 87 individual VOC compounds using Equation 1 below. These screening levels are based on the standard MTCA Method B and C carcinogenic and non-carcinogenic indoor air cleanup levels calculated using procedures in [WAC 173-340-750](#).²⁹ VI cleanup and screening levels are included in the [CLARC VI data tables](#).³⁰

²⁹ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-750>

³⁰ <https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC/Data-tables>

Equation 1: Generic groundwater VI screening levels. The groundwater screening level protective of indoor air is equal to the indoor air cleanup level over the vapor attenuation factor times a unit conversion factor times the Henry's Law constant.

| | |
|---|--|
| Equation 1 (Generic groundwater VI screening levels) | $SL_{GW} = \frac{CUL_{IA}}{VAF * UCF * H_{cc}}$ |
| SL_{GW} | Screening level in groundwater protective of indoor air, $\mu\text{g/L}$ |
| CUL_{IA} | Indoor air cleanup level, $\mu\text{g/m}^3$ |
| VAF | Vapor attenuation factor (VAF; unitless). ³¹ A default value of 0.001 has been used to calculate the groundwater VI screening levels in CLARC. ³² |
| H_{CC} | Henry's Law constant, unitless ³³ |
| UCF | Unit conversion factor, 1000 L/m^3 |

Groundwater screening levels calculated using Equation 1 are not site or building specific. The calculation assumes an attenuation of 1000 times from the concentration of contaminants volatilizing from the groundwater to what is present in indoor air. The default VAF of 0.001 is intended to provide a conservative screening level and was found to be protective for 95% of the buildings in EPA's vapor intrusion database (EPA 2012).³⁴ The default VAF was developed almost exclusively from sampling data for chlorinated compounds and will be an overly conservative prediction of attenuation if there is significant vapor phase aerobic degradation in the vadose zone.

³¹ An attenuation factor is a measure of how soil and building properties limit the intrusion of organic vapors into overlying structures. It is defined as the concentration of the compound in indoor air divided by the concentration in soil gas or groundwater. Chemical concentrations in groundwater will attenuate more than chemicals in soil gas due to the added limitations imposed by mass transfer across the capillary fringe. The larger the attenuation factor, the greater the intrusion of vapors into indoor air.

³² EPA's *Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface sources to indoor air* (June 2015) allows the use of a 0.0005 VAF for sites with laterally extensive layers of fine-grained vadose zone soil. Ecology will consider allowing this lower value on a case-by-case basis.

³³ Henry's Law constants for many VOCs can be found in Ecology's CLARC database or are available from EPA. The constants are temperature dependent. Screening Levels in the CLARC VI data tables have been calculated using Hcc values adjusted to 13°C (Washington's average shallow groundwater temperature).

³⁴ 85% of the buildings in this database were residences, 10% were institutional or commercial buildings, and 5% were "multi-use" (a mixture of residential and non-residential).

3.4.2 Situations where groundwater may not be impacting indoor air

When groundwater contamination near or below a building is the only VI source of concern, the groundwater VI screening levels can be used to determine if the measured concentrations are high enough to potentially cause unacceptable VI impacts in the building.

When contaminated groundwater is the only source of subsurface vapors and the measured concentrations are below their respective groundwater screening levels, it is unlikely indoor air exceedances from VI are occurring. However, before concluding that no further VI assessment is needed for the buildings of concern, it is important to verify that:

1. Groundwater measurements are accurately representing water table contaminant concentrations and when applicable, perched groundwater conditions, as close as possible to the building of concern.³⁵ The highest concentrations from recent sampling events should be compared to the appropriate screening levels;
2. The limitations for using groundwater data for VI screening set out in Section 3.4.3 below are not present; and
3. The cumulative risks from multiple VOCs (discussed in Section 3.8) are acceptably low.

3.4.3 Limitations on using groundwater data for screening

There are a number of site- and building-specific factors that if present, can limit the use of groundwater data for VI screening purposes. Specifically, if one or more of the conditions listed below apply to the site being evaluated, the potential to achieve the amount of attenuation calculated using the default VAF's is unlikely. If one of the following situations occur, Ecology generally recommends collecting Tier 1 soil gas samples (discussed in Section 3.6) or conducting a Tier 2 evaluation (discussed in Chapter 4):

1. Preferential pathways (as discussed in Section 3.1.1) are allowing vapors to quickly migrate toward or into adjacent buildings.
2. The seasonal high water table is very shallow, generally within five feet of the building's lowest floor.
3. The water table varies significantly over time, resulting in a "smear zone" that is significantly contaminated.³⁶

³⁵ This generally requires using short screens (10 feet or less) with a portion of the screen above the water table. Low-flow sampling techniques should be used to minimize VOC loss.

³⁶ While groundwater VI screening levels can be used to estimate the potential effects of the groundwater source, the soil gas concentrations may be higher than expected due to the presence of soil contamination when the smear zone is dewatered.

4. Light non-aqueous phase liquid (LNAPL) is present on top of the water table, which precludes using groundwater screening levels in those particular areas.

3.4.4 Shallow groundwater VOC concentrations exceed screening levels

Further evaluation and/or mitigation is needed if a) groundwater concentrations are above the CLARC VI screening levels and an occupied structure is present within the applicable lateral screening distance, or b) if one or more limitations in Section 3.4.3 apply. Options for next steps include:

1. Expanding the Tier 1 evaluation to include collection of soil gas data (see Section 3.6).
2. Collecting data inside one or more buildings as part of a Tier 2 evaluation (see Chapter 4).
3. Implementing mitigation measures (see Chapter 6).

Even if there are no buildings within the applicable horizontal screening distance, you may need to take additional efforts if a building could be constructed over or near the contaminated groundwater in the future. Section 3.10 provides specific direction for addressing this situation.

3.5 Contaminated vadose zone soil

Ecology's CLARC database does not contain VI screening levels for contaminated soil. When contaminated soil is below or in close proximity to a building, you should typically use soil gas sampling to determine if the applicable screening levels have been exceeded. There are two scenarios where bulk soil sampling data can be used to justify a VI screen-out decision:

1. **If petroleum hydrocarbons are the only VOCs of concern.** The process outlined in Appendix B can help determine whether VI is a potential concern.
2. If the vadose zone has been well characterized and the only VOCs present are not at levels that would be a significant VI source. These levels are defined in WAC 173-340-740(3)(b)(iii)(C)(III) and 173-340-745(5)(b)(iii)(C)(III) to be whenever the concentration is significantly higher than a concentration derived for protection of groundwater for drinking water beneficial use.³⁷

³⁷ The MTCA Cleanup Rule language does not define "significantly higher." Ecology's [Implementation Memo No. 15](#) states that Ecology generally considers benzene and TPH-Gx concentrations less than three times the Method A soil cleanup level for unrestricted land use to not be significant, provided that the selected remedial action results in only limited contaminant mass remaining in the soil. This would need to be assessed on a site-specific basis and will often require soil gas sampling to confirm.

3.6 Using soil gas concentration data

When the subsurface VOC contamination source is vadose zone soils, shallow groundwater, LNAPL, or simply soil gas itself,³⁸ soil gas data are commonly collected to help assess potential VI impacts. For Tier 1 evaluations, Ecology typically recommends using the maximum measured soil gas concentrations associated with each specific sampling location.

There are different reasons for performing soil gas sampling, and the reason will dictate how and where the sampling should occur. For example:

- **When groundwater is contaminated, soil gas samples can be collected from vadose zone soils just above the water table.** These samples are referred to as “near source.” They can be compared to the soil gas screening levels or used to estimate the nature and extent of soil gas contamination in the area of concern. Similarly, soil gas samples can be collected just above vadose zone soil contamination and would also be considered near source.
- **If soil gas samples are collected well above the vadose zone contamination,** the data may provide a better understanding of the three dimensional nature and extent of soil gas contamination. However, when the subsurface contamination includes VOCs resistant to aerobic biodegradation, sampling results typically should not be compared to screening levels for purposes of screening out the VI pathway, due to potential influences from barometric pressure changes or effects from nearby buildings. (This does not apply to results from sub-slab soil gas sampling). For petroleum compounds that degrade quickly in the presence of oxygen, shallow soil gas data can often provide a better indication of the potential for VI impacts.
- **Soil gas can be collected from the vadose zone directly below the building through sub-slab sampling.** Sub-slab soil gas samples require access to the building and are usually collected as part of a Tier 2 evaluation since they are often paired with indoor and ambient air sampling results. Specific information on sub-slab sampling is provided in Chapter 4.

3.6.1 Advantages of near-source soil gas sampling

Sampling soil gas close to the VOC source has at least four advantages:

1. There is the potential for limiting the number of individual samples you will need. For example, if contaminated groundwater is the only VI source, soil gas concentrations just above the water table should not vary significantly over relatively short distances.
2. There is the potential for limiting the number of sampling events. If soil gas samples are collected at depths that are largely unaffected by changes in atmospheric or building

³⁸ At some sites such as drycleaners, there is the potential for a vapor release to the subsurface that only contaminates soil gas, not groundwater or vadose zone soils.

induced pressure changes, the measured soil gas concentrations should not vary significantly over relatively short time intervals.

3. There is no need to access nearby buildings to install sampling probes through the slab.
4. You can use the resulting data for screening purposes regardless of the building's foundation type.

3.6.2 Calculating soil gas screening levels

In order to establish soil gas screening levels, Ecology first developed standard MTCA Method B and C carcinogenic and non-carcinogenic indoor air cleanup levels using the procedures set forth in WAC 173-340-750. Soil gas screening levels were then calculated for 87 individual compounds and three petroleum fractions using Equation 2 below. These cleanup and screening levels are included in the CLARC VI data tables. Equation 2 can also be used for calculating cleanup and screening levels for volatile compounds not included in the CLARC VI data tables.

Equation 2: Generic soil gas VI screening levels. Soil gas screening level that is protective of indoor air is equal to the indoor air cleanup level over the vapor attenuation factor.

| | |
|--|---|
| Equation 2 (Generic soil gas VI screening levels) | $SL_{SG} = \frac{CUL_{IA}}{VAF}$ |
| SL_{SG} | Screening level in soil gas protective of indoor air, $\mu\text{g}/\text{m}^3$ |
| CUL_{IA} | Indoor air cleanup level, $\mu\text{g}/\text{m}^3$ |
| VAF | Vapor attenuation factor (unitless). A default value of 0.03 should be used when SL_{SG} will be compared to a sub-slab or any other soil gas measurements. |

Note no. 1: Ecology no longer provides different VI screening levels for deep and shallow soil gas sampling locations. This is consistent with the recommendations provided by EPA in their June 2015 VI Guidance and should lead to conservative decision making for most situations.

Note no. 2: The soil gas screening levels calculated using Equation 2 are not site or building specific.

3.6.3 Collecting representative soil gas data

When soil gas samples are collected by applying a vacuum, atmospheric or indoor air may inadvertently be collected as well. While there are techniques available to minimize the introduction of air into the samples,³⁹ soil gas sampling protocols should also include using a tracer to help ensure that the vacuum applied to collect the sample was not significant enough to draw in atmospheric air.

Note: In general, the resulting VOC data should not be compared to soil gas screening levels without other lines of evidence, such as sub-slab sampling, before you make a decision to screen out a nearby building. This is because data from soil gas probes would likely underestimate soil gas concentrations immediately below the building. For petroleum compounds that degrade quickly in the presence of oxygen, you can typically locate soil gas probes at shallower depths to determine the amount of aerobic degradation occurring (but the probes shouldn't be located above the lowest point of the closest building).

Other factors that should be considered to help ensure that soil gas samples are representative include:

1. When barometric pressure is high, outside air has the potential to infiltrate the vadose zone, potentially reducing contaminant concentrations in shallow soil gas through dilution. In order to minimize this effect, shallow exterior soil gas sampling should be performed during periods when barometric pressure is and has been decreasing.
2. When indoor air pressure is higher than the pressure below ground, indoor air can migrate through the building floor and potentially dilute sub-slab concentrations. Sampling while a building is depressurized limits this effect.

The two most common methods for collecting soil gas samples for vapor intrusion decision making are Summa canisters (Method TO-15) and sorbent tubes (Method TO-17). Both methods can be used to analyze about 100 compounds. If only a limited number group of contaminants is being evaluated, lower detection limits are possible using Selective Ion-Monitoring Mode (SIM). Other techniques for obtaining soil gas data include using passive samplers and portable GC/MS analyzers. Samples can also be analyzed using Modified Method 8260 for defining areas of higher contamination, where low method detection levels are not needed.

A decision on which approach and method to use should be based on site-specific circumstances such as the contaminants of concern; the reporting limits and quantification certainty needed; sampling locations; and how many samples will be collected. Once sufficient information is available to confirm that the potential spatial and temporal variability of the data

³⁹ See Appendix D

have been adequately accounted for, the highest concentrations from recent sampling events should be compared to the VI screening levels.

Several good sources of information on sampling soil gas were prepared by the California EPA's Department of Toxic Substances Control and are available through their [website](#).⁴⁰

- Advisory – Active Soil Gas Investigations (July 2015)
- Summary of Advisory Changes (2015)
- Frequently Asked Questions (FAQs) (August 2015).

Another good reference is Appendix G of the [ITRC Petroleum Vapor Intrusion Guidance](#)⁴¹ available from their website at <https://itrcweb.org/home>.

Find more references and recommendations for soil gas sampling in Appendix D.

3.6.4 Soil gas may not be impacting indoor air

When soil gas measurements are below the applicable screening levels, it is unlikely indoor air exceedances from VI are occurring. However, before concluding that no further VI assessment is needed for the buildings of concern, it is important to verify that:

1. The data are accurate and representative of conditions at the site.
2. The limitations identified in Section 3.6.5 are not present, and
3. The cumulative risk for multiple contaminants as discussed in Section 3.8 are acceptably low.

3.6.5 Limitations on using soil gas data

Several site and building conditions can limit the use of soil gas data for VI screening purposes. When those conditions exist, Ecology recommends conducting a full Tier 2 evaluation (including indoor and ambient air sampling) as described in Chapter 4.

Conduct a Tier 2 evaluation when one or more of these apply:

1. The water table is very shallow and either contacts or is within several feet of the building foundation.
2. Vadose zone contamination is very shallow and either contacts or is directly adjacent to the building.

⁴⁰ <http://dtsc.ca.gov/vapor-intrusion/>

⁴¹ <https://projects.itrcweb.org/PetroleumVI-Guidance/Content/Resources/PVIPDF.pdf>

3. The potential for soil gas migration through preferential pathways has been confirmed or determined likely. In most situations, soil gas sampling wouldn't provide the necessary information to adequately evaluate potential impacts to indoor air. See Section 3.1.1 for recommended approaches.

3.6.6 Soil gas VOC concentrations exceed screening levels

When soil gas concentrations are above the CLARC screening levels and an occupied structure is present within the applicable lateral screening distance, or if one or more of the conditions in Section 3.6.5 apply, further evaluation and/or mitigation is needed. The options include:

1. Completing a Tier 2 evaluation (Chapter 4), or
2. Implementing mitigation measures (Chapter 6).⁴²

If the impacted property does not contain a building, or if the building is beyond the applicable horizontal screening distance, take additional efforts if a building could be constructed over or near the contaminated soil gas in the future. In these situations, available options include:

1. Collecting and evaluating soil gas data after remedial action has been completed to determine whether the mass of contamination that remains is significant enough to adversely affect future buildings, or
2. The property owner files an environmental covenant (if approved by Ecology) requiring that Ecology be contacted before any future building construction takes place on the impacted area.

For situations where soil gas has only been sampled at depth, it may be possible to collect additional samples at various depths between the initial sample and the building to better determine the actual degree of attenuation occurring in the vadose zone. This approach would typically apply at sites where the only contaminants of concern are petroleum hydrocarbons. All soil gas data, along with any other lines of evidence, should be evaluated before deciding on a future course of action.

If the Tier 1 evaluation concludes that VOC concentrations would only pose a VI threat if the use of an existing building changes, then an environmental covenant could help ensure the land use doesn't change without additional evaluation and notifying Ecology. This may result in additional sampling or remedial action to ensure that indoor receptors remain protected in the future.

⁴² As discussed in Chapter 2, a decision to preemptively mitigate a building can be reached at any point in the VI evaluation process. If it becomes apparent that shallow groundwater or soil gas concentrations near a building are very high, implementing mitigation measures can help protect residents and workers as soon as possible and potentially reduce investigation costs.

3.7 Factors affecting the number of samples and sampling events necessary

Tier 1 evaluations are based on the presumption that it may be possible to screen out the VI pathway without sampling inside a building. Groundwater and/or soil gas data are compared to VI screening levels to determine if subsurface VOC levels are low enough to prevent unacceptable VI impacts. For many sites, multiple soil and groundwater sampling events are often completed before initiating a VI assessment. In some cases, these data may be sufficient to complete a Tier 1 evaluation. However, Ecology cannot recommend a specific minimum number of samples and sampling rounds necessary to screen out VI, since numerous factors can affect this decision, such as media to be sampled and the site/building characteristics.

Two of the biggest factors are the spatial and temporal variability of the subsurface contamination. Tier 1 sampling plans need to address these variabilities in order to determine whether indoor air concentrations from VI potentially exceed the applicable cleanup levels. The rest of this section provides general information that should be considered to help determine the number of samples and sampling events necessary.

3.7.1 Spatial variability

In order to use shallow groundwater sampling results to evaluate the potential for VI, the investigation must adequately define the degree and extent of contamination. Obtain a conservative assessment by comparing a) the highest values measured in close proximity to any buildings of concern to b) the applicable screening levels.

Most Tier 1 evaluations will rely on exterior soil gas sampling to determine the potential for VI. Since variability in sampling results increases as the distance from the source increases, near-source sampling should be used to provide a conservative estimate of soil gas concentrations. However, near-source sampling may not be appropriate for compounds that aerobically degrade, such as petroleum. If the applicable near-source soil gas screening levels are exceeded, a sufficient number of samples are needed that accurately represent the variability in concentrations near the buildings of concern. If sub-slab sampling will be performed, collect enough samples to determine the variability across the building footprint.

3.7.2 Temporal variability

Ensure that the number and frequency of shallow groundwater and near-source soil gas sampling events are enough to determine near maximum concentrations. If the VI source is contaminated groundwater, the number and frequency of soil gas sampling events can be similar to the number for determining groundwater temporal variability.

Sub-slab VOC concentrations can vary significantly over time, most commonly due to changes in differential pressure between the lowest building floor and the soil gas beneath the slab. Since greater VI impacts typically occur when building pressure is lower than sub-slab pressures, design the Tier 1 sampling plans to collect samples during this period, and plan to

measure differential pressures across the slab to document that vapor flow is towards the building.

3.8 Multiple VOCs

When multiple VOCs are present below their respective screening levels, the cumulative risk also needs to be considered before concluding that VI does not pose a concern. Situations that should be considered are summarized below. If the maximum risk levels for any of these scenarios are exceeded, cleanup levels must be adjusted downward using the provisions in WAC 173-340-708.

Cumulative Risk Situations

- The individual Method B carcinogenic VI screening levels for groundwater and soil gas in the CLARC data tables are based on air cleanup levels set to an excess cancer risk of one in one million (1E-6, also known as 1×10^{-6}). If more than 10 carcinogenic compounds are present, determine the total excess cancer risk to ensure it does not exceed one in one hundred thousand (1E-5 also known as 1×10^{-5}).
- The individual Method C carcinogenic VI screening levels for groundwater and soil gas are based on air cleanup levels set to an excess cancer risk of one in one hundred thousand (1E-5). If multiple carcinogenic compounds are present, determine the total excess cancer risk to ensure it does not exceed 1E-5.
- For non-carcinogenic compounds, the individual Method B and C non-carcinogenic VI screening levels for soil gas in CLARC are based on air cleanup levels set to a hazard quotient (HQ) of 1.0. If multiple non-carcinogenic compounds are present, calculate the hazard index (HI) to ensure it does not exceed 1.

Note: The last scenario is most likely to occur with petroleum compounds. Appendix E includes several options to account for the cumulative effects of these compounds. Specifically, it provides TPH screening levels that account for the additive effects of the non-carcinogenic petroleum compounds present.

3.9 Use of predictive modeling

Predictive VI models can estimate indoor air concentrations based on site-specific information such as geology, building configuration, contaminant types, and groundwater or soil gas concentrations. While predictive modeling provides another line of evidence when evaluating the potential for VI, models should not be used as the sole method to support a “screen-out” determination. This is consistent with EPA’s 2015 VI guidance documents and more recent guidance issued by several states.

If a site is only impacted by petroleum compounds, a model that accounts for aerobic biodegradation such as BioVapor or PVI-Screen can be used. Provide documentation on why a specific model was selected and identification of all inputted values in the Tier 1 report.

3.10 Future building construction

Tier 1 evaluations focus primarily on whether VI could potentially impact nearby buildings. However, there may be situations where a building could be constructed in the future within a portion of the site currently undeveloped. Chapter 7 discusses this scenario, since the extent of the evaluation needed depends on the scope of the cleanup completed.

3.11 Documenting the results of a Tier 1 evaluation

Upon completing a Tier 1 evaluation, summarize the results in a report that meets the requirements outlined in WAC 173-340-840. The report should typically contain:

1. A statement of the purpose and objectives of the evaluation.
2. The address(es) of properties evaluated, along with names and addresses of the individual property owners.
3. A VI conceptual site model that includes:
 - a. A plan view drawing showing the spatial relationship of nearby buildings to the VOC contamination, including the location of any sewers, utility tunnels, or land drains. If groundwater is the source, include flow directions and iso-concentration contours for the VOCs of concern.
 - b. Cross-sectional views that identify how deep the water table is, the location of all potential VI sources, any perched saturated zones, the vadose zone strata, and any NAPL known to be present. Include the location of any sewers, utility tunnels, or land drains. Indicate ceiling heights and foundation depths for all buildings of concern, if available.
 - c. A narrative section that discusses the figures mentioned above and provides explanations for any critical assumptions made in depicting site conditions. The

discussion should describe the source of the VOC contamination, including estimates of the age and amount of mass released.

4. A list of all VOCs of concern along with:
 - a. Method B or C air cleanup levels.
 - b. Soil gas and/or groundwater screening levels.
 - c. Both the short-term indoor air action levels and associated soil gas/groundwater screening levels, if TCE is a VOC of concern.
5. A description of the sampling events including:
 - a. The type and location of the collected samples.
 - b. Other measurements or observations,
 - c. Meteorological conditions during each of the sampling events.
 - d. The analytical methods used.
 - e. All exceedances of the applicable screening or cleanup levels.
 - f. Any deviations from the SAP and why those changes were necessary.
6. A summary of the QA/QC efforts implemented, including how the data were reviewed and validated.
7. A discussion of the analytical reporting limits achieved for all VOC analytes.
8. The success of the VI investigation in addressing any identified data gaps.
9. An assessment of the potential for unacceptable VI impacts.
10. Conclusions and recommendations for next steps.
11. A schedule for performing any necessary follow-up work.
12. Maps, figures, drawings, and color photographs of all locations where data were collected, and tables provide information from each sampling or measurement point including:
 - a. Identification number.
 - b. Date and time.
 - c. Information collected.
 - d. Results for each medium with reporting limits shown for all non-detected VOCs.
 - e. Applicable screening levels for all VOCs of concern.
13. Appendices with all necessary supporting documentation including:
 - a. Boring logs.
 - b. As-built drawings of all wells and vapor probes.
 - c. Chain of custody forms.
 - d. Laboratory reports.
 - e. Data validation information.
 - f. Meteorological data such as ambient temperatures and barometric pressures.

- g. Literature citations and references, if not provided in the report.
- h. Any calculations performed such as those to derive building-specific screening levels or cumulative risk when multiple contaminants are present.

Note: If sub-slab sampling was conducted as part of the Tier 1 evaluation, you should include building- specific information, such as whether a vapor barrier is beneath the bottom floor or whether there are obvious preferential pathways present such as floor drains, utility penetrations, elevator shafts, interior pits, or sumps.

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Chapter 4: Tier 2 VI Evaluations

Tier 2 evaluations take place inside buildings and help determine if concentrations of VOCs from vapor intrusion in indoor air exceed applicable cleanup levels.

4.0 Introduction

Tier 2 evaluations are designed to determine whether vapor intrusion is causing unacceptably high levels of contaminants in indoor air. A Tier 2 should be implemented whenever any of these situations apply:

- The Preliminary Assessment concludes that groundwater and/or soil gas concentrations near a building are very likely to exceed the Tier 1 VI screening levels.
- The Preliminary Assessment concludes that TCE contamination of soil or groundwater is in close proximity to buildings where occupants include women of childbearing age.
- Site or building conditions such as preferential flow paths disqualify the use of Tier 1 screening levels for making building-specific screen out decisions.
- A Tier 1 evaluation concludes that groundwater and/or soil gas VOC concentrations near a building exceed VI screening levels.

An important objective of a Tier 2 evaluation is to estimate the amount of indoor air contamination caused exclusively by vapor intrusion. Indoor air quality is almost always affected by household products or other indoor sources and in some cases from ambient sources. As a result, it usually won't be sufficient to measure just VOC concentrations in indoor air. Whenever possible, indoor air sampling should be preceded by removing potential indoor sources, and then subsequently coupled with measuring sub-slab soil gas (or crawl space air) and upwind ambient air.⁴³

The conclusions of a Tier 2 evaluation are building specific and will likely depend on how the building is laid out and constructed; heated and ventilated; and currently occupied and being used. If these conditions change in the future, you may need to revisit the Tier 2 conclusions.

⁴³ For purposes of this guidance, "ambient air" means outdoor air, but does not include the air within a building's crawl space.

4.1 Developing the framework for a Tier 2 evaluation

As summarized in Figure 5, the first steps of the Tier 2 process are:

Step 1: Update the VI conceptual site model and identify critical data gaps that must be addressed. Provide information about each building that needs further evaluation, including descriptions of:

- a. Likely routes and mechanisms by which VI could impact indoor air quality.
- b. Type and use of the building, number of floors and foundation (e.g. slab on grade, basement or crawl space) and any changes in foundation or floor levels across the building footprint.
- c. Any significant building features such as elevators, attached garages, existing vapor barriers, or parking structures.
- d. Obvious preferential pathways for vapor migration toward or into the structure, including interior sumps, earthen floors, unconnected floor drains, or utility line penetrations.
- e. Method for heating and ventilating the building. If the information is available, include a drawing that shows where air enters, is mechanically moved through then exhausted from the building. Identify any rooms where the pressure exceeds atmospheric when the HVAC system is operating. Include exhaust fans and vent hoods.

Note: This type of information is typically collected during pre-sampling visits. For a detailed description of VI conceptual site models and their uses, see Chapter 2 in EPA's 2015 VI guidance: [Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface vapor sources to indoor air](https://www.epa.gov/vaporintrusion/technical-guide-assessing-and-mitigating-vapor-intrusion-pathway-from-subsurface-vapor-sources-to-indoor-air).⁴⁴

Step 2: Gather additional data to determine if impacts to indoor air are unacceptable.

This process is building-specific and since building access will be needed, develop a plan for interacting with owners/tenants and occupants. Chapter 5 provides details for public involvement actions that will often be necessary.

Step 3: Notify building owners and tenants that indoor access is needed to inspect the building and perform sampling. This can be done by phone or e-mail, but send a

⁴⁴ <https://www.epa.gov/vaporintrusion/technical-guide-assessing-and-mitigating-vapor-intrusion-pathway-from-subsurface-vapor>

follow-up letter to formally document the request. Provide a copy of the proposed access agreement to the building owner for review. The agreement should identify the inspection and investigation tasks that will be conducted.

Step 4: Upon receipt of the signed access agreement, perform pre-sampling visits to obtain building and property specific information needed to create a comprehensive sampling and analysis plan. This should include an evaluation of whether there are any chemicals present that could affect the indoor air sampling results. See Section 4.6 for more details.

Step 5: Prepare a Sampling and Analysis Plan (SAP)/Quality Assurance Project Plan (QAPP). See Appendix C for a list of items that are typically included in a SAP and QAPP.

