Guidance for Assessing and Remediating Vapor Intrusion into Buildings

Updated March 2025

DEQ

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State of Oregon Department of Environmental Quality

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Document development

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Executive summary

This guidance intends to improve Oregon's vapor intrusion evaluation process, identify and implement appropriate response actions when needed, and verify the effectiveness of response actions. This guidance has been prepared for DEQ project managers and members of the public, including environmental professionals, members of local, state, and tribal governments, property owners, housing representatives, community-based organizations, and all other interested parties. The overarching goal of the updated guidance is to protect all Oregonians from risks associated with breathing contaminants via vapor intrusion.

The accumulation of knowledge regarding vapor intrusion has grown considerably since the publication of DEQ's original guidance. This updated VI guidance replaces the original version that was published in 2010. DEQ updated the VI guidance to align with current science, standards, and technical advances in investigating VI sources and addressing associated risks. The final guidance is the product of many contributions from national and regional experts, DEQ's Environmental Cleanup Program VI Work Group, leadworkers, managers, staff, and input from the public.

This guidance provides technical updates based on current science and engineering while reflecting changes in policy including acute and chronic risk considerations. Specifically, this guidance:

- Presents revised DEQ risk-based concentrations which incorporate United States Environmental Protection Agency vapor intrusion screening levels developed on the best available science, including updated empirical-based attenuation factors
- Promotes better development and use of the VI conceptual site model throughout the process
- Outlines important considerations for the different VI processes of petroleum contaminants in comparison to non-petroleum volatile contaminants, such as chlorinated solvents
- Updates the recommended approach for heating oil tank sites
- Introduces new and updated process flow charts to refine and strengthen VI evaluations
- Emphasizes lines of evidence approach that is data-oriented and site-specific
- Clarifies Oregon's hot spot evaluations unique to VI
- Discusses the applicability of the Cleaner Air Oregon Program and a revised, streamlined approach to evaluating emissions from remediation and mitigation systems
- Expands on technical descriptions of VI mitigation technologies and performance monitoring framework
- Clarifies expectations for public outreach and engagement in VI evaluations

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List of Acronyms

AF	Attenuation Factor
AST	Above-ground Storage Tank
ASTM	American Society of Testing and Materials
bgs	below ground surface
cNFA	Conditional No Further Action
CalEPA	California Environmental Protection Agency
CAP	Corrective Action Plan
CAO	Cleaner Air Oregon
COC	Chemical of Concern
COI	Chemical of Interest
COPC	Chemical of Potential Concern
CSM	Conceptual Site Model
CSV	Crawlspace ventilation
CQA	Construction Quality Assurance
1,2-DCA	1,2,-Dichloroethane
DEQ	Oregon Department of Environmental Quality
DNAPL	Dense Nonaqueous Phase Liquid
DQO	Data Quality Objective
DTSC	CalEPA Department of Toxic Substances Control
EDB	Ethylene Bromide
EES	Easement and Equitable Servitudes
EHAP	Oregon Health Authority Environmental Health Assessment Program
EPA	United States Environmental Protection Agency
EPC	Exposure Point Concentration
FID	Flame Ionization Detector
FS	Feasibility Study
GC/MS	Gas Chromatography/Mass Spectrometry
HOT	Heating Oil Tank
HVAC	Heating, Ventilation, and Air Conditioning
IDLH	Immediately Dangerous to Life and Health
ITRC	Interstate Technology and Regulatory Council
LELs	Lower Explosive Limits
LNAPL	Light Nonaqueous Phase Liquid
LOE	Line of Evidence
LOF	Locality of Facility
HOT	Heating Oil Tank

LUST	Leaking Underground Storage Tank
μg/m^3	micrograms per cubic meter
MRL	Method Reporting Limit
MPE	Multiphase Extraction
NFA	No Further Action
NAPL	Nonaqueous Phase Liquid
O&M	Operation and Maintenance
OAR	Oregon Administrative Rules
OHA	Oregon Health Authority
ORS	Oregon Revised Statutes
OSHA	Occupational Safety and Health Administration
PAHs	Polynuclear Aromatic Hydrocarbons or Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCE	Perchloroethylene, Tetrachloroethylene, or Tetrachloroethene
PELs	Permissible Exposure Limits
PID	Photoionization Detector
PRT	Post Run Tubing
ppbv	parts per billion by volume
ppm	parts per million
PVI	Petroleum Vapor Intrusion
P.E.	Professional Engineer
QA/QC	Quality Assurance/Quality Control
RA	Risk Assessment
RAP	Remedial Action Plan
REL	Reference Level
RI	Remedial Investigation
R.G.	Registered Geologist
RBC	Risk-Based Concentration
RBC_{air}	Risk-Based Concentration for indoor air
RBC_{sv}	Risk-Based Concentration for vapor intrusion from soil vapor
RBC_{wi}	Risk-Based Concentration for vapor intrusion from groundwater
RME	Reasonable Maximum Exposure
RSL	Regional Screening Level
SAP	Sampling and Analysis Plan
SIM	Selective Ion Monitoring
SSD	Sub-Slab Depressurization
SSV	Sub-Slab Ventilation
SVE	Soil Vapor Extraction

SVOC	Semi-Volatile Organic Compound
TCE	Trichloroethylene or Trichloroethene
TPH	Total Petroleum Hydrocarbons
UIC	Underground Injection Control
UCL	Upper Confidence Limit
UST	Underground Storage Tank
VI	Vapor Intrusion
VIM	Vapor Intrusion Mitigation
VISL	Vapor Intrusion Screening Levels
VOC	Volatile Organic Compound
WADOE	Washington State Department of Ecology

1.0 Introduction

The term vapor intrusion, referred to as VI, describes the migration of chemical vapors originating from contaminated soil and groundwater sources through the subsurface and into the interiors of buildings. Vapor intrusion is one of the most commonly complete exposure pathways at Leaking Underground Storage Tank (LUST) and Environmental Cleanup Program sites and has the potential to impact properties hundreds of feet from the original source of contamination. Long-term (chronic) and short-term (acute) exposures to these chemicals have the potential to adversely affect human health. Typically, the levels of concern are below odor thresholds, and building occupants may be unaware of their exposure.

Vapor intrusion is a concern where there have been significant spills or releases of volatile hazardous substances, such as solvents and fuels. The investigation and cleanup of hazardous substance releases are regulated under Oregon Revised Statute (ORS) 465.200-465.485 and 465.900 and Oregon Administrative Rule (OAR) 340-122.

This guidance describes the essential elements and expectations regarding the investigation, screening, management, and monitoring of vapor intrusion risks at LUST and Environmental Cleanup sites. The priority of a VI investigation is to assess contaminant exposure and risks at existing buildings and to respond appropriately to address risks through remediation (e.g., removal or treatment) and/or mitigation as necessary. However, the investigation must also characterize vapor plumes that pose potential risks to future development and uses of the site. The building location, design, or use often results in an incomplete VI pathway even when subsurface volatile organic compound (VOC) sources are present. At these sites there may be no current VI risk, but subsurface vapor sources are still a concern if the use and development of the property change (e.g., conversion from industrial to residential). For this reason, indoor air data (and potentially sub-slab vapor) independently is insufficient for characterizing sources and defining potential future VI risks.

To be considered complete, a VI investigation must characterize the extent and magnitude of the subsurface vapor plume exceeding risk-based concentrations, or RBCs.

1.1 Notable exclusions

This guidance excludes the following scenarios:

- Highly concentrated sources of VOC contamination (e.g., free product gasoline) in the subsurface may produce vapor concentrations that exceed lower explosive limits in confined spaces or otherwise result in conditions that are immediately dangerous to life and health. These conditions should be addressed immediately in coordination with local fire departments and are outside the scope of this document.
- Landfill gases, such as methane and hydrogen sulfide, generated from the decay of organic wastes and debris can also migrate into indoor spaces. The investigation and

management of these gases and associated hazards are separate topics that are not covered in this guidance. Please consult with your DEQ project manager on how to assess methane and other landfill gases.

- Chemicals actively being used in commercial and industrial facilities (e.g., dry cleaners) can be another source of indoor air contamination. The chemical exposures associated with this active use are regulated by Occupational Safety and Health Administration and are outside the scope of this guidance. DEQ protects occupational workers from unacceptable risks that result from the release of hazardous substances into the environment. OSHA standards such as permissible exposure limits are not relevant to assessing vapor intrusion risks under DEQ regulations.

1.2 Document overview

The guidance is divided into the following sections:

Section 2: Vapor intrusion conceptual site model. Describes the elements of vapor intrusion conceptual site models that are used for planning VI investigations and interpreting the collected data.

Section 3: Vapor intrusion evaluation process. Describes the decision flow charts for screening and responding to VI risk.

Section 4: Vapor intrusion sampling and analysis. Discusses the objectives and minimum data requirements for VI investigations and various sampling methods.

Section 5: Vapor intrusion risk-based evaluation. Describes the derivation of risk-based concentrations, and how they are used to screen VI risk and prioritize response actions when acceptable risk levels or hot spots are exceeded.

Section 6: Vapor intrusion remediation and mitigation. Describes VI mitigation strategies, remediation of sources, and minimum expectations for performance and compliance monitoring.

Section 7: Community engagement. Describes the importance of proactive public outreach and risk communication with impacted parties and provides references to more comprehensive tools and resources.

1.3 Changes from previous guidance

This document builds on and supersedes previous vapor intrusion guidance published by DEQ in 2003 and 2010. Significant changes to previous guidance include:

- Revised and new decision flow charts for non-petroleum and petroleum sources
- Revised DEQ risk-based concentrations, which incorporate EPA's vapor intrusion screening levels and updated attenuation factors for soil vapor and groundwater
- Inclusion of acute chemical toxicity and short-term exposure (e.g., trichloroethene)
- Approach to demonstrating biodegradation at petroleum vapor intrusion sites
- Updated site investigation data reduction protocols to establish exposure point concentrations
- Response times for addressing chronic and acute vapor intrusion impacts to indoor air (Appendix A)
- Updated approach for heating oil tank (HOT) sites, including a HOT specific flow chart (Appendix B)
- Clarification of the process for identifying hot spots related to vapor intrusion sources of contamination
- Expanded discussion of vapor intrusion mitigation technologies and performance monitoring expectations
- Regulation of VOC emissions from remediation and mitigation systems under the Cleaner Air Oregon rules (OAR 340-245), including an updated screening process (Appendix E)
- Re-iteration of professional qualifications for various stages of work including professional engineer practice requirements regarding design, construction, and assessment of engineering controls
- Clarification of expectations for public outreach and engagement in vapor intrusion evaluations

Another important change to the screening process is the de-emphasis of soil data and the emphasis of soil vapor data for risk screening. Soil contamination is more heterogeneously distributed across sites than other contaminant phases such as soil vapor and groundwater contamination and it is an unreliable predictor of vapor intrusion risk, particularly at chlorinated solvent sites. This guidance highlights the utility of soil vapor data and considers it essential data for any VI investigation.

Readers are also encouraged to consult relevant guidance from United States Environmental Protection Agency (EPA), Interstate Technology and Regulatory Council (ITRC), and others to supplement the information in this document. Specific guidance is referenced throughout this document; in addition, new or updated guidance in the future will be published that may be relevant to assessing and addressing vapor intrusion.

1.4 How to use this guidance

DEQ has developed the following framework to assess the vapor intrusion pathway and evaluate strategies to address current and future risk. This updated VI framework emphasizes a more complete assessment of sources and risk, remediation of potent sources, and provides a detailed overview of mitigation options and related long-term risk management considerations. It is acknowledged that the objectives of an initial screening may be different than these overarching goals. It may also be appropriate to make adjustments from the general VI framework based on site-specific conditions when using multiple lines of evidence (LOEs), applying the best available science and engineering, and incorporating professional judgement to improve the VI assessment process and mitigation/remediation outcomes. The VI framework is intended to be used for a variety of sites, from simple to complex, with different site histories and future uses. The base approach should be founded on a good conceptual site model to determine the best path forward for each site.

1.5 Terminology

For consistency purposes, this guidance uses the terminology soil vapor to refer to vapor found in pore spaces between soil particles; however, soil gas can be used interchangeably to represent vapor within vadose zone soils (or unsaturated zone). Sub-slab soil vapor is considered soil vapor immediately below a structure regardless of the building foundation type (e.g., slab-on-grade, basement, crawlspace, etc.).

With respect to risk-based levels developed for vapor intrusion, EPA uses screening levels, or vapor intrusion screening levels (VISL), while DEQ uses risk-based concentrations or RBCs. As of 2023, DEQ recognized EPA's VISLs as the best available science and incorporated the VISLs into DEQ RBCs for VI risk screening with minor adjustments to account for Oregon specific environmental conditions (e.g., groundwater temperature).

This guidance also distinguishes between vapor intrusion resulting from petroleum hydrocarbons (referred herein as petroleum vapor intrusion or PVI) versus non-petroleum contaminants due to the differences in the chemical nature and transport in the environment. Predominantly non-petroleum VI sites are attributed to chlorinated VOCs or solvents.

2.0 Vapor intrusion conceptual site model

Conceptual site models (CSMs) are written and graphical representations of the physical, chemical, and biological processes influencing subsurface vapor migration into buildings and the dilution of these vapors within indoor air. Figure 1 illustrates these processes and Table 1 identifies basic elements to consider in preparing a preliminary CSM. CSMs provide essential context for data interpretation and guide the development of investigations and sampling plans to fill data gaps. Cross-sections and figures can be helpful to understand the vertical and lateral extent of source(s) and to evaluate the distance(s) to buildings. CSMs should be iteratively revised and refined throughout the life of the project as new information becomes available. CSMs are a critical part of a successful VI investigation or broader remedial investigation (RI) to determine whether a risk pathway is complete, and in the development and implementation of remedies when needed.

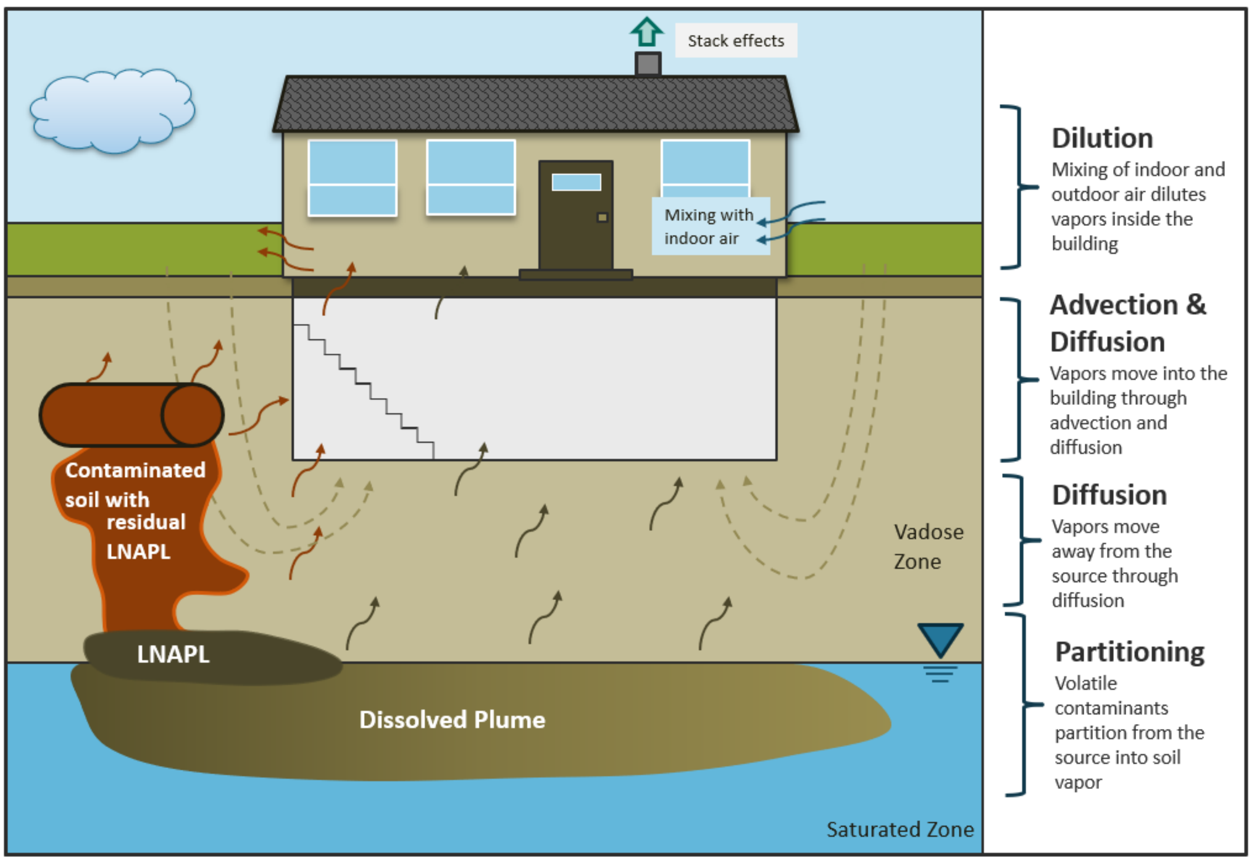

Figure 1. Graphical representation of vapor Intrusion conceptual site model (based on McHugh et al., 2017 and EPA, 2015a)

Conceptual site models should include the boundaries of the VI locality of facility (LOF) and distances, vertically and laterally, to nearby buildings. The LOF represents the area where humans, animals, or plants may come into contact with site-related chemicals.[1] The VI LOF is larger than a typical soil source due to the migration of vapor in the vadose zone, and, if present, underlying groundwater plumes can extend VI concerns farther downgradient. Correspondingly, off-site buildings may be part of the LOF depending on the extent of groundwater or soil vapor plumes.

Table 1. Basic elements of vapor intrusion CSM

Elements of vapor intrusion conceptual site models	
Primary Sources	Leaking USTs, ASTs, UICs, piping, pipelines, surface spills that have infiltrated/migrated
Secondary Sources	Contaminated soil, groundwater, free product, buried waste (e.g., location of maximum vapor concentration)
Migration Pathways	Unsaturated soil, buried utility lines
Transport Mechanisms	Chemical diffusion (concentration gradient), gas advection (pressure gradient)
Vapor Attenuation	Diffusion, biodegradation, dispersion (spreads), mixing and dilution
Enclosed Buildings	Commercial, residential, other
Foundation Type	Slab-on-grade, basement, crawlspace
Entry Points into Building	Crawlspace, foundation seams and cracks, utility lines, sumps, elevator shafts
Indoor Mixing and Dilution	Indoor air exchanges, seasonal stack effects, HVAC operation, division and use of interior space

2.1 Sources

As part of the development of the CSM, it is important to identify potential sources of VI contaminants. Relevant information that should be considered includes approximate dates, locations, depths, and mechanisms of hazardous substance releases. Potential releases include spills or leaks from above-ground storage tanks (ASTs), underground storage tanks (USTs),

[1] OAR 340-122-0115(35) defines LOF as any point where a human or an ecological receptor contacts, or is reasonably likely to come into contact with, facility-related hazardous substances (340-122-0115(35)), considering (a) the chemical and physical characteristics of the hazardous substances; (b) physical, meteorological, hydrogeological, and ecological characteristics that govern the tendency for hazardous substances to migrate through the environmental media or to move and accumulate through food webs; (c) any human activities and biological processes that govern the tendency for hazardous substances to move into and through environmental media or to move and accumulate through the food webs; and (d) the time required for contaminant migration.

pipelines, sewer lines, wastes in drain fields, underground injection systems (i.e., UICs), etc. The following sections describe various types of VI chemicals of interest and types of potential sources to inform the CSM.

2.1.1 Vapor intrusion contaminants of interest

Vapor intrusion is associated with hazardous chemicals that form gases at ambient temperatures. Whether a chemical presents a vapor intrusion concern depends both on its toxicity and volatility. Most hazardous substances with a Henry's law constant greater than 10^{-5} atm-m^3-mol^{-1} are VI contaminants of interest (COIs). This includes VOCs, such as chlorinated solvents trichloroethene (TCE) and tetrachloroethene (PCE), petroleum hydrocarbon VOCs such as benzene, and petroleum products such as gasoline. In addition, some hazardous substances typically classified as semi-volatile organic compounds (SVOCs) are sufficiently toxic that even with marginal volatility they pose a potential VI risk. Chemicals in this group include polycyclic aromatic hydrocarbons (PAHs), diesel, numerous chlorinated pesticides and a range of polychlorinated biphenyl (PCB) congeners and Aroclors. Site-specific VI COIs should be identified based on the preliminary CSM.

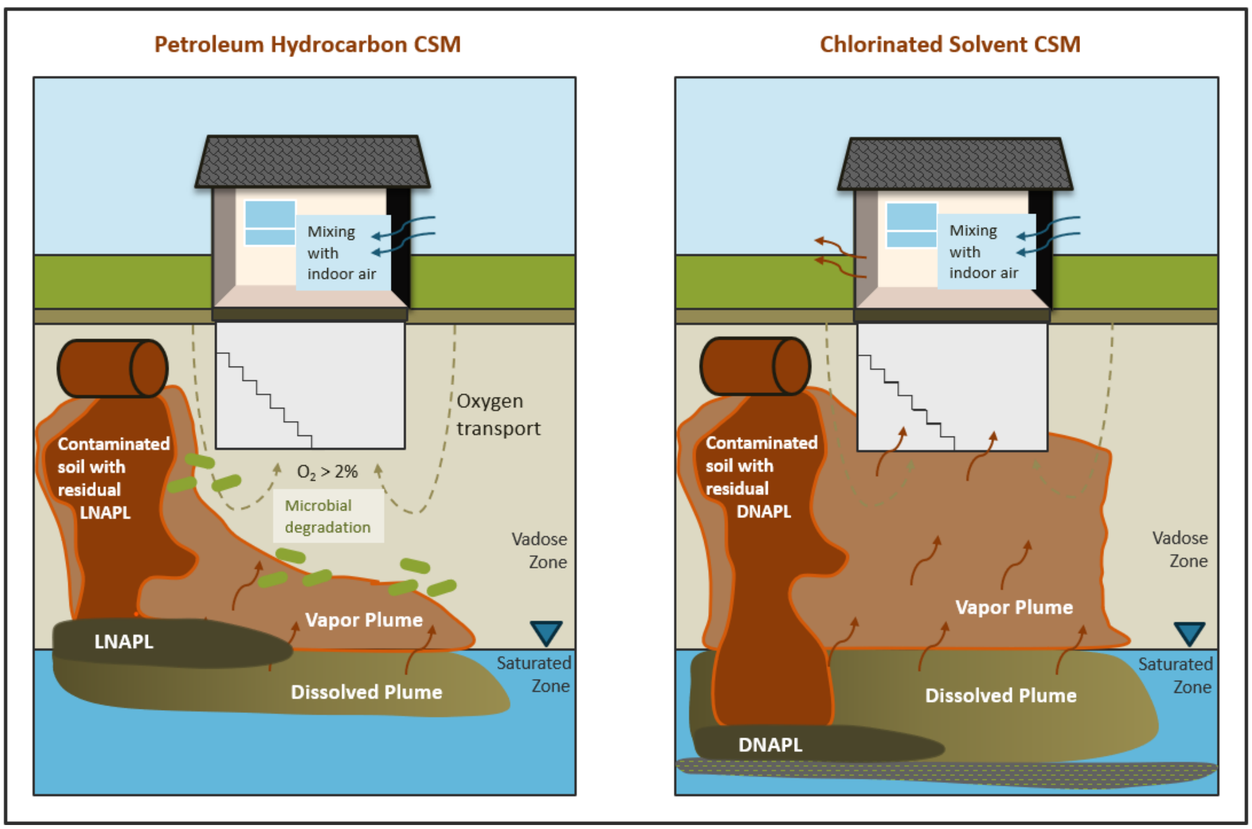

Figure 2. Typical transport scenarios for petroleum and chlorinated solvents

In this document DEQ acknowledges two common groups of VI chemicals, petroleum and non-petroleum, which exhibit notable distinctions in chemical characteristics and behavior in the environment as it relates to vapor intrusion. Accordingly, DEQ's guidance presents moderately different approaches to investigate and evaluate VI resulting from these two groups. Petroleum hydrocarbons include gasoline and diesel and related constituents. Non-petroleum VOCs, particularly chlorinated solvents, have been used in dry cleaning (e.g., TCE and PCE), as degreasing solvents in industry, and in manufacturing (e.g., plastics). Figure 2 illustrates an overview of the transport mechanisms for petroleum and chlorinated solvents.

2.1.2 Free product

Free product produces the strongest vapor sources and associated risks. At some sites, light nonaqueous phase liquid (LNAPL) (e.g., gasoline) or dense nonaqueous phase liquid (DNAPL) (e.g., TCE, PCE) residuals may be present in the vadose zone in the vicinity of where a release occurred. Petroleum LNAPL can accumulate at the capillary fringe (between unsaturated and saturated zones), while DNAPL can migrate deeper into the aquifer until encountering a layer of low permeability. Vapor concentrations associated with free product are predicted from the chemical's vapor pressure and, in the case of mixtures, the molar fraction of individual constituents and an application of Raoult's law (further described in DEQ's 2003 guidance for *Risk-Based Decision-Making for Remediation of Contaminated Sites*).

2.1.3 Contaminated soil

Contaminated soil refers to VOC contamination in unsaturated soils located above the water table (i.e., the vadose or unsaturated zone). In the vadose zone, chemical spills and releases primarily migrate vertically downward under the influence of gravity with some lateral spreading. Spatially, soil sources tend to be limited in extent relative to groundwater plumes. With respect to mobility and migration, soil sources stabilize relatively quickly once the release has been stopped.

Characterization of soil contamination is fundamental to the site investigation and provides a line of evidence for vapor intrusion; however, it is a poor predictor of vapor intrusion risks. Delineating sources of chlorinated solvent contamination in soil can be particularly difficult. It is not uncommon to measure high concentrations of chlorinated VOCs in soil vapor without identifying a corresponding soil source.

There are several reasons for this, including:

- The soil medium is more heterogeneous than soil vapor or groundwater.
- VOCs can be lost due to their volatile nature during soil sampling.
- Analytical method reporting limits may be high relative to screening levels used to identify a soil source.

While soil data is no longer recommended to assess VI risk, identifying where VI contaminants are detected in soil remains useful to inform the investigation strategy. Soil sources should be adequately characterized and depicted in three dimensions in the CSM. Other relevant information from soil samples or boring logs, such as grain size and presence of clays or sandy soil, should also be included in the CSM. This information is important for planning a VI investigation, such as selecting vapor sampling locations, interpreting data results, and screening viable remedial options if necessary.

2.1.4 Contaminated groundwater

Unlike soil sources, plumes of groundwater contamination can extend substantial distances (e.g., hundreds of feet) downgradient from the original release. A groundwater VOC plume may persist for decades after the release has stopped, for instance from a chlorinated solvent release. Additionally, the magnitude and spatial extent of groundwater plumes exhibit both seasonal variability and long-term trends. These changes and fluctuations in groundwater conditions (i.e., groundwater source location and strength) need to be discussed in the VI conceptual site model. This information is important for interpreting data and identifying the boundaries of the VI locality of facility and potentially affected buildings.

The strength of vapor sources associated with contaminated groundwater depends on the contaminant’s concentration at the water table, and more specifically concentrations within the capillary fringe. Therefore, when characterizing VI risk, groundwater samples should represent concentrations at the soil-groundwater interface to the extent feasible.

The depth to the water table and VI sources in groundwater can fluctuate several feet or more annually. Rising groundwater levels bring VOC sources closer to buildings and increase the potential for vapor intrusion. This is especially significant for petroleum contaminated sites with LNAPL contamination which can accumulate at the capillary fringe on top of the water table, as illustrated in Figure 4A. In addition, high-water tables may minimize biodegradation of petroleum vapors because less unsaturated soil is available. On the other hand, an influx of fresh water (e.g., during a heavy rain event) may decrease VI temporarily by introducing a clean water lens. Until data is collected to characterize seasonal conditions, it can be difficult to predict how water table fluctuations will affect vapor intrusion potential at any given site.

A lens or layer of clean water overlying a contaminant plume can act as a barrier to vapor migration and can effectively render the pathway incomplete (as shown in Figure 4B, Scenario B). This condition can occur in distal portions of large, chlorinated plumes in unconfined aquifers (e.g., western Oregon). If a plume of groundwater contamination sinks beneath the water table because of downward hydraulic gradients or precipitation recharge and a clean wedge of groundwater develops above the contaminated groundwater, the VI pathway is incomplete in these portions of the plume.

As the depth to the water table increases, chemical diffusion gradients weaken and the risk of vapor intrusion from groundwater sources declines. The depth at which groundwater sources cease to pose a VI risk will vary from site to site; however, groundwater plumes where the water table is 30 feet below ground surface (bgs) have been documented to cause VI. If it is suspected that a groundwater plume is not a significant source for VI due to its depth, soil vapor concentrations should be measured along a vertical profile in the vadose zone to demonstrate it directly.

2.2 Vapor migration pathways and transport mechanisms

Contaminant vapors from NAPL, soil, and groundwater sources migrate to the surface and into buildings through the unsaturated soils of the vadose zone. An example of vapor transport pathways is illustrated in Figure 3. The texture, moisture content, and oxygen levels of soils lying between a source of contamination and a receptor are factors that strongly influence the distribution of vapor contamination and rates of vapor transport. In addition to diffuse transport through natural soils, VI is commonly the result of vapor migration along preferential pathways, such as utility trenches and sewer lines, and identifying these features and their connection to buildings is an important component of the VI CSM.

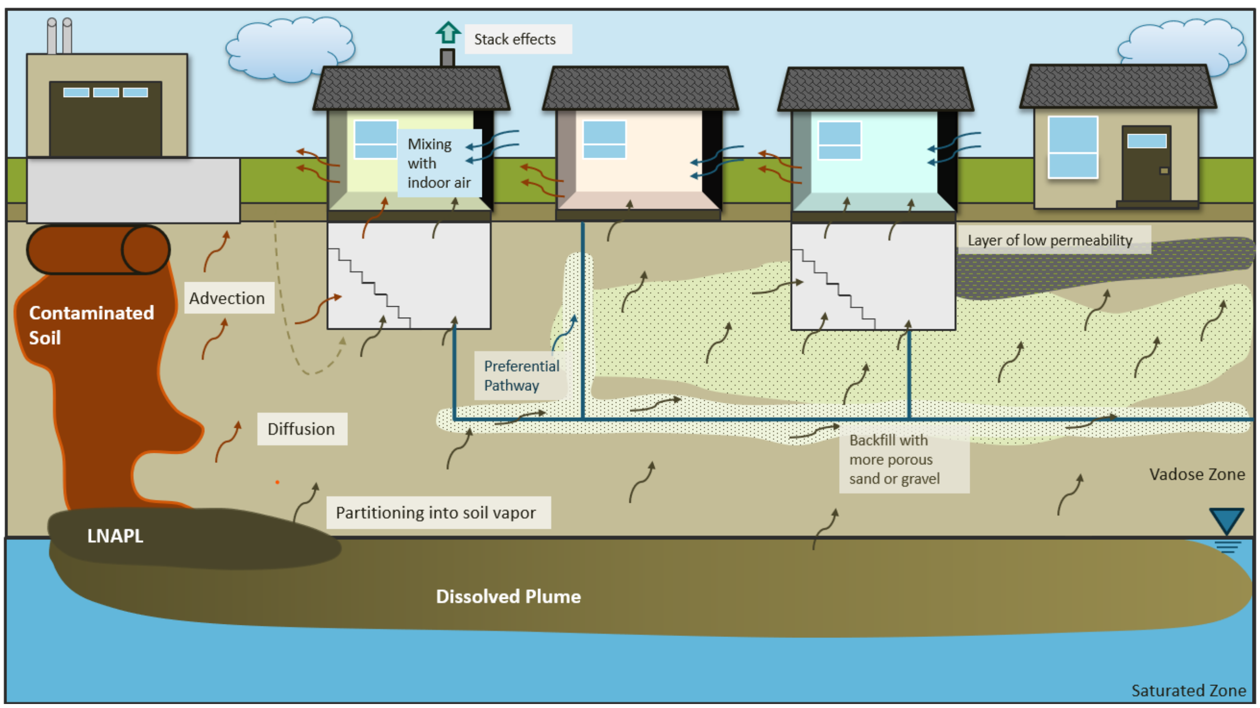

Figure 3. Vapor migration pathways and transport mechanisms

Vapor transport in the subsurface is driven by two mechanisms: (a) chemical diffusion driven by differences in concentration with net movement in the direction from regions of high to low concentration; and (b) gas advection driven by differences in air pressure with transport in the direction from high to low pressure. To a lesser extent, dispersion is another process by which a substance or chemical spreads and dilutes in moving groundwater or soil vapor. Most contaminant vapor transport models include advection and diffusion terms, and only rarely include a third term for dispersion (Yao et al., 2014).

2.2.1 Chemical diffusion

In the absence of preferential pathways, chemical diffusion is the primary contaminant vapor transport mechanism at depth, which this guidance assumes to be 5 feet bgs or 5 feet below the foundation of a building; however, depths will vary based on site-specific conditions including soil type. Rates of diffusion can vary greatly and are primarily a function of source strength, the separation distance between source and receptor, and the interconnected air-filled porosity of the soil.

The greater the separation distance between a VOC source and an overlying building, the weaker the concentration gradient, and the proportionally lower chemical diffusion rates and vapor intrusion risk. Chemical diffusion rates are also proportional to the interconnected or "effective" air-filled porosity of the soil. Water-filled pores effectively prevent vapor migration because of lower diffusion rates through water, which can be approximately three to four orders of magnitude lower than through air. Sandy, coarser-textured soils have higher air-filled porosities compared to fine-grained soils and, correspondingly, are much more transmissive to vapor flow. Conversely, fine-grained soils retaining high moisture levels are effective barriers to vapor migration (as illustrated in Figure 4B, Scenario C).

2.2.2 Gas advection

Advective transport is driven by pressure gradients and can change daily and seasonally with regular changes in atmospheric or barometric pressure. Advection overcomes chemical diffusion as the driving force in gas transport as vapors migrate toward the surface due to relative pressures generally being lower near the ground surface and inside buildings and underground utilities. Changes in atmospheric pressure induce "barometric pumping" with atmospheric gases driven down into the soil in a high-pressure weather system and soil vapors "exhaled" to the atmosphere (and buildings) during a low-pressure system.

In addition to changes in atmospheric pressure, air circulation within buildings generally lowers the pressure of the interior spaces relative to the underlying soil. The pressure differential between the building and sub-slab tends to be amplified seasonally when the weather is colder and buildings are heated. The heated air rapidly rises producing a "stack effect" or "chimney effect" and resulting in a strong pressure differential with the underlying soil. Greater pressure differential drives gas advection and therefore increases vapor intrusion. The stack effect can be limited or absent in modern commercial buildings that are well sealed and insulated, which reduces air leakage through the building shell. Building heating, ventilation, and air condition (HVAC) systems can have large impacts on the pressure differential between the building and sub-slab, either increasing or decreasing rates of VI as discussed in Section 2.3.3: *Mixing and dilution with indoor air*.

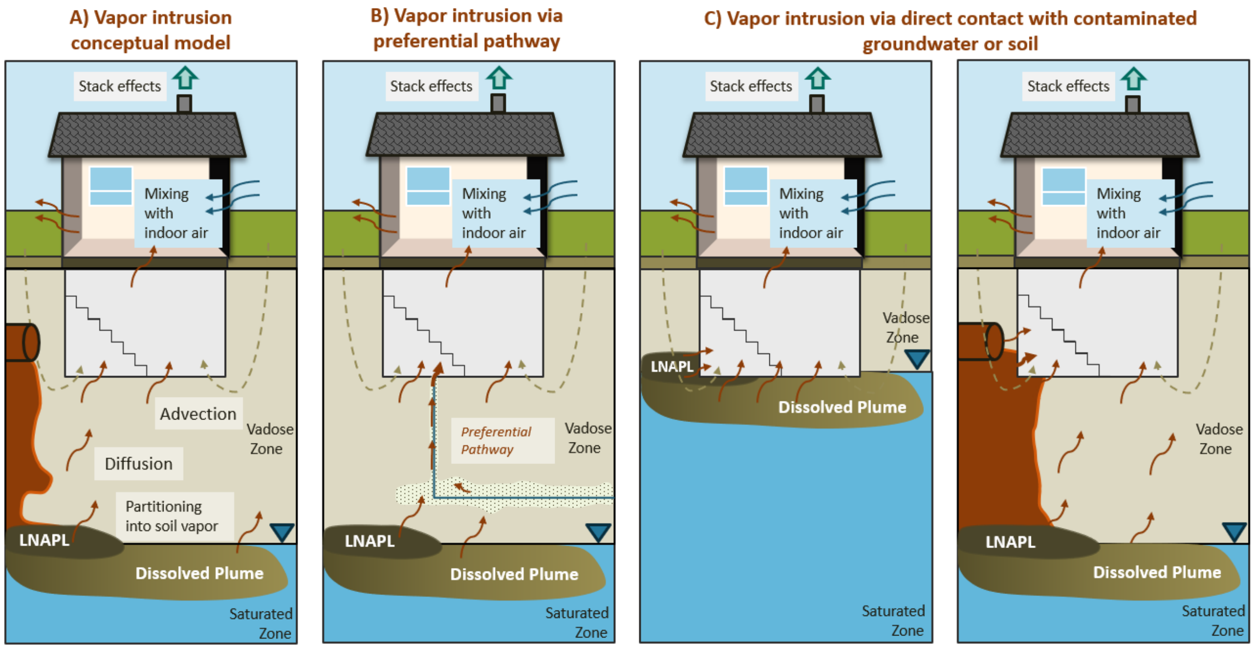

Figure 4A. Examples of conceptual site models with complete VI pathways

2.2.3 Vapor attenuation in the subsurface

The concentrations of contaminants in soil vapor decrease (i.e., attenuate) as vapors migrate from sources in soil and groundwater and spread via diffusion, dispersion, and advection up towards the surface and laterally. As vapors migrate up towards the ground surface and building foundations, they are mixed and diluted with atmospheric gases circulating in shallow soil, further reducing contaminant concentrations in soil vapor.

Biodegradation. At petroleum release sites, biodegradation is an important mechanism of attenuation that can effectively render the VI pathway incomplete (as illustrated in Figure 4B, Scenario A). Under aerobic conditions, petroleum vapor plumes can rapidly biodegrade into non-toxic byproducts such as carbon dioxide (CO_2) over relatively short vertical and lateral distances (ITRC, 2014; CalEPA, 2023).

At these sites it is necessary to collect subsurface data of fixed gases, such as CO_2, oxygen (O_2), and methane (CH_4) levels, in addition to contaminant data to validate that a CSM includes biodegradation. By developing a site-specific PVI CSM that integrates biodegradation, it may be possible to demonstrate the pathway is incomplete while still exceeding RBCs in groundwater or deep soil vapor samples (e.g., not at the sub-slab).

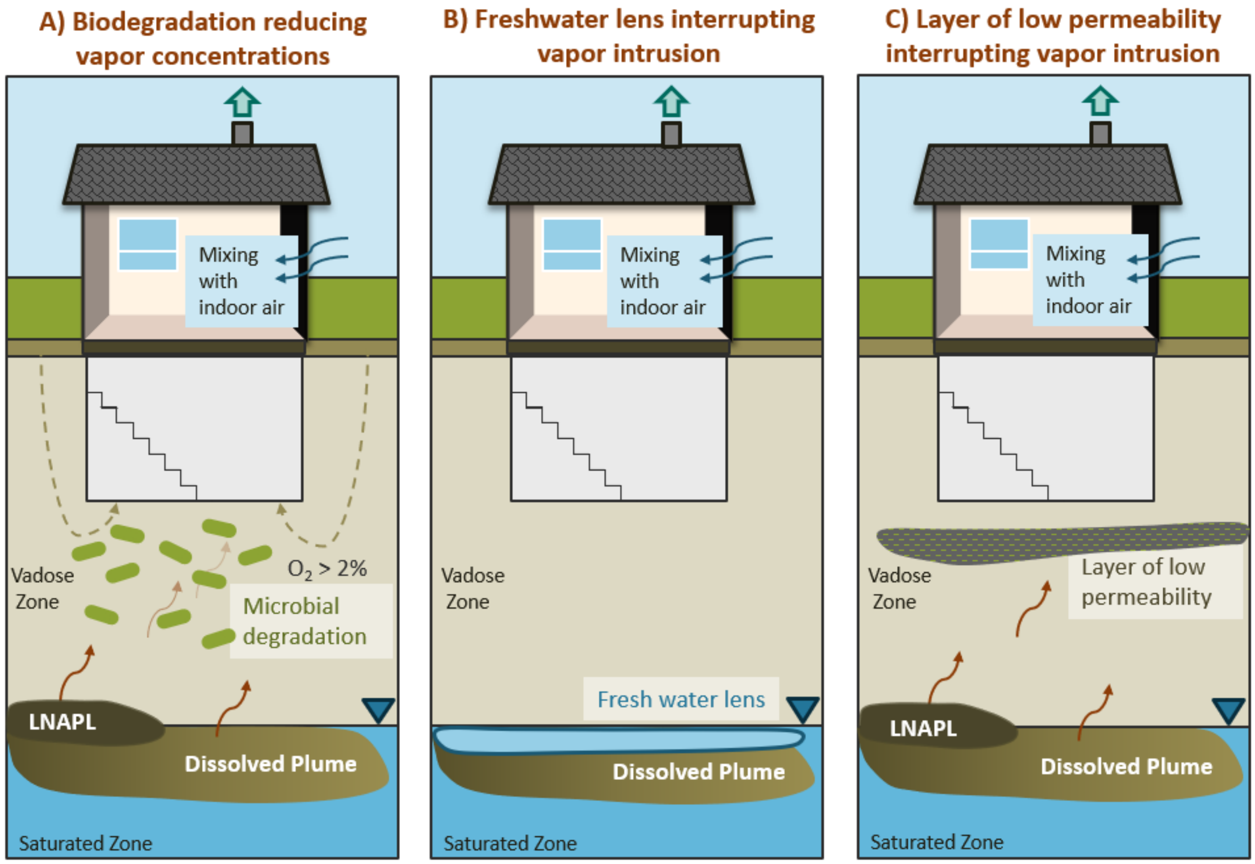

Figure 4B. Examples of conceptual site models that may result in an incomplete VI pathway

In contrast, biodegradation of non-petroleum contaminants (e.g., chlorinated solvents TCE and PCE) is not considered an important attenuating mechanism. Biodegradation of chlorinated solvents often relies on anerobic processes that are too slow to attenuate vapor levels along the vapor intrusion pathway. Furthermore, contaminants such as PCE and TCE degrade into toxic and more volatile intermediate daughter products that also contribute to VI risks.

Role of EPA and ITRC guidance in petroleum VI evaluations. EPA (2012a, 2015b) and ITRC (2014) have developed comprehensive guidance for assessing PVI sites that DEQ encourages the reader to consult when developing sampling plans. These documents provide screening criteria such as vertical and lateral separation distances between occupied structures and PVI sources for screening the PVI pathway, and they provide the qualifying criteria for applying them. DEQ believes these evaluations can provide strong lines of evidence regarding PVI risk; however, they must be accompanied by soil vapor analytical data to quantitatively assess risk (further discussed in Section 3.3: *Evaluation process for petroleum contaminants*).

2.3 Building considerations

Different building types vary in their susceptibility to vapor intrusion. Several important building characteristics may impact how much soil vapor enters a building, including the building age, condition, and foundation type, as well as how much mixing and dilution occurs inside the building. Common soil vapor entry points include crawlspace areas, utility entry points, sumps, drains, and cracks and seams in concrete foundations.

2.3.1 Foundation type

Buildings with basements tend to be the structures most vulnerable to vapor intrusion. In these buildings, vapor entry points can be located within the basement walls in addition to the floor, while the stack effects associated with heating the structure may be enhanced. Furthermore, basements bring the structure closer to the source of subsurface contamination and exhibit more seasonal vulnerability.

Buildings with slab-on-grade or crawlspace construction may behave similarly and can be susceptible to VI. Vapor intrusion investigations need to evaluate risks to both current and future buildings within the vapor intrusion LOF, the area where chemicals are present or may come to be present.

2.3.2 Soil vapor entry points

Vapor intrusion can potentially occur where the building shell contacts the subsurface, including below grade infrastructure such as basements. Direct openings through the building shell, such as cracks or openings around unsealed utilities, sumps, drains, cracks or seams in the foundation, or absence of a building shell (e.g., crawlspace) with the subsurface can serve as entry points and preferential pathways. Older buildings generally present more challenges, including aging infrastructure such as degraded building slabs, multiple entry points, and a higher potential for poor ventilation. These are important locations to consider for sampling and warrant closer inspection.

2.3.3 Mixing and dilution with indoor air

On average indoor air is primarily composed of outdoor air with contribution from soil vapor. In passively ventilated buildings the contribution of soil vapor to indoor air can change substantially from changes in weather and the heating and cooling of the building. Vapor intrusion rates and indoor air contaminant levels typically reach a maximum during the winter months when building stack effects are most pronounced and soil to indoor air pressure differentials are greatest. In Oregon, VI rates are typically at a minimum during summer months when indoor to outdoor air temperature differences are minimal. During warmer months opening windows is also more common, which can increase fresh air ventilation.

An important consideration in developing the VI CSM is understanding how a building can be influenced by operation of existing systems, such as radon mitigation, exhaust fans, and HVAC systems (as illustrated in Figure 4C). For instance, HVAC systems can reduce VI effects by means of increased air circulation through the building and vapors are diluted with ambient air. In addition to HVAC systems, room-specific ventilation equipment such as kitchen range hood or exhaust fans (residential and industrial), bathroom fans, and fume hoods in laboratories can impact indoor air circulation and pressure differentials. HVAC system operation often impacts the internal pressure in a building, under-pressurizing or over-pressurizing a portion or the entire building with respect to the underlying soil. These pressure gradients increase or decrease VI, respectively.

HVACs can be intentionally operated to over-pressurize indoor spaces, reversing the pressure gradient, pushing indoor air into the underlying sub-slab, and reducing vapor intrusion into a building. Relying on operating HVAC systems typically is not an acceptable standalone mitigation measure but often can supplement a mitigation system. Consistent operation of HVAC is difficult to maintain and monitor long-term. It is important to consider how HVAC system operation may vary with time, building use, and weather conditions. Seasonal changes for heating and cooling as well as daily and weekly changes in building use may impact VI.

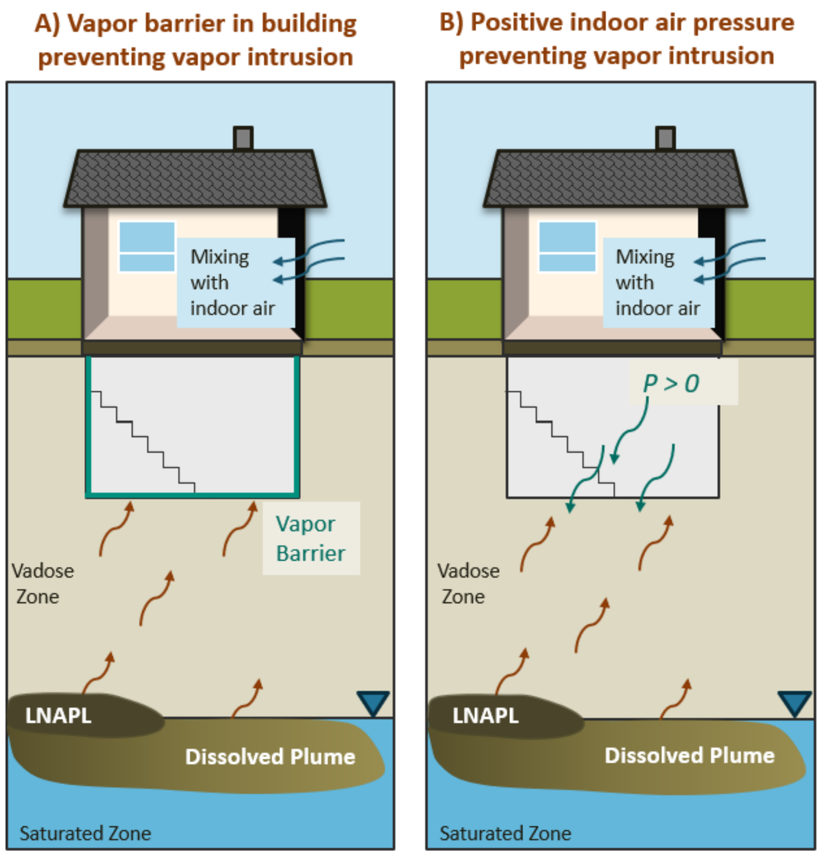

Figure 4C. Existing systems that may interrupt the VI pathway

Existing radon mitigation systems should be considered during VI CSM development and evaluation of VI investigation results. Radon systems are intended to increase sub-slab (or crawlspace) ventilation or depressurize the sub-slab. Under these circumstances, the system can disrupt the VI pathway, making it important to consider during the development of a VI sampling plan and data interpretation. Conditions in absence of the radon and/or HVAC systems will need to be taken into account during the risk evaluation. If mitigation is necessary, performance of an existing radon system can be evaluated to determine the appropriateness to integrate into a final mitigation strategy.

3.0 Vapor intrusion evaluation process

Three process flow charts are presented in this section to guide a VI evaluation. The applicable flow chart is determined by the type of assessment: non-petroleum contamination, indoor air, or petroleum contamination (e.g., LUST site). A new PVI specific flow chart includes an approach to demonstrate biodegradation is occurring. Each flow chart may direct you to another flow chart when additional evaluations or response actions are warranted.

These VI evaluation flow charts are introduced in the following sections:

- Section 3.1: *Non-petroleum source assessment and remediation process* (Figure 6)
- Section 3.2: *Indoor air assessment and mitigation process* (Figure 7)
- Section 3.3: *Evaluation process for petroleum contaminants* (Figure 8)

Additionally, Appendix B contains a strategy for evaluating vapor intrusion at Heating Oil Tank sites and includes a HOT specific flow chart. When source remediation and/or mitigation (Section 6) is the appropriate response action based on the VI assessment, monitoring will be necessary to demonstrate performance. A performance monitoring framework is presented in Section 6.3 and accompanied by a supporting flow chart.

Figure 5A illustrates an overview of the VI evaluation flow charts, their relationship to each other, and the subsequent phases of work when source remediation and/or mitigation is necessary.

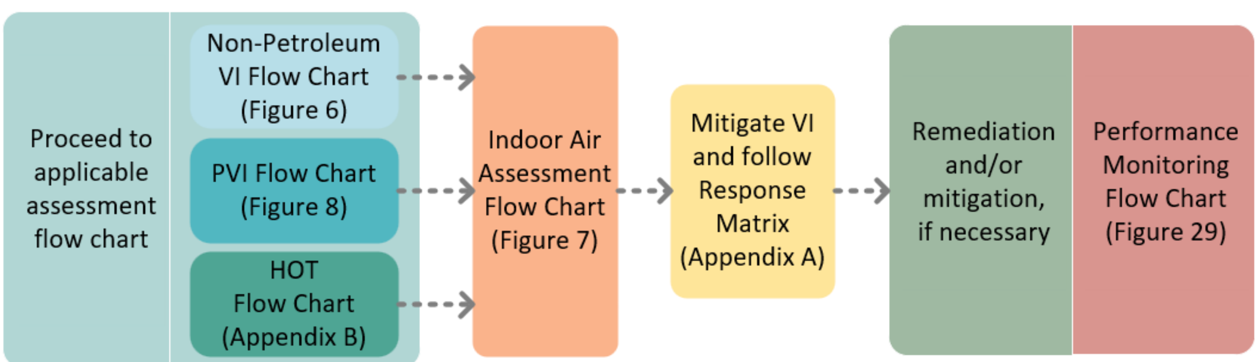

Figure 5A. Guide to flow charts

Each flow chart is followed by a more detailed description of each box and decision point. Scenarios are provided to help select the most applicable decision for different sites conditions. There is flexibility to propose an alternative approach during different phases of the process where reasonable and defensible.

Note: If at any point in the investigation information and/or data indicates vapor intrusion is likely occurring, the indoor air of vulnerable buildings should be sampled at the earliest opportunity. When indoor air exceeds applicable RBCs as a result of vapor intrusion, use Appendix A to determine an appropriate response and recommended timeline.

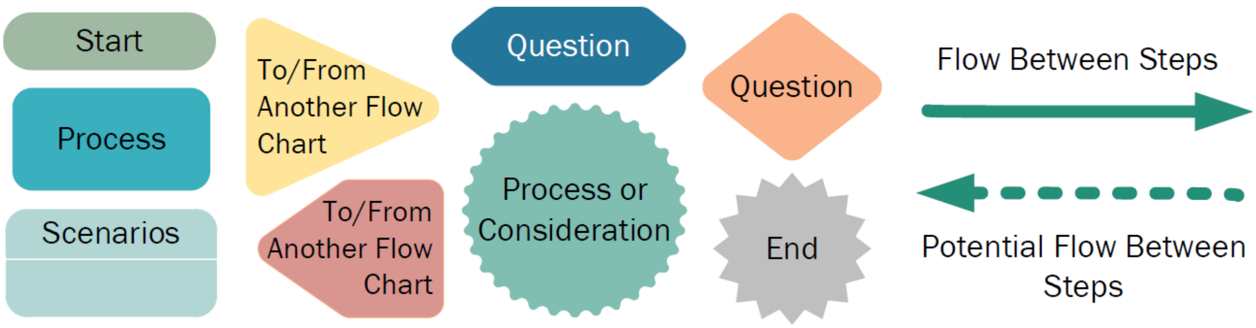

Figure 5B. Guide to flow chart symbols and meaning

3.1 Non-petroleum assessment and remediation process

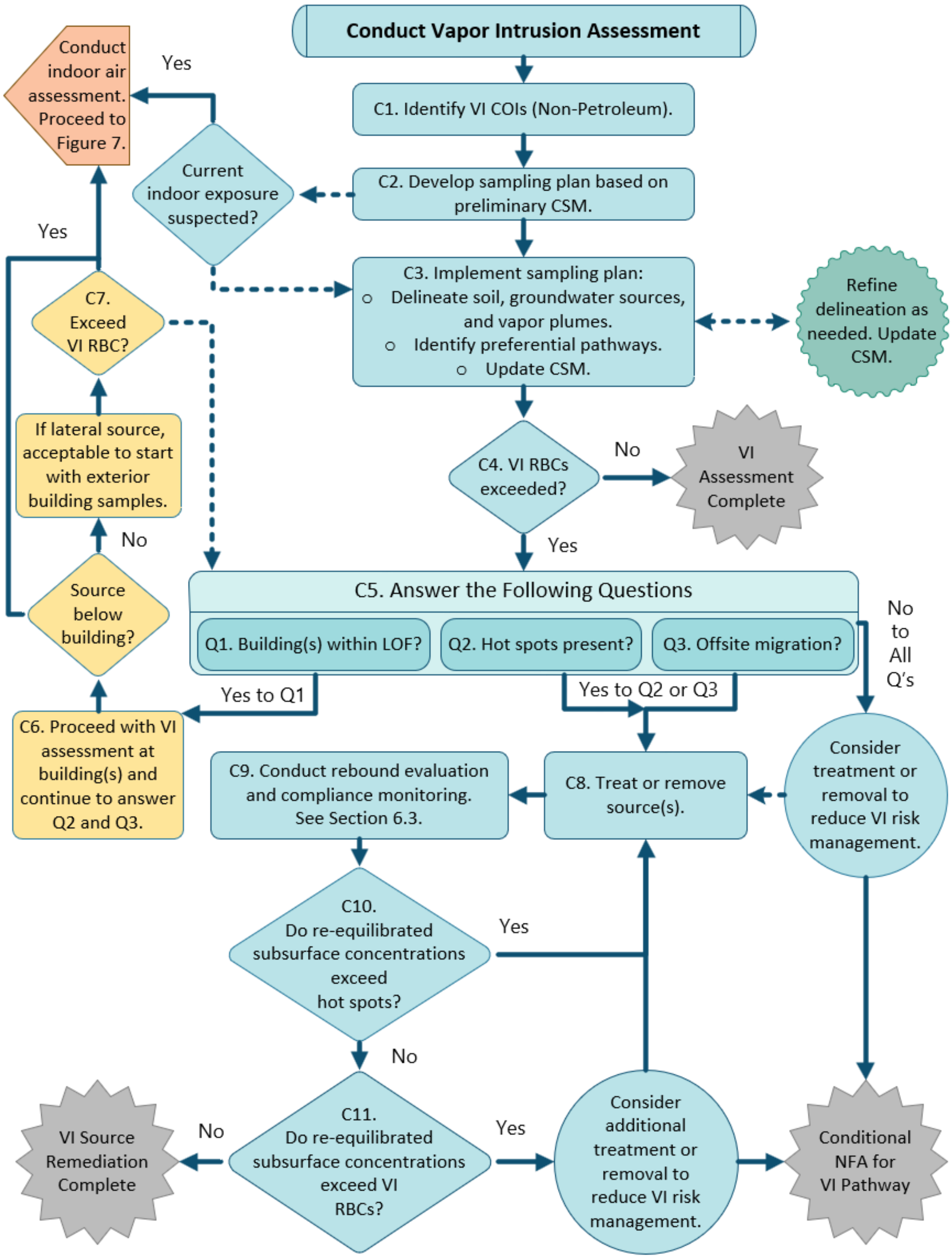

Figure 6. Non-petroleum process flow chart to evaluate the VI pathway

Box C1. Identify potential VI contaminants of interest.

