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Guidance for Assessing and Remediating Vapor Intrusion into Buildings

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DEQ

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Executive Summary

The intention of this guidance is to improve Oregon's vapor intrusion (VI) 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 publication of DEQ's original guidance. This updated VI guidance therefore replaces the original version that was published in 2010. DEQ updated the VI guidance to better 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 VI Work Group, lead workers, managers, and staff from DEQ's Environmental Cleanup Program, and pending input from the public.

This guidance provides technical updates based on current science and engineering, and reflects 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 representation of the VI conceptual site model starting with data collection and onward,
- Outlines important considerations for the different VI processes of petroleum contaminants in comparison to 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 a multiple 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 systems,
- Expands on technical descriptions of VI mitigation technologies and performance monitoring framework, and
- 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
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	California 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
ft bgs	feet below ground surface
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
$\mu g/m^3$	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 Statues
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
PHC	Petroleum Hydrocarbon
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_{so}	Risk-Based Concentration for vapor in outdoor air from soil
RBC_{wi}	Risk-Based Concentration for vapor intrusion from groundwater
RME	Reasonable Maximum Exposure
RSL	Risk Screening Level
SAP	Sampling and Analysis Plan
SIM	Selective Ion Monitoring
SMD	Sub-Membrane Depressurization
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
UCL	Upper Confidence Limit
UST	Underground Storage Tank
VI	Vapor Intrusion
VIM	Vapor Intrusion Mitigation
VISL	Vapor Intrusion Screening Levels
VOC	Volatile Organic Compound

1.0 Introduction

The term vapor intrusion (VI) describes the migration of chemical vapors originating from contaminated soil and groundwater sources through the subsurface and into 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 impact human health. In some cases, 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 basic 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. Often the building location, design, or use 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 are 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 (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 (LELs) in confined spaces or otherwise result in conditions that are immediately dangerous to life and health (IDLH). 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 cleaner) can be another source of indoor air contamination. The chemical exposures associated with this active use are regulated by Occupational Safety and Health Administration (OSHA) 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 (PELs) 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 vapor intrusion risk.

Section 4: Vapor Intrusion Sampling and Analysis Guidelines. 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 vapor intrusion mitigation strategies, remediation of hot spots 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 references 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.
- Inclusion of acute chemical toxicity and short-term exposure (e.g., trichloroethene).
- Updated attenuation factors for sub-slab vapor, soil vapor and groundwater, which provide a basis for revised VI screening criteria.
- 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).
- Expanded discussion of vapor intrusion mitigation technologies and a rebound analysis method.
- 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 the process for identifying hot spots related to VI sources of contamination.

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, including remediation and/or mitigation technologies. This updated VI framework emphasizes a more complete, full assessment of sources and risk, mitigation and related long-term management of controls, and remediation of potent sources to address current risk *and* minimize future risks. 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 preparation of 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 evaluating the distances 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 in broader terms a site remedial investigation (RI)) to determine whether a risk pathway is complete, and the development and implementation of remedies when needed.

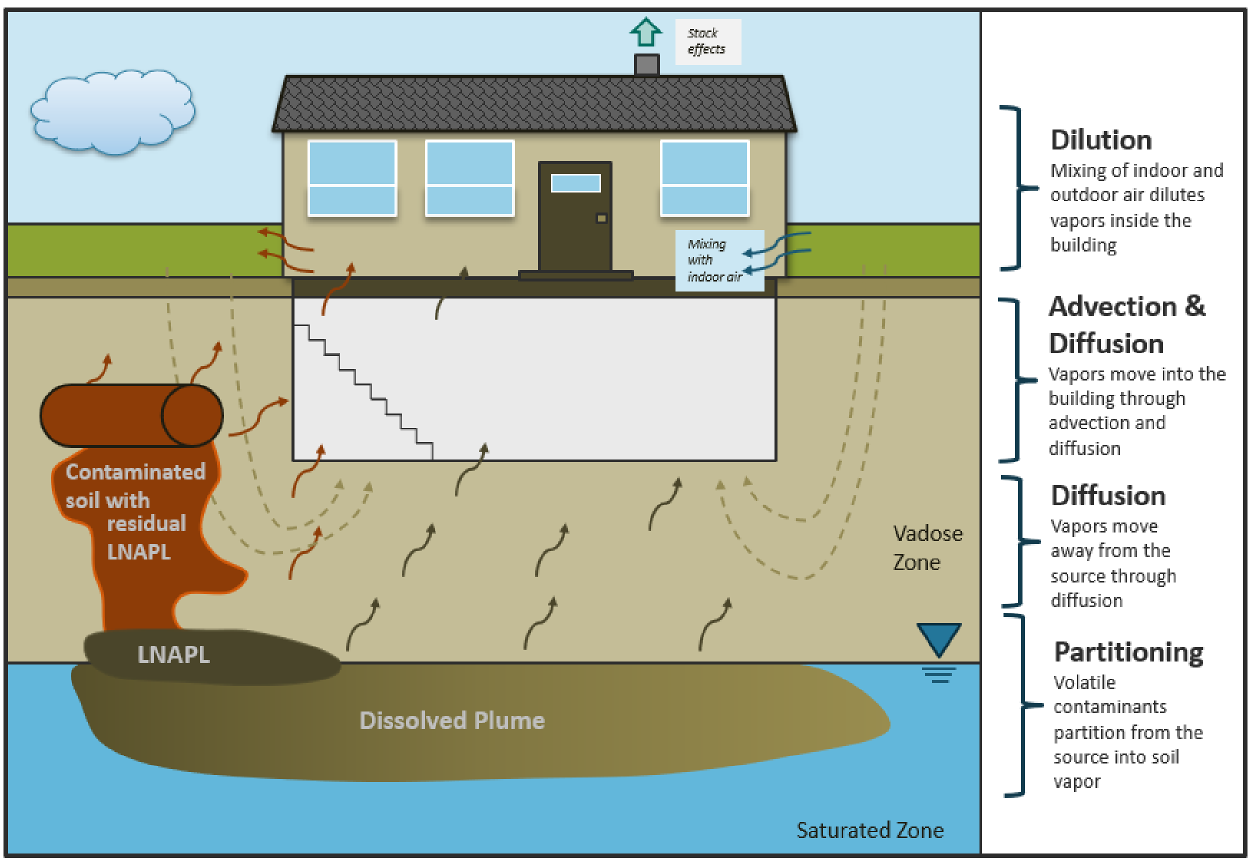

Figure 1. Graphical Representation of Vapor Intrusion CSM (based on McHugh et al., 2017 and EPA, 2015)

Conceptual Site Models should include the boundaries of the VI locality of facility (LOF) and distances (vertically and laterally) to nearby buildings. The LOF[1] represents the area where humans, animals or plants may contact site-related chemicals. 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, piping, pipelines, surface spills that have infiltrated/migrated
Secondary Sources	Contaminated soil, groundwater, free product, buried waste – 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, such as from spills, leaking above-ground storage tanks (ASTs), underground storage tanks (USTs), pipelines, dumping of wastes into drain fields, underground injection systems, sewer lines, etc. The following sections

[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.

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), and petroleum VOCs such as benzene and 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.

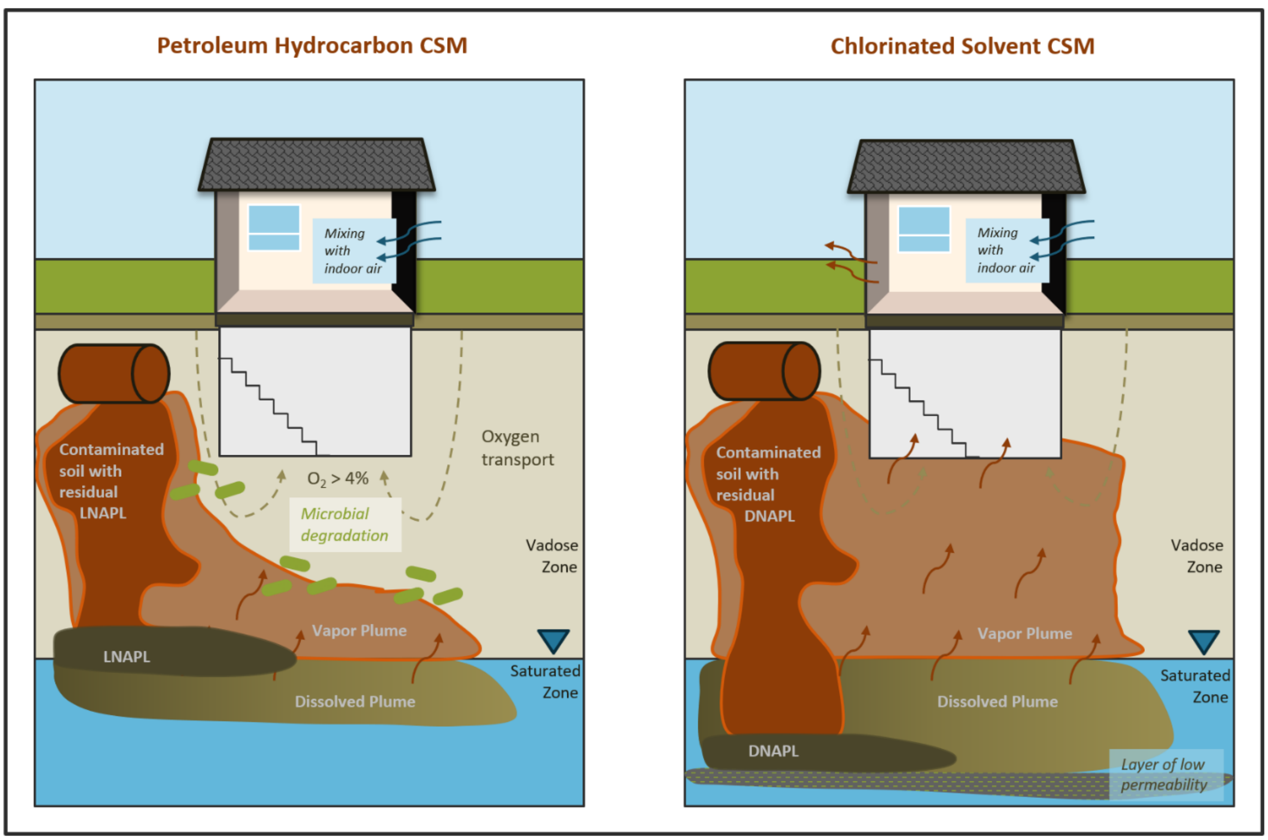

Figure 2. Typical transport scenarios for petroleum and chlorinated solvents

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 (PHCs) include gasoline and diesel and related constituents.

Non-petroleum VOCs, particularly chlorinated solvents have been used in dry cleaning (e.g., TCE and PCE) and as degreasing solvents in industry. 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., vadose 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.

Data on soil contamination is a fundamental site characterization need and provides a line of evidence in vapor intrusion investigations; 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 during soil sampling; and
- Relatively high analytical method reporting limits (MRLs) relative to screening levels present data quality challenges.

While soil is no longer recommended to assess VI risk, identifying where VI contaminants are detected in soil is useful data to inform the investigation strategy, for example in the selection of vapor sampling locations. 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, interpreting data results, and screening viable remedial options if necessary.

2.1.4 Contaminated Groundwater

Unlike soil sources, VOC plumes of groundwater contamination can extend substantial distances (e.g., hundreds of feet) downgradient from the original release. A groundwater 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 as it pertains to data interpretation, the boundaries of the VI locality of facility, and identification of 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.

Annually the depth to the water table (and VI sources in groundwater) can fluctuate several feet or more with rising groundwater levels bringing VOC sources closer to buildings and increasing the potential for vapor intrusion. This is especially significant for petroleum contaminated sites with LNAPL contamination in the vadose zone and where 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 rain event) may decrease VI potential by temporarily 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 (Figure 4B). 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 it, 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 (ft 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 emanating from NAPL, soil, and groundwater sources migrate to the surface and into buildings through the unsaturated soils of the vadose zone. 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.

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 concentration 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 ft bgs or 5 feet below the foundation of a building.[2] 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 resulting in 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 as a consequence 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.

[2] Depths will vary based on site-specific conditions including soil type.

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 generally lower relative pressures 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” 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, preventing 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.

2.2.2 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 a very important mechanism of attenuation that can effectively render the VI pathway incomplete. 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.

At these sites it is necessary to collect subsurface data of fixed gases, such as oxygen (O_2) and CO_2 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 groundwater or soil vapor RBCs in deep soil vapor samples.

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 ITRC and EPA Guidance in Petroleum VI Evaluations. ITRC (2014) and EPA (2012, 2015) 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).

2.3 Building Considerations

2.3.1 Foundation type

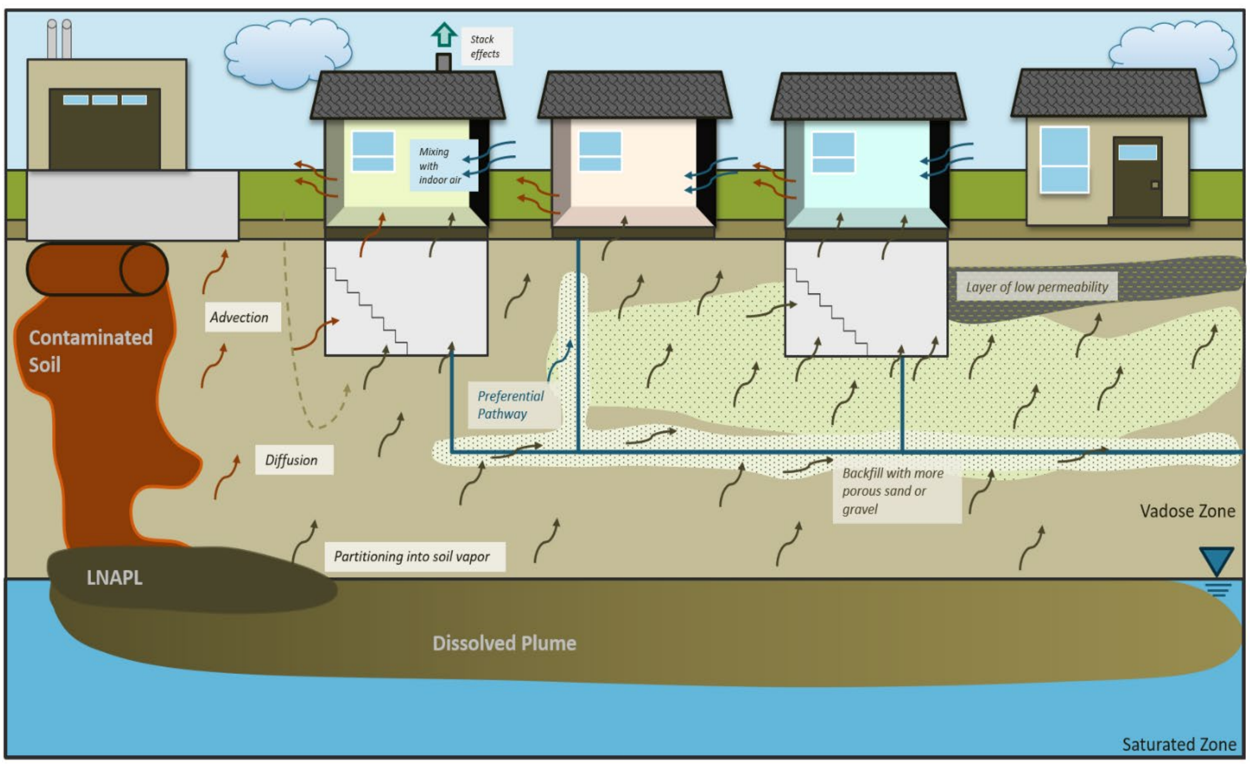

Figure 3. Factors Impacting Vapor Intrusion Migration

Different building types vary in their susceptibility to VI and those with basements tend to be the most vulnerable structures. In these buildings vapor entry points can be located within the 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

Common soil vapor entry points include crawlspace areas, utility entry points, sumps, drains, and cracks and seams in concrete foundations. 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, or absence of a building shell (e.g., crawlspace) with the subsurface can serve as entry points and preferential pathways. Generally older buildings 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 typically composed of outdoor air and to a lesser extent 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. 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. Furthermore, 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, pushing indoor air into the underlying sub-slab, soil, or crawlspace area.

HVAC systems typically are not acceptable standalone mitigation measure but often can supplement a mitigation system; however, 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 for building use may impact VI.