Tier 2 evaluation

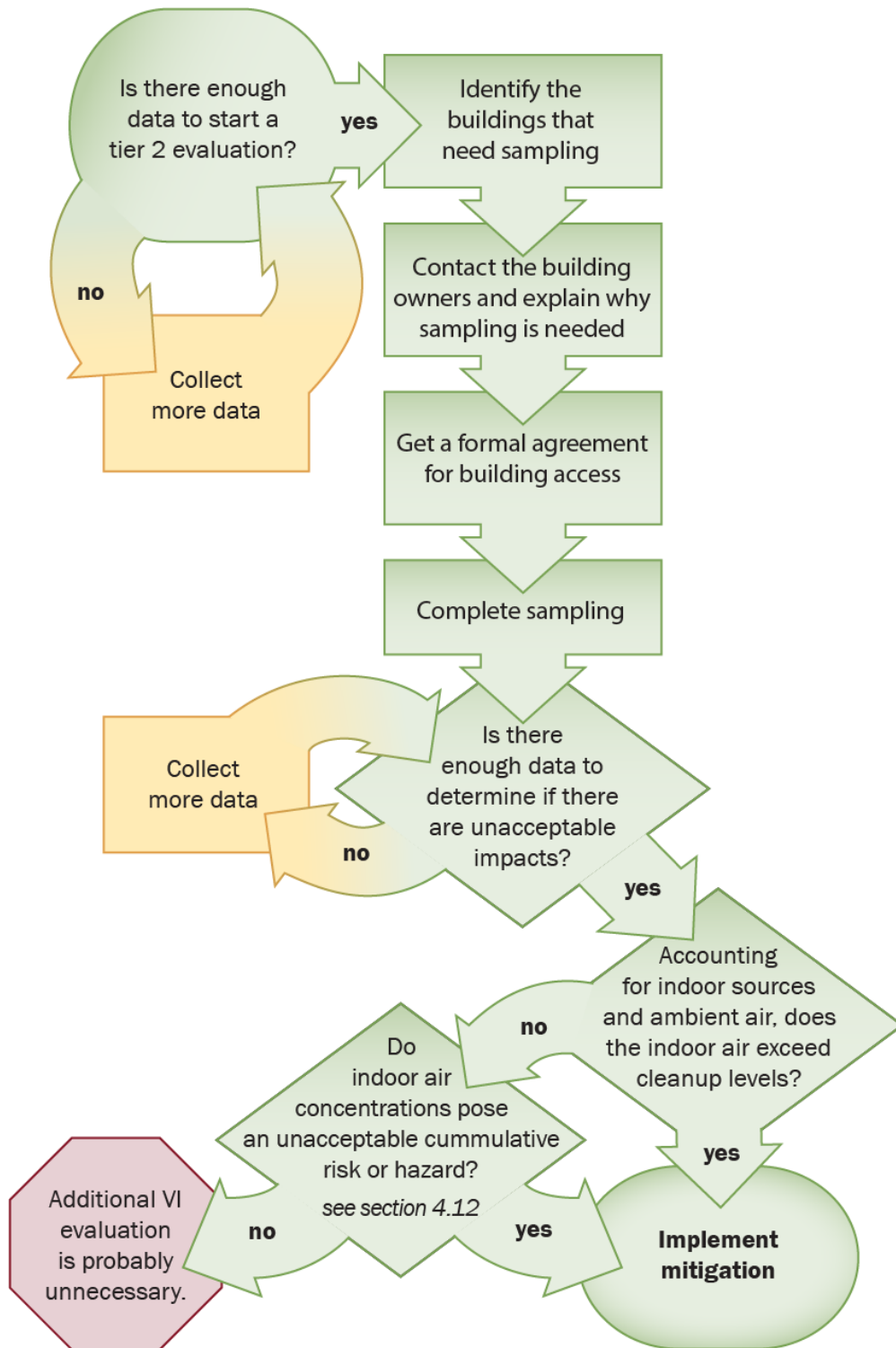


Figure 5: Basic steps for the Tier 2 assessment process.

4.2 Applicability of Tier 2 evaluations to petroleum contamination

As discussed in Section 3.2, when potential VI impacts cannot be screened out for buildings at petroleum sites using the criteria in Appendix B, further evaluation is needed. This will typically occur when preferential flow paths or other precluding factors have been identified and result in the need for a Tier 2 evaluation.

4.3 Applicability of Tier 2 evaluations when TCE is present

When a Tier 2 evaluation is determined to be necessary and TCE is a compound of concern, use Appendix A to help assess the VI pathway. The Appendix provides short-term indoor air TCE action levels and options for rapidly responding to situations where TCE concentrations from VI exceed these levels.

4.4 Indoor air VI cleanup and screening levels

As noted in Chapter 3, Ecology has established standard Method B (unrestricted indoor exposure) and Method C (industrial exposure) carcinogenic and non-carcinogenic indoor air cleanup levels using the procedures in WAC 173-340-750.⁴⁵ Find these VI cleanup levels in the [CLARC data tables](#).⁴⁶ Concentrations in indoor air solely from VI can be considered acceptable if the:

- Individual concentrations are below their respective cleanup levels,⁴⁷ and
- Cumulative risks and hazards are below the levels specified in Section 4.12.

Industrial exposures are limited to the specific scenarios defined by WAC 173-340-200 and -745. Unless a building meets the requirement for traditional industrial use, applicable indoor air cleanup levels are based on unrestricted exposure and determined by the Method B equations. Method B VI indoor air cleanup levels assume that receptors include children and are always present.

⁴⁵ When evaluating the potential for VI, use the cleanup levels in the CLARC data tables rather than EPA's risk levels. CLARC uses reference doses and carcinogenic potency factors, whereas EPA uses reference concentrations and unit risk factors. This means that Ecology's indoor air cleanup levels and the resulting soil gas and groundwater screening levels are different from EPA's levels.

⁴⁶ <https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC/Data-tables>

⁴⁷ TCE also has "short-term action levels" that should not be exceeded. See Section 4.3.

It may be possible to develop “risk-based indoor air levels” for commercial buildings that do not meet the definition of an industrial property but where only adult workers are present. In this situation, the default exposure assumptions could be adjusted as follows:

1. For non-carcinogenic cleanup levels, change the average body weight from 16 kg (representing a child) to 70 kg (representing an adult) and increase the breathing rate from 10 m³/day to 20 m³/day.
2. Modify the exposure frequency to better represent the amount of time workers are actually present (e.g. 45 hours/week x 50 weeks/year = 0.26 vs. a default of 1.0). This provision applies to both the cancer and non-cancer pathways.

Note: While Ecology anticipates the standard work week will often be 45 hours, it may be possible to justify a lower number on a case-specific basis.

Allowing for residential use: Risk-based indoor air levels in a commercial building are intended to be protective of existing workers, but since these levels are not cleanup levels, additional remediation would be necessary to allow for residential use. If the applicable cleanup levels for unrestricted use cannot be met, an institutional control would be needed to ensure long-term protectiveness.

4.5 Indoor air sampling events

Indoor air sampling data should be compared to applicable cleanup levels in CLARC. The analyte list should include those VOCs detected in the subsurface that would most likely be expected to impact the building(s) being evaluated. The indoor air results should represent:

- Only the VI contribution to the measured concentrations,
- Those parts of the building where occupants spend a significant amount of time, and
- The average concentration caused by VI over an extended period of time.⁴⁸

There are multiple options for obtaining indoor air measurements. The methods may serve different purposes and are sometimes combined to meet the overall needs of the VI evaluation. Below is a brief summary of the most common methods.. All of them have the capability to achieve accurate data at or below the applicable indoor air cleanup levels, but training is necessary to obtain high quality results.

- **Six-liter evacuated canisters** with Method TO-15 analysis provide average concentrations over the collection period which typically ranges from 8 to 24 hours. However, canisters can now be used to collect samples over several days and work is on-going to develop new longer term devices.

⁴⁸ Since the true average concentration of any contaminant over the long-term is unknown, a conservative approach should be used to estimate these values. More discussion on this topic is presented throughout this chapter.

- **Active sampling onto sorbent tubes** using a pump to draw a constant flow of air through the device. Samples are analyzed using Method TO-17 and typically use collection periods of no longer than 24 hours.
- **Passive air samplers** are generally used to provide long-term time integrated data, usually in the range of 2 to 3 weeks. They are typically not the best approach for uncharacterized sites since they cover a more narrow range of contaminants.
- **For more information on the use and accuracy of these devices see:**
 - a. McAlary, T., Wang, X., Unger, A., Groenevelt, H., Gorecki, T. (2014). *Quantitative passive soil vapor sampling for VOCs - part 1: Theory*. Environmental Science: Processes & Impacts, 16:482-490.
<http://dx.doi.org/10.1039/c3em00652b>
 - b. McAlary, T., Hester Groenevelt, Suresh Seethapathy, Paolo Sacco, Derrick Crump, Michael Tuday, Brian Schumacher, Heidi Hayes, Paul Johnson and Tadeusz Górecki. (2014). *Quantitative passive soil vapor sampling for VOCs- part 2: laboratory experiments*. Environmental Science: Processes Impacts, 16, 491-500. Retrieved from:
<https://pubs.rsc.org/en/journals/journalissues/em#!recentarticles&adv>
 - c. McAlary, T., [Hester Groenevelt](#), [Paul Nicholson](#), [Suresh Seethapathy](#), [Paolo Sacco](#), [Derrick Crump](#), [Michael Tuday](#), [Heidi Hayes](#), Brian Schumacher, [Paul Johnson](#), [Tadeusz Górecki](#) and [Ignacio Rivera-Duarte](#). (2014). *Quantitative passive soil vapor sampling for VOCs- part 3: field experiments*. Environmental Science: Processes Impacts, 16, 501-510
 - d. McAlary, T., Hester Groenevelt, Suresh Seethapathy, Paolo Sacco, Derrick Crump, Michael Tuday, Brian Schumacher, Heidi Hayes, Paul Johnson, [Louise Parker](#) and [Tadeusz Górecki](#). *Quantitative passive soil vapor sampling for VOCs – part 4: flow-through cell*. Environmental Science: Processes Impacts, 16, 1103-1111
 - e. McAlary, T., [Hester Groenevelt](#), [Stephen Disher](#), [Jason Arnold](#), [Suresh Seethapathy](#), [Paolo Sacco](#), Derrick Crump, Brian Schumacher, Heidi Hayes, [Paul Johnson](#) and [Tadeusz Górecki](#). (2015). *Passive sampling for volatile organic compounds in indoor air-controlled laboratory comparison of four sampler types*. Environmental Science: Processes Impacts, 17, 896-905
 - f. McHugh, T., Per Loll and Bart Eklund. (2017). *Recent advances in vapor intrusion site investigations*. Journal of Environmental Management 204(2), 783-792.
<https://www.sciencedirect.com/science/article/pii/S0301479717301196?via%3Dihub>
 - g. NAVFAC. (2015). *Passive sampling for vapor intrusion assessment*. Technical Memorandum TM-NAVFAC EXWC-EV-1503. Naval Facilities Engineering Command, Engineering and Expeditionary Warfare Center. Prepared for NAVFAC EXWC-EV by Dawson, H., McAlary, T., and Groenevelt, H., Geosyntec.

Retrieved from: <https://clu-in.org/download/issues/vi/VI-passive-sampling-EXWC-EV-1503.pdf>

- h. USEPA. (2014). Passive samplers for investigations of air quality: Method description, implementation, and comparison to alternative sampling methods. (EPA 600-R-14-434). Washington, DC: United States Environmental Protection Service, Engineering Technical Support Center. <http://nepis.epa.gov/Adobe/PDF/P100MK4Z.pdf>
- **Portable GC/MS instruments** have the advantage of being able to measure VOC concentrations in the field quickly and at a number of different locations within the building. These devices can help identify VOC-emitting indoor sources as well as pathways that allow preferential migration of vapors.
 - **Continuous automated real-time indoor air monitoring systems** are available from a limited number of providers. These systems are often deployed over several days and can provide information on the changes in VOC levels over very short time periods in multiple locations throughout a building. Since significant temporal variability of contaminant concentrations in indoor air can occur over relatively short periods of time, consideration should be given to collecting continuous samples in order to better assess the maximum influence of vapor intrusion. The Naval Facilities Engineering System Command (NAVFAC) fact sheet on Continuous Monitoring for Vapor intrusion provides a good summary of this technique. The fact sheet is available at: https://www.navfac.navy.mil/content/dam/navfac/Specialty%20Centers/Engineering%20and%20Expeditionary%20Warfare%20Center/Environmental/Restoration/er_pdfs/d/ContinuousMonitoring_FactSheet.pdf [copy link into browser]

Since many factors will dictate which equipment and methods will be most effective, this guidance does not offer specific recommendations for which equipment to use when collecting indoor samples or which method(s) for analyzing them. Those decisions will be based on the goals of your sampling effort, how you will use the data, the contaminants of concern, the required reporting limits, the duration of the sampling period, and the urgency of obtaining data.

The following guidance documents offer detailed discussions on indoor air sampling and factors to consider when selecting an indoor air sampling option:

- Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response, *Technical Guidance Manual, Section 7, Soil Vapor and Indoor Air Sampling Guidance, Interim Final – December 2017*. Retrieved from: <https://health.hawaii.gov/heer/tgm/>
- ITRC. (2014). *Petroleum Vapor Intrusion: fundamentals of screening, investigation, and management*. Washington, D.C.: Interstate Technology Regulatory Council, Vapor Intrusion Team. Retrieved from: <https://projects.itrcweb.org/PetroleumVI-Guidance/> [copy link into browser]
- Massachusetts Department of Environmental Protection. (2016). *Vapor Intrusion Guidance – Site Assessment, Mitigation and Closure, Appendix III, Section III.B*. Retrieved from: <https://www.mass.gov/files/documents/2016/10/nu/vapor-intrusion-guidance-10-14-2016.pdf>

- USDOD. (2019). Vapor Intrusion Handbook Fact Sheet No: 007, Matrix for Selecting Vapor Intrusion Investigation Technologies.
- New Jersey Department of Environmental Protection, Site Remediation and Waste Management Program. (2018). *Vapor Intrusion Technical Guidance*, Version 4.1. Retrieved from: <https://www.nj.gov/dep/srp/guidance/vaporintrusion>

4.5.1 Accounting for temporal variability

A greater degree of vapor intrusion is likely to take place when the interior pressure is less than the pressure immediately below and adjacent to the building, due to advective soil gas flow. Building depressurization typically occurs when outdoor temperatures are considerably lower than interior temperatures.

It will often be necessary to conduct multiple sampling events to determine potential worst case effects from VI. Two options for achieving the necessary conditions are:

1. Schedule sampling during periods when outdoor temperatures are falling and at least 30° F lower than indoor temperatures. This often coincides with the outdoor to indoor exchange rate being relatively low, or
2. Mechanically create negative pressure within the building that approximates the maximum subsurface to indoor air pressure differential.



Figure 6: Six-liter Summa canister

For more information about implementing and monitoring mechanical depressurization:

- Holton, C., Guo, Y., Luo, H., Dahlen, P., Gorder, K., Dettenmaier, E., and Johnson, P.C. (2015). *Long-term evaluation of the controlled pressure method for assessment of the vapor intrusion pathway*. *Environmental Science & Technology*. 49 (4): 2091–2098. doi 10.1021/es5052342. Retrieved from: <https://pubs.acs.org/doi/abs/10.1021/es5052342>
- McHugh, T., Beckley, L., Bailey, D., Gorder, K., Dettenmaier, E., Rivera-Duarte, I., Brock, S., and McGregor, I. (2012). *Evaluation of vapor intrusion using controlled building pressure*. *Environmental Science & Technology*. 46(9): 4792–4799. doi 10.1021/es204483g. Retrieved from: <https://pubs.acs.org/doi/10.1021/es204483g>
- Johnson, P.C., Holton, C., Guo, Y., Dahlen, P., Luo, H., Gorder, K., Dettenmaier, E., and Hinchee, R.E. (2016.) *Integrated field-scale, lab-scale, and modeling studies for improving our ability to assess the groundwater to indoor air pathway at chlorinated solvent-impacted groundwater sites*. (SERDP Project ER-1686). Rosslyn, VA: Department of Defense, Strategic Environmental Research and Development Program (SERDP). Retrieved from: <https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-1686/ER-1686>

- USDOD. (2017). *Use of building pressure cycling in vapor intrusion assessment*. (DoD Vapor Intrusion Handbook Fact Sheet Update No: 004). Washington, D.C.: U.S. Department of Defense, Environment, Safety and Occupational Health Network and Information Exchange. Retrieved from: <https://www.denix.osd.mil/irp/vaporintrusion/unassigned/fact-sheet-building-pressurecycling/> and <https://www.denix.osd.mil/>

Pressure differentials between indoor and subsurface air should be measured with micro-manometers, pressure transducers, and/or data loggers to help confirm the sampling is being conducted when the pressure gradient favors soil gas movement into the building.

While building depressurization is typically conducive to higher vapor migration rates and may overestimate the true long-term average concentration, VI impacts can also be influenced by a number of variables that may not always correlate with the periods when building depressurization occurs. For example, VI impacts on indoor air can be influenced by the magnitude of VOC concentrations entering the building, where the vapors enter, and how much dilution takes place. Since VI impacts can vary significantly over short timeframes and the number of sampling events are often limited, the goal should be to obtain measurements that provide a conservative estimate of the long-term average.

4.5.2 Accounting for spatial variability

Vapor intrusion impacts can also vary spatially within a building. Usually VI impacts on the lower floors, in particular the spaces located below grade, are slightly greater than impacts on the upper floors. Typically, sampling should target the lower floors where occupants spend a significant amount of time, where soil gas may preferentially enter and/or where lower outdoor-to-indoor air exchange rates are expected. However, in the case of multi-story buildings with elevator shafts, samples may also need to be collected on upper floors. Samples should be obtained at heights that correspond to the typical breathing zone for receptors in these areas.

Indoor air measurements can also be obtained for purposes other than comparing the concentrations to an indoor cleanup or mitigation level. For example, the evaluation may also be designed to determine if vapors are preferentially entering a building, or to pinpoint indoor sources of VOC emissions. In these cases, the Sampling and Analysis Plan should clearly describe the purpose of the measurements and how they will be obtained.

4.6 Non VI sources of indoor air contamination

Determining the VI contribution to any measured contamination in the building is complicated by the presence of other sources of indoor air contaminants. These are referred to as “background” and are typically either contaminants in ambient air or sources from inside the building. The latter category includes products containing VOCs stored or used indoors, such as paint strippers, cleaning solvents, and gasoline. The category also includes building materials such as carpets, furniture, and finished interiors.⁴⁹

If background sources of the contaminants of concern are not accurately accounted for, the applicable indoor air cleanup levels will often be exceeded without a significant VI contribution. This could result in unnecessary mitigation and costs for a system generally unable to reduce indoor air VOC concentrations to target levels.

4.6.1 VOC sources inside the building

Background concentrations of VOCs from indoor sources can be a significant confounding factor in determining how much impact, if any, subsurface contamination sources are having on indoor VOC levels. In most situations, people won’t attempt to estimate these contributions due to the inherent difficulties quantifying the actual amounts. Instead, they will usually focus on identifying potential sources, then minimizing the sources’ influence prior to sampling. The most common approach is to inventory all products and materials in the building that could potentially contribute the same chemicals to indoor air as those being assessed during the VI evaluation.⁵⁰ VOC-emitting materials identified in the building “walk through” (described earlier in this chapter) should be removed at least one week prior to sampling.

It may be beneficial to use portable field sampling devices such as a “Frog,” “Hapsite,” ppbRAE photoionization detector, or similar instrument to help identify indoor air sources. These have the potential to identify household or business items that may not be obvious sources of VOC. These devices can be used during the pre-sampling building “walk through,” or after potential contaminant sources have been removed.

Although pre-sampling practices such as these are standard, it can be difficult to identify all indoor VOC sources—and in some cases, not every potential VOC source can be removed or effectively isolated before sampling. Additionally, it isn’t always possible to control the behavior of building occupants. This necessitates combining indoor air sampling with sub-slab soil gas sampling and other assessment techniques to help determine whether the measured indoor air concentrations are due primarily to VI or to an indoor source.

⁴⁹ See EPA’s 2011 report, “Background indoor air concentrations of VOC’s in North American residences (1990-2015): A compilation of statistics for assessment of vapor intrusion.”

⁵⁰ The New York State Department of Health has a fact sheet identifying a number of household products that can potentially impact indoor air quality and the compounds those products can contain (<https://www.health.ny.gov/publications/6513.pdf>). Other sources of information include National Institute of Health’s Household Products database (<https://hpd.nlm.nih.gov/>) and Appendix L in ITRC’s Petroleum VI Guidance dated October 2014 (<http://www.itrcweb.org/Guidance/ListDocuments?TopicID=28&SubTopicID=48>).

Indoor air contamination caused by the commercial or industrial use of VOCs can pose challenges to a VI evaluation when the chemicals are the same substances found in soil gas contamination beneath the building. As discussed in Chapter 1, situations like these may make it impossible to fully evaluate VI's contribution to indoor air contamination. However, if there are subsurface VOCs not associated with indoor sources, measuring the indoor air and soil gas concentrations of these non-workplace VOCs can provide an indication of likely VI impacts.

Note: The background concentrations of certain VOCs in indoor air such as benzene, naphthalene, and TCE may be higher than ambient air levels, and higher than the established indoor air cleanup level, without any significant VI contribution. This can be the case even when you've located all obvious sources of indoor emissions and removed or isolated them prior to sampling. Even if these contaminants are present in the subsurface, the difference between a higher indoor concentration and a lower ambient contribution may not always be due to VI. When addressing situations like these, you may find indoor air background data and information helpful, such as EPA's 2011 *"Background indoor air concentrations of VOC's in North American residences (1990-2015): A compilation of statistics for assessment of vapor intrusion."*

4.6.2 VOC contributions from ambient air

When undertaking a Tier 2 evaluation, building-specific ambient air sampling should routinely accompany indoor air sampling events. One situation that may need to be considered when assessing ambient air is the contribution from an on-site remediation or mitigation system that emits VOCs to the atmosphere. In most cases, a VI evaluation would be completed before implementing a remedial action and often before a mitigation system is in place. The contaminants these systems discharge to the atmosphere would not be considered "background" and would need to be managed to prevent emissions from entering the building's outdoor air intake points and recirculating into the indoor air.

4.7 Measuring ambient air VOC concentrations

The purpose of ambient air sampling during a Tier 2 VI evaluation is to estimate how much ambient air is contributing to the measured indoor air concentrations. The purpose is not to characterize ambient air contamination, define background concentrations in accordance with WAC 173-340-709, or estimate likely points of exposure. Ambient air samples should be collected and analyzed using procedures similar to those for indoor air sampling.⁵¹

This guidance does not provide detailed recommendations on what equipment to use for collecting ambient air samples, or which methods to use for analyzing samples. For help finding options, see references in Section 4.5.

When you are conducting ambient air sampling, Ecology recommends locating the sampling device(s):

1. Upwind of the building's outdoor air intake points. Assess local on-line meteorological resources and field observations the day of sampling to obtain the predominant wind direction and determine sampling locations.
2. Near the building but far enough away so that VOC emissions from the building do not influence the samples.
3. Approximately 2 to 3 meters above the ground surface. If the building has an HVAC system with the air intake on the roof, this can be an appropriate ambient air sampling location. The sample inlet should correspond to the height of the building's air intake, upwind of any rooftop exhaust vents, and where there are no obstructions to normal airflow or to flow between the sampler and the building. Similarly, there should be no obstructions to normal air flow between sampling stations on the roof and the building's outdoor air intake point.
4. Away from local point sources of VOC emissions.

⁵¹ EPA's June 2015 guidance, *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*, generally recommends beginning ambient air sampling at least one hour and preferably two hours before indoor air monitoring begins, then continuing to sample until at least 30 minutes before indoor monitoring is complete. EPA recommends this approach because most residential buildings have between 0.25 to 1.0 exchanges per hour, which could impact indoor air. While a small offset in sampling times may have some merit, in practice it may be difficult or inconvenient to implement this approach. In most cases, an off-set to the start times for ambient air sampling isn't necessary unless there is information to suggest that ambient air concentrations vary significantly over very short timeframes.

If the results of the measured ambient air sampling accurately represent the VOC contribution to indoor air, it is reasonable to calculate indoor air concentrations due to VI by:

$$C_{ia-vi} = C_{ia-m} - C_{aa}$$

where:

C_{ia-vi} is the indoor air concentration of a VOC due to VI⁵²

C_{ia-m} is the concentration of that VOC measured in indoor air

C_{aa} is the concentration of that VOC measured in ambient air and represents the ambient air contribution to the measured indoor air concentration value

Then, compare the indoor air VOC concentrations due to VI, to VI indoor air cleanup levels and mitigation-trigger levels, to determine if additional actions are necessary.

Note: When the building-specific upwind ambient air VOC level is the same or higher than the maximum indoor concentration for that VOC, you can conclude that the presence of the compound is not likely from VI, since the ambient contribution to the indoor air concentration is likely near 100%. When the indoor air concentration of a particular site-related VOC exceeds the ambient concentration of that VOC, you can assume the contribution from ambient sources to indoor air is close to the measured ambient concentration, and therefore can subtract it from the measured indoor air concentration for that specific compound. If the remaining concentration is less than the cleanup level, then VI is unlikely to be significantly impacting indoor air quality.

4.8 Sub-slab or crawl space sampling

As discussed in Chapter 3, Tier 1 evaluations generally do not include collecting VI information inside buildings. In most cases, once the determination is made to sample inside, sub-slab sampling is conducted concurrently with indoor and ambient sampling to gather information necessary to reach conclusions about potential VI impacts to indoor air.⁵³

As discussed in Section 4.6.1, indoor sources can contribute to the measured indoor air concentrations. Sub-slab soil gas sampling can help estimate the VI contribution to measured indoor air concentrations, but the sampling typically needs to occur a) when the building is depressurized relative to the subsurface, and b) when the source includes multiple VOCs.

⁵² This assumes that the measured indoor concentration was not influenced by any indoor sources of the VOC.

⁵³ For buildings with crawl spaces, ambient and indoor air are often sampled concurrently with crawl space air. Crawl space sampling results are often similar to concentrations on the first floor of the building, and EPA's VI guidance recommends that no attenuation be assumed (i.e. a VAF of 1.0) between the crawl space and indoor air.

In such situations, if indoor air concentrations are solely the result of VI, relative magnitudes of the individual VOC levels should be similar to those detected in sub-slab soil gas. For example, if the level of one compound in indoor air is ten times higher than another detected compound, but the soil gas concentrations of both compounds are similar, it is reasonable to suspect that indoor air levels of the first compound are not due solely to VI.

Note: Because soil microbes are lacking, an indoor source of TCE will not degrade to cis-1,2 DCE or vinyl chloride. If TCE is present in indoor air, and neither cis-1,2 DCE nor vinyl chloride are measured in indoor air but are present in soil gas, then the source is likely inside the building. Further, if the ratio of TCE to cis-1,2 DCE is much higher in the indoor air than the subsurface soil gas, it suggests there is an indoor source contributing to the measured TCE concentrations.

Using a tracer compound may also help assess the primary source of VOC levels in indoor air. Radon can be used for this purpose when it is present in both soil gas and indoor air. The degree of radon attenuation between sub-slab soil gas and indoor air can help predict the amount of VOC attenuation between the two media.⁵⁴ If the measured radon attenuation is much higher than the attenuation measured for a particular VOC, it can indicate that VI may not be the primary contributor to that compound's indoor air level.

Note: While radon monitoring can provide another line of evidence to help identify potential indoor sources of contamination, this approach should not be used as the sole method for estimating a building-specific attenuation factor. Sampling sub-slab and indoor air concentrations for multiple contaminants, along with other parameters such as pressure differential across the slab, should also be completed.

Compound specific isotope analysis (CSIA) has also been used to help distinguish between subsurface and indoor sources of VOCs in indoor air. For more information, see *Use of compound-specific stable isotope analysis to distinguish between vapor intrusion and indoor sources of VOCs: User's guide for CSIA protocol* ESTCP Project ER-201025 (Beckley and Kuder 2014).

Comparison of indoor air concentrations to soil gas VOC levels (or to tracer compound levels when available) to help estimate just the VI contributions to indoor air levels assume that the contaminated soil gas being sampled is the only VI source. While this is often a good assumption, it is also possible for site-related vapors to enter a building via a conduit, such as a

⁵⁴ This can depend on a number of factors, including the difference between the areal extent of subsurface radon and VOC contamination. Literature cited in this chapter and in Chapter 8 provide examples that help determine when the degree of radon intrusion may or may not be a good indicator of the degree of VOC VI.

sewer pipe. The chemical composition of such vapors could be considerably different than the composition of vadose zone soil gas below the building.