Determine whether chemicals of interest have potentially been released on properties that are currently developed and occupied or could be in the future. EPA's VISL table and calculator provide the most comprehensive list of VI contaminants and screening levels. As of 2023, EPA's VISLs were incorporated into DEQ RBCs for VI risk screening with minor adjustments. Check DEQ's Cleanup Program website for periodic updates to these RBCs.[2]

Box C2. Develop sampling plan based on preliminary VI CSM.

The CSM should integrate available information on historical storage, use, and disposal of VOCs on the site. To the extent known, the CSM should also include relevant information on release mechanisms, known distribution of contamination in environmental media, potential receptors and subsurface soil and groundwater conditions (see Section 2: *Vapor intrusion conceptual site model*). Additional infrastructure, such as utilities or exterior confined spaces, should be identified and considered in the VI evaluation.

Occupied structures, either existing or future, are an essential element of the VI pathway. If zoning, land use restrictions, or current use of the site preclude or prevent future development (e.g., right-of-way), further evaluation of the VI pathway may be unnecessary.

If existing information indicates vapor intrusion is potentially occurring or has high potential to occur, indoor air samples should be collected in vulnerable buildings at the earliest opportunity. Move left on the flow chart to "Current indoor exposure suspected" and work through the Indoor Air Assessment Flow Chart (Section 3.2, Figure 7) to evaluate indoor air quality. Indications of active VI include but are not limited to: complaints of chemical odors or physiological effects by building occupants, chemically stained foundations, or soil vapor, groundwater, or soil data indicating a high probability of VI.

The sampling plan, or sampling and analysis plan, should achieve the following objectives:

- Determine the location, depth, and release mechanism of each VOC source.
- For each source, map the distribution of VOC contamination in soil and delineate groundwater plumes exceeding VI RBCs using a combination of field screening methods and analytical data.[3]
- Identify any potential preferential pathways into buildings, such as sewer and other utility lines or highly transmissive paths.
- Characterize subsurface soils with respect to soil texture, moisture content, redox conditions, secondary porosity, and other features relevant to vapor migration.
- Based on soil and groundwater data, field screening measurements, and other relevant information, soil vapor samples should be collected within each source area at a

[2] EPA Vapor Intrusion Screening Level Calculator Website.

[3] The concentration in groundwater as measured at the soil-groundwater interface.

minimum of two depths, 5 feet bgs and 10 feet bgs, at two separate locations.[4] Note that the depths may need to be adjusted based on site-specific conditions such as water table depth.

- If the source area samples exceed RBCs, adequately characterize the extent and magnitude of the subsurface vapor plume exceeding vapor intrusion RBCs in three dimensions. There is an emphasis to characterize vapor plumes in the vicinity of occupied and planned buildings.
- Account for seasonal variation for a full characterization. In most cases, this will require a minimum of a six-month investigation timeframe to capture variations to DEQ satisfaction. A realistic time frame to collect the needed data should be considered in site planning.

DEQ expects the results of these investigations will be used to revise the VI CSM, which is presented in plan-view and as cross-sections. More complex sites should prepare isopleth concentration maps.

Box C3. Implement the sampling plan and complete the following:

- Characterize sources, soil, groundwater, and vapor plumes.
- Identify preferential pathways (e.g., utilities).
- Update CSM.

Consult Section 4 for additional details on sampling methods and strategies.

Box C4. Do concentrations exceed VI RBCs?[5]

No – No further assessment of the VI pathway is necessary.

Yes – Proceed to Box C5.

Box C5. Questions 1, 2, and 3.

<u>Question 1: Are buildings located within the VI LOF?</u>

Existing or potential future buildings are located within the VI locality of facility if:

- They overlie or are within 100 feet of a source area including groundwater plumes that exceed VI RBCs or detectable chlorinated solvents in soil.

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[4] To avoid the effects of barometric pumping (the circulation of gases into and out of the vadose zone in response to changes in atmospheric pressure) and atmospheric gas exchange, collect soil vapor samples from 5 feet or more below the ground surface. The deeper depth of 10 feet is to further characterize the source and account for buildings with basements and similar infrastructure. Depths can be modified based on site-specific conditions, the CSM, and professional judgement.

[5] For unrestricted reuse of property, soil vapor concentrations must be in compliance with RBCs at both 5 feet bgs and 10 feet bgs.

- They overlie a vadose zone source of VOCs.
- They are located within 30 feet of a soil vapor plume exceeding RBCs.
- They are potentially connected to a VI source area through a preferential pathway.

If **any** of the above conditions are met, proceed to Box C6 and continue to answer Questions 2 and 3. If none of the conditions apply then proceed directly to Questions 2 and 3.

Questions 2 and 3: Are there hot spots in soil vapor or groundwater, or does contamination migrate offsite and onto properties that are or can be developed?

No to both – Consider treatment or removal to reduce VI risk management by remediating and eliminating VI risk. If this path is chosen, proceed to Box C8. If no treatment or removal is selected, engineering and/or institutional controls may be used to close the VI pathway with a conditional no further action (cNFA) for the VI pathway. These conditions or restrictions to maintain protectiveness are recorded in a deed restriction, commonly in the form of an Easement and Equitable Servitudes, until RBCs are met.

Yes to either – Hot spots in soil vapor are generally defined as concentrations exceeding RBCs by a factor of 10 or greater based on non-carcinogenic risk, and a factor of 100 or greater based on carcinogenic risk (see Section 5.7: *Determination of hot spots*), if they are demonstrated to be reliably containable in a site-specific evaluation. If contamination is not reliably containable, a hot spot may exist when concentrations exceed RBCs without the multiplying factors. Mitigation or remediation technologies can reliably contain contamination in soil vapor, which is demonstrated by a site-specific evaluation approved by DEQ in the feasibility study (FS) or equivalent and confirmed by performance monitoring. If a hot spot exists, DEQ has a preference for actively remediating (i.e., removing or treating) the source of contamination (go to Box C8). This evaluation should be based on soil vapor data to the greatest extent practicable. For example, if groundwater concentrations are above RBCs, further assessment of soil vapor should be conducted to determine whether a hot spot is present. A soil vapor hot spot determination can be made based on groundwater data on a site-specific basis if it is not possible to collect representative soil vapor data (e.g., shallow groundwater with no vadose zone). Additionally, off-site migration of vapor plumes that exceed applicable RBCs at off-site properties should be considered for remediation (go to Box C8). In limited instances, with property owner concurrence, this situation can be managed with institutional controls.

Determining whether hot spots are present (Question 2). When soil vapor concentrations exceed RBCs, an evaluation is necessary to support whether soil vapor contamination can be reliably containable to inform the appropriate application of a multiplier to determine the presence of hot spots. At this stage, a site-specific evaluation is conducted in the form of feasibility study or equivalent (scaled up or down based on site complexity) consisting of an evaluation of potential actions to reliably prevent vapors entering a building, and a strategy is recommended to address unacceptable VI risk. In general, a feasibility study is the mechanism for the development, screening, and detailed evaluation of alternative remedial actions (e.g., mitigation and/or remediation technologies, institutional controls, etc.). This includes evaluating the condition of any existing buildings, presence of preferential pathways, and CSM to determine the feasibility of containing or mitigating the contamination in soil vapor to ensure long-term protectiveness within any current or potential future buildings. The hot spot analysis and determination is based on the following outcomes:

1. The FS (or equivalent) demonstrates to DEQ satisfaction that VI contamination can be reliably contained and a multiplier (10x or 100x) of the RBCs is used to calculate hot spots.
2. The FS (or equivalent) does not adequately support that VI contamination can be reliably contained, a multiplier is not applicable, and an exceedance of the RBC corresponds to a hot spot.

Scenario #1: Soil vapor concentrations exceed RBCs and can be reliably contained. A site-specific evaluation conducted in the form of feasibility study or equivalent demonstrates to DEQ satisfaction that VI contamination can be reliably contained by the proposed approach or existing mitigation measures. Under this scenario, the FS would present a hot spot analysis and identify hot spots using the appropriate multiplier. The FS would also present alternatives to remediate sources containing hot spots, if identified, and viable options carried forward for further evaluation. With DEQ's concurrence, design and implementation plans would be prepared for DEQ review.

Scenario #2: Soil vapor concentrations exceed RBCs and cannot be reliably contained. A site-specific evaluation is conducted in the form of feasibility study or equivalent and does not adequately support that VI contamination can be reliably contained. The FS would need to identify hot spots as exceedances of RBCs (i.e., no multiplier) and if hot spots are identified, the FS should include active remediation (i.e., removal and/or treatment) alternatives that address the source of soil vapor contamination. DEQ may conclude the FS needs to be revised to include additional viable technologies and/or enhance the recommended approach to reliably contain VI contamination and address associated short and long-term risks.

Scenario #3: Site conditions limit or prevent sampling soil vapor (e.g., land with shallow groundwater and limited or no vadose zone). Soil vapor is a more direct approach to determine hot spots and to inform appropriate response actions; however, in some cases, contaminated groundwater may be in direct contact with the foundation or soil conditions (e.g., low-permeable soils, moisture content, perched water), which may render it impracticable to collect representative soil vapor samples. Under these circumstances, an evaluation should be conducted to determine whether contamination in groundwater is generating a soil vapor hot spot that needs to be actively remediated. The FS would then evaluate the ability to reliably contain soil vapor contamination generated from contaminated groundwater and whether a multiplier can be applied to determine hot spot levels.

Box C6. Proceed with VI assessment at building(s) and continue to answer Q2 and Q3.

Each building located within a VI LOF should be assessed separately. The approach will vary depending on the building's location relative to the source of contamination and the building foundation design as follows:

Scenario #1: Buildings overlie VOC sources in groundwater and/or soil. The sources are below the building and can be either groundwater plumes exceeding VI RBCs or soil with detectable levels of VOCs. Contaminated soil may be in direct contact with the foundation. Under these circumstances, soil vapor and/or sub-slab[6] samples should be collected contemporaneously with indoor air and outdoor air samples. See flow chart process for Indoor Air Assessments (Figure 7).

Scenario #2: Buildings do not overlie VOC sources but are within soil vapor LOF (i.e., 30 feet) or soil or groundwater source LOF (i.e., 100 feet). Under these circumstances, exterior soil vapor samples (i.e., soil vapor samples collected outside the footprint of the building) can be collected as a line of evidence to screen the structure in or out for further assessment and indoor air sampling. If the exterior soil vapor samples exceed RBCs, then sub-slab soil vapor and contemporaneous indoor and outdoor air samples should be collected. See flow chart process for conducting an Indoor Air Assessment (Figure 7).

Scenario #3: Buildings are connected to VOC sources through preferential vapor transport pathways. Subsurface utilities that intersect or directly overlie VOC sources in groundwater or soil contamination should be mapped to the buildings they serve. When utilities or utility trenches, which may be backfilled with material more permeable than the surrounding soil, intersect VOC sources, they can provide a more direct conduit for vapor migration. Under these circumstances, soil vapor investigations and sub-slab data alone may not be reliable indicators of VI. Accordingly, indoor air sampling should be conducted in addition to taking measures to prevent the preferential pathways identified. See flow chart process for conducting an Indoor Air Assessment (Figure 7). Evaluating whether a preferential pathway is present (e.g., along utilities) is recommended as part of the VI evaluation and can be conducted in advance or in addition to an indoor air assessment.

Box C7. Are VI RBCs exceeded?

No – Return to Questions 2 and 3.

Yes – Follow the flow chart process for conducting an Indoor Air Assessment (Figure 7).

[6] Compared to other subsurface media, sub-slab data shows the strongest correlation to indoor air concentrations. This is expected, and due to its proximity to receptors usually takes precedence over groundwater and soil vapor data.

Box C8. Perform remedy to remove or treat subsurface sources.

Consult guidance provided in Section 6: *Vapor intrusion remediation and mitigation*. Remedial actions should be conducted with oversight and input provided by a DEQ project manager and can be implemented as removal actions or selected remedies based on a feasibility study.

Box C9. Conduct post-remedy rebound evaluation.

An essential post-remedy evaluation for VI sites is an analysis of concentration rebound in the subsurface after active remediation has ceased. Concentration rebound can occur in both soil vapor and groundwater. Depending on the site and the amount of residual contamination left behind, the time required for subsurface concentrations to re-equilibrate can range from months to years in length. Rebound is considered complete when there is no discernable upward trend in concentrations. Additional details on conducting a rebound assessment are discussed in Section 6.3.3: *Assessment of rebound*.

Box C10. Do re-equilibrated subsurface vapor or groundwater concentrations exceed hot spot concentrations?

Yes – If concentrations rebound above hot spot concentrations, source remediation should be resumed and rebound testing repeated (see Section 6.3.3 for additional guidance). If there are buildings within the LOF, continue to monitor indoor air. Return to Box C8.

No – Go to Box C11.

Box C11. Do re-equilibrated subsurface vapor or groundwater concentrations exceed VI RBCs?

In general, the following applies:

No – If rebound sampling indicates subsurface levels have stabilized at levels below RBCs, and pre-remediation indoor air samples were less than RBCs, the site may be closed without restrictions for the VI pathway. If pre-remediation indoor air samples exceeded RBCs, compliance indoor air sampling is recommended to verify the cleanup is complete and conditions are protective under seasonal/temporal conditions. If indoor air sampling demonstrates compliance with indoor air RBCs, the site can be closed without restrictions for the VI pathway.

Yes – If rebound sampling indicates subsurface levels have stabilized above RBCs the following alternatives are available: 1) resume subsurface remediation and repeat rebound testing (return to Box C8), or 2) discontinue remediation and conduct compliance indoor air sampling. If indoor air RBCs are not exceeded, long-term risk management of subsurface contamination may still be required using engineering and/or institutional. These conditions or restrictions to maintain protectiveness are recorded in a deed restriction, commonly in the form of an Easement and Equitable Servitudes, until RBCs are met.

3.2 Indoor air assessment and mitigation process

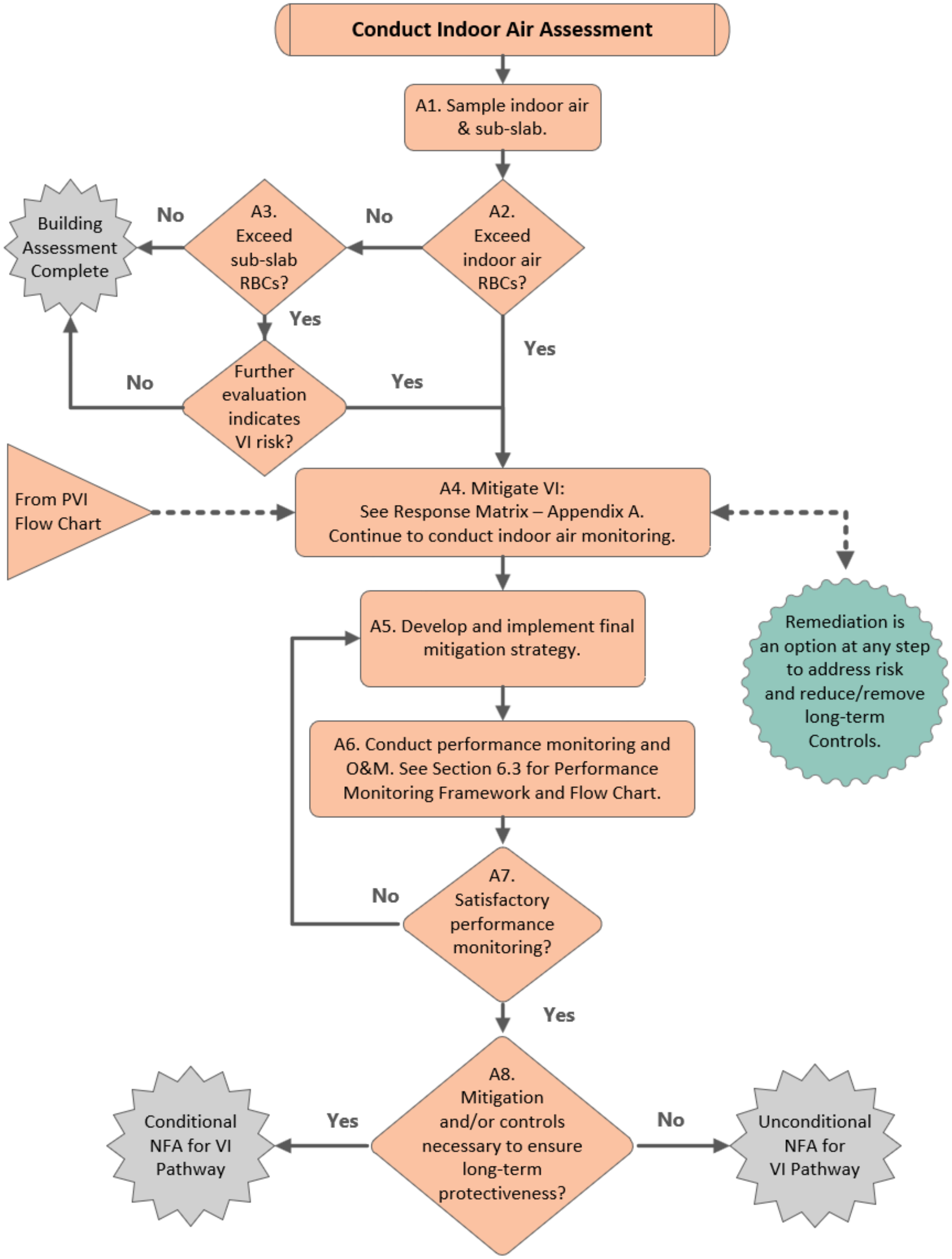

Figure 7. Indoor air assessment flow chart

Box A1. Sample indoor air and sub-slab vapor.

Consult Section 4 for additional details on sampling methods and strategies.

The number of indoor air and sub-slab vapor sampling events required to confidently screen out VI risk will vary depending on the initial indoor air sampling results and subsurface conditions; however, it will be typically a minimum of two events.

Throughout the flow charts, “Indoor Air Sampling” infers the collection of contemporaneous outdoor air samples.

Box A2. Do indoor air concentrations exceed RBCs (as a result of VI)?

To isolate VI risks, this determination should consider the contributions from indoor sources and outdoor background sources that are unrelated to chemical releases at the site.[7] Indoor sources are common and can be mistakenly attributed to VI.

If the results of a single indoor sampling event indicate vapor intrusion poses an unacceptable risk, a response is necessary (proceed to Box A4). Note that at any point, mitigation and/or remediation of the source can be considered and completed if feasible.

No – Go to Box A3 to consider sub-slab sample results.

Yes – Go to Box A4 for mitigation.

Box A3. Are sub-slab RBCs exceeded?

No – Building assessment is complete based on sufficient data; no VI risk identified.

Yes – Conduct further assessment.[8] If further assessment indicates unacceptable VI risk, proceed to Box A4 for mitigation. Alternatively, if further assessment reliably demonstrates no unacceptable risk to building occupants (current and future) using a multiple lines of evidence approach, then building assessment is complete. Note that if soil vapor RBCs are exceeded, institutional controls may be necessary.

Box A4. Mitigate VI.

Mitigation should be implemented in a timely manner that reflects the risk to building occupants (i.e., RBC exceedance factor); consult with a DEQ toxicologist and see the response matrix provided in Appendix A. Indoor air monitoring should continue into the post-mitigation period. Generally,

[7] If a VI contaminant of interest is currently in use in the building or ambient concentrations exceed RBCs, evaluation of VI risks will be based on subsurface data with appropriate attenuation factors. Consult with the DEQ project manager and Section 4 for more information.
[8] Further assessment includes results of additional subsurface investigation, evaluation of preferential pathways, spatial extent of the vapor plume, and seasonality of impacts.

these are interim measures that can be taken to rapidly reduce risk in days to weeks (consult Section 6.2.2 for prompt/rapid response options).

Box A5. Develop and implement final mitigation strategy.

Consult Section 6: *Vapor intrusion remediation and mitigation*. In general, viable technologies are evaluated and selected in coordination with DEQ review and concurrence. A final, long-term mitigation strategy may be a combination of initial immediate and long-term measures, which may include mitigation and/or remediation of VI sources. Mitigation design plans are prepared for DEQ concurrence and should describe the technology, operating parameters, maintenance schedule, and performance metrics.

Box A6. Conduct performance monitoring and system operations and maintenance.

See Section 6.3: *Performance monitoring of vapor intrusion mitigation systems* and respective flow chart (Figure 29) for additional details.

Box A7. Is the VI mitigation system performing satisfactorily?

No – Return to Box A5 and adjust, augment, or re-design system as necessary to achieve performance objectives.

Yes – Go to Box A8.

Box A8. Are mitigation and/or controls necessary to ensure long-term protection?

This will depend on the removal, treatment, and attenuation of vapor intrusion sources, the results of subsurface remediation rebound sampling, and indoor air compliance sampling.

No – Site can proceed with an unconditional no further action (NFA) determination for the VI pathway (or no further assessment for VI can be documented for the project while other site work continues).

Yes – Site can proceed with a conditional NFA to address VI with engineering and/or institutional controls (or continue with agreed upon controls while other site work continues). The conditions or restrictions to maintain protectiveness are recorded in a deed restriction, commonly in the form of an Easement and Equitable Servitudes, until RBCs are met.

3.3 Evaluation process for petroleum contaminants

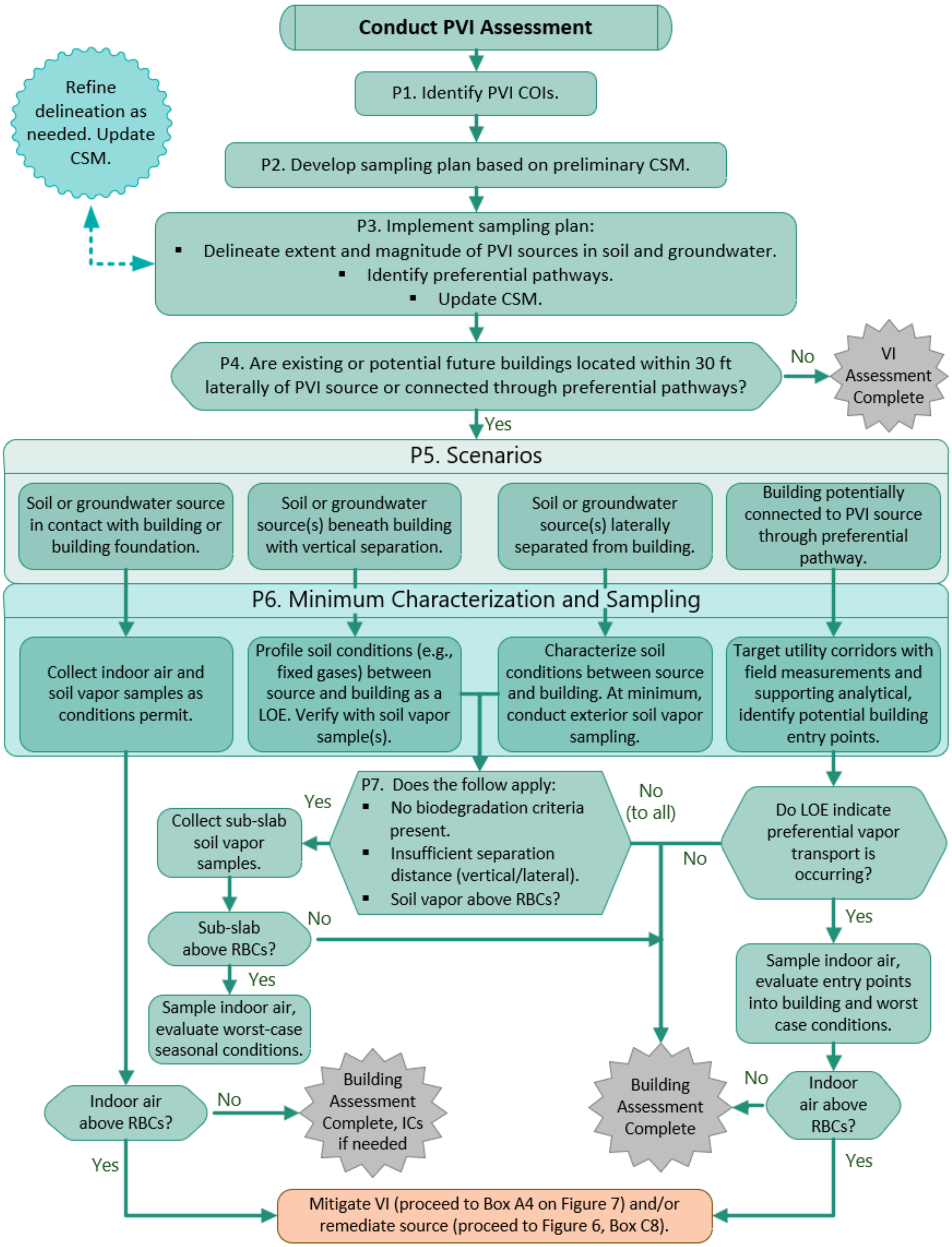

Figure 8. Petroleum process flow chart to evaluate the VI pathway

Box P1. Identify petroleum vapor intrusion contaminants of interest.

Determine whether chemicals of interest have potentially been released on properties, such as at LUST sites, that are currently developed and occupied or could be in the future. EPA's VISL table and calculator provide the most comprehensive list of VI contaminants and screening levels. As of 2023, EPA's VISLs were incorporated into DEQ RBCs for VI risk screening with minor adjustments. Check DEQ's Cleanup Program website for periodic updates to these RBCs.

Box P2. Develop sampling plan based on preliminary VI CSM.

The CSM is a crucial component of developing a sampling plan. See Section 2 regarding the development of site-specific CSM and Section 3.1, Box C2 for additional details on sampling objectives. The CSM should be updated as sampling results become available. At petroleum VI sites, the CSM should include the conditions that demonstrate biodegradation.

Box P3. Implement a sampling plan and complete the following:

- Delineate extent and magnitude of PVI sources in soil and groundwater.
- Identify preferential pathways (e.g., utilities).
- Update CSM.

The following are considered potential PVI sources:

- Soil contaminated with greater than 500 parts per million (ppm) by method Northwest Total Petroleum Hydrocarbon for diesel range organics (NWTPH-Dx) and 80 ppm by method Northwest Total Petroleum Hydrocarbon for gasoline range organics (NWTPH-Gx) or contaminant levels.[9]
- Groundwater contaminated at levels exceeding VI RBCs and VISL values. Note that trends in groundwater concentrations and future plume migration must be considered in delineating source areas and the VI CSM.

Consult Section 4 for additional details on sampling methods and strategies.

Use the field screening and analytical data to map the nature, extent, and magnitude of PVI sources. Identify the locations, alignments, and depths of utilities relative to sources of contamination.

[9] The UST Cleanup Rules (OAR 340-122-0218(d)(A)) require the use of the Northwest Total Petroleum Hydrocarbon Analytical Methods for samples "used to demonstrate compliance with remediation levels." NWTPH-Gx is a qualitative and quantitative method for volatile petroleum products such as aviation and automotive gasolines, mineral spirits, Stoddard solvent and naphtha. NWTPH-Dx is a qualitative and quantitative method for semi-volatile petroleum products such as jet fuels, kerosene, diesel oils, hydraulic fluids, mineral oils, lubricating oils, and fuel oils. The preference is that the laboratory report the combined diesel and heavy oil range organics as one result. If the laboratory reports diesel and heavy oil separately, these values should be summed before comparison to the RBC.

If existing information indicates vapor intrusion is potentially occurring or has high potential to occur, indoor air samples should be collected in vulnerable buildings at the earliest opportunity. Proceed to the Indoor Air Assessment Flow Chart (Section 3.2, Figure 7) to evaluate indoor air quality. Indications of active VI include but are not limited to: complaints of chemical odors or physiological effects by building occupants, chemically stained foundations, or soil vapor, groundwater, or soil data indicating a high probability of VI.

Box P4. Are existing or potential future buildings located within 30 feet laterally of a PVI source, or are they connected to a source through a preferential flow pathway?

Note: Preferential flow paths can facilitate the lateral transport of vapors much further than the 30 feet considered a reasonable maximum for natural soils.

No – No further assessment of the vapor intrusion pathway is required.

Yes – Go to Box P5.

Box P5 and P6: Pathway scenarios and associated minimal characterization and sampling.

Each building located within a VI LOF should be assessed separately. The approach will vary depending on the building's location relative to the source of contamination and its foundation design.

Scenario #1: Buildings in direct contact with petroleum sources in groundwater or soil. Although important data, soil vapor samples are less reliable for inferring risk when contaminated soil or groundwater is in direct contact with a building foundation. Furthermore, soil vapor sampling may not be feasible during certain seasons (e.g., periods of high-water table). To compensate for the uncertainty, indoor air sampling is recommended with contemporaneous soil vapor or sub-slab sampling when feasible. **Follow the Indoor Air Assessment Flow Chart (Figure 7).**

Scenario #2: Buildings overlie but are vertically separated from petroleum sources in groundwater or soil. Under these circumstances the following information should be collected to describe conditions and evaluate VI risk (see Section 4 on soil vapor sampling and additional detail on vertical profiling and degradation criteria):

- Vertical separation distance between source and building foundation,considering seasonal variability
- Soil conditions relevant to vapor transport and petroleum biodegradation
- Profiles of fixed gases (O_2, CO_2, CH_4) and photoionization detector (PID) measurements
- Soil vapor analytical data

There is a preference for sub-slab vapor data; however, a biodegradation evaluation can be conducted initially to inform the scope of vapor sampling. Vertical profiles of fixed gas samples, in addition to contaminant data, can demonstrate whether biodegradation is occurring and may be sufficient to show the pathway is incomplete even if groundwater or deep soil vapor samples exceed RBCs. If access is limited, deep soil profiling of fixed gas measurements can be performed from the exterior of the building; however, analytical data should be collected from beneath the building. This information is sufficient to develop a PVI CSM to determine whether the pathway is complete for the structure.

A vertical profile that indicates aerobic biodegradation is occurring shows decreasing O_2 levels with depth along with increasing CO_2 levels. Petroleum biodegradation consumes O_2 and produces CO_2 and water in aerobic conditions – and in anaerobic conditions relies on another electron acceptor and produces CH_4 (EPA, 2015b). Anaerobic conditions are often found in the source area (e.g., NAPL) where the oxygen demand exceeds oxygen availability. These anaerobic conditions are often characterized by CH_4 and the absence of O_2 in a vertical profile of fixed gases.

In addition to evaluating this data, the presence of precluding factors should be considered. Precluding factors include the following:

- Conditions with high oxygen demand such as high organic matter in soils (>4% weight by weight), higher ethanol blended fuels (>10% volume by volume)
- Conditions with reduced oxygen availability (low-permeability surface layers, high soil moisture from precipiation, large building footprint)
- Limited data, such as lack of information on lead scavengers ethylene bromide (EDB) and 1,2,-dichloroethane (1,2-DCA), or other VI contaminants at fuel terminal sites
- Excessively dry soils (< 2% volume by volume)
- Preferential pathways such as utility corridors or fractured rock – see Scenario #4 below (ITRC, 2014; EPA, 2015b)

Proceed to Box P7 to evaluate the data.

Scenario #3: Buildings are within 30 feet of PVI sources in soil or groundwater. Soils lying between a PVI source and vulnerable building(s) should be characterized for conditions relevant to vapor transport and petroleum biodegradation. Borings should be field screened for VOCs and intervals analyzed for fixed gases. Soil vapor samples (i.e., soil vapor samples collected outside the footprint of the building) can be collected as a line of evidence to screen the structure in or out for further assessment and sub-slab and indoor air sampling. In some cases, the delineation of the soil vapor plume at or near the source may be sufficient to demonstrate a structure is not at risk. However, exterior soil vapor samples are often necessary to confidently screen VI for a specific building. In these cases, samples should be collected within 10 feet of the structure at two locations and two depths. Shallow samples should be collected at 5 feet bgs and deep samples at 10 feet bgs (or as groundwater conditions allow) for a total of four samples.

Proceed to Box P7 to evaluate the data.

In addition:

If the exterior soil vapor samples exceed RBCs, then soil vapor samples within the building footprint should be collected.

If the exterior soil vapor samples do not exceed RBCs, then further assessment of the building is unnecessary.

Scenario #4: Buildings are connected to PVI sources through preferential vapor transport pathways. Subsurface utilities that intersect or directly overlie PVI sources in groundwater or soil contamination should be mapped to the buildings they serve. Under these circumstances, soil vapor investigations and sub-slab data alone may not be reliable indicators of VI. No maximum distance has been identified for vapor migration along a preferential pathway; however, transport of more than 200 feet along a line has been observed in Oregon. Where utilities do intersect a PVI source, the depth, alignments and building entry points should be identified. Gas measurements with a PID, flame ionization detector (FID) or similar device should be used to investigate vaults, the utility lines if possible, and the utility trench backfill as close to the building entry points as feasible. Note that a subset of points investigated can be analyzed for VOCs to correlate PID/FID readings.

Box P7. If the following conditions are demonstrated, then no futher building assessment is required:

- Fixed gas samples demonstrate that biodegradation is occuring (O_2 > 2%).
- Vertical separation distances are met (15 feet for LNAPL sources or 5 feet for dissolved phase contamination).
- Sub-slab vapor samples are below RBCs.

If fixed gas samples are unable to demonstrate that biodegradation is occuring (e.g. O_2 < 2%), lateral inclusion distances are not met (<15 feet for LNAPL sources or < 5 feet for dissolved), or soil vapor RBCs are exceeded, then additional sub-slab vapor samples for VI contaminants of interest are required. Oxygen concentrations above 2% indicate that biodegration criteria are likely met; oxygen concentrations above 4% are strong indicators that biodegradation is occuring (ITRC, 2014; CalEPA, 2023).

If the sub-slab vapor samples do not exceed RBCs, then further assessment of the building is unnecessary.

If sub-slab vapor samples exceed RBCs, then indoor air sampling should be performed. **Follow the Indoor Air Assessment Flow Chart (Figure 7).**

Do lines of evidence indicate that there is vapor transport along preferential pathways?

No – No further assessment of the building is necessary.

Yes – Conduct further assessment of the building, including evaluating indoor air and entry points during worst-case conditions. **Follow the Indoor Air Assessment Flow Chart (Figure 7).** In addition, take measures to prevent the preferential pathways identified.

For all scenarios:

Treatment or removal of PVI sources. Treatment or removal of PVI sources should be considered if indoor air RBCs are exceeded, if hot spots are identified below the building, or to reduce or eliminate subsurface sources to minimize or remove long-term risk management obligations. **Follow remediation process (Box C8, Figure 6) in the Non-petroleum VI Flow Chart and consult Section 6: *Vapor intrusion mitigation and mitigation*.**

Mitigation is appropropriate if hot spots are not exceeded in the sub-slab. See Box A4 in Figure 7 in the Indoor Air Assessment Flow Chart and consult Section 6.

4.0 Vapor intrusion sampling and analysis

A VI investigation should characterize the extent and magnitude of VI related chemicals to develop a thorough conceptual site model. The CSM should include the boundaries of the locality of facility, which includes the area where humans, animals, or plants may come into contact with site-related VI chemicals. Depending on the site, this may include collecting a variety of samples, including field parameters, soil, groundwater, soil vapor, and indoor air samples. This section describes the different types of samples and provides background information and recommendations for sampling and analysis approaches.

4.1 Vapor intrusion pathway investigation planning

To avoid erroneously attributing indoor air contamination from "background sources" to vapor intrusion, VI investigations usually start in the subsurface, confirming there is a source before moving into the indoor environment. They follow the approach typically taken to delineate soil and groundwater contamination by initially characterizing conditions at known sources of contamination and moving progressively outward to delineate to risk-based screening levels.

If at any point in the investigation information and/or data indicate VI is occurring, the indoor air of vulnerable buildings should be sampled at the earliest opportunity.

At a minimum, a VI investigation should accomplish these objectives:

- Determine whether VI is occurring in currently occupied buildings, and identify the appropriate response as described in Appendix A.
- Determine the extent and magnitude of VI sources in soil and groundwater.
- Characterize in three dimensions the extent and magnitude of subsurface vapor plumes. The delineation should have sufficient resolution to evaluate risks to existing and future buildings.
- Identify subsurface features such as utility trenches that may act as preferential vapor migration pathways.
- Evaluate seasonal fluctuations in subsurface conditions and their influence on VI.

The hierarchy of chemical data for VI evaluations is generally the following:

1. Indoor air: most direct measure of risk, when combined with subsurface data, strong line of evidence for VI. See Section 4.6.2 for more information on background sources.
2. Sub-slab vapor: has strongest correlation to indoor air.
3. Soil vapor: lower correlation to indoor air than sub-slab.
4. Groundwater: may have similar or potentially better correlation to indoor air as soil vapor, depending on site conditions.
5. Soil: generally a poor predictor of VI impacts to indoor air.

4.1.1 Using the data quality objective process

The data quality objective (DQO) process developed by EPA can be applied to vapor intrusion investigations to help ensure the investigation collects the necessary type and quality of data required to evaluate VI risks (EPA, 2006a). The following is an example of planning a VI investigation using the DQO process.

Step 1: State the problem.

The problem statement summarizes the preliminary CSM and serves as the framework for evaluating the VI pathway.

Example problem statement: "A release from a waste-oil UST containing benzene and the chlorinated solvent trichloroethene occurred to soil and groundwater next to the main production building at the facility. The release was discovered during the decommissioning of the tank based on visual and olfactory evidence, waste profiling of the tank contents, and confirmation soil samples. The former tank was 30 feet from the property boundary, which abuts a commercial strip mall with second floor apartments. Soil and groundwater contamination at the facility may pose unacceptable exposure risks to site workers through direct contact or migration of vapors from the subsurface into indoor air. Off-site workers and residential populations may also be at risk if contaminants have migrated to nearby structures at significant levels. Both benzene and TCE are known or suspected human carcinogens."

Step 2: Identify the decision.

Identify the decision that needs to be made. Does VI pose a current or future unacceptable risk that requires remediation, mitigation, or long-term monitoring?

This question must be answered for each potentially complete exposure pathway and exposure unit (e.g., each current or potential future building within the locality of the facility).[10] The LOF represents the area where humans, animals, or plants may contact site-related chemicals. The VI LOF is larger than a typical soil or groundwater source due to the migration of vapors in the subsurface and may encompass current or future buildings beyond the property boundary of the original release.

Step 3: Identify inputs to the decision.

Identify the kinds of sampling and analysis needed to evaluate the significance of a potentially complete exposure pathway. Site-specific data needed to evaluate VI pathways may include:

- Evaluating possible preferential pathways and building-specific considerations that impact soil vapor entry points
- Measurements of fixed gases and soil characteristics, particularly PVI sites

[10] See OAR 340-122-0115(35) and Section 2 for a more detailed LOF definition.

- Measurements of VOCs in soil vapor, soil, and/or groundwater within the exposure unit
- Measurements of VOCs in soil vapor within the fill or native soil below existing buildings
- Measurements of VOCs in indoor or outdoor air

Step 4: Define study boundaries.

The VI LOF defines the study area boundaries and may extend beyond the property line of the original release. The LOF may contain several separate VI exposure units (current and/or future buildings) depending on proximity of the release to buildings or likely migration patterns of groundwater or soil vapor. DEQ typically expects VI evaluations at sites where current and likely future buildings are within 30 feet of a petroleum source area, or 100 feet of a chlorinated solvent source area.

Step 5: Define the decision rule.

Identify threshold criteria to evaluate analytical sampling results and make a decision. For VI, use the generic VI RBCs for soil vapor, groundwater, and air data.

Example: "The evaluation requires comparison of groundwater data against generic RBCs. Reliable decision making requires LOF characterization data that permit accurate estimates of concentrations to compare to RBCs or use maxima described in Section 5.3 Data reduction techniques at VI sites. If data is not adequate for this purpose, it is appropriate to return to DQO development (Steps 1 through 4)."

Step 6: Managing decision errors.

In VI investigations, as in other types of exposure pathway evaluations, two types of decision error are possible:

- **False negative:** A determination that a pathway poses no unacceptable risks when, in fact, the risks are unacceptable.
- **False positive:** A determination that a pathway poses unacceptable risks when, in fact, the risks are acceptable.

Generally, using conservative RBCs prevents false negatives.[11] Other strategies to prevent false negatives are comparing RBCs to maximum site concentrations and using conservative estimators of a mean. Overall, a properly designed investigation that captures all significant contamination information is the best method to prevent false negatives.

A phased site investigation approach can minimize the chance of false positives. Simple, conservative CSMs can be progressively refined through additional data collection and site

[11] Conservative is a term frequently used in risk assessment practice that means uncertainties, with respect to exposure potential and toxicity, have been addressed by assuming that both intensity of exposure and toxicity are at the "high-end" of plausible values. These combined assumptions result in risk-based values that, when not exceeded, allow confident decisions of no unacceptable risks.

characterization, providing more accurate predictions of risk. Accordingly, this guidance document promotes iterative investigations with an increasing level of detail and information at each phase of investigation.

DQO Step 7: Optimize the study design.

Identify the most effective data collection approach that will achieve the DQOs. Include sample numbers, media, locations, analytes, and DQO-specific detection limits.

4.2 Field sampling and basic data

4.2.1. Documenting basic soil conditions

Soil descriptions from excavation work, borings and well installations, previous environmental investigations, and other sources should be used to characterize subsurface conditions as they relate to vapor intrusion. Relevant information includes:

- Soil stratigraphy and texture
- Moisture content
- Redox conditions
- Depth to water
- Depth, alignment, and building entry points of utilities lines

4.2.2 Field screening for VOCs with a PID/FID

Field screening soils for VOCs is an essential element of VI investigations. The most common devices used are the photoionization detector and flame ionization detector. They provide real-time qualitative results of the strength of volatile chemicals in soil vapor that can be used to identify vapor plumes, evaluate vapor migration along utility trenches, vapor accumulation in confined spaces and to infer the presence of contaminated soil and groundwater. Although they are limited with respect to identifying and quantifying a chemical concentration in air, they provide a good relative measure of VOC levels and should be used to screen and select sample locations and depth intervals for characterizing and delineating the vapor plume. PID and FID measurements should be documented in reports and used to supplement analytical data to describe the extent and magnitude of contamination and support the selection of soil vapor.

In general, soil vapor samples for delineation or characterization purposes should not be collected from intervals where PID measurements are relatively low or near background.[12] Instead, sampling should target locations and intervals where PID measurements indicate significant levels of VOCs.

[12] For compliance sampling purposes, vapor samples should be analyzed irrespective of PID/FID measurements.

In recent years, portable gas chromatography instruments and mobile laboratories have been used for VI investigations. These devices provide continuous real-time quantitative data on VOCs that can be used to measure temporal fluctuations in contaminant levels in indoor air, investigate the spatial distribution of contamination within a structure, and identify soil vapor entry points into a building.

4.2.3 Collecting fixed gas data for PVI

Primarily used as indicators of petroleum biodegradation, measurements and vertical profiles of fixed gases including oxygen, carbon dioxide, and methane in soil should be collected between PVI sources and vulnerable buildings. This information is essential for developing a CSM that includes biodegradation and for confirming that PVI separation distances are protective. Fixed gas measurements may also be helpful in describing soil gas conditions on a site more generally and as a line of evidence for evaluating the extent of vapor source areas. Field screening of VOCs using a PID/FID can also be valuable data collected along with fixed gas data.

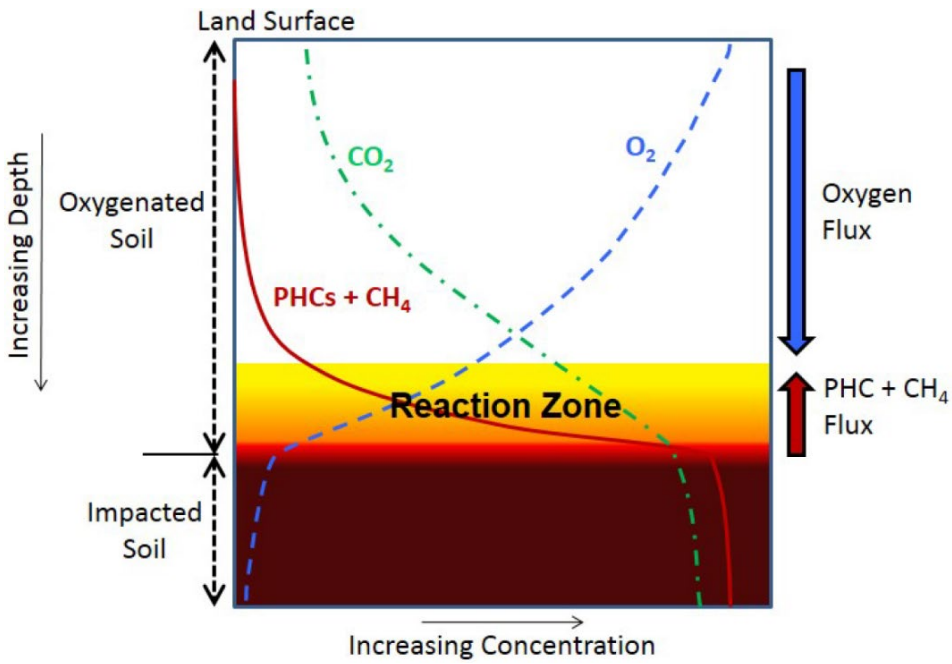

Figure 9. Vertical profile of fixed gases and petroleum hydrocarbons (EPA, 2015b)

A vertical profile that indicates aerobic biodegradation is occurring shows decreasing O_2 levels with depth along with increasing CO_2 levels as illustrated in Figure 9 (EPA, 2015b). Petroleum biodegradation consumes O_2 and produces CO_2 and water in aerobic conditions, and in anaerobic conditions relies on another electron acceptor and produces CH_4. Anaerobic conditions are often found in the source area (e.g., NAPL) where the oxygen demand exceeds oxygen availability. These anaerobic conditions are often characterized by CH_4 and the absence of O_2 in a vertical profile of fixed gases. For more information, please refer to EPA's 2015 *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*, Section 8: Soil gas profile.

4.3 Soil sampling

Soil data will no longer be used to screen out VI risk; however, soil sampling may provide essential data at VI sites for evaluating the strength and persistence of vapor sources. As soil data is acquired it should be integrated into the VI CSM. Specific uses of soil data include:

- Delineating extent and magnitude of VI sources in the vadose zone
- Guiding the location and depths for soil vapor sampling points
- Evaluating biodegradation criteria and building separation distances at PVI sites
- Tracking remedial progress and source reduction during cleanup

In general, vadose sources that are composed of petroleum products and less volatile chemicals are more easily detected and mapped in the subsurface, and thus soil data can more reliably guide vapor sample collection. In contrast, it is not unusual to detect the chlorinated solvent TCE (which sorbs poorly to soils) at unacceptable levels in soil vapor without detecting corresponding soil contamination. While an absence of TCE in soil does not reliably rule out vapor intrusion risks, significant detections of TCE in soil indicate a strong VI source.

Soil samples should be collected using methods and procedures that minimize loss of volatiles (e.g., EPA Method 5035).

4.4 Groundwater sampling

Groundwater samples provide important information for the VI CSM, including information about the strength and extent of vapor sources as well as the seasonal variability in groundwater levels which may impact vapor intrusion risk. Especially in areas with shallow contaminated groundwater, these sample results are an important line of evidence for vapor intrusion risk. Depending on site conditions and extent of a contamination plume, groundwater data may have a similar or better correlation to indoor air than soil vapor. For petroleum vapor intrusion risk, groundwater data may be a poor predictor due to the biodegradation of petroleum hydrocarbon contaminants in the vadose zone. Information about the well construction, screened interval, depth to groundwater, site geology, groundwater flow direction, and chemical characteristics are important to consider when reviewing groundwater data for evaluating vapor intrusion risk.

Groundwater sampling should accomplish the following objectives:

- Delineate the extent of NAPL and residual NAPL impacts
- Delineate plumes of contamination exceeding VI RBCs
- Determine long-term trends regarding plume migration/attenuation
- Characterize seasonal fluctuations in groundwater depth and contaminant concentration

Groundwater samples can be collected from permanent or temporary wells; however, to accurately characterize the strength of groundwater VI sources (and for comparison to RBCs), samples should represent contaminant concentrations at the soil-water interface. Data collected from wells with screens consistently submerged below the water table should not be used for VI risk screening. In addition, groundwater samples should be collected using procedures that minimize the loss of volatiles, such as low-flow purging and sampling or passive samplers (ITRC, 2014). Samples should be collected from as close to the structure or potential structures as possible.

See the ITRC Investigation Methods and Analysis Toolbox in Appendix G.2 for more information on groundwater sampling (ITRC, 2014).

4.5 Soil vapor sampling

Soil vapor data is the primary source of information for assessing the strength of VI sources in the subsurface. The data is also used to build vertical profiles of contaminant concentrations in the vadose zone that inform the CSM and enable calculation of vapor attenuation rates. Constructing vertical profiles of soil vapor concentrations is particularly important at PVI sites where biodegradation can sharply reduce contaminant vapor concentrations over relatively short vertical distances. There are several soil vapor sampling methods, and the one selected will depend on the data objectives, building design, and access limitations to sampling locations. Relative to groundwater and soil vapor, sub-slab data has the best correlation to VI impacts (Schumacher et al., 2012), and this needs to be considered when comparing the lines of evidence.

In addition to following best practices regarding sample point installation, sealing of the anulus and leak detection, it is important that adequate time is provided for subsurface conditions to re-equilibrate following the installation of permanent wells and temporary sampling points. Generally, locations where a sampling point has been augured or drilled (e.g., vapor monitoring well) should be allowed 48 hours to re-equilibrate before collecting a sample from the point. In contrast, where a temporary point has been driven (e.g., push-probe with post run tubing system or PRT) and the hole has not been exposed to ambient air, 20 minutes re-equilibration time is considered adequate.

Methods and protocols for soil vapor sampling that are acceptable to DEQ include the following:

- *Advisory - Active Soil Gas Investigations*. California EPA Department of Toxic Substances Control, July 2015.
- *Soil Gas Sampling*. EPA Region 4, April 2023.
- *Sub-Slab Vapor Sampling Procedures*. Wisconsin Department of Natural Resources, July 2014.

4.5.1 Soil vapor samples (exterior)

Exterior soil vapor samples refer to soil vapor samples collected outside the footprint of a building. This type of sampling provides information on source strength and VI risks without needing to access the interior of the building. This may be appropriate when a building is laterally separated from the source of contamination. Exterior soil samples are also used to screen VI risks at offsite properties and areas that are not currently developed. Near-slab (exterior) soil vapor samples may also be considered when it is impractical to collect deep soil vapor samples from inside a building. It's important to note that for equivalent sources, exterior soil vapor samples tend to bias contaminant concentrations low compared to samples collected directly beneath a structure. This is because the presence of a building essentially acts as a cap and prevents vapors migrating to the surface resulting in a build-up of concentrations relative to areas outside the building footprint (see Figure 10).

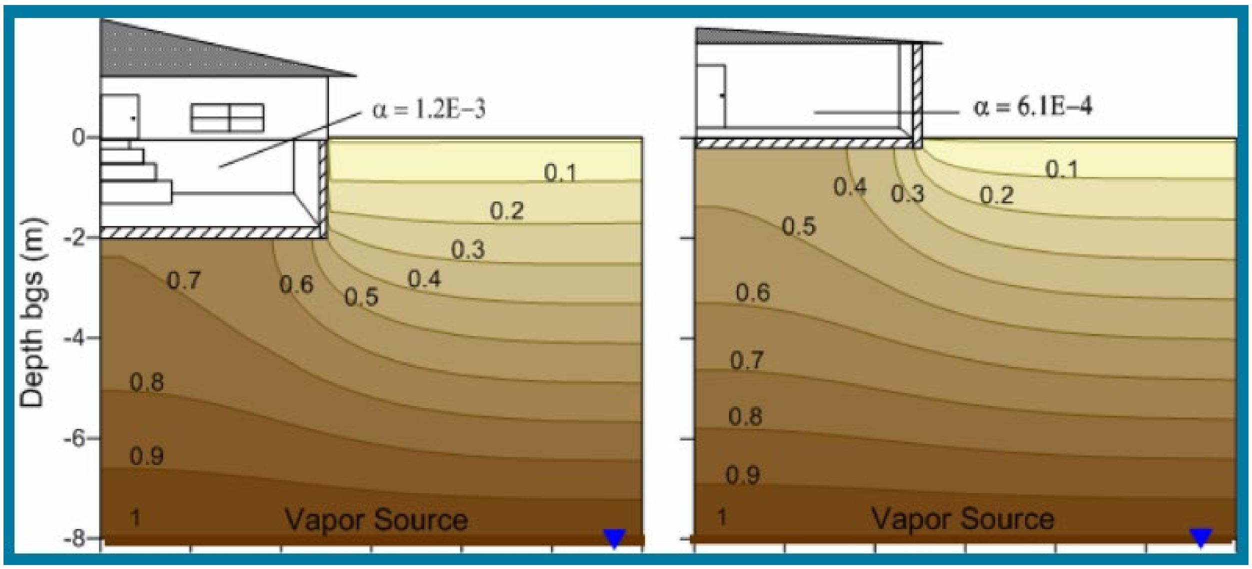

Figure 10. Influence of building design on subsurface vapor distribution (EPA, 2012a)

When targeting a specific building for a VI evaluation at a minimum, exterior soil vapor samples should be collected at 5 and 10 feet bgs (or other depths as site conditions dictate) at two locations within 10 feet of the building foundation. Note: PID readings and/or additional exterior soil vapor samples should be collected near or within utility trenches that intersect plumes of contamination.

4.5.2 Soil vapor samples (interior)

Interior soil vapor samples are those that are collected directly beneath a crawlspace and/or foundation slab from temporary or permanent vapor monitoring points. In general, soil vapor samples should be collected from 5 and 10 feet bgs. Soil vapor samples should be collected from 5 feet or more below the ground surface to avoid the effects of barometric pumping (the circulation of gases into and out of the vadose zone in response to changes in atmospheric pressure) and atmospheric gas exchange. Site-specific adjustments to these depths are appropriate, such as accounting for foundation depth or high-water tables, and adding sample intervals to develop the vertical profile of concentrations in soil column.