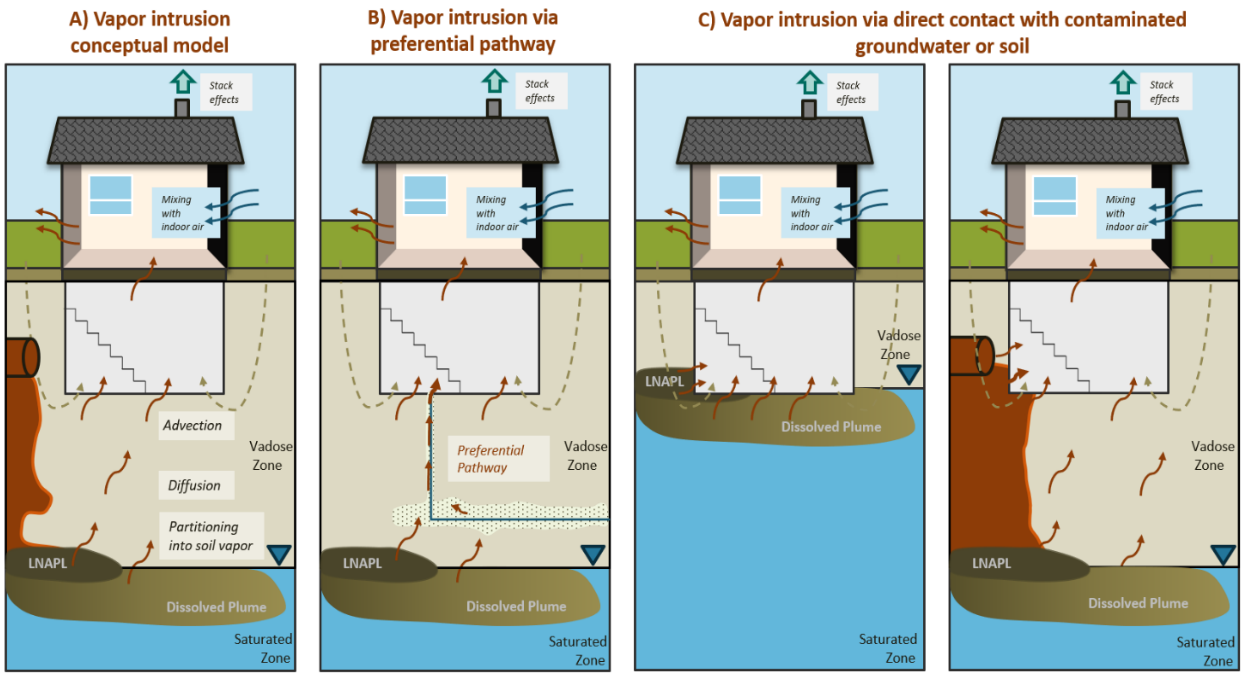

Figure 4A. Examples of Conceptual Site Models with Complete VI Pathways

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 appropriateness to integrate into a final mitigation strategy.

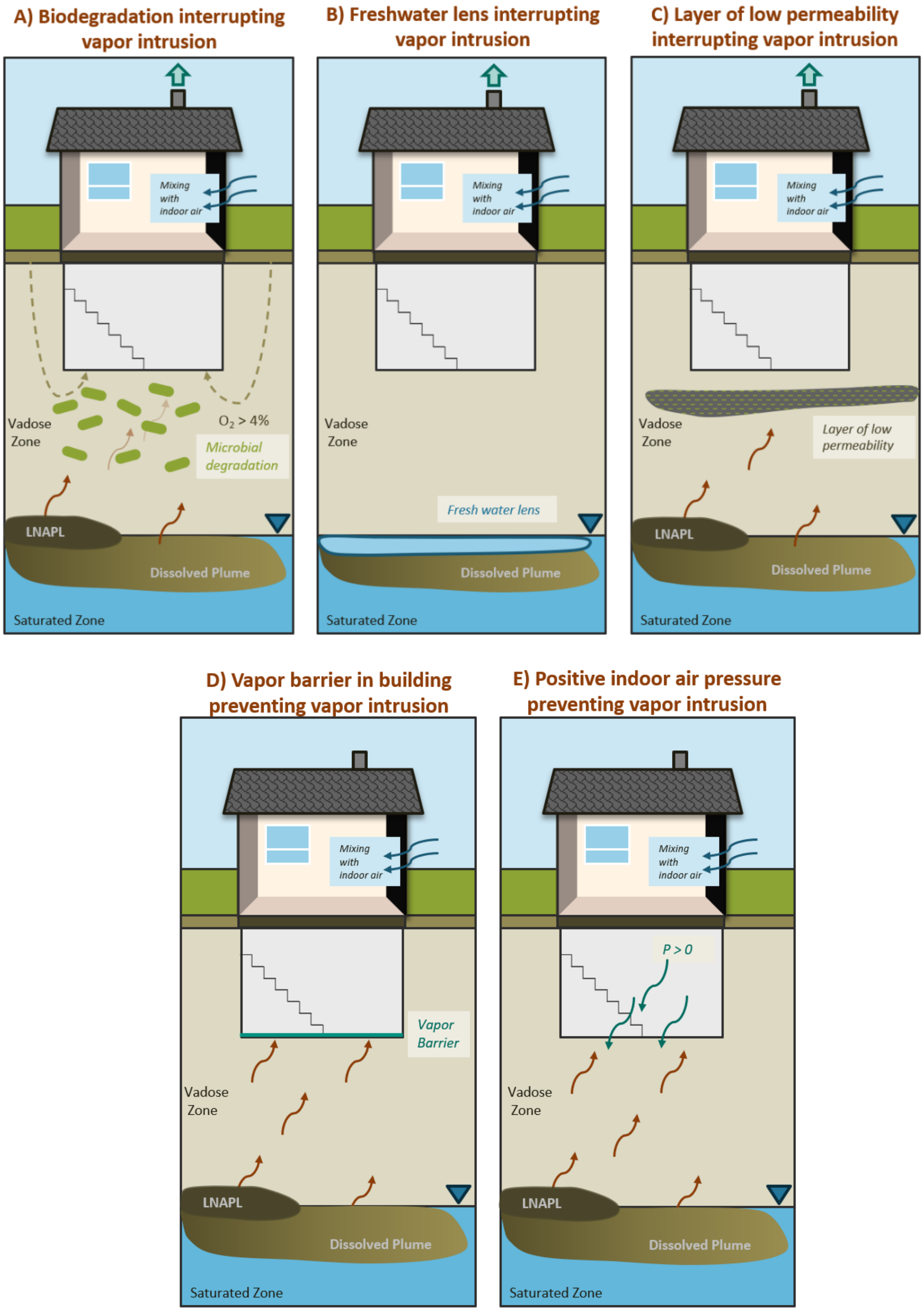

Figure 4B. Examples of CSMs That May Result in an Incomplete VI Pathway

3.0 Vapor Intrusion Evaluation Process

Three process flow charts are provided to guide a VI evaluation including a PVI specific flow chart that presents an approach to demonstrate biodegradation is occurring using multiple LOEs. The applicable flow chart is determined by the source type, non-petroleum versus petroleum (e.g., LUST site), and a complementary flow chart to conduct an indoor air assessment when 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)

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. Appendix B contains a strategy for evaluating VI at HOT sites including 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 supporting flow chart. Figure 5 illustrates an overview of the VI evaluation flow charts, relationship to each other, and subsequent phases of work when source remediation and/or mitigation is necessary.

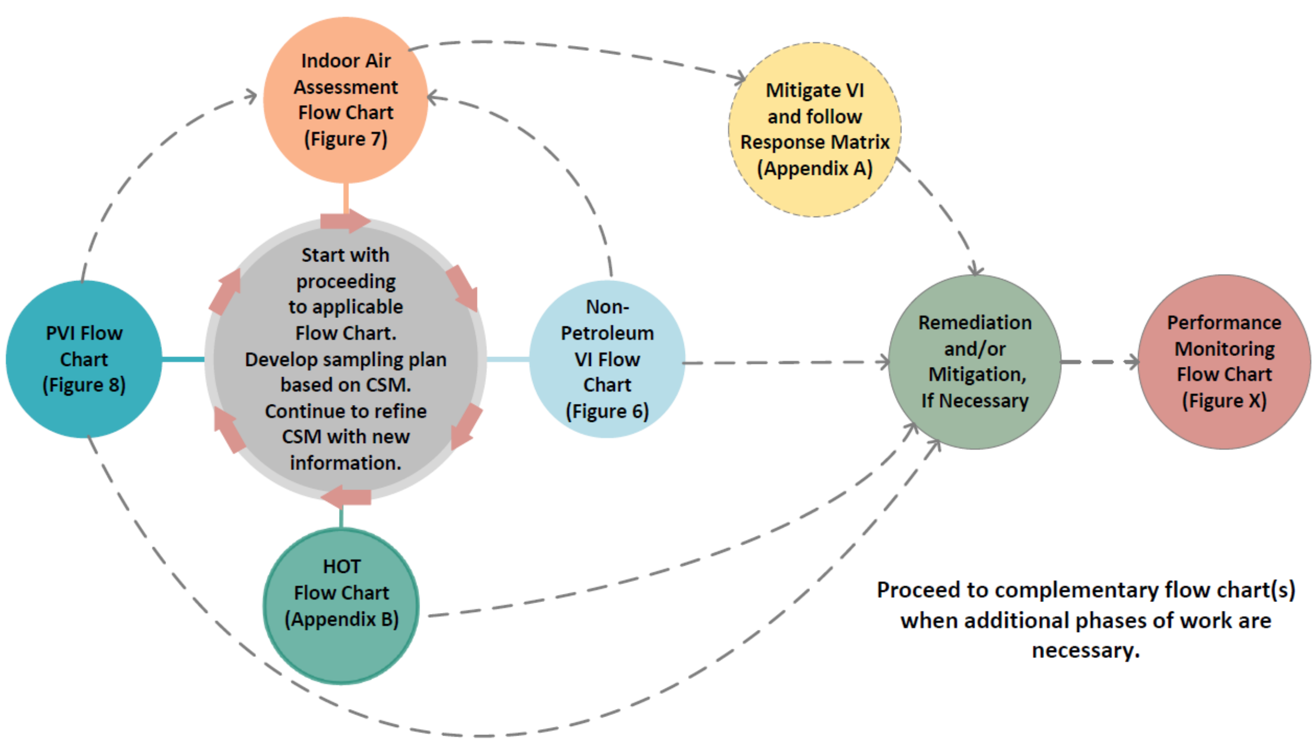

Figure 5. Guide to Flow Charts

3.1 Non-Petroleum Assessment and Remediation Process

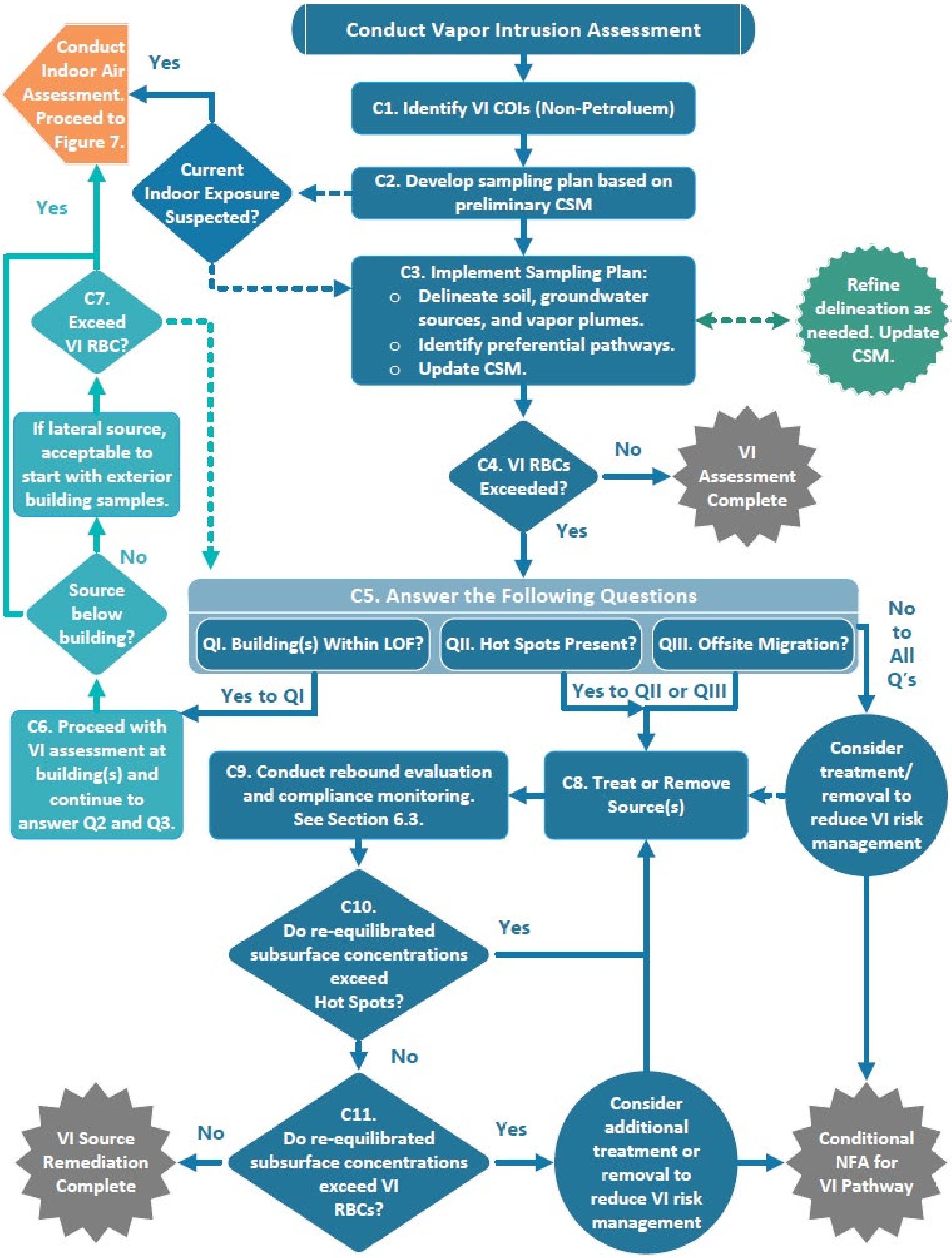

Figure 6. Non-Petroleum Process Flow Chart to Evaluate the VI Pathway

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.[3] As of 2023, EPA's VISLs were incorporated as DEQ RBCs for VI risk screening with minor adjustments. Check DEQ's website for periodic updates to these RBCs.

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, and 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). 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 maybe 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 to left on flow chart to "Current Indoor Exposure Suspected" step 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, soil vapor, or groundwater data indicating a high probability of VI.

The sampling plan, or sampling and analysis plan (SAP), 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.[4]
- 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

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[3] https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator

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

minimum of two depths, 5 ft bgs and 10 ft bgs, at two separate locations.[5] Note: 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 and presented in plan-view and as cross-sections, and for more complex sites preparation of isopleth concentration maps.

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

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

Box C4. Do concentrations exceed VI RBCs?[6]

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;
- They overlie a vadose zone source of VOCs;
- They are located within 30 feet of a soil vapor plume exceeding RBCs; and

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[5] 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.

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

- They are potentially connected to a VI source area through a preferential pathway.

If the above conditions are met, proceed to Box 6 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 – There are two options: 1) the site may be remediated to eliminate VI risks (Go to Box 8), and/or 2) the VI pathway may be closed with engineering and/or institutional controls.

Yes – 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 5.3: 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 8). 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 8). In limited instances, with property owner concurrence, this situation can be managed with ICs.

Determining Whether Hot Spots are Present (Answering 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 viable 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 addresses 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). While 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) 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 applicability of a multiplier 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 either groundwater plumes exceeding VI RBCs or the presence of detectable levels of VOCs in soil. Contaminated soil may be in direct contact with the foundation. Under these circumstances, soil vapor and/or sub-slab[7] samples should be collected contemporaneously with indoor air and outdoor air samples. See flow chart process containing Indoor Air Assessment (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 containing Indoor Air Assessment.

Scenario #3: Buildings are connected to VOC sources through preferential vapor transport pathways. When utility trenches backfilled with material more permeable than the surrounding soil intersect VOC sources, they can provide a more direct conduit for vapor migration into the buildings they're connected to. Under these circumstances, soil vapor investigations and sub-slab data are not reliable indicators of VI, and accordingly indoor air sampling should be conducted, in addition to taking measures to prevent the preferential pathways identified. See flow chart process containing Indoor Air Assessment. 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 RBCs exceeded?

No – Return to Questions 2 and 3.

Yes – Follow the flow chart process containing Indoor Air Assessment (Figure 7).

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

Consult guidance provided in Section 6.0: Vapor Intrusion Remediation and Mitigation. In general, remedial actions should be conducted with oversight and input provided by a DEQ project manager and can be implemented as removal action or as selected remedies based on a feasibility study.