4.9 Buildings covering large surficial areas

To ensure adequate evaluation, a building covering a large surface area (such as a warehouse) will typically need more sub-slab soil gas and indoor air samples than a single family home or small commercial business would require. Determining the appropriate number will be site-specific and should be based on factors such as:

- The extent of the subsurface contamination
- Preferential pathways and likely points where vapors could enter the structure
- Building construction and configuration
- How the interior spaces and HVAC systems are configured
- Areas where indoor air screening levels are more likely to be exceeded
- Building occupants (e.g. residential use, workers, sensitive receptors, etc.) and where the occupants spend most of their indoor time.

EPA and several states have guidance to help determine the appropriate locations and number of indoor air and sub-slab samples. New Jersey's Department of Environmental Protection has a [2018 VI guidance document](#)⁵⁵ with a detailed discussion on this topic.

Sub-slab soil gas data can exhibit significant spatial variability across the building slab, and this is especially true for larger buildings. Even with other supporting data such as temperature, barometric pressure, and indoor air, it is often difficult to accurately determine where soil gas VOC concentrations are likely to be the highest. As a result, the typical approach is to distribute the sampling locations uniformly across the slab.

Another option is to use "Large Volume Purge Sampling" with the goal of obtaining more representative data on the potential risks posed to the buildings being evaluated. The Hawai'i Department of Health's state contingency plan discusses this sampling option in more detail—see Section 7, [soil vapor and indoor air sampling guidance](#).⁵⁶

⁵⁵ http://www.nj.gov/dep/srp/guidance/vaporintrusion/vig_main.pdf?version_4

⁵⁶ <http://www.hawaiidoh.org/tgm-pdfs/TGM.pdf>

4.10 Factors affecting the number of sampling events

Once it is determined that a Tier 2 evaluation is needed, indoor air sampling should be conducted as soon as possible. This is especially important when concentrations of VOCs in soil gas or shallow groundwater near occupied buildings greatly exceed the VI screening levels. The first sampling event should not be significantly delayed just to obtain more desirable meteorological conditions like cold temperatures.

If the results from the first indoor air sampling event reveal concentrations significantly higher than the applicable cleanup levels, consider implementing mitigation without waiting for results from additional sampling events.

However, if the initial round of sampling is conducted when conditions are not conducive for measuring the maximum effects of VI, and if the results do not exceed cleanup levels, schedule follow-up sampling when conditions are conducive to the highest potential for VI impacts.

The number of sampling events needed will depend on how the indoor air measurements are obtained, how high the VI-caused VOC concentrations are, and whether these levels represent conservative measurements of indoor air levels. Options for obtaining indoor air measurements are described in Section 4.5 and can accurately represent actual levels present during the sampling period. Since VI impacts can fluctuate significantly over short periods of time, address the potential variability by conducting multiple indoor air sampling events.

If the sampling event simulates worst-case building depressurization conditions, and pressure cycling is performed to observe how indoor air concentrations respond to different positive and negative indoor pressures, then the maximum measured indoor air sampling results can typically be assumed to be a conservative estimate of VI impacts.

When indoor air sampling relies on meteorological conditions to achieve the maximum VI impacts, try to schedule sampling when the temperature difference between indoor and outdoor air is near or above 30° F and the temperature is falling. Since it can be challenging to schedule sampling to coincide with ideal meteorological conditions, collect additional lines of evidence that support the evaluation, such as measurements of pressure differentials across the building slab.

The following table has recommendations for the number of samples that may be needed when using canisters, sorbent tubes, or passive sampler methods. These recommendations do **not** factor in soil gas or indoor air concentration levels, meteorological conditions, long-term exposures to the receptors present, or whether mitigation will be implemented quickly—any of which can affect how many sampling events will be needed. The premise is that longer sampling periods should provide better chances for capturing temporal variability associated with VI.

Table 1: Recommended minimum number of sampling events for three sampling methods

| Sampling method | Recommended number of events to estimate short-term exposure concentrations ⁵⁷ | Recommended number of events to estimate long-term exposure concentrations |
|---|---|--|
| Canisters (EPA Method TO-15) (24- or 8-hour collection periods) | 3 sampling events | 2 sampling events |
| Active sampling with sorbent tubes (EPA Method TO-17) 24- or 8-hour collection periods | 3 sampling events | 2 sampling events |
| Passive samplers (multi-week collection periods) | 2 multi-week sampling events | 1 multi-week sampling event |

When a preponderance of data supports a conclusion that indoor air is not likely impacted by vapor intrusion, fewer indoor air sampling events should be necessary to screen out the pathway. Find more information about evaluating multiple lines of evidence in New Jersey Department of Environmental Protection's [2018 vapor intrusion technical guidance](#).⁵⁸

4.11 Factors affecting indoor air sample locations

VI impacts can vary spatially within a building and the highest values often occur on the first floor or in the basement. When considering possible sampling locations in these areas, focus on where building occupants spend a considerable amount of time and where the dilution of vapor concentrations by indoor air could be relatively modest.

If vapor transport could be occurring through a sewer lateral (see Section 3.1.2), the indoor air sampling locations may need to include areas that would not typically be selected. For example, bathroom plumbing has water-filled traps that prevent sewer gas from discharging into indoor air. However, even when properly installed, these traps can dry up and no longer serve as vapor transmission barriers. Wax ring seals on toilet bases are another example: these may eventually dry and crack and allow sewer gas to enter.

⁵⁷ At the time this guidance was published, these recommendations apply to just one VOC: TCE.

⁵⁸ https://www.nj.gov/dep/srp/guidance/vaporintrusion/vit_main.pdf

4.12 Multiple VOCs

When multiple VOCs are present in indoor air but are below their respective cleanup levels, cumulative risk must also be considered before concluding VI poses no concern. If the maximum risk levels for any of the following scenarios are exceeded, the cleanup level must be adjusted downward using provisions in WAC 173-340-708.

Cumulative Risk Situations

- The individual Method B carcinogenic VI indoor air cleanup levels in the CLARC data tables are based on an excess cancer risk of one in one million (1E-6). If more than 10 carcinogenic compounds are present, determine the total excess cancer risk to ensure it does not exceed one in one hundred thousand (1E-5).
- 1. The individual Method C carcinogenic VI indoor air cleanup levels in the CLARC data tables are based on an excess cancer risk of one in one hundred thousand (1E-5). If multiple carcinogenic compounds are present, determine the total excess cancer risk to ensure it does not exceed 1E-5.
- 2. For non-carcinogenic compounds, the individual Method B and C non-carcinogenic VI indoor air cleanup levels in CLARC are based on a hazard quotient (HQ) of 1.0. If multiple non-carcinogenic compounds are present, calculate the hazard index (HI) to ensure it does not exceed 1.

Note The last scenario is most likely to occur with petroleum compounds. Appendix E has several options to account for cumulative effects of these compounds in indoor air.

4.13 Decision making

If indoor air concentrations are above acceptable levels and available evidence indicates that vapor intrusion is likely the major contributor, evaluate and implement potential responses quickly. This typically means installing a vapor mitigation system that can minimize exposures until a more permanent remedy is implemented.

To conclude that VI is not causing unacceptable impacts to indoor air, a preponderance of data obtained during the evaluation should support this determination. These decisions are generally based on multiple lines of evidence, which at a minimum should include ambient air, indoor air, and sub-slab sampling results. Meteorological conditions encountered during sampling, along with building-specific information such as tracer measurements and cross-slab pressure differentials, should also be considered.

In those cases where indoor air concentrations are below the applicable cleanup levels, no immediate actions are necessary to reduce indoor exposures. However, if sub-slab soil gas concentrations exceed screening levels, the cleanup action selected should ensure the long-term protection of indoor receptors.

4.14 Documenting and communicating the results of a Tier 2 evaluation

In most situations, prepare a report documenting the Tier 2 results after each sampling event. The report should include all information collected for the Tier 2 evaluation, and any pertinent supporting information from the Tier 1 evaluation. In particular, information collected on the day of sampling should include:

- Heating and ventilation conditions of the building;
- Occupant actions that could affect the sampling results;
- Meteorological conditions such as local ambient air temperatures, wind direction and speeds, barometric pressure; and,
- If measured, the indoor/sub-slab pressure differentials.

In some cases, the Tier 2 report can also serve to communicate sampling and other measurement results to the building owner and tenants. However, these reports are generally technical in nature and often not completed until weeks after the sampling event occurs. Many owners and tenants may prefer to receive results more quickly, and in a concise and understandable format. When the access agreement is developed, it should identify who will be notified of the sampling results, when the notification will occur (timing), and what format will be used to communicate the results. Chapter 5 has recommendations for post-sampling communications and other VI-related outreach efforts.

Chapter 5: Public Involvement

Planning early for how to involve and inform the people impacted by vapor intrusion helps ensure no one is missed and builds trust in the process.

5.0 Introduction

Communications with the public should be initiated once sampling identifies subsurface VOCs in the vicinity of buildings. Interactions will typically be with the owner/occupants of the buildings being evaluated, or with those who live or work in close proximity to where work will be conducted.

[WAC 173-340-600](#)⁵⁹ outlines the minimum requirements for public participation under the Model Toxics Control Act. However, VI investigation and mitigation activities usually need more discussions directly with individual property owners, partly because access to the building's interior is needed to obtain environmental samples.

This chapter briefly discusses relations with the community, and focuses primarily on communicating with owners and occupants of buildings that are undergoing a VI evaluation. It does not prescribe a set process for interacting with these individuals, but instead identifies issues for consideration. Section 5.4 has resources to help with the communications process.

5.1 VI-related communication with the local community

The degree to which a community is informed about a particular site's environmental impacts can vary widely, but members of the public are often not familiar with a site before they're informed about the potential for vapor intrusion.

For formal cleanup sites that are governed by a consent decree or order, people residing within the known area of contamination will have the opportunity to review the Public Participation Plan as set out in WAC 173-340-600(9). However, even when a formal process like this is implemented, people may not be aware of actions being proposed to address the contamination, and most will not be familiar with the concept of VI.

Unless there is information to the contrary, Ecology recommends that the communications planning discussed in Section 5.3 assumes that building owners and occupants have a limited understanding of VI.

⁵⁹ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-600>

5.2 Communications during the VI evaluation process

During the early stages of a VI investigation (Preliminary Assessment and Tier 1 evaluation), it is typically not known whether unacceptable VI impacts are occurring in nearby buildings. Contact with the building's owners or tenants likely won't happen while most of this work is performed.⁶⁰ However, some situations may require obtaining specific information through a building visit, or gathering environmental samples on the property (including inside the building). When communicating with the owner/tenants in these cases, describe the contamination present, explain the concept of VI, and provide rationale for why the specific information is necessary.⁶¹

Tier 2 evaluations include indoor air sampling and other measurements within one or more buildings. This typically results in multiple contacts with the building owner or their designee and potentially with other occupants of the building. The following sections discuss interactions that will typically occur.

5.2.1 Pursue access agreements early

When the party responsible for conducting remedial action does not own the building being evaluated, consent from the owner (and possibly others) is necessary before any indoor air sampling can occur.⁶² This consent should be documented in an access agreement, which specifies the conditions under which access is granted and allows the project team to conduct sampling needed to complete the evaluation.

Although some property owners and tenants may allow access informally and may not be interested in either the process or the results, Ecology recommends developing formal written access agreements that when signed, allows the project team to conduct the sampling needed.⁶³ These formal documents set out each party's responsibilities and describe what information will be provided to the owners and tenants at each point in the process. They should include:

⁶⁰ The term "building owner/tenant" is used throughout this chapter to identify anyone who could be exposed to indoor air impacted by VI. This includes owners, tenants, workers, students, and visitors.

⁶¹ When a large number of buildings needs to be assessed, or whenever significant public interest is expected, it is advisable to assemble a multi-disciplinary team to plan and carry out communications with members of the public. Representatives from state and/or local health agencies can often provide risk communication assistance and answer questions that require toxicological or medical expertise.

⁶² With limited exceptions such as emergency situations.

⁶³ If building owners are reluctant to provide access for indoor air and/or sub-slab sampling, consider whether other options are available to complete the necessary evaluation. At a minimum, make an effort to explain the potential risks associated with VI and to determine the number of receptors present. If progress cannot be made, it may be appropriate to remind commercial building owners about language in MTCA that limits liability to property owners, but only when they cooperate with remedial investigations and actions (see RCW [70A.305.020\(22\)\(b\)\(iv\)\(D\)](#)).

1. What actions the property owner will or won't allow.
2. Length of time the agreement will remain in effect.⁶⁴
3. Process for scheduling visits to the property.
4. Procedures for coordinating fieldwork and document submittals when a building owner or tenant chooses to hire a private consultant or attorney to oversee the sampling.
5. An attachment with instructions for the building owner and tenants, explaining what activities should and shouldn't be conducted immediately before and during the sampling events.
6. Information and documents that will be provided to the building owner and tenants.
7. Estimated date the building owner and tenants can expect to receive copies of the sampling report. Sampling reports should include a cover letter addressed to the owner (and tenants when appropriate) that distills the data, summarizes the findings, and describes next steps. For reports that include indoor air data, it can be helpful to describe the range of typical indoor concentrations for the VOCs detected.⁶⁵

While most building owners are willing to provide access, it can take a long time to finalize these agreements. This usually happens when an owner seeks advice from legal counsel before entering into the agreement. There may also be protracted negotiations about other considerations such as access-related payments. While securing access is normally the duty of the party responsible for conducting remedial action, Ecology may become involved when disputes result in significant delays, including exercising its legal authority to ensure timely completion of the work.

5.2.2 During and after the sampling process

Multiple property visits will be necessary during the indoor air sampling process. Initial contact with people should occur shortly after determining that a building is potentially at risk for VI. During the first meeting, it is important to provide information about the type and extent of contamination present and explain the concept of VI. Since VI can be a difficult concept to fully comprehend, Ecology recommends providing written outreach materials that explain these issues in a clear, straightforward manner.

For buildings with multiple tenants, or where a property owner is not readily available, it is advisable that the party conducting the remedial action request a designated "building contact."

⁶⁴ Since multiple sampling events are often necessary, the agreement should remain in effect until the Tier 2 evaluation is completed.

⁶⁵ Even when a report summarizes the findings and describes next steps, Ecology and/or the Washington State Department of Health may be asked to provide an opinion on whether the report's conclusions are appropriate.

This person can help schedule future building visits, obtain access for sampling events, and take care of other activities that require entry into the building.

Building visits can be frequent. For example, a visit is usually needed several days before sampling begins to explain the sampling process; remove or isolate potential VOC emitting sources; and identify any activities that should be avoided before and during sampling.

During indoor air sampling, multiple building visits are also needed to set up and initiate sampling; ensure it's progressing adequately; complete sampling collection; and retrieve equipment.

Although the access agreement typically state when and in what format sampling results will be provided, sometimes the owner/tenant will request results before the detailed sampling report is completed. If so, owners/tenants should be informed that:

- a) The data may not yet be fully validated, which could affect the results provided, and
- b) Further assessment of data quality is possible, which could lead to different conclusions and next steps.

If the Tier 2 evaluation concludes that institutional controls will be needed to ensure that building occupants are protected, it typically results in filing an environmental covenant signed by Ecology and the building owner. Occasionally, this can happen before the cleanup is implemented but more likely will follow completion of the remedial action.

5.2.3 When TCE is a VI contaminant of concern

If TCE is a contaminant of concern, consult Appendix A for recommendations on communicating with building owners/tenants. It is critical to quickly complete the VI evaluation and associated outreach steps.

5.3 Communications during building mitigation activities

If VI is causing an exceedance of the indoor air cleanup levels or the short-term TCE action levels, consult with the building owner quickly to identify an approach for reducing VI exposures as soon as possible. The best option for addressing the indoor air impacts will depend on several factors, such as the measured indoor air concentrations, preferences of the building owner, and receptors being impacted. Making it happen promptly—that is, reaching a mutually acceptable decision and carrying it out—may require involvement from Ecology and state/local health departments.

Designing, installing, operating, and monitoring a VI mitigation system requires frequent communication with the property owner or their designee. The following sections discuss interactions that will typically occur.

5.3.1 Access agreements

Access agreements for VI mitigation are usually distinct documents from those developed for indoor air sampling (Section 5.2.1), although they often contain similar information. The agreement should not specify a set period of time—instead, it should remain in effect for as long as the system needs to operate. When mitigation systems are part of the final cleanup action, however, institutional controls (rather than the access agreement) may need to establish the future access and restrictions on future building use.

5.3.2 Working with building owners and occupants

Numerous steps need to be completed before constructing a mitigation system and these are discussed in detail in Chapter 6. Obtaining approval from the building owner is necessary before any construction can begin.

Once conceptual agreement on the need for mitigation has been reached, a more detailed discussion should take place about options for: routing the mitigation system piping; design and location of the fan(s); places for monitoring the system's performance; and ultimately decommissioning the system.

When designing the system, consider what criteria to use for determining it is no longer necessary. Ecology recommends providing and discussing this decision criteria with the building owner during the design stage. Having an upfront understanding of the pre-conditions for decommissioning the system should help avoid misunderstandings about needing to continue operating it.

Clearly identify the advantages and disadvantages for each of these approaches, with the goal of achieving a mutually agreeable system design.

5.3.3 Notifying the public about the mitigation design

Mitigation systems may be implemented as interim actions or as engineered controls that are part of a cleanup action. Public participation requirements for interim actions are found in WAC 173-340-600(16). For sites where an Order or Consent Decree has been issued, these and any applicable SEPA requirements will usually have already been met. For independent remedial actions, or for situations where the Order or Consent Decree did not anticipate the need for a VI interim action, compliance with WAC 173-340-600(16) and SEPA may still be needed. If the mitigation system will be part of the final cleanup action, follow the public participation requirements in WAC 173-340-600(14) and (15).

When prompt action is needed to protect human health, installing and operating the mitigation system should not be delayed while waiting for potential comments from members of the public who are not owners/tenants. If prompt action isn't necessary, public comments on the proposed VI mitigation system should be considered before finalizing the plans. For example, if the mitigation system that was initially installed as an interim action is now proposed to be a component of the overall cleanup action, consideration of comments and compliance with the

applicable provisions of WAC 173-340-600 should happen before selecting the final appropriate cleanup actions.

5.3.4 During construction and operation of the mitigation system

Multiple visits to the building will usually be necessary during construction of a mitigation system. Individuals who will require access include mitigation contractors, environmental consultants, electricians, and inspectors. These visits must be scheduled with the building owner or designee, and potentially with a tenant, so access can be obtained.

When mitigating single family residences and other small buildings, diagnostic testing is often completed concurrently with system installation. It can be very helpful in cases like these if the building owner or designee is available in person or by phone: if design changes are needed, they can be completed without making another trip to the site.

5.3.5 After installing a mitigation system

Upon completing the mitigation system, Ecology recommends preparing the two reports as discussed in Chapter 6. The first is a Construction Completion Report that should be completed shortly after installing the system. The second is a VI Mitigation Performance Report that should be completed after post-installation indoor air sampling results are available.

Building owners should receive copies of these reports, but some owners/tenants may prefer to receive just the sampling results as soon as they are available. Either way, both parties should agree on the process for communicating this information.

There are also circumstances when the owner/tenant should contact the party responsible for implementing the cleanup, such as when:

- The system malfunctions or appears to need repair,
- There has been a change in building ownership or use, or
- New construction or remodeling is anticipated that could affect mitigation performance.

5.3.6 When a mitigation system is no longer needed

As mentioned in Section 5.3.2, use the design stage to communicate what criteria will help determine when the mitigation system will no longer be necessary, then share the criteria again when you're ready to decommission.

Some building owners may want the system to remain operational even if the concentration of subsurface contaminants no longer poses a VI threat. In these situations, an agreement documenting the responsibility of each party should be developed. More specifics about decommissioning the system are provided in Section 6.7.

5.3.7 When TCE exceeds short-term action levels

If mitigation is being implemented because VI is causing or likely causing an exceedance of the short-term TCE indoor action level, and building occupants include one or more women of childbearing age, communications with owner/tenants should follow the recommendations in Appendix A. In some cases, it will be necessary to take action before the mitigation system is operational to ensure protection of building occupants. In these situations, immediately begin communications about the potential options for quickly reducing the indoor air concentrations to below the action level.

Note: Investigators should explain to owners and tenants that once Tier 2 test results are submitted to Ecology, the information is not confidential and is available to the public upon request.⁶⁶

5.4 Resources for communications with the public

Anticipating, listening, and responding to public concerns can be a major part of a VI investigation. Informing people that their homes or offices may be contaminated with harmful vapors requires thoughtful and considered communications. The previous sections only summarize the VI-related activities that are likely to require public engagement. The following references provide a fuller descriptions of recommended public involvement methods and practices. These citations are also found in Chapter 8: References at the end of this guidance.

- California Environmental Protection Agency, Department of Toxic Substances Control. (2011). *Guidance for the evaluation and mitigation of subsurface vapor intrusion to indoor air*.
- California Environmental Protection Agency, Department of Toxic Substances. (2012). *Vapor intrusion public participation advisory*.
- ITRC. (2007). *Vapor intrusion pathway: A practical guideline*.
- Massachusetts Department of Environmental Protection. (2016). *Vapor intrusion guidance: Site assessment, mitigation and closure*, Chapter 5.
- New Jersey Department of Environmental Protection, *Vapor intrusion technical guidance*. (2018). New Jersey Department of Environmental Protection, *Vapor intrusion template letters and results tables* (May 2017). Retrieved from: <https://www.nj.gov/dep/srp/guidance/vaporintrusion/templates/>

⁶⁶ Per Washington state's Public Records Disclosure regulations, [Chapter 308-10 WAC](#).

- New Jersey Department of Environmental Protection. (2012). *Community outreach for vapor intrusion sites*. Retrieved from: https://www.nj.gov/dep/srp/guidance/vaporintrusion/community_outreach_guidance.pdf
- USEPA. (2015). Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface vapor sources to indoor air. Chapter 9 – Planning for Community Involvement.
- Wisconsin Department of Natural Resources, *Vapor intrusion resources*, <https://dnr.wisconsin.gov/topic/Brownfields/Vapor.html>

Chapter 6: Mitigation

6.0 Introduction

Mitigation is a form of “protection” from potentially harmful exposure.
It is not a full cleanup remedy.

Mitigation is a supplemental and often short-term remedial solution intended to protect receptors from contaminated indoor air from VI.⁶⁷ A mitigation system, for example, won’t remediate the subsurface, but will re-route contaminated soil gas that could otherwise enter a building.

Mitigation can be “built into” a new structure or added to an existing structure. It can use passive measures exclusively, or incorporate active devices such as fans or blowers. Most VI mitigation technologies are those that successfully address radon in indoor air.

This chapter discusses topics related to evaluating, implementing, maintaining, and monitoring VI-mitigation actions. It does not provide a detailed discussion about specific types of mitigation technologies that are available, or when those types should be selected over others. For help selecting and designing specific mitigation options, Ecology recommends the following guidance documents:

- ASTM E2435-05 (Standard Guide for Application of Engineering Controls to Facilitate Use or Redevelopment of Chemical-Affected Properties).
- California Department of Toxic Substances Control. (2011). *Vapor Intrusion Mitigation Advisory, Revision 1*.
- ITRC. (2007). Vapor Intrusion Pathway: A Practical Guideline – Section 4.
- ITRC. (2014). Petroleum Vapor Intrusion – Fundamentals of Screening, Investigation and Management – Appendix J.
- ITRC. An introduction to Vapor Intrusion Mitigation Fact Sheets
- Massachusetts Department of Environmental Protection. (2016). Vapor Intrusion Technical Guidance: Site Assessment, Mitigation and Closure – Chapter 3: Mitigation of the VI Pathway and Appendix IV: Recommended Specifications for the Design and Construction of SSD Systems.

⁶⁷ Mitigating vapor intrusion is analogous to providing bottled water to people whose drinking water wells have become contaminated. While the people are protected from the contamination in their wells, the bottled water does not address the source of contamination. By definition, subsurface sources of vapor-phase VOCs intruding into buildings generally won’t be significantly remediated by mitigation.

- Naval Facilities Engineering Command (NAVFAC), *Vapor Intrusion Mitigation in Construction of New Buildings Fact Sheet*, August 2011, available at: <https://denix.osd.mil/irp/navyvaporresources/>
- New Jersey Department of Environmental Protection. (2018). Vapor Intrusion Technical Guidance – Chapter 6: Vapor Intrusion Mitigation and Appendices J through N.
- USEPA. (2008). *Indoor Air Vapor Intrusion Mitigation Approaches* (Engineering Issue, EPA 600-R-08-115).

6.1 The purpose of VI mitigation

Mitigation actions can be taken for primarily two reasons:

Reason 1: A Tier 2 evaluation reveals that unacceptable levels of VOCs from VI are present in indoor air.

Reason 2: It is unknown if VI impacts to indoor air quality are unacceptable but action is deemed appropriate because:

- a. Elevated VOC concentrations in soil gas or shallow groundwater have been measured near a building, and/or
- b. Measured indoor air concentrations have been below cleanup levels, but additional sampling events are needed to demonstrate that VI impacts are not occurring.

Actions taken under Reason 2 are called “preemptive mitigation” and are often implemented to minimize sampling-related costs, limit future disturbances to the building’s occupants, or quickly provide protection. A mitigation system can also be installed when a new building is being constructed in a contaminated area. This can minimize the risk that unacceptable VI impacts are discovered during post-construction indoor air sampling.

It is typically more expensive to retrofit existing buildings to incorporate active mitigation technologies (such as sub-slab depressurization in Figure 8), than it is to install systems during new building construction. This is especially true if the building is large or when other complicating factors such as low permeability soils or shallow groundwater are present.

Since the cost for mitigating single family homes is often relatively low, Ecology recommends that residences be preemptively mitigated when:

- Subsurface VOC concentrations are much higher than VI screening levels,
- The potential for VI impacts cannot be quickly ruled out, and
- The building owner supports this decision.

When unacceptable levels of VOCs from VI are detected in indoor air, mitigation is typically implemented as an interim measure to protect building occupants. Frequently, the expectation is that mitigation systems can be retired once subsurface VI screening levels are met. However, it may take a long time to achieve these levels and in some cases they may never be attained. In these situations, mitigation may need to be included as an element of the final cleanup action and expected to operate over a prolonged period.

Under many circumstances the purpose of mitigation will be to provide immediate but temporary receptor protection. Often these “stopgap” actions are implemented as a more permanent system is designed, constructed, and performance tested. Appendix A discusses these actions further, which include:

- Sealing obvious openings for preferential vapor entry into a building.
- Increasing ventilation to certain indoor spaces.
- Adjusting HVAC controls to positively pressurize the building's lowest floor.
- Installing indoor air treatment devices.
- Re-locating receptors.

Appendix A was developed for VI impacts from TCE, but can be used whenever a permanent system will take an extended period of time to provide the necessary protection.

6.2 Types of mitigation

Mitigation does not usually refer to actions that reduce VOC contamination, but depending on where the VI source is located, mitigation can effectively reduce VI impacts. For example, if a soil vapor extraction (SVE) system is designed to not only reduce soil VOC concentrations, but also de-pressurize the sub-slab zone beneath a VI impacted building, it can potentially serve as both remediation and mitigation.

There are three general types of mitigation systems that reduce indoor air VOC levels, but not necessarily source concentrations:

1. One type minimizes the mass flowrate of soil gas into the building via creation of a pressure gradient barrier. **These systems are typically classified as sub slab depressurization systems (SSDS)**
2. Another type minimizes the mass flowrate of vapors into the building by primarily relying on a physical barrier.
3. A third reduces indoor air VOC levels by treating or effectively diluting the contaminated air.

Sub-slab depressurization systems (SSDS) are used to create lower pressures below the slab or basement floor. **Sub-membrane depressurization systems (SMDS)** can be installed

during new building construction or in some cases within the crawl space of an existing structure. The goal of both systems is prevent advective flow of contaminated soil gas into interior spaces. Figure 8 is an example of an SSDS.

When a fan or blower is used to establish the pressure gradient across the slab (or membrane, if present) these systems are considered active, whereas passive systems only rely on venting (and in some cases a barrier) to minimize vapor migration. Active SSDS or SMDS systems are proven to effectively reduce VOC and radon concentrations from VI for a range of building types and site conditions when installed by a certified radon mitigator (or other environmental professional with similar experience and credentials).

There are certain **rare** situations where these systems may not be effective, such as when soil or fillmaterial directly below the slab are saturated, or have a relatively low permeability. In both of these cases, it can be difficult or impossible to achieve the necessary vacuum to maintain a negative pressure differential. It may also be possible for shallow, high concentration contaminants to diffuse across the slab and contaminate indoor air even when an SSDS is operating.