Interior soil vapor samples provide data on VI source strength directly beneath a structure; however, they are a less reliable indicator of VI risks than sub-slab data. This is particularly true for PVI sites where the additional 5 feet of soil column can provide opportunity for further biodegradation and vapor attenuation. It is recommended that crawlspace samples be collected at approximately the same time as the soil vapor samples to provide a more complete vertical profile of vapor concentrations.

VI Investigation reports should describe the soil vapor sampling methods, equipment used, and the leak detection and other quality assurance/quality control (QA/QC) procedure steps followed to ensure representative vapor samples are collected. They should also provide diagrams of sampling equipment and sampling systems.

DEQ does not have established or approved sampling methods for collecting soil vapor or sub-slab vapor samples. However, U.S. EPA, California EPA Department of Toxic Substances Control, and other regulatory agencies provide abundant resources on these topics, including those referenced in this document, and investigators are encouraged to utilize established, peer reviewed methods.

4.5.3 Sub-slab samples

Sub-slab samples are collected in soil or subgrade drainage layers immediately beneath (less than six inches below) the slab foundation. The proximity of sub-slab samples to potential receptors makes them the most reliable predictor of VI. To obtain the most representative results, collect sub-slab vapor samples at least 5 feet inside foundation edges with one or more samples relatively centrally located within the building footprint.

It’s important to document how a building is being ventilated when collecting sub-slab samples. A positively pressurized building can cause indoor air to exfiltrate through seams, penetrations, and cracks in the foundation into the shallow soil, displacing contaminant vapors. This may mask the presence of a subsurface vapor source and should be considered when developing a plan for sub-slab sampling and interpreting sub-slab data.

Leak testing for sub-slab samples is also important to ensure that the sampled air is representative of sub-slab conditions and does not include indoor air entering through leaks in the sampling system. DEQ encourages the use of the helium shroud method for leak testing. Helium is non-toxic, readily available, and can easily be used in the field with a hand-held helium meter to confirm whether the sampling probe is properly sealed. Other leak testing methods, such as the use of isopropyl alcohol, may be used. However, the isopropyl alcohol method has the disadvantage that the results of the leak test will only be known once the laboratory data is received. This means there may be substantial cost increases of remobilizing and resampling, which could be prevented by conducting leak testing with a helium shroud method.

When collecting sub-slab samples from basements, evaluate the CSM and location of contaminant source to determine whether additional samples collected through the side walls are also needed to accurately characterize potential vapor intrusion.

4.5.4 Circumstances when soil vapor sampling cannot be conducted or is unreliable

Subsurface conditions at some sites may prevent collection of soil vapor samples and require indoor air data to fully evaluate the pathway. Examples of sites where soil vapor and sub-slab data are unreliable indicators of VI include when contamination is in direct contact with a building, or when a preferential pathway directly connects a VI source to the structure, short-circuiting vapor migration through the soil. Examples where it can be difficult to collect a representative soil vapor sample include areas with shallow bedrock, shallow groundwater, or homes with wet basements.[13] Under these or similar circumstances, an investigation may need to bypass soil vapor sampling and move directly to indoor air sampling.

4.5.5 Sample locations

4.5.5.1 Bounding the vapor intrusion investigation area

An important objective of a VI investigation is to characterize the extent and magnitude of the vapor plume near structures and the areas where subsurface vapor levels exceed generic soil vapor/sub-slab RBCs. Due to the lateral diffusion and advection of vapors in the subsurface, vapor plumes extend beyond their soil and groundwater sources. While many factors affect vapor migration, in the absence of soil vapor data, the VI pathway should initially be considered a potential concern for all current or potential future buildings located within 30 feet of a soil or groundwater source of petroleum contamination, and 100 feet from a soil or groundwater source of chlorinated VOCs or other volatile chemicals. In this context, a groundwater source is concentrations above VI RBCs, and a soil source is petroleum hydrocarbon concentrations above Soil Matrix standards[14] or detectable levels of chlorinated solvents. As described in Section 4.3: *Soil Sampling*, soil data is no longer used to screen for VI risk; however, soil sources can contribute to a VI plume and should be delineated.

For shallow, biodegradable, or relatively localized sources of VOC contamination, or VOC sources in fine-grained soil with no preferential pathways, the initial soil vapor testing should be focused closer to the source as the 100-foot distance is likely overly conservative. For sites with deeper, larger contaminant sources or where sources are intersected by utilities or other preferential transport pathways, the distance may need to be increased. As an investigation progresses, the results of soil vapor sampling will be used to refine the VI LOF.

[13] Water accumulated in sumps should be sampled for VOCs.
[14] Soil Matrix standards are used by the Leaking Underground Storage Tank and Heating Oil Tank Program under OAR 340-122-0320.

4.5.5.2 Source areas

The objective of soil vapor sampling is to define the extent and magnitude of the soil vapor plume. The initial objective is to determine the maximum vapor concentrations at their source. For soil sources, this corresponds to areas where soil impacts are highest. For groundwater sources, it is the unsaturated zone immediately above the water table and capillary fringe.

In order to achieve data quality objectives and demonstrate the pathway is incomplete or does not pose a risk, a minimum of two soil vapor samples should be collected from each of two locations within each source area (for a minimum of four total samples) to determine maximum concentrations. Due to the sensitivity of the pathway, a lack of data in VI investigations is treated conservatively with respect to interpretation of risk, thus DEQ encourages investigators to err on the side of collecting more data to reduce uncertainty and overly conservative assessments of risk. Furthermore, more robust initial investigations can reduce the number of subsequent field deployments and accelerate the decision-making process.

4.5.5.3 Characterize vapor plumes

If the initial data indicates RBCs are exceeded and VOC sources are sufficiently strong to pose a VI risk, it is important to characterize the extent and magnitude of the vapor plume exceeding RBCs. To evaluate both current and future risks, soil vapor data should be collected from the default depths of 5 feet bgs and 10 feet bgs. Based on site conditions, other depths may be appropriate.

For the initial stages of the investigation, reconnaissance vapor sampling can be conducted, such as the post run tubing method to rapidly map the lateral and vertical extent of the vapor plume exceeding RBCs.[15] Reconnaissance sampling data is used to select permanent soil vapor monitoring wells for monitoring the vapor plume over time. At many sites, two depth intervals of soil vapor monitoring wells will be required to characterize the vapor plume. In general, the greater the heterogeneity in the subsurface, the more samples will be necessary to accurately characterize conditions.

4.5.5.4 Vapor sampling density

The number or density of vapor sampling points depends on building size, proximity to sources, the scale of soil and groundwater impacts, heterogeneity in subsurface conditions, and the purpose of the data collection. DEQ recommends collecting sufficient data to appropriately reduce uncertainty and better represent potential risks. See Table 2 below for a brief discussion of these factors and their influence on a sampling program.

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[15] More information on a post run tubing protocol can be found in the EPA Region 4 Operating Procedure *Soil Gas Sampling* (EPA, 2023).

Table 2. Influences on sampling density

Factor	Influence on sampling program	Rationale
Near primary spill/release area	Increased sample density	Soil contamination or free product can produce heterogeneous contaminant distribution; high concentrations can result in a disproportionately large influence on indoor air quality.
Large scale site	Reduced sample density	Groundwater as the primary VOC source tends to be more homogeneous than soil sources; contaminant concentrations within larger plumes are more spatially uniform.
Reconnaissance sampling mode	Reduced sample density	Lower precision required. Primary objective is to define geographic area of concern, not assess risk/compliance.
Geologic heterogeneity	Increased sample density	VI migration rates are sensitive to soil properties, and additional samples are needed to define subsurface variability.
Increasing building size	Reduced sample density	Conditions tend to be more homogenous in larger commonly ventilated spaces.

When evaluating VI potential at single-family residences, collect exterior soil vapor samples from two borings at 5 feet bgs and 10 feet bgs along the edge of the house nearest to the source of contamination or from two sub-slab samples per 1,000 square feet. See Table 3 for recommendations on minimum sample density for screening residential and commercial building. Additional sampling may be necessary based on initial screening.

Table 3. Recommended soil vapor and sub-slab sampling density beneath buildings

Building size	Soil vapor sample density	Minimum number of samples
Less than 1,000 ft^2	Not applicable	2
1,000 ft^2 -10,000 ft^2	Minimum one per 1,500 ft^2	3-7
Greater than 10,000 ft^2	Minimum one per 2,500 ft^2, or as otherwise determined through consultation with DEQ	7 or more

At sites where homes overlie groundwater contamination, a minimum of one sample should be collected near the center of the home and the second between the center of the structure and the wall of the building nearest the source of contamination. It is important to note ambient air can mix with and dilute contaminated soil vapors near the edges of buildings. To ensure sample quality and representativeness, sub-slab samples should be collected at least 5 feet inside exterior walls.

4.5.6 Soil vapor sample timing, frequency, and seasonal variability

Contaminant levels in soil vapor may vary seasonally up to an order of magnitude in response to fluctuations in the water table, infiltrating moisture fronts, and changes in barometric pressure (Dawson, 2004). High moisture content in the soil limits diffusion and temporarily reduces vapor concentrations. At many sites, contaminant levels in soil vapor reach a maximum in late summer and early fall when soil moisture levels are at an annual low. However, at other sites a rising water table will bring groundwater sources nearer to the surface along with higher concentrations in shallow soil vapor. This temporal variability needs to be incorporated into the VI CSM and considered when collecting and interpreting soil vapor data. In most cases, this will require a minimum of a six-month investigation timeframe to capture variations. **Understanding the seasonal variability at your site is a key element of a good VI CSM.**

Sites should be screened for potential VI risks based on seasonal maximum concentrations. It is difficult to predict which factors will have the greatest influence on soil vapor results and thus which season or set of conditions produce reasonable maximum contaminant levels. As a consequence, the results of a single sampling event are unlikely to fully characterize potential VI risks at a site. After collecting the first round of soil vapor samples, evaluate the need for additional sampling events based on the sample results, the CSM, and relevant hydrogeologic and hydrologic information. If there is a high concern about VI risk, DEQ recommends quarterly or at least two soil vapor sampling events to assess varying conditions and determine maximum concentrations.

In addition, avoid sampling during and immediately after significant rainfall events. These rainfall events can generate saturated conditions in the soil profile, and the high moisture content in soil limits diffusion and temporarily reduces vapor concentrations.

4.6 Indoor air sampling

Indoor air sampling is the most direct method of measuring VOC exposures at VI sites. In cases where very high levels of contamination are present or the contamination has a unique character, the data can provide relatively quick confirmation of VI impacts.

4.6.1 General guidelines

When multiple buildings are potentially affected, prioritize sampling of buildings at highest risk for vapor intrusion. To assess current exposure levels and risks, sampling should be conducted under typical HVAC and business operating conditions. In residences, windows and doors should remain closed during indoor air sampling. The number of samples needed to characterize exposure levels within a building is dependent on the subdivision of interior space and the distribution of vapor intrusion sources in the subsurface. Basements spaces are more sensitive to vapor intrusion and should always be sampled when present. At least one outdoor ambient air sample should be collected during each round of indoor air sampling to evaluate the influence of outdoor background sources.

VOC concentrations in the environment are highly variable and collecting enough data to thoroughly understand and predict their temporal and spatial distribution can be costly. To compensate for these inherent uncertainties, indoor air sampling plans should target the most vulnerable areas of buildings during reasonable maximum conditions. Developing appropriate sampling plans and accurate interpretations of indoor air data depends on an understanding of the sources and environmental factors that influence VOC levels in the environment.

4.6.2 Background sources of VOCs

For most sites, simply detecting these chemicals inside a building is not definitive evidence of VI. Buildings can have interior sources of VOCs/SVOCs including paints, cleaning solutions, dry-cleaned clothes, moth balls, personal care products, tobacco smoke, oil furnaces, and chlorinated drinking water (e.g., chloroform). It is important to inventory these potential sources, and, if possible, remove them prior to sampling indoor air. If they can't be removed, additional indoor air sample locations can be added to better isolate the influence and contributions of indoor air sources.

In addition to common household products, many of the VOCs encountered at VI sites are common contaminants in ambient outdoor air. A combination of these sources can confound analysis of indoor data and make it difficult to distinguish actual VI contributions. To reduce the frequency of false positives (see Section 4.1.1, Step 6: *Managing decision errors*), DEQ does not recommend indoor air sampling until other information indicates a potential VI risk. While sometimes definitive, indoor air data should be considered one line of evidence in a broader VI evaluation.

Outdoor or ambient air commonly has detectable levels of VOCs, sometimes exceeding ambient air RBCs. The largest sources of these contaminants are engine exhaust, fuel storage facilities, and emissions from commercial/industrial activities. Because outdoor air typically makes up >99% of indoor air, ambient VOC levels tend to represent the minimum or baseline concentrations measured in indoor air. To account for contributions of ambient air, contemporaneous outdoor air samples should be collected during each indoor air sampling event (see Sections 4.6.6: *Outdoor air sampling*).

In an occupational setting, where a COI for a site is in commercial use, indoor air data may not be useful for vapor intrusion assessments. DEQ RBCs are orders of magnitude lower than OSHA's occupational exposure limits, and therefore VOCs released during daily operations may overwhelm and obscure the contributions resulting from vapor intrusion. Under these circumstances, risk determinations and the need to mitigate and/or remediate a VI source will be based primarily on subsurface data.

4.6.3 Temporal variability in vapor intrusion

VOC levels in ambient air can vary greatly over time. They fluctuate diurnally due to the ebb and flow of automobile traffic and commercial activity, and as a result of atmospheric heating and cooling cycles, air pressure changes, and wind speed. These fluctuations and their impact on the data analysis can be reduced by collecting time-integrated samples. The sampling time period should reflect the exposure scenario being evaluated. For residential properties, it is assumed an occupant will be present 24 hours per day; therefore, the samples should also be collected and integrated over a minimum 24-hour period, preferably over multiple days. For occupational settings, the sampling period should coincide with the hours of operation, typically 8 hours per day. In their exposure assessments, EPA assumes indoor air undergoes a complete exchange every 1 to 2 hours. **To account for the lag time in equilibration between indoor and outdoor air VOC levels, outdoor sampling may begin approximately 1 to 2 hours before collection of indoor air samples and continue for the same exposure duration as the indoor samples.**

VI rates are affected by both short term and seasonal changes in weather conditions. Changes in barometric pressure associated with the arrival of weather fronts can move gases into or out of the vadose zone. This phenomenon, known as “barometric pumping,” enhances VI rates as low-pressure systems arrive and decreases rates when transitioning to higher pressure. Wind is another condition that can enhance VI rates by depressurizing a building relative to the underlying soil causing more vapors to enter the building from the subsurface. **To account for these influences, collect and record local barometric pressure and wind-speed data over the three days before and during an indoor air sampling event.**

Seasonal conditions also have a significant effect on VI rates (EPA, 2015a, Schumacher et al., 2012). During winter months, heated air rises within the structure and exits through the upper floors and roof. This produces a stack effect that reduces indoor air pressure, draws in soil vapor, and increases VI rates. In addition, saturation of soils surrounding a building can also enhance and focus the exchange of soil vapors beneath a building. Maximum VI impacts are therefore most likely in late winter and early spring. Building layout and HVAC operations affect peak VI periods, especially for commercial buildings. To account for seasonal variability, DEQ expects at least two indoor air sampling events to assess varying conditions; sampling should target time periods VI is occurring. **For seasonal climate conditions in much of Oregon, DEQ recommends one sampling event during the late summer to early fall and another during late winter to early spring.** Depending on the results, additional sampling may be necessary to make a risk determination. This seasonality is illustrated in the figure below.

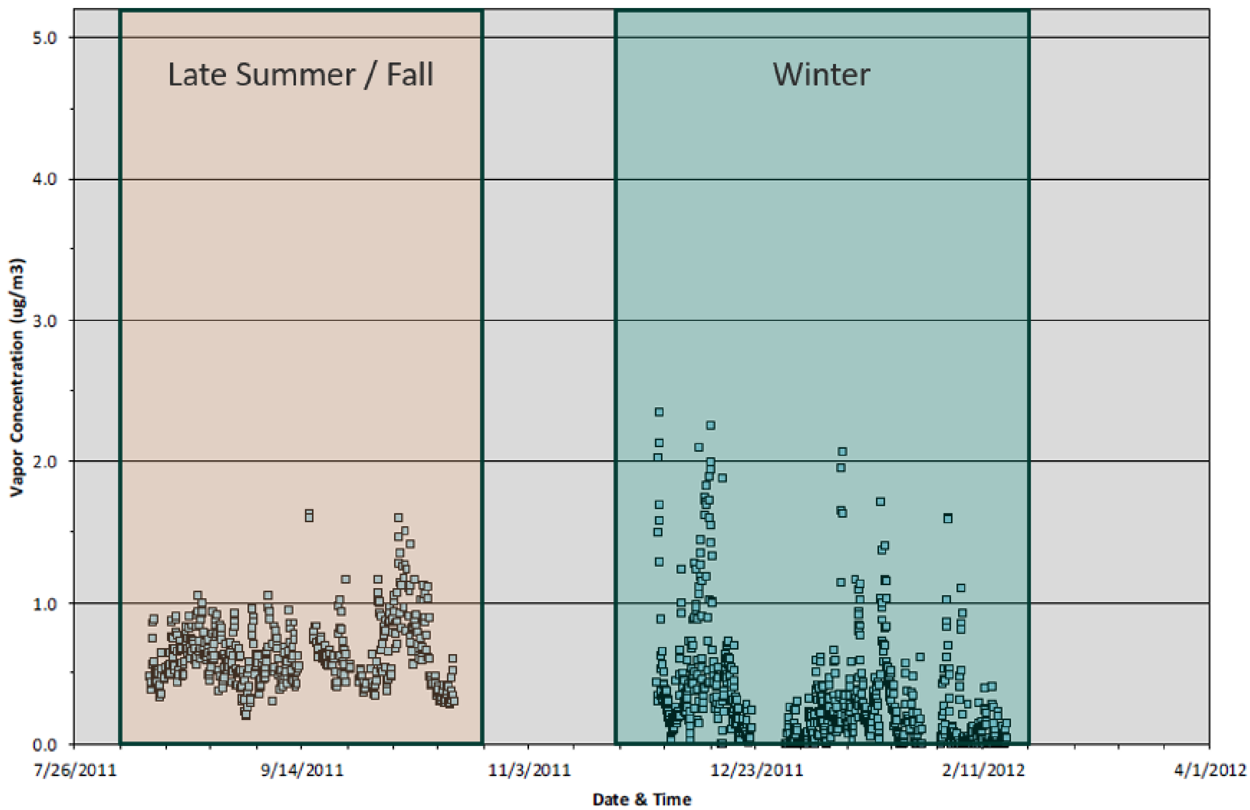

Figure 11. Seasonal variability in indoor air contamination from VI in a residential basement (base figure from Schumacher et al., 2012)

4.6.4 Sampling period duration (indoor air)

During winter months, vapor intrusion still tends to be an intermittent phenomenon with "on" and "off" periods that correlate strongly to changes in weather systems. "Off" periods when vapor intrusion is minimal can last several days or more, and as a result, short-duration 8-hour and 24-hour indoor air sampling events frequently miss significant VI events. DEQ has concluded that **longer duration indoor air samples, such as those obtained from passive samplers deployed for 14 to 28 days, more reliably detect VI risk and should be used when feasible.** Longer duration samples also provide better estimates of long-term average concentrations and chronic exposure levels. DEQ recognizes that long-term passive sampling may not be available for all petroleum hydrocarbons. Consult with the analytical laboratory on achievable detection limits for a proposed passive deployment period. Consecutive passive deployment events can be used to achieve longer deployment periods.

More information about passive samplers for vapor intrusion applications, including a comparison of methods and recommendations for placement of passive samplers, can be found in an EPA Engineering Issue: *Passive Samplers for Investigations of Air Quality: Method Description, Implementation, and Comparison to Alternative Sampling Methods* (EPA, 2014b).

When greater temporal resolution is sought, such as in the case of acute exposure to TCE, shorter duration 8-hour to 5-day samples can be collected to better define acute risks.

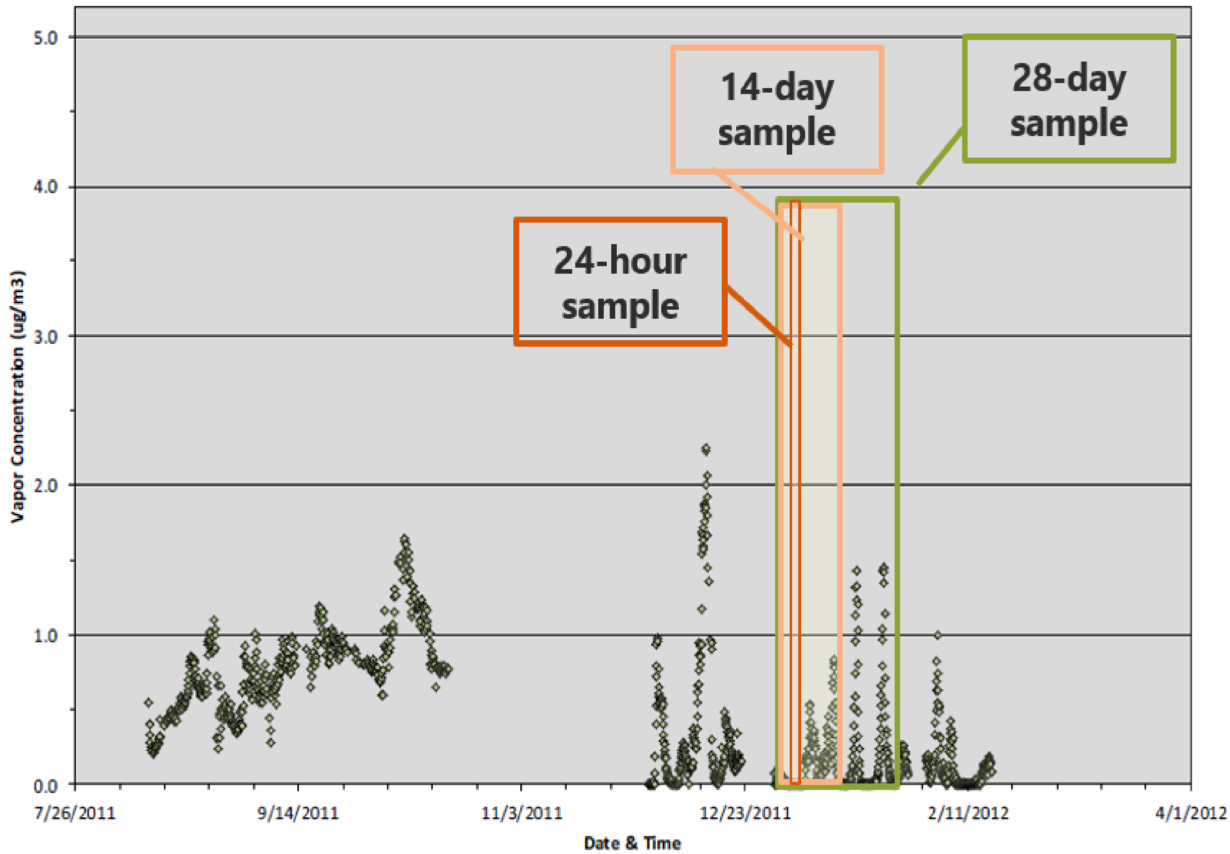

Figure 12. Concentration variability over length of time of sample collection (base figure from Schumacher et al., 2012)

4.6.5 Documenting barometric pressure changes and differential pressure measurements

As discussed above, rates of VI are intermittent in nature and highly influenced by barometric pressure differences between building interiors. Thus, it is important to always interpret the indoor data within the context of the barometric pressure conditions that existed during sample collection. Devices such as differential pressure data loggers can provide a continuous record of the pressure difference between indoor air and the subsurface during the indoor air sampling event. This is essential data to collect when sampling indoor air while HVAC, exhaust fans, or ventilation equipment are operating. If there is no active HVAC system, barometric pressure measurements from the nearest weather station are adequate.

4.6.6 Outdoor (ambient) air sampling

Outdoor, or ambient, air samples are collected at the same time as indoor air sampling events to evaluate background levels of VOCs in outdoor air. Sources such as automobile exhaust, service stations, dry cleaning operations, and other activities can elevate VOC levels in outdoor air. Comparing indoor data to background ambient concentrations provides a line of evidence on whether indoor air concentrations are impacted by site related VI sources.

Outdoor air samples should be collected from a representative upwind location away from obstructions (e.g., trees or buildings) and at a breathing-zone height of approximately 3 to 5 feet or near the height of the intake for the HVAC system. A representative sample is one that is not biased toward obvious sources of volatile chemicals, such as automobiles, lawn mowers, chemical storage tanks, gasoline stations, industrial facilities, etc. Passive outdoor air samples should be collected from a location protected from excess wind speeds, precipitation, and direct sunlight. If no such sheltered location is available, a shorter duration outdoor air sample using an evacuated canister may be appropriate.

At large vapor intrusion sites, contaminant volatilization from shallow soils and groundwater may impact ambient outdoor air. Under these circumstances, a network of outdoor air sampling stations should be set up to evaluate the outdoor volatilization pathway. In addition to outdoor air being another exposure pathway that should be considering in the CSM, the contribution from outdoor air is important to consider when evaluating the source of chemicals to indoor air.

4.7 Analytical methods

Select analytical methods for each medium that meet DQO-developed reporting limits. A few examples are presented below.

4.7.1 Measurement methods for soil and groundwater

Standardized methods for VOC analysis in water and soil are described in the EPA manual *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* also known as SW-846 (EPA, 2024c). Detailed discussion of these methods is beyond the scope of this document. EPA Method 8260D is the standard for analyzing VOCs in water and soil. The method manual is available at: SW-846 8260D.

The analogous standardized method for analysis of SVOCs is EPA Method 8270E, described at: SW-846 8270E. In most cases, use of selective ion monitoring (SIM) will not be required to meet detection limit goals. However, RBCs change periodically, and in every case, reporting limits of the selected method must meet project specific DQOs.

When sampling soil for VOCs, it's necessary to minimize evaporative losses that may occur during sample collection and preparation. DEQ recommends collection and preservation of soil samples according to EPA Method 5035, and the methodology is described in greater details at EPA's website: EPA-5035.[16]

Standardized methods for analyzing TPH, or total petroleum hydrocarbons, are described in *Analytical Methods for Petroleum Hydrocarbons* by Washington State Department of Ecology, and the associated guidance for silica gel cleanup protocol (WADOE, 1997; WADOE, 2023; WADOE, 2024). NWTPH-Gx and NWTPH-Dx provide quantitative analysis of gasoline range organics and diesel range organics, respectively. The NWTPH-Dx result includes diesel range organics (DRO) and heavy oil range organics (ORO), and the preference is that the laboratory report these combined fractions as one result. If the laboratory reports diesel and heavy oil separately, these values should be summed before comparison to the RBC.

4.7.2 Measurement methods for vapor and air

There are several alternatives for sampling VOCs in vapor and ambient air including:

- EPA Method TO-15, which uses a chemically inert, evacuated canister that passively draws in grab samples of air, typically from 20 minutes to 24 hours in duration
- TO-17, a method for sampling VOC and SVOCs where is air pumped or drawn through tubes and contaminants collect on a sorbent material
- Passive diffusion-based samplers using sorbents can be deployed from 1 to 30 days

These methods have been modified to make them applicable to soil vapor analyses as well. Certain details of these methods vary, depending on the compound and required reporting limits. Additional analytical methods will likely be developed in the future and DEQ may accept these methods. Overall, it is the ultimate responsibility of the investigator to ensure that laboratory reporting limits will meet investigation DQOs.

Low detection limits are usually required to evaluate a 10^{-6} excess cancer risk at the exposure point. As an example, the current TCE residential RBC for vapor inhalation is 0.47 micrograms per cubic meter ($\mu g/m^3$), and the occupational RBC is 2.9 $\mu g/m^3$. The TO methods must concentrate analytes from a large sample volume, followed by Gas Chromatography/Mass Spectrometry (GC/MS) analysis either in scan or SIM mode to reach sufficiently low detection limits. SIM may be appropriate when the analytes of interest are known. Select the analytical method based on which compounds are present, their relevant decision criteria (i.e., RBCs), and the expected concentrations and reporting limits for each method. Each laboratory analyzing samples by method TO-15 or TO-17 must follow the methods described by EPA as updated.

See Table 4 below for a summary of recommended analytical methods for sampling media described above, including the benefits and limitations of each.

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[16] Method 5035 for sample collection and preservation is not currently specified in DEQ's 2003 *Risk-Based Decision Making for the Remediation of Petroleum Contaminated Sites*; however, is recommended and will be added when that guidance document is updated.

Table 4. Sample preservation and analysis methods

Media	Name	Description	Benefits	Limitations
Soil	EPA Methods 5035,8260, and 8270	Method 5035 is a sampling/preservation protocol. Method 8260 is for VOCs, and method 8270 is for SVOCs.	Method 5035 is the recommended way to sample soils for VOCs to reduce VOC losses. Soil samples help identify and characterize sources.	Soil sampling may miss source zones, particularly for halogenated VOCs. Soil data is no longer used to evaluate VI risk.
Groundwater	EPA Method 8260 and 8270	Low-flow purge and sample methods are preferred. Method 8260 is for VOC analysis, and method 8270 is for SVOCs.	Defines and characterizes groundwater contamination.	May miss source area and vapor data recommended to capture VI risk.
Soil / Groundwater	NWTPH-Gx and NWTPH-Dx	Standard methods for quantitative analysis of petroleum products.	Identifies and delineates petroleum sources.	To capture VI risk, vapor data needed for soil and recommended for groundwater.
Vapor	EPA Method TO-3/TO-3 Modified for TPH	An evacuated canister or gas sampling bag is used to collect a vapor sample for lab analysis by GC.	Effective for C5-C10 hydrocarbons and TPH.	Only useful for petroleum hydrocarbons; care must be taken for QA/QC.
Vapor	EPA Method TO-13	A pump is used to send air through a puff cartridge and XAD resin media.	Lower detection limits for naphthalene and diesel range.	Must use a pump to collect sample.
Vapor	EPA Method TO-15 Scan or SIM	An evacuated canister with flow controller is used to collect a vapor sample for lab analysis by GC/MS.	Quantitative, can reach low detection limits if SIM certified. Less expensive for higher detection limits.	Useful for VOCs and some SVOCs; care must be taken for QA/QC.
Vapor	TO-17	A known volume of vapor is pumped across a sorbent material that captures contaminants.	Method has low detection limits on SVOC, diesel range hydrocarbons.	Must use a pump to collect sampler.
Vapor	Passive Diffusion Samplers	Air contaminants diffuse through a porous cylinder filled with sorbent material.	Long deployment periods. Best method for characterizing average exposures. Less expensive and obtrusive than TO methods.	Not available for TPH analyses and light end chlorinated compounds (e.g., vinyl chloride).

In some investigations, it will be desirable to collect additional information on gases such as oxygen, nitrogen, carbon dioxide, or methane in soil vapor to understand potential for biodegradation of contaminants. These gases are measurable by standard EPA methods and additional details will not be provided in this document.

Many laboratories will report vapor and air analytical results in units of parts per billion by volume (ppbv), although they may also report in units of analyte mass per volume of air (e.g., micrograms per cubic meter). **Results reported in units of ppbv need to be converted to μg/m^3 prior to comparing to RBCs.**

4.8 General field quality assurance and quality control

Take extreme care during all aspects of sample collection to ensure high quality data and minimize sampling error and loss of volatiles. Sampling team members should avoid actions that can cause sampling interference (e.g., fueling vehicles, using permanent marking pens, smoking, and wearing freshly dry-cleaned clothing or fragrances).

Follow appropriate quality assurance and quality control protocols for sample collection and laboratory analysis, such as using certified clean sample devices, meeting sample holding times and temperatures, etc. Deliver samples to the analytical laboratory as soon as possible after collection. Laboratory procedures must be followed for field documentation (sample collection information/locations), chain of custody, field blanks, field sample duplicates, and laboratory duplicates, as appropriate.

Maintain a field sample log sheet summarizing the following:

- Sample identification
- Sample location
- Date and time of sample collection
- Sampling depth
- Sampling height (indoor or outdoor)
- Identity of samplers
- Sampling methods and devices
- Purge volumes and devices used
- Starting and ending vacuum (negative pressure) of the evacuated canister recorded on the chain-of-custody and sampling forms
- Apparent moisture content (dry, moist, saturated, etc.) of the sampling zone
- Type of soil present in the sampling zone (e.g., clay, sand, gravel, etc.)
- Field measurements such as PID or fixed gas measurements
- Chain-of-custody records to track samples from sampling point to analysis

If sampling indoor air, determine status of HVAC systems and any relevant data available on pressure differentials.

5.0 Vapor intrusion risk-based evaluation

This section describes how to perform a risk-based evaluation of the VI pathway for current and reasonably likely future property uses.[17] Results from the VI investigation are part of the site-wide risk assessment (RA) that evaluates all potential exposure pathways at the site.

VI risk evaluations have two primary elements: 1) assessment of potential VI risks associated with subsurface contamination, and 2) assessment of risk to occupants of existing buildings.

The extent and magnitude of subsurface sources posing a potential VI risk to current and future occupants of the site are defined based on comparisons to generic groundwater and soil vapor RBCs. Evaluation of current risks to building occupants is based on a comparison of indoor air data to DEQ published air RBCs.

If soil vapor levels exceed hot spot concentrations (further discussed in Section 5.7), more immediate action may be required to protect indoor air quality and building occupants. When indoor air exceeds applicable RBCs as a result of vapor intrusion, use Appendix A to determine an appropriate response and recommended timeline. For additional resources regarding the health concerns, contact Oregon Health Authority (OHA) to address public health concerns and work with the responsible party to aggressively address the unacceptable exposure to building occupants, then continue with the rest of the VI evaluation.

5.1 Development of risk-based concentrations

5.1.1 Air RBCs

The overall goal of vapor intrusion investigations is to protect indoor air quality from subsurface sources of contamination. Air RBCs are used to evaluate indoor air quality and are the basis for vapor and groundwater RBCs.[18] DEQ's air RBCs are consistent with EPA's inhalation methodology (EPA, 2009) and Regional Screening Levels (RSLs) (EPA, 2024a), as discussed in Appendix C. To aid in conducting risk assessments, DEQ provides separate chronic RBCs for cancer and noncancer risks. In addition to chronic RBCs, DEQ's Cleaner Air Oregon (CAO) Program has acute air RBCs useful to the Cleanup Program. Another source of chronic air screening values is EPA's RSL table.

In 2023, DEQ used information from EPA RSL air values to develop Oregon chronic air RBCs for several reasons, including EPA's extensive database, regular updates to these screening values, and consistency with state exposure assumptions. EPA publishes RSLs for residential and

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[17] Consistent with OAR 340-122-0084.

[18] DEQ and EPA publish air risk levels for chemicals that can be found in air; however, only a subset of these chemicals is associated with vapor intrusion. For example, benzo(a)pyrene has an air RBC, but at ambient subsurface temperatures (<15 degrees Celsius) is not sufficiently volatile to pose a risk through vapor intrusion.

commercial exposure scenarios; however, not for urban residential exposure. **DEQ is no longer supporting default urban residential exposure values, and therefore DEQ did not develop vapor intrusion RBCs for this scenario.**

Acute air RBCs are based on those from DEQ's CAO Program, with some modifications. Appendix C provides information on the different sources of air RBCs used to develop vapor intrusion screening values. Because there are often questions about the CAO Program, Appendix C also provides an explanation regarding the applicability of Air Quality rules for emissions from remedial systems.

Soil vapor and groundwater RBCs are derived from air RBCs using attenuation factors (EPA, 2015a). Updates to the RBC_{air} for a specific compound will change the VI RBC_{SV} and RBC_{WI} values for that compound. As new toxicity information becomes available, EPA updates toxicity values used to calculate their RSLs, and DEQ in turn evaluates the updated values, and as appropriate, uses them to revise its RBCs. DEQ intends to update RBCs at the beginning of each year. Therefore, be sure to use the most current values in DEQ's vapor intrusion spreadsheet available from [DEQ's Cleanup Program website](#).

5.1.2 Soil vapor RBCs

This section describes the derivation of generic RBCs used to compare to sub-slab vapor data and soil vapor data collected inside or outside the footprint of a building. Vapor RBCs are developed from DEQ's air RBCs by applying default attenuation factors between the subsurface, where VOCs are measured, to the indoor air breathing zone. For media specific attenuation factors, DEQ incorporated values recommended in EPA's 2015 vapor intrusion guidance (EPA, 2015a).

EPA's Vapor Intrusion Screening Level calculator was used to calculate soil vapor and groundwater RBCs. The equation below and related Figure 13 illustrate the conceptual approach used by DEQ, where the air concentration is multiplied by an attenuation factor to calculate the soil vapor concentration.

$$RBC_{sv} = RBC_{air} * AF$$

where:

RBC_{sv} = Risk-based concentration in soil vapor medium[19] ($\mu g/m^3$)

RBC_{air} = Risk-based concentration in air medium, ($\mu g/m^3$)

AF = Attenuation Factor (unitless)

As with other RBCs, the soil vapor RBCs vary by exposure scenario (i.e., residential, occupational). See Appendix C for details of how DEQ developed the soil vapor RBC_{sv}.

[19] Applicable to either sub-slab vapor or soil vapor taken outside of building footprint, in accordance with an approved site-specific work plan.

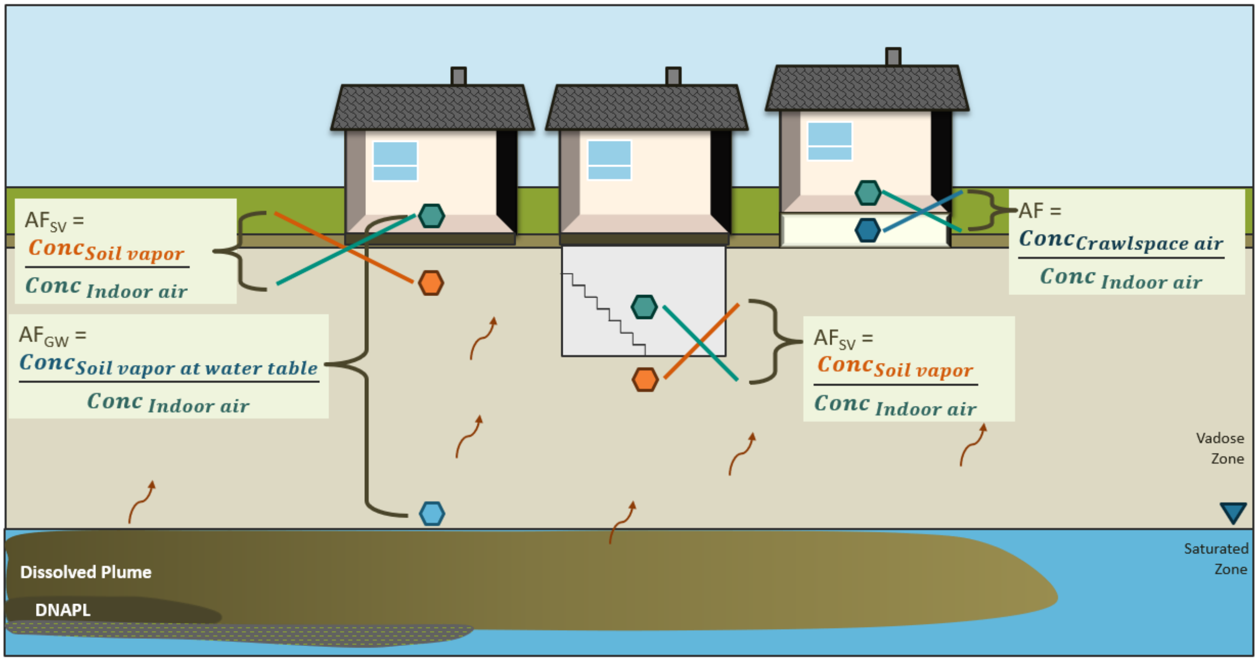


Figure 13. Matrix specific VI attenuation factors

Regarding attenuation factors, EPA's approach is to divide the air concentration by an attenuation factor. Consequently, DEQ's attenuation factors are the reciprocal of EPA's attenuation factors (Table 5). DEQ incorporated EPA's default attenuation factors; however, this document refers to attenuation factors using DEQ's definition. Thus, the default attenuation factor is 33 for residential and commercial properties.

Table 5. Medium-specific attenuation factors for VI to indoor air

Medium	EPA attenuation factor	DEQ attenuation factor
Crawlspace Vapor	1	1
Sub-Slab Vapor	0.03	33
Soil Vapor	0.03	33
Groundwater (generic)	0.001	1000

5.1.3 Groundwater RBCs

RBCs based on volatilization from groundwater are developed similarly to soil vapor values with one additional chemical partitioning step. This value relates the contaminant vapor levels in soil immediately above the water table in equilibrium with contaminant levels in groundwater as predicted by Henry's Law. DEQ incorporates EPA's recommended attenuation factor of 1000 for groundwater. The attenuation factor indicates contaminant vapor levels at the water table will be reduced by a factor of 1000 in indoor air. To calculate groundwater RBCs, DEQ used EPA's Vapor Intrusion Screening Level calculator with a mean Oregon groundwater temperature of 12.5° C instead of the default value of 25° C.

5.2 Use of default and site-specific building attenuation factors

Site-specific AF values (based on paired subsurface vapor and indoor air measurements) range over several orders of magnitude, constantly change over time, and are difficult to predict in advance of a VI investigation and collection of indoor air data. To address this uncertainty, generic groundwater and soil vapor AF values recommended by EPA and incorporated by DEQ were conservatively set to be protective of approximately 95% of buildings. The use of conservative AF values improves confidence and reliability in the decision to screen out a building from further evaluation of the VI pathway.

As indoor and subsurface vapor data are collected during an investigation, site-specific AFs can be calculated for a specific building. High site-specific AF values coupled with favorable indoor data is an important line of evidence in demonstrating a structure is not vulnerable to vapor intrusion.

As discussed above, the amount of attenuation along the vapor intrusion pathway is highly variable, and dependent on several factors including building design, foundation condition, and the method and rate of ventilation of indoor spaces (Section 2.3: Building considerations). For this reason, site-specific attenuation factors are only relevant to the existing structure as it is currently used and are not appropriate to carry forward for evaluating future VI risk under reasonably likely property use scenarios.

Generic AFs and associated RBCs are the basis for screening future potential VI risks at sites (which may require ICs) and for calculating VI hot spots in soil vapor. Due to the many varying factors that impact attenuation factors, including seasonal and temporal variability and building- and site-specific conditions, and the fact that future conditions at the site may change, DEQ will not allow site-specific AFs to replace default RBCs to determine hot spots.

5.3 Data reduction techniques at VI sites

DEQ's preference is to evaluate soil vapor and indoor air concentrations on a sample-by-sample basis. Standard risk estimation methods use a single statistical estimator of the arithmetic mean concentration in any media as the plausible upper-bound or high-end exposure consistent with OAR 340-122-0084(1)(f). Developing an accurate and reliable mean of soil vapor concentrations in an exposure unit can be difficult because of variability in the subsurface media, seasonal and temporal concentrations, access to sampling locations, and contribution to indoor air. In addition, soil vapor investigations sample a small fraction of the volume of soil vapor under a building, producing uncertainty in representativeness of analytical results.

At most sites, DEQ's default is to evaluate samples using maximum concentrations on a sample-by-sample basis; however, in some cases, sufficient data and information about the exposure unit may be available to use a statistical estimator of the mean.[20] In these circumstances, a statistical estimator of the mean is used rather than the mean from the samples to avoid underestimating the true mean concentration in the soil vapor. Typically, a minimum of 8 to 10 samples are required for each exposure unit to estimate the mean (EPA, 2022b). Uncertainty can be addressed by applying statistical methods that calculate "error bars" or confidence limits that expand or contract around the arithmetic mean based on factors such as the number of samples, variability and range of concentrations observed, data distribution, and the preferred level of confidence (e.g., probability that an Upper Confidence Limit, or UCL, encompasses the true mean). EPA has published extensive guidance and developed software to calculate UCLs for a variety of data distributions, such as normal, lognormal, and non-parametric (EPA, 2002). Many commercial software packages are available that are acceptable to estimate mean and UCLs on mean concentrations for risk assessment. Because it offers multiple statistics and addresses non-detected values, DEQ recommends using the most current version of the EPA supported public domain software ProUCL to calculate appropriate UCLs (EPA, 2022a).

Whether using the maximum or estimating the mean, **the site must be adequately characterized to cover the range of concentrations present and avoid underestimating potential exposure**. Make sure to anticipate and account for the use of either an estimator of mean or a maximum during project planning including data quality objectives (see Section 4).

[20] At most VI sites, risks will be assessed based on the analysis of less than 0.02% of the soil vapor beneath a building (six liters of soil vapor samples collected from upper 3 feet of soil beneath a 1,000 square foot building). This results in significant uncertainty that the full range of concentrations is represented and that true spatial variability has been characterized. This is why simple arithmetic means, or spatially weighted averages based on arithmetic means (i.e., Thiessen Polygon), are not appropriate.

5.3.1 Applicability of UCL calculations

Due to the data requirements for UCL calculations, statistical analyses of subsurface vapor data typically will be limited to commercial and industrial sites. EPA guidance recommends a minimum of 8 to 10 discrete samples for UCL calculations (EPA, 2022b). **Sites with fewer data points should use the maximum concentration in the risk assessment.**

Subsurface vapor concentrations vary both spatially and temporally; however, UCL calculations can only address one source of variability at a time. While it is typically important to understand how seasonal changes affect subsurface vapor levels, UCL calculations usually analyze spatial distribution of contaminant levels as the variable. Valid UCL calculations of subsurface vapor concentrations require all data in a set to be collected within days or weeks of each other. When soil vapor data from several depths are available for evaluating potential current risk in slab on grade buildings, the data from the near subsurface (e.g., 4 to 5 feet bgs) and sub-slab should be used. As discussed in Section 4.6: *Indoor air sampling*, DEQ prefers longer duration (14 to 28 days) samples over shorter-term (e.g., 24-hour) samples.

If current or future buildings have a basement or below grade areas that are occupied, deeper samples on the order of 8 to 11 feet bgs may be needed to assess their vulnerability to VI.

5.3.2 Documenting statistical analyses of vapor data

In reports that include statistical analyses of vapor data, include both data tables and graphical displays of data distributions. DEQ recommends using EPA ProUCL or similar statistical software for this purpose. Include the summary of raw statistics, the program’s analysis of data distributions, and its recommended method of UCL calculation in the report. DEQ also recommends preparation of figures identifying each individual exposure unit along with the data set used to evaluate potential vapor intrusion within each unit.

5.4 Exposure units

On developed properties, a site may have more than one structure, or a large internally partitioned building with each building or partitioned area representing a separate exposure unit. In these cases, it is important to delineate the data points that will be used in the assessment for each exposure unit. DEQ recommends treating portions of buildings served by separate HVAC systems, or where ventilation or worker use is limited or isolated, as separate exposure units.

Sites partly or completely undeveloped with the expectation of future development may be considered to have potential vapor intrusion risk if individual data points exceed vapor intrusion RBCs. However, it is also possible to perform a statistical analysis of subsurface data as described above if the location of future buildings is known and individual exposure units can be delineated.

5.5 Interpretation of results

5.5.1 Comparison to RBCs

When evaluating VI risks based on indoor air data, compare exposure point concentrations from each exposure unit to DEQ's published indoor air RBCs. Residential RBCs should be applied at residential properties, schools, daycares, and other locations where children have a long-term presence. Residential RBCs also apply to condominiums and apartment complexes. At commercial/industrial properties, occupational RBCs are the relevant screening levels. Note: OSHA occupational exposure limits do not apply to environmental contamination. **Compare RBCs to the maximum seasonal concentrations detected in indoor air.** If indoor concentrations are below RBCs for all sampling events, DEQ concludes that VI is not causing unacceptable risks for current building occupants and uses.

Exceedance of soil vapor RBCs by a low order does not automatically demonstrate unacceptable risk. If data indicates acceptable risk and was collected in accordance with an approved work plan designed to meet project objectives, DEQ is likely to determine that risks by the assessed pathway are indeed acceptable, as described below. When indoor air and/or soil vapor data collected during VI investigations marginally exceed generic RBCs, consider these items to determine the need for further assessment:

- Round the data to the appropriate significant figure.
- Evaluate performance criteria for the analytical method. Specifically, identify what is the margin of error associated with the analytical method.
- Compare constituent ratios (comparing subsurface and indoor air values) to determine if other sources are contributing to indoor air concentrations.

5.5.2 Comparing indoor VOC concentrations to outdoor ambient levels

If indoor air concentrations exceed RBCs, evaluate possible contributions from ambient air and indoor sources other than VI. To account for the contribution from ambient air, DEQ recommends collecting contemporaneous outdoor air samples during indoor air sampling events. DEQ discourages the use of literature values as a substitute for site-specific data. In trying to determine the actual contribution of VI to indoor air VOC levels, it is reasonable to consider ambient outdoor concentrations from those levels measured indoors. If indoor air concentrations are roughly equivalent to or less than outdoor levels, this can suggest ambient sources. Conceptually, several interpretations of indoor/outdoor air ratios are possible, as shown in Figure 14.

If outdoor air concentrations are a result of site related sources, these concentrations would not be considered background ambient levels. The outdoor sample is a line of evidence; however, indoor air results should not be adjusted by subtracting the outdoor concentration. Always present the indoor air sampling results as reported by the analytical laboratory.

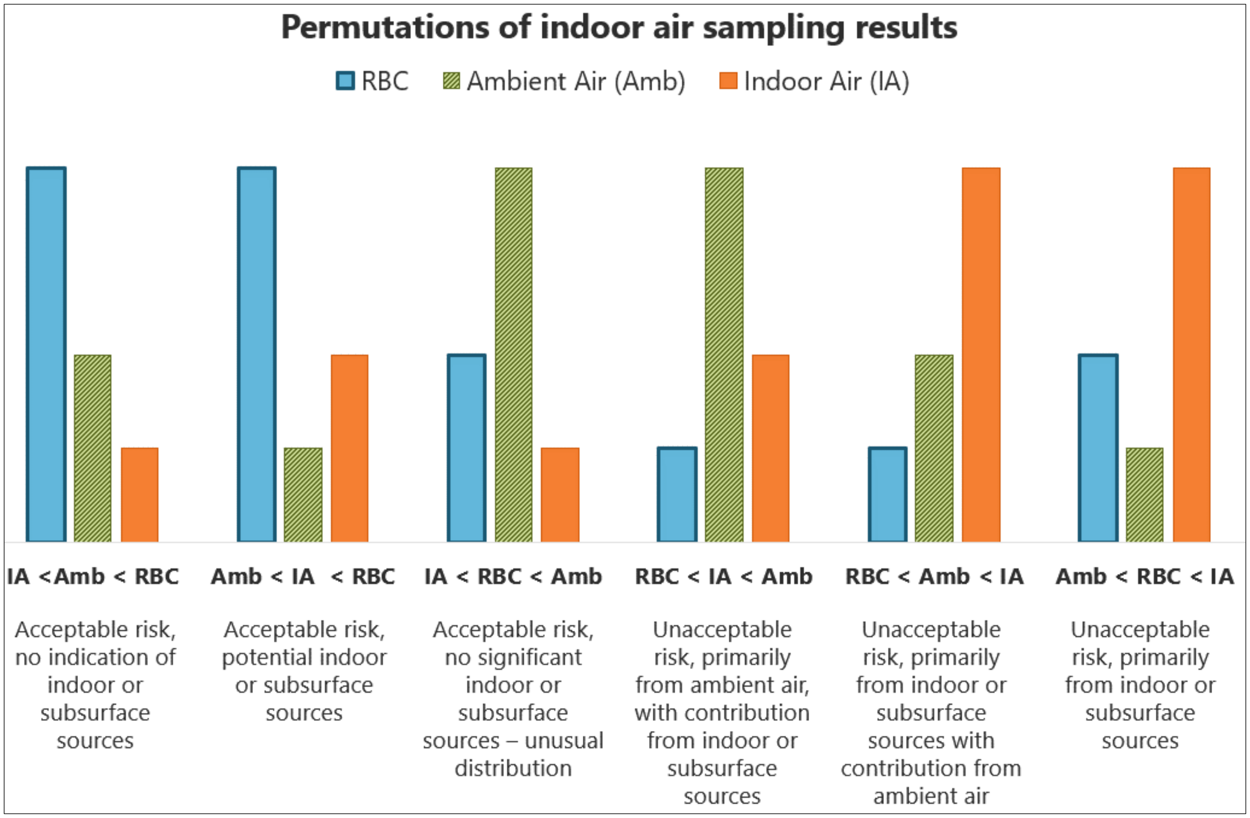


Figure 14. Potential risk screening outcomes for indoor air

5.5.3 Using lines of evidence

Best practice is to use multiple lines of evidence and professional judgment to make vapor intrusion decisions (ITRC, 2007a; EPA, 2015a). Using multiple appropriate LOEs supports developing a comprehensive CSM and considers all relevant factors to evaluate vapor intrusion and associated risks as accurately as possible. Common LOEs to consider are described below.

Comparing VOC composition of soil vapor to indoor air. At sites with VOC releases, typically multiple VOCs will be present in soil vapor. A comparison of the soil vapor composition to that of indoor air can assist in identifying VI impacts. Comparisons of chromatograms, VOC ratios, degradation daughter products, or the occurrence of chemicals unique to the subsurface release can be useful in identifying the source of VOCs in indoor air (Ginevan, 2007; Feenstra, 2006). Due to variability in the spatial distribution of subsurface VOCs and variability in analytical methods, this line of evidence alone may not be definitive.

Spatial distribution of VOCs. Sources of indoor air contamination can be inferred by examining the spatial distribution of VOCs. Proximity to subsurface sources and limited air circulation tend to result in basements having the highest vapor intrusion impacts in a building. A distinct concentration gradient from lower to higher floors in a building can be evidence of VI. The absence of such a gradient, or higher concentrations in upper levels of the building (when preferential pathways have been ruled out), suggests that ambient air or indoor sources are dominating VOC concentrations, unless the ventilation system provides good air mixing throughout the building.

Correlation to meteorological conditions. When reviewing the results of multiple indoor air sampling events, consider the prevailing meteorological conditions during each event. Indoor air VOC levels that fluctuate in response to seasonal conditions (i.e., soil vapor intrusion rates) can be a compelling line of evidence that contamination is a result of VI.

Using radon as a tracer gas. Radon gas can be a useful tracer for estimating building-specific attenuation rates and distinguishing VI contributions to VOC contamination to indoor air (Lutes et al., 2019). The calculated attenuation rates can then be used as a line of evidence to evaluate the vulnerability of existing buildings to VI.

Building pressure cycling tests for isolating VI impacts. This method allows a controlled assessment of reasonable maximum vapor intrusion risks without having to wait for seasonal conditions (Lutes et al., 2019). It works by cycling through reductions and increases in indoor air pressure to alternately increase and decrease vapor intrusion and observe corresponding changes in indoor contaminant levels. Through this method, both reasonable maximum VI conditions can be evaluated and the contributors to indoor air contamination (i.e., subsurface VI versus background sources) can be more easily differentiated, as described in *Optimization of Building Pressure Cycling Methods for Vapor Intrusion Studies in Large Buildings* (CH2M Hill, 2021).

5.5.4 Risk determinations based on indoor data

DEQ's preference is to evaluate risk using indoor air data while taking into account the site conceptual site model and multiple lines of evidence.