[7] Note: 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 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 concentration?

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 8.

No – Go to Box C11

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

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, active controls are not required but related conditions or restrictions are identified (to maintain protectiveness) are recorded, commonly in the form of deed restrictions, until RBCs are met.

Note: for soil vapor extraction (SVE) systems if asymptotic conditions have not been achieved in terms of mass removal, resuming source remediation should be considered (see Section 6.3.3).

3.2 Indoor Air Assessment and Mitigation Process

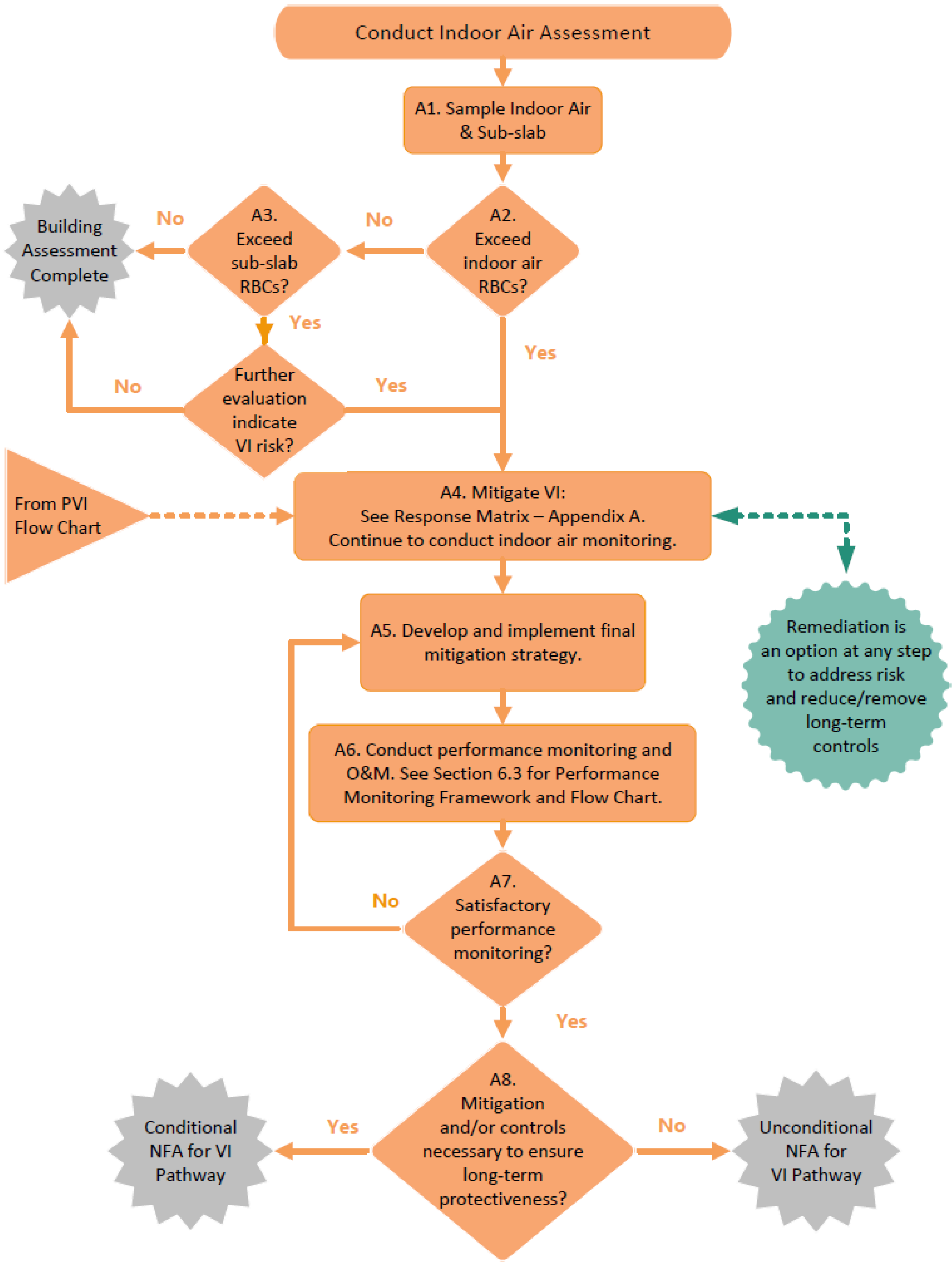

Figure 7. Indoor Air Assessment Flow Chart

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[8] and outdoor background sources that are unrelated to chemical releases at the site. Indoor sources are common and can be mistakenly attributed to VI.

If the results of a single indoor sampling event indicate vapor intrusion is resulting in unacceptable risk, a response a necessary (proceed to Box A4). Note: 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.[9] If further assessment indicates unacceptable VI risk proceed to Box 4 for mitigation. Alternatively, if results 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: 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 response matrix provided in Appendix A. Indoor air monitoring should continue into the post-mitigation period. Generally,

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[8] 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 PM and Section 4 for more information.

[9] 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 6.2.1 for prompt/rapid response options).

Box A5. Develop and Implement Final Mitigation Strategy.

Consult Section 6.0: 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 measures and technologies to mitigate VI risk long-term and may incorporate remediation or removal methods to mitigate risk and/or reduce the mitigation timeframe. Mitigation design plans are prepared for DEQ concurrence and should describe the technology, operating parameters, maintenance schedule, performance metrics.

Box A6. Conduct Performance Monitoring and System Operations and Maintenance.

See Section 6.3: Performance Monitoring of Vapor Intrusion Mitigation Systems and flow chart for additional details.

Box A7. VI System is Performing Satisfactorily?

No – Return to Box 5 and adjust, augment or re-design system as necessary to achieve performance objectives.

Yes – Go to Box 8.

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) 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).

3.3 Evaluation Process for Petroleum Contaminants

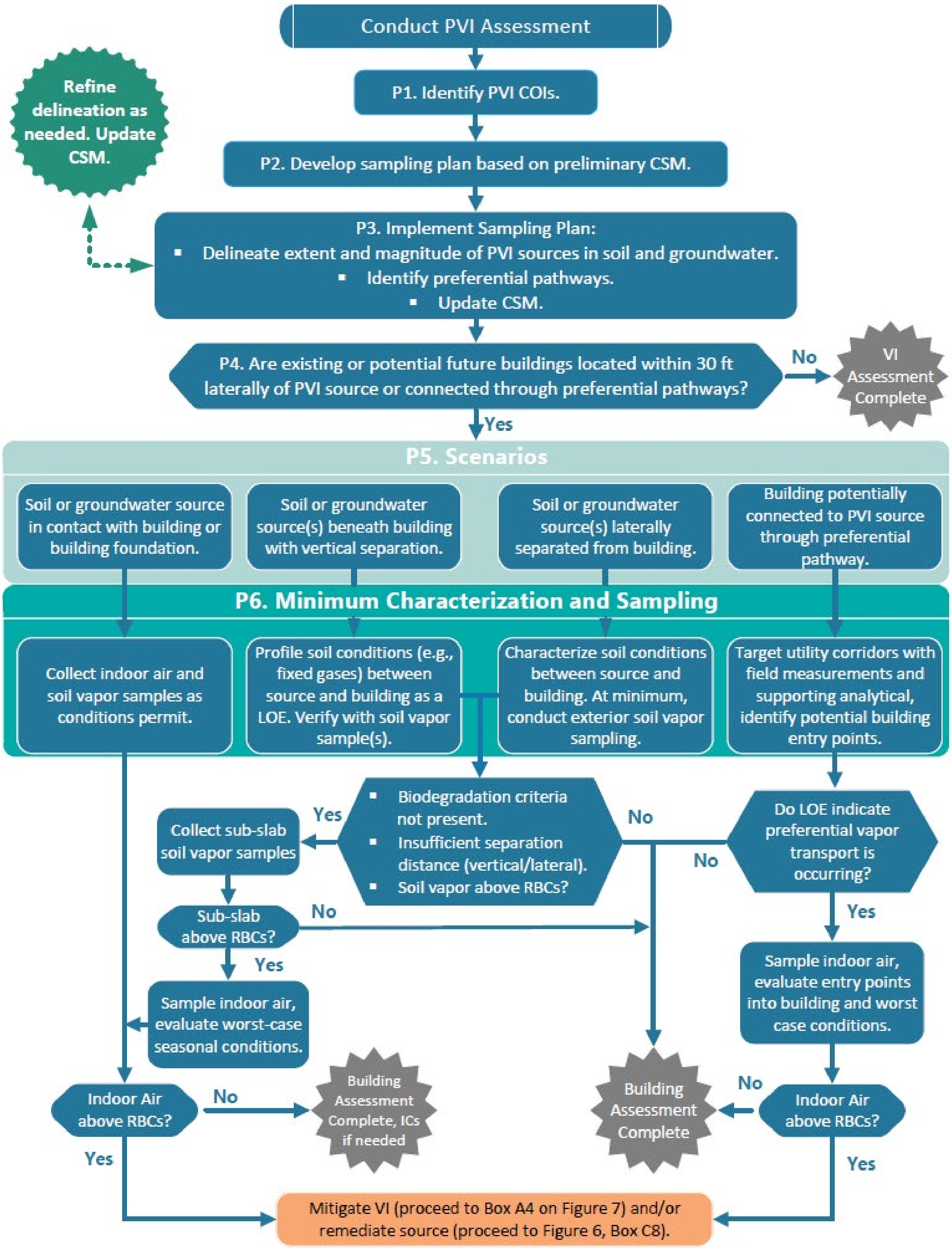

Figure 8. Petroleum Process Flow Chart to Evaluate the VI Pathway

Box P1. Identify petroleum vapor intrusion contaminant 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 as DEQ RBCs for VI risk screening with minor adjustments. Check DEQ's 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 to complete the following:

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

Based on field screening and analytical data map the nature, extent, and magnitude of PVI sources.

- Soil contaminated with greater than 500 parts per million (ppm) by method NWTPH-Dx and 80 ppm by method NWTPH-Gx or contaminant levels are considered potential VI sources.[10]
- Groundwater contaminated at levels exceeding VI RBCs and VISL values. Note: trends in groundwater concentrations and future plume migration must be considered in delineating source areas and VI CSM

Identify the locations, alignments, and depths of utilities relative to sources of contamination.

If existing information indicates vapor intrusion is actively occurring, indoor air samples should be collected in vulnerable buildings at the earliest opportunity (Refer to Section 3.2: Indoor Air Assessment and Mitigation Process). Indications of active VI include: complaints of chemical odors or physiological effects by building occupants, chemically stained foundations, or soil and groundwater data indicating a high probability of VI.

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[10] The UST Cleanup Rules (OAR 340-122-0218(d)(A)) require the use of the Northwest Total Petroleum Hydrocarbon (NWTPH) 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.

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 Pathway Scenarios

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 to collect 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 Indoor Air Assessment Flow Chart (left half of 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 (15 feet for LNAPL sources or 5 feet for dissolved phase contamination) 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; and
- Soil vapor analytical data.

There is a preference for sub-slab vapor data; however, a biodegradation evaluation can be conducted initially and 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. Note: 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, 2015). 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 gasses.

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% w/w), higher ethanol blended fuels (>10% v/v);
- 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% v/v); and
- Preferential pathways (utility cooridors, fractured rock – see Scenario #4) (ITRC, 2014; EPA, 2015).

If 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), and sub-slab vapor samples are below RBCs, no further building assessment is required.

If either fixed gas samples are unable to demonstrate that biodegradation is occuring (e.g. O_2 < 2%) or lateral inclusion distances are not met (<15 feet for LNAPL sources or < 5 feet for dissolved), then additional sub-slab vapor samples for VI contaminants of interest are required.

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

Scenario #3: Buildings are within 30 feet of VOC 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, often exterior soil vapor samples are 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 ft bgs and deep samples at 10 ft bgs (or as groundwater conditions allow) for a total of four samples.

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. 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, utility trench backfill, and potentially the lines themselves as close to the building entry points as feasible. Note: a subset of points investigated can be analyzed for VOCs to correlate PID/FID readings.

If there is no evidence utilities are facilitating VI, then further assessment of the building is unnecessary.

For all scenarios:

Treatment or removal of PVI sources. Treatment or removal of PVI sources should be considered if indoor air RBCs are exceeded, 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.**

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.

4.0 Vapor Intrusion Sampling and Analysis Guidelines

The data quality objective (DQO) process developed by EPA (EPA, 2006) 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. 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 (TCE) 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).[11] 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.

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

- Measurements of fixed gases and soil characteristics, particularly PVI sites.
- 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 permits accurate estimates of concentrations to compare to RBCs or use maxima described in Section 5. If data are 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[12] RBCs prevent false negatives. 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

[12] 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.

4.1 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.

Note: if at any point in the investigation information and/or data indicate vapor intrusion is likely 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 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 vapor intrusion.
- Determine whether VI is occurring in currently occupied buildings, and identify the appropriate response as described in Appendix A.

Hierarchy of chemical data for VI evaluations is the following:

1. Indoor air: most direct measure of VI risk, strongest line of evidence.
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 Basic Data and Information

4.1.1.1 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; and
- Depth, alignment, and building entry points of utilities lines.

4.1.1.2 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. Note: for PVI sites fixed gas measurements should be collected along with PID measurements to incorporate biodegradation in the CSM.

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.[13] Instead, sampling should target locations and intervals where PID measurements indicate significant levels of VOCs.

In recent years, portable gas chromatography (GC) 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 to identify soil vapor entry points into a building.

[13] Note, for compliance sampling purposes vapor samples should be analyzed irrespective of PID/FID measurements.

4.1.1.3 Collecting Fixed Gas Data

Primarily used as indicators of petroleum biodegradation, measurements and vertical profiles of fixed gases including oxygen (O_2), carbon dioxide (CO_2) and methane (CH_4) 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.

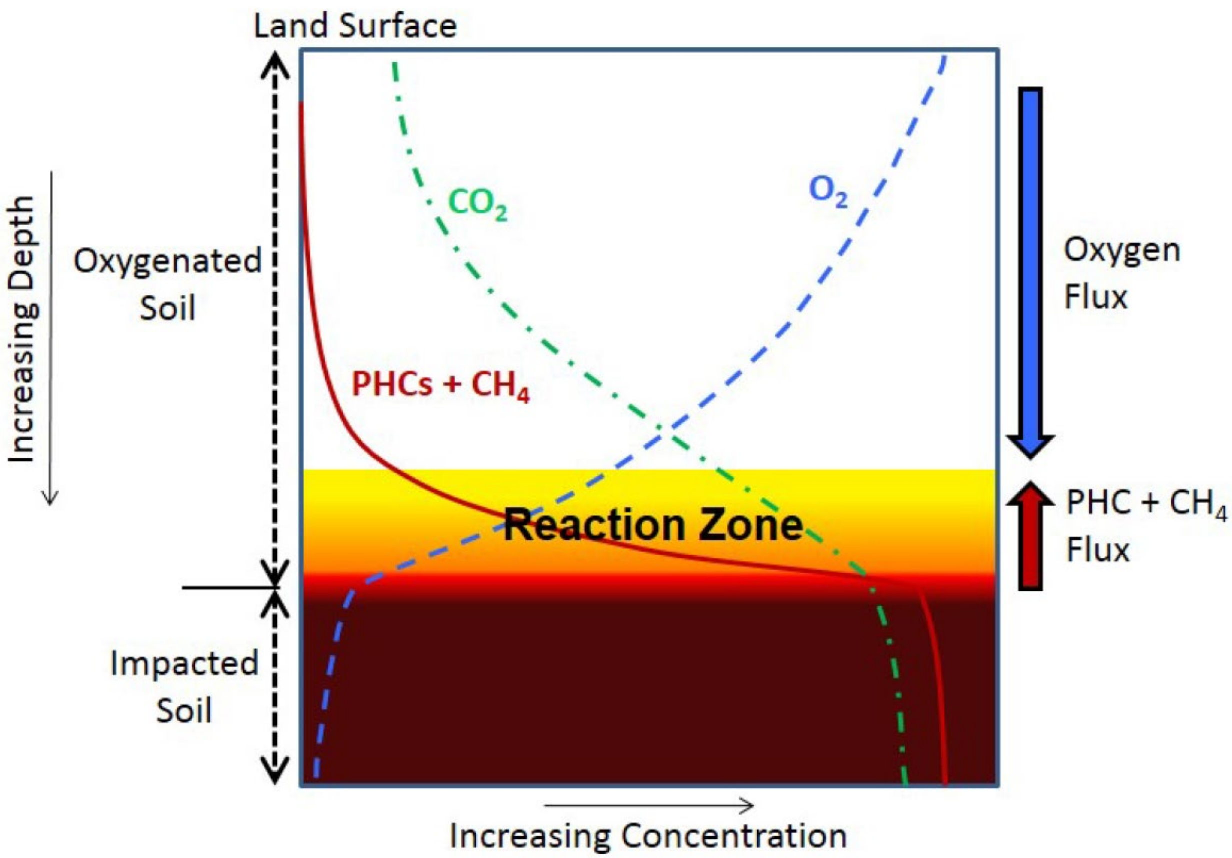

Figure 9. Vertical Profile of fixed gases and petroleum hydrocarbons (EPA, 2015)

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, 2015). 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, 2015). 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.