Another approach for mitigating high soil gas concentrations is to **increase the interior pressure to provide a downward gradient across the slab**. Some HVAC systems may have this capability. To be most effective, a positive pressure should be continuously maintained—and not just when occupants are present. Contaminant concentrations can also be diluted by improving building ventilation through an increase in the air exchange rate. **This mitigation approach typically is accompanied by high energy penalties and can have operational costs as high as 8 times as much as traditional SSDS solutions.**

Using a physical barrier as the primary mechanism for reducing VI impacts can potentially achieve mitigation goals. Their effectiveness often depends on the type of barrier, how well it blocks any preferential pathways for vapor entry, and how much contaminant reduction is needed. Barrier installation could be a small scale effort, such as sealing openings in the basement floor and walls or the floor above the crawl space. Larger scale efforts are also possible, such as installing a membrane barrier during new building construction within an area of subsurface contamination to provide preemptive mitigation. Membranes can extend beyond the building footprint and should be combined with a venting system to exhaust soil gas to the atmosphere. **Barriers in themselves do not mitigate the pressure gradient driving force that causes vapor intrusion. This approach only works when there is good slab integrity and the ability to seal nearly all soil gas entry points.**

One final option is **installing an indoor air treatment device** that typically uses carbon adsorption to reduce contaminant concentrations. For a discussion of the types and effectiveness of indoor air treatment devices, see EPA's August 2017 Engineering Issue: *Adsorption-based treatment systems for removing chemical vapors from indoor air* (EPA/600/R-17/276).

6.3 Mitigating contaminated vapors that enter a building via conduits

As discussed in Chapter 3, sewer lines and other piping that connect to the building's interior plumbing can transport vapors directly indoors. The mitigation systems described above that are designed to minimize sub-foundation soil gas entry into buildings will not prevent the direct movement of conduit vapors to indoor spaces. Mitigation actions for these scenarios will need to focus on either a) reducing VOC vapors in the conduits exterior to the building, b) sealing indoor fixtures and/or effectively trapping vapors within the piping, or c) treating the indoor air contaminants. See McHugh and Beckley (2018) for a detailed discussion of these options.

6.4 Mitigation design

Since the types of mitigation systems discussed in Section 6.2 include a wide range of options, the level of detail needed for system planning, design, and documentation will depend on which mitigation is selected. Recommendations provided in this section assume that a more comprehensive system will be installed—such as an active SSDS—and that mitigation plans haven't yet been developed for implementation. Some of these recommendations will not be applicable to smaller scale actions.

To expedite mitigation for single family residences and most small buildings where a standard radon type system like an SSDS or SMDS will be installed, diagnostic testing can be done concurrently with system installation. This may require design modifications to achieve the desired performance, and if so, the VI Mitigation Work Plan recommended in Section 6.4.2 can be adjusted to provide more flexibility.

6.4.1 Pre-design activities

The party responsible for conducting the remedial action should provide written notice to the building owner and others (as appropriate) that mitigation is necessary. The notice should also request a meeting with the owner or designee at the building, so any building- or site-specific information needed to complete the design can be obtained. It may also be worthwhile to discuss the overall project schedule and next steps. This will provide the building owner with an opportunity to ask questions and provide feedback.

If an immediate “stopgap” mitigation is necessary, submit a brief narrative that identifies:

1. The type of mitigation that will be implemented.
2. The schedule for implementation.
3. A monitoring program to determine the effectiveness of the system.
4. A contingency plan if the applicable indoor air levels are not met.
5. The anticipated timeframe for completing a more permanent system.

6.4.2 Mitigation system work plan and checklist

VI Mitigation Work Plans should be prepared when a mitigation system is determined to be necessary. Unless otherwise specified by Ecology, the work plan must meet requirements in WAC [173-340-840](https://app.leg.wa.gov/wac/default.aspx?cite=173-340-840).⁶⁸ In addition, it should also contain:

1. A building-specific VI conceptual site model that includes:
 - a. A description and diagram of the building foundation;
 - b. The current use of the building;
 - c. Indoor spaces where receptors spend the majority of their time;
 - d. A description of the HVAC system and its operating parameters; and
 - e. Elements listed in Section 3.11 of this guidance.
2. An overview of the proposed mitigation approach, the expected timeframe over which the system will operate, and description of the criteria for determining when the system can be retired.⁶⁹
3. Mitigation goals including specific performance objectives and post-mitigation indoor air target levels. **If the system is an SSDS, the minimum pressure differential goal should be .004" w.c. (1Pa) at the outer extent of the negative pressure field during adverse weather or pressure conditions.**
4. The mechanism for ensuring the integrity and effectiveness over the operational lifetime including:
 - a. Safeguards to prevent tampering or modifications to the mitigation system and the HVAC system as applicable, which could negatively affect system performance.
 - b. Regular access for system inspections, maintenance, and monitoring.
 - c. Limiting building uses to be consistent with the indoor air concentrations achieved.⁷⁰ **Clear performance objectives are to be stated in terms of pressure differential or air exchange rates shall be stated in the text of the design.**
5. The engineering design and operation parameters including:
 - a. A detailed description of the mitigation system and its associated components.
 - b. Design criteria, assumptions, and calculations.

⁶⁸ <https://app.leg.wa.gov/wac/default.aspx?cite=173-340-840>

⁶⁹ For an active mitigation system to be most effective, it should be designed to operate continuously.

⁷⁰ Environmental covenants or other legal instruments are often used to limit or prohibit certain activities.

In cases where the building owner is not a potentially liable person under RCW 70.105D.040, alternative mechanisms often need to be used.

- c. The results of any pre-construction diagnostic testing.
- d. An assessment of whether emission controls will be necessary.
- e. Monitoring devices such as gauges, manometers, alarms, and/or telemetry systems for evaluating performance.
- f. Building-specific characteristics that may affect system design, construction or operation.⁷¹
- g. An assessment of the potential for system back drafting.⁷²
- h. If applicable, a description of how the mitigation system will be integrated with any stopgap response actions or other site remediation efforts.
- i. A general description of the long-term operation, maintenance and management requirements for the system.

More about engineering design and operation. When you are implementing VI mitigation on a property that isn't owned by the party who is responsible for remediating the site, try to minimize impositions on the building owner. The California Department of Toxic Substances' VI Mitigation Advisory (October 2011) recommends that whenever possible, consider the concerns and needs of current and future building occupants during the design process.

For existing buildings (for example), ask owners and occupants their opinions about where blowers and piping should be located; what level of blower noise is acceptable; how readable different system operation gauges and meters are; and what quality of construction craftsmanship is satisfactory. When there are multiple mitigation options, give the building owner and occupants the advantages and disadvantages associated with each option, along with an explanation of which alternative is preferred and why. Ecology recommends that you and your team consider these provisions as part of the system design and construction.

6. If applicable, a description of any activities needed prior to system construction, including pre-construction diagnostic testing, and sealing building foundation points of entry.
7. Identification of necessary federal, state or local permits, inspections, and approvals.⁷³

⁷¹ For example, consider the location of building windows and intake vents when designing an SSD's venting system, to prevent VOC emissions from re-entering the building that's being mitigated.

⁷² Carbon monoxide detectors should be considered for homes where mitigation back drafting is a potential concern.

⁷³ Most single dwellings will typically require an electrical permit and inspection when the mitigation system is an SSDS or SMDS. Mitigation of commercial/industrial buildings may be subject to other regulatory requirements such as mechanical and other permits.

8. Copy of the executed access agreement.
9. Construction information including:
 - a. A general building map.
 - b. Figures depicting proposed locations of system components.
 - c. Engineering drawings and material specifications prepared in conformance with currently accepted engineering practice. A **schedule for permanent test ports to measure pressure differential, riser test ports to measure applied vacuum and airflow, test ports before the inlet of the blower to measure vacuum and airflow.**
 - d. A proposal for construction quality assurance/quality control (QA/QC) including testing of system components to verify that blowers, gauges, alarms, and other devices will function properly. **This should include documenting the sealing completed as specified, the physical performance metrics such as pressure differential, applied vacuum at risers, airflow at risers, total system applied vacuum, total airflow discharge, power consumed by the blower at maximum and operational speeds, gate valve positions on individual risers, and other site-specific data that is considered to have operational relevance.**
 - e. System labeling specifications.
 - f. An appendix with a Health and Safety Plan describing how construction procedures will meet the requirements of WAC [173-340-810](#).⁷⁴
10. Description of the system performance criteria during start-up and subsequent operation. **See comments at 9d (above).**
11. Proposed schedule for performing the work described and completing the post-installation reports.
12. Sampling and Analysis Plan (SAP).

Mitigation standards are available from ASTM and ANSI/AARST. The following documents primarily cover component specifications for addressing radon, but can also help when designing VI mitigation systems:

- ASTM E 2121-13, Standard Practice for Installing Radon Mitigation Systems in Existing Low-rise Residential Buildings.
- ANSI/AARST SGM-SF-2017, Soil Gas Mitigation Standards for Existing Homes.
- ANSI/AARST RMS-LB-2018, Radon Mitigation Standards for Schools and Large Buildings.
- ANSI/AARST RMS-MF-2018, Radon Mitigation Standards for Multifamily Buildings.

6.4.3 Mitigation emissions

~~In general, mitigation systems do not remediate the subsurface but instead re-route~~

contaminated soil gas that could otherwise enter a building. For most residential and small commercial structures, the soil gas being emitted is not treated prior to discharge. There are

⁷⁴ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-810> (Worker safety and health)

certain scenarios that necessitate evaluating whether emissions could have an unacceptable effect on ambient air quality, such as these scenarios:

- Active depressurization systems for many large buildings often require more powerful blowers than the mitigation fans typically used for a residence. As a result, the VOC emission rates can be much higher.
- If an SVE system is removing soil gas from beneath a building slab, the untreated emissions will typically have much more impact on ambient air quality as compared to a standard SSDS or SMDS system.
- When multiple active depressurization systems are operating in close proximity to one another, the combined impact on local ambient air quality may be pronounced even if the VOC emissions for the individual systems are relatively low. **Since latent pockets of soil gas can influence delineation and plan design, and the majority of the air that is discharged from a SSDS system originates from leakiness associated with the slab and foundation, the soil gas concentrations and airflow in the riser(s) and total system discharge should be measured to develop a soil gas yield profile from which mass contaminant discharge can be calculated. These measurements should be made not less than 10 but not more than 30 days after the system has been started.**

Air modeling can be used to determine whether pre-discharge treatment is necessary to reduce emissions to acceptable levels. Several screening level models are available for this purpose, which can estimate the reasonable maximum exposure (RME) concentrations in ambient air that are associated with anticipated or measured emissions.

6.5 Integrating public participation with mitigation

Once the decision is made to mitigate a building, notify and obtain consent from the owner then begin implementation as soon as possible to minimize potential impacts to human health. If public noticing has not already been done, proceed to notify the intent to implement an interim mitigation action.

Although this broader public notification needs to comply with WAC [173-340-600](#)(16),⁷⁵ soliciting and considering public comments should not impede implementation if public health is at risk.

6.6 Post-construction considerations

Initiate start-up when construction is complete, then conduct monitoring once the system is fully operational to ensure mitigation goals are being met. When the system is confirmed to be operating as designed, routine inspections, maintenance, and monitoring can be carried out.

The following sections recommend what type of documentation should be provided after completing construction and after performance data is available. Although this guidance separates the two reports, in many cases, it will be possible to submit this information as one comprehensive document.

⁷⁵ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-600> (Public notice and participation)

Note: The following recommendations assume that an active system such as an SSDS was installed. Some mitigation systems are small-scale efforts that will only require minimal post-construction documentation and indoor air sampling. You can tailor how much information you'll need to provide based on the complexity of your project.

6.6.1 Construction Completion Report and checklist

A Construction Completion Report should include:

1. A summary of the field activities associated with system construction and startup.
2. Final as-built drawings that depict the locations of all system components and monitoring points.
3. A description of the constructed system, including any deviations from the design plans and rationale for the changes made.
4. A description of results produced by all third-party inspections.
5. If applicable, a description of any work related to the decommissioning or continued operation of any previously implemented stopgap response actions.
6. Documentation that system-induced back drafting is not occurring. **This requirement is primarily for residential mitigation scenarios as there is no criteria suitable for isolating combustion drafting cause and effect in large buildings. Further, there is an absence of documentation where a properly sealed SSD system has resulted in the back-drafting of combustion appliances.**
7. Any proposed modifications to the indoor air Sampling and Analysis Plan (SAP).
8. Photographs of the constructed system, including all monitoring points.
9. Copies of all related permits and approvals.

6.6.2 System Performance Report and checklist

A VI mitigation performance report should be prepared after system operations and sampling information becomes available. The report should include:

1. Indoor air sampling results along with all raw data. **Indoor air alone is not always the best indicator of system performance, as the presence of indoor air contaminants can originate from latent discharge from building materials, extrinsic sources such as outgassing from manufacturing and contaminated ambient air as is common adjacent drycleaners. Additionally, indoor air concentrations have demonstrated to be highly variable both seasonally and daily. A more suitable method is maintaining a nominal pressure differential of .004" w.c. (1Pa) during adverse weather conditions. This may be continuously monitored through telemetry and is often preferred since continuous data demonstrates performance and lowers liability.**

2. Conclusions regarding system performance and its ability to meet the established mitigation levels.
3. If applicable, a description of any on-going monitoring related to previously implemented stopgap response actions.
4. The criteria and process for determining when system decommissioning is warranted.
Mitigation systems are to be considered a permanent component of the building until such time when it can be demonstrated that source removal or significant source depletion has occurred. This criteria should involve a 30 day shut down of the system during the heating season which would be defined from December 1 to March 1 and determined by soil gas samples collected after the system has been shut down for 25 days. During the shutdown period, precautions should be taken to protect mechanical equipment.

5. A plan describing system operation, maintenance, inspection, and monitoring should be developed that contains:
 - a. The names, phone numbers, and affiliations of the individuals responsible for completing these task and the contacts for securing building access.
 - b. A description of the operating procedures and parameters; system controls; monitoring program; and safety features. **This should include documenting the sealing completed as specified, the physical performance metrics such as pressure differential, applied vacuum at risers, airflow at risers, total system applied vacuum, total airflow discharge, power consumed by the blower at maximum and operational speeds, gate valve positions on individual risers, and other site-specific data that is considered to have operational relevance.**
 - c. Performance goals and measures to indicate the system is operating correctly and preventing unacceptable VI impacts.
 - d. System maintenance requirements.
 - e. Inspections for evaluating whether:
 - Building or foundation changes have occurred that could impact system performance.
 - System components are operating properly.

Note: Inspection protocols should be designed to confirm that the system has operated in accordance with established specifications. Changes to building ownership or use should also be assessed.

6. A description of the system monitoring, including:
 - a. Methods and frequency for verifying performance goals including indoor air concentrations. **It is recommended that inspections occur quarterly for the first year, and annually thereafter. In cases where pressure differential is measured using telemetry at the outer extent of the negative pressure field and other metrics such as applied system vacuum and power consumption, telemetry may be substituted for online quarterly inspections.**
 - b. Pressure measurements within the system and across the slab.
 - c. The party responsible for completing the various monitoring programs.
7. Contingency procedures for loss of power or system malfunction, including notification requirements. **Due to power requirements of SSDS blowers, it is not reasonable to maintain backup power for these systems. Most power outages are short lived, SSD systems reach down vertically into the vadose zone, the floors are sealed and passive**

venting will maintain some level of convective flow. Telemetric notification of power outage related malfunctions is an advisable option.

8. The timing for the next system performance report.
9. Standard Operating Procedures (SOPs) used for performance monitoring. **These SOPs should include all of the metrics above in section 6.4**

6.7 Terminating and decommissioning the system

As discussed in Section 5.3.2 and Section 6.4, mitigation design plans should include the criteria and process for ending the system's operation. This recommendation primarily applies to active systems, as well as to mitigation achieved by making HVAC adjustments to provide positive building pressure. Once indoor air quality is protected from VI impacts, operation can be terminated.

To avoid terminating a system's operation prematurely and potentially exposing indoor receptors to unacceptable VI impacts, compliance with CLARC's soil gas screening levels is recommended. As discussed in Chapter 3, there are certain scenarios where VI screening levels may not be conservative enough, such as when subsurface conduits are present.

In general, decommissioning should not be done concurrently with terminating system operation, but should be considered only after data confirm that unacceptable VI impacts are no longer occurring. There should be a high degree of certainty that future mitigation won't be necessary before taking this final step.

The process for terminating operation of the mitigation system and (when applicable) implementing decommissioning, needs to involve the building owner, since there could be many reasons why they may not agree with the approach. In situations like this, the communications between the person responsible for site cleanup and the building owner should focus on developing a mutual understanding about:

- Which on-going tasks will continue to be performed, and
- Who has future liability responsibilities associated with the continued presence of the system, whether it is operating or not.

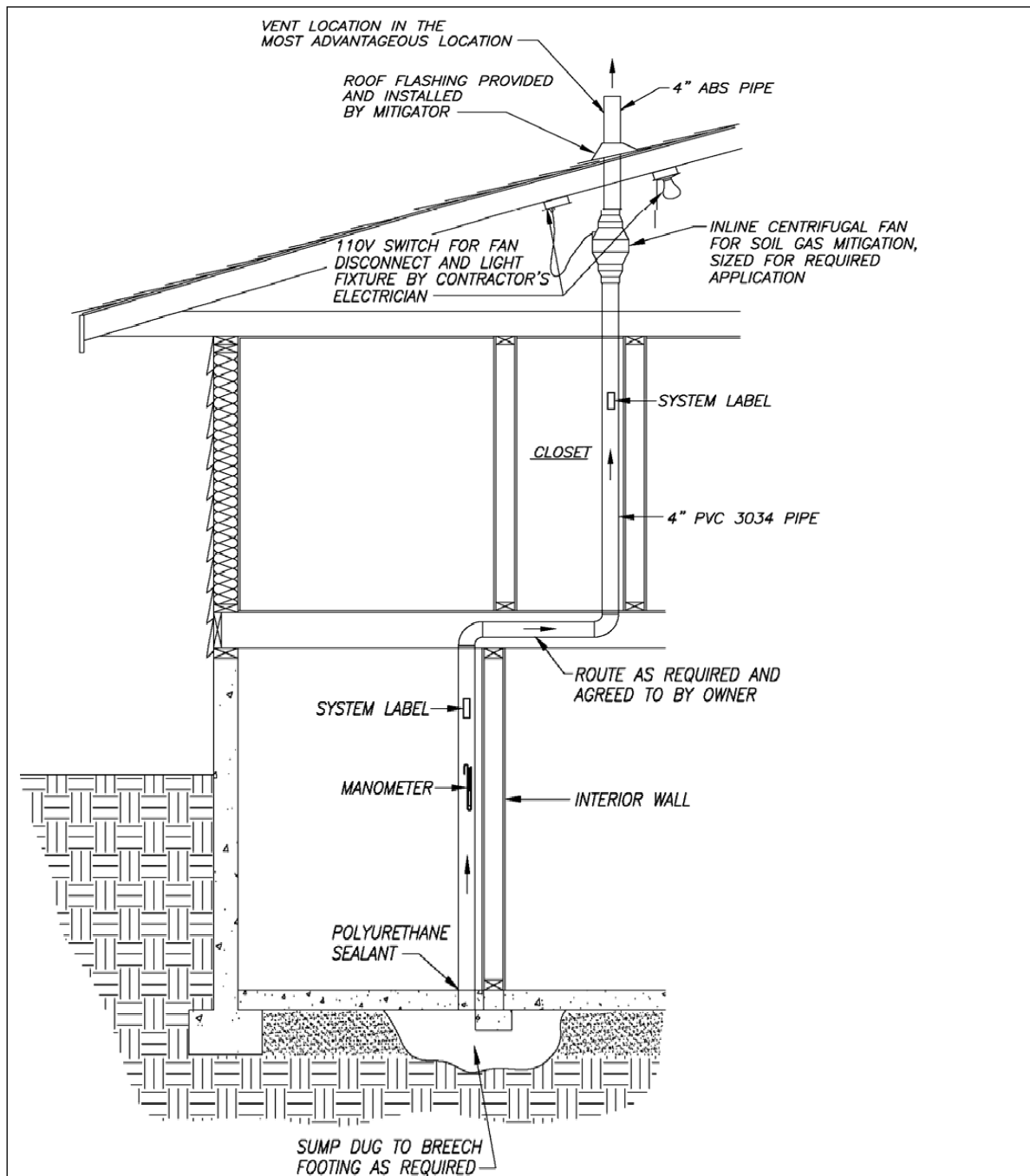


Figure 7: Residential Cross-section of a sub-slab depressurization system. Source: Tri-Services Handbook for the Assessment of the Vapor Intrusion Pathway (February 2008). **Note:** Installing a mitigation fan in the attic is an option only if the attic is not—and will not be—occupied.

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Chapter 7: Completing VI Cleanup Actions

7.0 Introduction

Remedial action will be needed if vapor intrusion from subsurface contamination still threatens indoor air quality, even after a mitigation system is installed.

Ecology does not expect mitigation systems to achieve VI media cleanup or screening levels (with the exception of indoor air levels that protect building occupants). If subsurface contamination causes an exceedance of the applicable indoor air cleanup levels, remedial action will be necessary to address the source of contamination, even if a mitigation system was installed to prevent unacceptable exposures. This chapter discusses issues that should be considered when implementing and completing cleanup at a site where contamination poses, or potentially poses, an unacceptable threat to indoor air quality from VI.

7.1 Establishing media cleanup standards for the VI pathway

For the VI exposure pathway, acceptable air quality occurs when the contribution from VI and any emissions from site remediation activities do not exceed the appropriate Method B or Method C air cleanup levels.

WAC [173-340-750](#)⁷⁶ provides a process for establishing Method B *unrestricted* (residential) air cleanup levels and Method C (industrial) air cleanup levels. Method B is the default process for calculating acceptable indoor air levels, while Method C is only applicable when the building of concern is located on an “industrial” property as defined in WAC [173-340-200](#)⁷⁷ and [-745](#),⁷⁸ and the receptors are industrial workers.⁷⁹ Ecology has calculated both Method B and C indoor air cleanup levels, which are available in the [CLARC VI data tables](#).⁸⁰

The MTCA Cleanup Rule (Chapter 173-340 WAC) does not contain a specific process for establishing groundwater, soil, or soil gas cleanup levels protective of indoor air. However the CLARC groundwater and soil gas VI screening levels discussed in Chapter 3 are based on the cleanup levels for each of the volatile compounds and are included in the data tables referenced

⁷⁶ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-750> (Cleanup standards to protect air quality.)

⁷⁷ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-200> (Definitions.)

⁷⁸ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-745> (Soil cleanup standards for industrial properties)

⁷⁹ Method C also applies to manholes or underground vaults where worker exposure is the concern.

⁸⁰ On a site-specific basis, Ecology may require more stringent cleanup levels than specified in the CLARC database when it's necessary to protect other beneficial uses or protect human health and the environment. Ecology's imposition of more stringent requirements must comply with WAC 173-340-702 (General policies) and 173-340-708 (Human health risk assessment procedures).

above. These screening levels can be used to help ensure that the subsurface media cleanup levels are protective of indoor air from VI.

At sites where subsurface contamination is limited to petroleum hydrocarbons, Appendix B should be used to determine the potential for VI. This often results in concluding that the contamination will not unacceptably impact indoor air. When a site cannot be screened out using this process, establish groundwater and soil cleanup levels as recommended in this Chapter and Appendix E.

7.1.1 Establishing groundwater cleanup standards

When groundwater cleanup levels are protective of drinking water beneficial use, the concentrations will often be low enough to protect indoor air quality, and most Method B groundwater VI screening levels in CLARC are above the applicable drinking water standards. However, there are several common substances that have groundwater VI screening levels lower than the drinking water cleanup levels.⁸¹ When these substances are present, it will be necessary to either a) gather additional evidence (typically soil gas data) to document that the source is not strong enough to cause an exceedance of the indoor air cleanup levels, or b) adjust the groundwater cleanup levels downward.

Note: If contamination remains after you've completed the cleanup and there is no building present, it becomes more difficult to determine whether VI could be an issue in the future. Appendix E has a discussion on future land use related to petroleum contamination, and many of those concepts can be applied to sites with other types of contamination. One option for addressing future building construction is to use an environmental covenant (if approved by Ecology) that requires evaluating the VI pathway before constructing a new building. This could result in more sampling based on the location and configuration of the building, or installation of a VI barrier as part of the construction.

If preferential pathways are present that could allow vapors to migrate near or directly inside a building (see discussion in Section 3.1.1), then the groundwater screening levels may not be conservative enough to prevent an exceedance of indoor air cleanup levels. The potential for preferential pathways should be evaluated during the Tier 1 process.

Establishing VI protective groundwater cleanup standards requires selecting a groundwater point of compliance, as well as groundwater cleanup level concentrations. Unlike points of compliance chosen for groundwater, the vertical point of compliance for VI protection does not need to extend throughout the water column. Only the shallowest zone of groundwater contamination (that is, at or near the water table, or in a shallow perched zone) can volatilize and contaminate soil gas.

⁸¹ Examples include benzene; 1,2- DCE; naphthalene; xylene; and trichloroethene.

When a conditional point of compliance is established, groundwater cleanup levels must be achieved only at this location and all areas downgradient. If upgradient areas of groundwater contamination include VOC concentrations higher than VI groundwater screening levels, the cleanup action will need to incorporate institutional controls and (if necessary) engineered controls to protect indoor air from unacceptable VI impacts.

At those sites with vadose zone soil contamination, establishing groundwater cleanup standards will not necessarily prevent VI from unacceptably impacting indoor air. The standards are only applicable when contamination is limited to the saturated zone.

7.1.2 Establishing soil cleanup standards

Section 740 of the MTCA Cleanup Rule outlines the unrestricted land use soil cleanup standards and WAC 173-340-740(3)(b)(iii)(C)(III) states:

(C) Soil vapors. The soil to vapor pathway shall be evaluated for volatile organic compounds whenever any of the following conditions exist:

(III) For other volatile organic compounds, including petroleum components, whenever the concentration is significantly higher than a concentration derived for protection of ground water for drinking water beneficial use under WAC 173-340-747(4).

In general, soil cleanup levels established to be protective of groundwater under WAC 173-340-747(4) will be considered sufficiently protective of the VI pathway. However, soil contamination can also impact indoor air quality directly through volatilization from the vadose zone. Soil cleanup levels must be established to address both pathways.

Although the term “significantly higher” is used in multiple places throughout the MTCA Cleanup Rule, it is not defined in the Model Toxics Control Act. As discussed in [Implementation Memo No. 15](#),⁸² Ecology generally considers benzene and TPH-Gx concentrations are not significant if they are less than three (3) times the Method A soil cleanup levels for unrestricted land use, as long as the selected remedial action results in only limited contaminant mass remaining in the soil. This assessment would need to be on a site-specific basis.

In situations where soil contaminant concentrations that remain after implementing a cleanup action are significantly higher than soil cleanup levels derived for protection of groundwater as drinking water, additional evaluation will be necessary to determine next steps. In most cases, this will be soil gas sampling to assess whether the remaining contamination is sufficient to cause exceedances of the soil gas screening levels.

CLARC does not contain VI screening levels for bulk soils. When the vadose zone is contaminated with VOCs, the next step is typically collecting soil gas samples and comparing the results to applicable screening levels. If the results are below screening levels, the existing

⁸² <https://apps.ecology.wa.gov/publications/SummaryPages/1609047.html> (FAQs on empirical demonstrations and related issues)

soil impacts will not likely pose an unacceptable VI threat. The exception to this approach is when a petroleum release has occurred and benzene and TPH are present in the soil. Appendix B provides soil screening values that should be used for these constituents.

7.1.3 Establishing cleanup standards when there are multiple VOCs or pathways of exposure

When multiple volatile organic compounds are present, the total VI-related indoor cancer risk or hazards may exceed the thresholds in Chapter 173-340 WAC, even if all the measured concentrations are below their respective cleanup levels (see Sections 3.8 and 4.12 in this guidance for more discussion). In situations like these, it may be necessary to adjust the cleanup levels downward to ensure that indoor air quality is adequately protected. The approaches to consider include:

1. **Soil.** When Method B is used to establish soil cleanup levels (CULs), use the process in WAC [173-340-740\(5\)\(a\)](#).⁸³ When Method C establishes CULs, use WAC [173-340-745\(6\)\(a\)](#).⁸⁴
2. **Groundwater.** Use the process in WAC [173-340-720\(7\)\(a\)](#).⁸⁵

Although this guidance focuses on vapor intrusion, all viable exposure pathways must be assessed during the site investigation process. It is possible that an indoor receptor who is breathing air impacted by VI may also be exposed through another route, such as consuming contaminated groundwater. When multiple pathways are likely to expose receptors in a non-mutually exclusive manner, cleanup levels will likely need to be adjusted downward to ensure that cumulative risks are acceptable.