- If the subsurface VOC contribution to indoor air VOC levels exceeds air RBCs, then there is an unacceptable current and future risk to building occupants, and corrective action, mitigation, removal, and/or remediation are necessary (Appendix A).
- If soil vapor or sub-slab vapor concentrations exceed RBCs, but based on sufficient data, indoor VOC levels are below air RBCs, this implies current VI risks are acceptable. Note that future VI risks will still need to be managed.
- When adequately demonstrated to DEQ that ambient levels are not affected by site sources, these can be a line of evidence to determine if indoor air concentrations constitute an unacceptable risk due to vapor intrusion. For example, indoor air concentrations may exceed the benzene RBC due to vehicle emissions.

If representative indoor air data cannot be collected, soil vapor becomes the default for evaluating VI risk.

5.6 Responses to risk

5.6.1 Short-term risk

In some cases, it is important to consider short-term exposure to vapors in indoor air, especially for chemicals with developmental effects. For these chemicals, exposure periods of a few hours to a few days could result in adverse effects. Previously, DEQ did not have RBCs for acute exposure. This guidance incorporates acute RBCs based on the acute RBCs developed for DEQ’s CAO program. The development of acute air RBCs is described in Appendix C. Acute RBCs are provided in the associated vapor intrusion RBC spreadsheet.

In addition to adverse health effects, another threat from high air concentrations of chemicals is the potential for explosions. Although this may be a rare occurrence, it is prudent to provide lower explosive limits to assist with interpreting monitoring data. Lower explosive limits for relevant chemicals are included in table of acute RBCs in the associated vapor intrusion spreadsheet.

Sampling methods and data objectives may change when evaluating short-term risk. At many sites, the objective of indoor air sampling is to calculate average exposure point concentrations (EPCs), which longer duration sampling periods help define. However, when evaluating short-term risks, greater temporal resolution may be necessary to demonstrate acute concentrations are not exceeded. Under these circumstances, a combination of long-term passive sampling may be supplemented with short-term evacuated canister samples to evaluate short-term peak concentration.

5.6.1.1 Responses to short-term risk

Appropriately responding to elevated indoor air levels and effectively communicating concerns about acute risk can be challenging. DEQ developed potential response actions based on guidance from other agencies regarding TCE, a chemical with serious developmental effects that can occur following short-term exposure (see Appendix D). DEQ’s general response actions are presented in Appendix A.

The approach is general for any chemical with an acute RBC; however, accelerated response action limits and urgent response action limits may be modified on a site- and chemical-specific basis if DEQ determines that higher levels are warranted based on consideration of factors such as severity of effects and degree of uncertainty used to develop toxicity values.

5.6.1.2 Communicating short-term risks

For sites with potential short-term risks, DEQ will consult with the Oregon Health Authority Environmental Health Assessment Program (EHAP) for assistance in communicating risks to the public. EHAP reviewed and concurred with the accelerated and urgent response levels presented in Appendix A.

EHAP makes evaluations of acute exposure on an individual site basis, to ensure that chemicals do not pose an imminent and substantial endangerment to public health. EHAP considers several factors including:

- The health effect that the acute screening level is based on and how far above the screening level the concentration is (i.e., if it is slightly above or orders of magnitude above)
- The total number of uncertainty factors in the screening level (i.e., how much higher is the actual concentration than the concentration that caused the critical effect in toxicological studies)
- The population being exposed (i.e., are children, women of childbearing age, or other vulnerable receptors present)

EHAP has an internal protocol for assessing acute exposures to determine if chemicals present in the environment could present an imminent and substantial endangerment to public health. Part of this protocol requires that EHAP respond within 24 hours of receiving analytical data from another government agency.

5.6.2 Long-term risk

Similar to short-term exposures and acute risk, appropriately responding to elevated indoor air levels and effectively communicating concerns about chronic risk can also be challenging. DEQ developed potential response actions presented in Appendix A. Standard and prompt response action limits may be modified on a site and chemical-specific basis if DEQ determines that higher levels are warranted based on consideration of factors such as severity of effects and degree of uncertainty used to develop toxicity values. For sites with unacceptable risk, DEQ may consult with Oregon Health Authority's EHAP to assist with determining appropriate responses and communicating risk, particularly concerning elevated concentrations or hot spots.

5.7 Determination of hot spots

Identification of hot spots is an essential element of a VI investigation. For the purposes of identifying hot spots, soil vapor and indoor air meet the definition of media other than groundwater and surface water. Hot spots for media other than groundwater and surface water are defined in Oregon Administrative Rule as areas with unacceptable risk **and** A) concentrations exceeding multiples (10x for noncancer or 100x for cancer) of acceptable risk levels, **or** contaminants that B) are reasonably likely to migrate to such an extent that the chemicals are not reliably containable, **or** C) are not reliably containable (OAR 340-122-0115(32)(b)(A-C)). Acceptable risk is evaluated by comparing concentrations with chronic and acute RBCs. Concentrations above RBCs indicate a potential excess cancer risk above one-in-one million for carcinogens or a hazard quotient above 1 for non-carcinogens. Hot spot determinations are discussed below for indoor air, soil vapor, and groundwater; however, DEQ focuses on soil vapor for hot spot evaluations. In addition to the text below, Section 3.1 presents example scenarios to help with hot spot determinations.

Indoor air. If there is an RBC exceedance in indoor air, first consult Appendix A (Response Matrix for Indoor Air) to identify the appropriate initial response action and timeframe based on the magnitude of the RBC exceedance(s). When evaluating potential hot spots, DEQ's default assumption is that indoor air is not reliably containable and therefore represents a hot spot when RBCs are exceeded (without a multiplier). In rare cases, it may be possible to demonstrate that concentrations in indoor air are reliably containable and that multipliers may be used to define hot spot concentrations. **Regardless, the determination of a potential hot spot in indoor air should also include an evaluation of the source of the vapors (e.g., from groundwater, soil vapor, or preferential pathways) to confirm that the indoor air concentrations observed are from an environmental release.** For petroleum vapor intrusion, this evaluation would include evaluating additional lines of evidence, as described in the Petroleum Process Flow Chart (Figure 8). This is a more direct assessment of the source material impacting indoor air concentrations and will better inform the appropriate response action (e.g., remediation and/or mitigation) to ensure both short and long-term protectiveness.

For the VI pathway, DEQ is focusing hot spot evaluations to the soil vapor medium.[21] While indoor air concentrations may be used to determine whether human exposure is occurring, this evaluation does not reliably represent potential future conditions. Although soil vapor data is both screened for risk and hot spots on a point-by-point basis, it's important to note the data are interpolated and extrapolated to infer and represent concentrations over areas and not limited to the discrete locations where they were collected.

Soil vapor. To evaluate whether there is a potential hot spot in soil vapor, first evaluate whether the contamination is reliably containable based on current science and site conditions in the feasibility study or equivalent. This evaluation should be site-specific and incorporate multiple lines of evidence (e.g., preferential pathways; efficacy of building foundation, differential pressure). This evaluation should also consider the ability of contamination in soil vapor to migrate such that it is no longer reliably containable. If this evaluation indicates that the vapor is reliably containable based on current science and site conditions, there is a hot spot if the concentrations exceed the multiples (10x for noncancer, 100x for cancer) of acceptable risk levels. Mitigation measures may be considered when evaluating whether it is possible to reliably contain contamination in soil vapor; however, performance monitoring is required to demonstrate the efficacy of measures put in place to contain soil vapor contamination. If this

[21] Petroleum free product is required to be removed to the extent practical for LUST sites. See DEQ *Underground Storage Tank Cleanup Manual* (OAR-122-0205 through OAR-122-0360).

evaluation indicates that the vapor is not reliably containable, there is a hot spot without a multiplier of RBCs. If there is a hot spot, regardless of the calculation method, source remediation should be evaluated. If sources of contamination to soil vapor remain in place after remediation, institutional controls and/or engineering controls are necessary to ensure long-term protectiveness.

Seasonal variability in soil vapor concentrations can result in intermittent or sporadic exceedance of hot spot levels. DEQ considers areas exceeding hot spot thresholds seasonally or intermittently to be hot spots, with a preference for treatment or removal. Unless an appreciable declining trend in vapor levels is evident or anticipated as a result of site remediation, hot spots should be identified based on a comparison of the maximum concentration measured at a location (i.e., permanent soil vapor monitoring point) rather than the average value measured over time.

Groundwater. Groundwater can be a source of contamination to hot spots in media other than groundwater and could therefore be targeted for remediation. For contaminants volatilizing from groundwater, an evaluation of potential hot spots is not made directly. Where groundwater contamination indicates the potential for vapor intrusion, soil vapor and potentially indoor air should be investigated. The soil vapor hot spot determination should begin with evaluating whether volatilized contamination from groundwater is reasonably likely to migrate such that it is not reliably containable based on current science and conditions. If the contamination volatilizing from groundwater is shown to be reasonably likely to migrate such that it is not reliably containable, the hot spot determination should be based on soil vapor concentrations or indoor air concentrations. Contamination volatilizing from groundwater is considered “media other than groundwater” (OAR 340-122-0115(32)(b)) in the context of a potential hot spot evaluation. If it is not possible to make a hot spot determination based on soil vapor or indoor air because representative data cannot be collected, a hot spot determination will be made based on groundwater concentrations on a site-specific basis.

5.8 Evaluation of remedial system emission risks

A revised streamlined approach to managing hazardous substances from remedial systems is provided in Appendix E to reflect the current practice of science and engineering and acknowledge Cleaner Air Oregon rules (adopted in November 2018). Appendix E replaces the original DEQ *Guidance for Managing Hazardous Substance Air Discharges From Remedial Systems* published in 2006. DEQ Cleanup Program rules require consideration of the effectiveness not only of a proposed site remedy but also the potential risks posed by implementation of the remedy itself on human health and the environment. An implementation risk evaluation is applicable to remediation and mitigation systems that discharge hazardous substances into the atmosphere at Environmental Cleanup sites in Oregon.

DEQ’s CAO Program developed a screening approach using conservative assumptions for evaluating potential risks from facility discharges. Appendix E describes how to use a modified version of CAO’s screening approach to assess potential risks from remedial system emissions.

An evaluation of implementation risks for emissions from a remedial system can be evaluated by using a simple "look-up" table. When further assessment is necessary based on initial screening, or Level 1 modeling assumptions are not applicable for the project, site-specific air dispersion modeling (i.e., CAO Level 3 risk assessment) can be conducted to further evaluate risk. In some cases, site-specific modeling may be the preferred approach, for instance to inform remedial design, and therefore the initial screening step would be skipped. A DEQ engineer should be on the review team for any treatment system including the air discharge modeling evaluation.

To meet DEQ's Cleanup Program and CAO substantive requirements, the following steps are recommended:

- Evaluate risks from remedial system emissions using modified CAO Level 1 lookup tables (available on DEQ's Cleanup Program website). Sampling and analysis should include all VOCs present at the site to evaluate potential risks from system emissions.
- The evaluation should use Cleanup Program **and** CAO RBCs, and correspondingly present risks for both evaluations. The results will likely be similar. The assessment should include an evaluation of acute risk in addition to chronic risk.
- If initial screening fails the applicable screening criteria, options include following: 1) treat the effluent vapor; 2) run an appropriate DEQ-approved air dispersion model with site-specific data to further evaluate the potential risk posed by effluent vapor discharging into the atmosphere; or 3) consider alternative remedial technologies that eliminate or reduce effluent vapor discharges below levels of concern.
- If subsequent site-specific modeling results still exceed applicable RBCs, treat effluent vapor or modify remedial design specifications and re-run modeling steps.
- If effluent vapors do not exceed applicable RBCs based on the initial screening or appropriate site-specific model evaluation, this supports that treatment is unnecessary as long as emission concentrations are generally stable or declining. Monitor system operations to document and evaluate system performance.

To assist facilities in conducting risk assessments of emissions from remedial systems, DEQ developed example spreadsheets where the user can input site-specific data and the subsequent tables in the spreadsheet will screen and present results compared to Cleanup and CAO RBCs. This interactive spreadsheet can be downloaded from DEQ's website. Additional instructions are provided in Appendix E. For detailed information on conducting air dispersion modeling and toxic air contaminant risk assessments, refer to CAO recommended procedures (DEQ, 2022a; DEQ, 2022b). Details regarding modeling protocol and assumptions can be found on DEQ's CAO "Step-by-Step Guide for Facilities" website.

6.0 Vapor intrusion remediation and mitigation

At VI sites remediation means the removal or treatment of subsurface contaminant vapor sources through active measures such as excavation, soil vapor extraction, and groundwater treatment. The objective of remediation is to reduce or eliminate subsurface sources of VOC contamination and minimize the need to manage them over the long-term to protect public health. In Oregon, there is a preference for removal and/or treatment of hot spots (i.e., elevated concentrations) that pose greater risk (OAR 340-122-0090).

In contrast, the objective of VI mitigation is to provide protection from vapor intrusion into buildings and exposure to occupants, even if a residual source of contamination remains in-place or while the VI source is being remediated. Common technologies and strategies for VI mitigation include sub-slab depressurization, sub-slab ventilation, sub-slab venting, and pressurization of indoor air spaces. Vapor barriers are standard components to these technologies. A combination of mitigation and source remediation may be necessary to fully address both current and future VI risks.

Vapor intrusion mitigation (or VIM) is necessary when an investigation and corresponding risk assessment (or risk screening for less complex sites) indicate there is an unacceptable VI risk in an occupied building or planned development. Mitigation may also be conducted at sites where more definitive data on the vapor intrusion pathway (e.g., paired sub-slab and indoor air data) is unavailable but potentially unacceptable risk is inferred from other site data and information. When the results of a VI assessment conclude building occupants are being exposed to unacceptable levels of contaminants, actions to mitigate VI should be taken promptly. Appendix A provides general response action levels and recommended timeframes.

The VI pathway is considered complete when there is a VI source, migration route into a structure, and a receptor at risk. Vapor mitigation functions to limit subsurface sources of volatile contaminants from entering a structure sufficiently to protect building occupants (i.e., below risk levels). This requires an interruption of the VI pathway to reduce the mass flux of VI contaminants entering the building. (Note: Increasing indoor ventilation rates to further dilute infiltrating contaminant vapors can also reduce indoor air contaminant concentrations but is generally not a reliable long-term approach to address VI.) Under DEQ's Cleanup Program, mitigation systems are engineering controls used to protect human health from hazardous substances posing unacceptable risk. When remediation technologies control vapor transport in the subsurface, they can also function as a VI mitigation system. VI can also be "mitigated" through institutional controls such as restricting use(s) until conditions are restored to protective levels, requiring conditions on future development, long-term compliance monitoring, or operation and maintenance (O&M) of a remedial system.

It is important to acknowledge the advantages as well as constraints of a technology when selecting a remedial strategy, which may consist of remediation and/or VI mitigation. An important limitation of typical VI mitigation systems is they do not deplete VOC sources at an effective rate but rather are designed to influence conditions at the building-soil interface. Thus, they typically only manage indoor air VI exposure risks and often do not address or remediate the source of the contamination. The zone of influence of a typical VI mitigation system, including "active" systems with a fan or blower, is relatively shallow and generally limited to the building footprint. In comparison, VOC sources can extend several feet below the ground surface, far beyond the influence of standard mitigation systems.

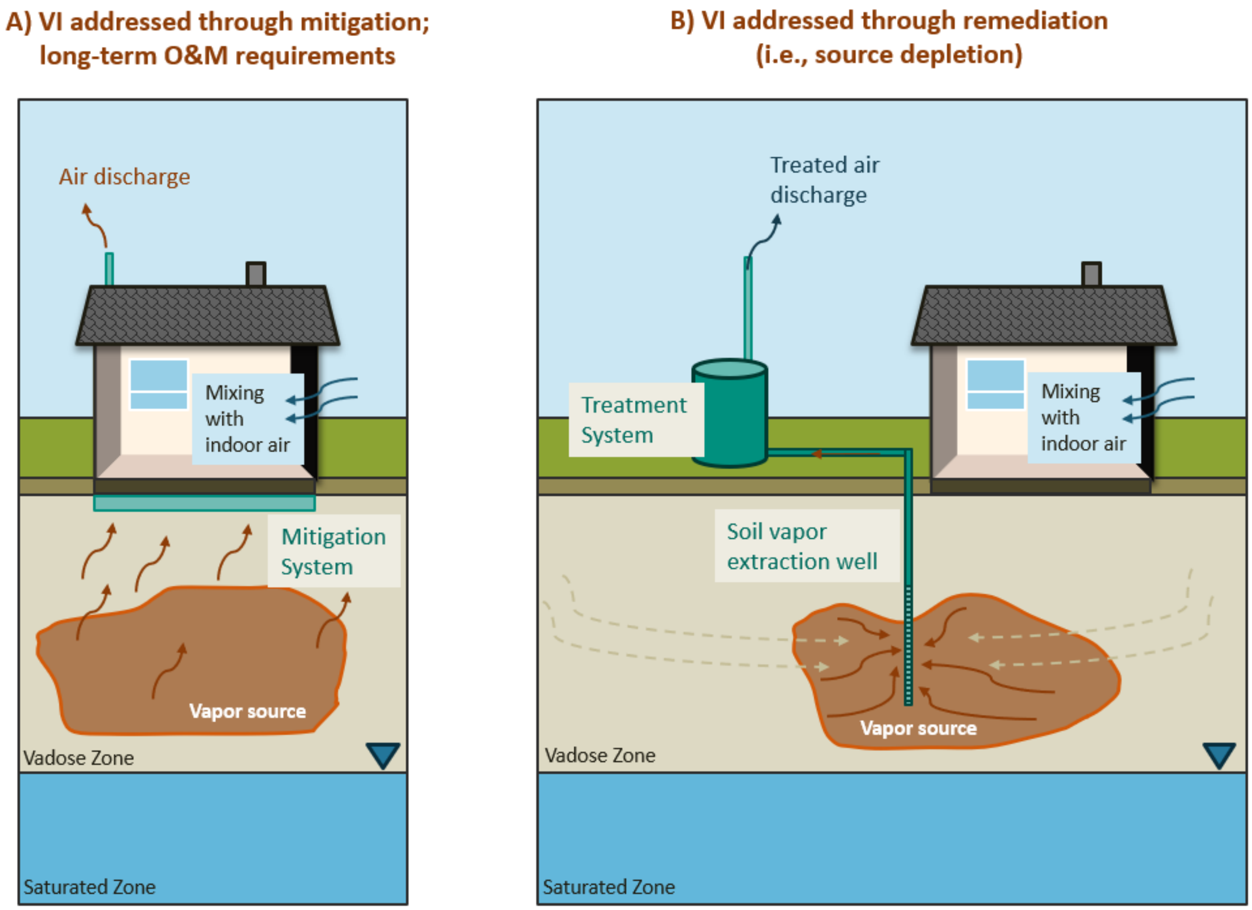


Figure 15A. VI addressed through different remedial approaches

Remediation systems on the other hand are designed to treat or remove contaminant source mass occurring deeper in the soil profile and groundwater. For example, typical soil vapor extraction (SVE) systems use wells constructed in the vadose (unsaturated) zone to extract shallow to deep soil vapor contamination. In addition to targeting soil vapor removal in closer proximity to VI source(s), SVE systems are operated under greater vacuum (negative pressure) and extraction rates than mitigation systems. Depending on the subsurface geology, the radius of influence of these wells can extend in the lateral direction from several to greater than 30 feet.

The duration of operating and maintaining VI remediation and mitigation systems will depend on the nature and extent of the contaminant source(s) and the efforts made to eliminate them.

VI sources in the unsaturated zone can generally be remediated within one to five years. However, groundwater plumes are typically more persistent and difficult to treat, leading to longer cleanup timeframes. Untreated, chlorinated VOC sources can persist for decades in the subsurface. In comparison, petroleum VOCs generally degrade under natural conditions in shorter timeframes or may break down at a sufficient rate to acceptable levels before reaching a building foundation (which would need to be confirmed during a site-specific study). Large petroleum releases left untreated may also persist for decades. VI mitigation may be required while source remediation is implemented and, in the absence of remediation efforts, may be necessary indefinitely.

Screening and selecting a remedial approach, remediation and/or mitigation, should be based on a sound CSM and supporting environmental data. To identify the optimal remedial approach, which may be one or a combination of engineering and institutional controls, DEQ will request an evaluation of alternatives in the form of a feasibility study or corrective action plan (CAP) with a proposed remedy for DEQ review and approval. Depending on the stage of the project, this may also be called a remedial action plan (RAP) or equivalent design proposal. These documents should present an evaluation of remedial strategies and how they will modify the VI pathway to reduce risk. Only technologies compatible with site conditions that can reasonably restore conditions to protective levels should be carried forward for further examination.

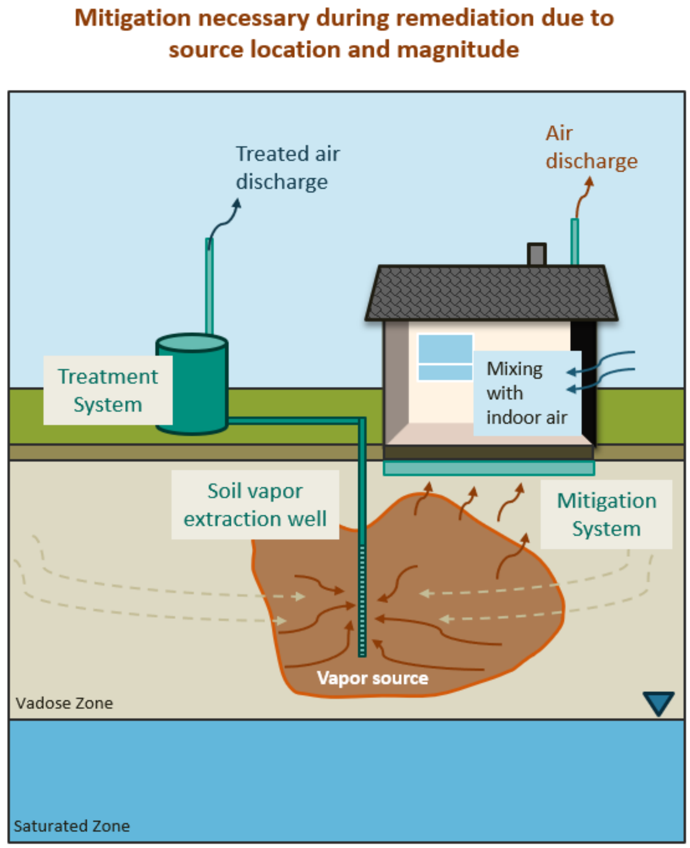


Figure 15B. VI addressed through a combination of remedial technologies

The FS (or equivalent) should describe how performance (e.g., effectiveness and reliability) of the remediation or mitigation measure will be evaluated. Performance objectives should be identified during remedy selection to support remedial design. DEQ recommends defining clear, quantifiable, and obtainable data quality objectives, such as reductions in indoor air concentrations and sub-slab concentrations. Early scoping of performance monitoring is necessary for remedial design, such as identifying monitoring locations that will be installed with the accompanying engineering controls. Regardless of the remedial approach, monitoring is necessary to demonstrate performance objectives are achieved following construction and that those standards continue to be met until VI controls are longer necessary.

6.1 Removal, remediation, and early/interim remedial actions

A removal, remediation, and/or early action is recommended to contain and remediate VI sources. DEQ has a preference for source remediation (e.g., removal or treatment) when contaminant concentrations exceed hot spot concentrations (see Section 5.7: *Determination of hot spots*). LUST sites also require removal of petroleum free product to the maximum extent practicable. Early action can occur while site investigations proceed and a final remedy is identified and implemented. Early actions to address risks in the interim may also become the final remedy if proven effective and reliable. Remediation of elevated sources, particularly chlorinated VOCs or VOCs exceeding hot spot levels, is typically necessary and can reduce cleanup timeframes considerably.

Precautionary/Preemptive VI mitigation. Mitigation is an appropriate early or interim action to protect building occupants prior to completion of an RI/FS or while source remediation is implemented, and mitigation may continue to be useful following a source removal/treatment action to address remaining residual contamination. As noted previously, VI investigations may require multiple lines of evidence and phases of assessment to arrive at a definitive conclusion regarding VI risks. To ensure building occupants are adequately protected in the interim, it may be appropriate to mitigate VI as a precautionary measure, particularly when preliminary site data or other information indicate vapor intrusion may be occurring. VI mitigation can be implemented relatively quickly to address potential risks and can alleviate concerns and reduce disruptions to building occupants. In some cases, a rapid response may be warranted. Potential prompt response options, discussed further in Section 6.2.2, are generally focused on what can be implemented immediately inside an occupied building before a long-term strategy is determined. Appendix A provides general response action levels and timeframes under a range of scenarios when VI is suspected or site data indicates unacceptable risk.

Remediation methods. Remediation methods to reduce or remove sources are often necessary and preferred to address elevated concentrations of VOCs posing a greater vapor intrusion risk. Remediation methods can entail physical removal (e.g., excavation or soil vapor extraction) or treatment technologies such as enhanced bioremediation, thermal remediation, and chemical treatment. Generally, active remediation occurs *in situ*; however, treatment can occur *ex situ*. Physical removal and/or treatment will be driven by accessibility of source media or delivery of treatment agents to the source, efficiency, and ability to be effective. An FS or equivalent should be presented for DEQ approval as well as a performance monitoring plan to assess the effectiveness of the remedial action during and following implementation.

Extensive guidance is available on the evaluation and selection, design and construction, and operation of remediation technologies for subsurface vapor sources.[22]

[22] Additional guidance includes: *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with VOCs in Soils* (EPA, 1993); *In Situ Treatment Technologies for Contaminated Soil* (EPA, 2006b); and *Contaminants in the Subsurface: Source Zone Assessment and Remediation* (NRC, 2004).

Soil vapor extraction is one example of a common technology implemented in Oregon that targets removal of shallow to deep volatile contamination within the vadose zone. An appropriately sized blower connected to an extraction well or trench provides the vacuum (negative pressure) to move vapor from the soil matrix. SVE systems are designed to extract vapor contaminant mass at sufficient rates to deplete a VI source in a reasonable timeframe (typically assumed to be between one and five years under optimal conditions). A conventional SVE system consists of one or multiple extraction wells screened at target remediation depths, well manifold piped to a blower, vapor/liquid (condensate) separator, treatment system(s) for vapor and/or liquid waste streams, sampling ports, and related instrumentation and controls (e.g., valves, flow meters, vacuum gauges, and other sensors). Figure 16 illustrates a typical vertical SVE well design. Angled SVE wells are also options, for example to provide greater access to a VI source below an existing structure. SVE wells can be horizontal or trenches and designed to extract vapors in shallow unsaturated zones, such as below a building or in conditions where a high groundwater table restricts the viability of vertical extraction wells. In addition to remediation, SVE systems can function as the mitigation mechanism by preventing migration of VI into a structure or offsite.

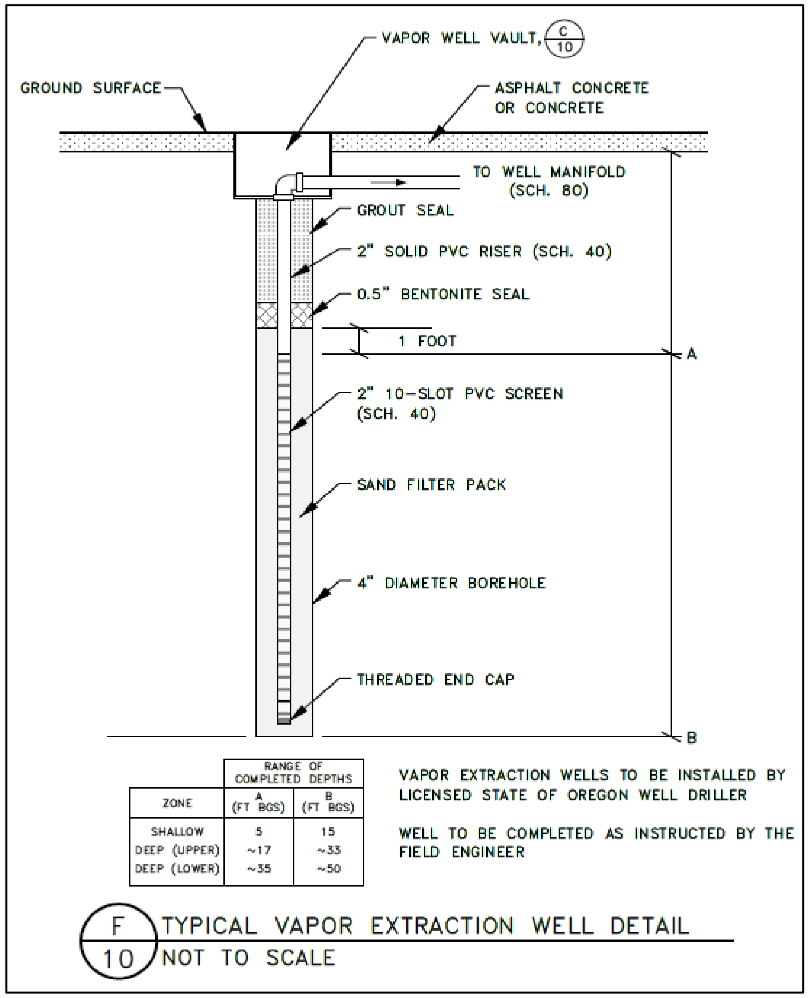


Figure 16. Example soil vapor extraction well detail (drawing by Apex Companies, LLC)

Adequate permeability, moisture content, and depth to groundwater are important considerations for carrying forward SVE as a potential remedy. SVE does not remediate groundwater sources but can be used in combination with other technologies, such as multiphase extraction (MPE), to remediate vadose and saturated zones. System effluent typically requires treatment prior to disposal/discharge. The assessment of air discharge from remediation systems is discussed in Section 5.8: *Evaluation of remedial system emission risks* and Appendix E: *Managing air discharge from remedial systems*.

DEQ recommends remediation systems operate until reaching asymptotic or plateau conditions to reduce the likelihood of "rebound" of vapor intrusion contaminants. Assessment of rebound is discussed further in Section 6.3.3 as an element of performance monitoring. Optimization and pulsing with periods of on-off can remove additional mass and reduce potential rebound conditions. The U.S. Department of Energy (USDOE) 2013 *Soil Vapor Extraction System Optimization, Transition, and Closure Guidance* builds on previous EPA and federal published documents (AFCEE, 2001; EPA, 2001b; USACE, 2002) and provides a stepwise approach for assessment of SVE performance.

Remediation of sources can reduce risk, shorten cleanup timeframes, potentially remove the need for long-term controls such as VI mitigation or site restrictions, or decrease the timeframe to maintain these controls. Source remediation may also address more than one exposure pathway. In general, remediation is the preferred long-term approach to remove or substantially deplete contaminant source(s) below levels of concern and achieve a permanent remedy.

6.2 Vapor intrusion mitigation technologies and strategies

Vapor intrusion mitigation systems can be relatively inexpensive and easy to install, but long-term monitoring, operation, and maintenance are critical to continued system performance and effectiveness can add considerable cost and effort. Mitigation measures are particularly cost-effective to install in new buildings where they can be easily integrated into a building foundation design. Comparatively, retrofitting an existing building is more challenging, potentially disruptive to building occupants, and generally more expensive. A developer may also elect to install vapor mitigation controls proactively as a conservative or preemptive measure. This guidance focuses on the most common mitigation technologies and strategies successfully implemented under DEQ's Cleanup Program to mitigate residual VI risk.

The mitigation approach will need to disrupt vapor entry into a building which may consist of more than one route, particularly for older buildings. Vapor intrusion can potentially occur at any point where a structure interfaces with subsurface soil including the building slab, flooring, exposed soil, or foundation walls below grade such as basements, sumps, vaults, and elevators. Direct openings through the building shell and subsurface such as cracks in the building slab or foundation wall, slab penetrations, unsealed utilities, conduit openings, or wall/floor joint openings can serve as preferential pathways for VI.

It is important to conduct a comprehensive building inspection which provides crucial information for designing and constructing a VI mitigation system. Section 2.3 provides additional discussion regarding building considerations and entry points, and Section 6.2.2.4 reinforces the value of sealing preferential pathways and presents potential methods that can provide immediate and long-term benefits to prevent VI. Generally, older buildings present comparatively more VI pathways than newer buildings due to aging infrastructure, such as degraded building slabs, increased number of entry points for VI, multiple foundation depths, or subsequent building additions, as well as higher potential for poor ventilation or limited to no building pressurization. Building additions often represent different types of foundations and underlying subgrade conditions. Industrial buildings commonly have multiple active and abandoned utility lines. Detailed information should be collected on the building construction including carefully cataloging entry points, building slab composition and thickness, subsurface characteristics, and mechanics (e.g., HVAC). Older and industrial buildings are more likely to contain multiple VI pathways, and therefore a combination of VI control strategies may be necessary.

Subsurface conditions, such as shallow groundwater or perched water, can impact mitigation efforts and strategies should be adjusted accordingly. Anticipated changes to site conditions, such as redevelopment, should also be considered during the design phase. For example, covering a site with a new or larger building and pavement may result in increased vapor accumulation under these new structures than previously observed in their absence.

A vapor intrusion mitigation plan should be built on a good CSM and updated when new information is available. Fundamentally, sources and preferential pathways should be identified to the extent possible to inform the VI mitigation strategy. Buildings lying above high strength VOC sources will require a comprehensive mitigation strategy to adequately mitigate soil vapor entry into a building. A combination of mitigation approaches is customary.

Mitigation systems are typically installed where the building shell comes into contact with the subsurface and function to disrupt the VI pathway. Exceptions are rapid/immediate response measures that focus on what can be implemented quickly within building spaces (see Section 6.2.2 for details). It is important to ensure the mitigation system installed spatially mitigates vapor intrusion impacts to a building (e.g., area of mitigation is consistent with the CSM).

The most common active mitigation technology is sub-slab depressurization, which utilizes a mechanical component using a fan or blower to generate a vacuum (i.e., negative pressure) to pull vapors from the sub-slab. Passive systems use no mechanical component and function on relatively weak natural forces (e.g., thermal stack effect and wind) to enhance ventilation of sub-slab soil vapors. Passive systems rarely generate measurable sub-slab negative pressure. Active operation using a fan or blower increases the strength and reliability of the sub-slab vacuum and correspondingly expands the zone of influence (e.g., volume of underlying soil where vapor transport is controlled by the mitigation system) below the sub-slab.

Standard design elements of sub-slab VI mitigation systems include a sub-slab venting network, permeable gravel conveyance layer to promote vapor collection, and a low-permeable chemically compatible vapor barrier above the venting system. Active systems include the additional of an appropriately sized fan to distribute and maintain a negative pressure field beneath occupied buildings.

Mitigation systems typically incorporate a vapor barrier, particularly for new construction. In existing buildings, mitigation technologies may utilize the existing building slab as the “barrier.” However, manufactured low-permeable vapor barriers are recommended and there are opportunities to install a VI barrier when the existing building slab is already being removed to address sub-slab contamination. For instance, a vapor barrier can be installed over areas excavated for construction of the sub-slab mitigation system or following a soil excavation (to remove a source area) beneath a building. Nonetheless, when applied at existing buildings the extent of the VI barrier is generally limited in area compared to a newly constructed building that can more seamlessly integrate a VI barrier.

Based on the CSM, additional active or passive engineering methods may be necessary to prevent offsite migration and/or vapors coming into proximity of a building. Techniques to capture and restrict vapor migration may consist of subsurface extraction systems or interceptor trenches. Leaky utilities may need to be lined or replaced if found to be a preferential pathway. If backfill around utilities is determined to be a preferential movement of vapor, utility cut-off collars can be installed to prevent migration. These strategies are incorporated into the overall remedial approach.

Several types of VI mitigation techniques are available, and standard applications for passive and active mitigations are described in the following sections. Note that potential mitigation technologies or approaches are not limited to what is presented in this document. As with any technology, only viable mitigation options should be carried for further consideration. A combination of techniques may be necessary to address site-specific conditions and reliably mitigate VI risk. **Mitigation plans submitted to DEQ for review and approval should be based on site-specific conditions.** A mitigation technology or VI barrier approved for implementation at one site may not be appropriate for a different site. Chemical compatibility (e.g., VI barriers), constructability, and quality control are important considerations when evaluating vapor intrusion mitigation technologies.

At the design phase, plans submitted to DEQ should include the basis of design, critical design criteria and objectives, engineering calculations and drawings/specifications, air dispersion modeling if needed, roles and responsibilities, and a construction quality assurance quality control (also referred to as an QA/QC or CQA) plan. The scope of design plans will be driven by the complexity of the site and applicability to the project. Following construction, documentation of activities and as-built drawings are submitted in a construction completion report or equivalent documentation. These systems normally require post-construction performance monitoring to demonstrate the system meets the design criteria and objectives to mitigate risk and restore conditions protective of human health. Accordingly, design plans should include performance monitoring locations and design details.

It is an expectation that evaluation and design of remediation and mitigation systems (i.e., engineering plans, specifications, and drawings) are prepared and stamped by an Oregon registered Professional Engineer. The P.E. identified as the engineer-in-charge is also responsible for supervision of construction and certifies as-built plans provided to DEQ following construction. In general, the engineer-in-charge ensures the project adheres to specifications, standards, and regulations. Refer to Section 6.4 and 6.6 for additional details regarding Cleanup Program document expectations and professional certifications.

Additional guidance and resources regarding vapor intrusion mitigation include but are not limited to the VI references provided below. It is recommended to periodically check federal and national institutions, like Interstate Technology and Regulatory Council, which continue to provide new and updated guidance and factsheets.

- ITRC has developed comprehensive web-based technical resources for vapor intrusion mitigation details in the form of fact sheets, technical sheets, and checklists (hereafter referred to ITRC VIM Factsheets) including an overview of mitigation options and key considerations from the conceptual site model to an exit strategy (ITRC, 2020).
- EPA presents a summary of mitigation approaches in the *OSWER Technical Guide for Assessing and Mitigation the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (EPA, 2015a) and the *EPA Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches* (EPA, 2008).
- EPA's *Vapor Intrusion Handbook* contains a useful summary of mitigation options (EPA, 2020).
- Naval Facilities Engineering Command has published factsheets on mitigation technologies and considerations for new buildings and existing buildings (NAVFAC, 2011a-b).

Table 6. Common VI mitigation and remediation technologies

Vapor Intrusion Mitigation and Remediation Technologies	
Prompt/Rapid Response	Increased indoor ventilation, building pressurization (e.g., HVAC modifications), indoor air treatment, preferential pathway sealing
Passive Mitigation	Vapor barrier, sub-slab venting, building design, interceptor trench, preferential pathway prevention (e.g., coatings/sealants, utility collars), aerated floors
Active Mitigation	Sub-slab depressurization, sub-slab ventilation, crawl space ventilation, aerated floors, vapor pits, inceptor trench
Source Remediation (Treatment/Removal)	Soil vapor extraction (SVE), multiphase extraction (MPE), groundwater treatment (e.g., bioremediation and chemical oxidation), soil excavation

Table 6 provides a summary of common remedial technologies to address VI. More comprehensive tables and details regarding VIM technologies (description, pros/cons, etc.) can be found in the following documents:

- Table 9-1. Mitigation Technique Matrix from EPA's *Vapor Intrusion Handbook*.
- Table 1. Overview of Mitigation Methods with Cost Data from EPA's 2008 *Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches*.

While outside the scope of this guidance, mitigation systems are commonplace for radon and methane gas. Several vapor intrusion mitigation technologies have been adopted and/or modified from well-established techniques that also mitigate exposure to radon gas (e.g., at residential homes) and methane gas (e.g., at landfills). Many of these technologies are analogous in that they function to prevent gas and vapor from entering structures; however, the hazards attributed to these different gases vary substantially. Accordingly, mitigation standards and practices vary depending on the risk posed. For instance, methane mitigation standards are generally conservative. While radon and VI mitigation strategies do share many similarities, VI mitigation systems are typically designed, constructed, inspected, and verified more thoroughly (ITRC, 2020).

Radon Mitigation. Radon mitigation is not overseen by DEQ. Radon is a naturally occurring radioactive gas that can also migrate from soil vapor into indoor spaces. The risks of radon exposure have been known for several decades, and radon mitigation systems have been routinely installed in Oregon homes since the 1990s. Many cities now incorporate radon gas mitigation into city code for building construction to address local radon concerns.[23] A radon system may also mitigate VOC vapor intrusion at a site to a certain extent, and an evaluation can be conducted to assess how a radon system (as proposed to meet code requirements and/or already installed) impacts a VI mitigation strategy and whether it can be incorporated as a supporting component.

Methane Gas Mitigation. Methane gas is regulated as a hazardous substance in Oregon but is outside the scope of this guidance.[24] Similar VI mitigation technologies may be utilized to mitigate methane from migrating from sources and entering site structures; however, a comprehensive and conservative approach is integral given the severity of hazards posed by methane gas. In general, multiple engineering controls may be incorporated in the overall mitigation strategy and monitoring to increase the factor of safety and provide a high level of confidence. Los Angeles Department of Building and Safety (LABDS), Public Works Los Angeles County, and Orange County File Authority (OCFA) have developed methane mitigation standards and requirements to address methane gas present in these regions. Note that DEQ considers these standards as helpful resources to guide methane mitigation design; however, has not adopted these standards, and proposed mitigation strategies should be based on site-specific considerations.

[23] For example, currently according to Oregon Structural Specialty Code construction of public buildings and generally apartments, hotels, etc. (e.g., R2 and R3) require radon mitigation in Baker, Clackamas, Hood River, Multnomah, Polk, Washington, and Yamhill Counties. VI mitigation can be designed to meet the radon code, but in general radon designs that only meet the minimum radon code requirements will not be sufficient for VI mitigation.

[24] See OAR 340-122-0115(30) and OAR 340-122-0040(3). Additional rules and statutes may apply.

6.2.1 Early scoping of mitigation technologies and performance monitoring

Performance monitoring is critical in demonstrating a mitigation system is effective. A demonstration period, or performance monitoring, is required to verify that the competence of the vapor mitigation system as constructed protects human health short- and long-term. The VI mitigation technologies selected should be able to provide quantifiable evidence that the VI pathway has been sufficiently mitigated, such as acceptable indoor air concentrations, reduction in sub-slab VOC concentrations, and/or adequate sub-slab vacuum field, etc. These conditions should be maintained throughout the duration VI related risks require mitigation.

Technology reliability and ability to demonstrate effective mitigation will also drive monitoring needs. Passive systems may be protective in many situations (e.g., lower VI risk to manage). In comparison, active systems are generally more effective and predictable to mitigate VI. Anticipated mitigation performance will inform the initial scope of monitoring. Afterwards, system performance during the demonstration period (e.g., ranging from satisfactory to unsatisfactory) will inform whether additional monitoring or long-term compliance monitoring is necessary. Initial upfront investment in most cases can limit prolonged monitoring periods and potentially onerous or restrictive institutional controls.

Site-specific conditions may warrant additional monitoring including potency and stability of the VI source as well as building use and age. An important factor is the ability of a mitigation strategy to reliably perform. Systems that provide marginal to sporadic performance typically demand more monitoring (such as additional indoor air sampling) to demonstrate VI risk has been addressed and/or require long-term periodic (or compliance) monitoring to provide assurance performance metrics are met over time. If a system needs to be augmented, another performance monitoring period will also be necessary. In contrast, mitigation strategies designed to provide exceptional performance or integrate redundancy measures to increase the factor of safety typically can demonstrate effectiveness in shorter timeframes and provide greater assurance that protectiveness can be sustained over the life of the project.

In some cases, a lower threshold of performance is acceptable to address VI risk, such as when initial concentrations in the sub-slab marginally exceed RBCs. For more potent and persistent sources or site uses that dictate lower risk thresholds (e.g., residential dwelling, school, etc.), performance standards increase along with dependence on systems to provide effective mitigation long-term. A recommended framework for performance monitoring is presented in Section 6.3.

6.2.2 Prompt/Rapid response

If vapor intrusion is occurring at an occupied building, there are easily implementable measures that can be taken to rapidly reduce risk in days to weeks. If VI contaminants detected in indoor air exceed short-term risk criteria or RBCs, an immediate response is expected. Appendix A provides indoor air response action levels, including recommended timeframes when an accelerated response (within a few weeks) and urgent response (within days) is warranted. Several technologies and strategies are available to mitigate conditions that require a more immediate response, such as deployment of portable air treatment systems. These are considered interim measures until a long-term strategy is determined. Administrative measures (or institutional controls) such as risk communication and notification can also be implemented and can be as substantial as a property owner limiting, relocating, or eliminating occupant access to a building until conditions are restored to protective levels. For sites requiring immediate response actions, DEQ recommends coordinating with Oregon Health Authority in determining appropriate actions, public outreach, and communication with impacted parties (see Section 5.6: *Responses to risk*).

Common engineering controls used to immediately mitigate vapor intrusion generally target the building interior or shell and include increasing ventilation, improving building pressurization, indoor air treatment, or preventing vapor entry into the building. The following are potential options to consider. EPA guidance documents (2008, 2017, 2020) and ITRC VIM Factsheets (2020) also provide additional detail about immediate mitigation options.

6.2.2.1 Building ventilation

Increasing the exchange of indoor and outdoor air (e.g., air exchange rate or AER) in a building space will provide some improvement in air quality. Increasing building ventilation rates further dilutes the intruding vapors and provides some reduction in exposure levels, particularly smaller enclosures that may be more susceptible to vapor intrusion or occupied regularly. Short-term steps to improve ventilation can be as simple as keeping doors and windows open (when compatible with outdoor weather and human compliance) until more reliable methods are implemented. Adjustments to HVAC systems that simply increase fresh air exchange rates can dilute indoor air contaminant concentrations. However, the method of ventilation should consider potential changes that decrease building pressurization and increase the rate of vapor intrusion. It may also be cost prohibitive to maintain high ventilation rates throughout the year. In general, increasing ventilation rates can be an effective mitigation strategy for buildings with marginal and infrequent exceedances of indoor air RBCs. The benefits of increased ventilation will vary seasonally, and the performance over time is less predictable. When present, ventilation of crawlspaces is also an option.

6.2.2.2 Building pressurization

In some buildings an HVAC system can be operated to positively pressurize indoor air spaces relative to the underlying soil and sub-slab areas by maintaining an outdoor intake rate slightly greater than the exhaust rate. Positive pressurization drives indoor air out of the building, including forcing indoor air downward through floors and foundations into the underlying subgrade material or soil, thereby reversing the flow of vapor across the foundation and preventing soil vapor entry. Adjustments to an existing HVAC system can be easy and immediate to implement, minimally intrusive, and can effectively reduce or mitigate vapor intrusion.

HVAC modifications as VI mitigation measures are most applicable to commercial or industrial facilities and more likely to be effective at newer facilities. Effectiveness will also depend on building tightness and openings such as doors and windows. Regular maintenance, changing of filters on fresh air intakes, air balancing, and appropriate pressure tests and monitoring should be incorporated into the design to ensure that sufficient positive pressures are maintained (NAVFAC, 2011a, 2011b). In practice, HVAC performance can be highly variable, vulnerable to building age and uses, and is difficult to monitor. While building pressurization is not a reliable standalone mitigation technique, it has been proven useful in combination with sub-slab mitigation systems.

6.2.2.3 Indoor air treatment

Air purification units (APUs) can filter contaminants of concern. Their ability to be effective in reducing exposure will depend on several factors such as appropriate sizing or number of units (based on concentrations and room size), maintaining power, preventing human interference, and routine maintenance of filter media. APUs can be deployed quickly but are generally short-term measures. In-duct and HVAC-mounted filtration system options are also available. Air treatment devices use sorption media such as carbon and zeolite, ozone oxidation, or photocatalytic oxidation (EPA, 2008; EPA, 2017). EPA's 2017 engineering issue recommends activated carbon as a potential effective adsorption medium for air filtration to treat TCE.

6.2.2.4 Sealing preferential pathways

Inspections of a building sub-slab and foundation should be conducted to locate potential preferential pathways, such as seams or cracks in the concrete, sumps, or unsealed conduits through the building foundation. These entry points can be sealed in a relatively short timeframe and provide immediate and long-term benefits when properly maintained. These measures include sealing foundation surfaces and cracks as well as filling annular voids around utilities and conduits that enter the structure from underground. Flooring sealants, such as epoxy or elastomeric polymer floor coatings, can be applied to existing concrete building slabs. Sealants can also be applied over semi-porous flooring that has been impacted from chemical spills, for example PCE at a dry cleaning facility. As with vapor barriers, sealant product specifications should be carefully examined for the desired properties (bonding to flooring, chemical compatibility, impact resistance), and contractors should adhere to installation specifications as well as safety measures to protect building occupants during and after application.

Sealing preferential pathways can improve indoor air quality but is generally not a standalone approach to VI mitigation, as sealants can degrade over time and new openings can develop. Sealing methods can be used as a short-term mitigation measure and are often used as an enhancement to an overall mitigation approach. For instance, minimizing leakage through the foundation can also improve the performance of other mitigation methods (e.g., SSD).

6.2.3 Passive mitigation technologies and design considerations

Passive mitigation techniques are generally easier to integrate into the construction of new buildings. These include installing a low-permeable floor with a sub-slab venting layer, a vapor barrier membrane (low-permeability, chemically compatible, and well-sealed), and vertical riser pipes, which combined with weak natural forces (e.g., thermal stack effect) ventilate the buildup of sub-slab vapor contaminants. The low-permeable floor with sub-slab venting layer can also be created using aerated floor technology (when combined with well-sealed penetrations, joints, etc.). For existing buildings, passive mitigation typically includes sealing openings in the floor slab and installing vertical riser pipes to ventilate sub-slab vapor contaminants. Specialized concrete coatings to reduce the potential for diffusion of vapor contaminants through the slab are often included in passive mitigation system design (as well as active approaches). Techniques described above for new construction are used at existing buildings but typically would require removing portions of the building slab, installing the sub-slab venting features, and restoring the building sub-slab (preferably with an underlying vapor barrier).

6.2.3.1 Vapor intrusion barriers

Vapor barriers (also referred to as membranes) are generally not stand-alone controls to mitigate vapor intrusion; however, they can be highly effective when used in conjunction with compatible technologies, such as a sub-slab depressurization system. More robust vapor barrier qualities (e.g., thicker, greater tensile strength and puncture resistance, enhanced chemical and diffusion resistance to site specific contaminants, etc.) may be appropriate based on the CSM and mitigation approach (e.g., passive versus active system) to provide greater certainty that the overall mitigation approach will be effective. At sites where subsurface conditions are demonstrated to be conducive to natural venting and sub-slab vapor contaminants are low, a vapor barrier with riser pipes alone may be adequate to mitigate vapor intrusion. VI barriers are also employed as precautionary measures.

Vapor barriers can be valuable passive engineering controls when appropriately applied and properly installed. In practice, vapor barriers can be difficult to install due to the likelihood of punctures, perforations, tears, and incomplete seals. A competent QA/QC program helps ensure the integrity of the vapor barrier during installation. Weld tests and post-installation tests are examples of QA/QC testing that should be documented and included in a post-construction report.

Not all vapor barriers are equal, and the product specifications from the manufacturer should be carefully examined to ensure the barrier is sufficient for the application and compatible with the contaminants that will come into contact with the barrier (e.g., resistant to degradation and permeation). High-density polyethylene (HDPE) and low-density polyethylene (LDPE) based vapor barriers (membranes and spray-on types) have proven to be effective and are widely used, including at municipal landfills, due to their chemical resistance, low permeability, and durability. Many composite vapor barrier alternatives also integrate polyethylene as part of the composite.

Vapor barriers are commonly supplied in the form of sheeting rolls or alternatively installed using a fluid-applied process. Barrier sheets are welded or sealed together by certified professionals during installation. Fluid-applied (or spray-on) barriers are typically installed by a certified applicator, are intrinsically seamless, provide a seal around penetration and termination points, and can be mechanically bonded to the foundation slab. Figure 17 illustrates a typical 60-mil spray-on low-permeable membrane specification underlying a building slab at a building perimeter.

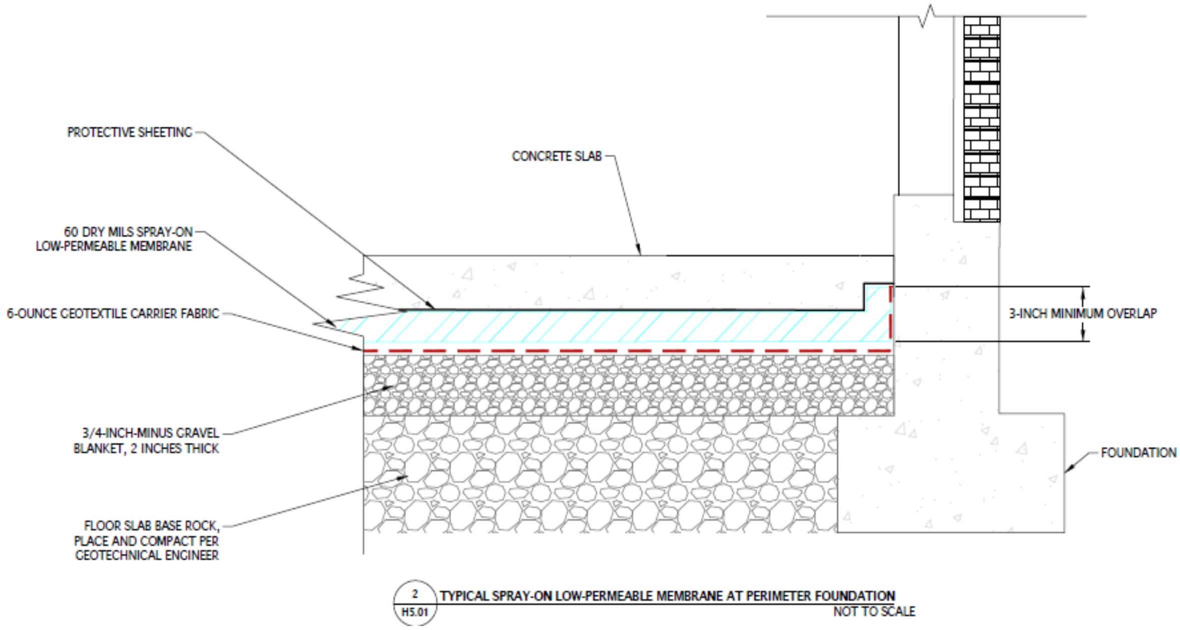


Figure 17. Example of a vapor barrier, fluid-applied (drawing by GeoDesign Inc.)

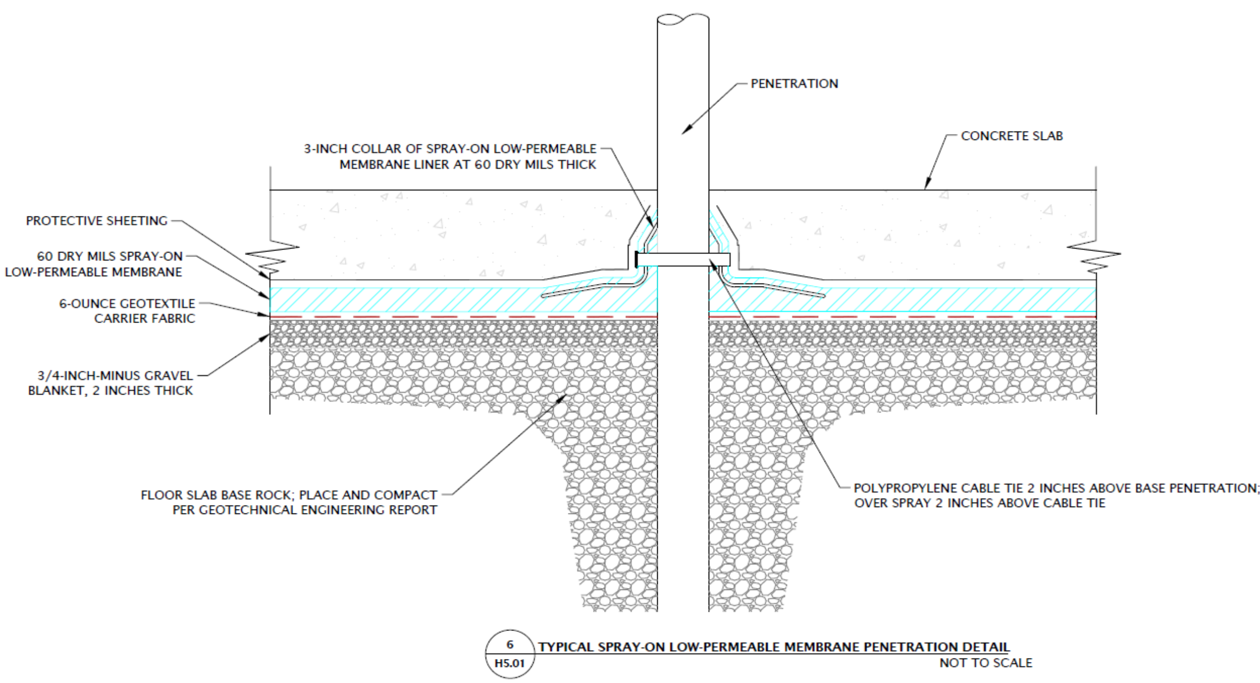


Figure 18. Example of a vapor barrier collar (drawing by GeoDesign Inc.)