4.1.2 Soil Data

Soil data will no longer be used to screen out VI risk; however, it remains an essential data need 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.
- During cleanup, tracking remedial progress and source reduction.

In general, vadose sources that are composed of petroleum products and lower volatility 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 data should be collected using methods and procedures that minimize loss of volatiles (e.g., EPA Method 5035).

4.1.3 Groundwater Sampling

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; and
- 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.

4.1.4 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 are 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 (EPA, 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 Department of Toxic Substances Control (DTSC), July 2015
> https://dtsc.ca.gov/wp-content/uploads/sites/31/2021/11/VI_ActiveSoilGasAdvisory_FINAL_a.pdf
>
> *Soil Gas Sampling*. EPA Region 4, April 2023.
> https://www.epa.gov/sites/default/files/2015-06/documents/Soil-Gas-Sampling.pdf
>
> *Sub-Slab Vapor Sampling Procedures*. Wisconsin DNR, July 2014.
> https://dnr.wi.gov/DocLink/RR/RR986.pdf

4.1.4.1 Soil Vapor Samples (Interior)

Interior soil vapor samples are those that are collected directly beneath crawlspace and foundation slabs from temporary or permanent vapor monitoring points. In general, soil vapor samples should be collected from 5 ft bgs and 10 ft 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 particularly for PVI sites where the additional 5 feet of soil column can provide opportunity for further biodegradation and vapor attenuation. It's 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) procedures 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, EPA, California DTSC and other regulatory agencies provide abundant resources on these topics and investigators are encouraged to utilize established, peer reviewed methods.

4.1.4.2 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). When targeting a specific building for a VI evaluation at a minimum, exterior soil vapor samples should be collected at 5 ft bgs and 10 ft 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.

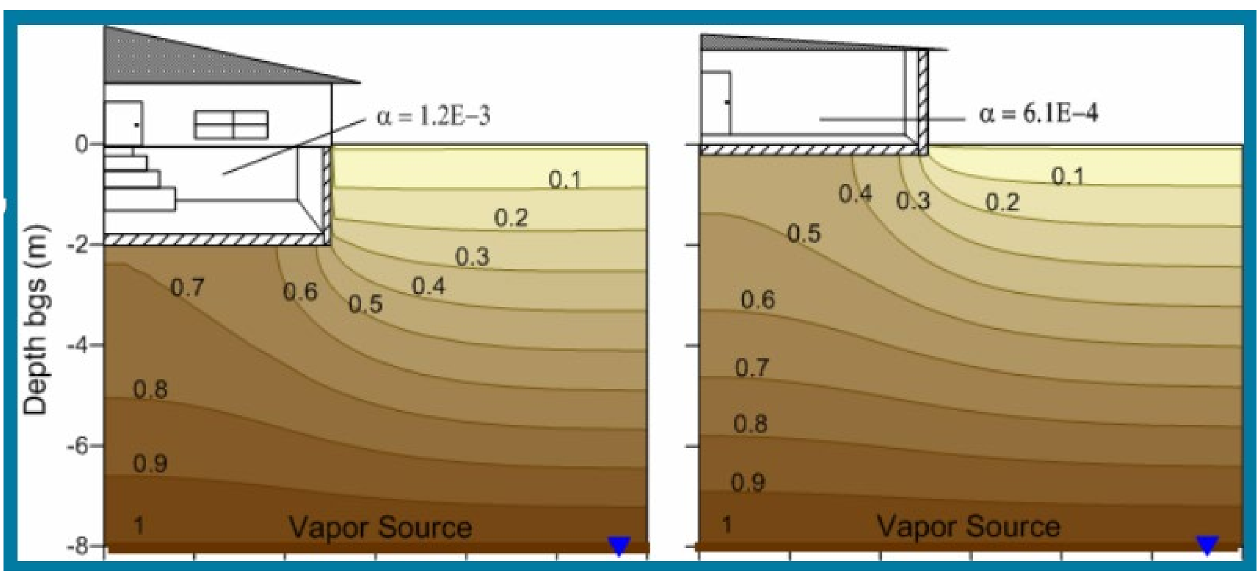

Figure 10. Influence of Building Design on Subsurface Vapor Distribution (EPA, 2012a)

4.1.4.3 Sub-Slab Samples

Sub-slab samples are collected in soil or sub-grade drainage layers immediately beneath (less than 6 inches) 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.

Note: 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.

4.1.4.5 Characterizing Seasonal Variability

At individual sites, soil moisture levels and fluctuating water table elevations can cause seasonal variability in soil vapor concentrations of up to an order of magnitude. 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.

4.1.4.6 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.[14] Under these or similar circumstances, an investigation may need to bypass soil vapor sampling and move directly to indoor air sampling.

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[14] Water accumulated in sumps should be sampled for VOCs.

4.1.5 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[15] or detectable levels of chlorinated solvents. As described in Section 4.1.2. 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.

4.1.6 Sample Locations

4.1.6.1 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 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.

[15] Soil Matrix standards are used by the Leaking Underground Storage Tank (LUST) and Heating Oil Tank Program under 340-122-0320.

4.1.6.2 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 ft bgs and 10 ft bgs. Note: 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.[16] 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, more samples will be necessary to accurately characterize conditions.

4.1.6.3 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.

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.

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

When evaluating VI potential at single-family residences, collect exterior soil vapor samples from two borings from 5 ft bgs and 10 ft bgs along the edge of the house nearest to the source of contamination or from two sub-slab samples per 1,000 square feet (ft^2). 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.

4.1.7 Timing and Frequency of Soil Vapor Sampling

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. 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 may not definitively 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. However, in general, avoid sampling during periods of and immediately following significant rainfall events that can generate saturated conditions in the soil profile.

4.2 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.

4.2.1 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 be remained 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 VOCs levels in the environment.

4.2.2 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, 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 4.2.6 and 4.2.7).

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 remediate source will be based primarily on subsurface data.

4.2.3 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 dampened by collecting time-integrated samples. The time period that a sample is collected over should reflect the exposure scenario being evaluated. For residential properties, it is assumed an occupant will be present 24 hours/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. 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 and 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, 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.

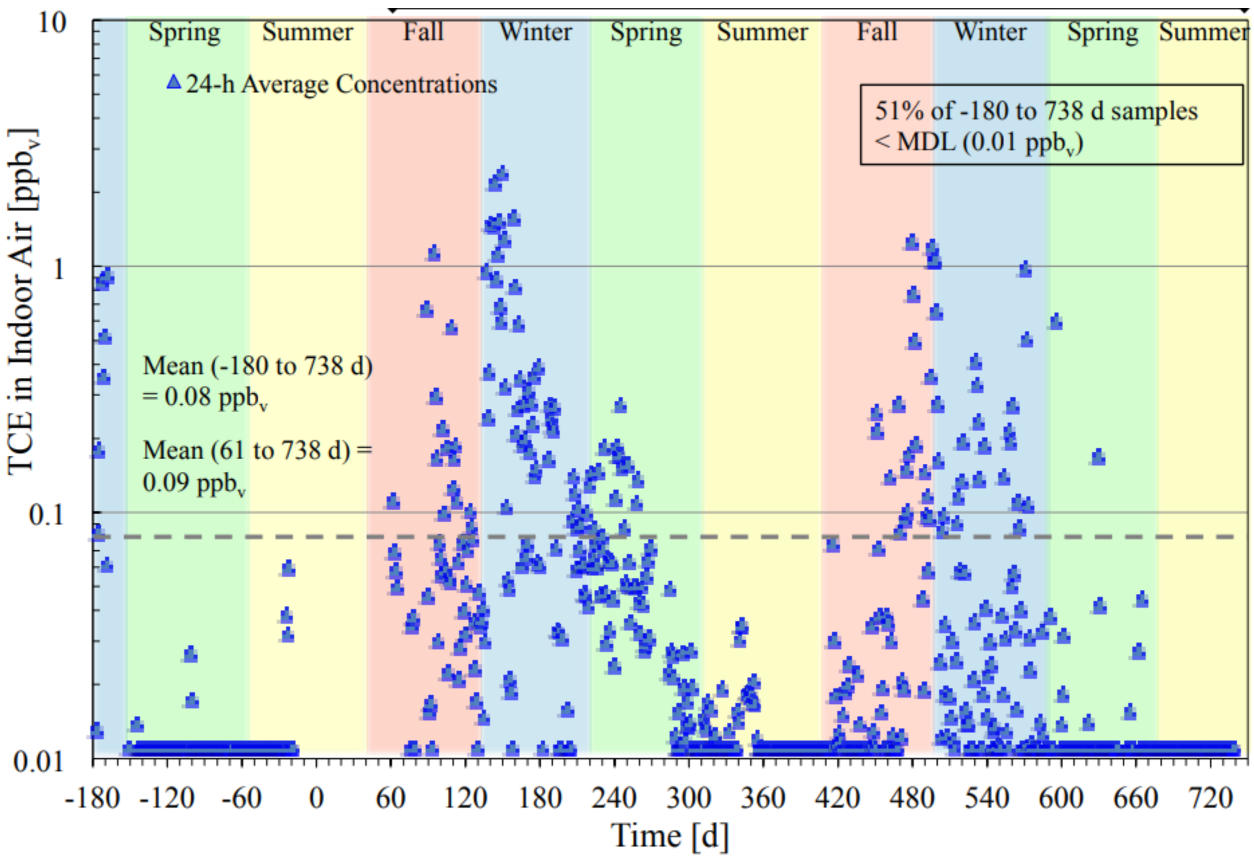

Figure 11. Seasonal Variability in Indoor Air Contamination from VI at a Single Residence (Holton et al., 2013)

4.2.4 Sampling Period Duration

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 sampling events frequently miss significant VI events. DEQ has concluded that longer duration 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 the achievable detection limits for a proposed passive deployment period. Consecutive passive deployment events can be used to achieve longer deployment periods.

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.

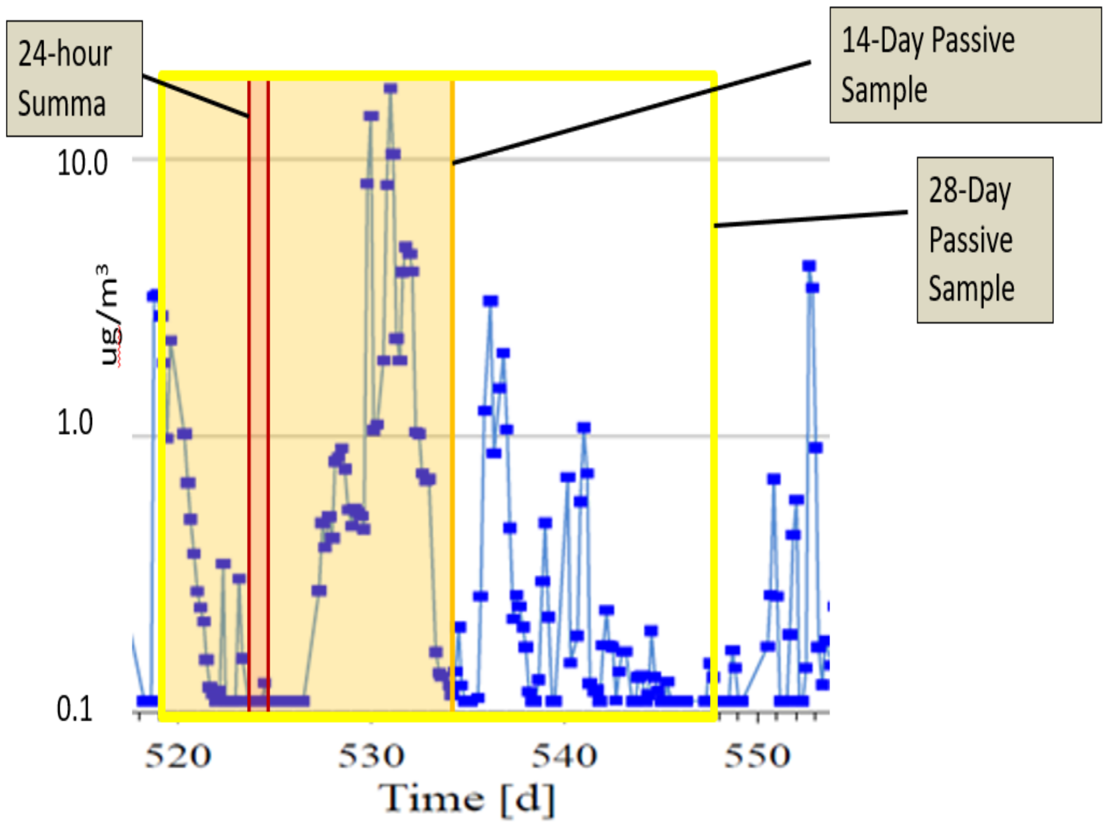

Figure 12. Concentration Variability Over Length of Time of Sample Collection (Data excerpt from Holton et al., 2013)

4.2.5 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's important the indoor data is always interpreted 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 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 or exhaust fans or ventilation equipment are operating. If there is no active HVAC system, barometric pressure measurements from the nearest weather station are adequate.

4.2.6 Outdoor (Ambient) Air Sampling

During indoor air sampling events, background levels of VOCs in outdoor air should also be measured for the same duration. Sources such as automobile exhaust, service stations, dry cleaning operations and other activities can elevate VOCs levels in outdoor air. By comparing indoor data to background ambient concentrations, VI impacts on air quality can be isolated.

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 (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 (e.g., automobiles, lawn mowers, chemical storage tanks, gasoline stations, industrial facilities, etc.).

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 conceptual site model, the contribution from outdoor air is important to consider when evaluating the source of chemicals to indoor air.

4.2.7 Analytical Methods

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

4.2.7.1 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 (US EPA 1987). 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,[17] and the methodology is described in greater details at EPA's website: EPA-5035.

4.2.7.2 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 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; and
- Passive diffusion-based samplers using sorbents can be deployed from 1 day 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. 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.

[17] Method 5035 for sample collection and preservation is not currently specified in DEQ guidance (DEQ, 2003) but is recommended and will be added when that guidance document is updated.

Table 4. Sample Preservation and Analysis Methods (EPA, 1999)

Media	Name	Description	Benefits	Limitations
Soil	EPA Methods 5035 and 8260	Method 5035 is a sampling/preservation protocol and 8260 is the standard method of analyzing VOCs.	Method 5035 is the recommended way to sample soils for VOCs to reduce VOC losses.	Soil sampling may miss source zones, particularly for halogenated VOCs.
Groundwater	EPA Method 8260	Low-flow purge and sample methods are preferred. Method 8260 is the standard VOC analysis.	Defines groundwater plume.	In some cases. This method may miss SVOCs that may be COIs.
Vapor	EPA Method TO-3/TO-3 Modified for TPH	A vacuum canister or Tedlar® 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 a specified volume of 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	A vacuum 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 if low detection limits are not required.	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 (e.g., Radiello®, Waterloo Membrane Sampler, SKC Ultra, ATD Tubes, etc.).	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).

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 $\mu g/m^3$ prior to comparing to RBCs.

4.2.8 General Field QA/QC

Take extreme care during all aspects of sample collection to minimize sampling error and ensure high quality data. 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 QA/QC protocols for sample collection and laboratory analysis, such as use of certified clean sample devices, meeting sample holding times and temperatures, chain-of-custody, 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 (pressure) of the Summa 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.); and
- 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.[18] 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 5.3), 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.[19] DEQ's air RBCs are consistent with EPA's inhalation methodology (EPA, 2009) and Regional Screening Levels (RSLs) (EPA, 2023b), as discussed in Appendix C. 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.

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

[19] DEQ and EPA publish air RBCs 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.

In 2023, DEQ used information from EPA RSL air values to develop state 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 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 to remediation system.