⁸³ <https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-740> (Unrestricted land use soil cleanup standards.)

⁸⁴ <https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-745> (Soil cleanup standards for industrial properties.)

⁸⁵ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-720> (Groundwater cleanup standards)

7.2 Other considerations when establishing media cleanup standards

Related issues can affect the process to develop media cleanup standards. This section provides additional direction on those issues.

7.2.1 Soil gas sampling to verify VI protectiveness

The MTCA Cleanup Rule does not contain requirements for calculating or achieving soil gas cleanup standards. However, the CLARC data tables provide both Method B and C soil gas screening levels, which in most cases will be protective of indoor air quality. While these screening levels are not cleanup levels, they can often be used to demonstrate whether the selected soil and groundwater cleanup levels are sufficiently protective of indoor air quality.

It may also be possible to show that even though the selected soil and groundwater cleanup levels have not yet been met, the soil gas screening levels have been attained and the VI pathway has been adequately protected.

Like the groundwater screening levels in CLARC, soil gas screening levels apply to most site and building conditions. However, when preferential pathways are present, the soil gas screening levels may not be protective of indoor air quality. See Section 3.1.1 for more discussion.

7.2.2 Indoor air sampling to verify VI protectiveness

Ecology is frequently asked, if the measured indoor air concentrations are below the appropriate cleanup levels, but the soil and groundwater cleanup levels have not yet been achieved, why is any additional VI work necessary? The reason is found in WAC [173-340-702\(4\)](#)⁸⁶ which specifies that cleanup standards and cleanup actions shall be established to protect human health and the environment **for current and potential site and resource uses**.

Many factors could affect whether indoor air concentrations remain protective over the long term such as:

- Modifications to or replacement of the existing structure.
- Changes to the types of occupants present and how long they typically spend in the building.
- Modifications to the building's heating, ventilation and air conditioning system.

Measurements of indoor air VOC concentrations should not be used as the sole method to demonstrate protectiveness, since changes identified above could cause exceedances of the established indoor air cleanup levels. These exceedances would not be detected without

⁸⁶ <https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-702> (General policies.)

ongoing monitoring, which the party responsible for site cleanup may not want to continue. For this reason, Ecology recommends using subsurface screening levels and other compliance measurements to help minimize the potential for unacceptable VI impacts.

7.2.3 Indoor air cleanup levels different than those in the CLARC data tables

Ecology uses vapor attenuation factors (VAFs) to calculate groundwater and soil gas screening levels that are consistent with those recommended by EPA. The EPA VAFs are based on VOC measurements from co-located groundwater, soil gas, and indoor air data points from a large number of residential buildings at multiple cleanup sites.

In most situations, the VAFs will be conservative and result in more attenuation between the levels present in groundwater and soil gas, and the levels detected in indoor air. This occurs because the VAFs:

- Have been intentionally selected to under predict attenuation for most buildings, and
- Are based on sampling results from chlorinated compounds and therefore don't account for enhanced attenuation from aerobic biodegradation. Many volatile petroleum compounds are known to significantly degrade in this manner when sufficient oxygen is present in the vadose zone.

Rather than use the conservative non-site specific VAFs, responsible parties can establish VI protective cleanup levels based on site-specific VAFs.⁸⁷ Some options for developing these VAFs include the following and are briefly discussed below:

- Empirically deriving the values from site measurements of VOCs in multiple media, and
- Using a predictive model to estimate the values.

Empirically deriving site-specific VAFs.

A VAF can be calculated if co-located data for groundwater, soil gas, and indoor air are available, which most Tier 2 evaluations will provide. However, many factors can influence the data used for calculating a VAF such as:

- contaminant type and concentration
- slab thickness
- building size and configuration
- underlying soil conditions

⁸⁷ For volatile petroleum hydrocarbons, the methodology for determining if subsurface contamination can potentially result in unacceptable VI impacts is described in Appendix B. This approach does not require developing or using VAFs.

These variable components will generally result in a calculated building-specific VAF. It is possible that at relatively large VI sites, a sizeable database of co-located sampling data will be available. In such situations, it may be possible to use the information to derive site-specific VAFs for buildings that have similar characteristics but no available data. This effort is likely to be challenging as any site-specific VAF used for establishing cleanup levels must be shown to be representative and sufficiently conservative.

Deriving site-specific VAFs using a predictive model.

Predictive models can be used during a Tier 1 evaluation to provide another line of evidence when evaluating the potential for VI. The VAFs generated by these models are likely to be lower than the VAFs Ecology uses to calculate soil gas and groundwater screening levels. Without measuring VOC levels in indoor air, it is difficult to be certain that the model's VAF predictions are reasonably conservative, and for this reason, Ecology recommends that model predictions not be used as the primary justification for a VI screen-out decision. For the same reason, model predictions of protective subsurface screening levels should not be used.

7.3 Ensuring long-term protectiveness from VI

VI evaluations during a site investigation differ from VI-related remedial actions in two general respects: present vs. future building use and at what stage mitigation happens.

During a site investigation, a VI evaluation focuses primarily on *existing* buildings and whether VI impacts need to be mitigated. If necessary, mitigation is usually implemented through an interim action.

Conversely, addressing VI concerns as part of the site cleanup action not only focuses on existing buildings, but also on *future* actions like new building construction, or significant modifications to existing structures, or changes to the types of occupants present.

To ensure that cleanup actions are protective of both current and future uses, one of these two options should be implemented:

1. Achieve subsurface levels low enough that VI is unlikely to result in indoor air concentrations higher than the air cleanup levels, or
2. Use institutional controls, and if needed engineered controls, to assure that VI will not result in indoor air cleanup level exceedances.

When establishing a site's cleanup levels, cleanup actions are limited to unrestricted and industrial exposure situations. The criteria for establishing Method C air cleanup levels are different than the provisions for Method B cleanup levels. Specifically, WAC 173-340-750(4)(b) requires that Standard Method C "ambient air" cleanup levels must be met. Ecology recommends consulting our staff before basing VI cleanup decisions on the hope of attaining Method C air cleanup levels.

7.3.1 Institutional controls

The term “institutional controls” refers to non-engineered measures to limit or prohibit activities that may interfere with the integrity of an interim action or cleanup action, or result in exposure to hazardous substances at the site. WAC [173-340-440](#)⁸⁸ outlines the regulatory requirements for establishing institutional controls. This section discusses why certain controls may be needed at sites where VI is a concern or potential concern.

In some cases, the site investigation will conclude that there is no potential for unacceptable VI impacts, regardless of whether buildings are present or could be constructed in the future. This usually occurs when a) subsurface VOC concentrations are below Ecology’s VI screening levels and b) there are no limitations, such as preferential pathways, to using these levels. It could also occur if the contamination is limited to petroleum releases and the methodology set out in Appendix B indicates VI impacts are unlikely. At other sites, the cleanup action will address the VI pathway by quickly and effectively reducing the strength of the source.

For the sites described above, there is likely no need for VI-related controls to protect human health or the integrity of the site remedy. However, when the subsurface contamination cannot be addressed quickly or still remains after implementing the remedial action, controls will either need to be included as part of the cleanup action or at least be considered for inclusion. Some examples of when institutional controls may be needed:

Structural modifications. Depending on the modification, VI impacts to indoor air could be increased and potentially result in unacceptable indoor air VOC levels. Institutional controls can be designed to require that Ecology is notified before any significant changes are implemented, and a new VI evaluation is completed after the modifications are done.

Building use. If redevelopment of the property results in building occupants changing from workers to residents, a VI evaluation may be needed to ensure that new receptors are protected.

HVAC system modifications. Evaluate whether the change enhances the potential for VI related indoor air contamination.

Change in chemical use. Provide notification to Ecology when one or more chemicals are no longer being used, the presence of which had prevented a complete VI evaluation.

Denial of access. Provide for notification to Ecology if the previous property owner denied access for Tier 2 sampling or mitigation.

New building construction. Provide for notification to Ecology when a new building is planned to be constructed in close proximity to contamination that remains at the site. In this case, either a new evaluation will be necessary to determine if VI will pose a problem, or a mitigation system will need to be part of the new construction.

⁸⁸ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-440> (Institutional controls.)

A number of the examples above specify that Ecology be notified when certain changes are planned. Depending on the specific situation, it may be necessary to obtain Ecology's approval prior to implementing the proposed change.

Note: When contamination remains after completion of the cleanup, it can be difficult to determine whether VI could be an issue if future buildings were constructed in the area. Appendix E contains a discussion on future land use related to petroleum impacts and many of the concepts can be applied to sites with other types of contaminants.

Protecting receptors at the site is key. If one or more of the above scenarios apply, site specific decisions should be made as to whether an institutional control is necessary to ensure continued receptor protection. Whenever the circumstances listed below are applicable, WAC 173-340-440 requires the establishment of institutional controls:

- There is an inability to achieve Method A or B soil or groundwater cleanup levels.
- Engineering controls are implemented to protect the VI pathway.
- Method C is used to establish cleanup levels.
- A conditional groundwater point of compliance is established.

7.3.2 Environmental covenants

In some cases, legal instruments such as environmental covenants can be used to establish the protections that must be implemented or maintained to minimize potential VI impacts. Examples of protections might be continued operation of a vapor mitigation system or restrictions on new building construction without prior approval from Ecology. However, environmental covenants cannot always be established quickly. For example, when groundwater contamination has migrated off the source property, downgradient property owners who are not potentially liable persons may be hesitant to file covenants that place restrictions on their property.

7.3.3 Other controls

Another kind of common land use restriction is a zoning designation that often applies to multiple properties within an area. Enforcement and permit tools, such as administrative orders and Consent Decrees, can also contain institutional control components that limit or require the performance of certain activities. If the potentially liable person is under an order or consent decree, or is a RCRA owner/operator with a permit, legal instruments like these may be appropriate to require VI-related actions in the future. In some cases, the instruments may just serve as a temporary means of control that would be effective until VI-protective cleanup levels are achieved or environmental covenants are recorded.

Finally, “informational devices” such as public notifications and public advisories can also be useful. While they typically do not provide enforceable restrictions, they can help provide additional protection when used in conjunction with the other scenarios described throughout Section 7.3

7.4 Addressing buildings with large volumes of indoor air

Commercial buildings often have higher volumes of indoor air and higher indoor air exchange rates (AERs), which can result in more dilution of contaminants than for residential structures. AERs can vary considerably because HVAC systems may operate differently depending on the time of day, weather conditions, and activities happening inside the building. In general, AERs are higher when employees are present.

Some HVAC systems can be designed to induce positive indoor air pressures. This could result in certain commercial buildings, or parts of buildings, being positively pressurized with respect to the subsurface at the time the building’s indoor air is sampled. As a result, determining whether the selected remedial action has been sufficient for large commercial buildings usually requires that at least one sampling event be conducted during periods of cold ambient air temperatures when the building is being heated. During other times of the year, sampling should occur when the HVAC system is not operating, in order to avoid the potential for the building to be pressurized, thus temporarily minimizing the effects of VI.

Note: The pressure-driven volumetric flow rate of soil gas into a typical residential home is often estimated to be about 5 liters/minute. For commercial buildings that are considerably larger than the average home, flow rates are generally much higher. When evaluating potential VI affects, you should consider the higher flow rates in conjunction with the larger volumes of air present and the effect of the HVAC system.

Glossary

| Term | Definition |
|-------------------------------------|---|
| action level | The concentration of a hazardous substance in indoor air that may pose short-term risks to potential receptors. Action levels are not MTCA Method B or C air cleanup levels. |
| advective | Movement of a compound with flowing air or water. |
| ambient air | Outdoor air, but does not include the air within a building's crawl space. |
| back drafting | A current of air that flows backwards down a pipe or other conduit. |
| cleanup actions | A subset of remedial actions. Any remedial action, except interim actions, taken at a site to eliminate, render less toxic, stabilize, contain, immobilize, isolate, treat, destroy, or remove a hazardous substance that complies with WAC 173-340-350 through 173-340-390. |
| cleanup level | The concentration of a hazardous substance in soil, water, air, or sediment that is determined to be protective of human health and the environment under specified exposure conditions (WAC 173-340-200). |
| cleanup site | Also known as a contaminated site or hazardous waste site. |
| Consent decree or decree | A legal document issued under Chapter 70A.305 RCW or the federal cleanup law. |
| contaminated site | Also known as a hazardous waste site or cleanup site. Any site that Ecology has confirmed a release or a threatened release of a hazardous substance requiring remedial action (WAC 173-340-200). ⁸⁹ As of May 1, 2021, Ecology identified 13,698 contaminated sites in Washington state. |
| environmental covenant | A legal document that puts institutional controls into place, and often used when contamination remains on a site. It outlines restraints on how a property can be used or developed to ensure human health is protected at the site. |
| groundwater | Water in a saturated zone or stratum beneath the surface of land or below a surface water. |
| hazardous waste site | Also known as a contaminated site or cleanup site. |
| independent remedial actions | Conducted by property owners on their own or with technical assistance from Ecology or the Pollution Liability Insurance Agency (PLIA). |
| Institutional control | A prohibition of certain activities that could expose people to hazardous substance remaining at a site, or impact a cleanup's integrity over time. For example, an institutional control might restrict new building construction in an area where residual contamination remains until an updated VI evaluation is completed. |

⁸⁹ Ecology expects to replace the phrase "hazardous waste site" with "contaminated site" in the MTCA Cleanup Rule when rule changes are adopted in 2022 (Chapter 173-340 WAC, Rulemaking No. 1).

| Term | Definition |
|---|--|
| lateral inclusion zone | The area surrounding a contaminant source through which vapor phase contamination might travel and intrude into buildings. |
| Model Toxics Control Act (MTCA statute) | Washington’s environmental cleanup law, Chapter 70A.305 RCW |
| Model Toxics Control Act Regulations (MTCA Cleanup Rule) | Washington’s regulations that set standards and procedures for cleaning up contaminated sites Chapter 173-340 WAC. This is one of two cleanup rules in Washington adopted under the Model Toxics Control Act, Chapter 70A.305 RCW. The other rule is the Sediment Management Standards (Chapter 173-204 WAC), known as the SMS Cleanup Rule. |
| order | A legal document that includes enforcement orders and agreed orders issued under MTCA, and unilateral administrative orders and administrative orders on consent issued under the federal cleanup law (WAC 173-322A-100 (33)). |
| perched groundwater | Unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone. It occurs when subsurface water percolating downward is held by a bed or lens of low-permeability material. |
| receptor | A person potentially affected by VI, generally an occupant of a building. |
| remedial actions | Any action or expenditure consistent with the purposes of MTCA to identify, eliminate, or minimize any threat posed by hazardous substances to human health or the environment (WAC 173-322A-100 (45)). For example, all steps in the MTCA cleanup process ⁹⁰ are considered remedial actions, from discovery and initial investigation through de-listing. Compare to “cleanup action.” |
| rule, also called regulations | A law adopted by an executive branch agency (such as the Department of Ecology) under the authority of a statute to carry out programs authorized or directed by the statute. Rules specify procedures and set standards and other requirements to implement a statutory program. Rules are developed and enacted through a rulemaking process specified in statute. The public process allows stakeholders to participate in the creation of rules. Agencies can’t exceed their statutory authority when adopting rules, and rules can’t change statutes. Rules can clarify confusing or unclear statutory directives. Washington’s Legislature and voters can change rules by passing new bills or initiatives. The Washington Administrative Code (WAC) codifies rules and arranges them by subject or agency |
| screening level | The concentration of a hazardous substance derived from standardized equations that if exceeded may result in indoor air concentrations above the applicable cleanup level. |
| sorbent tubes (Method TO-17) | Glass tubes containing material that adsorbs chemicals in vapor or air for subsequent analysis using EPA’s TO-17 analytical method. |

⁹⁰ <https://ecology.wa.gov/Spills-Cleanup/Contamination-cleanup/Cleanup-process>

| Term | Definition |
|---|---|
| spatial variability | The measured concentration of a contaminant varies over the sampling area being evaluated. |
| statute | A law passed by the Legislature in a bill or by voters in an initiative. Statutes usually direct or authorize the establishment and implementation of government programs (such as Ecology's Remedial Action Grant Program). Agencies (such as Ecology) are part of the executive branch of state government, and are tasked with carrying out the programs directed or authorized by statute. To carry out these programs, agencies are usually authorized by statute to adopt rules. The Revised Code of Washington (RCW) codifies statutes and arranges them by subject. |
| sub-slab sampling | Sampling of soil gas immediately below the building's lowest floor |
| subsurface contamination | Soils, groundwater, soil gas, or vapors contaminated by hazardous substance releases, including non-aqueous phase liquids (NAPLs) |
| subsurface remediation | Any cleanup action taken to reduce soil gas volatile organic compound (VOC) levels. |
| Summa canisters (Method TO-15) | A stainless steel device that uses a vacuum to collect vapor or air samples. The collected sample is analyzed using EPA's TO-15 analytical method. |
| temporal variability | The variation of chemical concentrations at a uniform sampling location over time. |
| total petroleum hydrocarbons (TPH) | A term describing any mixture of hydrocarbons that are derived from the refining of crude oil. |
| vadose zone | Also known as the unsaturated zone and extends to the top of the water table, where the water in the soil pores are at atmospheric pressure. |
| vapor intrusion | Migration of hazardous volatile chemicals from the subsurface into the indoor air of nearby buildings. |
| vapor intrusion mitigation | Actions that reduce VI-caused indoor air contamination. |
| weight of evidence approach | A method for decision making that involves consideration of multiple sources of information and lines of evidence. |
| What's in My Neighborhood | Toxics Cleanup Program's interactive map of cleanup sites in Washington state. https://apps.ecology.wa.gov/neighborhood/ |

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Appendix A: Vapor Intrusion (VI) Investigations and Short-term Trichloroethene (TCE) Toxicity

A-1 Introduction

Appendix A provides recommendations for addressing the VI pathway at sites contaminated with TCE and discusses:

- Indoor air action levels that are protective of short-term exposures to TCE.
- Default (non-site-specific) subsurface VI screening levels that are protective of the short-term indoor air TCE action levels.
- Options for effectively and rapidly responding to those situations where TCE concentrations in indoor air from VI are above action levels.
- A goal to keep indoor air TCE concentrations from VI below short-term action levels.
- Public notification and other outreach-related tasks that responsible parties should perform when VI may be resulting in indoor air concentrations that exceed action levels.

Information in this Appendix assumes that Ecology is directly involved at the site. Section A-5.2 provides recommended steps that should be followed by the parties performing independent site investigation and cleanup.⁹¹

A-2 Background

In 2014, EPA concluded that short-term inhalation exposures to TCE in indoor air have the potential to cause serious heart defects in a developing fetus.⁹² The damage can occur early in a pregnancy, possibly before the pregnancy is recognized. This Appendix focuses on issues that are specific to situations where short-term TCE exposures are occurring or likely to be occurring. These issues are:

⁹¹ In later portions of Appendix A, we use the term “responsible party” to refer to the party who is conducting remedial actions at the site. In many cases, the responsible party will be a person meeting the statutory definition of a “potentially liable person” (see RCW [70A.305.040](#)).

⁹² (USEPA 2014) *Memorandum: Compilation of Information Relating to Early/Interim Actions at Superfund Sites and the TCE IRIS Assessment*.

1. **Response speed.** Actions to protect a fetus from unacceptable TCE exposures should occur as rapidly as possible after discovering the contamination, usually within days or weeks, depending on the likelihood and degree of potential exposure.
2. **Focus on women of childbearing age (which includes pregnant women).** The developing fetus is sensitive to the effects of short-term TCE exposure, and preventing harm to the fetus relies on reducing the mother's exposure.
3. **Public outreach.** Promptly contacting people who live and work near TCE contamination is crucial for three reasons: 1) to identify women of childbearing age; 2) to explain the potential health hazards to building occupants and, 3) if warranted by site-specific conditions, to obtain permission to access buildings for property-specific investigation and exposure-reduction activities. Whenever possible, outreach activities should be conducted in collaboration with public health departments.

This degree of urgency, and the need for more intensive outreach to specific individuals, is not typically required at most MTCA sites. These three issues are further discussed in Sections A-4 through A-6.

A-3 VI screening and action levels for TCE

A-3.1 Indoor air action levels for TCE

A **screening level** is the concentration of a hazardous substance derived from standardized equations that if exceeded may result in indoor air concentrations above the applicable cleanup level. A **cleanup level** is the concentration of a hazardous substance in soil, water, air, or sediment that is determined to be protective of human health and the environment under specified exposure conditions (WAC [173-340-200](#)).⁹³ An **action level** is the concentration of a hazardous substance in indoor air that may pose short-term risks to potential receptors. Action levels are not MTCA Method B or C air cleanup levels.

Indoor air cleanup levels for TCE are provided in the [CLARC Air data tables](#).⁹⁴ Cleanup levels are used during Tier 1 and Tier 2 evaluations to determine whether further sampling, interim actions, or cleanup actions are indicated. The concentrations for indoor air cleanup levels are the same as for standard cancer and non-cancer Method B and C air cleanup levels in CLARC's Air data tables.

Air cleanup levels for TCE are lower than indoor air action levels. Cleanup levels apply to long-term average air concentrations (over at least one year) for the entire population, all genders and ages. Short-term indoor air action levels, on the other hand, only apply to three-week average concentrations for women of childbearing age.

⁹³ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-200> (Definitions.)

⁹⁴ Cleanup Levels and Risk Calculation (CLARC). <https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Contamination-clean-up-tools/CLARC/Data-tables>

The average indoor air TCE concentration due to vapor intrusion over **any** three-week interval should not exceed the applicable action level.

VI indoor air cleanup levels for long-term TCE exposures, and action levels for short-term exposures to women of childbearing age, are provided in Tables A-1 and A-2 below. The table's indoor air cleanup and action levels are compared to average indoor air TCE concentrations that result solely from VI. In some cases, this means that contributions to indoor air measurements from non-VI sources, such as outdoor or indoor sources, will need to be distinguished from contributions due solely to subsurface sources.

The short-term action levels for TCE in Table A-2 are based on values recommended by EPA Region 10 (memorandum dated December 13, 2012) and EPA Region 9 (memorandum dated July 9, 2014).⁹⁵ The Region 10 memorandum from 2012 states that, pursuant to an IRIS toxicological review, exposure to TCE can cause fetal cardiac malformations during a 21-day gestation window. To protect against the possibility of this occurring, the average concentration of TCE in residential indoor air should not exceed 2.0 µg/m³ during any consecutive 21-day period in a given year. For commercial / industrial settings, where receptors of concern are workers, indoor air TCE should not exceed 8 µg/m³. The Region 9 memorandum identifies “accelerated” and “urgent response action levels” for residents and workers. The “accelerated” levels range from 2 to 8 µg/m³; the “urgent” levels vary from 6 to 24 µg/m³. The range of levels for both categories accounts for the varied lengths of time that receptors are expected to be exposed.

Table A-1: Vapor intrusion TCE Indoor Air Cleanup Levels, chronic (mean long-term air concentration for RME receptor)*

| Level of Concern | Concentration (µg/m ³) | Risk Basis |
|----------------------------------|------------------------------------|-------------------|
| Method B (unrestricted land use) | 0.37 | Cancer risk 1E-6 |
| Method B (unrestricted land use) | 0.91 | Hazard quotient 1 |
| Method C (industrial land use) | 6.3 | Cancer risk 1E-5 |
| Method C (industrial land use) | 2.0 | Hazard quotient 1 |

* These values are available in CLARC (Ecology 2018a).

Table A-2: Vapor intrusion TCE Indoor Air Action Levels, short-term (maximum 3-week mean concentration for women of childbearing age)

| Level of Concern | Concentration (µg/m ³) | Risk Basis |
|---|------------------------------------|---|
| Unrestricted (residential) land use | 2.0 | Noncarcinogenic effect based on 24 hours/day, 7 days/week |
| Workplace scenario (commercial or industrial) | 7.5 | Noncarcinogenic effect based on 45-hour work week |

⁹⁵ For the Region 9 and 10 memoranda, see Ecology's Vapor Intrusion webpage at <https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Vapor-intrusion-overview>

A number of other EPA Regions and states, including Massachusetts, New Jersey, New Hampshire, Minnesota, Ohio, Alaska, and Connecticut, have also adopted short-term TCE levels and recommended responses. The levels and response timeframes vary.

Consistent with guidance from EPA Region 10, TCE action levels in Table A-2 are intended to be compared to the highest measured (or estimated) VI-caused indoor air levels averaged over any 21-day period. It is unknown whether potential fetal health effects from an exposure to action level concentrations could occur over a period less than three weeks, or whether shorter periods would only be harmful if TCE concentrations were significantly higher than action levels.

Given this uncertainty, Ecology recommends that, if any 24-hour or 8-hour measurements of average indoor air TCE concentrations exceed Table A-2's action levels (for residents or workers, respectively), **take prompt action**. This could include either reducing those concentrations or reducing the degree to which women of childbearing age are exposed. Ecology will revisit this recommendation as more information becomes available about the health effects attributable to short-term TCE exposures.

Table A-2 provides short-term TCE indoor air action levels for residential land use and commercial/industrial workers.

- The residential concentration is intended to protect women of childbearing age who reside in the building and are continuously exposed to indoor air contaminated by VI.
- The commercial/industrial concentration is protective of women of childbearing age who work full-time shifts up to 45 hours per week.⁹⁶
- However, other women of childbearing age who occupy a building where VI is occurring may also be receptors of concern. For example, building visitors, part-time workers, and students could also be potentially be exposed to contaminated indoor air over extended periods of time.

Use the short-term action levels in Table A-2 to determine whether prompt and protective measures like interim actions should be implemented (see [WAC 173-340-430](#)).⁹⁷ Remember that **action levels are not MTCA Method B or C air cleanup levels** and that the MTCA cleanup regulations require that cleanup levels be established for one of two specific land uses: *unrestricted* or *industrial* site use.

⁹⁶ This paragraph refers to the protection of the developing fetus. Exposures to TCE can also potentially affect the health of women themselves and this should be assessed using the indoor air cleanup levels in the CLARC data tables, not the short-term action levels.

⁹⁷ <https://app.leg.wa.gov/wac/default.aspx?cite=173-340-430>

A-3.2 VI short-term screening levels for TCE in groundwater and soil gas

CLARC's data tables also provide groundwater and soil gas screening levels that can be used to assess the potential for chronic exposure threats posed by a subsurface source.

CLARC's groundwater screening levels are intended to be protective of corresponding indoor air cleanup levels, and assume there will be 1,000-times attenuation between groundwater VOC concentrations (in equilibrium with vapor concentrations) and indoor air levels.

CLARC's sub-slab soil gas screening levels are also expected to be protective of indoor air cleanup levels. They assume there will be 33-times attenuation between soil gas VOC concentrations just below a building's slab and indoor air levels. (For further discussion on attenuation factors, see the note box following Table A-4.)

VI groundwater and sub-slab soil gas screening levels protective of short-term TCE indoor air action levels are presented in Tables A-3 and A-4 below. These screening levels embody the same attenuation assumptions used to calculate the chronic subsurface screening levels provided in CLARC (as discussed above). In summary:

- The short-term VI screening levels for groundwater and soil gas are higher than CLARC's VI TCE cleanup levels, which are calculated for chronic indoor exposures.
- For residential buildings, the short-term screening level for groundwater is about twice as high as CLARC's chronic-based non-carcinogenic screening level (8 µg/L versus 3.8 µg/L, respectively), and approximately five times higher than CLARC's carcinogenic screening level (8 µg/L versus 1.6 µg/L).
- Similarly, the short-term screening level for TCE in soil gas is about twice as high as CLARC's chronic-based non-carcinogenic sub-slab screening level (67 µg/m³ versus 31 µg/m³), and a little more than five times higher than CLARC's carcinogenic sub-slab screening level (67 µg/m³ versus 12 µg/m³).