Vapor barriers must also be sealed around penetrations using boots and collars or equivalent technologies and fastened to termination points (e.g., battens, etc.) using methods recommended by the membrane manufacturer and the mitigation design engineer. Figure 18 provides an example of sealing a vapor barrier around piping conveyed through a vapor barrier.

The techniques of welding vapor barrier seams are well-established, and the welded areas are subjected to industry standard tests during installation by certified welders as well as other established construction quality control standards. Accordingly, there is high confidence in welding and fluid-applied vapor barriers given the reliability in the process, embedded QA/QC protocol, and successful implementation at numerous vapor mitigation projects in Oregon. Vapor barrier options are also available where manufacturer protocol has integrated taping seams with manufacturer specified tape. Advancements in fusion/sealing methods and barrier composition continue to evolve. Verification of complete seals between barrier sheets and termination points requires thorough inspection and testing. The construction QA/QC plan should include a method for testing the competency of seams, termination, and boots. Figure 19 provides an example of overlap at membrane seams that would be sealed by the chosen method.

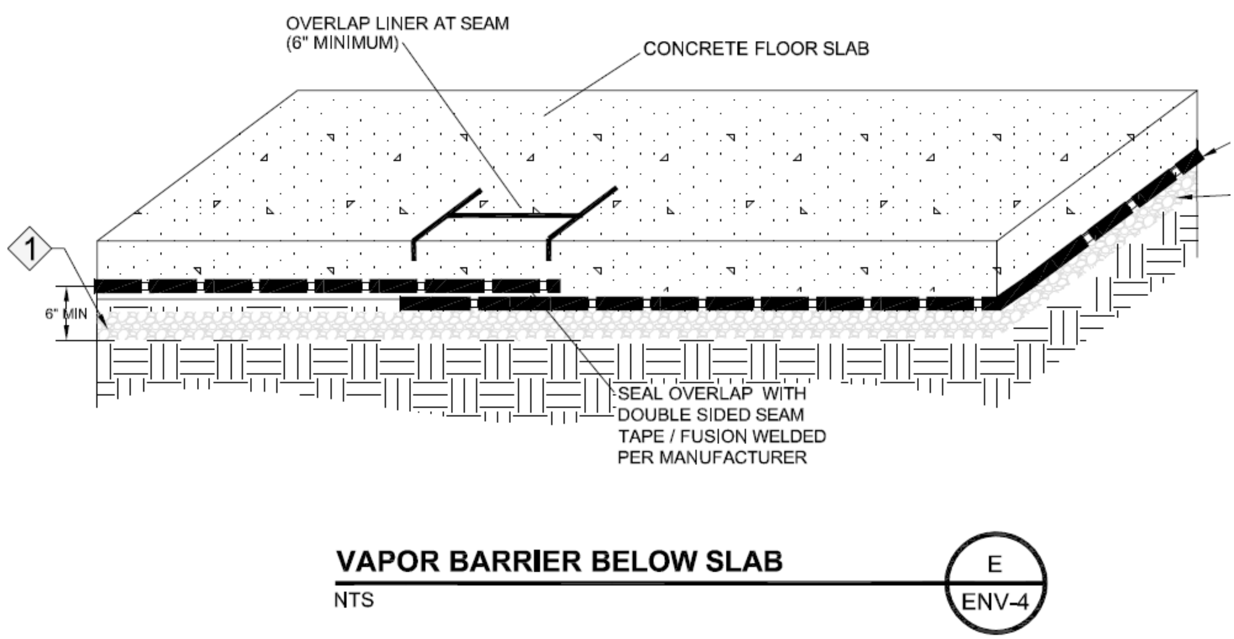


Figure 19. Example vapor barrier overlap at a seam (drawing by AMEC)

In addition to chemical resistance and impermeability, vapor barriers should be sufficiently durable to resist damage during installation and, following construction completion, resist damage due to barrier degradation, normal building stresses, and earth movement. Consistent with EPA and other guidance, DEQ recommends a minimum thickness of 30 mil for VI barriers and 40 to 60 mil is common.[25] Thinner barriers can be easily punctured, and an opening can

[25] Mil is a measurement commonly used in manufacturing and is equal to one-thousandth of an inch (or 0.0254 millimeter). Therefore, 30 mil is equivalent to 0.03 inch (0.762 millimeter).

become an opportunity for potential vapor intrusion. For these reasons, careful installation is also critical for this type of passive control, and a construction QA/QC plan should be prepared for DEQ review as part of the remedy proposal. A sub-membrane vapor collection and venting system is recommended in combination with a vapor barrier to alleviate vapor accumulation below the building.

There are several vapor barrier products available that meet the minimum chemical and physical requirements with different options that may suit site constraints better, such as constructability. For example, some vapor barriers can be installed with greater ease in an existing building versus incorporating into new construction. Access to the target mitigation area may also be a key consideration in selecting a vapor barrier technology. For example, sufficient space to weld barrier sheets versus spray-on options may drive barrier selection, or stiffness of a vapor barrier can be a hindrance for constructability in limited access areas, such as a crawlspace.

Before selecting a vapor barrier, review the manufacturer specifications and applicable testing performed that certify stated physical and chemical properties, such as from the American Society for Testing and Material (ASTM) or alternative credible independent laboratories and universities. Industry standard testing evaluates barriers for certain performance characteristics including diffusion coefficient of contaminants (e.g., PCE, TCE), permeance, contaminant exposure/degradation tests, tensile strength and elongation, seam strength, seam peel adhesion puncture and tear resistance, freeze-thaw resistant, microorganism resistant, oil resistant, effects under heat/aging, hydrostatic head resistant, water vapor permeance, thickness, density, etc. Many standards stem from experience with vapor barriers developed, installed, and tested at landfills. Vapor intrusion barriers have evolved accordingly to strike a balance between an overly or less than conservative product for VI contamination, improve constructability for new or existing buildings, cost-effectiveness, and lessons learned from inadequate barriers (e.g., thin, generic construction barriers such as for moisture protection or radon specific). Product specifications and reported testing standards should be assessed and compatible with site-specific conditions.

The following is a summary of considerations for design and installation of vapor barriers:

- Thickness of barrier (e.g., minimum of 30 mil is recommended). For spray-on barriers thickness is verified during installation.
- Vapor barrier composition meets specifications for low permeability, strength, and chemical resistance to contaminants. Note that lesser known or new vapor barrier products may require additional DEQ review to determine suitability.
- Preference for welded seams and minimum overlap of seams (e.g., 6-inches), or spray applied versions. Properly secures to walls, footing, and other foundation structures (e.g. using battens or equivalent technology). It is good practice for certified welders to conduct weld performance tests before and after welding, such as pre-weld tests and non-destructive tests. It is recommended that testing is observed and documented by the project engineer or third-party inspector.

- Installation of a vapor barrier below the entire building footprint is recommended for new structures when practicable and based on the CSM. For existing buildings, extend vapor barriers across the entire sub-slab or sub-structure of occupied spaces at risk to VI to the extent feasible.
- Install protective layers above and below vapor barriers, such as geosynthetic liner options (also referred as geonets) or appropriate alternatives.
- Limit foot traffic on the barrier during and after barrier installation. Nothing should be installed through the barrier unless properly sealed with the barrier (e.g., using barrier-material boots or equivalent technology).
- Implement a robust construction QA/AC plan that adheres to product installation specifications and design plans unless otherwise approved by the engineer-in-charge. Confirm qualifications of installation team, field testing, etc. During installation, inspect for punctures, observe testing, and confirm membrane is puncture free through testing prior to covering (pre-pour) of overlying building slab. Field tests can consist of vacuum tests (e.g., vacuum box), air pressure, tracer or smoke tests, or other applicable methods.
- Incorporate sub-membrane vapor collection network and venting via vent riser(s) to minimize vapor accumulation below the vapor barrier.
- Consider and incorporate building use into mitigation design. For instance, for spaces that may be subject to tenant remodels, DEQ recommends integrating design consideration that can limit future modifications to VI mitigation components including cuts/repairs. For example, the design could incorporate placement of the vapor barrier below utilities to allow for future utility modifications without penetrating the liner. Note that modifications to mitigation systems, including barriers, typically require advance DEQ notification and approval and documentation of repairs.

6.2.3.2 Passive sub-slab venting

Passive venting relies on wind effects, thermal effects, and pressure differentials to induce the movement of vapors up through sub-slab vents to the atmosphere. Typically, air inlets are incorporated to allow for “make up” air to enter the sub-slab to facilitate dilution of contaminant concentrations. Measurable or consistent differential pressures are not typically observed in passive venting systems. Accordingly, these techniques are more suitable for scenarios with low VOC concentrations and when conditions are conducive to sub-slab venting. Performance monitoring would need to adequately demonstrate consistent reduction of sub-slab vapor (and indoor air) contaminant concentrations below RBCs.

This technology is typically used in conjunction with a vapor barrier which can improve performance of the venting system, integrates design redundancy, and increases reliability of VI mitigation. The venting design varies but commonly a vapor collection piping system consists of a perforated pipe or low-profile vent. Further design considerations for a sub-slab vapor collection network, vapor discharge, and performance monitoring locations are presented in the following sections. The venting design should ensure the system can be converted to an "active" system using a fan or blower.

Aerated Floors. Aerated floors are less commonly used in Oregon and, if used independently (along with riser pipes), can be considered a passive venting technology. When incorporated into an active depressurization system, aerated floors are a means to provide depressurization or ventilation below the building slab. Aerated floor design varies but the intention is to provide a continuous void space under the building slab and can be used in place of a sand or gravel layer below the sub-slab. For aerated floor system design, potential leakage points in the building slab (e.g., penetrations, joints, slab-footing joints) should be sealed. Refer to sealing options in Section 6.2.2.4: *Sealing preferential pathways* and Section 6.2.3.1: *Vapor intrusion barriers*.

6.2.3.3 Building design

Building design in some cases can disrupt the VI pathway or complement VI mitigation systems. Examples include the presence of a vented parking structure below occupied spaces, raised foundations, or vented crawlspaces. Venting may occur naturally or can be enhanced using fans. Preferential pathway prevention can be incorporated into new building design, for example sealing around conduits and limiting entry points through the sub-slab or basement.

Intentional design can also address different levels of risk (low, medium, high), particularly for multi-use properties. For example, green space or parking could be placed over higher risk areas, while a building would be placed over lower risk areas. Lower floor levels (e.g., ground or subgrade) could also be reserved for commercial use or parking garage. In urban areas, new buildings often integrate commercial space, storage, or common areas on the ground floor. This may also be a suitable mitigation strategy when residential exposure is a potential concern, but commercial or limited duration exposure is acceptable. It is also recommended to check existing city and state building codes related to the mitigation of radon or carbon monoxide and whether there are opportunities to utilize or augment mitigation infrastructure required by building code.

Revitalization of urban commercial-industrial areas can also coincide with changes in zoning that allows for expanded uses. For new construction, it is easier and beneficial to integrate building design features that anticipate a combination of uses, including residential, and enhance the protection for building occupants, including from VI. More challenging opportunities are available for existing buildings to lessen vulnerability to vapor intrusion through intentional design improvements. For new construction, forward-thinking building design can also reduce the potential need to alter or repair passive or active mitigation systems in the future and reduce related monitoring, documentation, and reporting. For instance, commercial retail spaces can be subject to frequent tenant remodels, and limiting utilities through or adjacent to mitigation controls, such as vapor barriers, can reduce future disruption to VI controls.

6.2.4 Active mitigation technologies and design considerations

Active depressurization technologies, or "active" mitigation, include sub-slab depressurization (SSD), sub-slab ventilation (SSV), and crawl space ventilation (CSV). A description of each of these is provided in ITRC VIM Factsheets. Sub-slab depressurization is one of the most common mitigation strategies discussed in greater detail below. Depressurization systems do not treat contamination and instead rely on pressure gradients to keep the vapors from reaching receptors.

Active depressurization systems use a blower or fan to draw air from beneath the building through a vapor collection network, such as a network of pipes or similar technology, to induce a negative pressure or vacuum below the slab (i.e., sub-slab air pressure is less than indoor air pressure). This causes indoor air to be drawn into the sub-slab through openings in the foundation, reversing the typical flow of gases and preventing vapor from entering the building. Captured vapor is vented to the building exterior away from indoor air intake locations such as windows and HVAC intakes. Effluent vapors from mitigation systems may need to be treated prior to being discharged to the atmosphere. Appendix E provides guidance on completing an implementation risk evaluation to determine whether vapor discharge management is necessary.

Predesign tests are used to evaluate the efficacy of mitigation technologies and to inform the system design, including distance between vapor collection pipes (or trenches), number of suction points, and potential fan/blower size needed to achieve design objectives. Communication testing (or pressure field extension testing) evaluates whether vapor can be drawn from across the building sub-slab and estimates the extent of the negative pressure field generated from suction (i.e., extraction) points. These sub-slab diagnostic tests generally consist of applying a range of vacuum levels using a fan/blower and collecting the pressure differential (e.g., using a manometer) at sub-slab monitoring locations, offset radially and with distance (e.g., 5, 10, 15, 20, 25 feet) from the extraction point. Diagnostic tests can assess vacuum propagation to inform mitigation design. Collecting pre-mitigation "baseline" conditions (e.g., differential pressure measurements) is recommended in addition to predesign diagnostic tests. It is important to record barometric pressure and other conditions that may influence test results including building ventilation.

6.2.4.1 Sub-slab depressurization

Sub-slab depressurization is the most common active vapor mitigation technology for new buildings and is typically used in combination with a vapor barrier. When coupled, these mitigation controls complement each other: Vapor barriers improve SSD performance by preventing leakage through the building slab via cracks and openings, while the vapor collection network provides a mechanism to vent vapor that would otherwise accumulate below the vapor barrier. For SSD systems installed in existing buildings, incorporating a sub-slab vapor collection network and/or vapor barrier may not be practicable. Building design and HVAC systems can also improve or augment SSD performance. The main elements of SSD systems are discussed below and include the vapor collection network, vacuum design, fan or blower selection, above slab conveyance piping, vapor emissions assessment and treatment options, and selecting performance monitoring locations.

6.2.4.1.1 Vapor collection network

Sub-slab vapor collection networks are incorporated into many passive and active mitigation systems, and in general designs are comparable between depressurization systems or passive sub-slab venting. It is easier to install a permeable base layer to promote vapor transport beneath a structure during construction of a new building compared to an existing building. Many options are available, and typical designs include vented or perforated horizontal pipes embedded in a permeable base layer beneath the building. A permeable medium, such as clean ¾-inch gravel, is placed around and between the vent pipe network to promote movement of vapor. In some cases, a permeable base layer (e.g., gravel) and vapor barrier membrane alone may be sufficient if the building foundation provides for unobstructed air flow. The design will need to consider compatibility with underlying subgrade conditions. The vapor collection network is routed to a riser pipe where suction is applied. Sections of piping are typically joined at a manifold.

Vapor mats (or venting mats) are alternative vent pipe technologies that consist of a geotextile mat with channels allowing for airflow and compressive strength to keep the air channels intact. Figure 20 illustrates an example. The mats are typically supplied in rolls and installed across the subsurface prior to pouring the building slab.

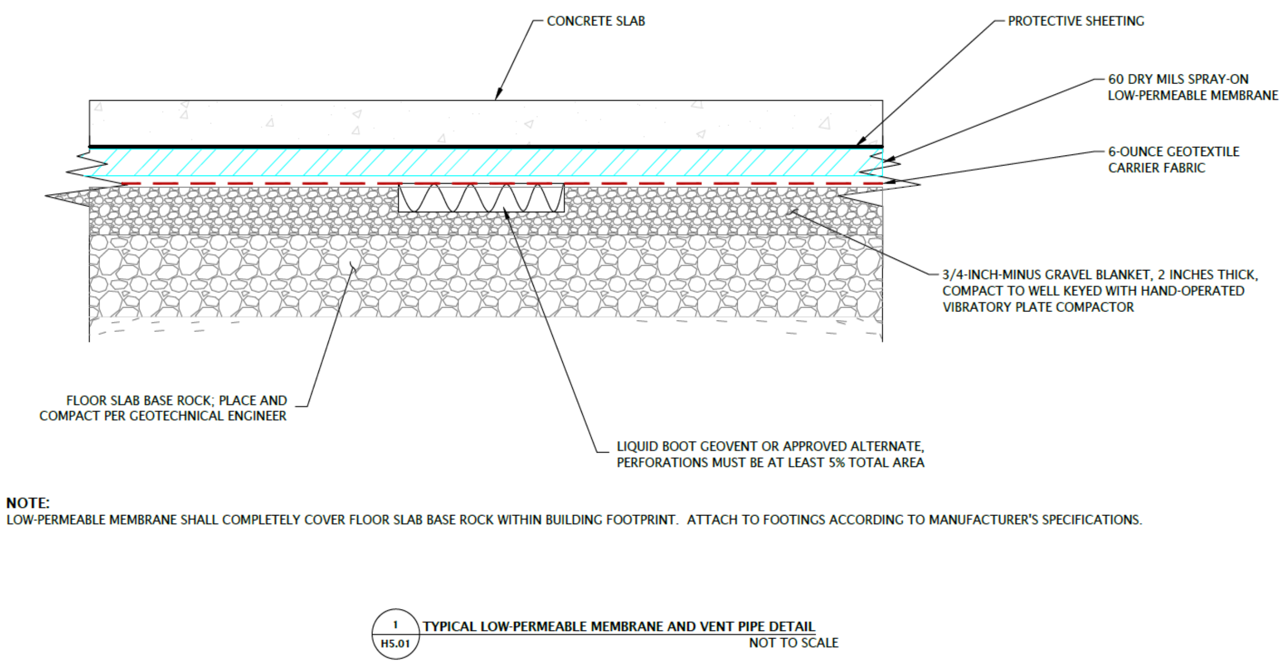


Figure 20. Example of low-permeable vapor barrier and vent pipe (drawing by GeoDesign Inc.)

The perforated pipe system (or similar venting system technology) should provide adequate coverage of the contaminated area and piping spaced sufficiently from each other to maintain negative pressure throughout the building sub-slab area requiring mitigation. The piping network should be configured to evenly distribute vacuum throughout the network and minimize short-circuiting portions within the system. Piping is sized based on square footage (or linear feet) of pipe and required (or estimated) airflow. Pipe spacing should be designed to be close enough to create overlapping zones of influence and configured to minimize "dead" (no-influence) zones. In addition, preferential pathways such as other building pipes, drains, and utility trenches should be mapped relative to the vapor collection piping because they can also short-circuit airflow and reduce the zone of influence of the system. The vapor collection network should also be designed and sized to anticipate operation in active and passive modes.[26] Figure 21 provides an example of a piping network design and monitoring locations.

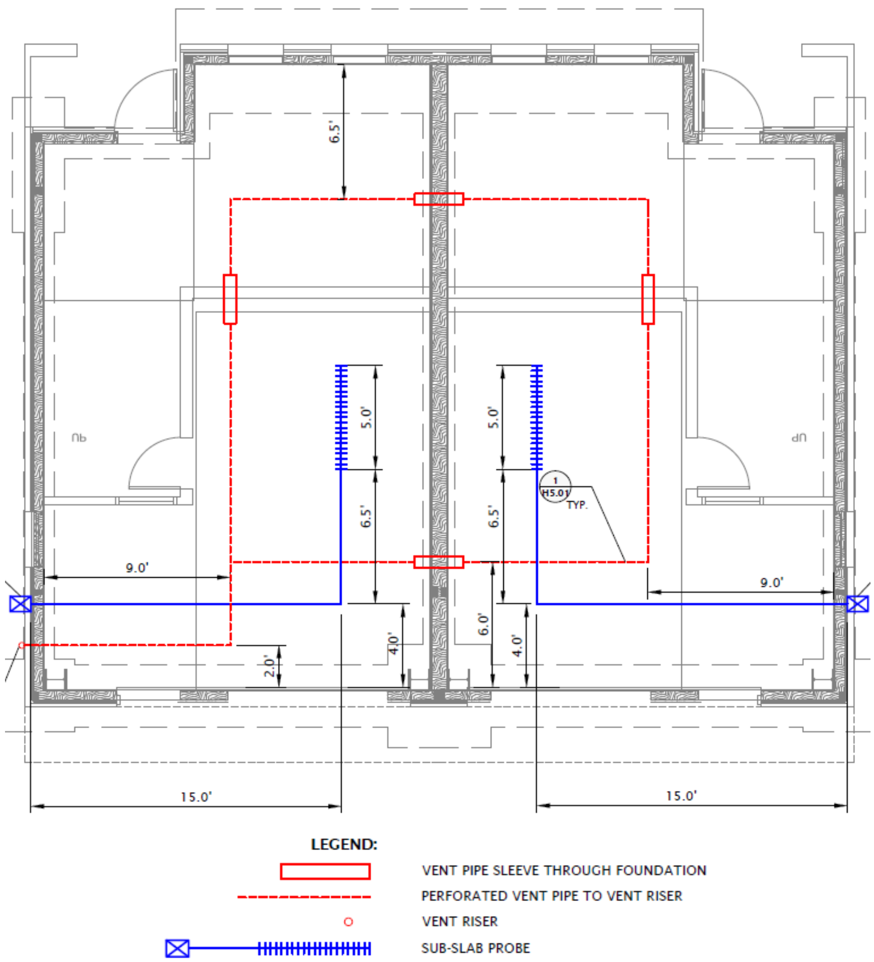


Figure 21. Example design of vapor collection network and monitoring Locations (drawing by GeoDesign Inc.)

[26] In passive mode, this application is considered a sub-slab venting system, which relies on temperature and pressure differences between the building and atmosphere to induce vapor movement.

6.2.4.1.2 Vacuum design

Active depressurization systems are designed to reduce the air pressure beneath the foundation slab relative to interior spaces. An essential design objective of a depressurization system is to achieve a sufficient vapor extraction flowrate and pressure differential (i.e., vacuum) below the sub-slab such that soil vapor is mitigated prior to entry into the indoor air. Vacuum will be greater near the extraction components of the system (e.g., vapor collection network or vapor pit) and decline with distance to a boundary where vapor is no longer captured. This perimeter is not fixed and is an estimate of the zone or radius of influence (ZOI or ROI). EPA recommends a minimum vacuum of 4 to 10 pascal (EPA, 2008) and this range accounts for seasonal variabilities. Some US States identify generic values as guidelines, ranging between a minimum of 1 to 6 pascal (ITRC, 2020). There are several types of devices to measure differential pressure that are accurate to 1 pascal or less, such as a digital micromanometer.

In practice, a range of vacuum measurements from 0.01 inches of water (2.4 Pascal) and greater is recommended to estimate the system ZOI. For example, an estimated ZOI may be calculated as the distance to the edge or peripheral of the system influence where vacuum is measured at 0.02 inches of water. The estimated ZOI will expand and contract temporally, such as with seasonal and atmospheric barometric changes, as well as site-specific conditions. For example, heating during the winter months can reduce the indoor air pressure and increase vapor intrusion. For additional information, refer to Section 4.6.3: *Temporal variability in vapor intrusion*.

For depressurization systems, vacuum should be achieved across the sub-slab area posing VI risk including in the weakest areas in the mitigation system, such as sub-slab features preventing vacuum propagation. The minimum vacuum of a system is not measured in proximity to extraction/venting features or near the building exterior (preferable distance greater than 5 feet if possible). Sub-slab depressurization will need to overcome the pressure gradient between the building and the sub-slab considering the range in differential pressure due to weather and building ventilation conditions. For instance, adequate vacuum across the building slab (or crawlspace) should reliably minimize reversal periods in pressure gradients between the sub-slab indoor air that would allow for VI (i.e., sub-slab pressure greater than indoor air).

Vacuum design should account for anticipated reasonable maximum conditions (typically January in Oregon), provide an overlap of ZOI when there is more than one extraction location, extend coverage of the vapor plume requiring mitigation, and integrate a factor of safety to offset uncertainties. While the estimated ZOI may not provide information to overcome higher strength vapor sources, diagnostic testing and ZOI-based designs are used in practice, and adequate depressurization of a mitigation system is verified through performance monitoring. A conservative design approach is recommended, particularly for elevated levels of sub-slab vapors and in absence of good characterization of the nature and extent of subsurface and contributing sources. Following construction completion, performance monitoring will need to verify whether adequate vacuum is consistently achieved. For instance, strong lines of evidence to demonstrate reliable mitigation include:1) maintaining sufficient pressure differential over the area requiring mitigation, and 2) reduction of sub-slab vapor concentrations (e.g., below RBCs).

6.2.4.1.3 Fan or blower design

Negative pressure (vacuum) is applied to active mitigation systems using a fan or blower. Sizing the fan/blower will need to account for sub-slab permeability, vacuum design objectives, area/volume requiring mitigation, piping network flow capacity (diameter and pipe length), pipe flow losses, building type and size, construction quality, and other factors. Building slab leakage and vapor barrier sealing quality will also affect blower performance to deliver the predicted vacuum field. In general, vapor network system design and negative pressure applied by fan(s)/blower(s) and corresponding flowrate should be adequate to sustain sufficient vacuum below the building slab or crawlspace. When applicable, pipe flow calculations including fan/blower performance curves (example shown in Figure 22) should be provided with design plans as supporting documentation for blower selection.

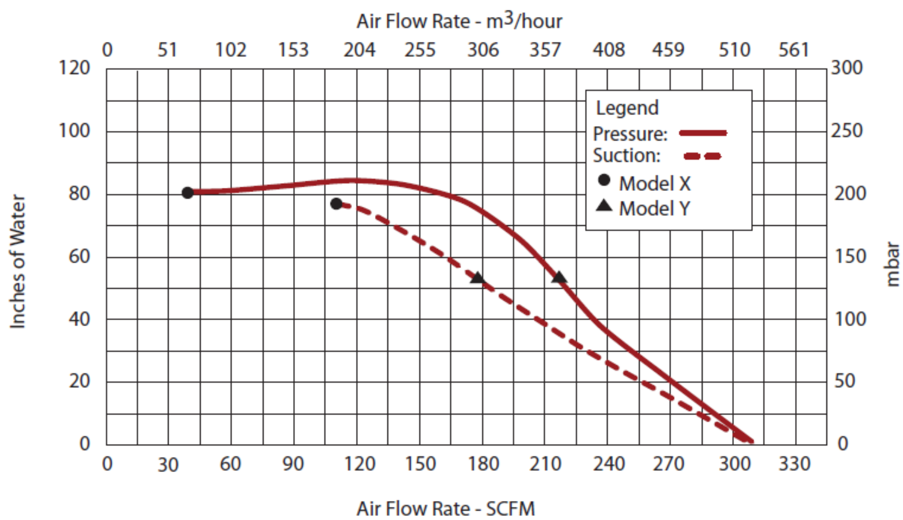


Figure 22. Example performance curve

Selection of a fan or blower will be driven by project scale and power requirements to achieve performance objectives. Off the shelf fans or radon fans are electrical devices that can provide low to moderate airflow and may be sufficient for smaller-scale mitigation systems and lower VOC concentrations. Blowers supply greater horsepower which is typically required to reliably sustain vacuum for a larger active mitigation system. Blowers also consume more energy, may require more maintenance, and are more expensive to repair and replace. Radon fans on the other hand are readily available, less powerful, less expensive, and require less energy. Generally, fan size is dictated by the mitigation approach (e.g., SSD or SSV), sub-slab permeability, slab leakage, and number/scope of extraction features connected to a fan. In some cases, multiple radon type fans may be used instead of a blower to mitigate a larger area when supported by mitigation design plans, including calculations, and verified through performance monitoring. A fan is typically adequate for a house or smaller building depending on the potency of the vapor source.

Fans and/or blowers should be located outside, mounted on the exterior of the building, or in an unoccupiable space that does not have an occupiable space above. Piping on the pressure side of the fan should not be routed through occupiable space.

Mitigation systems require an O&M plan, and the detail and scope will depend on the scale and complexity of the mitigation system and related operational parameters including the fan/blower type.

6.2.4.1.4 Vapor discharge design

Vapor collected by mitigation systems, including SSD and SSV, should be routed to the building exterior via solid vent pipe risers above the roof or alternative approved location. Figure 23 provides an example drawing of a vent riser. Vented pipe through building walls should be adequately protected and well-marked to prevent damage or punctures during future remodeling activities. Vent discharge locations at the roof or elsewhere should be conservatively distanced away from any building openings (windows) and HVAC in-take (greater than 10 feet). *Never vent collected vapor into a building space.*

Vapor effluent from mitigation systems contains hazardous substances, and emissions can potentially result in unacceptable health risks to people living or working in the area. Therefore, implementation risks must be evaluated prior to system startup to determine whether vapor treatment is necessary. Assessment of vapor discharge includes air dispersion modeling concepts and is covered in greater detail in Appendix E.

If necessary, emissions from mitigation systems can be treated using granular activated carbon (GAC) or other appropriate technology. Technologies

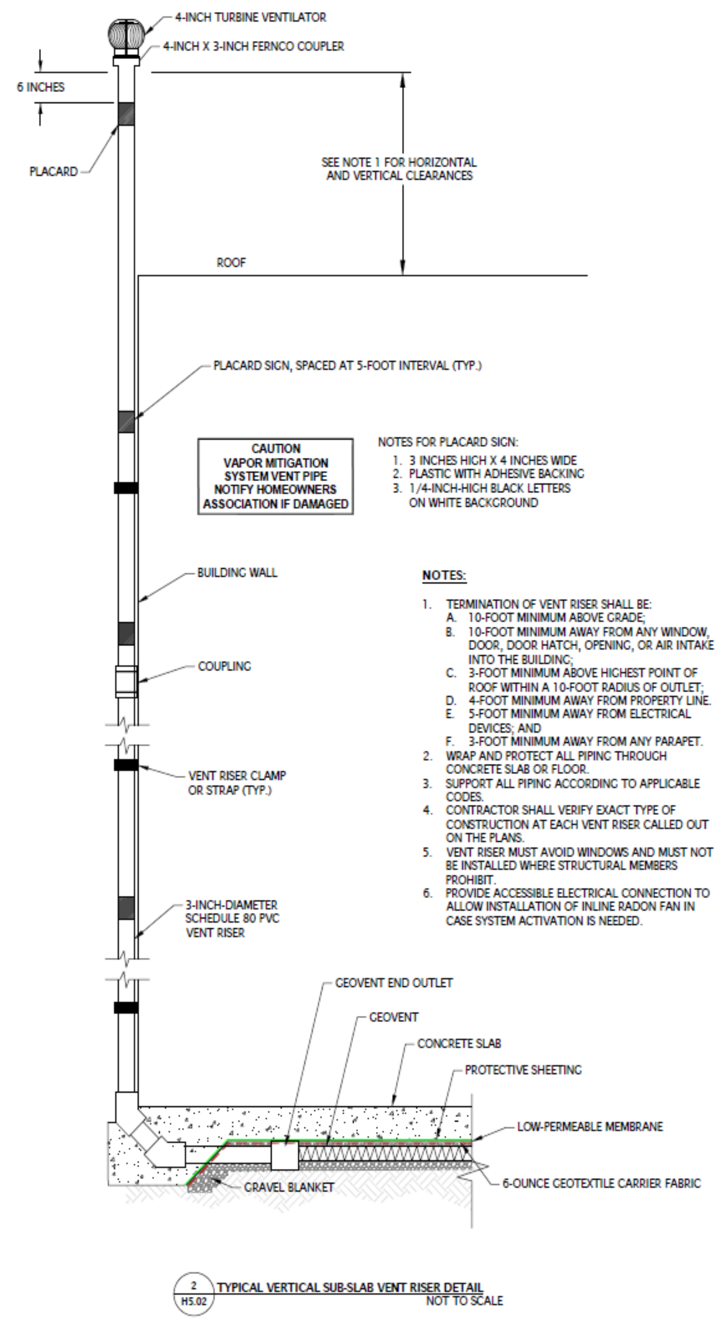


Figure 23. Example vent riser (drawing by GeoDesign)

for larger systems may include thermo-oxidation or catalytic oxidation. Figure 24 illustrates an example of an air discharge treatment process.

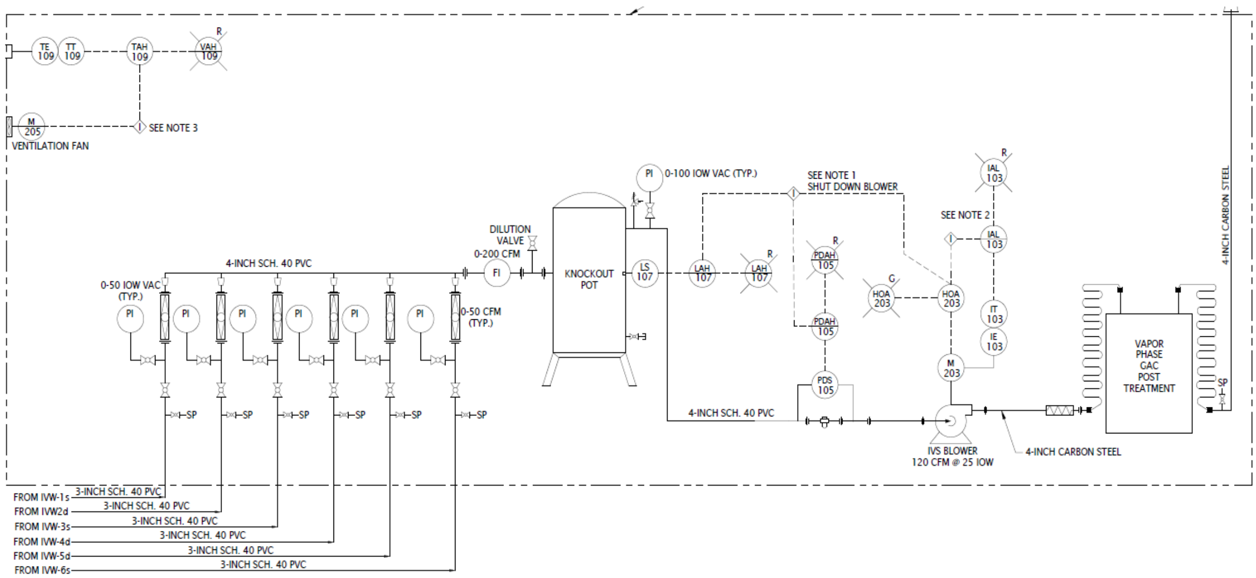


Figure 24. Example air discharge treatment for a larger mitigation system (drawing by GeoDesign)

Maintaining and monitoring for breakthrough of the air treatment system is integrated into the O&M plan. Larger mitigation systems or remediation systems (e.g., SVE) may require periodic replacement of treatment media. Time periods of higher mass loading on the air treatment technology should be closely monitored, such as after startup and initial phases of the project. Accordingly, monitoring (and potential change out of treatment media and proper disposal) is initially regular in nature and may decrease throughout the project.

6.2.4.2 Vapor collection pits

It is not always practical to install a vapor collection network across a large area in an existing building. SSD options for retrofits of existing building may consist of sub-slab sumps, trenches, or perforated pipe placed within trenches as suction features connected to a fan. These technologies depend on existing subgrade permeability properties beyond the suction features to reduce sub-slab vapors. Pre-installation diagnostic testing is necessary to evaluate the suitability of these mitigation strategies to understand sub-slab permeability, slab leakage, and other features affecting flow and/or vacuum propagation (e.g., grade beams, utility conduits, high transmissivity trenches).

In general, sub-slab suction pits or sump collection points (such as vertical pipe, pit, or cavity) are installed into the base layer (e.g., 12 inches deep) beneath the slab, and a vacuum is applied. For multiple points, the suction points are manifolded to a fan and a conduit for vapor to evacuate to the outdoor air away from the building openings. Designs will vary depending on the granular material beneath the slab and competence of the flooring/slab of the building (e.g., leakage via cracks and openings). If the base layer is permeable, such as crushed gravel, fewer suction pits may be necessary to be effective. In comparison, buildings constructed directly on native soil typically require more suction points to develop a vacuum below the sub-slab. This strategy may not be suitable for low-permeable native soils, such as clayey soil, without the assistance of a granular base layer. In cases where low-permeability soils are directly below the slab, consider additional sub-slab collection pits, adding an engineered granular base layer and/or other mechanisms that will most effectively mitigate the building. These systems should also have pre-installed permanent monitoring points for monitoring performance of the mitigation system (e.g., vacuum across the building sub-slab, demonstrating reduction in sub-slab concentrations, etc.), but temporary points are acceptable.

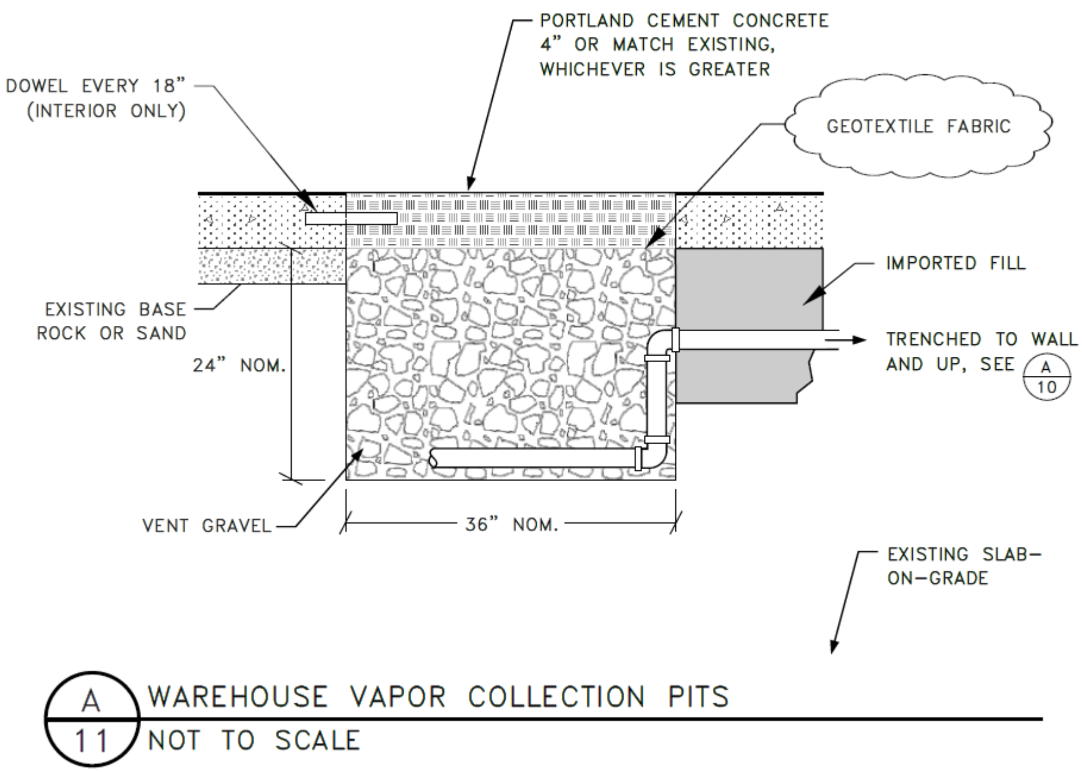


Figure 25. Example vapor pit detail (drawing by Apex Companies, LLC)

6.2.4.3 Sub-slab ventilation

Sub-slab ventilation (SSV) may be an option in cases where sub-slab concentrations are low, subgrade is highly permeable, and reduction of sub-slab vapor concentration to below levels of concern are achievable. Elements of SSV are analogous to SSD, including a fan or blower connected to an engineered venting system; however, the performance metrics do not require sustaining vacuum to achieve VI mitigation. Note that measurable sub-slab vacuum may be achieved. For SSV, the design objective is to reduce sub-slab concentrations enough by providing air flow and diluting the sub-slab concentration and consequently maintain acceptable indoor air concentrations.

This approach takes into consideration that discernible flow can be achieved at vacuum levels that may be too low to measure when building subgrade is highly permeable. Correspondingly, this mitigation strategy is most often used at sites with relatively low sub-slab contaminant concentrations where occasional reversal of the cross-slab pressure gradient will not result in unacceptable vapor transport into an occupied building.

Crawlspace ventilation. Crawlspace ventilation uses a fan to dilute concentrations in a crawlspace, generally in residential homes with access limitations. This technology is considered active mitigation but is typically not a practicable or suitable technology to depressurize the crawlspace. Heating and cooling effects must also be considered for the building. Installation of a low-permeable membrane will improve performance.

6.2.5 Performance monitoring design

System design plans and drawings should identify sampling locations and methods for post-construction performance monitoring. This is typically also provided in detail in the system O&M plan and locations mapped in monitoring plan(s). Sub-slab monitoring locations should be included at remote distances from the extraction system piping network (or suction features) and exterior walls (greater than 5 feet if possible) to evaluate spatial variability of system performance including the weakest anticipated performance areas of the mitigation system. An example of monitoring locations is provided in Figure 21.

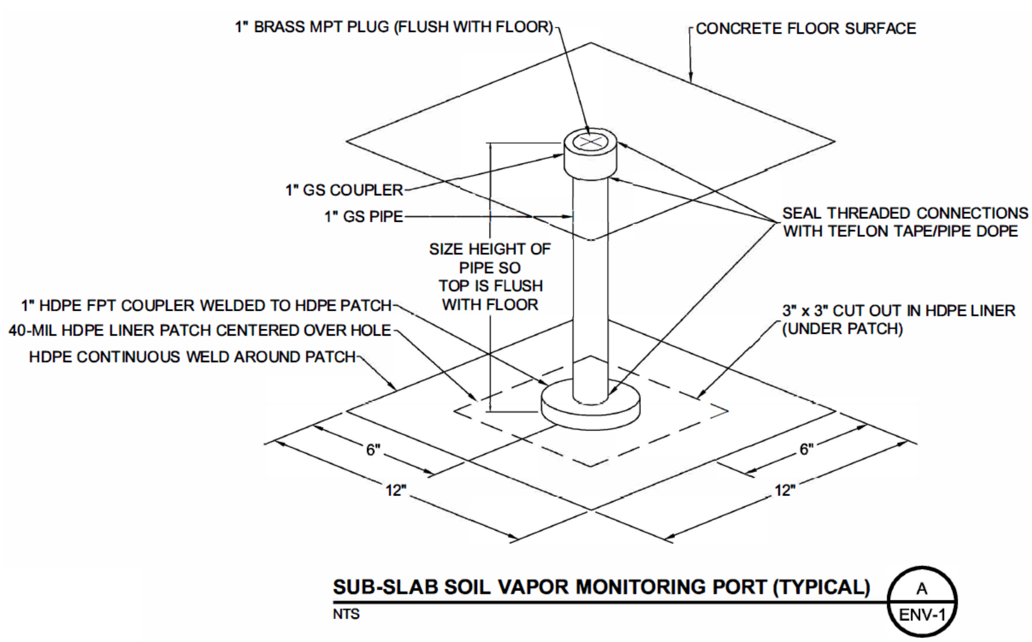


Figure 26. Example of a monitoring port and sealing considerations (drawing by AMEC)

Preparing or outlining a performance monitoring plan early on will help distinguish monitoring data needed to demonstrate mitigation success. As noted earlier in Section 6.2.1: *Early scoping of mitigation technologies and performance monitoring*, the mitigation system reliability and ability to demonstrate effective mitigation will also drive monitoring needs. The appropriate number of monitoring locations and design should be identified with mitigation design plans including drawings and specifications. Integrating sampling locations beneath buildings (i.e., sub-slab or deeper probes) in the mitigation design and construction phases will minimize disturbance to the foundation or subgrade materials after construction. For new construction, sampling design can also incorporate connections to exterior building ports which may be preferred by some building owners to limit disruption to building occupants.

Sub-slab monitoring points typically consist of a probe or pin drilled/pushed through the building slab and sealed for permanent sampling locations to prevent VI. Figure 26 is an example of sampling port (underlying probe not shown) and sealing mechanisms with the building slab and underlying vapor barrier. Sub-slab monitoring methods can also consist of horizontal perforated pipe to collect a wider area of soil vapor compared to a single point. Figure 27 illustrates this monitoring design approach plumbed to exterior sampling ports. Details for different types of monitoring (probes, pins, wells) will be a part of the overall system design package.

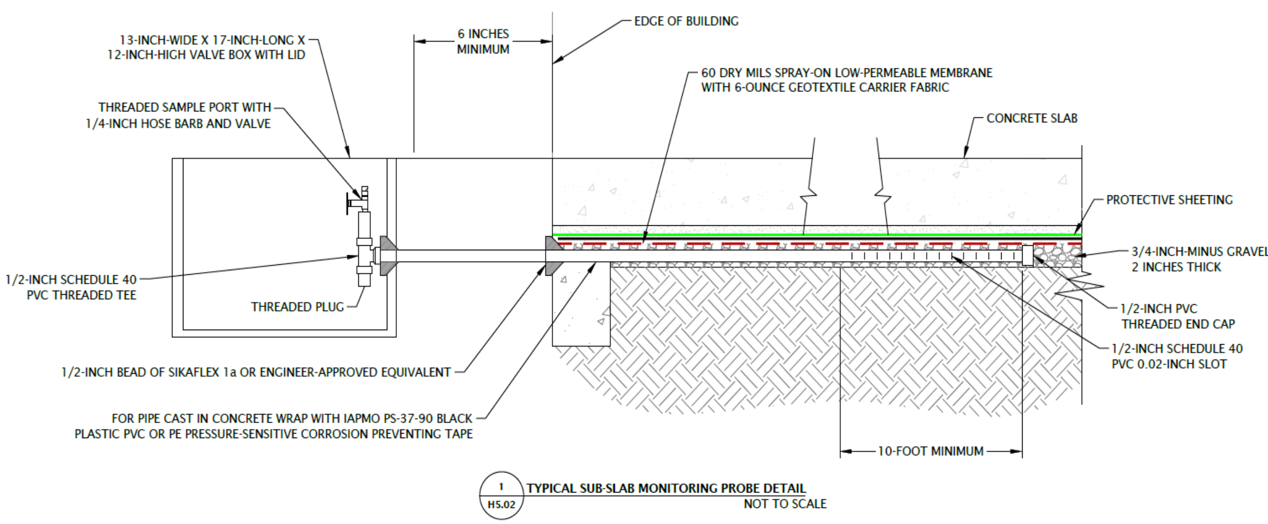


Figure 27. Example sub-slab monitoring probe design (Drawing by GeoDesign Inc.)

6.3 Performance monitoring of vapor intrusion mitigation systems

Monitoring is required following installation of a VI mitigation system to assess performance and verify conditions are protective for building occupants. While performance monitoring is integral to assess the progress of source remediation, the following discussion generally applies to demonstrating adequate VI mitigation at buildings.

There are two main phases of monitoring: 1) a performance assessment period immediately following construction to demonstrate the remedial system is effective and to establish long-term operational parameters that assure the system adequately and consistently mitigates VI; and 2) a subsequent compliance phase to confirm mitigation continues to achieve performance standards when contamination remains in-place at levels of concern. Compliance monitoring may be an extension of the performance monitoring stage or continue as long-term obligations required as part of project closure.

The performance objectives of the mitigation or remedial system should be defined during the remedy selection process to support remedial design. The performance monitoring plan is developed in advance and should define clear, measurable, and obtainable data quality objectives such as the reduction of vapor contaminant concentrations in sub-slab and indoor air and/or measurable sub-slab vacuum influence at monitoring locations. In this way, metrics to measure performance can be selected and implemented in the performance monitoring schedule. The identification of clear objectives ensures that all parties involved understand and agree on the purpose of the project, increasing the likelihood that a verifiably effective system is installed and operated.

The primary lines of evidence to evaluate mitigation system performance are the following:

- **Indoor air sampling and crawlspace sampling results**
  The results of indoor air and crawlspace sampling provide the most direct and accurate measure of system effectiveness; however, the data only represents relatively short, discrete periods of time. In addition, indoor air is highly variable temporally and spatially due to daily and seasonal variations and the habits of building occupants. Consequently, there are greater challenges in obtaining a defensible indoor air dataset (see Section 4.6.3 regarding temporal variability). Accordingly, additional lines of evidence are valuable to evaluate if VI is sufficiently mitigated. If indoor air data cannot be collected, sub-slab vapor becomes the default for evaluating there is no indoor air exposure.

- **Soil vapor concentrations**
  Another indirect measure of mitigation system performance is the extent to which it reduces contaminant concentrations in sub-slab soil vapor. Reduction to levels below soil vapor RBCs is a strong line of evidence.

- **Cross-slab differential pressure measurements**

  An indirect but important measure of performance is the cross-slab differential pressure measurements. From these data, the direction of vapor transport across the slab can be inferred and whether vapor intrusion is occurring or not. The data can be collected continuously at minimal cost while providing a continuous record of system performance.

These lines of evidence are used to assess the effectiveness and reliability of the mitigation system and to inform a long-term risk management strategy if needed. Monitoring is also used to identify the "new normal" VI conditions (i.e., the extent and magnitude of the subsurface vapor after conditions have re-equilibrated) following implementation of a remedial action and/or operation of a mitigation system. When developing a monitoring schedule, the project will need to anticipate potential rebound of concentrations (e.g., after a soil removal action or shutdown of a SVE system). More detailed information is provided in Section 6.3.3: *Assessment of Rebound*. Deeper vadose zone or groundwater sources may also lengthen the duration for the subsurface to equilibrate.

A competent understanding of the VI CSM is valuable to inform the mitigation and performance monitoring strategy and when interpreting data results. Development of a monitoring program for a mitigation system should be based on site-specific conditions and the mitigation approach to address vapor intrusion risk, current and long-term. Important considerations in developing a monitoring strategy and schedule include but are not limited to:

- The scale and extent of VI risk being mitigated under typical conditions including magnitude of source, stability, soil vapor concentrations, type of contamination and location of source(s) left unremediated. Chlorinated VOCs are generally more persistent in the environment than petroleum contamination.
- Building design, age, and condition.
- Current and anticipated building uses.
- Coordination with source remediation activities and/or accounting for other remedial actions in the vicinity, or changes in subsurface conditions including ongoing migration (e.g., groundwater plume).
- Allowing time for subsurface conditions to re-equilibrate following substantial changes to a property such as a significant removal action or a new development covering a previously permeable site.
- Seasonal conditions that are the most challenging to mitigate and represent reasonable maximum estimates of contaminant exposure from VI (e.g., when buildings are experiencing stack effects or the water table reaches its annual high).

Typically, a minimum of four quarters of performance monitoring after subsurface conditions have stabilized is needed to demonstrate the system is performing adequately. Monitoring is initially more frequent until subsurface conditions stabilize and effectiveness of the selected remedial strategy is demonstrated. Several variables may lengthen or shorten the monitoring period, including:

- Extent, magnitude, and persistence of contaminant source
- Building vulnerability to VI
- Subsurface re-equilibration
- Mitigation strategy and performance monitoring results

This guidance emphasizes that mitigation performance reliability is an important criterion to demonstrate VI risks have been adequately addressed at a site. Greater confidence in mitigation performance is warranted when there are increased VI risks to manage (e.g., elevated concentrations are present below an occupied building) and when dependable mitigation is required over long periods of time.

A comprehensive mitigation approach increases the likelihood of achieving DQOs during performance monitoring and often results in reduced compliance monitoring obligations. In contrast, mitigation systems that provide marginal to sporadic performance can result in extended monitoring periods and long-term compliance monitoring to compensate for less dependable mitigation performance.

Figure 28 illustrates several site-specific factors that can impact the scope of required monitoring (before, during, and after performance monitoring) and institutional controls (for long-term risk management). Monitoring needs generally increase for conditions presented on the right and potentially decrease for conditions identified on the left.

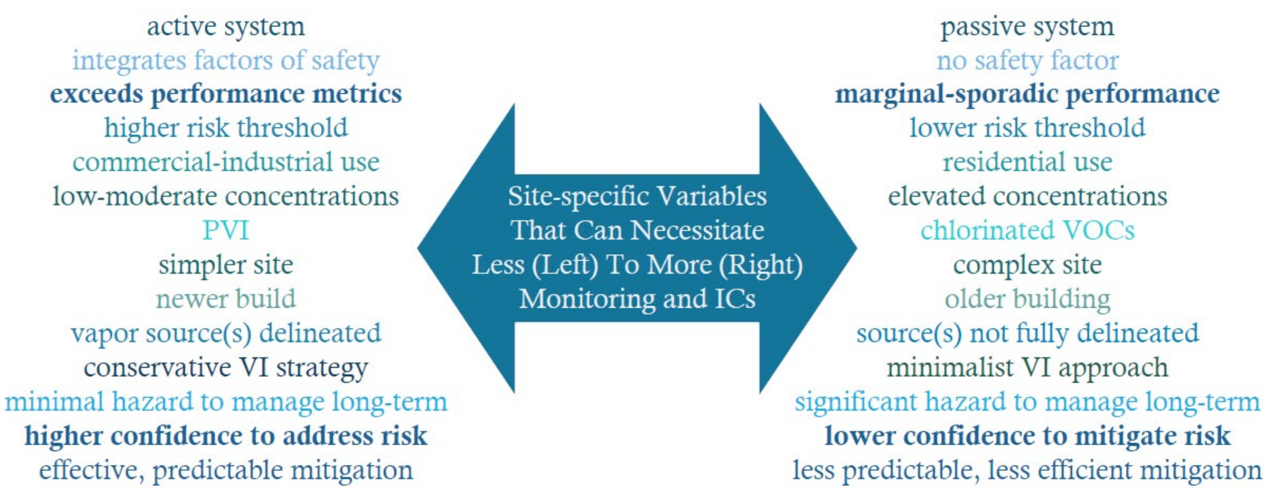


Figure 28. Site-specific factors that can impact scope of monitoring and ICs

VI remedial strategies that are more robust typically will demonstrate successful performance more readily and in a shorter timeframe than a less conservative approach. When sampling indicates VI contaminants continue to exceed indoor air RBCs, the mitigation approach will need to be augmented, and additional source removal or treatment may be needed. The following section describes a monitoring framework using LOEs to demonstrate project completion.

6.3.1 Performance sampling approach

Performance monitoring is typically a combination of indoor air and sub-slab vapor sampling along with differential pressure measurements. DEQ recommends collecting multiple lines of evidence to demonstrate the VI pathway has been reliably disrupted for the duration that mitigation is necessary. It is also necessary to tailor the performance sampling strategy to account for site-specific conditions and to reflect the VI CSM. Additional sampling approaches such as tracking a deeper source with soil vapor monitoring wells may also be necessary. An example of an additional LOE that may benefit a project is a mass flux evaluation conducted by monitoring extraction riser pipes for VI contaminants to understand the mass captured by the mitigation system over time. DEQ recommends collecting data prior to installing or actively operating a mitigation system to obtain a baseline for comparing to post-mitigation data. Note that this may not be possible when immediate active mitigation is required to address risk.