Soil vapor and groundwater RBCs are derived from air RBCs using attenuation factors (AFs; EPA, 2015a). Updates to the RBC_{air} for a specific compound will change the VI RBC_{SV} and RBC_{GW} values for that compound. As new toxicity information becomes available, EPA updates toxicity values used to calculate their RSLs, and DEQ in turn uses the updated values to revise its RBCs. Therefore, be sure to use the latest values in DEQ's vapor intrusion spreadsheet available from DEQ's Cleanup Program website and webpage containing Risk-Based Decision Making for the Remediation of Contaminated Sites: https://www.oregon.gov/deq/hazards-and-cleanup/env-cleanup/pages/risk-based-decision-making.aspx.

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 by EPA in their 2015 vapor intrusion guidance.

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[20] ($\mu g/m^3$)

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

AF = Attenuation Factor (unitless)

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

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}.

Note: 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 (EPA, 2015a); however, this document refers to attenuation factors using DEQ's definition. Thus, the default attenuation factor is 33 for residential and commercial properties.

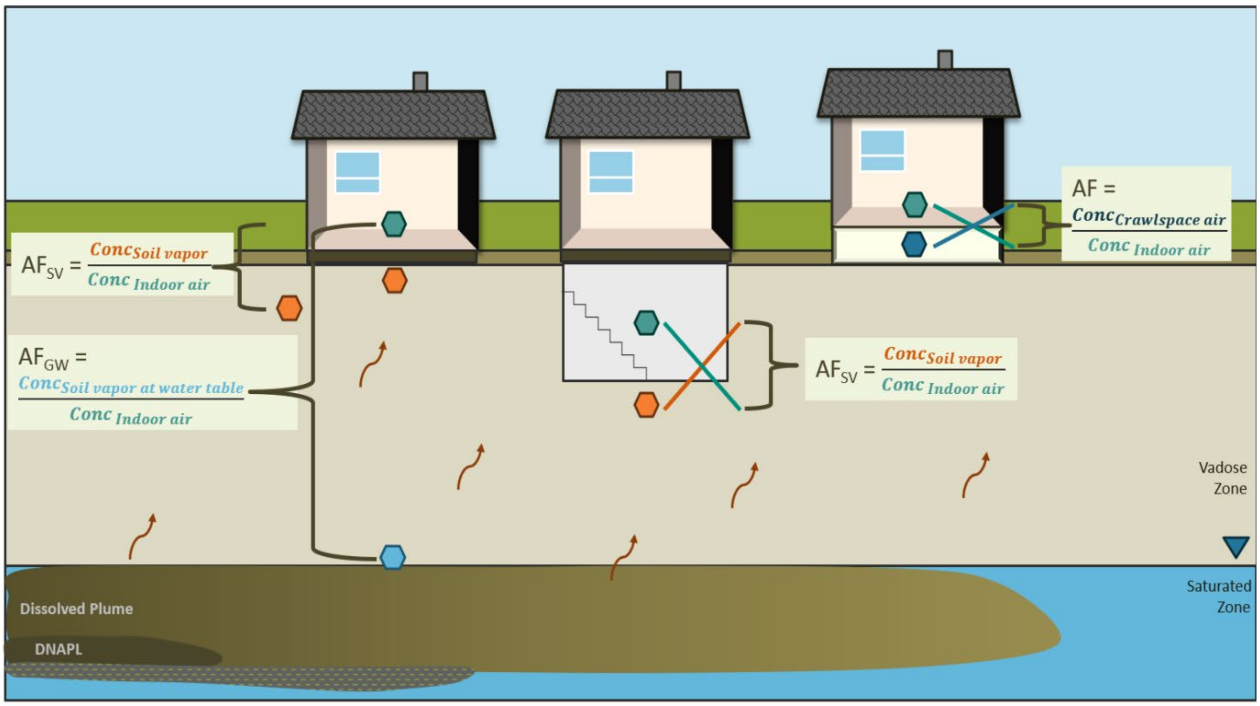


Figure 13. Matrix Specific VI Attenuation Factors

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. DEQ will not allow site-specific AFs to replace default RBCs to determine hot spots.

5.3 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 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 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 spots determinations are discussed below for indoor air, soil vapor and groundwater.

Indoor Air. The determinations of appropriate action to address RBC exceedances in indoor air should include a risk-based determination, as outlined in Appendix A (Response Matrix for Indoor Air). 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. *In either scenario, an evaluation of the presence of hot spot concentrations in the subsurface (e.g., soil vapor and/or groundwater) is necessary*. This is a more direct assessment of the source material impacting indoor air concentrations and will better inform the appropriate response action (e.g., removal/treatment/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. For soil vapor, to evaluate whether there is a potential hot spot, 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., identify if preferential pathways exist; evaluate efficacy of building foundation to contain vapor). 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,

[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).

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 data is required to demonstrate the efficacy of measures put in place to contain soil vapor contamination. If this evaluation indicates that the vapor is not reliably containable, there is a hot spot without a multiplier of RBCs. In this case, additional remediation focused on source treatment or removal must 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 soil vapor risk, 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” (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.

5.4 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.[22]

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*. 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 to10 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 (UCL) encompasses the true mean). EPA has published extensive guidance and developed software to calculate UCLs for a variety of data distributions (*e.g.*, normal, lognormal, non-parametric; EPA, 2002b). Many commercially 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 DQO planning (see Section 4).

5.4.1 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

[22] 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 are 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.

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 4.2: 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.

5.4.2 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.

5.5 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.

5.6 Interpretation of Results

5.6.1 Comparison to RBCs

When evaluating VI risks based on indoor air data, compare 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 indicate acceptable risk and were 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.

5.6.2 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. *If outdoor air concentrations are a result of site related sources, these concentrations would not be considered background ambient levels and should not be subtracted from indoor air concentrations for risk evaluation purposes.* Conceptually, several interpretations of indoor/outdoor air ratios are possible, as shown in Figure 14.

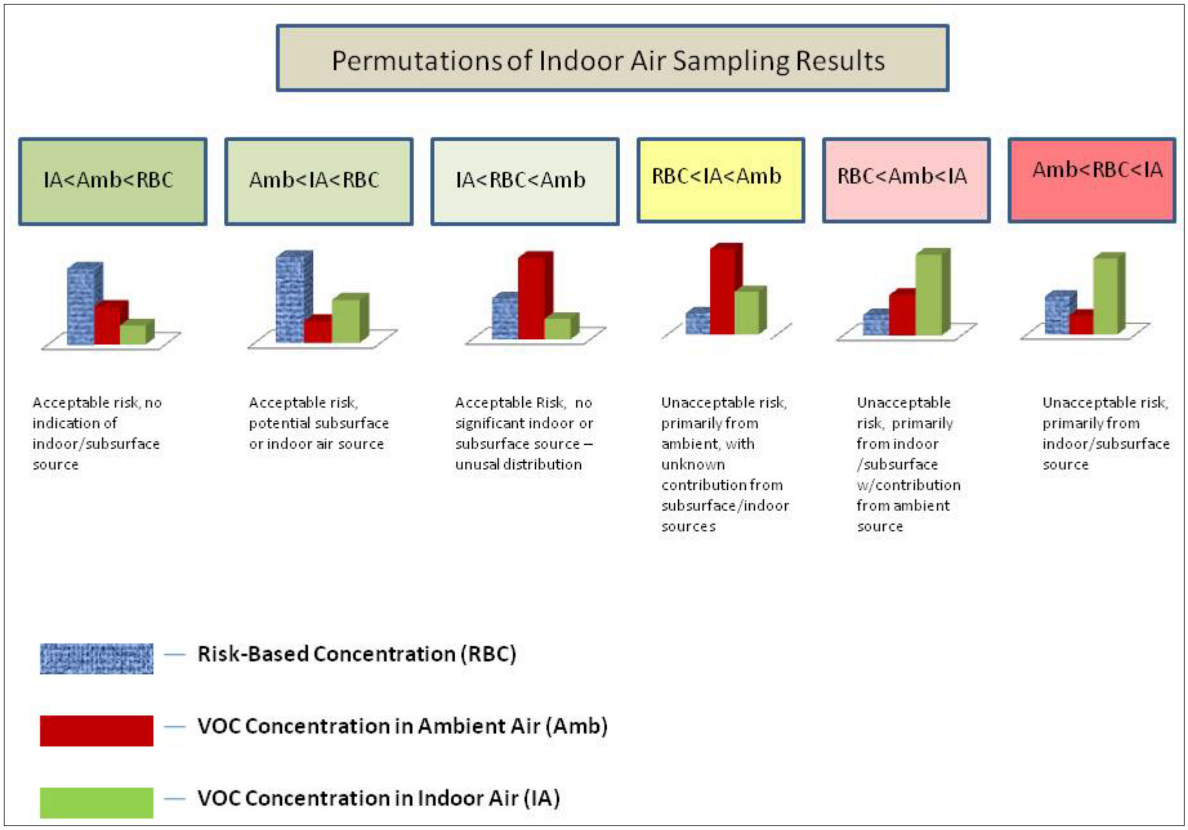


Figure 14. Potential Risk Screening Outcomes for Indoor Air

5.6.3 Using Lines of Evidence

Best practice is to use multiple lines of evidence and professional judgment to make vapor intrusion decisions (ITRC, 2007a; EPA, 2015). Using multiple appropriate LOEs supports developing a comprehensive CSM and considering 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, the occurrence, degradation daughter products, or the occurrence of chemicals unique to the subsurface release can be useful in identifying the source of VOCs (Ginevan, 2007; Feenstra, 2006) in indoor air. 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 vs 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).

5.6.4 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.
- If soil vapor or sub-slab vapor concentrations exceed RBCs, but the subsurface contribution to indoor VOC levels is below air RBCs, current VI risks are acceptable. Note: future VI risks will still need to be managed.
- If ambient levels exceed RBCs (not affected by site related sources), they become the de-facto compliance level for mitigation or remediation of indoor air. For example, it is common for indoor air concentrations to exceed the benzene RBC due to vehicle emissions. Under these circumstances the background benzene concentration becomes the RBC.

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

5.7 Responses to Risk

5.7.1 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 summa canister samples to evaluate short-term peak concentration.

5.7.1.1 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.

5.7.1.2 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 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); and
- 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.

5.7.2 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.

5.8 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 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 website).
- 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 and currently located at: https://www.oregon.gov/deq/aq/cao/Pages/CAO-Risk-Assessment-Resources.aspx

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 (e.g., elevated concentrations) that pose greater risk (OAR 340-122-0090).

In contrast, the objective of VI mitigation is to provide current and immediate 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 common 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 actions and 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 (e.g., below risk-based screening 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.) When remediation technologies control vapor transport in the subsurface, they can also function as a VI mitigation system. Under DEQ's Cleanup Program, mitigation systems are engineering controls used to protect human health from hazardous substances posing unacceptable risk. VI can also be "mitigated" through institutional controls, such as restricting use(s) until conditions are restored to protective levels or 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 related VI exposure risks and often do not address or remediate the source of the contamination. The zone (or radius) of influence (ZOI or ROI) 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 common mitigation systems, such as vapor pits and sub-slab depressurization systems.

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 systems use vertical wells that extend with depth to target zones of VOC contamination in the vadose zone. Angled and horizontal SVE well designs are also options. SVE systems are operated at higher extraction rates and under greater vacuum 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. Figure 15 illustrates a typical vertical SVE well design and Figure 16 presents an angled SVE well design.

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. Vadose zone sources can generally be treated with active remediation 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 breakdown 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 action, 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 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.

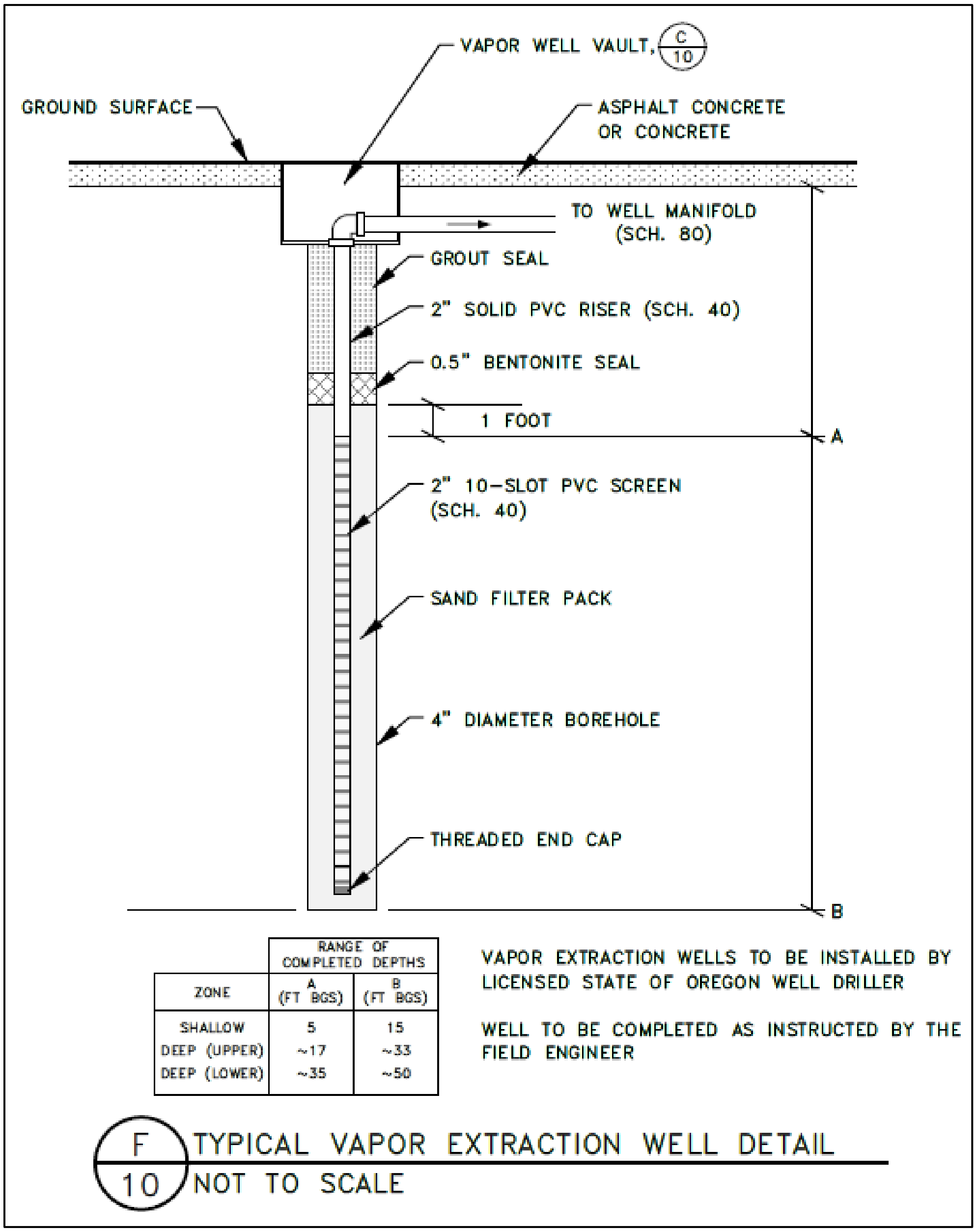


Figure 15. Example SVE Well Detail (Drawing by Apex Companies, LLC)

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, or early action are 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 5.3: 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 a 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 above, 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 6.2.1, 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 actions 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 SVE) 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. A 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.[23]