Table A-2. Vapor intrusion subsurface screening levels for groundwater for short-term exposures to TCE

| Short-term TCE Subsurface Screening Levels | Concentration | Basis |
|---|----------------------|--|
| residential short-term VI screening level for groundwater | 8 µg/L | <ul style="list-style-type: none"> • TCE as a non-carcinogen • receptor of concern: women of childbearing age • residential indoor scenarios |
| non-residential short-term VI screening level for groundwater | 31 µg/L | <ul style="list-style-type: none"> • TCE as a non-carcinogen • receptor of concern: women of childbearing age • commercial/industrial workplace scenarios |

Table A-3: Vapor intrusion subsurface screening levels for soil gas for short-term exposures to TCE

| Short-term TCE Subsurface Screening Levels | Concentration | Basis |
|---|-----------------------------|--|
| residential short-term VI screening level for sub-slab soil gas | 67 µg/m³ | <ul style="list-style-type: none"> • TCE as a non-carcinogen • receptor of concern: women of childbearing age • residential indoor scenarios |
| non-residential short-term VI screening level for sub-slab soil gas | 250 µg/m³ | <ul style="list-style-type: none"> • TCE as a non-carcinogen • receptor of concern: women of childbearing age • commercial/industrial workplace scenarios |

Note: The 2009 Draft VI Guidance had differentiated between the amount of attenuation that should be assumed for soil gas VOC concentrations that are located immediately below the building (like sub-slab), versus those concentrations that are at significantly greater distances below ground surface (called “deep”). CLARC’s VI data tables also make this distinction. “Deep” soil gas screening levels in CLARC assume 100-times attenuation between soil gas VOC concentrations and indoor air levels. This distinction was based on the approach set out in EPA’s 2002 Vapor Intrusion guidance.

However, EPA’s [Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface vapor sources to indoor air](#)⁹⁸ (USEPA June 2015) does not recommend that soil gas levels be assumed to attenuate more than 33 times, regardless of depth. As a result, Ecology has now eliminated the use of deep soil gas VI screening levels.

A-4 VI Investigation

This section provides site investigation recommendations when short-term inhalation exposures to TCE from VI are a potential concern.

A-4.1 Identify any buildings where VI may result in indoor TCE concentrations above the short-term action level.

Note:

- **Section A-4.1’s** discussion assumes that indoor air sampling for TCE has not been conducted.
- If indoor air has already been sampled, and indoor TCE concentrations due to VI exceed the applicable short-term action level, see the appropriate responses described in **Section A-5**.
- If indoor air was sampled and TCE concentration measurements were below the short-term action level, the VI assessment team should determine whether those measurements represent the highest 3-week average indoor TCE concentration. See **Section A-4.4** for additional discussion.

Determining which buildings are a potential concern is commonly accomplished by mapping site areas where TCE is, or may be, present in soils or shallow groundwater. Buildings above or close to these areas can then be identified. In parts of the site where soils are contaminated

⁹⁸ <https://www.epa.gov/vaporintrusion/technical-guide-assessing-and-mitigating-vapor-intrusion-pathway-subsurface-vapor>

with TCE, soil gas samples are typically collected and analyzed.⁹⁹ CLARC's VI soil gas screening levels the short-term soil gas screening levels in Tables A-2 and A3 can then be used to determine if VI could potentially result in indoor air cleanup level or action level exceedances (respectively) at nearby buildings.

Regardless of whether the potential subsurface VI source is contaminated soil or shallow groundwater, investigators can collect soil gas samples below or near a building and use the measured TCE levels to determine the potential for an indoor exceedance of indoor air cleanup levels and/or action levels. However, if TCE concentrations in shallow groundwater are above CLARC's VI screening levels, or if significant soil contamination or residual non-aqueous phase liquid (NAPL) is close to a building and likely to contain elevated TCE concentrations, investigators should not delay indoor air sampling (see Section A-4.3). When these conditions are present, the first indoor sampling event(s) should be a priority and performed immediately, without waiting for a preliminary soil gas investigation.¹⁰⁰

In areas where soils are not contaminated and shallow groundwater is the only potential VI source, investigators can use groundwater VI screening levels in CLARC and short-term groundwater screening levels in Tables A-2 and A-3 to distinguish between buildings where VI could potentially result in exceedances of indoor air cleanup (chronic) or action (short-term) levels, and those where exceedances are highly unlikely.

In addition to the exceedance of subsurface VI screening levels, there may be other building- or site-specific reasons for suspecting that indoor air TCE concentrations could exceed the short-term action level. For instance, at some building locations, contaminated shallow groundwater may be the only potential VI source and TCE concentrations in this groundwater may be below the short-term screening level. However, the short-term groundwater screening levels assume a certain amount of attenuation and dilution of vapor-phase TCE between the groundwater surface and the indoor environment. While these are conservative assumptions for most buildings, they may not be if:

- There are preferential subsurface pathways that may result in higher soil gas VOC levels below the building than the short-term groundwater screening levels assume, or if

⁹⁹ *De minimis* levels of TCE in vadose zone soils (i.e., above the seasonal low water table) are unlikely to pose a VI threat. WAC [173-340-740\(3\)\(b\)\(iii\)\(C\)\(III\)](#) defines such levels as concentrations no higher than concentrations "derived for protection of groundwater for drinking water beneficial use under WAC [173-340-747\(4\)](#)." Concluding that TCE levels in soils are this low requires adequate characterization of vadose zone contamination.

¹⁰⁰ Ecology does not recommend that soil gas sampling be *initiated* at this point to determine if TCE concentrations exceed short-term soil gas screening levels. This is because it takes time to prepare (and approve) soil gas Sampling and Analysis Plans (SAPs); obtain access; schedule and mobilize the related work; and review the sampling results. Indoor air sampling should not be delayed while these activities are being performed. It is prudent to obtain soil gas data during or immediately following the first indoor air sampling event.

- There may be a higher soil gas flowrate into the building than the short-term groundwater and soil gas screening levels assume.¹⁰¹

A-4.2 Notify and involve Ecology

This Appendix presumes that Ecology will be involved throughout the VI evaluation process, including owner/tenant notifications, the initial building visit, indoor air sampling, data analysis, and post-sampling decision making described in the rest of this section and Sections A-5 and A-6. The recommended actions and decisions identified below are therefore intended for both the party conducting the remedial actions (the responsible party) and Ecology.¹⁰² However, when responsible parties are acting independently and choose not to involve Ecology during some or all of these actions and decisions, they should complete the applicable and recommended steps themselves.

Regardless of whether Ecology oversees the site throughout the cleanup process, or whether another party independently conducts the remedial actions, the following should occur:

1. Ecology should be contacted as soon as the responsible party determines that women of childbearing age are current building occupants and indoor air sampling is needed to assess the potential for a short-term TCE action level exceedance (see Section A-4.3 below).
2. If an Ecology staff person has already been assigned to the site, this individual should be notified. Otherwise, the responsible party should contact their local Ecology regional office. They should not wait for Ecology's response before moving to the next steps of the investigation / response process. Find Ecology's contact information at <https://ecology.wa.gov/About-us/Get-involved/Report-an-environmental-issue>

¹⁰¹ The short-term groundwater screening levels assume that vapor-phase TCE concentrations will attenuate by a factor of 1000 between soil gas levels immediately above and in equilibrium with contaminated groundwater and indoor air. This is generally a conservative assumption, but may over-predict the degree of subsurface attenuation in certain cases, such as sites with a shallow water table, or sites with subsurface conduits capable of transporting elevated soil gas levels to areas directly below the building with minimal attenuation.

The short-term soil gas screening levels assume that vapor-phase TCE concentrations will attenuate by a factor of at least 33 times between soil gas levels immediately below the building and indoor air. This is usually a conservative assumption, but less attenuation is possible if the building or its foundation allows soil gas to enter interior spaces relatively unimpeded. This can occur when slab or basement wall penetrations or large cracks provide preferential conduits for entry.

¹⁰² As noted in Section 1.1, "PLP" in this Guidance broadly refers to the individual or party responsible for cleaning up the site. It is not intended to limit responsibility to only those who are designated as PLPs per RCW [70A.305.040](#). Instead, it is a general reference to the *responsible party*.

A-4.3 Prepare for indoor air sampling

As soon as one or more site buildings have been identified as a location where VI may potentially result in indoor air TCE concentrations above the short-term action level, investigators should quickly plan for the next steps of the evaluation, unless they confirm that women of childbearing age do not regularly occupy the buildings. At this point in the investigation, it is only *potentially possible* that indoor TCE concentrations actually exceed the action level, but several actions should occur without delay including:

1. **Contact building owner and/or tenant.** The owner/tenant of the building should be contacted to determine if women of childbearing age are current occupants, and to schedule a building and property visit. This initial contact should occur soon after the building has been identified as potentially at risk. The owner and tenant(s) of these buildings should be notified that there is the *possibility* that VI-caused indoor air TCE concentrations exceed the acceptable chronic and/or short-term screening/action levels.
2. **Schedule a building visit.** If women of childbearing age are current building occupants, a building visit should be scheduled as soon as possible. During this visit Ecology and the responsible party need to be prepared to discuss the potential TCE risk, explain next steps, and answer exposure-related and other questions.¹⁰³ If the responsible party does not own the building, they should also be prepared at this time to request building access for the purpose of collecting indoor air samples. Interactions with building owners and tenants preceding indoor air sampling are further discussed in Section A-6.0.
3. **Prepare and finalize a SAP.** Following the visit to the building and property, an indoor air Sampling and Analysis Plan (SAP) should be expeditiously prepared, reviewed, and finalized.¹⁰⁴ The SAP should identify the timeframes for gathering and reviewing the data. The SAP should also include a site/building-specific VI conceptual site model (CSM) that serves as the basis for selecting data quality objectives and sampling design. The VI CSM is a combination of information, assumptions, and hypotheses that investigators use to help evaluate the adequacy of available site-specific information, and guide the identification of critical data gaps. The VI CSM is discussed in Section 2.4 of this guidance and Section 5.4 of EPA's 2015 *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (USEPA June 2015).

¹⁰³ Please see VI-related risk communications in Section A-6.1.

¹⁰⁴ This assumes that: a) an exceedance of the short-term TCE indoor air action level has not yet been measured, and b) the responsible party has decided not to pursue a "preemptive" response action. If an exceedance of the action level has already been measured, no additional pre-mitigation sampling may be needed. See Section A-5.0 for a description of appropriate response actions.

Preemptive mitigation is a term often used to describe VI mitigation efforts implemented without (or prior to) confirmation that VI-caused indoor air contamination exceeds acceptable levels. When preemptive mitigation has been chosen as the next step in Section A-4.3, indoor air sampling is not typically conducted until after mitigation has been implemented. Section 7.8 of EPA's OSWER VI guidance document (USEPA June 2015) provides additional information about preemptive mitigation.

- **Schedule indoor air sampling.** Immediately schedule the first indoor air sampling event as soon as the SAP is final. . It should not be delayed to coincide with more desirable seasonal or meteorological conditions.¹⁰⁵

A-4.4 Determine if 3-week average indoor air TCE concentrations exceed the short-term action level.

For those buildings occupied by women of childbearing age, the VI investigation should provide sufficient information to determine whether 3-week average indoor air TCE concentrations ever exceed the short-term action level. A single indoor air sampling event is unlikely to provide evidence of it unless it coincides with a period when maximum VI impacts are occurring. This is because VI impacts can vary significantly over time, and because this variability cannot be easily predicted. As a result, it is very difficult to schedule an indoor sampling event that represents the highest 3-week average unless the sampling program is designed to intentionally create near-maximum VI conditions.¹⁰⁶ Unless the first sampling event finds TCE concentrations exceeding the short-term indoor air action level, the investigation will need multiple sampling events.

When the receptor of concern is a current occupant of the building, and air samples are being analyzed at an off-site laboratory, request expedited turnaround times. For at least the first sampling event, the goal should be to receive the laboratory's sampling data within three business days.

Immediately after the data have been received, share with members of the decision-making team including the Ecology site manager.¹⁰⁷ For at least the first indoor air sampling event, the goal should be to distribute the results to the decision-making team within seven days of sample collection. The objective of the decision-making team's review is to quickly determine if: 1) the relevant TCE short-term indoor air action levels listed in Table A-1 are being exceeded, and 2) VI is the likely cause.

The immediate review, and the decisions arising from that review, will not have the benefit of a sampling-data quality assessment or validation. These activities will typically occur later, when the results of the sampling event are being integrated into a VI evaluation report. It is possible that a later assessment of data quality will lead to a conclusion that VI is *not* causing short-term indoor air action level exceedances, and that the earlier determination was incorrect. However, if the receptors of concern are current occupants of the building, the importance of providing

¹⁰⁵ Additional sampling events may be necessary even if the measured indoor air concentrations were less than cleanup levels.

¹⁰⁶ Sections 4.5.1 and 4.10 of this Guidance provide additional direction for mechanically creating negative pressures within a building.

¹⁰⁷ If an Ecology site manager has not been assigned to the project, send the results to the designated Regional contact.

timely information to those receptors should outweigh the potential that the information provided might later need to be revised.

This section (A-4) is specifically devoted to recommendations related to the potential for *short-term* inhalation exposures to TCE. As discussed in Section A-3, CLARC's VI indoor air cleanup levels for TCE are lower concentrations than action levels established to be protective of short-term indoor exposures. This is because the indoor air cleanup levels in CLARC are based on chronic VI-caused exposures. Therefore, remedial actions such as VI mitigation may be needed to protect long-term indoor exposures, regardless of whether the short-term indoor air TCE action level is exceeded.

A-5 Responding to exceedances of the short-term TCE indoor air action level

If VI is causing an exceedance of the TCE short-term indoor air action level, prompt action is needed. Such actions should be taken in consultation with the building's owner (and tenant, if applicable). Protecting people inside affected buildings is a high priority and action should not be delayed. If follow-up indoor air or other sampling is scheduled before the selected action is fully implemented, this sampling must be conducted in a manner that does not interfere with efforts to quickly and effectively reduce indoor exposures to TCE.

A-5.1 Systems for mitigating vapor intrusion

VI *mitigation* generally refers to actions that reduce VI-caused indoor air contamination, and the focus is often on reducing the amount of contaminated soil gas entering the building.¹⁰⁸ Mitigation systems creating **depressurization** of the sub-slab zone or crawl space will often be the most effective approach for reducing VI impacts (until subsurface cleanup permanently remediates the source of elevated soil gas concentrations). However, these types of systems can take weeks to design, construct, and fully implement. Additional time is then needed to demonstrate that target VOC concentrations in indoor air have actually been achieved.

Active VI mitigation systems such as sub-slab and sub-membrane depressurization are often able to reduce VI-caused TCE indoor air contamination to concentrations below the short-term action levels. But before the mitigation system has been successfully implemented, TCE action levels can be exceeded. If a woman of childbearing age lives or works in an area of the building where elevated TCE concentrations are present and does not relocate, she will continue to be exposed. Mitigation should therefore be designed, constructed, and implemented as quickly as

¹⁰⁸ Subsurface *remediation*, on the other hand, includes cleanup actions designed to reduce soil gas VOC levels. Although these actions will also reduce VI-caused indoor air contamination, they are not typically referred to as VI "mitigation" unless they can be successfully implemented within a relatively short timeframe.

possible,¹⁰⁹ and other actions considered that would effectively reduce exposures during the interim.

A-5.2 EPA-recommended actions and MTCA cleanups

Prompt actions to reduce TCE exposures include the recommended responses described in EPA Region 9's [2014 TCE Memorandum](#)¹¹⁰ under two headings: "Implementation of early or interim measures to mitigate TCE inhalation exposure," and "Tiered response actions" (USEPA 2014a). Many of EPA's recommendations in these sections are appropriate guides for selecting proper response actions in Washington state. However, Ecology has clarified three of the Region 9 recommendations in terms of their applicability at MTCA cleanup sites:

1. EPA's recommendation to increase building pressurization/ventilation.

Ecology: Positively pressurizing the building (with respect to the subsurface) can create a pressure barrier to advective flow of soil gas into the structure and mitigate VI impacts. However, it will not always be possible or sufficiently effective. Likewise, increasing ventilation can dilute VI impacts if the outdoor-to-indoor air exchange rate is increased. But it may not be practicable to increase the ventilation rate enough to reduce indoor air TCE below cleanup/action levels. Moreover, if the methods to increase the outdoor-to-indoor air exchange rate result in greater building depressurization, VI impacts may actually be exacerbated. Regardless, follow-up monitoring of indoor air quality should be performed to ensure TCE concentrations have been reduced to an acceptable level.

2. EPA's recommendation to seal potential conduits.

Ecology: It is possible that a single foundation or building feature is primarily responsible for the degree of vapor intrusion, leading to short-term indoor air TCE action level exceedances. For instance, there could be an uncovered earthen floor in part of the building, an unsealed basement sump, a disconnected floor drain, or an unsealed utility line penetration at ground level or sub-grade. If the building has a crawl space, there could be unsealed first floor openings around pipes or wiring that run between the two levels. The crawl space could also be walled-in, preventing any significant sub-floor ventilation and dilution of soil gas emissions.

Often, however, it won't be obvious where the most significant soil gas entry points are located. For this reason, consider using a portable field sampling device to identify these locations, and then subsequently implementing conduit-sealing measures to limit this influence.

¹⁰⁹ A qualified individual or firm should be identified early, which is often during the planning phase of the investigation.

¹¹⁰ Available on Ecology's website at <https://ecology.wa.gov/DOE/files/4f/4fb8c34a-f785-41f7-8dea-e2ee341a31a2.pdf>

If a portable device isn't used, Ecology recommends promptly initiating sealing efforts that are:

- a. Focused on any easily observable and obvious major routes by which soil gas is likely entering the building;
- b. Only undertaken as the initial response if the sealing activity can be completed quickly; and
- c. Promptly followed up with indoor air sampling to verify the sealing's effectiveness.

3. EPA's recommendation to respond differently, based on whether the "urgent" response action level has been exceeded.

Ecology: The EPA Region 9 Memorandum states that the response to exceeding an "accelerated" action level should be "completed and confirmed within a few weeks." If the higher "urgent" action level is also exceeded, the response time should be reduced to "a few days."

Ecology agrees that, all else being equal, there should be a greater sense of urgency when TCE concentrations are much higher than the short-term action level established for the site and building. It is also true that the types of responses likely to be effective will often partly depend on how high the indoor air TCE concentrations are. **But Ecology believes any exceedance of the short-term action level merits prompt action.**

This means that if VI is causing an exceedance of the TCE short-term indoor air action level, quickly consult with the building's owner (and if applicable, the tenant) and determine which action will be taken. The goal should be to reduce TCE exposures for women of childbearing age as soon as possible. This may require that a "stopgap" response be taken right away, while plans for long-term mitigation proceed on a parallel track. Stopgap responses include temporarily relocating the receptor, and/or installing effective indoor air treatment.

Carbon-based indoor air VOC treatment devices, sometimes referred to as air purification units (APUs) or "air cleaners," can be installed relatively quickly. These devices can be used for extended periods, but their typical VI application is temporary use. They are often operated only while a more permanent form of mitigation is being designed/constructed. As discussed in EPA's 2017 *Engineering Issue*¹¹¹ that describes these devices, indoor air treatment can be accomplished with portable air cleaning units or HVAC in-duct systems (USEPA 2017). The former usually employs a built-in air circulation fan and carbon sorbent bed.

¹¹¹ Engineering Issue (USEPA 2017) at https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=337835

Indoor air treatment devices may not always be able to quickly reduce TCE concentrations to acceptable levels. Regardless of which treatment device is selected, investigators cannot assume that the installed unit will *sustainably* reduce indoor air TCE to concentrations below the short-term action level. As noted in the 2017 *Engineering Issue*, this must be confirmed with air sampling.¹¹²

A-6 Working with people who are affected by vapor intrusion

This section discusses interactions with the owners and occupants of buildings where vapor intrusion is, or may be, contaminating indoor air with TCE.

In the simplest case, the building is a single-family residence owned by the occupants. The responsible party and Ecology are then interacting primarily with a head of household.

But the property where the building is located will not always be owned by the responsible party, and other scenarios will also be common, such as:

- a. The building is a single-family residence where the owner resides elsewhere.
- b. The building is occupied by a single business, which also owns the property.
- c. The building is occupied by a single business, which does not own the property or building.
- d. The building is occupied by multiple businesses, none or only one of which owns the property or building.

Throughout this Appendix, we've used the term "building owners/tenants" when referring to notifications, access requests, information sharing, and other interactions with the affected public. We use this term for simplicity, but recognize that owners are not always building occupants and receptors, and building occupants are not always owners or tenants. Women of childbearing age who occupy a building could be owners, tenants, employees or other workers, students, or visitors.

For communication purposes, it is helpful for the responsible party and Ecology to have no more than two designated "building contacts." Communications about scheduling building visits,

¹¹² In the EPA 2017 *Engineering Issue* discussion of treatment systems, Attachment A lists a large number of VOC air cleaners by brand name. In 2014, the California DTSC reported the use of Air Rhino and AirMedic Vocab stand-alone air purifiers. The New Hampshire Department of Environmental Services and Massachusetts Department of Environmental Protection reported the use of portable Austin HealthMate units in 2015 and 2016, respectively. (See "TCE Vapor Intrusion Case Study" presented at the 2015 NEWMOA conference, <http://www.newmoa.org/events/event.cfm?m=157> and the October 2016 Field Assessment and Support Team (FAST): "An Expedited Approach to the Investigation and Mitigation of the Vapor Intrusion Pathway").

Ecology does not endorse these particular products. We include these references here only to indicate that the products have been used in at least three states to reduce VI-caused indoor air contamination.

obtaining access, sharing sampling data and data evaluations, and consultations concerning any response actions, can then be limited to a small number of individuals (who may or may not be potential “receptors”). It will be incumbent upon these building contacts to not only disseminate the information they receive from the responsible party and Ecology to (other) building occupants who are potentially being exposed, but to relay those occupants’ concerns and questions back to the decision makers.

A-6.1 Outreach before indoor air sampling

As discussed in Section A-4.1, any site building where VI may potentially result in indoor TCE concentrations above the short-term action level should be identified based on subsurface sampling and other site data. When women of childbearing age are occupants in these buildings, perform the planning, notification, and pre-sampling activities described in Section A-4.3. This includes visiting the building itself.

In addition to obtaining the building and receptor-behavior information usually needed to prepare a VI indoor air SAP, during building visits Ecology and the responsible party should:¹¹³

1. Verify whether women of childbearing age regularly occupy the building. If they do (especially for non-residential buildings), ascertain which areas these women spend most of their time, and the hours they are typically present in the building.
2. Determine if women of childbearing age may be occupants in the foreseeable future, even if they aren’t currently present.
3. Discuss site contamination and how vapor intrusion can potentially contaminate indoor air; discuss next steps and the need for sampling access; and answer their questions.

During the building visit, Ecology and the responsible party will need to be prepared for questions the occupants may have regarding potential short- and long-term TCE health effects and how to reduce their exposures. Decisions should be made during the planning period (described in Section A-4.3) about how and when this information should be provided, and who should communicate it.

Pursuant to health-related VI questions, Ecology staff are expected to answer only the most basic health-related VI questions. Routinely refer the public to local health departments or their family physicians for answers to questions that require toxicological or medical expertise.

Washington’s state and local health departments are generally more familiar with local communities and their concerns than Ecology site management staff. Health departments also have more expertise at conveying health-related information. If women of childbearing age are

¹¹³ As noted in Section A-4.2, Appendix A assumes that Ecology will be involved throughout the VI evaluation process. When this is not the case, parties performing the site investigation and cleanup should independently complete the recommended steps outlined in this Appendix.

potentially exposed to site-related TCE contamination, it is recommended that site managers and the responsible party rapidly coordinate with state/local health departments. These agencies can better explain the potential health hazards to building occupants and/or help gain access to buildings for investigation and remediation if needed. If Ecology has assigned a Community Outreach and Environmental Education Specialist (COEES) to the site, the site manager should also confer with this individual during the pre-sampling period.¹¹⁴

Before any indoor air sampling can occur, the party performing that sampling must obtain owner/tenant consent.¹¹⁵ Typically during VI investigations, this consent is documented in an “access agreement,” which usually specifies the conditions under which access is granted. Finalizing an access agreement can be a lengthy process. Sometimes it is difficult to make timely contact with the building owner or tenant. Sometimes the owner will elect to get the advice of legal counsel before entering into an agreement. There can be protracted negotiations regarding considerations such as access-related payment, or other site-specific issues. While securing access is normally the duty of the responsible party, Ecology may become involved with disputes or delays when the health threat relates to a short-term exposure to site contamination. The parties must realize that Ecology will make best efforts, including – if needed – exercising its legal authorities, to ensure access agreements are finalized as soon as possible.

A-6.2 Outreach after indoor air sampling

Indoor air sampling results, together with other lines of evidence, should indicate whether VI is causing an exceedance of the TCE short-term indoor air action level. Once the indoor air sampling data have been received from the laboratory (assuming no “real time” sampling was performed), the responsible party and Ecology should: 1) discuss the results, 2) make a preliminary decision as to whether VI is likely to be resulting in a TCE short-term action level exceedance, 3) agree on next steps, then 4) contact the building owner/tenant.

As discussed in Section A-4.4, when women of childbearing age are current occupants of the building, this decision-making and outreach process should begin as soon as the data are initially received, without waiting for data quality assessment. In these cases, the goal should be to quickly determine the likelihood of a TCE short-term indoor air action level exceedance and then inform building owners/tenants of the sampling results. Unless owners, tenants, and other concerned building occupants would prefer to wait until the quality of sampling data has

¹¹⁴ Ecology’s COEESs are typically not assigned to independent cleanup sites or those in the Voluntary Cleanup Program (VCP). However, if a COEES has been assigned to a site where VI is causing or may potentially result in indoor TCE concentrations above the short-term action level, their assistance can improve communications with the owners, tenants, and occupants of the affected buildings, as well as other members of the concerned public.

¹¹⁵ With limited exceptions, such as emergency situations.

been rigorously assessed and validated, they should be notified of sampling results soon after results arrive from the laboratory.¹¹⁶

The responsible party and/or Ecology should tell the building owner/tenant what the sampling results indicate and what the next steps should be. During this discussion, it is important to:

1. Explain how the conclusions were reached.
2. Differentiate between what is known (e.g., the results from this single sampling event), what was inferred from the information collected, and what is not known.
3. Urge the owner/tenant to share and explain these results – as well as plans for follow-up actions – with concerned building occupants. This includes all women of childbearing age who live or work in affected portions of the building.

Coordinating with the site's assigned COEES and state/local health departments is critical at this stage and can improve the effectiveness of these communications.

If sampling data indicate that VI is likely to be causing an exceedance of the TCE short-term indoor air action level, and if a woman of childbearing age is a building occupant, quickly determine the proper response in consultation with the building's owner (and tenant, if applicable). Section A-5.0 lists various response actions that may apply. The selected action will depend on a number of building-specific factors, such as how high the indoor air TCE concentrations appear to be, and the preferences of the building's owner/tenant and receptors of concern. Promptly reaching and carrying out a mutually acceptable decision may require the involvement of state/local health departments.

If measured levels of indoor air TCE are below the action level, however, the next step may simply be to schedule a re-sampling event for the future.¹¹⁷

¹¹⁶ When the data are shared this quickly, the building occupants should be informed that implications of the sampling results could change after the data quality is evaluated. Also inform them that if the implications did change, the responsible party and/or Ecology would immediately notify the owner/tenant .

¹¹⁷ Typically, a sampling report is prepared after the data have been quality assured and validated. A copy of the report, and a copy of any Ecology response letter(s), should be provided to the building owner/tenant.

Appendix B: Process for Initially Assessing the Potential for Petroleum Vapor Intrusion (PVI)

B-1 Introduction

Appendix B provides guidance on how to initially assess whether VI is a potential concern at sites with petroleum contamination. The term “initially” is used throughout this appendix and refers to the portion of the VI assessment process for determining if VI is likely to be occurring and whether additional follow-up work is necessary. This will generally occur at the time a remedial investigation is being conducted to define the nature and extent of contamination at the site. When the screening criteria specified in this appendix are met, the initial assessment process is complete and the existing situation does not pose a current vapor intrusion threat.

If the initial assessment indicates existing conditions may pose a potential for petroleum vapor intrusion, then a Tier 1 and (if necessary) a Tier 2 evaluation should be completed. If the approved cleanup action results in contamination remaining on the site, further vapor assessment or potential restrictions on building use or new construction may be necessary. These situations are discussed in more detail in Appendix E.