The primary performance objective for a vapor intrusion mitigation system is to consistently prevent indoor air concentrations from exceeding RBCs as a result of vapor intrusion. To demonstrate this is achieved, EPA recommends collecting indoor air samples to characterize and capture a "reasonable maximum" vapor intrusion condition for a given building (EPA 2015a). Multiple paired indoor air and soil vapor sampling events are generally necessary to develop an understanding of temporal variability and sufficiently represent reasonable maximum levels. While indoor air monitoring directly assesses exposure, it does not provide information on the system's effect on vapor concentrations below the sub-slab.

Monitoring for negative pressure below the sub-slab and reduction of sub-slab vapor concentrations are important secondary performance metrics for demonstrating satisfactory mitigation and can become critical elements of a long-term monitoring program. Correspondingly, these LOEs can be integral to informing long-term risk management conditions that may be necessary to ensure indoor air performance metrics are met over the lifetime of the project. The following combination of LOEs are a strong demonstration that VI risks are adequately managed and provide a straightforward path to project closure:

- Indoor concentrations are below air RBCs.
- Soil vapor concentrations beneath buildings are below RBCs.
- Negative pressure is sustained across the building slab (or areal extent of vapor plume).
- Vapor migration is not occurring along preferential pathways.

The following flow chart (Figure 29) provides a framework to demonstrate VI risk has been mitigated.

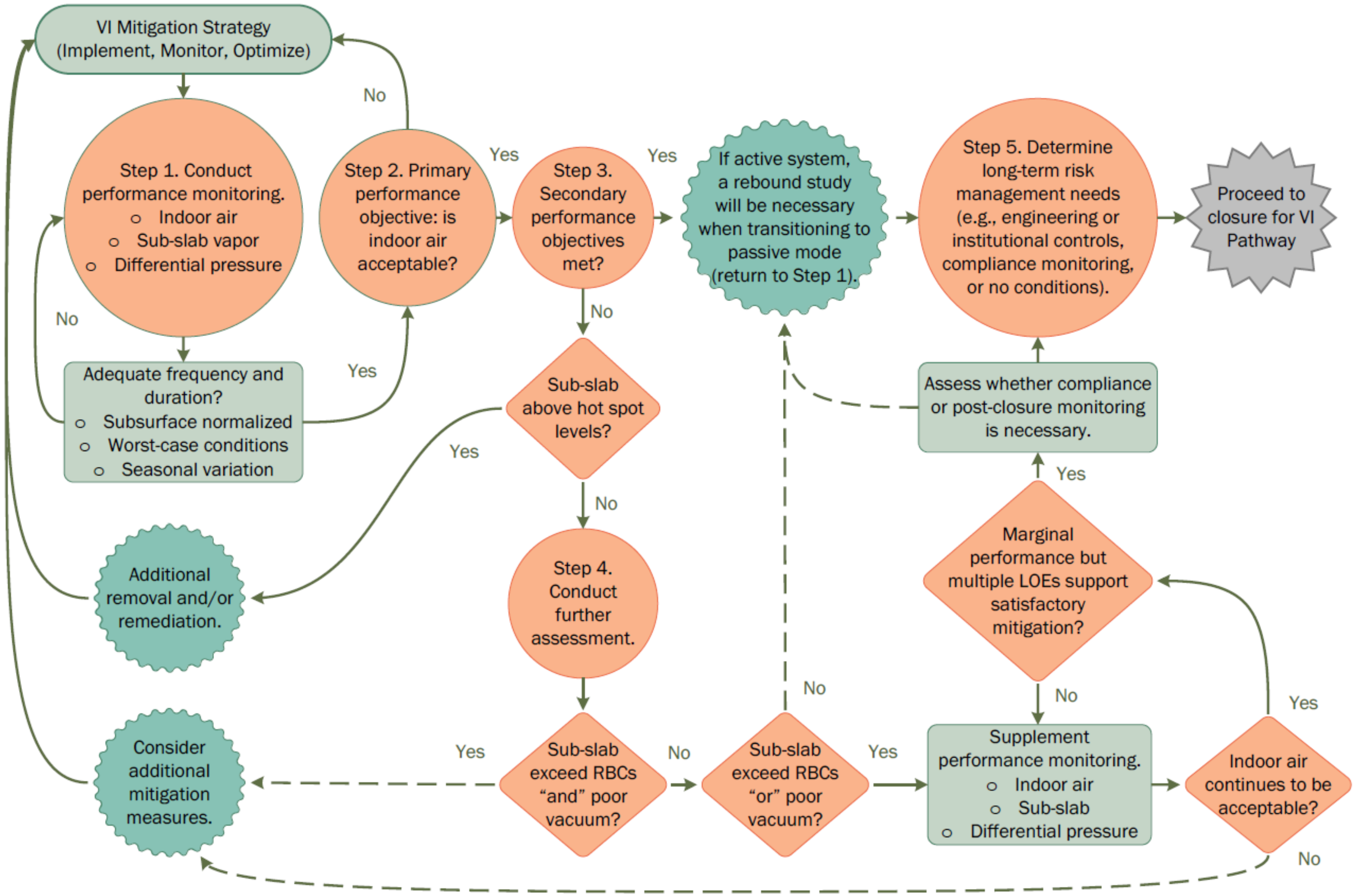


Figure 29. Performance Monitoring Flow Chart

Step 1. Conduct performance monitoring.

An initial indoor air sampling event is valuable immediately following implementation of a remedial measure to verify conditions are safe for building occupants. **However, to evaluate VI potential over the annual range of seasonal conditions, four quarters of indoor air and soil vapor sampling are typically recommended after subsurface conditions have equilibrated post-remedial and mitigation actions**. Note that subsurface equilibrium and rebound of vapor concentrations may take time, particularly following substantial changes to the subsurface such as a removal action (see Section 6.3.3: *Assessment of rebound*).

Due to the sensitivity of VI to barometric pressure trends and differential pressures across slab foundations, it is critical to characterize these parameters prior to and during all indoor sampling events. In addition to this data, other lines of evidence should be considered when evaluating overall system performances.

A performance monitoring work plan is developed in advance for DEQ review and concurrence prior to implementation. Performance sampling can be scaled up or down as appropriate based on site-specific conditions and initial sampling results. An abbreviated sampling program may be acceptable to DEQ when defensible but does not supersede evaluating seasonal variations that may stress the mitigation performance. It is often necessary to increase sampling with increased site complexity; however, there is flexibility and opportunities to streamline or modify the monitoring program after preliminary sampling results. See Section 6.3.2 for additional information regarding sampling methods, frequency, and considerations. Once sufficient duration and frequency of sampling has been implemented, proceed to Step 2.

Step 2. Demonstrate achievement of primary objective: indoor air concentrations below RBCs.

If indoor air sampling over the performance period is below RBCs, proceed to Step 3.

When indoor air concentrations below RBCs cannot be immediately achieved or sustained over the performance monitoring period, the VI mitigation strategy will need to be augmented and mitigation performance revaluated. Note that initial indoor air results detected above risk levels may also warrant an immediate response to protect building occupants. After implementation of additional mitigation measures, proceed to Step 1.

When indoor air cannot be sampled due to site-specific considerations, the secondary performance metrics become increasingly important to demonstrate adequate mitigation is occurring. Indoor air sampling should be conducted to the extent practical and capture reasonable maximum exposure conditions.

Step 3. Demonstrate achievement of secondary performance metrics: sustained differential pressure across the sub-slab and reduction in sub-slab vapors below RBCs.

If four quarters of sampling sub-slab vapor and differential pressure demonstrate secondary performance metrics have been achieved, then the project can proceed to project closure with applicable conditions to ensure long-term protectiveness. Move forward to Step 5. Under some scenarios (e.g., low pre-mitigation concentrations, PVI, etc.), fewer than four quarters of sampling may be sufficient.

For instance, reduction of sub-slab vapor concentrations below RBCs and predictable negative pressure across the sub-slab (e.g., >0.02 inches of water) are strong lines of evidence to support satisfactory mitigation performance.

If these secondary LOEs do not achieve their respective performance metrics, additional assessment may be necessary to determine if system performance provides sufficient mitigation to ensure building occupants will remain protected long-term. Proceed to Step 4 to conduct additional assessment(s).

Other considerations include:

- Removal and remediation options should be evaluated if hot spot levels remain present below the building.
- Augmenting the VI mitigation strategy and/or transitioning to an active mitigation system. For instance, if sub-slab concentrations remain elevated above RBCs and vacuum cannot be sufficiently sustained below the building slab (e.g., marginal or sporadic).
- A performance period will need to be repeated when additional remedial actions or mitigation technologies are implemented. See Section 6.3.3 regarding sampling for rebound when transitioning from an active status to passive operation.
- Following implementation of additional mitigation measures, proceed to Step 1.

Step 4. Conduct further assessment to demonstrate sufficient mitigation in absence of secondary performance metrics being met.

In some cases, effective mitigation is demonstrated without achieving secondary performance metrics. However, in the absence of these LOEs, indoor air monitoring becomes the sole measure of effectiveness and thus may be required more frequently or comprehensively to compensate for the uncertainty. It may also be necessary to continue periodic indoor air monitoring after the performance monitoring period as part of a compliance monitoring program and/or as a required condition for site closure specific to the VI pathway.

Incorporating additional sampling methods or LOEs at this stage can also be useful to strengthen the performance assessment. Additional assessments should be proposed in advance for DEQ concurrence prior to implementation. If sub-slab RBCs are exceeded, continue to sample indoor air periodically until adequate mitigation is demonstrated.

Generally, project sites that do not meet secondary performance objectives fall under one of three scenarios that are described below with potential options to consider.

Scenario 1. Minimum differential pressure criteria are not consistently met, and sub-slab concentrations remain above RBCs. Consider augmenting the mitigation system and return to Step 1 after implementation. Soil vapor concentrations that exceed hot spot levels may require additional source removal or treatment. While supplemental monitoring is an option, there is a possibility that additional data will not change the conclusion, and it should be anticipated that periodic and potentially extensive indoor air compliance monitoring (as well as ICs) will be necessary to verify conditions remain protective for building occupants.

Scenario 2. Differential pressure criteria are met, but sub-slab concentrations are above RBCs. Vacuum maintained across the sub-slab, particularly levels that consistently exceed the performance metric, is a strong LOE when RBCs are exceeded below the building. However, if VOCs remain elevated above RBCs, additional mitigation technologies should be considered. Conduct supplemental sampling to verify satisfactory mitigation and assess whether a compliance monitoring program or post-closure monitoring is necessary to confirm protectiveness long-term. If indoor air continues to be acceptable and multiple LOEs support satisfactory mitigation, assess whether compliance (or post closure) monitoring is necessary, and proceed to Step 5.

Scenario 3. Sub-slab vapors are reduced below RBCs, but differential pressure criteria are not consistently met. Supplemental monitoring can be conducted to confirm conditions that mitigation is effective and that sub-slab concentrations are consistently below RBCs. Tools are available to identify when cross-slab differential reversals occur (see Section 6.3.2: *Sampling methods, frequency, and considerations*). If indoor air continues to be acceptable and multiple LOEs support satisfactory mitigation, assess whether compliance (or post closure) monitoring is necessary, and proceed to Step 5.

Step 5. Determine long-term risk management strategy and ICs.

A long-term risk management strategy is necessary when a VI hazard remains at the site, and which in absence of controls would pose an unacceptable risk. Examples of ICs are provided in Section 6.5: *Engineering and institutional controls*. To the extent practical, the engineering controls and ICs should be generally scoped and agreed upon ahead of time. Required controls are commonly recorded on the property deed, such as in the form of an Easement and Equitable Servitudes (EES), or other binding agreement with DEQ.

Compliance monitoring or post-closure monitoring is also recommended as part of the long-term risk management of the site, particularly if concentrations exceed sub-slab RBCs and additional assurance is necessary to ensure performance objectives are sustained long-term. In general, the greater the extent and magnitude of contamination left in-place, the greater the need for additional monitoring to ensure building occupants are protected. Performance monitoring results will help inform long-term risk management needs.

To the extent possible, ICs should be limited and not encumber the current and/or future owner. Common obligations are maintaining engineering controls and infrastructure to prevent VI, such as maintaining the competency of the building slab and preventing preferential pathways. **Onerous restrictions or conditional uses, or reliance on conditions for which compliance is difficult to manage or verify, should be avoided.**

Step 6. Proceed to project closure for VI pathway.

Building mitigation systems will need to be maintained until source(s) are remediated. If not remediated, and concentrations in soil vapor remain above RBCs, it is anticipated that mitigation will be necessary long-term or until it is demonstrated mitigation is no longer necessary.

A project can proceed to project closure for the VI pathway when a mitigation system is proven to be effective, and a long-term risk strategy and ICs have been identified to address remaining contamination. Conditions for project closure will include maintaining engineering controls and other agreed upon institutional controls. If the site still has other risk pathways to address, satisfactory mitigation and long-term risk management strategy may be documented for the project administrative file until all applicable exposure pathways have been addressed to receive a site-wide conditional no further action. Closure steps may entail a public comment period, such as when conditions are proposed for a DEQ no further action determination (i.e., cNFA).

When engineering or institutional controls are no longer required to address VI risk, project closure can proceed without conditions for the VI pathway (e.g., no further action for the VI pathway). For instance, if following successful source remediation, soil vapor levels have reliably declined below applicable RBCs.

6.3.2 Sampling methods, frequency, and considerations

A performance monitoring plan identifies the monitoring methods, locations, analytical testing, frequency, and preliminary schedule for collecting data. Monitoring is initially more frequent and then can be reduced as more data is available, trends or "stable” conditions post-construction are established, and certainty is attained that remedial (mitigation) objectives are being achieved. Modifications to the monitoring plan can be an iterative process as new information becomes available. Adjustments may be warranted to focus on data that provides the best value, removing less useful sampling points, filling in data gaps, identifying better sampling methods, and so on. Site-specific conditions will dictate monitoring needs.

Quarterly sampling is typical in the first year following implementation of a VI mitigation system and/or “startup” of an active system; however, the sampling strategy and schedule is adjusted based on site-specific conditions and duration for the subsurface to equilibrate. A reduced performance monitoring plan will need to be well supported for DEQ concurrence and should not replace capturing seasonal variations that could impact mitigation performance. Note that one sampling event is insufficient. It is normal that an expanded sampling program is necessary for complex projects and when elevated sub-slab VI concentrations are present below occupied buildings; however, streamlining a sampling program is acceptable and can be iterative. The monitoring plan should also consider an exit strategy including mapping out when/how to demonstrate mitigation is no longer necessary. If planning on a shutdown of "active" mitigation in coordination with DEQ, an adequate period of assessment should be anticipated in "passive" mode to assess potential rebound in sub-slab concentrations and demonstrate concentrations remain below RBCs (see following section for more detail).

Sub-slab monitoring locations should provide adequate coverage of the mitigation or treatment area and should be located in the areas that are anticipated to provide the "weakest" performance, such as away from vapor collection piping and exterior walls. Sub-slab sampling locations should be proposed and installed during mitigation system construction (see Section 6.2.5: *Performance monitoring design* for recommended sub-slab monitoring locations and design options).

Indoor air sampling locations should include spaces anticipated to be more susceptible to vapor intrusion, including portions of the building above elevated sub-slab vapor concentrations, and take into account building infrastructure and use. Building features to consider when selecting monitoring locations include basements/bottom floor areas, spaces with limited to no ventilation or away from windows, spaces that are occupied or could be occupied, and small or confined spaces.

Sampling procedures are described in Section 4: *Vapor intrusion sampling and analysis*. The following are considerations when conducting indoor air and sub-slab vapor sampling:

- Longer duration passive samplers are preferred for indoor air monitoring (see Section 4.6: *Indoor air sampling*). Longer sampling timeframes are more likely to capture VI events and more accurately estimate chronic exposure levels. Analytical testing of indoor air using evacuated canisters is also acceptable and may be preferred to target certain analytes with acute risks. The limitations of any sampling method will need to be taken into account.
- Longer duration indoor air sampling methods are generally comparable as part of the data analysis with sub-slab sampling methods using shorter duration events (e.g., less than 24 hours using evacuated canister methods) and to the extent possible collected during similar timeframes. Sub-slab conditions vary considerably less compared to indoor air, and the greatest changes in the sub-slab are observed over seasons. In comparison, variability within indoor air can be significant throughout the day (e.g., frequent fluctuations and at greater magnitude).
- A PID or FID can be used to supplement analytical data to assess concentration trends over time (see Section 4.2.2: *Field screening for VOCs with a PID/FID*).
- Continuous, cross-slab differential pressure measurements collected over longer durations can provide valuable information and target different timeframes of the year.

One method is attaching digital micromanometers (with pressure transducers and data loggers) to sub-slab probes. These measurements can be a strong LOE to demonstrate adequate differential pressure is consistently achieved but can also be useful information to identify potential reversals between the sub-slab and indoor air. Identifying potential reversals at monitoring points within a mitigation system can help focus additional mitigation or monitoring needs.

- While the frequency or duration may be different, indoor air and sub-slab sampling events should coincide to the extent practical.
- Sub-slab probes or pins can be used to monitor differential pressures for a direct indication of the pneumatic performance of depressurization systems.
- It is helpful to coincide/co-locate sub-slab sampling and pressure differential measurements.

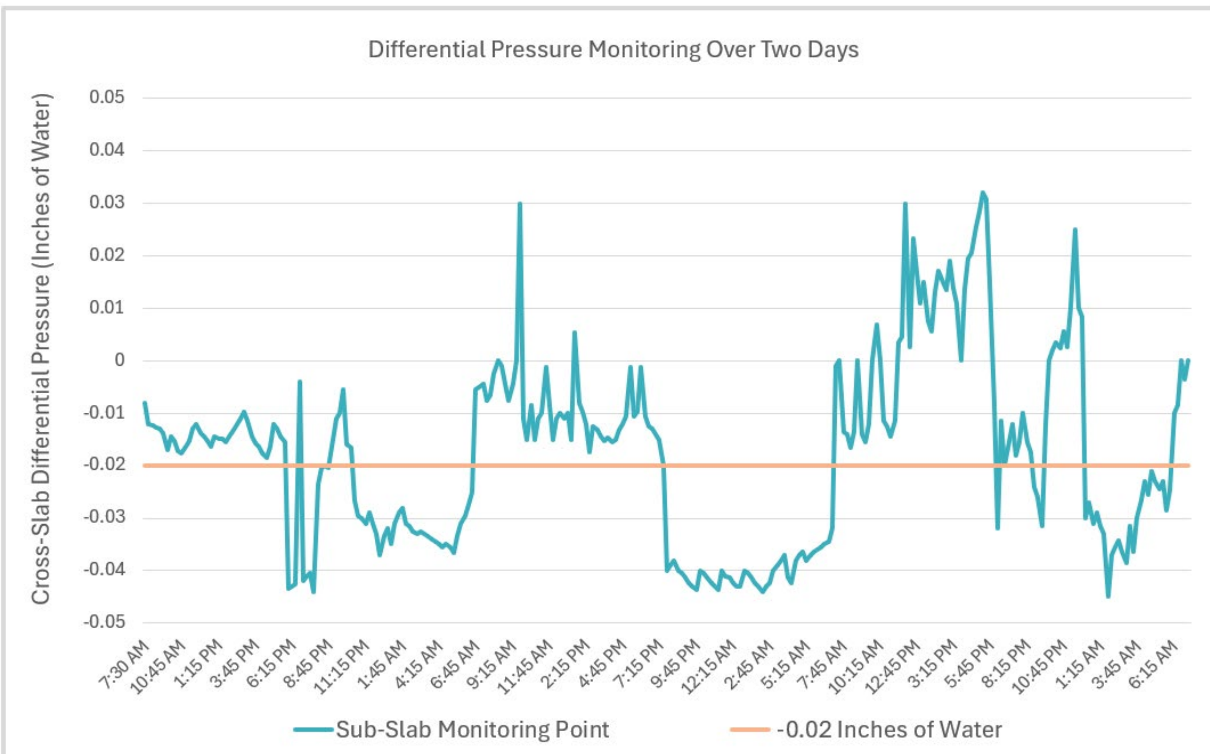


Figure 30. Example of cross-slab differential monitoring

There are multiple methods to evaluate the VI pathway. For example, continuous cross-slab differential monitoring can be valuable site-specific data to better understand temporal variability or trends over longer periods. Figure 30 illustrates an example scenario where reversals in cross-slab pressure (i.e., sub-slab pressure becomes greater than indoor air) are observed during brief periods at one performance monitoring location. While the example consists of data collected over approximately three days, longer monitoring periods are possible over weeks to document cross-slab differential pressure and over different periods of the year to capture seasonal variations. Consistent sub-slab negative pressure at representative monitoring locations is a strong LOE. Alternatively, identifying periods of intermediate or sustained periods of VI transport reversals can be useful to better understand what timeframes a building is vulnerable as part of mitigation performance evaluation but also during early stages of the VI assessment.

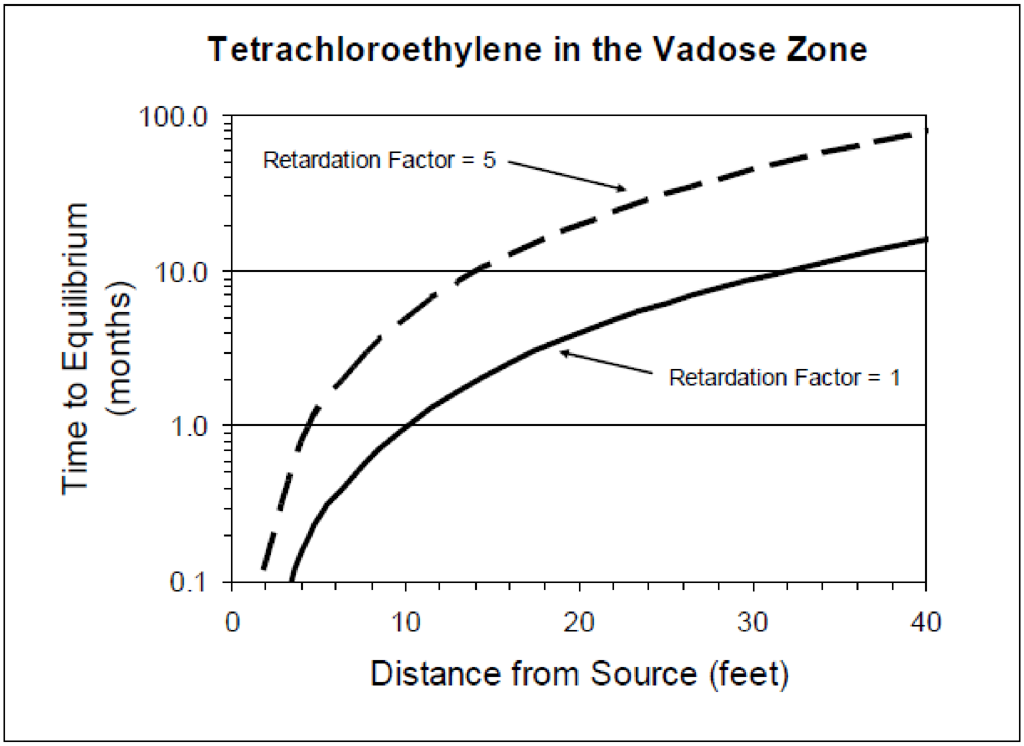
The performance monitoring period is generally complete when a defensible dataset has been collected and supporting LOEs provide confidence that the mitigation strategy consistently and reliably prevents VI. Periodic or intermittent sampling of indoor air may still be warranted when VI contamination remains below a building exceeding RBCs and indoor air data provides direct confirmation that exposure levels are acceptable.

6.3.3 Assessment of rebound

Rebound is assessed following implementation of source remediation (removal or treatment), including after shutdown of an SVE system. Rebound occurs when a source has not been sufficiently removed or controlled. California EPA guidance presents methods developed by Johnson and others to roughly estimate the time to reach steady-state conditions. Figure 30 illustrates this concept and contains an example of timeframes for approaching steady-state for TCE at a hypothetical site (CalEPA, 2011a). Timeframes to equilibrate may be prolonged after substantial site changes, such as following large excavations, and unstable sources.

Performance monitoring, when applicable, should integrate an assessment of rebound of soil vapor or sub-slab vapor concentrations following completion or changes to a remedial strategy. Rebound represents an upward trend of concentrations until equilibrium or stable conditions are achieved. In this context, “equilibrium” is a form of dynamic equilibrium that has long-term stability but includes seasonal variability in concentrations. When interpreting soil vapor data with respect to rebound and stability, seasonal fluctuations must be factored into the data analysis. VI evaluations should be based on steady-state conditions, otherwise potential VI risk may be underestimated.

The duration of rebound monitoring should be based upon the time needed to re-establish subsurface equilibrium. When rebound timeframes are incompatible with expected schedules for site closure and/or property transactions or redevelopment, consideration should be given to expanding the scale of the proposed remedial approach.



The figure demonstrates the estimated time to reach near steady-state vapor concentration at some distance from a contaminant source (Johnson et al., 1999; Equation 4) for PCE in the vadose zone. The figure shows time to equilibrium for two retardation factors. Sandy conditions were assumed (effective diffusion coefficient = 0.012 centimeters squared per second) with PCE physical properties from USEPA (2002a).

Figure 31. Example of timeframe to reach steady-state conditions

It is also recommended to evaluate potential rebound in concentrations below the building when transitioning an active system mitigation system to passive status. In general, rebound from active to passive mode of a VI system occurs relatively quickly.

A rebound assessment and related recommendations may be applicable for the following scenarios.

Removal action. The magnitude of the removal, source composition, age, and distance will impact the timeframe necessary to monitor rebound. For deeper sources, soil vapor probes screened closer to the source or below a removal area can be early indicators that rebound is occurring before it is observed below a building slab. For some projects, this can be a valuable LOE to assess whether additional remedial technologies or system modifications are necessary to augment the existing remedial strategy. Examples include incorporating VI controls into a planned development or transitioning operation of a mitigation system from passive to active operation and vice versa.

SVE shutdown. Data collected beginning at the startup of an SVE system can be used to calculate and extrapolate mass removal rates to predict when and whether the system has reached asymptotic or plateau conditions. Figure 31 presents an example of an SVE system approaching asymptotic conditions which is demonstrated by plotting data collected at system startup and over time. If measurable mass removal continues, the system still functions to a certain extent, but its effectiveness has declined or stalled. At this stage (or earlier when appropriate), system operations can be modified through "pulsing" methods consisting of on and off operational periods. Duration of off periods can be extended and on periods shortened as mass removal rates decline or as concentrations take longer to rebound following a shutdown period. Rebound of subsurface vapor should continue to be monitored. If concentrations rebound above VI RBCs, additional pulsing is recommended. If rebound persists and minimal to no discernible mass removal is measurable, alternative remedial measures such as mitigation may be more suitable to address residual VI contamination.

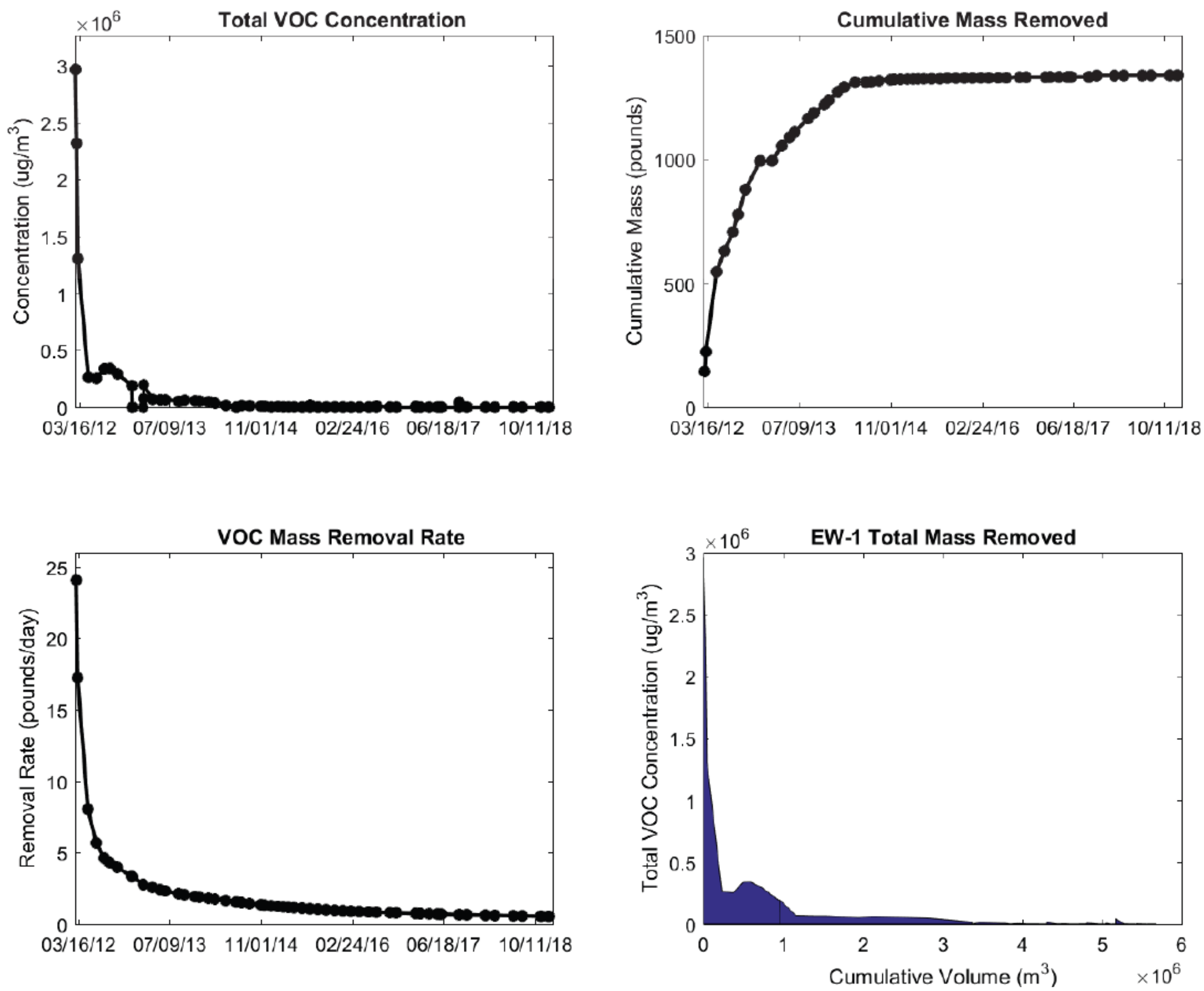


Figure 32. Example of SVE system approaching asymptotic conditions

The USDOE's 2013 *Soil Vapor Extraction System Optimization, Transition, and Closure Guidance* provides a stepwise approach for assessing SVE performance after a system begins to show diminishing contaminant removal rates and determining whether the system should be optimized, terminated, or transitioned to another technology to replace or augment SVE.

Active to passive operation. If transitioning from an active to a passive mode of operation, system mitigation performance will need to be reexamined, including an assessment of potential rebound conditions. In contrast to a remediation, the subsurface should equilibrate in a short period, and "rebound" in this case would be a result of no longer mechanically applying vacuum below the sub-slab.

Transition from active to passive operation is appropriate when sub-slab vapor concentrations are below RBCs, and correspondingly active mitigation should continue if RBCs are frequently detected above RBCs. There is a lower likelihood for rebound to occur when sub-slab concentrations in active status are consistently measured below risk-based levels.

A rebound period should also take into account seasonal variability and reasonable maximum conditions. If sub-slab concentrations rebound substantially above RBCs, a mitigation system should resume active mode. Moderate (or infrequent, elevated) detections above RBCs may be acceptable if it can be demonstrated that rebound conditions in the sub-slab will not impact indoor air conditions while continuing operation under a passive status.

6.3.4 Compliance monitoring

Compliance monitoring may be required to demonstrate that the remedy continues to function as intended to protect building occupants from vapor intrusion. When this type of periodic monitoring is necessary following the performance monitoring period, these requirements can be carried forward as required conditions for project closure for the VI pathway. Compliance monitoring can be an extension of the performance monitoring strategy but generally at a reduced frequency. Long-term compliance monitoring programs often compensate for underperformance of a remedial action and/or mitigation strategy but may also be driven by VI sources that could pose VI risk in the future. Depending on the nature and extent of contamination left in-place and reliability of the mitigation system to control VI, the scope of compliance monitoring will vary as part of long-term risk management at a property. Compliance monitoring is typically considerably reduced in scope compared to performance or rebound monitoring. For example, sufficient monitoring may entail collecting differential pressure across the sub-slab as a performance metric instead of analytical testing but may incorporate periodic analytical testing as warranted.

6.3.5 Reporting

Reporting should occur within a reasonable timeframe following sampling events (e.g., 30 days or less after receiving analytical laboratory results) and should include a presentation of data results, supporting tables and figures, laboratory reports, interpretation of the results, and recommendations. Less frequent reporting is generally acceptable following initial phases of work in consultation with DEQ. Proposals for monitoring reductions, additional focused studies, or changes to a remedial system operational status (as well as vapor emissions treatment if applicable) should be submitted to DEQ for approval prior to implementation. Please continue to coordinate with DEQ on appropriate next steps and necessary documentation for the project administrative file.

6.4 Planning and documentation

At sites where remedial engineering controls are necessary to protect human health, proposals of work (e.g., work plans, studies, and summary reports) are submitted to DEQ for review and approval. Note that document preparation and reporting can be scaled down, consolidated, or enhanced depending on the complexity of the project. VI assessments and related evaluations should be conducted and prepared by qualified environmental professionals (e.g., scientists, toxicologists, geologists, engineers). Preparation of "engineering" design plans, construction oversight, and assessments of engineered systems (e.g., practice of engineering) requires certification by a Professional Engineer (P.E.) licensed in the State of Oregon (see Section 6.6: *Professional registrations and certifications*). Likewise, an Oregon Registered Geologist (R.G.) conducts and certifies geologic services. DEQ's *Internal Management Directive: Professional Stamping of Cleanup Program Documents* (DEQ, 2019) provides additional details regarding professional stamping of documents prepared by external parties, agency staff, and contractors.

Example deliverables (following investigation and risk screening steps) for a vapor intrusion project are presented below in customary chronological order from evaluation of remedial options to implementation.

- Feasibility study or equivalent document presenting an evaluation of viable VI remedial alternatives (remediation and/or mitigation technologies) and recommended VI strategy with assessment and recommendations of engineering controls prepared and stamped by a P.E.
- Remedial design plans specifically containing engineering and related construction details prepared by a P.E. for DEQ review and concurrence prior to implementation. The remedial design package should include, where applicable and not limited to, summary of proposed work, basis of design and performance objectives (e.g., DQOs), design drawings and specifications, supporting calculations, results of pre-monitoring or diagnostic testing to support remedial design, manufacturer specifications, identification and documentation of necessary permits, roles and responsibilities, and a construction quality assurance and control plan. Note that it is unnecessary to submit the entire

engineering drawing set for new construction required by local planning, development and review departments. The DEQ Cleanup Program only requires the VI related construction specifications and drawings.

- Supervision by the project P.E. during construction of engineering design plans
- Construction completion report or equivalent documenting the engineer system as-built certified by the project P.E. and related details submitted to DEQ for the project administrative file
- Performance monitoring plan for DEQ approval prior to implementation. Early development of a performance monitoring plan is encouraged to support development of performance standards and remedial design considerations. Sampling probes/locations, when applicable, are typically installed during system construction and specifications are presented in the design package.
- Supplemental monitoring plans or addendums prepared as needed. For example, compliance monitoring that may be necessary based on performance monitoring results or a rebound study following shutdown of a remediation system or transitioning from active to passive mitigation.
- O&M plan, if applicable, for DEQ approval and implementation
- Project schedules and updates as needed
- Required engineering and institutional controls documented with the property, such as an EES, to ensure the remedial action remains protective. These controls would also be conditions for project closure for the VI pathway.

6.5 Engineering and institutional controls

Engineering and institutional controls are mechanisms for managing exposure risks when contaminants remain present at levels of concern. A combination of controls may be necessary until the site is restored to protective levels.

Oregon Administrative Rules OAR 340-122-0115(23) defines "Engineering Control" as *"…a remedial method used to prevent or minimize exposure to hazardous substances, including technologies that reduce the mobility or migration of hazardous substances…."* Engineering controls can be either removal, treatment, or mitigation actions to remediate VI sources and/or protect building occupants.

OAR 340-122-0115(33) defines "Institutional Control" as *"…a legal or administrative tool or action taken to reduce the potential for exposure to hazardous substances. Institutional controls may include but are not limited to, use restrictions, environmental monitoring requirements, and site access and security measures."* These could have many applications at VI sites, such as restricting building uses when VI levels exceed risk levels.

Institutional controls are often necessary to ensure the continued integrity of a remedial action and/or mitigation system remains protective for site uses. Typical mechanisms to ensure that controls are maintained include deed restrictions, such as in the form of an Easement and Equitable Servitudes, and Prospective Purchaser Agreements. DEQ's 1998 *Guidance for Use of Institutional Controls* addresses the implementation of controls as a long-term VI remedy. Note that when this guidance is revised (anticipated for 2025-2026), the updated version will supersede the 1998 guidance.

Anticipated ICs for vapor intrusion sites may consist of but are not limited to the following:

- Maintaining VI mitigation controls and building infrastructure supporting the functionality of the VI mitigation system. For example, implementation of a DEQ-approved O&M plan, periodic inspections, and maintaining building sub-slab.
- Potentially restrictions on building modifications; however, tedious restrictions or conditions that are difficult to manage should be avoided.
- Maintaining building pressurization, for example HVAC operation. As noted previously, HVAC systems generally should not be a stand-alone long-term mitigation strategy.
- Inspections following earthquakes or other applicable extreme events that may have impacted controls.
- Remodels or building modifications that will disturb the VI mitigation system require pre-notification/approval by DEQ including submittal of plans to restore necessary controls and assure protectiveness to building occupants, as well as documentation of modifications and post-monitoring, if needed.
- If applicable, periodic compliance or post-closure monitoring to verify long-term protectiveness of building occupants.
- If applicable, restrictions on site uses (e.g., residential) until a vapor source is remediated to allow for expanded uses. Proposed changes to site restrictions will need to be coordinated and approved by DEQ, including providing the appropriate plans and documentation.
- While not directly related to VI mitigation, on properties where contamination is contained onsite or may be encountered, a contaminated media management plan (CMMP) is prepared for implementation during earth-disturbing activities.

Engineering and/or institutional controls are most often recorded on the property in a deed restriction (e.g., EES), but other appropriate agreements with DEQ are used.

Termination of engineering controls (e.g., mitigation system) or ICs requires DEQ approval. It is recommended to coordinate with DEQ early and agree on the appropriate steps, which may include additional data collection to demonstrate site controls are no longer necessary to address VI risk. Note that collecting data without a DEQ approved plan or oversight may not suffice to demonstrate one or more conditions are unnecessary.

6.6 Professional registrations and certifications

Regulations governing the practices of Engineering and Geology are defined in ORS 672, OAR 820, and OAR 809, and must be followed when submitting reports and system design documents to DEQ. DEQ must ensure that engineering and geological work related to environmental investigations and remedial designs complies with applicable Oregon laws and regulations.

Under DEQ's Cleanup Program, engineering controls are used to protect human health from hazardous substances posing unacceptable risk. Professional qualifications and accountability are necessary to ensure quality work that protects Oregonians. The process of screening technologies, design, construction, and developing performance monitoring programs for engineering controls requires an understanding of engineering principles and practice. Accordingly, DEQ expects that a professional engineer stamp and certify engineering system designs and as-built plans, including vapor intrusion mitigation systems. This requirement is consistent with DEQ's *Internal Management Directive: Professional Stamping of Cleanup Program Documents* (DEQ, 2019a) and understanding of regulations for practicing engineering in the State of Oregon overseen by the Oregon State Board of Examiners for Engineering and Land Surveying (OSBEELS).

DEQ Cleanup Program engineers have also prepared a memorandum regarding *Engineering Review of Vapor Intrusion Mitigation Systems* (provided in Appendix F) to assist Cleanup Program project managers in identifying when to engage engineering support in the evaluation and approval of engineering controls at cleanup sites to address unacceptable vapor intrusion risk (DEQ, 2019b).

7.0 Community engagement

It is critical to effectively communicate about vapor intrusion risks to members of the public who are directly impacted (EPA, 2015a; ITRC, 2007a; ITRC, 2014; WADOE, 2022). DEQ recommends proactively reaching out and engaging communities impacted by VI early on and throughout the process of investigating and mitigating any potential risks. VI risks can be imminently concerning to impacted parties. Communicating clearly and openly using established risk communication techniques is key to establishing trust. Developing a plan for proactive community engagement (such as a Community Involvement Plan) is important to ensure meaningful engagement with all parties involved. Multiple other regulatory bodies have developed comprehensive guidance on this topic, and DEQ recommends consulting them for guidance.

DEQ recommends the following documents for helpful information on effective community engagement and public outreach related to vapor intrusion:

- Chapter 5, "Public Involvement", and Section A-6 of Appendix A, "Working with people who are affected by vapor intrusion." *Guidance for Evaluating Vapor Intrusion in Washington State*. Washington Department of Ecology, March 2022.
- Appendix A, "Community Stakeholder Concerns." *Vapor Intrusion Pathway: A Practical Guideline*. Interstate Technology & Regulatory Council, 2007.
- Section 7, "Community Engagement." *Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management*. Interstate Technology & Regulatory Council, 2014.
- Section 9, "Planning for Community Involvement." *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, June 2015.
- Section 4, "Community Engagement." *Vapor Intrusion Handbook*. U.S. Environmental Protection Agency, Region 5 Superfund and Emergency Management Division.
- Risk Communication Toolkit. Interstate Technology & Regulatory Council, 2020.
- Risk Communication. U.S. Environmental Protection Agency, Last Modified January 2025, accessed February 2025.

Some key takeaways from these guidance documents are summarized below.

Why is it important to communicate effectively about vapor intrusion investigations and risks?

The vapor intrusion pathway is one of the most commonly complete exposure pathways at Cleanup sites and can present imminent risk to human health. Learning that there might be risks to human health and that sampling is being conducted in and around buildings may be concerning and disruptive to building occupants. Vapor intrusion risks in residential spaces can represent extended exposures that are very personal to those affected. Further, input from community members supports using conservative screening levels, mitigation efforts, and responses to ensure that risks associated with vapor intrusion are mitigated as fully as possible – this may have implications on the appropriate approach at a given vapor intrusion site (ITRC 2014). Further, building occupants may not have known that they could have been or are exposed until you communicate with them. Because of this, carefully planning for community engagement and proactive risk communication with impacted parties is extremely important.

When is it important to communicate effectively about vapor intrusion investigations and risks?

When indoor air concentrations exceed RBCs, public outreach is important to inform building occupants that a potential risk has been identified in indoor air. Please consult Appendix A for the appropriate response actions in these cases. In the absence of indoor air concentrations exceeding RBCs, it is still important to communicate with potentially impacted parties.[27] Proactive communication with the public is important in any case where VOCs are detected near or within an occupied building.

The Washington Department of Ecology VI Guidance provides more helpful suggestions for when and how to support public outreach during a VI investigation and mitigation, referenced in this section and in the references section below (WADOE, 2022). Acknowledging and responding to impacted parties' concerns throughout the VI investigation and remediation process is key to effectively engaging with the public on VI evaluations.

What are best practices for communicating effectively about vapor intrusion investigations and risks?

Effective risk communication is critical for the success of any outreach effort involving potential health risks (ITRC, 2014; ITRC, 2020; EPA, 2025). It is important that information about risks related to VI exposures are communicated effectively to the individuals most impacted. Effective risk communication requires building trust with impacted parties and tailoring communication strategies to the specific audiences involved. There has been extensive research on effective risk communication strategies, and multiple resources are available, such as from ITRC and EPA.

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[27] Minimum public notice and participation requirements for different steps in the process of the Cleanup Program and Leaking Underground Storage Tank Program are outlined in Oregon Administrative Rules OAR 340-122-0100 and 340-122-0260, respectively. Vapor intrusion sites present additional communication needs due to the potential for current exposures and need for access agreements to sample occupied buildings. Coordination should occur between the property owner or representative(s) on their behalf, DEQ, and Oregon Health Authority as necessary to develop a public outreach plan and appropriate next steps.

Recommendations for effectively communicating about vapor intrusion risks include:

- Involve impacted parties throughout the process.
- Seek to understand the perspectives of impacted parties.
- Listen to input received from impacted parties.
- Be transparent, honest, and respectful.
- Speak in plain language, and ensure all supporting materials are translated into any languages necessary.
- Be compassionate.

Goals of effectively communicating about vapor intrusion risks include:

- Build trust.
- Provide enough information in accessible formats to empower residents and other impacted parties to make informed decisions regarding the impacts of VI.
- Create and maintain open channels for communication.

Building trust with impacted parties is critical to effectively communicate about health risks with individuals potentially exposed to VI contamination. Seeking to proactively understand the impacted community and consider the context in which exposures to VI contaminants are occurring is an important component of building trust with them. For example, it can be very upsetting for residents to learn that they have been exposed to contamination inside their home or that their children may have been exposed in spaces they considered safe. Communicating clearly, openly, and consistently throughout the VI evaluation and mitigation process is also key to establishing trust with impacted parties.

Best practices also include developing a site-specific communication strategy and communications materials geared specifically for the communities impacted by contamination from a site. For example, the ITRC PVI guidance (ITRC, 2014) includes specific examples of community engagement tools and support for communication approaches, such as alternative terms to use to explain PVI concepts in plain language instead of technical jargon that is often not accessible to broader audiences. ITRC, Washington Department of Ecology, and EPA have also compiled factsheets, brochures, and web pages to share answers to frequently asked questions about VI. DEQ recommends reviewing and drawing from these resources to support proactively and effectively communicate about potential or confirmed vapor intrusion exposures and/or risks.

Finally, a successful approach incorporates a mix of communications tools that are accessible to all members in the impacted community. It is important to consider language barriers to make sure impacted parties can understand the information provided. Check with the building operator, local health department, or other local government resources to identify what languages should be used to communicate, especially if there are any health risks. EPA's Environmental Justice Screening Tool (EJScreen) has information on the percentage of households that are limited English speaking households based on U.S. Census data. In addition, some communities have more exposures to environmental contamination than others. Tools such as EPA's EJScreen and a future Oregon-specific environmental justice mapping tool can help identify if a site is in an area with a larger burden of environmental contamination and help inform community engagement and outreach. Setting clear expectations, openly answering questions, and responding to concerns are all key to establishing trust and collaborative working relationships with impacted communities.

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Appendix A

Vapor intrusion response matrix for indoor air

Indoor air response action levels are provided in the following table. Compare sampling results to acute and chronic risk-based concentrations and use lines of evidence to inform response.

Table A. Vapor Intrusion General Response Matrix for Indoor Air

Indoor Air Concentration (Attributed to VI)[a] – Acute Exposure[1]			
No Data	**≤ acute RBCair**	**> acute RBCair to ≤ 3x acute RBCair[e]**	**> 3x acute RBCair[e]**
Monitor Initiate sub-slab and/or indoor air sampling if vapor intrusion is suspected.	**Monitor/ No Action** Use LOEs to determine need for additional sampling.	**Accelerated Response** • Evaluate and implement interim mitigation measures[b] within a few weeks. • Confirm effectiveness through monitoring. • Public outreach recommended.[d]	**Urgent Response** • Evaluate and implement interim mitigation measures[b,c] within a few days. • Confirm effectiveness through monitoring. • Public outreach recommended.[d]
Indoor Air Concentration (Attributed to VI)[a] – Chronic Exposure			
No Data	**≤ chronic RBCair**	**Noncancer:** **> chronic RBCair to ≤ 3x chronic RBCair[e]** **Cancer:** **> chronic RBCair to ≤ 10x chronic RBCair[e]**	**Noncancer:** **> 3x chronic RBCair[e]** **Cancer:** **> 10x chronic RBCair[e]**
Monitor Initiate sub-slab and/or indoor air sampling if vapor intrusion is suspected.	**Monitor/ No Action** Use LOEs to determine need for additional sampling.	**Accelerated Response** • Evaluate and implement interim mitigation measures[b] in a reasonable timeframe (e.g., 6 months). • Confirm effectiveness through monitoring. • Public outreach recommended.[d]	**Urgent Response** • Evaluate and implement interim mitigation measures[a,b] within a month. • Confirm effectiveness through monitoring. • Public outreach recommended.[d]

Notes:

[1]Acute based on EPA Region 9 recommendations (EPA, 2014).

Acute RBCair = Acute Risk-based concentration for air

Chronic RBCair = Chronic Risk-based concentration for air

a. Indoor air concentrations exceeding indoor air RBCs are considered hot spots if air concentrations are not reliably contained.

b. Potential actions include but not limited to the following, with additional detail provided in Section 6.2:

- Increasing building pressurization and/or ventilation
- Sealing potential conduits where vapors may enter the building
- Treating indoor air using carbon filtration, air purifiers, etc
- Installing and operating engineered exposure controls, such as sub-slab or crawlspace depressurization systems

c. Temporary relocation of residents or workers may be necessary under certain circumstances until VI risks are mitigated. ORS 465.210 gives DEQ authority to conduct removal actions, and ORS 465.200(25) defines "removal" as including "temporary evacuation and housing of threatened individuals."

d. Coordination should occur between the property owner or representative(s) on their behalf, DEQ, and Oregon Health Authority as necessary to develop a public outreach plan and appropriate next steps. See Section 7: *Community engagement* for more resources. Elements of public outreach and community engagement to potentially exposed people include:

- Identify women of childbearing age for developmental contaminants.
- Explain the potential health hazards to building occupants.
- Obtain permission to access buildings for investigation and exposure reduction if warranted.

e. Accelerated response action limits and urgent response action limits may be raised on a site- and chemical-specific basis if DEQ determines that higher levels are warranted based on consideration of factors such as severity of effects and degree of uncertainty used to develop toxicity values.

Appendix B

Recommended assessment approach at HOT sites

Figures

B.1 Introduction

The Oregon Department of Environmental Quality's Heating Oil Tank (HOT) Program has developed this specific guidance for assessing the risk associated with vapor intrusion (VI) into indoor air at HOT sites. This appendix is updated from and supersedes Appendix B: *Heating Oil Tank Program Guidance for Assessing and Remediation Vapor Intrusion in Residential Buildings* in DEQ's 2010 Vapor Intrusion Guidance.

Assessing the VI risk associated with HOT sites is unique and differs from many other sites in the Cleanup or Leaking Underground Storage Tank Program as outlined below:

- The product (diesel) characteristics are well known and less volatile than gasoline or solvents.
- The depth and pattern of the typical HOT release is well known and generally extends under only a portion of the building foundation.
- The source of contamination (the leaking HOT) is frequently located immediately adjacent to the foundation of the residence or habitable structure.
- Due to the proximity of the source of contamination to the structure foundation, excavation of source material is not always feasible without jeopardizing the structural integrity of the building.
- Many residential lots, particularly in the Portland metropolitan area, are no more than 50 feet wide making access difficult for excavation of contaminated source material.
- Data used for calculating attenuation factors was collected from sites where the contamination source was under the entire building footprint. However, heating oil tank releases are often very localized to a side or corner of a building.

This Appendix has been developed to facilitate the assessment of the VI risk associated with HOT sites and any remaining levels of contaminants in the subsurface. This HOT VI guidance should be used as a supplement to the VI Guidance presented in the main body of this document. A flow chart specific to HOT sites is included in Section B.3 of this appendix.

Three scenarios typically exist at HOT release sites:

1. All contaminated media is far enough away from the structure to rule out vapor intrusion concerns.
2. Contaminated media are located close to a structure but are not in contact with the structure, in which case vapor intrusion may be ruled out by following certain steps.
3. Contaminated media are in contact with the structure or are connected to the structure via a preferential pathway, in which case vapor intrusion is assumed to occur and must be assessed by testing indoor air.

Advances in the understanding of vapor intrusion have happened since the release of DEQ's 2010 VI guidance. Below are some of the key changes we have identified for HOT sites:

- The new risk-based concentrations (RBCs) reflect updated data available from EPA. As of 2023, DEQ incorporated EPA's vapor intrusion screening levels (VISLs) as DEQ RBCs for VI with minor adjustments to account for Oregon conditions (see Section 5.1: *Development of risk-based concentrations* for more information). EPA updates these values regularly (twice a year in 2023), and in response DEQ's RBCs will change over time. Service providers should check DEQ's vapor RBCs regularly for updates.
- Bioremediation will now be considered as an attenuating factor for HOT-related VI.
- Soil sampling below structures to delineate soil impact is now needed in many situations.
- Previously a source had to be over 30 feet away to eliminate vapor intrusion as a potentially complete pathway of exposure. The new guidance allows that distance to be reduced to 15 feet if certain criteria demonstrating biodegradation are met.
- Documentation of the material from which the supply and, if present, the return lines are constructed is now strongly recommended. Samples should be collected adjacent to or below galvanized steel product lines.

A checklist that addresses the scenario applicable to a given site is presented at the end of this appendix and should be submitted with certified reports that involve soil vapor and/or indoor air sampling.

B.2 Background information to support the HOT vapor intrusion guidance

This section describes key elements and considerations for heating oil tank VI investigations. More detailed information on these concepts can be found in the main text of this Vapor Intrusion Guidance.

In this guidance, DEQ refers to vapor samples collected immediately below the basement floor **and** vapor samples collected at greater depths as "soil vapor samples." A soil vapor sample could be taken sub-slab or at depth (which may be referred to as soil gas samples elsewhere).

B.2.1 Conceptual site model

Having a strong conceptual site model (CSM) is a key part of assessing vapor intrusion risk. Conceptual site models provide important information to understand the site, decide where to collect samples, and how to interpret the sample test results. CSMs are written and pictorial representations of the site, including the contamination source, the receptors who would be exposed to the contamination (the building occupants), and the pathways that the contamination may follow to reach building occupants via the indoor air of the structure. A CSM is updated as data becomes available and the contamination plume(s) are delineated.

To properly characterize VI risk, a HOT CSM should include a site figure which at minimum identifies these points:

- An outline of the building, and the location of the heating oil tank, with approximate distance from the tank to building
- Below ground depth of basement or crawlspace
- The location and depths of all underground utility corridors (potential preferential pathways)
- The location and depth of all samples collected
- The extent of the contaminated soil (TPH Dx > 500 ppm) which equivalent to the most common Soil Matrix standard (i.e., level 2)
- The extent of contaminated groundwater, if present
- A summary of key laboratory results at each sample location

B.2.2 Characterization and delineation

Most heating oil tank investigations will use four sampling points to define the lateral extent of the plume of soil contamination. This appendix emphasizes the need to collect a lateral delineation soil sample **between the plume of contamination and the structure** (Figure B.1). This sample is critical to ensure contaminated soils are not in contact with the foundation of the structure. Contamination in contact with a structure can allow vapor to migrate directly to indoor air. Alternative methods of sample collection, such as coring a foundation wall, may be needed to satisfy this lateral delineation requirement or to demonstrate that contaminated soil is **not** in contact with a foundation wall.

In addition, characterizing the supply lines is important because line leaks may release contamination in direct contact with the structure. Document the material (galvanized steel, copper, etc.) of the supply line. Soil samples should be collected adjacent to or below galvanized steel lines, as these are more likely to corrode and leak. Leaks from product lines and leaks in direct contact with structures are the most common scenarios where DEQ’s heating oil tank program has identified concentrations of heating oil in indoor air above RBCs.