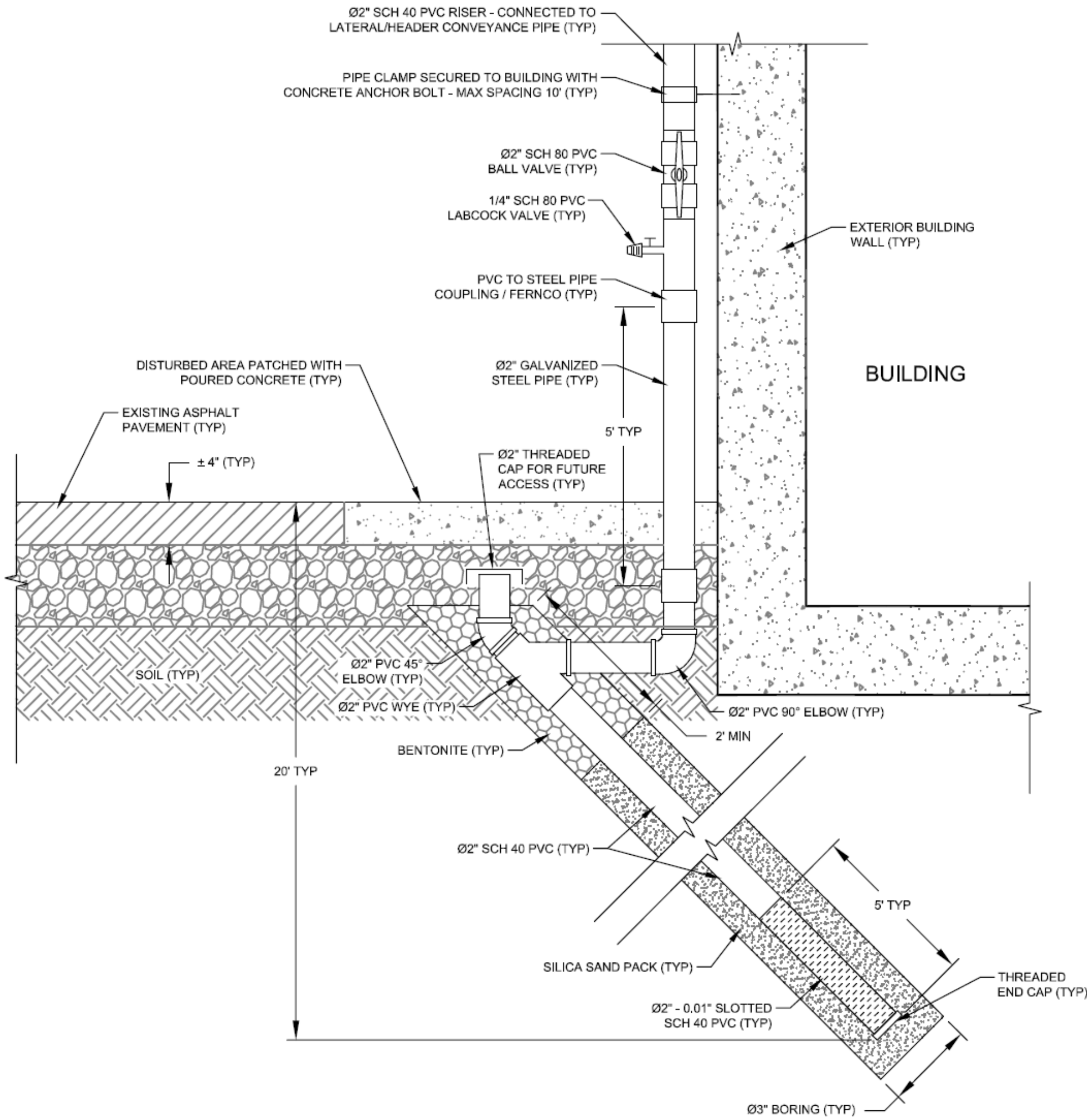


Figure 16. Example SVE Angled Well Detail Under an Existing Building (Drawing by AMEC)

[23] Additional guidance include:

Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with VOCs in Soils (EPA, 1993);

In Situ Treatment Technologies for Contaminated Soil (EPA, 2006c); and

Contaminants in the Subsurface: Source Zone Assessment and Remediation (NRC, 2004).

SVE is a common technology implemented in Oregon that targets treatment within the vadose zone. 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 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's *Soil Vapor Extraction System Optimization, Transition, and Closure Guidance* (USDOE, 2013), which builds on previous EPA and federal published documents (AFCEE, 2001; EPA, 2001b; USACE, 2002), provides a stepwise approach for assessment of SVE performance.

A source removal and/or remediation strategy is recommended for elevated concentrations, particularly chlorinated VOCs, though it can also be used as pre-treatment in combination with mitigation systems. As previously emphasized, remediation of sources will reduce the cleanup timeframe and may remove the need for long-term controls, such as VI mitigation or reduce the timeframe to maintain these controls. Treating sources may also address more than one exposure pathway. Institutional controls may be necessary to ensure the continued integrity of the cleanup is protective for site uses. In general, remediation is the preferred long-term approach to eliminate or substantially reduce contaminant source(s) below levels of concern and achieving 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 and operation and maintenance, 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 at greater expense. 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 contamination posing a 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, or exposed soil, foundation walls below grade such as basements, sumps, vaults, and elevators. Direct openings through the building shell and subsurface can serve as preferential pathways for VI, such as cracks in the building slab or foundation wall, slab penetrations, unsealed utilities, conduit openings, wall/floor joint openings.

It is important to conduct a comprehensive building inspection which provides crucial information for designing and constructing a VI mitigation system. See Section 2.3 for more discussion regarding building considerations. Generally older buildings present comparatively more VI pathways than newer buildings due to aging infrastructure, such as degraded building slabs, but also a higher potential for poor ventilation or limited to no building pressurization, increased number of entry points for VI, multiple foundation depths or subsequent building additions, etc. Building additions often represent different types of foundations and underlying sub-grade conditions. Industrial buildings commonly have multiple active and abandoned utility lines. Detailed information should be collected on the building construction including but not limited to carefully cataloguing entry points, building slab composition/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 common.

The most common mitigation technologies are sub-slab depressurization, which utilizes a mechanical component (e.g., fan/blower) to generate a vacuum, and passive systems (e.g., no mechanical component) such as sub-slab venting. Passive systems 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 vacuum. “Active" operation using a fan or blower increases the strength and reliability of the sub-slab vacuum and extends the zone of influence (e.g., volume of underlying soil where vapor transport is controlled by the mitigation system) below the sub-slab.

These mitigation systems are typically used in conjunction with a vapor barrier, particularly in new construction and to a lesser extent at existing buildings. In existing buildings, mitigation technologies often utilize the existing building slab as the “barrier”; however, there are opportunities to install a VI barrier when the existing building slab is removed. For instance, a vapor barrier can be installed over trenches excavated for construction of the sub-slab mitigation system and/or soil excavation of source areas 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 seamlessly integrate a VI barrier.

Several types of VI mitigation techniques are available that can be implemented within building or below a building, and common applications are described in the following sections. Suitable mitigation technologies or approaches are not limited to what is presented in this document. A combination of techniques may be necessary to address site-specific conditions and reliably mitigate VI risk. Proposed mitigation plans are provided to DEQ for review and concurrence to proceed with implementation is site-specific.

Additional guidance and resources regarding vapor intrusion mitigation include:

- ITRC has recently 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 – currently found at: https://vim-1.itrcweb.org/).
- EPA also provides 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, 2008a – https://www.epa.gov/vaporintrusion/indoor-air-vapor-intrusion-mitigation-approaches).
- EPA Region 5, *Vapor Intrusion Handbook,* recently updated (EPA, 2020 - https://www.epa.gov/vaporintrusion/region-5-vapor-intrusion-guidebook) also contains a useful summary of mitigation options.
- Naval Facilities Engineering Command has published factsheets on mitigation technologies and considerations for new and existing buildings (NAVAC, 2011a-b – https://clu-in.org/download/contaminantfocus/vi/vi_mit_new_bldg_fs.pdf and https://clu-in.org/download/contaminantfocus/vi/vi_mit_new_bldg_fs.pdf).

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 2020 Vapor Intrusion Handbook.
- Table 1. Overview of Mitigation Methods with Cost Data from EPA's 2008 *Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches*.

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 system, building design, interceptor trench, preferential pathway prevention (e.g., coatings/sealants, utility collars), aerated floors
Active Mitigation	Sub-membrane Depressurization (SMD), Sub-slab depressurization (SSD), Sub-slab ventilation (SSV), Vapor Pits, Aerated Floors
Source Treatment/Removal	Soil vapor extraction (SVE), multiphase extraction (MPE), groundwater treatment (e.g., bioremediation and chemical oxidation), soil excavation

While outside the scope of this guidance, other types of vapor mitigation are common for radon and methane. However, it is helpful to recognize that vapor intrusion mitigation technologies have been adopted from well-established techniques that 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 are intended to prevent vapor from entering buildings; however, the hazards attributed to these different gases vary substantially. Consequently, standards and practices in mitigating exposure vary depending on the contaminant hazard and reliability in mitigation techniques to interrupt the exposure pathway. For instance, methane mitigation standards are generally conservative and comprehensive due to the hazards posed. 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 is a naturally occurring radioactive gas that can also be transported into indoor spaces by soil vapor. 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. Radon mitigation is not overseen by DEQ. With that said, many cities have started to incorporate radon gas mitigation into city code for building construction to address local radon concerns.[24] A radon system may also mitigate VOC vapor intrusion at a site to a certain extent and an evaluation can be conducted t 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.

[24] 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.

Methane Gas Mitigation. Methane gas is regulated as a hazardous substance in Oregon but is outside the scope of this guidance. DEQ does oversee the design and implementation of controls to address methane risks in accordance with rules requiring the prevention of methane gas into structures including interior spaces and exterior confined spaces. Similar mitigation technologies are utilized as described in this guidance to address methane concerns; however, a comprehensive and conservative approach is integral given the severity of hazards posed by methane gas. In general, several engineering controls are implemented and monitoring to increase the factor of safety and provide a high level of confidence of effective mitigation. Resources for further information include Los Angeles Department of Building and Safety (LABDS), Public Works Los Angeles County, and Orange County File Authority (OCFA), which have a developed methane mitigation standards and requirements for their area given the prevalent naturally occurring methane gas. Note: DEQ considers these standards as resources to guide methane mitigation design; however, has not adopted these standards and proposed mitigation strategies should be based on site-specific considerations.

Early Scoping of 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 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 based on site-specific conditions (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 investment upfront in most cases can limit prolonged monitoring periods and potentially onerous or restrictive institutional controls.

Site-specific conditions where 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 reassurance 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 initial concentrations in the sub-slab marginally exceed RBCs. For more potent and persistent sources or where lower risk thresholds are present (e.g., residential dwelling, 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.

6.2.1 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 VOCs 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 to evaluate and implement interim mitigation measures. 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, can also be taken such as risk communication, notification, and 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 5.7.1).

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 (2008, 2017, 2020) and ITRC VIM Factsheets (2020) also provide additional detail about immediate mitigation options.

Ventilation. Increasing the exchanges 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 the HVAC system can also increase ventilation. 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 is an effective mitigation strategy for buildings with marginal exceedances of indoor air RBCs (e.g., less than a factor of three). 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.

Positive 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 and into the underlying soil, thereby reversing the flow of vapor across the foundation and preventing soil vapor entry. This approach is minimally intrusive and can effectively reduce or mitigate vapor intrusion by increasing ambient air intake *and* pressurizing a building. HVAC adjustments are generally not appropriate long-term controls as a stand-alone technology given inconsistent performance and ability to control performance, particularly in older buildings, but can be integrated into a long-term mitigation strategy.

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, 2017). EPA's 2017 engineering issue recommended activated carbon as most effective adsorption medium for air filtration to treat TCE.

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. 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 is 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).

6.2.2 Passive and Active Subsurface Mitigation

Mitigation systems are typically installed where the building shell comes into contact with the subsurface and function to disrupt the VI pathway. Common design elements of vapor intrusion mitigation systems installed beneath buildings include sub-slab venting network for vapor collection, a permeable gravel conveyance layer, and a low-permeable chemically compatible vapor barrier above the venting system. Sub-slab suction pits are common variations of a venting network and easier to install at existing buildings. Active systems include an appropriately sized fan/blower to distribute and maintain vacuum beneath occupied buildings, effluent treatment systems if needed, control panels and fail-safes. Design plans should include performance monitoring locations and sampling ports, utility trench dams and conduit seal-offs as needed. 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). Chemical compatibility, constructability and quality control are important considerations when evaluating vapor intrusion mitigation technologies.

At some sites based on the CSM, additional engineering methods may be necessary to prevent offsite migration and/or coming into proximity of a building. Appropriate technologies may consist of subsurface extraction systems and interceptor trenches, and techniques to prevent preferential movement such as installation of cutoff collars along utilities or consolidating/limiting utilities in certain areas of the property. These strategies are incorporated into the overall remedial approach.

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 (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.

Remedial and mitigation design plans consist of engineering controls must be stamped by an Oregon Registered Professional Engineer. The P.E. identified as the engineer-in-charge is also responsible for direct supervision of construction of the proposed design plans and certification of as-built plans provided to DEQ following construction. Performance monitoring of engineering controls and preparation of pertinent documents (e.g., Operation & Maintenance Plan) is also a requirement. Refer to Section 6.4 and 6.6 for additional details regarding Cleanup Program document expectations and professional certifications.

6.2.2.1 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 in concentration 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 of openings in the floor slab and installation of 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 building but typically would require removing portions of the building slab, installation of the of sub-slab venting features, and restoration of the building sub-slab preferably with an underlying vapor barrier.

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 other technologies such as a sub-slab depressurization system. When used in concert with compatible technologies, a vapor barrier can also enhance their performance. More robust vapor barrier qualities (e.g., thicker, high tensile strength and puncture resistance, enhanced chemical and diffusion resistance to site specific contaminants, etc.) may be appropriate based on the CSM and corresponding mitigation design (e.g., passive versus active system) to provide greater certainty that the overall mitigation approach will be effective. In situations where the potential for vapor intrusion is low, a vapor barrier with riser pipes can be installed as a precautionary measure. 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. Vapor barriers can be valuable passive engineering controls when appropriately applied and installed properly.

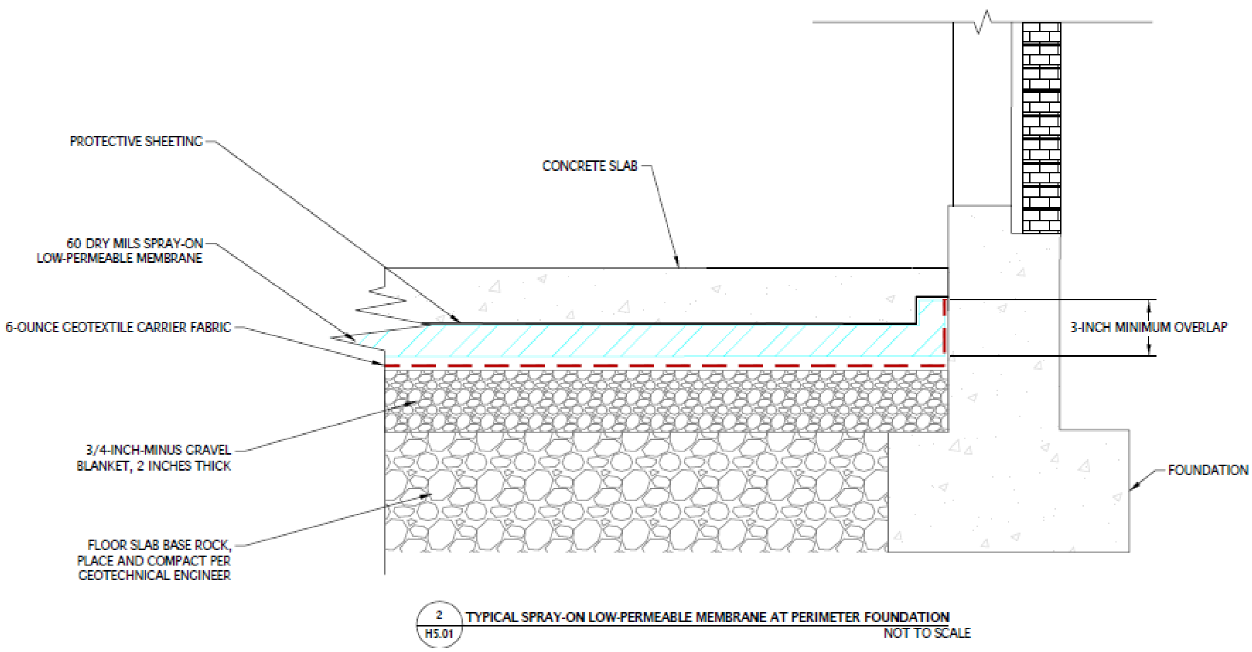


Figure 17. Example of Low-Permeable Membrane, Fluid Applied (Drawing by GeoDesign Inc., an NV5 Company)

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 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 or layered within the composite barrier.

Vapor barriers are commonly supplied in the form of sheeting rolls or alternatively the process is fluid applied (spray on). 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, intrinsically seamless, 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.

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 a vapor barrier collar when piping passes through a vapor barrier.