B-2 Background

This appendix applies to releases of petroleum from underground storage tanks. The information can also be used for the initial screening of other petroleum releases of similar magnitude (e.g. small spills), as well as for releases from home heating oil tanks. When working with large releases such as those from bulk tank farms, this appendix should only be used with concurrence from the Ecology cleanup project manager.

The screening criteria in Figure B-1 were developed based on information in EPA’s [*Evaluation of empirical data to support soil vapor intrusion screening criteria for petroleum hydrocarbon compounds*](#) (USEPA 2013b).¹¹⁸ The document contains an evaluation of VI sampling data from a large number of petroleum-contaminated sites. Based on this information, Ecology believes that using the empirical data to derive vertical separation distances is a reasonable approach for initially assessing the VI pathway at most sites impacted by petroleum. If a site can’t be screened out using the concentration and distance-based criteria, complete further investigation work using the applicable portions of Ecology’s Tier 1 and Tier 2 evaluation process.

¹¹⁸ https://www.epa.gov/sites/production/files/2014-09/documents/pvi_database_report.pdf

B-3 MTCA Cleanup Rule requirements regarding vapor intrusion

As discussed in Section 7.1.2, the MTCA Cleanup Rule specifies that the VI pathway be evaluated when soil concentrations are significantly higher than a concentration derived for the protection of groundwater. However, the phrase “significantly higher” is not defined in the rule. This provision should continue to be used for non-petroleum contaminants. However, when sites are only impacted by petroleum, the process outlined in this appendix should be used for the initial evaluation, which includes using the benzene and TPH soil screening levels provided in Figure B-1.

The MTCA Cleanup Rule also specifies that for sites with diesel contamination, the vapor pathway must be evaluated when TPH concentrations in soil are greater than 10,000 mg/kg. This concentration-based criteria was developed in the late 1990s as part of the 2001 MTCA rule revisions.

Since that time, additional research has been completed (particularly by the [Hawai'i Department of Health](#), HDOH 2012)¹¹⁹ that indicates a number of petroleum products including diesel have a significant amount of aliphatic compounds in the mixture. These compounds have much higher Henry's Law constants than either the aromatics or specific petroleum compounds such as BTEXN, and therefore may present a VI risk at concentrations lower than the 10,000 mg/kg level found in MTCA.

EPA's guidance uses a diesel TPH screening value of 250 mg/kg or greater as an indication that:

1. Light non-aqueous phase liquid (LNAPL) is present, and
2. Additional vertical separation is necessary between the contamination and any overlying structures.

Both EPA and the Hawai'i Department of Health recommend fully characterizing the fractions of TPH present to accurately assess the potential for vapor intrusion. Given existing research and the guidance developed by EPA, the VI pathway should routinely be evaluated even when soil TPH concentrations for diesel-range organics are below 10,000 mg/kg.

¹¹⁹ hawaiiidoh.org/references/HDOH_2012c.pdf via <http://hawaiiidoh.org/TGM.aspx?p=2600a.aspx>

B-4 Assessing the vapor intrusion pathway for sites with petroleum contamination

This section provides recommendations on how to assess the VI pathway when there are no other volatile contaminants besides petroleum. Each step is discussed below and summarized in the flowchart (Figure B-2).

Note: This process assumes that sufficient site characterization work has been performed to allow each step to be completed.

STEP 1: Confirm the release.

When a release of petroleum is suspected, confirm that a release has occurred. In most cases this will consist of soil and groundwater sampling to determine potential impacts to the environment, but occasionally it may be a qualitative assessment. A good discussion of options for completing this evaluation is found in Chapter 3 of Ecology's [Guidance for Remediation of Petroleum Contaminated Sites](#)¹²⁰ (Ecology 2016).

STEP 2: Determine if an immediate action is necessary.

While most sites do not pose safety concerns or acute exposure threats from vapor intrusion, there are several scenarios where this could be the case, as identified in Section 1.1. This VI guidance was not developed to respond to relatively rare situations such as these, and instead assumes that an immediate action is either unnecessary or has already been completed.

STEP 3: Characterize the site and develop a conceptual site model (CSM).

Conduct a site characterization and prepare a conceptual site model. If there are data gaps that prevent preparation of an adequate CSM, gather additional information and update the CSM accordingly. For more information, see Chapter 3 of EPA's technical guide, [Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites](#)¹²¹ (USEPA 2015).

STEP 4: Evaluate whether there are any contaminants besides petroleum.

If any volatile contaminants other than those typically found in petroleum are discovered, the site is typically not eligible to use this process for assessing the VI pathway. With the

¹²⁰ <https://apps.ecology.wa.gov/publications/SummaryPages/1009057.html>

¹²¹ <https://www.epa.gov/sites/production/files/2015-06/documents/pvi-guide-final-6-10-15.pdf> via <https://www.epa.gov/ust/technical-guide-addressing-petroleum-vapor-intrusion-leaking-underground-storage-tank-sites>

exception of polychlorinated biphenyls (PCB's) and Halogenated VOC's, the compounds in MTCA Table 830-1 are considered to be those "typically found in petroleum."

STEP 5: Determine if there are precluding factors.

"Precluding factors" are site conditions "that may justify a greater separation distance" during the vapor screening process (see EPA's *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (USEPA 2015) and [Evaluation of Empirical Data to Support Soil Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Compounds](#)¹²² (USEPA 2013b). Use the site characterization information and conceptual site model to determine if there are any factors like these, such as:

- a. Changing site conditions, such as an expanding plume or planned development above/adjacent to the contamination.
- b. Preferential pathways, such as utility corridors or highly permeable soil zones.
- c. Extremely low soil moisture content.¹²³
- d. Limited oxygen in the soil due to the presence of relatively impermeable ground cover surrounding the building of interest, large structures, or methanogenesis (due to the release of higher ethanol blends of gasoline or the presence of very high organic material in the soil).
- e. The presence of lead scavengers such as 1,2-dibromoethane (also known as ethylene dibromide or EDB) or 1,2-dichloroethane (also known as ethylene dichloride or EDC) in the released fuel.
- f. The presence of other additives in the released fuel that may aerobically biodegrade more slowly than benzene.
- g. Subsurface petroleum VOC contamination in direct contact with the building's foundation.

If precluding factors are present, the site may require additional characterization so evaluate whether using the screening criteria in Steps 6 and 7 would be appropriate. If it appears that one or more precluding factors could undermine the conservativeness of the distance-based screening criteria, Steps 6 and 7 would not be appropriate for assessing the VI pathway. Instead, use the Tier 1 or Tier 2 process to continue the evaluation.

¹²² https://www.epa.gov/sites/production/files/2014-09/documents/pvi_database_report.pdf

¹²³ EPA's guidance defines this as less than two percent (2%) soil moisture. This should only be a potential issue at some locations in Eastern Washington.

STEP 6: Determine if buildings are within the lateral inclusion zone.

The lateral inclusion zone is defined as the area surrounding a contaminant source through which vapor phase contamination might travel and intrude into buildings. Determining the lateral distance within which buildings or other structures might be threatened by petroleum vapors is a site-specific decision. EPA's petroleum VI guidance indicates that "though in theory the length of the lateral separation may be on the same scale as the vertical separation distance, a greater lateral distance is generally warranted in the down gradient direction because the lateral boundaries of a migrating plume are more difficult to accurately delineate, as they are not stationary."

EPA developed a technical paper that can be used to calculate a lateral inclusion zone: [An Approach for Developing Site-Specific Lateral and Vertical Inclusion Zones within which Structures Should be Evaluated for Petroleum Vapor Intrusion due to Releases of Motor Fuel from Underground Storage Tanks](#)¹²⁴ (USEPA 2013b). The paper provides an approach for calculating a lateral inclusion zone using the separation distances between clean monitoring points. ITRC's 2014 petroleum VI guidance, as well as numerous state agencies' vapor intrusion guidance documents, rely on a 30-foot horizontal separation distance from the edge of the contamination to provide an adequate separation distance.

Ecology recommends using the following criteria to determine which buildings need further evaluation:

If the degree and extent of contamination is well defined and the dissolved phase plume is stable or receding, then a horizontal separation distance of 30 feet is generally appropriate for establishing a lateral inclusion zone.

If limited site characterization information is available, then reference EPA's technical paper above to develop the lateral inclusion zone.

If no existing buildings are in the lateral inclusion zone, then the initial VI assessment process is complete.

STEP 7: Evaluate the vertical screening distances for buildings in the lateral inclusion zone.

Use the site characterization data and guidance contained in Chapter 5 of EPA's Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites (EPA June 2015) to determine the appropriate vertical separation distances. Table 3 (p. 52) of EPA's guidance contains the recommended vertical separation distances and is included as Figure B-1. If the vertical separation distance criteria are met, based on the measured soil and groundwater concentrations for benzene and TPH, then the initial VI assessment process is complete.

¹²⁴ <https://www.epa.gov/sites/production/files/2014-09/documents/epa600r13047.pdf>

STEP 8: Approach to use if the vertical screening distance criteria are not met.

If the site cannot be screened out because the applicable vertical separation distance has not been met, the next step is to complete a Tier 1 or Tier 2 evaluation as described in Chapters 3 and 4 respectively.

Table B-1: Recommended vertical separation distances between contamination and building basement floor, foundation, or crawl space surface.

| Media | Benzene | TPH | Vertical Separation Distance (feet)* |
|--------------------|-------------|--|--------------------------------------|
| Soil (mg/Kg) | ≤10 | ≤ 100 (unweathered gasoline), or ≤ 250 (weathered gasoline, diesel) | 6 |
| Soil (mg/Kg) | >10 (LNAPL) | > 100 (unweathered gasoline) >250 (weathered gasoline, diesel) | 15 |
| Groundwater (mg/L) | ≤5 | ≤30 | 6 |
| Groundwater (mg/L) | >5 (LNAPL) | >30 (LNAPL) | 15 |

The thresholds for LNAPL indicated in this table are indirect evidence of the presence of LNAPL. These thresholds may vary depending on site-specific conditions (e.g., soil type, LNAPL source). The value of 5 mg/L benzene is from EPA (2013a, p.31). A study by Peargin and Kolhatkar (2011) suggests that a dissolved source with benzene greater than 1 mg/L may behave like a LNAPL source in terms of vapor-generating capability.

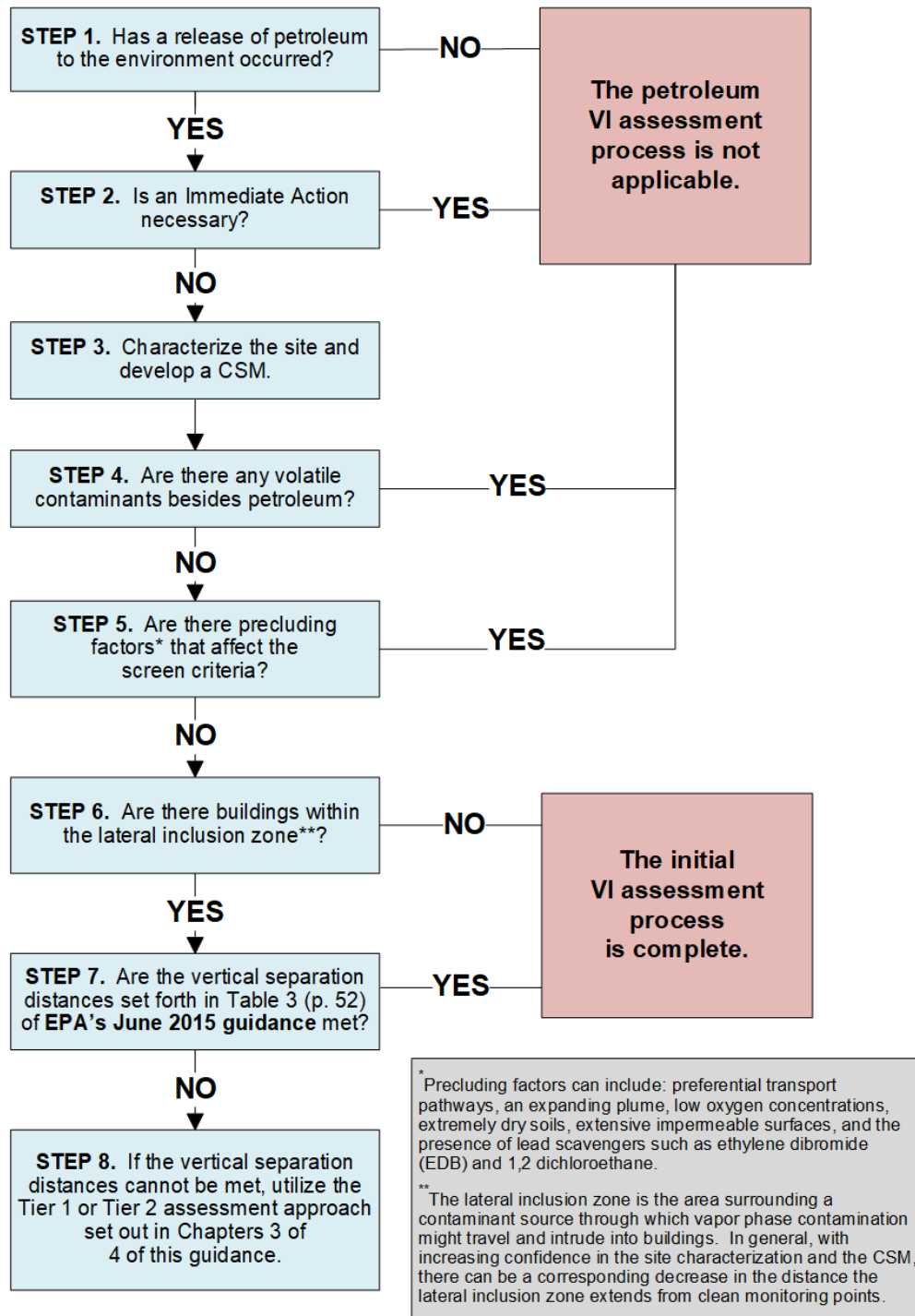
Bulk soil samples should be analyzed for Total Petroleum Hydrocarbon (TPH) and BTEX (plus any other potential contaminants). The objective of measuring TPH is to quantify the total vapor phase concentration of PHCs. See Table 830-1 in WAC 173-340-900 for more information on the specific testing requirements for petroleum releases.

*The vertical separation distance represents the thickness of clean, biologically active soil between the source of PHC vapors (LNAPL, residual LNAPL, or dissolved PHCs) and the lowest (deepest) point of a receptor (building basement floor, foundation, or crawl space surface).

Adapted from source: [Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites](#)¹²⁵ (USEPA 2015)

¹²⁵ <https://www.epa.gov/ust/technical-guide-addressing-petroleum-vapor-intrusion-leaking-underground-storage-tank-sites>

Figure B-2: Petroleum vapor intrusion decision making flowchart



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Appendix C: Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP)

C-1 Introduction

Appendix C provides a comprehensive list of the information that may be necessary when preparing a SAP and QAPP for gathering additional vapor intrusion data. Since data needs can vary widely, the scope of the effort should be tailored to the specific site and buildings being evaluated. In some cases, the necessary information will vary between individual buildings or the location on the site.

Note: As discussed in Section 3.1, your first step in the Tier 1 process should be to determine whether preferential pathways are present that could be potential vapor transport conduits to nearby buildings. If additional information is needed to complete this determination, that should be the initial focus of your data-gathering effort.

C-2 VI Sampling and Analysis Plan

The general requirements and expected content for SAPs are provided in WAC [173-340-820](https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-820).¹²⁶ The SAP should be designed based on the VI conceptual site model and address the critical data gaps that must be filled. For VI work being done under an order or consent decree, the SAP must be approved by Ecology before sampling and analysis can begin.

C-2.1 Tier 1 Evaluations

Tier 1 evaluations should typically provide the following information:

1. Statement of purpose and objectives of the investigation and assessment.
2. Address of the source property; and the name, address, and contact information of property owner and potentially liable person (PLP), if different than the property owner.
3. The VI conceptual site model serving as the basis for identifying the critical assessment data gaps; data quality objectives; and sampling design.
4. The volatile organic compounds (VOCs) of concern for the VI investigation.

¹²⁶ <https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-820> (Sampling and analysis plans)

5. The respective soil gas and groundwater screening levels protective of the applicable indoor air cleanup levels for all VOCs of concern.

Note: If TCE is a VOC of concern, include the soil gas and groundwater screening levels protective of the applicable short-term indoor air action level.

6. An identification and justification for all VOC sampling locations by media.
7. The number of sampling events, the parties responsible for the sampling and analytical tasks, and the projected schedule for when sampling will be conducted.
8. A description of the meteorological and other conditions under which sampling events will occur.
9. An identification and justification for all sampling and sample-handling methodologies.
10. The parameters to be sampled and analyzed, or otherwise measured. For those parameters to be measured in the field, an identification of the equipment that will be used.
11. For those samples collected for laboratory analysis, the analytical methods to be used.
12. A brief description of all field and other related activities that will be conducted following SAP finalization. This should include efforts to obtain access to the sampling area, if such access has not already been granted.
13. A schedule for performing the work described in the SAP.
14. Maps, figures, drawings, photographs, and tables needed to clarify SAP information or sampling-related proposals.
15. Appendices that include a copy of the executed access agreement, sampling-related SOPs, literature citations, and other references (if these are not already in the body of the SAP) and any calculations used as the basis for SAP proposals.

C-2.2 Tier 2 Evaluations

When a Tier 2 evaluation will be implemented, the SAP should be designed to provide sufficient information to determine whether indoor air concentrations caused by VI exceed the indoor air cleanup levels based on chronic exposures.

Note: For TCE, the SAP should also provide information to evaluate whether the short-term indoor air action levels are exceeded.

Tier 2 SAPs should typically contain the same information listed for Tier 1 evaluations (above) as well as the following:

1. Address of the property(ies), as well as name and contact information of the property owner, for all buildings from which indoor samples will be collected.
2. The applicable indoor air cleanup levels.

Note: If TCE is a VOC of concern, include the applicable short-term indoor air action level too.

3. Map showing the building floorplan and location where samples will be collected.
4. The meteorological and building conditions under which sampling events will occur. The SAP should identify whether the building will be occupied and heated/ventilated as would normally occur based on the time of year sampling is scheduled. If an alternative approach will be used, justification should be provided. If one or more sampling events are intended to produce indoor air VOC data representative of maximum or near-maximum VI impacts, the SAP should describe the meteorological and building conditions needed to achieve these results.

Note: Consider collecting cross-slab pressure measurements to help you determine whether soil gas migration into the building is occurring. If you pursue using alternative attenuation factors, you should include analysis for radon as part of the sampling protocol.

5. A description of how VOC sources other than from VI will be identified and what actions will be taken to minimize these contributions during indoor air sampling.
6. A description of all field and other related activities that were conducted prior to finalization of the SAP. This could include pre-sampling activities such as obtaining building access, notifying building occupants, and what process was used to identify and remove potential VOC sources from the building.
7. A summary of the information collected during building visits. Include a copy of any written day-of-sampling instructions that will be provided to building occupants. These items can be included in an Appendix.

C-3 Quality Assurance Project Plan

The QAPP for a vapor intrusion SAP should typically include:

1. A discussion of how Data Quality Indicators such as precision, accuracy, representativeness, comparability, sensitivity, and completeness will be determined and assessed.
2. A description of the quality assurance activities (such as field and laboratory quality control samples essential for ensuring that quality data are obtained).
3. A description of how the data will be reviewed, validated, and reported.
4. Sample handling and custody procedures.
5. A list or table of all analytical methods to be used, and identification of the lab(s) that will analyze the samples.
6. The anticipated reporting limits for all parameters that will be quantified.
7. For those times when soil gas samples will be collected and analyzed: identify which measures will be implemented that will ensure the resulting data are representative of the concentrations present.

Appendix D: Soil Gas Sampling for VI Evaluations

D-1 Introduction

This appendix summarizes techniques and methods for sampling soil gas during a Tier 1 or Tier 2 vapor intrusion evaluation. It provides fundamental information regarding soil gas sampling that should be considered when developing sampling plans and assessing study data.

However, many components of soil gas sampling can be technically complicated and require detailed Standard Operating Procedures (SOPs) that are beyond the scope of this guidance document. The references listed in Section D-5 of this Appendix can provide much of that technical detail.

The purpose of a Tier 1 evaluation is to determine if soil gas concentrations are high enough to pose a potential threat to current or future indoor air quality. At this point in the investigation, groundwater and soil sampling data have likely been used during the Preliminary Assessment to conclude that VI could be a pathway of concern. During a Tier 2 evaluation, sub-slab soil gas is routinely collected in conjunction with indoor and ambient air samples. The purpose of sampling sub-slab soil gas during the Tier 2 evaluation is to help determine the contribution VI is potentially making to the measured indoor air concentrations.

D-2 Sub-slab soil gas sampling

“Sub-slab sampling” generally means sampling soil gas immediately below the building’s lowest floor. While it is possible to collect soil gas at depth (that is, to collect soil gas samples several feet or more below the slab), this Appendix assumes that sample collection occurs just below the building slab. Since sub-slab gas sampling requires drilling holes through the building’s slab, it won’t always be possible to complete it because some building owners may not give permission to drill.

In most cases, however, drilling will be allowed so sub-slab sampling data will supplement the Tier 2 indoor air sampling event. Soil gas concentrations from directly below the building will help determine if VOC levels measured indoors are due to VI or from other sources. The relative levels of VOCs in sub-slab soil gas sampling results can also be compared to indoor measurements. For example, if two compounds are found in sub-slab soil gas at a concentration ratio of 10:1, a similar ratio would be expected in the indoor measurement, provided there are not contributions from other sources.

Sub-slab samples are often collected the day immediately after the indoor sampling event in order to minimize potential impacts to indoor air quality. Before drilling holes in the slab, contact local utility companies to identify and mark utilities coming into the building from the outside

(e.g., gas, water, sewer, electrical, and other utilities). Electricians, plumbers, or others may also need to be consulted to identify the location of utilities inside the building.



Figure D-1: Drilling through a concrete slab using a rotary hammer drill (Photo credit: EPA 2006)

Consider the following recommendations when developing a sub-slab sampling plan:

1. Do not install sampling probes if groundwater is in contact with the floor/slab.
2. Do not collect sub-slab samples from areas in the immediate vicinity of underground utilities, large floor cracks, drains or sumps.
3. Base the number of sub-slab sample locations on the size of the slab/floor, the types and variability of the underlying soils, and the concentration of contaminants in the subsurface. Use multiple sampling locations to ensure that the range of sub-slab soil gas VOC levels have been accurately represented.
4. Collect grab samples when sampling from a sub-slab probe. To avoid creating an excessive vacuum that potentially induces indoor air flow into the sample, collection rates should not exceed 0.2 liters/minute. In most cases detection limits at or below the applicable screening levels can be achieved using a 1-liter collection device.
5. Depending on the location of the subsurface contamination and preferential flow paths, it's possible that the primary entry points for vapors may be through the basement walls rather than from below the floor. This may necessitate collecting some samples through the walls of the structure or from exterior sampling points.
6. If sub-slab sampling probes are not adequately sealed, it's possible for indoor air to cause the sampling results to be either higher or lower than the actual concentrations present. To ensure that representative samples are collected, place a shroud containing a tracer such as helium over the probe during the sample collection process. When the

sample is analyzed, the tracer compound can also be quantified, which provides an estimate of how much indoor air may have entered the sample; see illustrations in Figure D-2. If the concentration of the tracer in the sample exceeds 5% of the concentration in the shroud, find and fix the leak, then collect a subsequent sample. It is also possible to measure helium concentrations in real time and fix any leaks before collecting the sample.

7. The most common method for assuring that tubing, valves, and other sampling components are air tight is to perform a **shut-in test** prior to sampling. This consists of sealing the tubing and other components between the vapor probe and sampling container. A vacuum is applied then the system is shut off. If the vacuum does not hold for at least 30 seconds, check all valves and other connections and repeat the test.

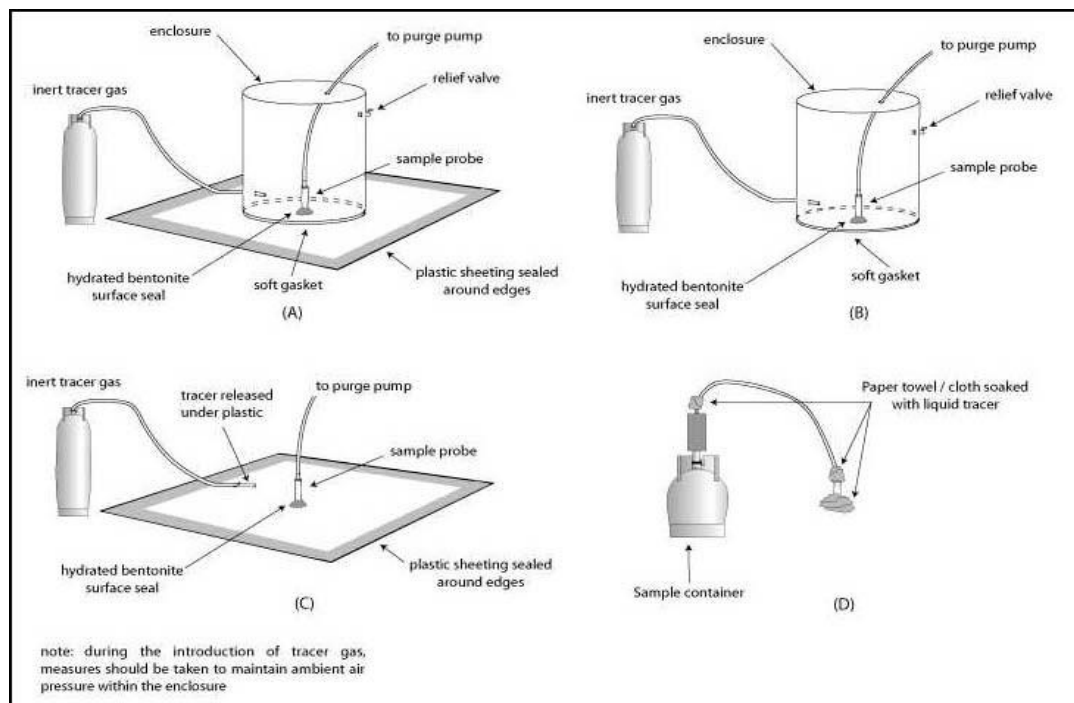


Figure D-2: Tracer gas applications when collecting soil gas samples (Credit: NYDOH 2006)

8. Sub-slab samples can be collected from permanent or temporary probes. Permanent probes are preferred if multiple soil gas sampling events will be needed. If permanent probes are used they must be air tight and capped when not in use so they are protected from damage. Similarly, if temporary probes are used, the slab penetration must be sealed to prevent the hole from being a soil gas conduit. A general sub-slab probe installation schematic for a “permanent” probe is depicted in Figure D-3.
9. Multiple sampling events are often necessary to assure that representative soil gas conditions have been measured. At least one sampling event should be scheduled when the building is likely to be depressurized with respect to the subsurface. Often this event is scheduled for the winter heating season, when temperatures inside the building are significantly higher than outdoor air temperatures. Another option is to mechanically

depressurize the building in order to ensure a negative pressure and create a scenario that will likely result in worst-case soil gas and indoor air concentrations.

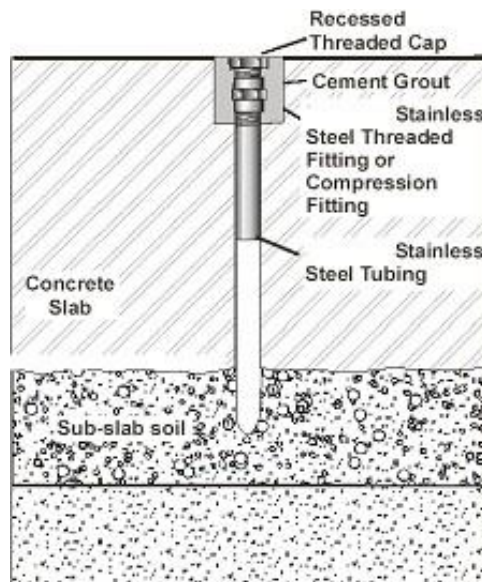


Figure D-3: Sub-slab soil gas probe schematic (Credit: NJDEP 2005)

D-3 Soil gas sampling beyond the building footprint

Tier 1 soil gas samples are typically collected through a probe or rod driven into the ground, or through a vapor well. The latter generally consists of small diameter (1/8" to 1/4") inert nylon or Teflon tubing sealed into a borehole. In general, consider collecting samples as close as possible to the structure while still accounting for underground drains and utilities.¹²⁷

The following recommendations should be considered when developing soil gas sampling plans. These recommendations are under general and typical circumstances:

1. Collect soil gas samples just above the contaminant source. Samples collected near the source often display less spatial variability in measured concentration levels and as a result it may be possible to limit the number of sampling points. Conversely, when collecting samples at shallower depths and far from the source, a larger number of collection points will often be necessary.
2. There are some advantages to sampling shallow soil gas when the VI source is at depth. Shallow samples can provide an indication of how much attenuation has occurred between the source and the measurement point, and may provide different results than if the generic attenuation factors are used. This can be especially important for petroleum

¹²⁷ When assessing parcels without buildings, adequate sampling coverage will be needed over the entire parcel.

compounds that undergo significant biodegradation in the vadose zone. Shallow samples can also provide an indication of soil gas concentrations near the building of concern, which can help determine next steps.