When contaminated soil is found in contact with the foundation wall, it is important to continue delineating the plume beneath the building to below Soil Matrix concentrations. The area of contamination beneath the structure impacts potential risk posed by vapor intrusion. Soil samples collected beneath a structure for soil delineation should be collected from the same distance below the tank bottom as the other samples collected to define the lateral spread.

If contaminated soil is in contact with the foundation of a residential structure, the soil vapor to indoor air pathway will be considered complete. Indoor air sampling that returns test results below the applicable RBCs will rule out unacceptable exposure to contaminants of concern. Targeted soil removal can be used to disrupt direct contact, but replacement of the removed soil with low-permeability material may be necessary to prevent the creation of a preferential pathway. Sites with contamination in contact with the foundation are complex; please reach out to a HOT project manager for guidance.

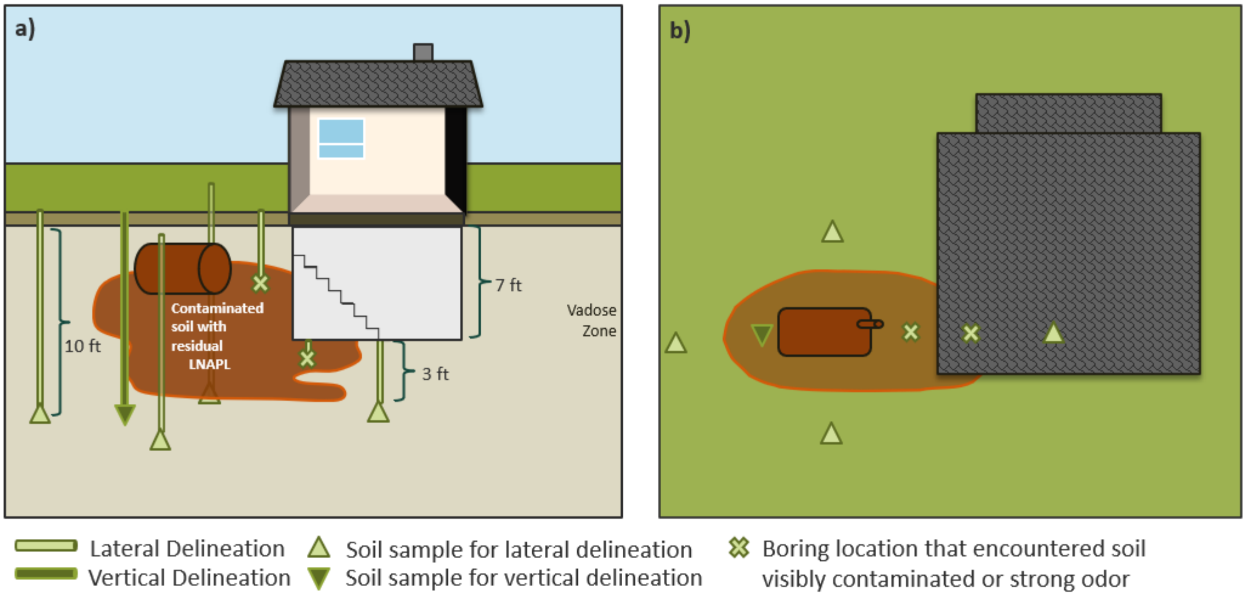

Figure B.1: (a) Cross-sectional view and (b) plan view of soil sample locations to laterally and vertically delineated contaminated soil. All soil samples are collected from the same distance below the tank bottom (10 feet below ground surface). Figure shows offset samples to show dimensionality.

B.2.3 Preferential pathways

Preferential pathways provide a way for contaminated vapors to move through the ground and into the building. Examples could include underground utility corridors such as sewer, water, or gas pipes, or underground electrical, telephone, or internet lines (Figure B.7). Part of the conceptual site model should include a map of the building including the location of all underground utility corridors including the heating oil supply and return lines between the HOT and the furnace.

If the utility corridor potentially connects the contamination to the building, further evaluation is needed. Due to the site-specific conditions, please confer with a HOT project manager for guidance. It may be appropriate to collect samples along the utility corridor or seal up the utility entrance. Sampling methods may include vapor sampling within the fill material of the corridor. Care must be taken to avoid damage to utilities, and manual sampling methods or vacuum excavating may be necessary to determine the exact location of the utility corridor. If vacuum excavation is used, additional equilibration time may be needed prior to soil vapor sample collection. Cross section figures can be very helpful to show the relationship between utility corridors and contaminated soil.

B.2.4 HOT biodegradation

Petroleum is composed of organic molecules and can be broken down by microbes naturally found in soil. This process is called biodegradation and may happen at leaking HOT sites when the right conditions exist. Factors that support biodegradation include a moderate level of moisture, low levels of other organic matter, space in soil for gasses to move, adequate oxygen levels in soil (greater than 2%), and other factors conducive to microbial activity. You can find more information about petroleum biodegradation in Section 2.2.3: *Vapor attenuation in the subsurface* of the main VI guidance and from Interstate Technology and Regulatory Council's 2014 guidance *Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management* (ITRC PVI-1), and EPA's 2015 *Technical Guide for Addressing Petroleum Vapor Intrusion At Leaking Underground Storage Tank Sites*.

B.2.5 Fixed gas screening at HOT sites

To help assess the biodegradation potential of sub surface soils, we recommend collecting fixed gas measurements (O_2, CO_2, methane) and PID readings from multiple locations at a heating oil tank site. Below is an example of how to collect fixed gas data at a site. High groundwater or tight soils may prevent the collection of these measurements. It is important to treat the measurements like you would a soil vapor sample; DEQ expects bore holes to be purged before fixed gas measurements are made.

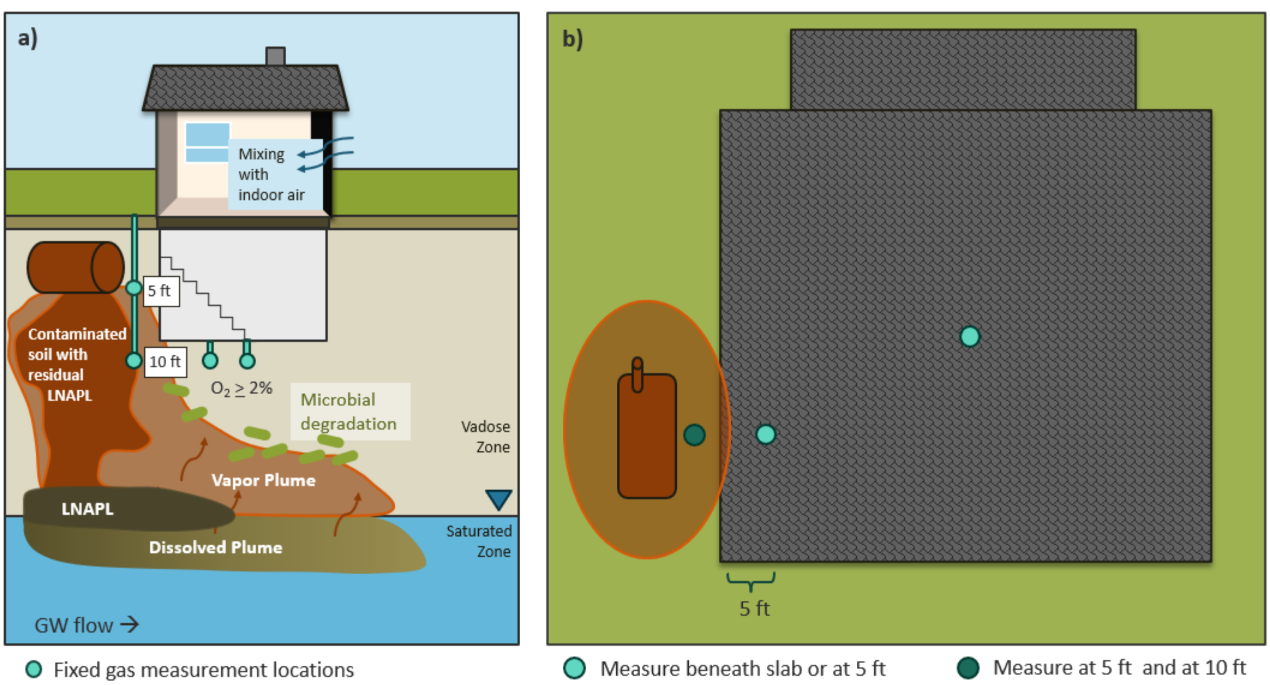

Figure B.2: (a) Cross-sectional view and (b) plan view of fixed gas measurement locations to establish whether biodegradation conditions are present. Measurements beneath the building should be collected at least 5 feet in from the foundation wall.

Contaminated soils vary in distance from the building; fixed gas measurements should characterize the conditions between the building and contamination.

1. Install a fixed gas measuring point outside the house at a location near the HOT for collection of readings from depths of 5 feet and 10 feet below surface grade at the HOT (see Figure B.2). The 5 feet reading must be collected prior to advancing the fixed gas sampling probe to the 10 feet depth. This point might collect data from inside the soil contamination plume which provides a useful baseline for other points of comparison. These measurements will vary based on site conditions and do not need to meet the 2% oxygen standard. DEQ recommends the use of equipment and techniques similar to those used for collection of soil vapor samples to ensure the exclusion of atmospheric air from the measurements.
2. Install two fixed gas reading points under the home (see Figure B.2). Measurements from these two points should be compared to the 2% oxygen standard for establishing biodegradation conditions.

Generally, O_2 levels increase with increasing distance from the contamination source, and PID readings decrease. Demonstrating a gradient helps prove the soil supports biodegradation. Oxygen concentrations greater than 2% indicate conditions that allow for biodegradation. If a zone of biodegradation with oxygen concentrations greater than 2% cannot be documented, then a separate sampling scheme should be used (described below). If fixed gas screening indicates biodegradation is likely but soil vapor RBCs are still exceeded, then proceed with sampling as if fixed gas screening failed.

B.2.6 Soil vapor sampling

For the majority of HOT VI assessments, properly installed and leak-tested temporary soil vapor sampling points will be adequate to characterize the site.

Depending on the extent of soil and/or groundwater impact, the size of the occupied structures, the highest remaining concentrations of contaminants, and other site-specific factors, the number of HOT soil vapor sampling points may vary from the VI guidance. If site conditions vary from scenarios presented in this guidance, reach out to a HOT project manager to discuss a sampling plan that is protective of the occupants of your site.

Soil vapor samples should be collected from locations approximately 5 feet inside the exterior wall nearest the contaminant source in soil or groundwater. Samples taken from borings that are too close to foundation walls may be influenced by exterior air. Guidance for how many samples to collect and specifically where to place soil vapor sample points is found in the flow chart (Figure B.3).

The HOT Program encourages the collection of soil vapor samples from within crawlspaces at depths of five feet below the surface.

- For occupied structures that have a crawlspace under the entire footprint of the structure, ambient air samples may be collected from the crawlspace provided that the crawlspace area is sealed off completely (including the sealing of vents) for a minimum of 3 days prior to collecting the ambient air sample from within the crawlspace. If a furnace is located in the crawlspace area, this technique may be inappropriate due to increased air exchange unless the furnace is shut off for the 3-day waiting period.
- An upgradient outdoor air (ambient) background sample must be collected in conjunction with the crawlspace air sample.
- The detection limit for the contaminant(s) of concern are at or below appropriate RBCs for indoor air.
- No attenuation factor is allowed for ambient air in the crawlspace (i.e., the air concentration detected in the sample collected from the crawlspace is the air concentration that is presumed to be present in the living space of the structure).

Further resources for soil vapor sampling can be found in the main guidance in Section 4.5: *Soil vapor sampling*, copied below for convenience.

- *Advisory - Active Soil Gas Investigations*. California EPA Department of Toxic Substances Control, July 2015.
- *Soil Gas Sampling*. EPA Region 4, April 2023.
- *Sub-Slab Vapor Sampling Procedures*. Wisconsin Department of Natural Resources, July 2014.

Although important, soil vapor samples are less reliable for determining risk when contaminated soil or groundwater is in direct contact with a building foundation. Furthermore, soil vapor sampling may not be possible during certain seasons (e.g., periods of high-water table). Indoor air sampling is most appropriate whenever contaminated media is in contact with a building foundation. Collecting indoor air samples simultaneously with soil vapor samples can make it easier to interpret indoor air data.

B.2.7 Sampling soil vapor in low-oxygen soil

In low-oxygen conditions, biodegradation cannot be relied on to mitigate potential impacts of petroleum vapors. In these situations, additional testing is needed to perform correct assessments of VI pathways. To better account for the low-oxygen conditions, collect three soil-vapor samples along a transect that starts at the source and continues through the center of the structure. Samples should be collected 5 feet from the foundation wall nearest the source, at the center of basement or crawlspace, and 5 feet from the far foundation wall (Figure B.6b).

Releases from HOTs may have unique characteristics. The empirical values used to calculate the Soil Vapor RBCs are based on a source that is present beneath the entire footprint of a building. HOT releases are typically not as large as other petroleum releases and are often localized to one side of a structure. To measure the impact across the entire footprint of a structure, **three**

soil vapor samples should be analyzed at applicable sites. The average of the three soil vapor sample test results should be compared to the soil vapor RBCs to evaluate whether or not indoor air samples are needed. Non-detect values should be included in the average at one-half the detection limit (MDL). The individual lab test results should still be reported to DEQ. If soil vapor data indicates the vapor plume extends beneath the entire foundation, then averaging the test results is no longer appropriate, and the **single highest** soil vapor sample test result for each contaminant of concern should be compared to the appropriate RBCs.

Averaging the test results together balances out the potential high VOC input from the contaminated area beneath one portion of the structure with the low or null contribution from unimpacted areas below the structure. If your soil vapor sample test results show large variation between sample locations or are inconsistent with your CSM, we encourage reaching out to a HOT project manager for discussion.

B.2.8 Seasonality

The risk of vapor intrusion into buildings changes over the course of a year due to weather conditions, the changing depth to groundwater, and the heating and cooling of the home. The highest impacts to indoor air from vapor intrusion usually occur in the late winter and early spring. At other sites, the contaminant levels in soil vapor reach a maximum in late summer and early fall when soil moisture levels are lowest. See Section 4.5.6: *Soil vapor sample timing, frequency, and seasonal variability* in the main guidance document for more information.

It is important to describe the seasonal characteristics of potential vapor intrusion in the CSM. For most commercial and industrial sites, DEQ expects at least two indoor air sampling events during different seasons. DEQ acknowledges that most HOT releases are discovered during residential real estate transactions, and the rapid pace of such a sale may preclude assessment of seasonal fluctuation of soil vapor intrusion. The measures outlined in Appendix B are conservative measures meant to compensate for the typical lack of residential seasonal data to incorporate into risk assessment. Homeowners particularly concerned about vapor intrusion risk may want to ensure that one soil vapor sample is collected in the late summer and/or one indoor air sample is collected in the late winter to early spring.

B.2.9 Indoor air sampling

HOT service providers are generally more familiar with the collection of soil vapor samples than with the collection of indoor air samples. Section 4.6 of the main guidance describes indoor air sampling. An example of an indoor air sample checklist can be found in Appendix D of New Jersey's VI Guidance (NJDEP, 2021).

While sampling soil vapor over variable seasonal conditions is not required, assessment of indoor air conditions may require sampling that is seasonally appropriate. Pressure cycling may be employed in an attempt to induce low indoor pressure that mirrors seasonal high indoor air concentrations.

B.2.10 Engineering controls and deed restrictions

If indoor air testing produces test results above the RBCs, an engineering control such as a soil vapor mitigation system may be selected as the remedy. In this case, the proposed plans should be stamped by a professional engineer, as required by Oregon Revised Statute 627.020 et seq., and submitted to DEQ for review and approval. A deed restriction, called an Easement and Equitable Servitudes (EES), will be required for the property to ensure the proper on-going operation and maintenance (O&M) of the engineering controls. The deed restriction may be removed once contaminant levels drop below the RBCs. Review Section 6: *Vapor intrusion remediation and mitigation* of the main guidance, including the Performance Monitoring Flow Chart for more information regarding vapor remediation systems.

B.3 Heating oil tank vapor intrusion evaluation process

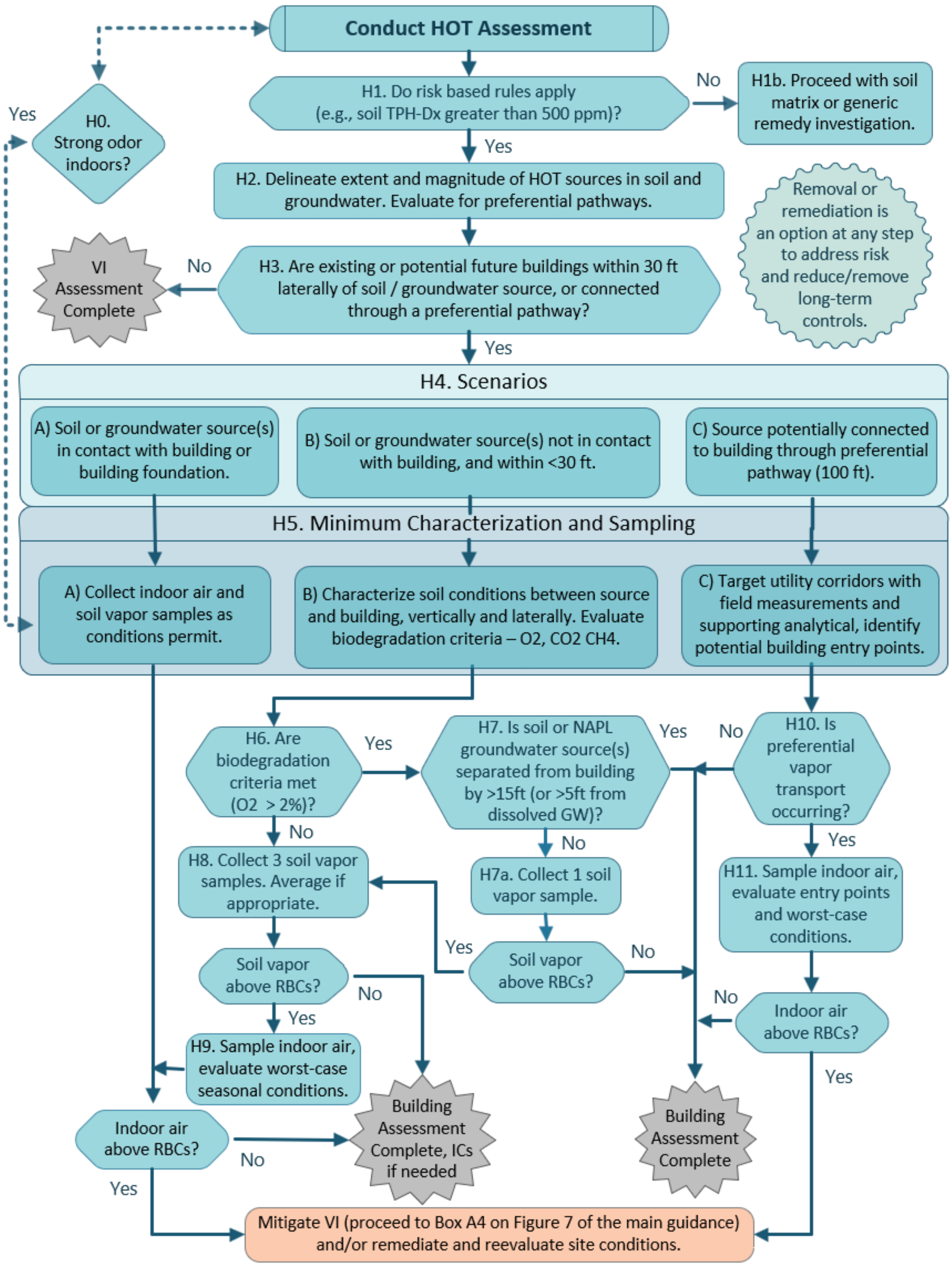

Figure B.3: Flow Chart to Evaluate the VI Pathway for Heating Oil Tank Sites

The HOT project-specific flow chart has been created to facilitate the investigation and decision-making process for VI at HOT sites (Figure B.3). The following section describes the steps from the flow chart in more detail. If indoor air samples exceed RBCs, please refer to the Indoor Air Assessment Flow Chart to evaluate the VI pathway in the main guidance document (Section 3.2, Figure 7).

Box H0. Strong odor indoors?

Strong diesel odors indoors may indicate that a significant release may have occurred if vapors are not related to the presence of an indoor oil tank or furnace. These situations may be due to a sudden release from an underground tank or a large release from the product supply or return lines. The presence of free product or large areas of stained concrete are common signs of a significant impact. In these scenarios, indoor air RBCs are likely exceeded, and remediation and/or institutional controls such as sub-slab depressurization may be needed to address risk. At these highly impacted sites, it is important to move directly to indoor air sampling to evaluate risk to current building occupants. **If indoor air samples exceed RBCs, refer to Appendix A** which describes the DEQ response matrix for indoor air impacts. Then proceed to Box A4 on the Indoor Air Sampling Flow Chart in the main guidance (Figure 7).

Box H1. Do risk-based rules apply?

HOT projects are certified and closed using one of three different evaluation criteria: (i) Soil Matrix standards, [28] (ii) HOT Generic Remedy,[29] and (iii) risk-based closure.[30] If soil TPH-Dx concentrations are greater than Soil Matrix levels, and the site does not qualify for the HOT Generic Remedy, then the project falls under the risk-based closure category by default.

Soil Matrix sites are generally the least complex and HOT Generic Remedy sites represent those with intermediate complexity. As of the writing of this document, closing a HOT site under either the Soil Matrix or HOT Generic Remedy rules does not require a soil vapor investigation. Please refer to the relevant rule or guidance documents to proceed with your HOT project.

Box H2. Delineate extent and magnitude of HOT sources in soil and groundwater. Evaluate for preferential pathways.

It is very important to clearly delineate soil and/or groundwater plumes at HOT sites, especially in soil between the tank, building, and groundwater beneath the building if applicable (Figure B.1). Please read the characterization and delineation text above (Section B.2.2). Contamination in direct contact with the building or sites where there is a preferential pathway into the structure is much more likely to have indoor air impacts. Additionally, soil vapor samples

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[28] Soil Matrix standards are used by the Leaking Underground Storage Tank and Heating Oil Tank Program under 340-122-0320.
[29] DEQ's 2013 Heating Oil Tank Generic Remedy Guidance Document per Administrative Rules Chapter 340 Division 177 and Division 122-0252.
[30] See Section 3 of DEQ's 2003 Risk-Based Decision Making for the Remediation of Contaminated Sites.

collected outside a preferential pathway or away from an area of direct contact between the impacted soil and the outer wall of a foundation will likely fail to identify the risk posed by these direct pathways of exposure.

Box H3. Are existing or potential future buildings within 30 feet laterally of soil or groundwater source, or connected through a preferential pathway?

Determine the separation distance between the contamination source and current or future buildings. Map subsurface utilities that intersect or directly overlie PVI sources in groundwater or soil contamination, including HOT product supply lines, to the buildings they serve.

No – No further assessment of the vapor intrusion pathway is required, and the building assessment is complete.

Yes – Proceed to Box H4: Pathway Scenarios

Soil vapor is very unlikely to travel further than 30 feet from a source, unless there is a preferential pathway that connects the source to the building. See supporting information in the *Site Screening Using Vertical Screening Distance* Section in the ITRC Petroleum Vapor Intrusion Guidance. If all structures are further than 30 feet from a source, there are no plans for further nearby development on the site, and no preferential pathways exist, then no further investigation of soil vapor is necessary. It is important to consider potential future use or development. If structures are installed within 30 feet of the source of contamination, those structures should be evaluated for vapor intrusion. It may be necessary to implement institutional controls (EES or deed restrictions) at a site to formally prevent development within 30 feet of a HOT leak.

Box H4 and H5. Pathway scenarios and associated minimal characterization and sampling.

Each building located within a zone with potential VI impacts should be assessed separately. The approach will vary depending on the building's location relative to the source of contamination and its foundation design. Identify which scenario is occurring at your site and proceed to the page describing that scenario.

Scenario A: Soil or groundwater source(s) in contact with building or building foundation.

Scenario B: Soil or groundwater source(s) not in contact with building and within 30 feet.

Scenario C: Source potentially connected to building through preferential vapor transport pathways.

Scenario A: Soil or groundwater source(s) in contact with building or building foundation.

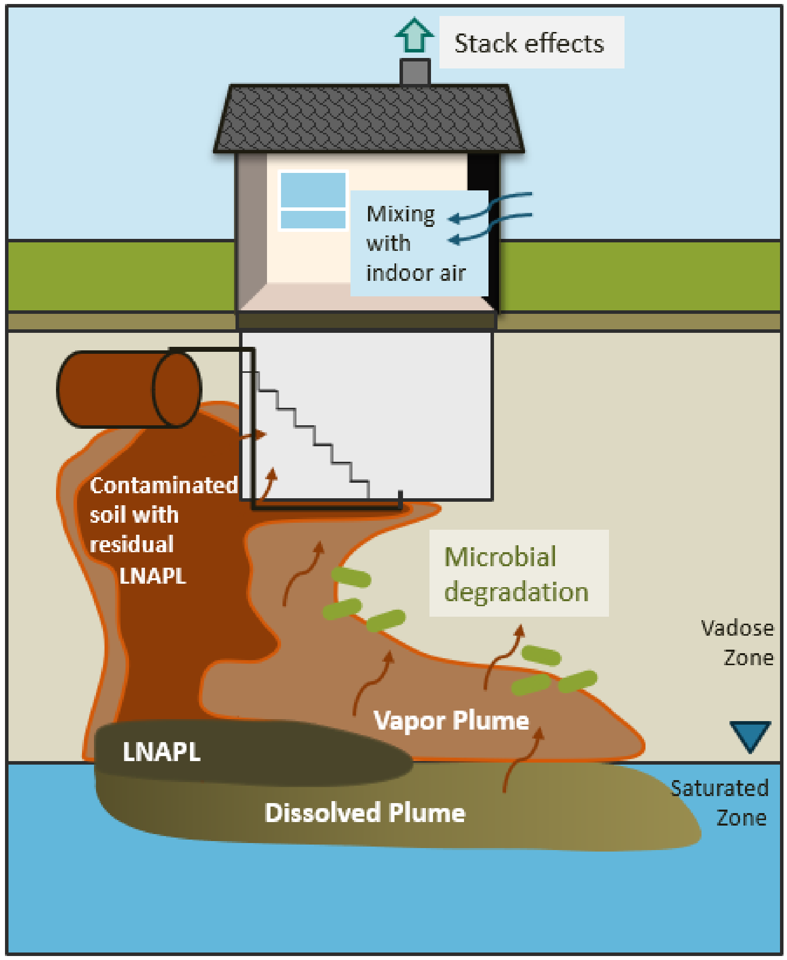

Figure B.4: Scenario A: Soil sources in contact with building. Line leaks are also of particular concern as they can produce strong VI impacts.

Contaminated soil or groundwater sources in contact with the building pose a high risk for vapor intrusion. In these scenarios, proceed directly to indoor air sampling. Paired indoor air and sub-slab vapor samples are preferable but may not be possible in situations where groundwater is in contact with the building.

Line leaks are also of particular concern and may present another mechanism for contamination to be released in direct contact with the building. If you have high soil vapor results or PID readings, consider checking for line leaks. Galvanized steel lines are more likely to corrode, causing leaks.

In cases where contaminated soil is in contact with the foundation, targeted soil removal can be used to disrupt direct contact and allow characterization of the site from a different perspective. It can be difficult to mitigate line leaks with a vapor remediation system; removal may be the best option. If contaminated soil is removed from direct contact with a foundation, low-permeability material should be considered as a replacement for the removed soil. The use of typical fill materials like sand or gravel may create a preferential pathway connecting the source and structure that negates any benefit from the soil removal.

If indoor air samples exceed RBCs, refer to Appendix A which describes the DEQ response matrix for indoor air impacts. Then proceed to Box A4 on the indoor air sampling flow chart in the main guidance (Figure 7).

Scenario B: Soil or groundwater source(s) not in contact with building and within 30 feet.

If buildings are separated from the contamination source, there is the possibility that biodegradation may reduce the risk posed by vapor intrusion. In these scenarios, characterize soil conditions between the source and a building to demonstrate whether the right soil conditions are present to allow for biodegradation. Specifically, oxygen concentrations of greater than 2% oxygen in soil support biodegradation (ITRC, 2014), and the other fixed gases (CO_2 and methane) can be used to support the oxygen measurement.

See Section B.2.5: *Fixed gas screening at HOT sites* and Figure B.3 for information on how to measure fixed gases (O_2, CO_2, methane). Using a field measure instrument is appropriate if it has been properly calibrated. See Section B.2.4: *HOT biodegradation* for more information, as well as the checklist in Section B.5 and Figure B.5

Box H6. Are biodegradation criteria met?

Biodegradation criteria can be established by demonstrating that O_2 measurements are consistently greater than 2% and the other fixed gases support this result. If biodegradation criteria are met, then proceed to Box H7 to evaluate the separation distance. If biodegradation criteria are not met, proceed to Box H8 to collect three soil vapor samples.

Box H7. Separation distance between source and building

If the structure is separated from the contaminated soil source or a NAPL source by at least 15 feet and biodegradation criteria are met (Box H6), then the collection and testing of soil vapor samples is not required. The building assessment is complete. Groundwater concentrations of TPH-Dx above 6,800 ppb are considered indicative of NAPL (DEQ, 2003).

If the structure is separated from a dissolved GW plume by at least 5 feet, then the collection and testing of soil vapor samples is not required. The building assessment is complete.

If biodegradation criteria are met and the distance to a structure – or future structure – is less than 15 feet (soil/NAPL) or 5 feet (dissolve GW plume), proceed to Box H7a and collect and test at least one soil vapor sample. See Section B.2.6: *Soil vapor sampling* and Figure B.6a for information on how to sample soil vapor.

- If test results from that single soil vapor sample are below soil vapor RBCs, then the building assessment is complete.
- If the test results from the first soil vapor sample exceed RBCs, then two more soil vapor samples should be collected and tested. See Section B.2.7: *Sampling soil vapor in low-oxygen soil* and Figure B.6b for more information. Proceed to Box H8.

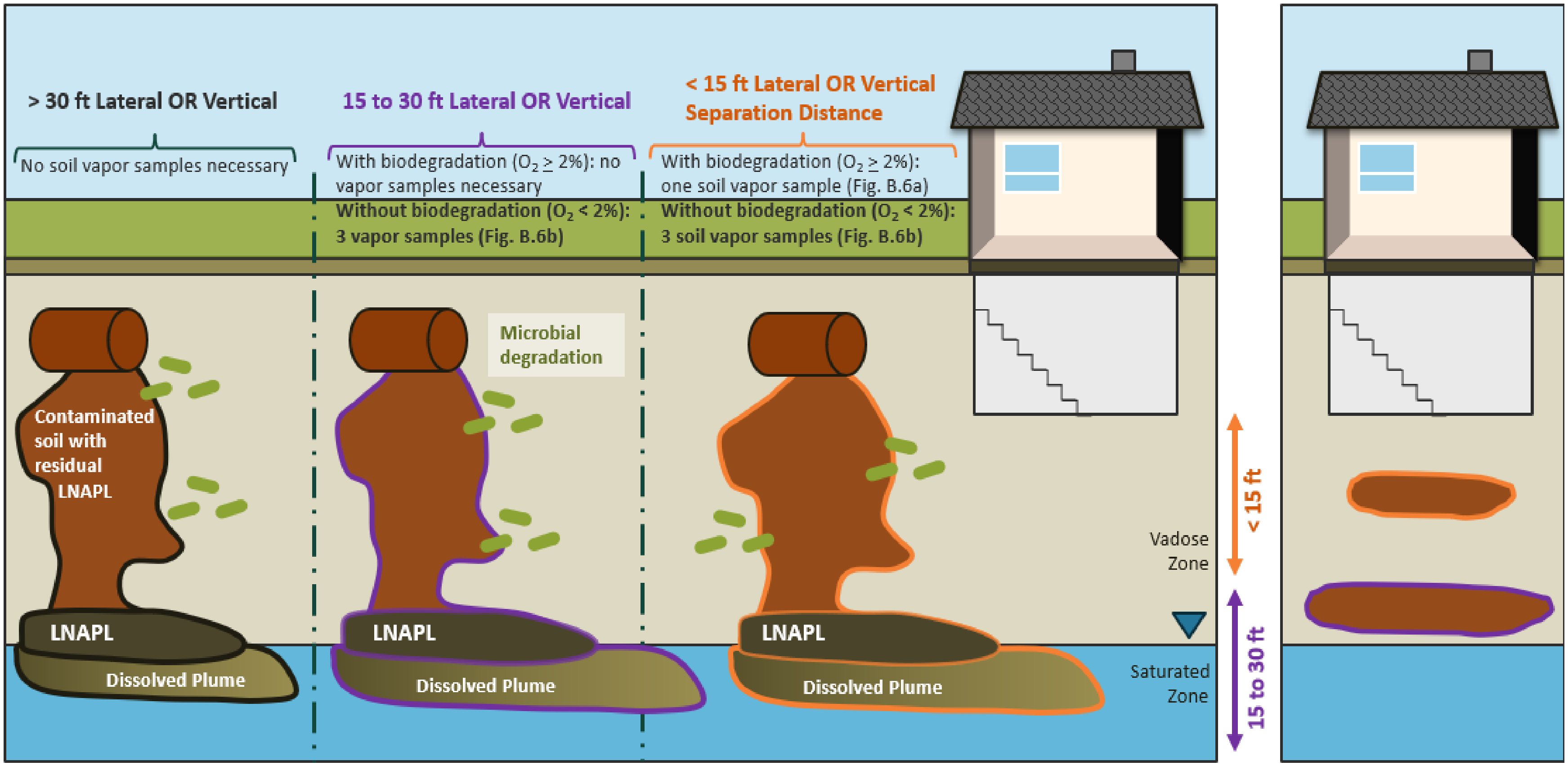

Figure B.5a: Soil vapor sampling with lateral distance for a soil source

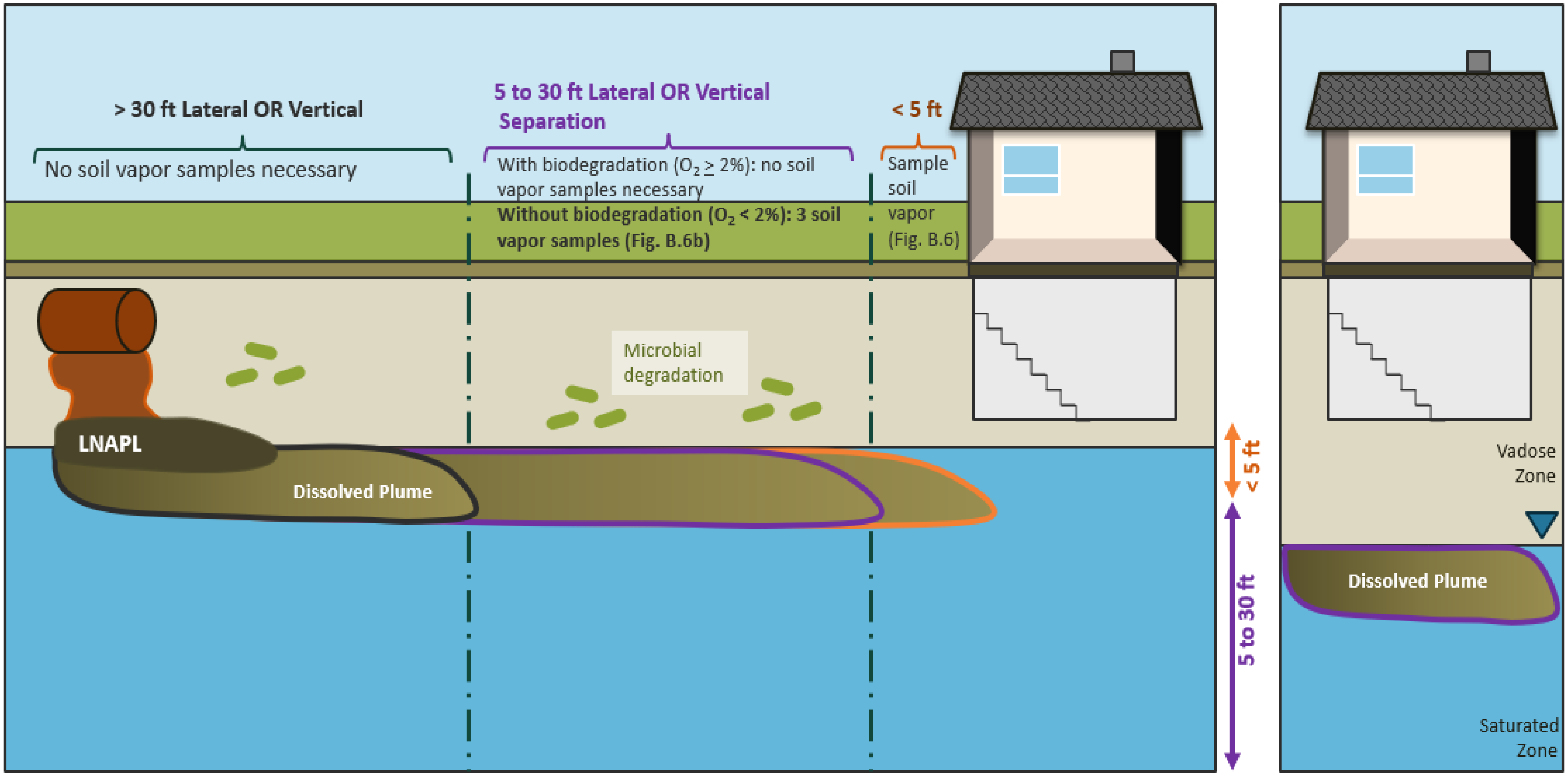

Figure B.5b: Soil vapor sampling with lateral distance for a dissolved groundwater source. Groundwater concentrations of TPH-Dx above 6,800 ppb are considered indicative of NAPL (DEQ, 2003).

Box H8. Collect three soil vapor samples.

If biodegradation criteria are not met, or if a single soil vapor sample exceeded RBCs, then three soil vapor samples should be collected at a typical residential building and tested beneath the structure as shown in Figure B.6b. See Section B.2.6: *Soil vapor sampling* for information on how to sample soil vapor. Note that for buildings larger than 4,500 square feet, refer to Table 3 in the main guidance, and reach out to your DEQ project manager to identify the appropriate number of soil vapor samples.

This testing scenario is appropriate if biodegradation criteria are not met (that is, the O_2 concentrations are below 2%) and the source is not in direct contact with the structure and is less than 30 feet away. This scenario also applies if you have established biodegradation conditions but test results from the single soil vapor sample exceed RBCs.

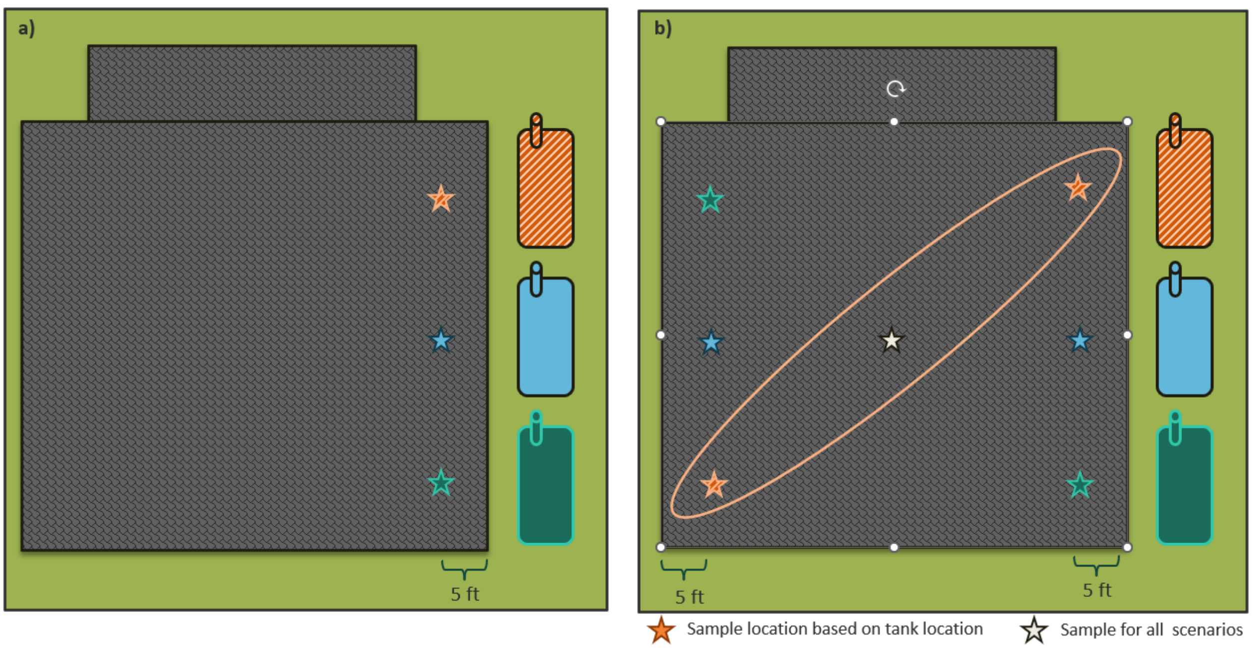

Figure B.6: Plan view and map view of (a) a single sampling location and (b) three sample locations based on tank location. Soil vapor samples should be collected from beneath the building at least 5 feet in from the foundation wall.

In most situations, the average of the test results of the three samples can be compared to the RBCs. The recommendation to collect three samples for testing is to evaluate the conservative assumption that the vapor plume is beneath the entire structure.

If test results indicate the presence of vapor in all three sampling locations, then averaging is not appropriate, and the highest soil vapor sample test result should be compared to the RBCs. If RBCs are exceeded in either of these scenarios, proceed to Box H9.

Scenario C: Source potentially connected to building through preferential vapor transport pathways.

If buildings are potentially connected to a source through a preferential pathway, vapors can migrate over much larger distances (Figure B.7). No maximum distance has been identified for vapor migration along a preferential pathway, and transport of more than 200 feet along a line has been observed in Oregon. In these scenarios, targeted investigation is needed. The depth, alignments, and building entry points should be identified. Gas measurements with a PID, FID or similar device should be used to investigate vaults, the utility lines if possible, and the utility trench backfill as close to the building entry points as feasible. See Section B.2.5: *Fixed gas screening at HOT sites* for information on how to measure fixed gases (O_2, CO_2, methane). Note that a subset of points investigated can be analyzed for VOCs to correlate PID/FID readings to laboratory test results. Preferential pathways can also occur naturally in specific geological conditions, see more here: [ITRC PVI-1 (itrcweb.org)](itrcweb.org).

Preferential pathway scenarios are site-specific and it is recommended to reach out to a HOT project manager to ensure your soil vapor investigation plan addresses risk.

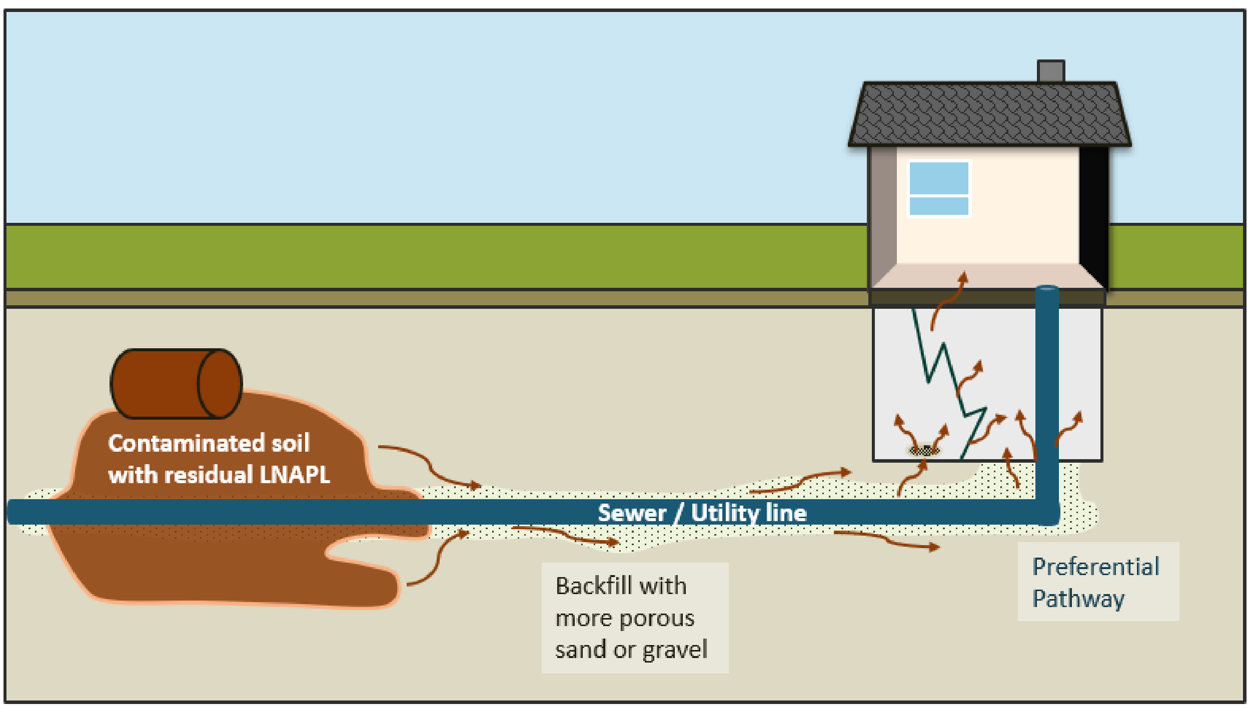

Figure B.7: Cross-sectional view of preferential pathways that facilitate vapor transport along long distances to enter the structure. Examples shown include a basement drywell drain or unsealed sump pump, a sewer line that transects the contaminated soil, and a large crack in the foundation wall of the structure.

For all scenarios:

Box H9 and H11. Indoor air samples.

Refer to Section B.2.9: *Indoor air sampling* and main guidance Section 4.6: *Indoor air sampling* for information on how to sample indoor air. Consider building-specific conditions, typical HVAC operation, barometric pressure, and seasonal impacts on vapor intrusion (Section B.2.8). For example, sample indoor air in late winter to early spring to capture maximum VI impacts. Pressure cycling may also be used to induce lower indoor pressures that mirror the seasonal high indoor air concentrations.

To sample indoor air for all contaminants of concern related to heating oil, both TO-17 and TO-15 methods may be necessary.

If indoor air samples exceed RBCs, refer to Appendix A which describes the DEQ response matrix for indoor air impacts. Then proceed to Box A4 on the indoor air sampling flow chart in the main guidance (Figure 7).

If indoor air sample results do not exceed RBCs, then the building assessment is complete.

Treatment or removal of PVI sources. Treatment or removal of PVI sources should be considered if indoor air RBCs are exceeded or to reduce or eliminate subsurface sources to minimize/remove long-term risk-management obligations. Sometimes, not all contaminated soil is accessible for removal. Partial removal of contaminated soil can still be helpful for addressing VI risk. When removal is complete at a site, give careful consideration to project milestones as shown on the flow chart (Figure B.3). Documentation indicating where a project should re-enter the workflow should be included in the final report.

B.4 Additional considerations

The potential for VI at neighboring structures should be evaluated according to the same process as the subject site structures, following the flow chart (Figure B.3). Be sure to obtain consent from any neighboring property owners, if applicable. If fixed gas measurements indicate conditions are suitable for biodegradation and the separation distances are met, then the VI assessment of that building may be complete (Figure B.8).

Additionally, future construction of a building within 30 feet of a leaking HOT should be considered when assessing a site. Soil vapor samples from within the footprint of the future structure may help assess future VI risk.

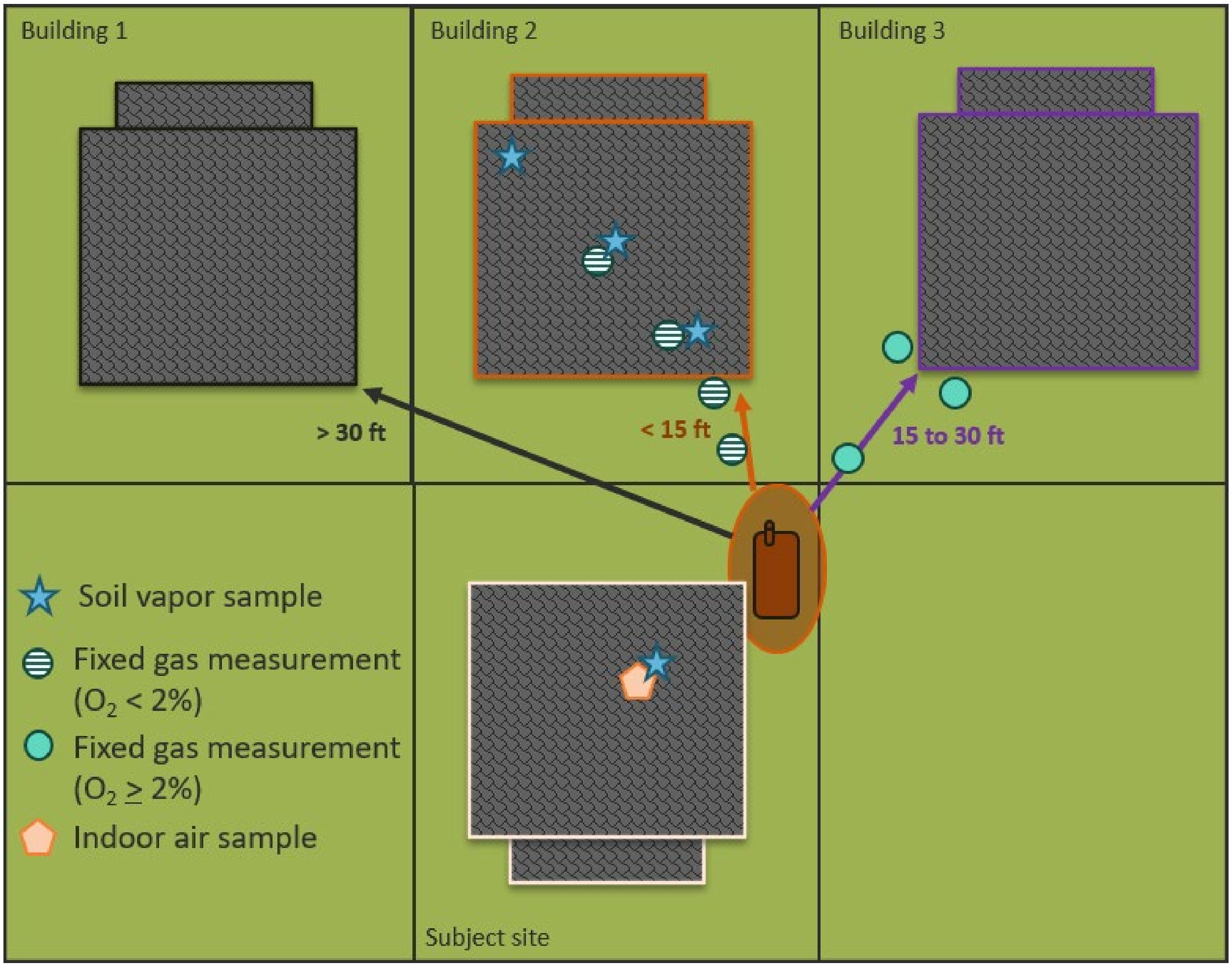

Figure B.8: Sampling at neighboring properties. Structures on neighboring properties may need to be sampled depending on distance from contaminated soil and whether biodegradation criteria can be established. Note that requesting access to a neighbor's property may take additional time. This figure shows a potential assessment strategy. At the subject site, because contamination is in contact with the building, sample collection proceeds directly to paired indoor air and soil vapor sampling. At Building 3, because the distance to source is between 15 and 30 feet, fixed gas measurements are collected between the source and the building. When all the O_2 measurements are greater than 2%, indicating conditions support biodegradation, the building assessment is complete. For Building 2, because the distance to the source is less than 15 feet and the O_2 measurements are below 2%, soil vapor samples are collected. At Building 1, no building assessment is needed because it is separated from the source by a distance greater than 30 feet.

B.5 Checklists for HOT program vapor intrusion evaluation

These series of checklists are intended to assist report writers and field technicians with assessing VI risk following the HOT Appendix guidance. Using this checklist will help ensure a thorough investigation has been conducted at a site to prepare for certification. Attach a completed checklist to each risk-based report.

B.5.1 Soil sampling checklist

- ☐ Appropriate sample locations for vertical (depth) delineation:
  - Near location of most contaminated assessment sample
- ☐ Appropriate sample locations for horizontal (lateral) delineation:
  - Between tank and building
  - Note that delineation of contaminated soil beneath a building may be needed if a clean soil boring cannot be established between the HOT and the building; borings through-slab on-grade foundations, or within basements or crawlspaces may be needed.

B.5.2 Preferential pathways

Conduct records research first: historic plumbing records, if available, may depict abandoned on-site septic lines related to connection to municipal sewage lines in older buildings. Conduct in-person assessment to identify points where utilities enter the basement, any large openings or cracks in a foundation, and the depth of utility corridors in relation to the plume. Take photos to document condition of foundation and present them in the certification report. Use multiple lines of evidence to support the CSM.

B.5.3 Biodegradation checklist

- ☐ If no fixed gas measurements will be collected, proceed to **B.5.5**
- ☐ Appropriate location(s) for fixed gas measurements (see Figure B.2 / Figure B.8 for neighbors)
- ☐ Fixed gas meter calibration date: ____________
- ☐ PID calibration date: _______________
- ☐ Percentages for all fixed gases at measurement points:

Table B.1: Fixed gas percentages (as applicable)

Location and depth	O_2 %	CO_2 %	CH_4 %	PID
Near HOT 5 feet				
Near HOT 10 feet				
5 feet from wall				
Center of building				
Neighbor				
Neighbor				
Neighbor				

B.5.3.1 Soil vapor sampling (oxygen 2% or greater) checklist

- ☐ Contaminated media not in contact with the structure?
- ☐ Do methane and CO_2 concentrations support biodegradation scenario (as O_2 decreases CO_2 and CH_4 typically increase)?
- ☐ If criteria are met, collect one soil vapor sample 5 feet from the foundation wall. If the structure has a basement, collect a soil vapor 6 inches below the sub-slab. For a crawlspace, collect a soil vapor sample 5 feet deep.
- ☐ Use checklist B.5.6 for sample collection.
- ☐ Photo of the sample point and the collection setup taken
- ☐ Consider neighboring structures (see Figure B.8)
  - o Is a soil vapor sample necessary between plume and neighboring property/properties?
  - o Ask for permission to collect neighboring soil vapor samples.

If oxygen is less than 2% beneath structure, proceed to B.5.3.1.

B.5.3.2 Soil vapor sampling (oxygen less than 2%) checklist

- ☐ Contaminated media not in contact with the structure?
- ☐ Appropriate sample locations for soil vapor sampling for laboratory analysis: 6 inches below sub-slab (basement) or 5 feet deep (crawlspace)?
  - o 5 feet from wall of foundation at the point nearest to the contaminant plume
  - o Center of building
  - o Five feet from opposite wall of building, following a line through first two sampling locations.
- ☐ Consider neighboring structures (see Figure B.8)
  - o Is a soil vapor sample necessary between plume and neighboring property/properties?
  - o Ask for permission to collect soil vapor samples on neighboring properties.