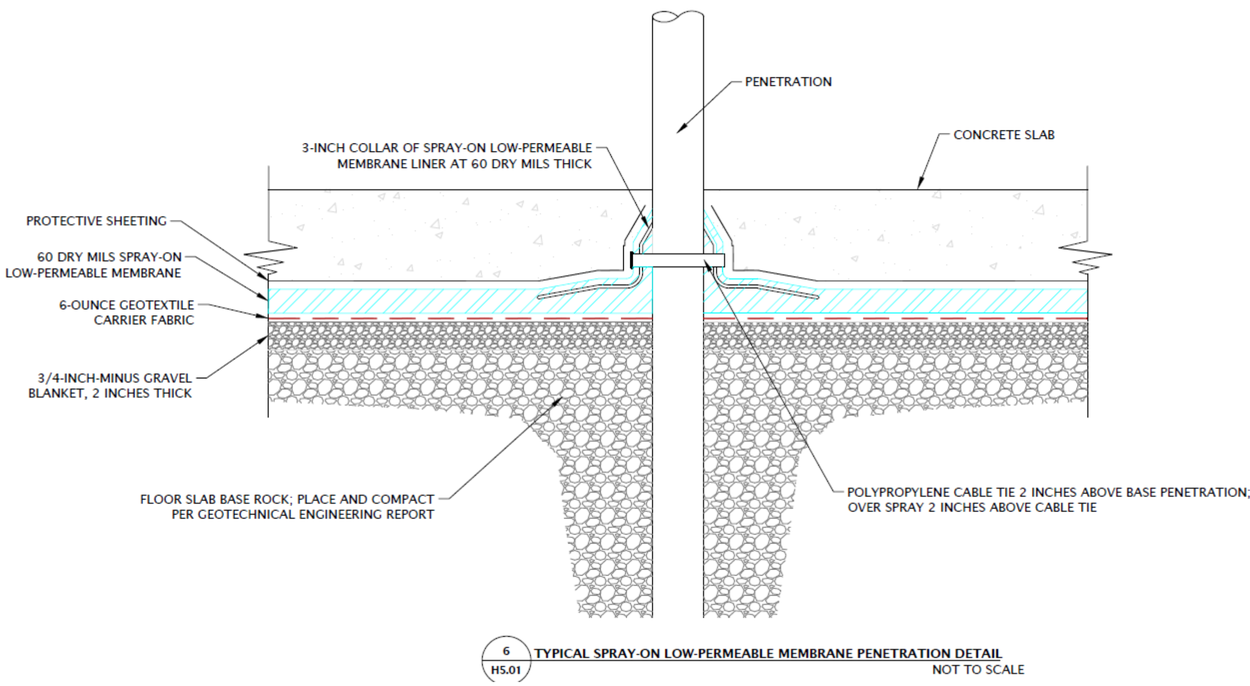


Figure 18. Example of a Vapor Barrier Collar
(Drawing by GeoDesign Inc., an NV5 Company)

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 material. Advancements in fusion/sealing methods continue to evolve, including vapor barrier composition. Complete sealing between barrier sheets and termination points requires rigorous 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.

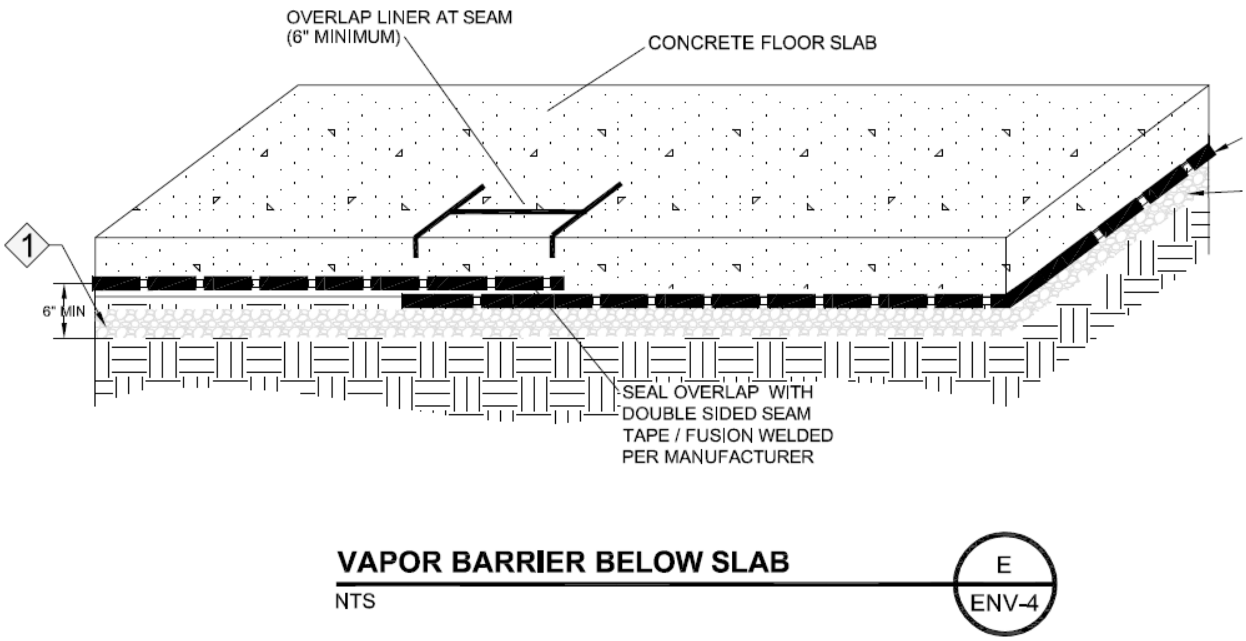


Figure 19. Example Vapor Barrier Overlap at a Seam (Drawing by AMEC)

In addition to chemical resistance and impermeability, vapor barriers should be sufficiently durable to prevent damage during installation, building construction or remodels, and resist failure due to normal earth movement and age. Consistent with EPA and other guidance, DEQ recommend as a minimum thickness of 30 mil for VI barriers and 40-60 mil is common.[25] Thinner barriers can be easily punctured, and an opening can become an opportunity for potential vapor intrusion. For these reasons, careful installation is also critical for this type of passive control and 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 a site better, such as constructability. For instance, some vapor barriers (while providing the chemical resistance and durability) can be

[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).

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 hinderance for constructability in limited access areas, such as a crawlspace.

Before selecting a vapor barrier, review the manufacturer specifications and applicable tests 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 (methane, radon, BTEX), contaminant exposure/degradation tests, tensile strength and elongation, seam strength, seam peel adhesion puncture and tear resistance, freeze-thaw resistant, microorganism resistant, oil resistant, heat/aging, environmental stress-cracking, soil burial, 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 over or under conservative product for a VOC vapor intrusion site, 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.

Features to consider during design and installation of a vapor barrier:

- 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, chemical resistance to contaminants. Note: 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 secure 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 engineer or third-party inspector.
- Extend vapor barriers across the entire sub-slab or sub-structure of occupied spaces, to the extent feasible. Installation of a vapor barrier below the entire building footprint is recommended for new structures when practicable and based on the CSM.
- Install protective layers above and below vapor barriers, such as geosynthetic liner options (also referred as geonets), or appropriate alternative.
- 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 method.
- Incorporate sub-membrane gas collection network and venting via vent riser(s) to minimize gas 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.

Modifications to mitigation systems, including barriers typically require advance DEQ notification and approval, and documentation of repairs.

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 provided 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. 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 gas collection piping system consists of a perforated pipe or low-profile vent. The venting design should ensure the system can become "active" using a fan or blower.

Aerated Floors

Aerated floors are less common and, if used independently (along with riser pipes), can be considered a passive technology. When incorporated into an active depressurization system, aerated floors are a means to provide efficient 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 with field fabricated vapor barrier membrane boots/strips. Refer to vapor intrusion barrier details regarding membrane and sealing requirements provided in previous sections.

Preventing Preferential Pathways

Preventing preferential pathways can be easily implemented in a relatively short timeframe and provide long-term benefits, when properly maintained. Preferential pathways into buildings should be sealed as part of the mitigation strategy. The measures include sealing foundation surfaces and cracks, and filling annular voids around utilities and conduits that enter the structure from underground. Note: other benefits of sealing the entire floor include mitigating the off-gassing from semi-porous flooring or slab (e.g., concrete) that has been impacted from chemical spills, for example PCE at a dry cleaning facility.

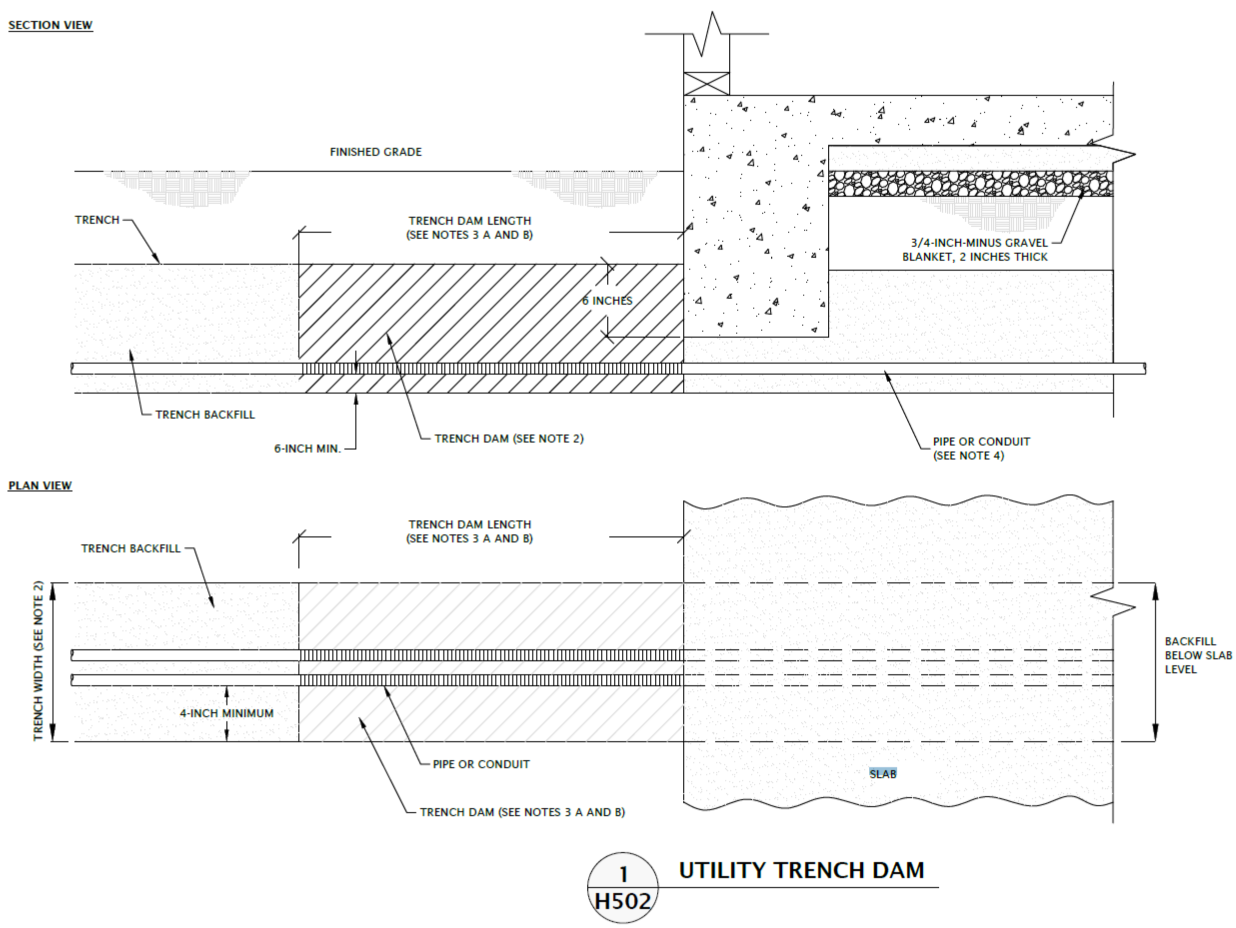


Figure 20. Example Trench Dam Along Utility (Drawing by GeoDesign Inc., an NV5 Company)

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. Flooring sealants, such as epoxy or elastomeric polymer floor coatings, can be applied to existing concrete building slabs. As with vapor barriers, sealant product specifications should be carefully examined for the desired properties (bonding to flooring, chemical compatibility, impact resistant) and contractors should adhere to installation specifications as well as safety measures to protect building occupants during and after application.

Utility cut-off collars or trench dams (see example provided in Figure 20) can be installed to prevent migration where utilities enter the footprint of a building but may also be applicable at property boundaries or other site facilities.

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 through openings or can be enhanced using fans. As noted above, building design can also incorporate preferential pathway prevention techniques. Intentional design can also address different levels of risk (low, medium, high), particularly for multi-use properties. For example, placement of green space or parking (over higher risk areas) versus a building (overlying lower risk areas) or reserving lower levels for commercial use or parking garage.

In urban areas, new buildings often integrate commercial space, storage, or common areas at the ground floor which is also 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 mitigation of radon or carbon monoxide and whether there are opportunities to utilize or augment mitigation infrastructure required by building code.

Revitalization of the 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 can enhance the protectiveness of building occupants, including from VI and anticipates a combination of uses including residential. While more challenging, existing buildings can use building design concepts to address spaces vulnerable to vapor intrusion through building improvements and, if necessary, add mitigation technologies to allow for expanded uses and minimize restrictions or long-term controls.

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.

6.2.2.2 Active Mitigation Technologies and Design Considerations

Active depressurization technologies or "active" mitigation include sub-slab depressurization (SSD) sub-membrane depressurization (SMD), sub-slab ventilation (SSV), and crawl space ventilation (CSV). A description of each of these is provided in the ITRC VIM Factsheets (https://vim-1.itrcweb.org/). 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 the pressure barrier to keep the vapors from reaching receptors. Note: source removal or other remediation method should be implemented for elevated sources (e.g., exceeding hot spot concentrations).

Active depressurization systems use a blower or fan to draw air from beneath the building through a gas 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 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 gas collection pipes (or trenches), number of suction points, and potential fan/blower size needed to achieve design objectives. Communication testing or vacuum tests are used to estimate the radius of influence from a suction (i.e., extraction) point below the building foundation. The range of negative pressures that can be achieved with distance is estimated by applying a range of vacuum levels using a fan/blower and taking pressure measurements at sub-slab monitoring locations offset radially and with distance (e.g., 5, 10, 15, 20, 25 feet) from the source of vacuum. Collecting pre-mitigation "baseline" conditions (e.g., differential pressure measurements) is recommended in addition to predesign diagnostic tests, such as communication testing. It is important to record barometric pressure and other conditions that may influence test results.

Sub-Slab Depressurization

Sub-slab depressurization is the most common active vapor mitigation technology for new buildings and typically used in combination with a vapor barrier; when coupled these mitigation controls complement each other. Vapor barriers improve SSD performance (i.e., SMD) by preventing leakage through the building slab via cracks and openings, while the gas 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 gas 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 gas collection network, vacuum design, fan or blower selection, above slab conveyance piping, air discharge treatment assessment, and selecting performance monitoring locations.

Gas Collection Network. 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/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 sub-grade conditions. The gas 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 21 illustrates an example. The mats are typically supplied in rolls and installed across the subsurface prior to pouring the building slab.

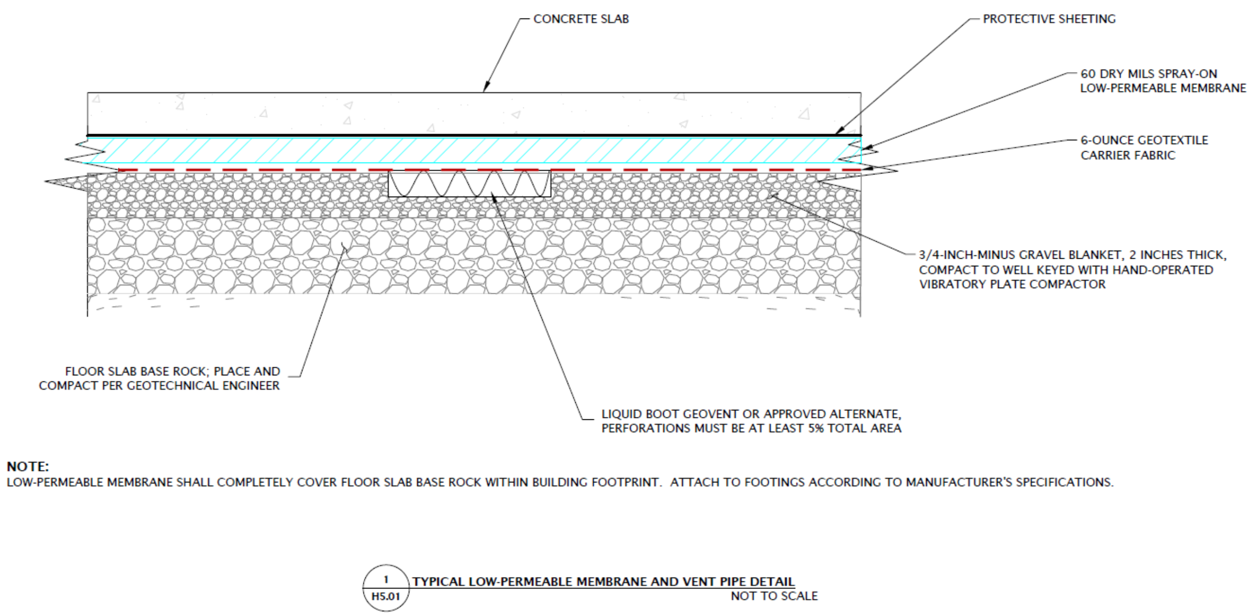


Figure 21. Example of Low-Permeable Membrane and Vent Pipe (Drawing by GeoDesign Inc., a NV5 Company)

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 gas 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 22 provides an example of a piping network design and monitoring locations.