3. Samples should seldom be collected from depths shallower than five feet below grade,¹²⁸ due to the possibility of diluting the collected soil gas with atmospheric air from either short circuiting during sampling, or from barometric pumping effects.
4. The number of soil gas samples needed to assess the vapor pathway will depend on several factors, including:
 - a. The degree and extent of the contamination,
 - b. The type and variability of the soil conditions, and

For sites with groundwater impacts, whether the plume is stable or expanding.

5. Soil gas samples should be collected over short time periods and consist of relatively small sample volumes (e.g., 1 liter). Sampling flowrates should not exceed 0.2 liters/minute in order to limit the potential for ambient air leakage into the sample. Perform soil gas sampling when VOC concentrations are expected to exhibit near-maximum values.
6. The analytical detection limits should be at or below the screening levels for all compounds of concern. In some cases, this may result in needing to collect larger sampling volumes. Prior to sampling, purge the probe to help ensure a representative sample is collected. In general, remove at least three times (3x) the well casing volume before sampling.
7. Typically, two or more separate soil gas sampling events will be necessary before concluding that the VI pathway does not warrant further assessment. This will depend on a number of factors including:
 - a. Proximity of the sampling locations to occupied buildings;
 - b. Extent of the soil gas sampling effort; and
 - c. Variability in soil gas concentrations over time.
8. Don't collect soil gas samples during or immediately following a heavy rain. This is primarily because if the vadose zone soil pores are filled with water, the measured soil

¹²⁸ One example where a shallow soil gas sample may be necessary is when the depth to groundwater is less than five feet and access to the building of concern could not be obtained. The sampling protocol should include a tracer (such as lab grade helium) to help ensure that the vacuum applied to collect the sample was not significant enough to draw in atmospheric air.

gas concentrations may not be representative of the concentrations that are typically present.¹²⁹

9. In order to avoid the inadvertent collection of ambient air during sampling, perform leak testing using a tracer such as helium to determine whether sufficient ambient air was collected to affect the usability of the sample. If the concentration of the tracer in the sample exceeds 5% of the concentration in the shroud, find and fix the leak then collect a subsequent sample. See Figure D-2 for examples of potential leak testing options.
10. Soil gas samples can be collected from permanent or temporary probes. See Figures D-4 and D-5 for a schematic and photograph of a typical permanent soil gas sampling probe installation.

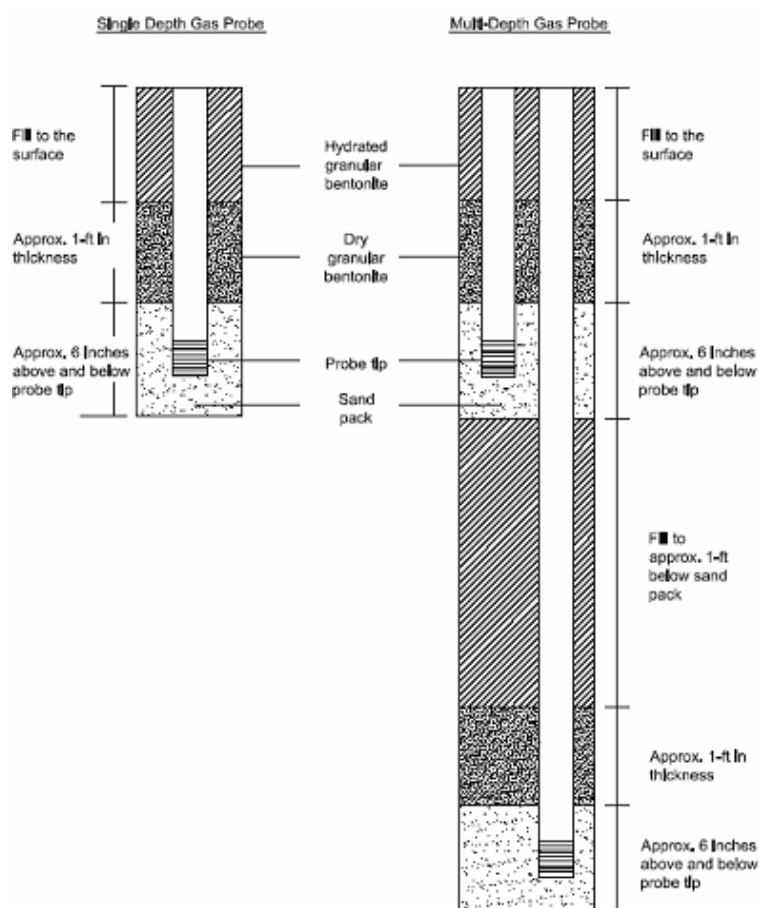


Figure D-4: Soil gas probe construction diagram (Credit: Missouri Risk-based Corrective Action for Petroleum Storage Tanks, Soil Gas Sampling Protocol, April 21, 2005)

¹²⁹ Several states including California, New Jersey, and Massachusetts have similar recommendations in their VI guidance documents.

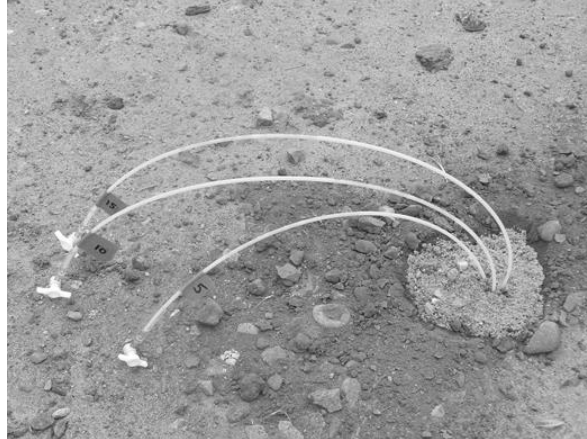


Figure D-5: Photograph of a multi-depth nested vapor well utilizing small diameter, inert tubing
NOTE: Valves are turned off. (Credit: H&P Mobile GeoChemistry, Inc. website, “How to Collect Reliable Soil-Gas Data”).

D-4 Passive soil gas sampling

Soil gas sampling typically uses vacuum to pull vapors into a container. However, passive devices are also available that rely on soil gas contact with a special adsorbent matrix. These devices are placed into the subsurface environment for several hours and up to several days then retrieved and analyzed. In the past, results were usually qualitative and reported in units of mass, but the technology now exists to obtain quantitative concentration measurements that are consistent with active soil gas sampling methods.

Passive samplers offer certain advantages in that once installed, they can remain in place for several days, thereby providing measurements over longer periods than *active* soil gas sampling. Another advantage: once they're in place, they exert few influences on the subsurface environment.

For deeper soil gas locations, this approach measures what effect diffusion from the VOC source is having and not the advective flow of soil gas. Using a negative pressure to collect a sample from depth could potentially result in advective soil gas flow that may affect the representativeness of the sample concentration. Passive sampling can also be conducted relatively cheaply, can be deployed in tighter and wetter soils than active methods, and can often detect the presence of some semi-volatile organic compounds (SVOCs) better than active methods.

The following sources provide technical information on the ability of passive samplers to provide accurate quantitative soil gas sampling results:

1. McAlary, T., X. Wang, A. Unger, H. Groenevelt, T. Gorecki. (2014). *Quantitative passive soil vapor sampling for VOCs - part 1: Theory*. Environmental Science: Processes Impacts, 16:482-490. Retrieved from: <http://dx.doi.org/10.1039/c3em00652b>.

2. McAlary, T., H. Groenevelt, S. Seethapathy, P. Sacco, D. Crump, M. Taday, B. Schumacher, H. Hayes, P. Johnson, T. Gorecki. (2014). *Quantitative passive soil vapor sampling for VOCs - part 2: laboratory experiments*. [Environmental Science: Processes Impacts](#), 16, 491-500.
3. McAlary, T., H. Groenevelt, P. Nicholson, S. Seethapathy, P. Sacco, D. Crump, M. Taday, H. Hayes, B. Schumacher, P. Johnson, T. Gorecki, I. Rivera-Duarte. (2014). *Quantitative passive soil vapor sampling for VOCs - part 3: field experiments*. [Environmental Science: Processes Impacts](#), 16, 501-510.
4. McAlary, T., H. Groenevelt, S. Seethapathy, P. Sacco, D. Crump, M. Taday, B. Schumacher, H. Hayes, P. Johnson, L. Parker, T. Gorecki. (2014). *Quantitative passive soil vapor sampling for VOCs - part 4: flow-through cell*. [Environmental Science: Processes Impacts](#), 16, 1103-1111.

D-5 Sources of information for soil gas sampling

Ecology recommends consulting the following documents when developing soil gas sampling plans:

1. California Environmental Protection Agency, Department of Toxic Substance Control. (2011). *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air*. Appendix G.
2. California Environmental Protection Agency, Department of Toxic Substance Control. (2015). Los Angeles Regional Water Quality Board/San Francisco Regional Water Quality Board. *Advisory for Active Soil Gas Investigations*.
3. ITRC (2014). *Petroleum Vapor Intrusion - Fundamentals of Screening, Investigation and Management*. Appendix G.
4. Massachusetts Department of Environmental Protection. (2016). *Vapor Intrusion Guidance*. Site Assessment, Mitigation and Closure.
5. New Jersey Department of Environmental Protection. (2016). *Installation Procedures for Permanent Sub-slab Sampling Procedures*.
6. New Jersey Department of Environmental Protection. (2018). *Vapor Intrusion Technical Guidance* – Chapter 3 and appendix H.
7. USEPA. (2015). *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. (OSWER Publication 9200.2-154). Washington, D.C.

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

E-1 Introduction

This Appendix provides information to help account for:

1. The additive effects of non-carcinogenic compounds present in petroleum mixtures.
2. Indoor air contaminants from sources other than PVI.
3. Whether PVI represents a reasonably likely threat to future buildings.
4. Developing Tier 1 and Tier 2 PVI sampling plans.

This Appendix primarily applies to releases of petroleum from underground storage tanks, spills, home heating oil tanks, and bulk tank farms. It should be used when sites do not initially “screen out” using the process established in Appendix B, or when further evaluation of vapor is necessary after implementing the selected cleanup action.

E-2 General overview

Petroleum is made up of hundreds of different chemical compounds. Because there is a large number of constituents present, MTCA’s Method A tables provide default cleanup levels for the broad family of chemical compounds called “total petroleum hydrocarbons” (TPH), a term describing any mixture of hydrocarbons that are derived from the refining of crude oil. 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.

E-3 Petroleum mixtures

E-3.1 Background

WAC [173-340-750\(3\)\(b\)\(ii\)\(C\)](#)¹³⁰ 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.

¹³⁰ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-750> (Cleanup standards to protect air quality)

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 Section E-8.0 of this Appendix 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. Sections 3.8 and 4.12 of this guidance provide additional direction for addressing this situation.

E-3.2 Accounting for the cumulative effects of petroleum mixtures

CLARC provides Method B air cleanup levels for individual petroleum compounds based on a target hazard quotient of 1 for each compound. In practice, the concentrations of individual compounds have been compared to their individual air cleanup levels, but the additive hazards of the mixtures have often not been considered. The CLARC VI data tables now include a note that if multiple individual non-carcinogenic petroleum constituents are present, the additive effects must be accounted for.

To ensure that the additive effects of the non-carcinogenic petroleum constituents are properly addressed, Ecology developed a Method B generic indoor air TPH cleanup level of $140 \mu\text{g}/\text{m}^3$ along with corresponding TPH soil vapor screening levels that can be used when assessing the potential for petroleum VI. 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 Hawai'i Department of Health (HDOH). See Section E-7.0 for the specific assumptions that were used, along with the supporting data.

NOTE: See Section E 7.2 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 $140 \mu\text{g}/\text{m}^3$.

E-4 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 E-1 below compares Ecology's indoor air cleanup levels with a range of potential "background" concentrations for indoor air compiled by the Hawai'i Department of Health. 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 visually identify or use a portable field sampling device to identify all products or other PVOC-emitting materials and remove those from the building several days to a week prior to sampling. Section 4.6 provides additional details to help evaluate non-VI sources of indoor air contamination including contaminants from ambient air.

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

| Compound | Ecology Indoor Air Cleanup Levels ($\mu\text{g}/\text{m}^3$) | Range of Potential Background Concentrations ¹³¹ ($\mu\text{g}/\text{m}^3$) |
|-------------|--|--|
| Benzene | 0.32 | <Reporting Limit – 4.7 |
| Naphthalene | 0.074 | 0.18 – 1.7 |
| TPH | 140 or a site-specific determination | 116 – 594 |

¹³¹ The benzene range was compiled by the Environmental Protection Agency and represents the 50th percentile of the data evaluated. The naphthalene range was provided in an article by Jia and Batterman titled *A Critical Review of Naphthalene Sources and Exposures Relevant to Indoor and Outdoor Air* (2010). The TPH values were compiled by the Massachusetts Department of Environmental Protection and represent the 50th to 90th percentile.

E-5 Assessing the potential threat of Petroleum VI on future buildings

E-5.1 Background

Future site use

WAC [173-340-702\(4\)](#)¹³² 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:

1. A building is not currently present in the area of contamination but could be constructed within it.
2. The building that is currently located in the area of contamination could be replaced or significantly modified.
3. 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](#).¹³³ 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

¹³² <https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-702> (General policies)

¹³³ https://www.epa.gov/sites/production/files/2015-09/documents/oswer_2010_database_report_03-16-2012_final_witherratum_508.pdf (retrieved August 2021)

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 protecting future buildings 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 indoor receptors are protected.

E-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 several scenarios where additional evaluation may be necessary.

For soil, MTCA specifies that the VI pathway should be evaluated whenever soil concentrations are significantly higher than a concentration derived for protection of groundwater.

EPA has only developed soil screening levels for benzene and TPH. The benzene soil screening level for sources of non-aqueous phase liquids (non-NAPL) is 10 mg/kg, which is well above the Method A level of 0.03 mg/kg. The TPH soil screening level for both weathered and un-weathered gasoline is not below the Method A cleanup levels. In both of these cases, six feet of vertical separation distance is necessary.

However, the TPH soil screening level for diesel is 250 mg/kg while the Method A soil cleanup level is 2,000 mg/kg. In these situations, it will generally be necessary to gather soil gas data to ensure the measured concentrations are protective of the VI pathway.

Regarding groundwater, four petroleum compounds 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 E-2.

Table E-2: Groundwater screening and cleanup levels for four petroleum compounds.¹³⁴

| 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 ¹³⁵ | 1000 | 333 |

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/L¹³⁶ and 500 µg/L, respectively. EPA's [Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites](#)¹³⁷ (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. PVI guidance from the Interstate Technology Regulatory Council (ITRC) 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/m³ at vertical separation distances as small as zero (0) feet. ITRC indicated that benzene requires the greatest distance to biodegrade and that vertical screening

¹³⁴ 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.

¹³⁵ The xylene groundwater screening level was calculated using an estimated Henry's Law constant at 13° C of 0.138 that was determined by taking the mean of the three individual isomers.

¹³⁶ The higher value is allowed if there is no detectable benzene in groundwater.

¹³⁷ <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100MLX1.PDF?Dockey=P100MLX1.PDF>

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](#)¹³⁸: [Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors: Implications for Potential Vapor Intrusion Hazards](#)¹³⁹ (HDOH 2012).
4. Washington's Method A petroleum groundwater cleanup levels are less than the groundwater PVI screening levels used by other states, including Hawai'i, Massachusetts, New Jersey, and Oregon.

Information in this section 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, any 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.

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.

Situation No. 3. If soil DRO concentrations are at or above 250 mg/kg but below the Method A value of 2,000 mg/kg

If any of these situations are present, 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.

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

WAC [173-340-740](#)(3)¹⁴⁰ 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, the MTCA Cleanup Rule generally requires that the soil-to-vapor pathway be evaluated whenever petroleum constituents are significantly higher than a

¹³⁸ <http://hawaiiidoh.org/tgm.aspx>

¹³⁹ <http://hawaiiidoh.org/references/HDOH%202012c.pdf>

¹⁴⁰ <https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-740> (Unrestricted land use soil cleanup standards.)

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 the MTCA Cleanup Rule’s [Table 740-1](#),¹⁴¹ 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).

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, use one of the following approaches 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 contamination remaining 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.
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.

E-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 after cleanup because structural impediments are present or 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](#)

¹⁴¹ <https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-900> (Tables.)

[Covenants under the Model Toxics Control Act](#)¹⁴² (Ecology 2016b). Section E 7.0 contains example provisions when vapor migration is a potential concern, including language that prohibits future building construction unless approved by Ecology.

E-6 Considerations when developing a Tier 1 or Tier 2 sampling plan to evaluate the potential for petroleum vapor intrusion

As discussed earlier, this guidance applies to sites that do not initially screen out of the PVI assessment process using the procedures established in Appendix B. This guidance 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 1 or Tier 2 vapor intrusion evaluation. Developing a Tier 1 or 2 petroleum vapor intrusion sampling plan should take four components into account.

1. It is generally not necessary to use both Method TO-15 (Summa canisters) and Method TO-17 (sorvent tubes) for determining compliance with established PVI cleanup or screening levels.¹⁴³ 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, analyzing oxygen, carbon dioxide, and methane will require alternative methods such as ASTM D1946.
2. Indoor air samples should generally be analyzed for:
 - a. Petroleum equivalent carbon (EC) fractions¹⁴⁴
 - EC5-8 (aliphatics),
 - EC9-12 (aliphatics), and
 - EC9-10 (aromatics)

¹⁴² <https://apps.ecology.wa.gov/publications/SummaryPages/1509054.html>

¹⁴³ TO-17 analysis may be needed for situations where there are very high concentrations of soil and groundwater concentrations of naphthalene, such as at Manufactured Gas Plant (MGP) sites.

¹⁴⁴ These three carbon fractions should be analyzed using the Massachusetts Department of Environmental Protection Air Phase Hydrocarbon (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.

- b. Petroleum VOC's¹⁴⁵
- benzene
 - ethylbenzene
 - toluene
 - xylenes
 - naphthalene
- c. Other petroleum compounds¹⁴⁶
3. In addition to analyzing the compounds listed in item No. 2 above, analyze soil gas samples for oxygen, carbon dioxide, and methane. Sampling for these constituents is 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. If methane concentrations are determined to be a concern, Ecology recommends using ASTM procedure E2993-16 (*Standard guide for evaluating the potential hazard as a result of methane in the vadose zone*).
 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](#)¹⁴⁷ (Ecology 2016a) provides several examples of when an adjustment would be necessary.

E-7 Process to establish a generic TPH indoor air cleanup level

E-7.1 Evaluated 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 [Hawai'i 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 in the following list.

¹⁴⁵ It may be necessary to use the selective ion mode (SIM) for TO-15 analysis to obtain reporting limits below the necessary indoor air cleanup levels.

¹⁴⁶ Analyze for petroleum compounds such as EDB, EDC, and MTBE when soil, groundwater, or product analysis confirms their presence at the site.

¹⁴⁷ <https://apps.ecology.wa.gov/publications/SummaryPages/1009057.html>

1. Petroleum vapors from gasoline consisted primarily of aliphatic compounds in the C5-8 range.
2. There was an increased proportion of aliphatic compounds in the C9-12 range when middle distillates (such as diesel) were evaluated.
3. Aromatics, including BTEXN, make up a small portion of the overall mixture—especially for older sites.
4. 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.
5. Samples analyzed using sorbent tubes indicated that there were minimal petroleum VOCs above C-12 in petroleum vapors.
6. Toluene, ethylbenzene, xylene, and naphthalene were not significant risk drivers for the evaluated sites.
7. Benzene typically drives risk for fresh releases, while TPH typically drives risk for older releases and releases from middle distillates.
8. Of the sites evaluated, TPH alone would have been adequate to screen the sites for potential vapor intrusion hazards.

E-7.2 Developed the generic TPH cleanup and screening levels

Given the availability of more detailed information on petroleum vapors, Ecology concluded that it was possible to develop a sufficiently protective generic indoor air TPH cleanup level. The first step was determining 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, Ecology selected a concentration of just below the cancer cleanup level for each constituent, then divided by the non-carcinogenic cleanup level.

For MTBE, $9.5 \mu\text{g}/\text{m}^3$ was used (which is just below the cancer cleanup level of $9.62 \mu\text{g}/\text{m}^3$). This level would represent a hazard quotient of 0.007 ($9.5 \mu\text{g}/\text{m}^3/1,370 \mu\text{g}/\text{m}^3$). Using the same methodology and a concentration of $0.3 \mu\text{g}/\text{m}^3$ for benzene, its contribution would be 0.022 ($0.3 \mu\text{g}/\text{m}^3/13.7 \mu\text{g}/\text{m}^3$). 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 wasn't 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 12-16 aromatic fraction has the lowest cleanup level for all of the non-carcinogens (see Table E-1). However, work done by the Hawai'i DOH found that there are minimal petroleum VOCs above EC 12. The next lowest non-carcinogenic cleanup level is for the EC 10-12 aromatic fraction, but the toxicity of this fraction is based on naphthalene, which will be accounted for individually using the carcinogenic cleanup level. Hawai'i 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 EC 8-12 aliphatic fraction is typically makes up a significant portion of petroleum vapors, Ecology 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](#)¹⁴⁸ results in a generic Method B TPH indoor air cleanup level of 46 µg/m³. When the currently accepted attenuation factor of 0.03 is applied, it results in a sub-slab TPH screening level of 1500 µg/m³

NOTE: Ecology evaluated the same process 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 µg/m³, while the non-cancer cleanup level is 30 µg/m³. If benzene was measured just below the cancer cleanup level (e.g. 3 µg/m³) 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, Ecology concluded it wasn't appropriate to use a similar approach for establishing a generic Method C indoor air TPH cleanup level. For sites that qualify under WAC [173-340-706](#)¹⁴⁹ to use Method C cleanup levels, you can use either the Method B level of 46 µg/m³ or a site-specific approach.

The generic Method B cleanup level is intended for those situations where the site does not initially screen out using the process established in Appendix B of this guidance. While this

¹⁴⁸ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-750> (Cleanup standards to protect air quality.)

¹⁴⁹ <https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-706> (Use of Method C.)

appendix (Appendix E) focuses on establishing a generic TPH cleanup level, it does not preclude analyzing indoor air for each petroleum fraction and the individual petroleum compounds in order to calculate a site-specific TPH air cleanup level.

E-7.3 Evaluated Washington state's vapor intrusion sampling data

To assess the degree of protection afforded by the generic TPH cleanup level, Ecology evaluated actual site-specific vapor intrusion sampling data from Washington state. 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 46 $\mu\text{g}/\text{m}^3$ but where the Hazard Index exceeded 1.

Ecology identified a limited number of sites where a Tier 1 or Tier 2 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 to determine if any modifications are warranted.

E-7.4 Researched 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. We identified states 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, only one of which uses total TPH screening levels for assessing the petroleum vapor pathway (Hawai'i). Specifically, Hawai'i uses a screening level of 600 $\mu\text{g}/\text{m}^3$ for a gasoline release and 130 $\mu\text{g}/\text{m}^3$ for a diesel release. There were six 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.

E-7.5 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 E-3: Inhalation reference doses for non-carcinogenic parameters

| Non-Carcinogenic Parameters | Inhalation Reference Dose (RfDi) (mg/Kg-day) |
|------------------------------------|---|
| EC 5-8 Aliphatics | 1.7 |
| EC >8-12 Aliphatics | 0.029 |
| EC >12-16 Aliphatics | 0.029 |
| EC 9-10 Aromatics | 0.114 |
| EC >10-12 Aromatics | 0.00086 |
| EC >12-16 Aromatics | 0.00011 |
| Benzene | 0.00857 |
| Ethylbenzene | 0.286 |
| Toluene | 1.4 |
| Total Xylenes (m, o, p) | 0.029 |
| Naphthalene | 0.00086 |

Table E-4: Inhalation cancer potency factors for carcinogenic parameters

| Carcinogenic Parameters | Inhalation Cancer Potency Factor (CPF_i) (Kg-day/mg) |
|--------------------------------|---|
| Benzene | 0.0273 |
| EDB | 2.10 |
| EDC | 0.091 |
| MTBE | .00091 |
| Naphthalene | 0.119 |

E-8 Process for calculating a site-specific TPH indoor air cleanup level (with example)

E-8.1 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 3: Equation for Method B cleanup level for TPH. The TPH cleanup level is equal to the hazard index times the average body weight times the unit conversion factor times the averaging time over the breathing rate times the exposure duration times the exposure frequency times the sum of the fraction by weight of the petroleum components times the inhalation absorption fraction for the petroleum components over the inhalation reference dose for the petroleum components.

Equation for Method B CUL for TPH:

$$C_{TTTTT} = \frac{HHH \times AAAAA \times CCCC \times AAA}{AAB \times EEE \times EEU \times \sum_{i=1}^{i=n} \frac{UU_{ii}}{AAAAA_{ii}}}$$

Equation 4: Simplified form of Equation 3. In first equation, the individual petroleum component cleanup level is equal to the inhalation reference dose for the petroleum component times the average body weight times the unit conversion factor times the hazard quotient times the averaging time over the breathing rate times the inhalation absorption fraction for the petroleum component times the exposure duration times the exposure frequency. In second equation, the TPH cleanup level is equal to one over the sum of the fraction by weight of the petroleum components over the air cleanup level for the petroleum components.

Simplified Form of the Equation:

Individual petroleum component: $C_i = \frac{R_i \times BW \times UC \times HQ \times AT}{A \times I \times ABS \times ED \times EF}$
 (WAC 173-340-750, Equation 750-1)

TPH cleanup level: $C_{TPH} = \frac{1}{\sum_{i=1}^n \frac{FF_i}{C_i}}$

E-8.2 Parameter definitions, values, and cleanup levels

Table E-5: Parameter definitions.

| Abbreviation | 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 |
| RfD _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 E-5. The result was used with the specific parameter values in Table E-6 to calculate the individual cleanup levels.

Table E-6: 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/m³) |
|---------------------------------------|---------------------------------------|---|--|
| Aliphatics EC>5-8 | 1 | 1.7 | 2.72E+03 |
| Aliphatics EC>8-12 | 1 | 0.029 | 4.64E+01 |
| 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 E-7: Non-carcinogenic example measurements and calculations.

| Petroleum Fraction or Compound | Measured Conc. Site-Specific Sample ($\mu\text{g}/\text{m}^3$) | Fraction of Total Concentration (F_i) | Total TPH Non-carcinogenic CUL_i ($\mu\text{g}/\text{m}^3$) | F_i / CUL_i |
|--------------------------------|--|---|--|----------------------|
| Aliphatics EC>5-8 | 319 | 0.91 | 2.72E+03 | 3.35E-04 |
| Aliphatics EC>8-12 | 12 | 0.03 | 4.64E+01 | 7.4E-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 | 715 | --- |

Note: The Total TPH Non-carcinogenic $\text{CUL} = 1 / \sum (F_i / \text{CUL}_i)$

Based on the composition of the sample shown in Column 2 in Table E-7, the measured total TPH concentration of $349.7 \mu\text{g}/\text{m}^3$ does not exceed the calculated site-specific TPH air cleanup level of $715 \mu\text{g}/\text{m}^3$. 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 $0.321 \mu\text{g}/\text{m}^3$ 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 in soil, water or product samples.

Table E-8: Carcinogenic example measurements and evaluation.

| Carcinogenic Compound | Measured Conc. Site-Specific Sample ($\mu\text{g}/\text{m}^3$) | Carcinogenic CUL ($\mu\text{g}/\text{m}^3$) | Carcinogenic CUL Exceeded? (Yes/No) |
|------------------------------|--|---|--|
| Benzene | 0.2 | 0.321 | No |
| Naphthalene | <0.07 | 0.074 | No |