B.5.4 Soil vapor sampling checklist

- ☐ Sampling method and analysis appropriate for site? The following combinations of test methods may be appropriate for a given site:
  - TO-15 for BTEX and naphthalene + TO-17 for TPH-Dx (suitable for low detection limits)
  - TO-17 for TPH-Dx, BTEX, and naphthalene
  - Other (please explain)

    ____
- ☐ Appropriate sample container (check all applicable)
  - Evacuated Canister (TO-15)
  - Sorbent Tube (TO-17)
- ☐ Appropriate tubing?
  - PEEK
  - PTFE
  - Stainless Steel
  - Other (please explain)

    ____
- ☐ Appropriate sample depth(s)?
  - Sub-slab soil vapor (basement or slab-on-grade construction): immediately below slab, usually no more than six inches
  - Typical soil vapor: 5 feet below the ground surface within the crawlspace or outdoors
- ☐ Appropriate seal for typical soil vapor borehole and/or sub-slab sampling point?
    - Indicate type of seal used:

      ____
- ☐ Appropriate equilibration time allowed? (Minimum of 30 minutes from the time the probe is installed to the time when purge, leak check, and sampling is conducted).
- ☐ Appropriate purging prior to sample collection?
  - Purge minimum of two borehole volumes
  - Indicate how sample train was purged:

    ____
- ☐ Appropriate flow rate?
  - Less than 200 mL/minute for TO-15
  - Low flow vacuum pump set at 50 ml/minute for TO-17 analysis
- ☐ Appropriate leak detection? Helium shrouds and 2-Propanol are common, no more than 5% leak allowed.
  - Type of leak detection used:

    ____
- ☐ Appropriate sample time and volume?
  - TO-15, appropriate starting and ending pressure (usually a drop of 20 mm Hg)
  - TO-17, usually 1 L of air required to pass over sampling media for appropriate detection limits.

B.5.5 Indoor air sampling checklist

Note that this includes air samples collected from the crawlspace of a residence.

- ☐ Have indoor sources been addressed? Consider furnace, cleaning supplies, paint, household chemicals, and other potential VOC sources.
- ☐ Consider completing an indoor air questionnaire to help identify factors that impact indoor air quality. An example is presented in Appendix G of ITRC's 2007 Vapor Intrusion Guidance Document.
- ☐ Take a photo of the sample set up to include in the report.
- ☐ Sampling method and analysis appropriate for site?
  - TO-15 for BTEX and naphthalene + TO-17 for TPH-Dx
  - TO-17 for TPH-Dx, BTEX, and Naphthalene
  - Other (please explain)

    ____
- ☐ Appropriate indoor air sample collection time (refer to Section 4.6: *Indoor air sampling* in main guidance)

No attenuation factor is allowed for ambient air samples collected from the crawlspace of a habitable structure. If conducting air sampling, detection limits must be at or below applicable inhalation RBCs.

Appendix C

Development of risk-based concentrations for air

C.1 Cleaner Air Oregon Program

Because there are often questions about the applicability of Air Quality rules to remediation systems, we provide an explanation of DEQ's Cleaner Air Oregon Program in this appendix. Cleaner Air Oregon is a health-based toxic air contaminant regulatory program that closes gaps in DEQ's existing air permitting program which allowed some facilities to operate legally but still emit pollutants that could increase health risks to neighbors. CAO Program rules were adopted in November 2018 and revised in November 2021. Facilities are required to report emissions of toxic air contaminants and calculate potential health risks to people nearby. Facilities would have to reduce risk from their emissions of air toxics if calculated air concentrations result in risks that exceed health risk benchmarks, called Risk Action Levels.

Larger new facilities applying for an air permit need to identify potential toxic air contaminant emissions and assess associated risks before submitting their permit application. Most new facilities applying for coverage under Basic or General Air Contaminant Discharge Permits will not be required to perform assessments at this time.

Existing facilities are not required to perform risk assessments until DEQ notifies them that they are called in to the program, unless they are making a major modification to their facility. DEQ called in the first group of existing facilities in early 2019 based on the results of a prioritization process. The process considered types and amounts of emissions, information about existing controls and the surrounding community, and other factors.

C.1.1 CAO applicability and usefulness

CAO Program rules do not apply to vapor intrusion and would rarely apply to Cleanup Program remediation system projects. However, there are many relevant elements of the CAO Program that can be used by the Cleanup Program either directly or with some modification. These include the following:

- Extensive list of cancer and chronic non-cancer RBCs
- Acute non-cancer RBCs
- For vapor treatment systems:
    - Default air dispersion modeling results incorporated into a look-up table
    - Tiered approaches for assessing risk

As appropriate, the following sections incorporate applicable elements of the CAO Program.

C.2 Chronic air RBCs

C.2.1 DEQ air screening values

DEQ's Cleanup Program currently has risk-based concentrations (RBCs) for air to protect residents and workers. DEQ's CAO program specifies chronic air RBCs for residents, non-residential children (e.g., schools, daycare) and workers. CAO RBCs are specified in rule OAR 340-245-8010 Table 2. However, CAO rules do not apply to vapor intrusion. CAO rules would generally only apply to Cleanup Program projects if a new treatment system were constructed that would either emit substantial amounts of VOCs or would result in substantial risk.

There are CAO RBCs for over 250 chemicals, more than twice the number of chemicals with Cleanup RBCs in 2018. Even though CAO rules do not apply to vapor intrusion, it is reasonable to address the relevance of CAO RBCs. The exposure assumptions used in the CAO Program for chronic exposure are more appropriate for statewide or airshed exposure and do not match the typical exposure assumptions for a cleanup site. For example, the CAO Program assumes a 70-year lifetime of exposure for residential exposure, whereas the Cleanup Program uses an upper bound of 26 years for living in an individual residence. Occupational exposure assumptions are the same in both programs.

Another element of CAO Program RBCs is that they include multi-pathway adjustment factors to incorporate exposure to persistent and bioaccumulating chemicals that may be deposited to soil and result in exposure by pathways other than inhalation. These types of indirect exposure, such as contact with soil or consumption of produce grown in soil contaminated by air deposition, are not relevant to exposure through vapor intrusion.

CAO Program RBCs can provide a resource for additional applicable RBCs in the Cleanup Program as long as there is appropriate consideration of exposure assumptions. This would include adjustment of exposure duration for residential exposure and removal of multi-pathway adjustment factors for both residential and occupational exposure.

C.2.2 EPA air screening values

EPA maintains a table of risk-based screening values called regional screening levels (EPA 2023). EPA's RSLs for air are generally equivalent to DEQ Cleanup Program RBCs. The air RSLs are for chronic effects, not acute effects. The RSL table is updated semiannually and includes many more chemicals than DEQ's older RBC table. For these reasons, DEQ's Cleanup Program now evaluates and, as appropriate, incorporates EPA air RSLs directly as DEQ air RBCs for chronic screening. Chronic air RBCs are provided separately for cancer and noncancer risks in the associated vapor intrusion RBC spreadsheet.

C.3 Chronic vapor intrusion RBCs

EPA's VISL calculator can provide soil vapor to indoor air and groundwater to indoor air vapor intrusion screening values for default residential and worker exposure scenarios. DEQ incorporated default residential and worker soil vapor screening values directly as RBCs. A modification was made to groundwater screening values: the average groundwater temperature was revised from the default value of 25° C to the mean Oregon value of 12.5° C. Chronic soil vapor and groundwater vapor intrusion RBCs are provided in the associated vapor intrusion RBC spreadsheet.

C.4 Acute air RBCs

Previously, Cleanup Program default RBCs were developed only for chronic exposure, and we also provided an option to calculate construction and excavation worker RBCs based on short-term exposure (nine days) using subchronic toxicity values rather than chronic values. However, we did not have acute RBCs for shorter-term exposures on the order of 24 hours or less. Acute exposure to high concentrations is typically not encountered at cleanup sites. However, in some circumstances, acute exposure can be important for indoor vapor, especially for chemicals with developmental effects. For these chemicals, exposures of a few hours to a few days could result in adverse health effects. Therefore, DEQ's Cleanup Program decided to incorporate acute RBCs into the vapor intrusion screening process.

To address short-term risk from toxic air contaminates in ambient air, DEQ's CAO Program developed acute air RBCs for about 100 chemicals. As part of this development, DEQ evaluated toxicity reference values (TRVs) from:

- Oregon Health Authority (OHA) and DEQ Air Quality Program short-term values.
- The Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profiles, acute minimal risk levels, and intermediate minimal risk levels.
- California's Office of Environmental Health Hazard Assessment (OEHHA) acute reference levels (RELs).

The resulting acute RBCs are established in rule (OAR 340-245-8010 Table 2). Given the extensive scientific review effort by DEQ and OHA to develop acute TRVs, and the external stakeholder review that was part of the rule-making process, DEQ's Cleanup Program is confident in using existing acute RBCs from the Air Quality Program as the basis for acute RBCs in the Cleanup Program. However, because of differences in application of RBCs in the different programs, some modification of CAO Program acute RBCs is needed as discussed in the next section.

C.4.1 Development of acute air RBCs for the Cleanup Program

The CAO Program uses one set of acute RBCs with application to all potential exposure scenarios, such as residential, occupational, school, or park user. This is a protective approach.

According to CAO rules, acute exposure applies if someone is present more than a few hours in a day. The air concentration is modeled (or measured) as a 24-hour average. Very few acute TRVs, which serve as the basis for acute RBCs, are based on exposures less than 24 hours.

In the Cleanup Program, vapor intrusion exposure is evaluated in buildings with known or reasonably likely uses. For residential exposure, the default assumption is that a resident will be present 24 hours per day. In these cases, CAO Program acute RBCs are appropriate screening values. For occupational exposure, the default assumption is that a worker will be present at the workplace 8 hours per day. DEQ considers it appropriate to take into account this difference in exposure frequency when developing occupational acute RBCs from CAO Program acute RBCs. We therefore applied a factor of 3 (24 hours divided by 8 hours) to CAO Program acute RBCs to calculate Cleanup Program acute RBCs for occupational exposure. Residential and occupational acute RBC air values are provided in the associated vapor intrusion RBC spreadsheet.

C.5 Acute vapor intrusion RBCs

EPA's VISL calculator could not be used for developing acute vapor intrusion RBCs because the bases for the EPA calculations are chronic air screening values. However, vapor intrusion RBCs are directly proportional to air RBCs, so DEQ developed acute vapor intrusion RBCs by multiplying the acute RBC by the ratio of chronic vapor intrusion RBC to chronic air RBC. The resulting acute vapor intrusion RBCs for soil vapor and groundwater are provided in the associated vapor intrusion RBC spreadsheet.

Appendix D

Other agency regulatory responses to TCE exposure

In December 2012, EPA Region 10 issued a memorandum with recommendations for the Northwest states regarding evaluation of short-term exposure to TCE (EPA 2012). EPA noted that the Integrated Risk Information System (IRIS) evaluation provided recommendations on toxicity values for chronic noncancer and cancer exposure but not for acute exposure. However, the IRIS Toxicological Profile based the RfC and RfD in part on immunotoxic and developmental effects, including fetal cardiac malformations that may occur when the mother is exposed to TCE during a 21-day early gestation window. Region 10 took this information and recommended acute levels for residential and occupational exposure. EPA recommended that these acute TCE levels to protect against fetal heart malformations be considered as not-to-be-exceeded concentrations averaged over any 21-day period when women of reproductive age may be exposed. If these concentrations are exceeded, measures to expeditiously reduce exposure should be considered. The 2012 memorandum did not discuss potential response actions.

In July 2014, EPA Region 9 issued a memorandum intended to identify those TCE exposures that exceed the RfC by a magnitude sufficient to warrant a more urgent response (EPA 2014). Region 9's practice is to immediately initiate response action to address exposures at or above an HQ = 3 level. EPA Region 9 developed a tiered response approach, as follows:

- HQ ≤ 1. For indoor air TCE concentrations at or below HQ of 1, EPA recommends routine periodic confirmation sampling and/or monitoring, as appropriate.
- HQ > 1. For indoor air TCE concentrations greater than HQ of 1, but less than HQ of 3, EPA recommends an accelerated response action that would implement early or interim mitigation measures within a few weeks. These potential actions include:
  - Increasing building pressurization and/or ventilation
  - Sealing potential conduits where vapors may enter the building
  - Treating indoor air using carbon filtration, air purifiers, etc.
  - Installing and operating engineered exposure controls, such as sub-slab or crawlspace depressurization systems
- HQ > 3. For indoor air TCE concentrations greater than 3, EPA recommends mitigation measures be initiated immediately, within a few days, to reduce air concentrations to a level with an HQ less than 1. EPA notes that temporary relocation of residents or workers may be indicated.

In 2014, California's San Francisco Bay Regional Water Quality Control Board supported EPA Region 9's recommendations for accelerated and urgent response action levels (SFRWQCB, 2014), as did the California EPA Department of Toxic Substances Control (CalEPA, 2014).

In October 2019, Washington Department of Ecology issued guidance addressing short-term exposure to TCE. They based their approach on recommendations in the memoranda from EPA Regions 10 and 9. Ecology updated their prior draft guidance to address three issues:

- Need for a rapid response to protect a fetus from unacceptable TCE exposures
- Focus on women of childbearing age (to prevent harm to a fetus before the mother may know she is pregnant)
- Public outreach to promptly contact potentially exposed people to:
  - Identify women of childbearing age
  - Explain the potential health hazards to building occupants
  - Obtain permission to access buildings for investigation and exposure reduction, if warranted

Ecology incorporated the terms **accelerated** and **urgent response action levels**, which will also be used by DEQ. They apply the 21-day exposure averaging period discussed by EPA Region 10. However, Ecology also recommends that if any 24-hour (for residential exposure) or 8-hour (for worker exposure) measurement of indoor air TCE concentrations exceed their action levels, prompt action should be taken to either reduce those concentrations or reduce the degree to which women of childbearing age are exposed.

Appendix E

Managing air discharges from remedial systems

Appendix E

Guidance for Managing Hazardous Substance Air Discharges from Remedial Systems

March 2025

Table of Contents

Acronyms

BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CAO	Cleaner Air Oregon
CAP	Corrective Action Plan
CSM	Conceptual Site Model
DEQ	Oregon Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
EQC	Oregon Environmental Quality Commission
FID	Flame Ionization Detector
FS	Feasibility Study
GAC	Granular Activated Carbon
HQ	Hazard Quotient
LUST	Leaking Underground Storage Tank
MPE	Multi-Phase Extraction
MTBE	Methyl Tertiary-Butyl Ether
NIOSH	National Institute of Occupational Safety and Health
OAR	Oregon Administrative Rules
ORS	Oregon Revised Statutes
PID	Photoionization Detector
RBC	Risk-Based Concentration
SSD	Sub-Slab Depressurization
SVOC	Semi-Volatile Organic Compounds
SVE	Soil Vapor Extraction
TPH	Total Petroleum Hydrocarbons
UST	Underground Storage Tank
VI	Vapor Intrusion
VIM	Vapor Intrusion Mitigation
VOCs	Volatile Organic Compounds

1.0 Introduction

Cleanup of sites contaminated with volatile chemicals, such as gasoline and solvents, often requires purging or extracting of the volatile components from groundwater or soil vapor and discharging these chemicals into the atmosphere. If left untreated, the discharge of "effluent vapor" from a remedial system can produce unacceptable health risks to people living or working in the area. Removing contaminants from soil and groundwater may be a critical step to protect human health and the environment over the long term; however, transferring these chemicals to the air may, in fact, increase exposures in the short term. Oregon's environmental cleanup rules require DEQ to consider the effectiveness of a proposed site remedy and the potential risks posed by implementing the remedy itself on human health and the environment.

This guidance document is designed to help: 1) evaluate effluent vapor (i.e., emissions) associated with remedial actions; and 2) determine under what circumstances treatment of effluent vapors from remedial systems (i.e., remediation and/or vapor intrusion mitigation) is necessary prior to discharge to the atmosphere. This document provides information on assessment methods, compliance point locations, screening criteria for evaluating potential impacts from remedial system emissions containing hazardous substances, and incorporates applicable Cleaner Air Oregon (CAO) rules. This guidance supersedes the original, which was published in 2006.

1.1 Document overview

The document is divided into the following sections:

Section 1: Introduction. Introduces scope, applicability, and regulatory authority to appropriately manage effluent vapor from remedial systems at environmental cleanup sites.

Section 2: Evaluate Vapor Discharge from Remedial Systems. Describes the process to assess remedial system emissions starting with an initial screening utilizing modeling protocols developed by CAO and if needed conducting a site-specific air dispersion model on a case-by-case basis.

Section 3: Remedial System Operation. Describes minimum performance monitoring expectations when vapor treatment is necessary or alternatively verifying model results.

1.2 Application

This guidance applies to the remediation of contaminated soil vapor, soil, or groundwater under Hazardous Substance Remedial Action Rules (OAR 340-122-0010 through 340-122-0115) and Cleanup Rules for Leaking Petroleum Underground Storage Tank (UST) Systems (OAR 340-122-0205 through 340-122-0360). This guidance is applicable to remediation and mitigation systems that emit effluent vapor containing hazardous substances into the atmosphere at environmental cleanup sites in Oregon. Examples of remediation systems that contain a vapor management component include soil vapor extraction (SVE), multi-phase extraction (MPE), thermal remediation, and air stripping. An evaluation of vapor intrusion mitigation (VI mitigation or VIM) systems that extract and discharge effluent vapors is also required. For example, active mitigation systems such as sub-slab depressurization (SSD), should assess potential impacts of emissions which typically occurs utilizing a stack (or riser pipe) to convey vapor to the building roof top. Passive mitigation systems may also warrant an evaluation of emissions and at minimum an initial screening of whether there is a potential for impacts to ambient air in the proximity of a building, such as produced by building downwash. The presumptive default is treatment of effluent vapors from remediation and active mitigation systems is necessary until it is demonstrated these emissions are protective of human health and the environment without effluent treatment.

1.3 Regulatory authority

When DEQ selects and approves cleanup remedies for Cleanup, UST and other hazardous substance release sites, the agency must consider "Any short term risk from implementing the remedy posed to the community, to those engaged in the implementation of the remedy and to the environment" [ORS 465.315 (1)(d)(D)]. The Oregon Environmental Quality Commission (EQC) has adopted administrative rules to implement this statutory requirement. The EQC also adopted Cleaner Air Oregon rules [OAR 340-245-0005 through OAR-245-8010] in November 2018 to close the regulatory gaps left after the implementation of federal air toxics regulations. CAO is a state health risk-based toxic air contaminant regulatory program that adds requirements to DEQ's existing air permitting framework.[1] While a permit may not be required under other DEQ programs for remedial systems, substantive requirements must be met.

For cleanups conducted under Hazardous Substance Remedial Action rules:

OAR 340-122-0090 (3)(d): *Implementation Risk. Each remedial action alternative shall be assessed for the risk from implementing the remedial action, by considering the following, as appropriate:*

- *(A) Potential impacts on the community during implementation of the remedial action and the effectiveness and reliability of protective or mitigative measures;*
- *(B) Potential impacts on workers during implementation of the remedial action and the effectiveness and reliability of protective or mitigative measures;*
- *(C) Potential impacts on the environment during implementation of the remedial action and the effectiveness and reliability of protective or mitigative measures;*
- *(D) Time until the remedial action is complete; and*
- *(E) Any other information related to implementation risk.*

[1] In addition to CAO [OAR 340-245-0005 through OAR-245-8010], it is important to acknowledge that DEQ's Air Quality Program has rules pertaining to discharge of VOCs from a wide range of facilities (OAR 340, Division 216); however, they are intended to manage concentrations of ozone (a by-product of VOC photolysis) on an *airshed* scale. Contact air quality staff in the appropriate DEQ regional office for questions regarding air quality permitting requirements.

For cleanups conducted under UST rules:

OAR 340-122-0250 (5): *The Department shall approve the corrective action plan only after ensuring that implementation of the plan, including any applicable remediation levels, will adequately protect human health, safety, and welfare and the environment, and after providing any public notice consistent with the requirements of OAR 340-122-0260.*

OAR 340-122-0250 (11): *A responsible party may begin remediation of soil and groundwater before corrective action plan approval provided that the responsible party: (a) Notifies the Department of its intention to begin remediation; (b) Complies with any conditions imposed by the Department including halting remediation or mitigating adverse consequences from remedial activities.*

For cleanups conducted under UST Program rules, DEQ recognizes the importance of allowing site remediation to begin before DEQ approves the corrective action plan (CAP). However, the UST Program rules require DEQ to pre-approve remedial activities that could cause air discharges of hazardous substances.

In adopting the Hazardous Substance Remedial Action and UST rules, the EQC gave DEQ the authority to evaluate the impact of remedial actions and assure they do not pose an unacceptable risk to human health and the environment. The Legislature set and the EQC implemented risk-based standards to protect human health and the environment. This guidance provides a process that supports compliance with the statutes and rules on a case-by-case basis. However, this guidance should not be interpreted as rule or requirement. A project may propose alternative approaches to comply with these statutes and rules.

1.4 Terminology and definitions

Regarding terminology, this guidance refers to effluent vapor as the mixture of gases that exits a remedial system. Effluent vapor containing hazardous substances associated with remedial actions are the subject of this guidance to complete an implementation risk evaluation. In the Cleanup Program hazardous substances (for definition see ORS 465.200)[2] are regulated chemicals also referred to as contaminants. Emissions is a term used in air quality programs to describe air contaminants (e.g., gases and particles) that are emitted into the air typically from a source, such as a facility. In general, effluent vapor and emissions can be used interchangeably in this guidance. More specificity on air quality definitions is detailed in OAR 340-200-0020.[3]

[2] Removal or Removal Action Definitions under ORS 465.200(9) “Hazardous substance” means:
(a) Hazardous waste as defined in ORS 466.005. (b) Any substance defined as a hazardous substance pursuant to section 101(14) of the federal comprehensive Environmental Response, Compensation and Liability Act, P.L. 96-510, as amended, and P.L. 99-499. (c) Oil. (d) Any substance designated by the commission under ORS 465.400.

[3] General Air Quality Definitions under OAR 340-200-0020:
(3) "Actual emissions" means the mass emissions of a regulated pollutant from an emissions source

1.5 Summary of required actions

DEQ requires projects covered by this guidance to submit an evaluation of implementation risks before full-scale remediation or VI mitigation begins. This evaluation, described in greater detail in Section 2, is based on site-specific data and design specifications of the remedial system and includes a determination of the need for effluent vapor treatment and the rationale for that decision.

For cleanups conducted under UST rules, the evaluation of implementation risks should be included as part of the corrective action plan. For cleanups conducted under Hazardous Substance Remedial Action rules, the evaluation of implementation risk should be included in the feasibility study (FS), or removal action plan (RAP) or equivalent document. For projects without real-time DEQ oversight, project documentation should demonstrate that acceptable risk levels are met during implementation of the remedy. Acceptable risk is demonstrated by comparison of either modeled or monitored remedial system effluent vapor concentrations with applicable risk-based concentrations (RBCs).

If there is a possibility that remedial system emissions may require an air quality discharge permit, contact air quality staff in the appropriate DEQ regional office prior to implementation.

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during a specified time period as set forth in OAR chapter 340, divisions 214, 220 and 222.
(8) "Air contaminant" means a dust, fume, gas, mist, odor, smoke, vapor, pollen, soot, carbon, acid, particulate matter, regulated pollutant, or any combination thereof, exclusive of uncombined water.
(12) "Ambient air" means that portion of the atmosphere, external to buildings, to which the general public has access.
(51) "Emission" means a release into the atmosphere of any regulated pollutant or any air contaminant.
(57) "Emissions unit" means any part or activity of a source that emits or has the potential to emit any regulated pollutant.
(165) "Source" means any building, structure, facility, installation or combination thereof that emits or is capable of emitting air contaminants to the atmosphere, is located on one or more contiguous or adjacent properties and is owned or operated by the same person or by persons under common control.

2.0 Evaluate vapor discharge from remedial systems

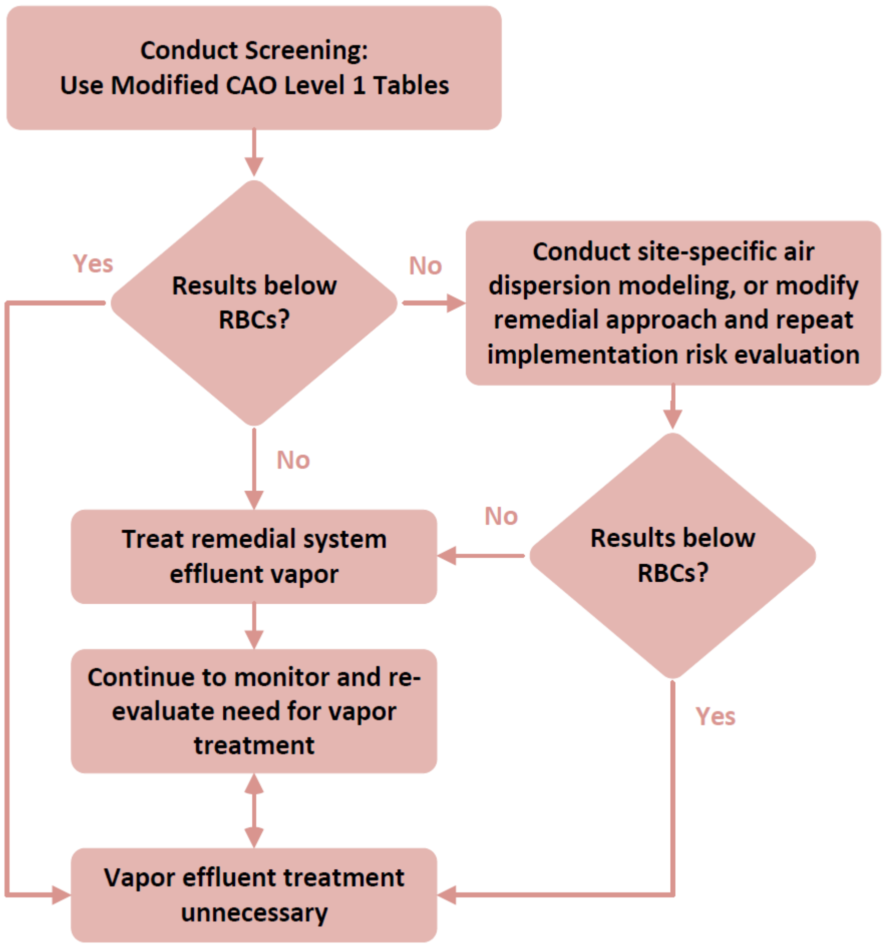

Figure E.1: Flow chart for effluent vapor discharge management process

The following actions and decision points are recommended to assess and manage vapor discharge containing volatile organic compounds (VOCs) or semi-volatile compound (SVOCs) from a remedial system (e.g., remediation or VIM):[4]

[4] This includes VOCs, such as chlorinated solvents trichloroethene (TCE) and tetrachloroethene (PCE), and petroleum VOCs benzene and products such as gasoline. In addition, some hazardous substances typically classified as SVOCs are sufficiently toxic that even with marginal volatility they pose a potential VI risk. Chemicals in this group include polycyclic aromatic hydrocarbons (PAHs), diesel, numerous chlorinated pesticides and a range of polychlorinated biphenyl (PCB) congeners and Aroclors. Site-specific VI contaminants are identified based on the preliminary CSM. Sampling of system emissions should include all volatile contaminants of interest and not be limited to a subset of contaminants, as the risk evaluation needs to take into account the cumulative risk of contaminants.

- Conduct initial screening using modified CAO Level 1 risk assessment tables (provided on DEQ's website) with site-specific data. CAO tables are developed from dispersion factors generated from air dispersion modeling using conservative assumptions; however, on a case-by-case basis site-specific air dispersion modeling may be necessary when default assumptions are unsuitable (e.g., elevated terrain, stack height, proximity to receptor, etc.).
- If initial screening fails the applicable screening criteria (i.e., exceeds Cleanup and CAO RBCs, chronic or acute), the following options are available: 1) treat the effluent vapor; 2) run an appropriate DEQ-approved air dispersion model with site-specific data to further evaluate the potential risk posed by effluent vapor discharging into the atmosphere; or 3) consider alternative remedial technologies that eliminate or reduce effluent vapor discharges below levels of concern.
- If subsequent site-specific modeling results at receptor locations still exceed applicable RBCs, treat effluent vapor or modify remedial design specifications and re-run modeling steps.
- If effluent vapor do not exceed applicable RBCs based on the initial screening or appropriate site-specific model evaluation, this supports that treatment is unnecessary as long as emission concentrations are generally stable or declining. Continue to periodically monitor system operations to document and evaluate system performance.

Figure E.1 illustrates these steps in a flow chart format. Each step in the flow chart is described in more detail below.

2.1 Conduct screening

Cleaner Air Oregon has developed a modeling protocol which specifies the risk assessment level selected, facility and source characteristics, modeling assumptions, and receptor placement. In general, the risk assessment level selected is based on the complexity of the facility and the toxic air contaminants released. This guidance incorporates this modeling protocol with modifications as the default screening approach to assess remedial system emissions.

An evaluation of implementation risks related to emissions from a remedial system can be evaluated by using a simple "look-up" table developed for DEQ's CAO Program (or alternatively conduct a site-specific air dispersion model). Under CAO, the different options are designated Level 1 (lookup table), Level 2 (screening air dispersion model), and Levels 3 and 4 (full air dispersion model).

For initial screening of remedial system emissions, it is appropriate to conduct a Level 1 risk assessment and additional details are presented in the following section. Assumptions will need to be checked to verify suitability with the project site. The Level 1 modeling protocol requires input of site-specific parameters including stack height, estimates of chemical emission rates, and the distance to nearest residents, nonresidential worker and child, and acute exposure locations. Consult with DEQ in cases with elevated terrain within 1500 meters, less than 50 meters to a receptor, or stack height less than 5 meters. Additional modeling considerations may also be applicable. Additional details regarding modeling protocol and assumptions, visit DEQ's "CAO Step-by-Step Guide for Facilities" website.

When further assessment is necessary based on initial screening or Level 1 modeling assumptions are not applicable for the project, proceed with a site-specific air dispersion modeling (i.e., CAO Level 3 risk assessment). In some circumstances, site-specific modeling may be the preferred approach, such as to support remedial design and therefore the initial screening step is skipped. It is recommended that projects coordinate with DEQ regarding the preferred implementation risk evaluation approach and modeling protocol, such as a component of a FS or CAP. Note: that a Cleanup Program engineer should be on the review team for any treatment system including the air discharge modeling evaluation.

In summary, to meet DEQ's Cleanup Program requirements and CAO substantive requirements, follow the following steps:

- Evaluate risks from remedial system emissions using modified CAO Level 1 lookup tables. Alternatively, conduct a more comprehensive site-specific air dispersion model.
- The evaluation should use Cleanup Program *and* CAO RBCs, and correspondingly present risks for both evaluations. The assessment should include an evaluation of acute risk in addition to chronic risk.
- To assess acceptable risk, use both Cleanup Program and CAO RBCs, and present results for both programs. The results will likely be similar.

2.1.1 Level 1 screening protocol

To assist facilities in conducting risk assessments of emissions from remedial systems, DEQ developed example spreadsheets where the user can input site-specific data and the subsequent tables in the spreadsheet will screen and present results compared to Cleanup and CAO RBCs. This interactive spreadsheet can be downloaded from DEQ's VI Guidance website. Typically, remedial systems are intended to treat or mitigate chlorinated solvents or petroleum hydrocarbons and therefore these chemicals are included as an example in the spreadsheet. Additional site-specific chemicals of interest will need to be added, if applicable. This air dispersion calculator is intended for stacks that are 50 meters from the nearest receptor. For other scenarios, such as a stack on top of a building roof or near the HVAC intake, please contact DEQ. In some cases it may be inappropriate to use a dispersion factor.

These example tables to evaluate emissions from remedial systems are provided in a spreadsheet format with a series of tabs, as described below:

Intro. Tab with more detailed instructions on how to use the spreadsheet.

Table E-1: Emission unit information. Site-specific parameters that need to be identified and entered into Table E-1 include stack height and distance to the nearest resident, nonresident child, worker, and any acute only (i.e., 24-hour exposure) locations. When using the spreadsheet, replace the examples provided with site-specific data. The user needs to look up the dispersion factor in OAR 340-245-8010 Table 3 (included) for annual exposure (Table 3A) or acute exposure

(Table 3B) based on your site-specific stack height and distance from the stack to the nearest exposure location. The dispersion factor needs to be manually entered into Table E-1; it will then be automatically transferred into Table E-2.

If multiple emissions locations are present at a site, such as multiple stacks or more than one remedial system (e.g., SVE and mitigation vapor discharge), the combined contributions will need to be accounted for in the risk evaluation. The example spreadsheet is set up for a single emission location, called an emission unit. To evaluate a second emission unit, save a copy of the spreadsheet and run it for the second emission unit. When presenting the final results, it is important to report the total site risk by summing results for all emission units by exposure type presented in Tab E-3 for CAO and CU (i.e., total chronic residential, total chronic worker, total acute residential, total acute worker). The final report should also include the individual emission unit results displayed in the spreadsheet summary tables (Tab E-3-CAO and Tab E-3-CU).

Table E-2: Calculation of air concentrations. Review the list of chemicals and identify all chemicals emitted at your site, replacing the examples provided. Double check for chemicals that may be listed under other names or as part of a chemical class. Enter the site-specific annual and daily emission rates, which are calculated based on site data, pilot testing, and/or remedial system design specifications. Provide all calculations and assumptions used to arrive at the annual and daily emission rates. Dispersion factors are automatically copied from Table E-1. The average annual concentration and the maximum daily concentration are automatically calculated from the emission rates and dispersion factors.

Table E-3 CAO: CAO program risk calculations. No entries are necessary on this table, but it is recommended to review the list of chemicals, whether there is a CAO RBC for the chemical, and the associated risk. Annual and daily concentrations are automatically updated from Table E-2. RBCs will be automatically identified and copied from the CAO RBC tab based on the lookup function using CAS numbers. Excess cancer risk and hazard quotient calculations will be automatically performed and shown in Table E-3 CAO. These results are used to assess exceedance of acute and chronic CAO RBCs. For sites with multiple emission locations (e.g. multiple stacks), the sum of risks from all emission units must be reported, in addition to risks for individual emission location results provided in this tab.

Table E-3 CU: Cleanup program risk calculations. As with Table E-3 CAO, no entries are necessary on this table. The list of chemicals, annual and daily concentrations will be automatically copied from Table E-2. Cleanup Program RBCs will be automatically identified and copied from the CU-VI_RBC tab based on the lookup function using CAS numbers. Excess cancer risk and hazard quotient calculations will be automatically performed and shown in Table E-3 CU. Note: results are reported in units of excess cancer risk per million for carcinogens, and hazard quotients for non-carcinogens. These results are used to assess exceedance of Cleanup Program RBCs (e.g., HQ > 1).

For sites with multiple emission locations (e.g. multiple stacks), the sum of risks from all emission units must be reported, in addition to risks for individual emission location results provided in this tab.

Additional supporting tables included in subsequent tabs:

- Dispersion Factors: This table presents the dispersion factors from stack emissions for the CAO Program from OAR 340-245-8010 Table 3 and is used to look up dispersion factors to be entered into Table E-1.
- CAO RBC Table: This table presents the chronic and acute RBCs for the CAO Program from OAR 340-245-8010 Table 2.
- CU VI RBC Table: This table presents the Cleanup Program chronic and acute RBCs (modified from EPA VI Screening Levels and CAO acute RBCs).

The spreadsheet includes the tables and RBCs current as of the date of the spreadsheet. Check whether more recent values may be available. The Cleanup RBCs are planned to be updated on an annual basis. The CAO RBCs are in rule and will be updated periodically with rule changes.

Any level of assessment should be based on site-specific parameters, data, and/or estimated from design specifications to the extent possible. For treatment systems, pilot tests may be performed to inform design and the results can be used estimate emission rates for model inputs. Additional guidance to estimate emission rates for pilot tests is provided in the following section.

For mitigation systems a pilot test is typically not performed; however, diagnostic testing such as sub-slab vacuum tests or communication testing at varied fan/blower rates are useful to inform design. To evaluate vapor discharge from mitigations systems at the design stage, the maximum sub-slab contaminant concentrations and mitigation design specification are used to inform model input parameters (Level 1 or more comprehensive modeling).

Following installation and operation of a remedial system, monitoring is conducted (see Section 3.2) under mainly two scenarios:

- When treatment is installed, to confirm and track vapor results before and after treatment, or
- When there is no treatment, to verify the conclusions of the implementation risk evaluation (e.g., model results relative to RBCs) and confirm concentration trends don't significantly increase.

2.1.2 Pilot testing

This section is specific to a project incorporating a pilot test to assess a technology suitability and inform full-scale remedial design. Pilot testing is not necessary to proceed with the Level 1 screening protocol or more comprehensive air modeling. However, chemical emission estimates and risk modeling can be based on data from stack discharge (i.e., effluent vapor) samples or *influent* vapor concentrations collected from a pilot test prior to treatment. A pilot test is generally completed before beginning full-scale, continuous operation of the treatment system, and after any significant expansion or redesign of the system. Coordinate with DEQ in advance on whether treatment of emissions during pilot testing is necessary which can depend on a variety of factors, such as type and concentration of hazardous substances potentially discharged, pilot test length, and the proximity to people. It is customary that treatment is necessary during pilot testing, such as incorporating a granular activated carbon unit to treat vapors prior to discharge during a SVE pilot test.

Pilot test results are indicative of emission discharge rates at the start of a cleanup action. While emission rates may vary over time as source(s) of chemicals are removed from soil or groundwater, and as groundwater levels fluctuate, it is difficult to estimate accurately how these rates will change over time. Therefore, pilot test results can be used to make initial exposure estimates and to assess the need for effluent vapor treatment. Once the system is operational, performance is monitored, and if influent concentrations change it may be necessary to re-evaluate the need for treatment.

Commonly, remedial systems are designed in absence of pilot testing while building in conservative design assumptions, such as placement of SVE wells to overlap anticipated radius of influence of a SVE system (based on site-specific parameters like lithology, depth of groundwater/contaminant source, etc.) and equipment and pipe sizing, etc. For the initial level screening and subsequent modeling if applicable, site-specific input parameters are based on the design specifications. It anticipated the design approach may be modified based on model results.

2.1.2.1 Pilot Test Considerations

Testing vapor extraction and dual-phase extraction systems. For the best estimate of emission rates, vapor samples should be collected from the manifold of all recovery wells/trenches expected to be used in the full-scale cleanup. Alternatively, a sample from a single extraction well or trench will suffice for the pilot test as long as it is in the region of highest contamination. An estimate of total emissions should capture the maximum sample results and the maximum anticipated airflow for the full-scale system.

Before collecting any samples, the system should be operated at the full-scale operational air flow rate for at least 12 hours (unless site conditions allow pressure equilibrium to be reached more quickly). After purging, two samples should be collected from an in-line sampling port and submitted for analysis. The second sample is a quality-control duplicate. As mentioned above, samples should be collected from either: 1) all recovery wells/trenches expected to be used in the full-scale cleanup; or 2) only from the region of highest contamination. All samples should be stored, preserved, and analyzed within acceptable holding times as specified by the EPA-approved analytical method.

Testing groundwater extraction/air stripping systems. Prior to operating a groundwater extraction/air stripping system, groundwater monitoring data can be used to estimate vapor emission rates and determine the need for off-gas treatment. However, these estimates and determinations must be validated through routine sampling once the system begins operation. For operating systems, emissions from an air-stripping tower can be estimated using data from influent water samples (assuming a 100% contaminant removal efficiency). Alternatively, it is acceptable to collect both influent and effluent water samples and determine the stripping efficiency from the difference between influent and effluent contaminant concentrations. Before collecting samples, the pumping system should be operated continuously at the maximum design flow rate for at least 24 hours. There may be permitting requirements for discharging treated groundwater. Discuss the disposal options and permitting requirements with the DEQ project manager.

2.1.2.2 Pilot Test Sampling and Analyses

Effluent vapor. Analytical methods of vapor samples are selected by the constituents of interest (or concern) slated for remediation or mitigation at the site and based on the site conceptual site model (CSM). The following analytes and analytical testing methods are recommended, where applicable:

For gasoline or diesel contamination, analyze effluent vapor samples for total petroleum hydrocarbons (TPH); benzene, toluene, ethylbenzene, and xylenes (BTEX), trimethylbenzenes, naphthalene, and methyl tertiary-butyl ether (MTBE).

For gasoline, measure TPH, BTEX, and MTBE levels using EPA Method TO-15 or TO-3, and for diesel-range hydrocarbons, EPA Method TO-17.

For sites with chlorinated solvents or other non-petroleum VOCs, use EPA Method TO-14a, TO-15, or other EPA approved analytical methods that provide a method reporting limit (MRL) low enough to evaluate the risk to people.[5]

Table E.1: Summary of recommended analytical methods

Chemical *Medium*	TPH-Gasoline	TPH-Diesel	BTEX, MTBE	Non-Petroleum VOCs
Vapor (System) Samples	EPA Method TO-3	NIOSH Method 1550 or a modified EPA Method TO-13	EPA Methods TO-3, TO-14a or TO-15	EPA Method TO-14a, TO-15, or other appropriate methods
Groundwater Influent Samples	NWTPH-Gx	NWTPH-Dx	EPA Methods 8021 or 8260	EPA Method 8260 or other appropriate methods

[5] DEQ's Tanks and Cleanup Programs generally require the use of analytical methods from *Test Methods for Evaluating Solid Waste*, SW-846 (EPA).

Influent water. For a groundwater treatment system where effluent vapor discharge estimates will be based on concentrations in the influent water, analyze groundwater samples for TPH using method NWTPH-Gx and/or NWTPH-Dx, BTEX, trimethylbenzenes, naphthalene, and MTBE using EPA Methods 8021 or 8260. Use EPA Method 8260 or other EPA approved analytical methods for chlorinated VOCs.

2.2 Evaluate screening results

The Level 1 Assessment provides excess cancer risk and hazard quotient results. Using the example tables, these results are found in Table E-3 CAO: CAO Program Risk Calculations and Table E-3 CU: Cleanup Program Risk Calculations. An exceedance ratio above 1 represents an exceedance of a RBC. If Cleanup Program or CAO RBCs, chronic or acute, are exceeded this indicates potential implementation risks associated with the vapor discharge from site remediation and/or VIM.

As noted above, at a site with multiple emission locations (e.g., multiple stacks), the sum of risks from all emission units must be reported. These risks are screened using both excess cancer risk and hazard index for each exposure scenario.

A summary of results, methods, populated spreadsheets, related calculations and assumptions should be presented to DEQ.

If RBCs are exceeded, this decision point includes the following are options:

1. Treat effluent vapor treatment as a process component of the remedial system. Monitoring will be necessary to assess treatment performance (Section 3.2).
2. More comprehensive site-specific modeling can be conducted to further evaluate risks (Section 2.4).
3. The remedial system can be modified to eliminate/reduce emissions to levels that do not result in unacceptable risk, as confirmed by an implementation risk evaluation.

If the results of Level 1 screening or other air dispersion modeling support chemical levels do not exceed acute and chronic RBCs at receptor locations/compliance points (i.e., exceedance ratios are less than 1), this supports the remedial system does not present an unacceptable risk in terms of effluent vapor discharge, and treatment is unnecessary. Monitoring is still conducted to verify model screening results. When performance monitoring data indicates a significant increase in chemical concentrations in emissions, a re-evaluation of treatment needs may be necessary.

2.3 Air dispersion modeling

If Level 1 screening results indicate potential risk due to remedial system emissions, the project can elect to conduct site-specific air dispersion modeling (e.g., CAO Level 3 risk assessment) that is more representative of site conditions to support that emissions are protective of human health in absence of vapor treatment. EPA continues to update and support air dispersion models that can be downloaded at no cost. If a project elects to conduct a site-specific air dispersion model, consult with DEQ for the most current appropriate models and methods, which may include coordination with CAO. An engineer should be part of the review team.

For example, at the time of the guidance AERSCREEN, AERMOD-MAKEMET, or another EPA-approved dispersion model are potential options to estimate the impact on site-specific ambient air concentrations. AERSCREEN is a free, downloadable program that can currently be found on EPA's Air Quality Dispersion Modeling – Screening Models website. The accompanying model user's manual provides description and discussion of the model and its input parameters. AERSCREEN is a conservative model that calculates 1-hour average vapor concentrations at specified distances from a discharge stack and converts them into longer term averages. Risk assessment methods are then applied to evaluate the potential impact to people. For evaluating emissions beyond a screening evaluation, AERMOD is an option that incorporates actual meteorological data. For detailed information on conducting air dispersion modeling and toxic air contaminant risk assessments, refer to CAO recommended procedures (DEQ 2022a, DEQ 2022b), in addition to coordination with the assigned DEQ project manager.

In preparation for conducting the air dispersion modeling, certain site-specific information must be collected to input into the model. This information is typically related to operating parameters of the remedial system, building dimensions, and the surrounding land use and terrain. Data needs include locations and distances from the discharge stack to residential and commercial structures, workstations, and sensitive receptors. Building downwash calculations are an element of the model.

The receptor location is essentially the point of compliance where contaminant concentrations released from the system must meet acceptable risk levels. For the purpose of this guidance when using the Level 1 screening table, this compliance point is *the distance from the discharge stack to the nearest location where people live and/or work*. A compliance point may be a residence, school, commercial building, or outdoor workstation. It is appropriate to measure the distance from the base of the discharge stack to the nearest occupied structure or workstation. For site-specific modeling, the compliance point is the location with the greatest calculated risk, which may be different for chronic and acute effects.

As emphasized previously, model inputs should be based on site-specific data to the extent possible, including remedial design specifications (planned or constructed). In turn, modeling may inform remedial design modifications to consider to reduce risks.

Similar to the process of evaluating Level 1 screening results and decision points, if the site-specific modeling results exceed Cleanup and CAO RBCs, effluent vapor treatment is necessary to reduce chemical concentrations to acceptable levels, or the remedial system will need to be modified to be protective of human health and the environment. In contrast, if RBCs are not exceeded, this supports treatment is unnecessary to be protective of receptors.

3.0 Remedial system operation

3.1 Vapor treatment

A variety of treatment technologies are available to treat remedial system vapors prior to discharge to the environment and capable of achieving chemical removal efficiencies of at least 95 percent. Vapor treatment can be physical (adsorption and condensation), chemical (oxidation), and biological (biodegradation). For example, vapor-phase carbon adsorption (e.g., granular activated carbon (GAC); thermal oxidation; catalytic oxidation; and internal combustion. Guidance is widely available to support selection of vapor treatment technologies and monitoring considerations.

3.2 Monitoring system performance

Once full-scale operation of the remedial system begins, pre-treatment and stack discharge samples (or water samples for groundwater extraction/air stripping systems) should be collected and analyzed monthly, or at some other mutually agreed upon frequency, to:

- Verify that emission rates remain below acceptable levels;
- Monitor for breakthrough of treatment media, if applicable (e.g., GAC), and to inform frequency of treatment media replacement;
- Determine when vapor treatment can be discontinued, or should be installed;
- Monitor system efficiency and progress in achieving cleanup goals; and
- Determine when it is appropriate to shut down the remediation system or for an active VIM system, or when it may be appropriate to transition from active to passive operation (see DEQ's VI Guidance, Section 6.3.3: Rebound Assessment).

Regular sampling should occur whether or not the remedial system includes vapor treatment. In addition to monthly sampling, trends in system performance can also be monitored with field screening tools such as an appropriately calibrated photoionization detector (PID) or flame ionization detector (FID). Once a good correlation between PID or FID readings and laboratory results is established, some of the samples can be replaced by PID or FID monitoring. However, at least one sample should be submitted to the laboratory monthly, or other mutually agreed to frequency.

Monitoring for remedial systems not requiring vapor treatment. Routine sampling should be conducted as described above, both to demonstrate that chemical discharges remain within acceptable limits and to track overall performance of the remedial system (more details provided in DEQ's VI Guidance, Section 6.3). While regular sampling is recommended, as remediation of the site progresses, data on emission rates may support less frequent sampling. DEQ should be notified if monitoring events indicate emission rates are increasing significantly. If two consecutive sampling events show that emissions have increased above acceptable risk values at receptor locations, a vapor treatment technology should be installed.

Monitoring for remedial systems with vapor treatment. Monthly discharge sampling should be conducted as described above to verify vapor treatment system effectiveness. When two consecutive months of pre-treatment (e.g., treatment system influent vapor) sampling show that concentrations have declined below RBCs at receptor locations, and there is a consistent trend of stable or declining influent concentrations, vapor treatment can be discontinued. Under these circumstances, DEQ should be consulted in advance about discontinuing vapor treatment. Note: to ensure vapor treatment units are operating at a minimum 95% removal efficiency (or monitor for treatment media breakthrough if applicable), it is appropriate for the project to monitor emissions regularly with an appropriately calibrated PID or FID, and to report monitoring results to DEQ.

3.3 Summary of milestones for managing vapor discharge of remedial system

- Evaluate the need for remedial system vapor treatment to protect human health by completing an implementation risk evaluation as described in this guidance.
- If vapor treatment is not (or is no longer) needed, sample untreated vapor at regular intervals and share results with DEQ, to confirm emission levels and to document trends that may support remedial system shutdown.
- If vapor is being treated, sample influent concentrations (e.g., prior to treatment) and system emissions monthly (or other mutually agreed to frequency) and share results with DEQ, to verify treatment effectiveness and to document trends that may support discontinuing treatment.
- Consult with DEQ at all key decision points related to remedial system operation.

4.0 References

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EPA, 2015. *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (OSWER Publication 9200.2-154). U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response, June 2015.

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EPA, 2024b. *AERMOD Implementation Guide (*EPA-454/B-24-009*).* U.S. Environmental Protection Agency, November 2024.

Federal Remediation Technologies Roundtable, *Remediation Technologies Screening Matrix and Reference Guide, Version 4.0*.

USDOE, 2013. *Soil Vapor Extraction System Optimization, Transition, and Closure Guidance* (PNNL-21843 RPT-DVZ-AFRI-006). U.S. Department of Energy, Pacific Northwest National Laboratory, February 2013.

5.0 Record of Revisions – Appendix E

Revision	Date	Changes	Editor
Update	March 2025	Updated tables and text - included as Appendix E in the 2025 Revised Vapor Intrusion Guidance	DEQ Cleanup Program VI Workgroup
Contact information	September 2017	Updated contact information and links	DEQ Cleanup Program
Original publication	January 2006	Guidance for Managing Hazardous Substance Air Discharges from Remedial Systems	DEQ Cleanup Program

Appendix F

Engineering review of vapor intrusion mitigation systems

Please note that this document dates from an earlier period and may not meet current accessibility standards.

Memorandum

To: Cleanup Program Management Team

From: Engineering Work Group, Sarah Greenfield, P.E., Heidi Nelson, P.E., Erin McDonnell, P.E.

Date: July 24, 2019

Subject: Engineering Review of Vapor Intrusion Mitigation Systems

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DEQ is a leader in restoring, maintaining and enhancing the quality of Oregon's air, land and water.

Purpose

This memorandum is intended to assist Oregon Department Environmental Quality (DEQ) project managers in the evaluation and approval of engineering controls at cleanup sites with unacceptable vapor intrusion risk. This memorandum also serves to clarify what constitutes an engineering control and when to engage a professional engineer.

Applicability

This memorandum applies to cleanup sites where engineering controls are used to mitigate an unacceptable vapor intrusion risk. A cleanup project may be regulated under one or more programs, collectively referred to as Cleanup Program: Cleanup, Emergency Response, Leaking Underground Storage Tank (LUST) and Heating Oil Tank (HOT).

Background

Soil and groundwater contaminated with volatile organic compounds may produce an unacceptable vapor intrusion risk to building occupants. Engineering controls are often used to mitigate these risks, typically in conjunction with institutional controls. Engineering controls may include sub-slab or sub-membrane depressurization systems, sub-slab venting (passive or active), soil vapor extraction, a vapor barrier or enhanced building ventilation. Institutional controls may consist of maintaining engineering controls, site use restrictions, contaminated media management plans, periodic monitoring or notification requirements.

DEQ project managers should engage a Cleanup Program engineer when evaluating vapor mitigation systems, including:

- Sizing system components such as piping and fan/blowers
- Specifying engineered materials such as underlayment geotextiles and vapor barrier membranes
- Installation of an engineering control including subgrade preparation, seam and penetration sealing, system testing and /or startup testing
- Conducting system performance evaluations
- Preparing long-term operation and maintenance plans

In terms of engineered materials, a growing catalogue of vapor barriers (or membranes) are available and marketed as effective options to mitigate vapor intrusion. Several factors including composition (chemical resistance, permeability, durability, strength) and thickness is a short list of considerations in selecting an appropriate vapor barrier for a site.

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Keep in mind, products not previously considered by a Cleanup Program engineer will require a more detailed evaluation of the material's physical and chemical properties to determine suitability as a vapor barrier, especially when used as a sole engineering control.

Stamping of Documents Submitted to the Cleanup Program

Final documents containing original engineering work that are submitted to the Cleanup Program must be stamped by the Oregon professional engineer (P.E.) in responsible charge of that work, as specified in Oregon Revised Statute (ORS) Chapter 672 and Oregon Administrative Rule (OAR) 820.[1]

Key Points

- Environmental consultants employed by property owners, developers or potential responsible parties should engage an Oregon registered P.E. in evaluating vapor mitigation systems.
- DEQ project managers should engage a Cleanup Program engineer in evaluating proposals for vapor mitigation systems and reviewing pertinent documents (workplans, corrective action plans, feasibility studies, remedial action plans, construction completion reports, monitoring and maintenance plans and similar documents).
- Site-specific conditions will determine the nature of the engineering control or combination of controls to achieve protectiveness.
- Verification of the performance and effectiveness of a selected mitigation system is necessary for long-term risk management.
- DEQ will not issue Agency decision documents, such as records of decision, certificates of completion and no further action letters, unless the supporting documents have been stamped by an Oregon registered P.E., in accordance with ORS 672 and OAR 820.

Additional Resources

The relevant guidance document for vapor intrusion in buildings is DEQ's 2010 *Guidance for Assessing and Remediating Vapor Intrusion in Buildings*. While DEQ intends to update this guidance to incorporate the latest understanding of how to evaluate and address risks related to vapor intrusion, it remains the most comprehensive reference for DEQ cleanup project managers. Additional vapor intrusion guidelines are available, including publications by the U.S. Environmental Protection Agency (EPA) and the Interstate Technology & Regulatory Council (ITRC).

DEQ has recently prepared an Internal Management Directive (IMD) concerning *Professional Stamping of Cleanup Program Documents*. Oregon Revised Statute 672 requires certain geologic and engineering documents to be "stamped" with the seal of the registrant with responsible charge for the work. The IMD addresses documents prepared by external parties, agency staff and agency contractors. The IMD formalizes the approach

[1] Oregon State Board of Examiners for Engineering and Land Surveying (OSBEELS) regulates the practice of engineering, land surveying, photogrammetric mapping, and water right examination in the State as they relate to the welfare of the public in safeguarding life, health and property. Practice of engineering is identified in ORS 672 and OAR 820.

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for identifying work that may require stamping by a registered geologist or professional engineer, assigning the work to appropriate staff and determining whether the work product will be stamped. The IMD emphasizes the need for supporting documents, such as those prepared by environmental consultants, to be stamped before DEQ issues decisions such as Records of Decision and No Further Action determinations.

Disclaimer

This memorandum and any referenced IMDs are intended solely as guidance for DEQ employees. It does not constitute rulemaking by the Environmental Quality Commission and may not be relied upon to create an enforceable right or benefit, substantive or procedural, enforceable at law or in equity, by any person. With written managerial approval, DEQ employees may deviate from these directives. DEQ anticipates revising IMDs from time to time as conditions warrant.

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Record of revisions

Revision	Date	Changes	Editor
Entire document	03/27/2025	2025 Revised Vapor Intrusion Guidance	DEQ Cleanup Program VI Workgroup
Entire document	3/25/2010	2010 Vapor Intrusion Guidance	DEQ Cleanup Program