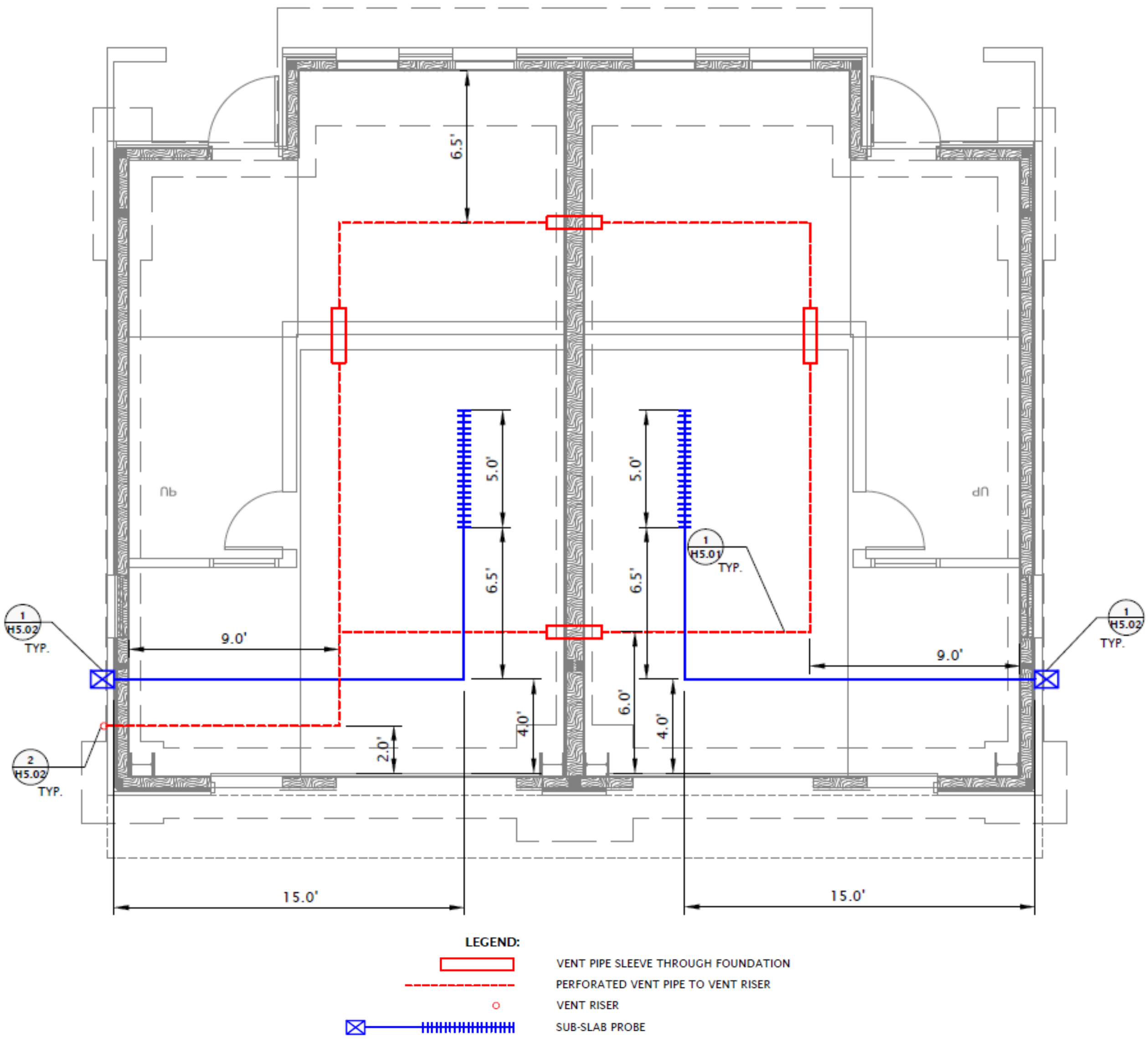


Figure 22. Example Design of Pipe Network and Monitoring Locations (Drawing by GeoDesign Inc., a NV5 Company)

[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.

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 pressure differential (i.e., vacuum) below the sub-slab such that sub-slab soil vapor entry into the indoor air space of the building is mitigated. For example, strong lines of evidence to demonstrate reliable mitigation include: i) maintaining sufficient pressure differential over the area requiring mitigation; and ii) reduction of sub-slab vapor concentrations (e.g., below RBCs).

The movement of vapor follows the path of high to low pressure, and the rate of the flux is driven by the gradient between high to low. Therefore, in most instances pressure differential across the slab should be sustained continuously for as long as the engineering control is needed. The vacuum is greater near the suction point (e.g., gas collection network or vapor pit) and decreases with distance to a boundary where vapor is no longer drawn in. 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. A minimum vacuum of 0.02 inches of water (approximately 5 Pascal) is also commonly applied. In practice, a range of vacuum measurements from 0.01 inches of water (2.4 Pascal) and greater is used to estimate the system's ZOI. There are several types of devices to measure differential pressure that are accurate to 1 Pascal or less, such as a digital micromanometer.

Specifically, a minimum vacuum should be achieved at the weakest point of the mitigation system, such as the perimeter of the ZOI from the suction point. 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. The induced vacuum field should consistently be able maintain a minimum vacuum, withstanding a variety of factors (e.g., building heating/cooling, slab leakage, seasonal variabilities).

The vacuum of the depressurization system should be sufficient to overcome a variety of conditions to prevent vapor intrusion including:

- Daily and seasonal fluctuations in meteorological conditions building HVAC operation. For example, heating during the winter months can reduce the indoor air pressure and increase vapor intrusion. For additional information, refer to Section 4.2.3: Temporal Variability in Vapor Intrusion.
- Interactions with indoor air as a result of building design and any leakage across the building slab.

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, 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 (e.g., exceed RBCs multiple times) and in absence of good characterization of the nature and extent of subsurface and contributing sources.

Applied air flowrate (e.g., blower selection and design spacing of suction element of the depressurization system) should minimize sporadic periods of pressure differential dipping below minimum vacuum levels to prevent vapor intrusion.

Fans or Blower Design. Vacuum is applied 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, piping design and air flow rate should be adequate to sustain sufficient vacuum. When applicable, pipe flow calculations including performance curves (example in Figure 23) should be provided with design plans as supporting documentation for blower selection.

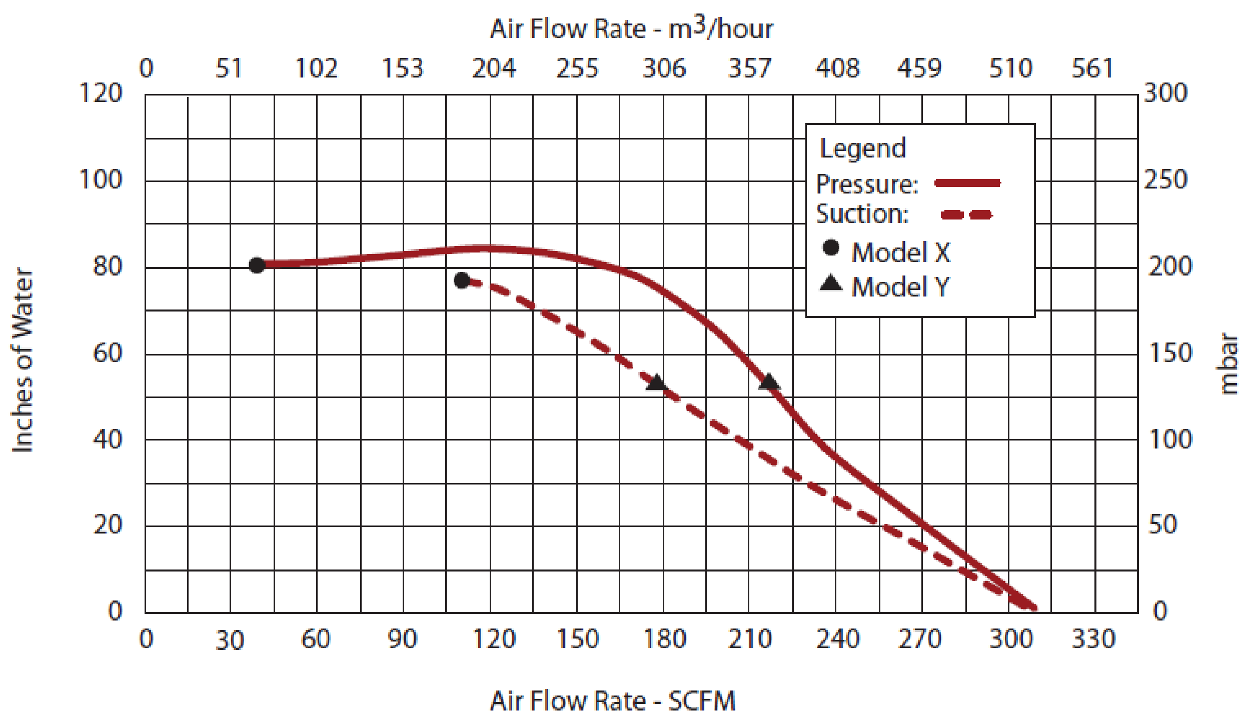


Figure 23. Example Performance Curve

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), such as at a residence or condo. 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.

In practice, larger mitigation areas will require a blower to sustain sufficient vacuum at greater distances. Generally, fan size is dictated by the mitigation approach (e.g., SSD or SSV), sub-slab permeability, slab "leakiness", and number of suction points 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 mounted on the exterior of the building, or in an unoccupiable spaces that does not have an occupiable space above. For example, a fan can be mounted in an attic or an attached garage, provided there is not occupiable space above the attic or garage. Piping on the pressure side of the fan should not be routed through occupiable space.

Mitigation systems require an O&M plan, and the fan/blower type, as well as the scale of the mitigation system will dictate the complexity of the plan and related operational parameters.

Vapor Discharge Design. Vapor collected by SSD and similar systems should be routed to the building exterior via solid vent pipe risers above the roof or alternative approved location. Figure 24 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.*

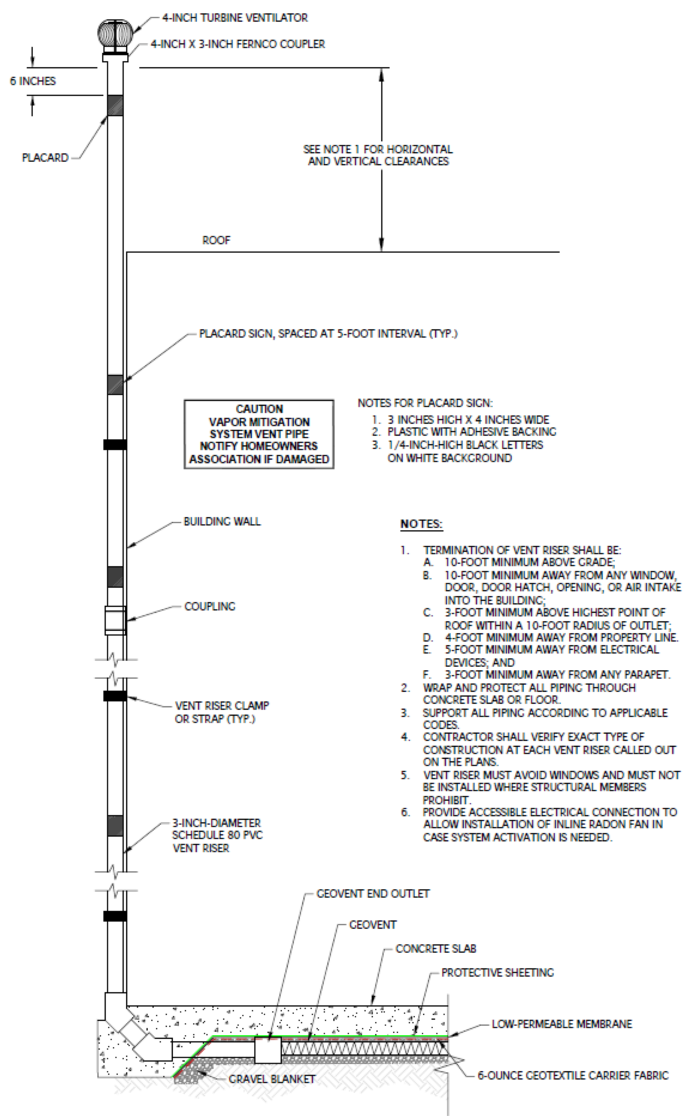


Figure 24. Example Vent Riser
(Drawing by GeoDesign Inc., a NV5 Company)

Vapor effluent from mitigation systems contain 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 and is covered in greater detail in Appendix E. If necessary, emissions from SSD-type systems can be treated using granular activated carbon (GAC) or other appropriate technology. Technologies for larger systems may include thermo-oxidation and catalytic oxidation. Figure 25 illustrates an example of an air discharge treatment process. 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.

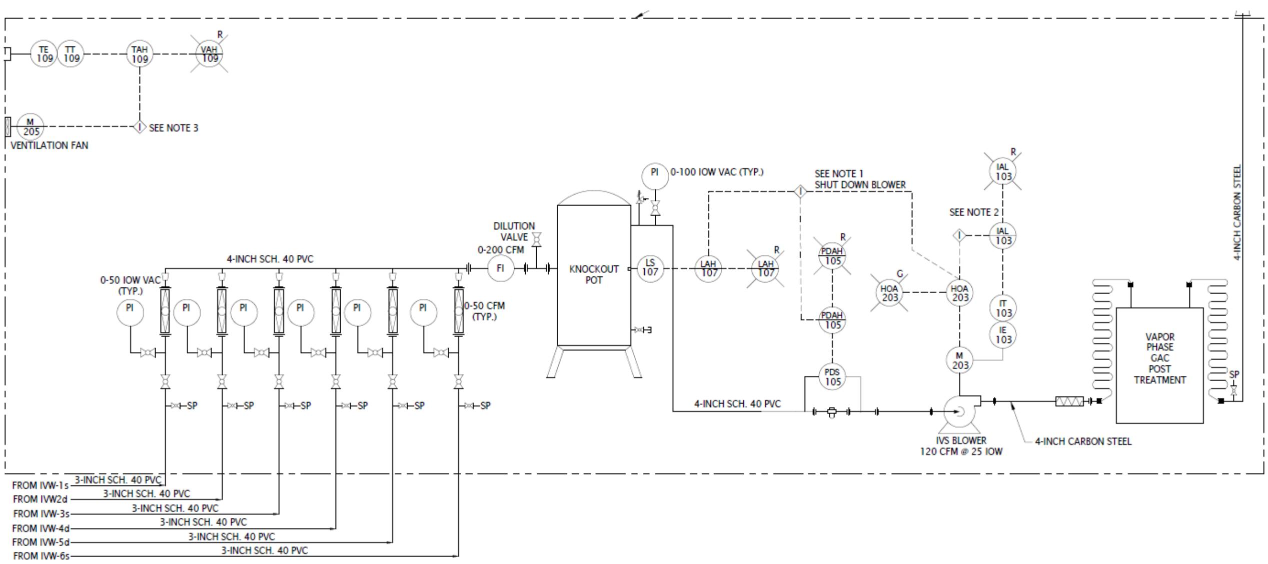


Figure 25. Example Air Discharge Treatment for a Larger Mitigation System (Drawing by GeoDesign Inc., a NV5 Company)

Performance Monitoring Design. System design plans and drawings need to identify sampling locations and methods for post-construction performance monitoring. This is typically included in the system operation, maintenance, and monitoring plan(s). Sampling should include locations in the weakest anticipated performance areas of the SSD system. 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. Different types of monitoring will be a part of the overall system design package.

Preparation of a performance monitoring plan identifying monitoring needs, such as pressure differential and analytical testing of sub-slab vapor and indoor air, will help inform mitigation design. Sub-slab sample ports can be included in the mitigation design and construction to minimize disturbance to the foundation or sub-grade materials after construction. For new construction, sampling design can also incorporate connections to exterior building ports, which is may be preferred by some building owners and occupants to limit disruption to occupants. Figure 26 illustrates a monitoring design approach plumbed to exterior sampling ports.

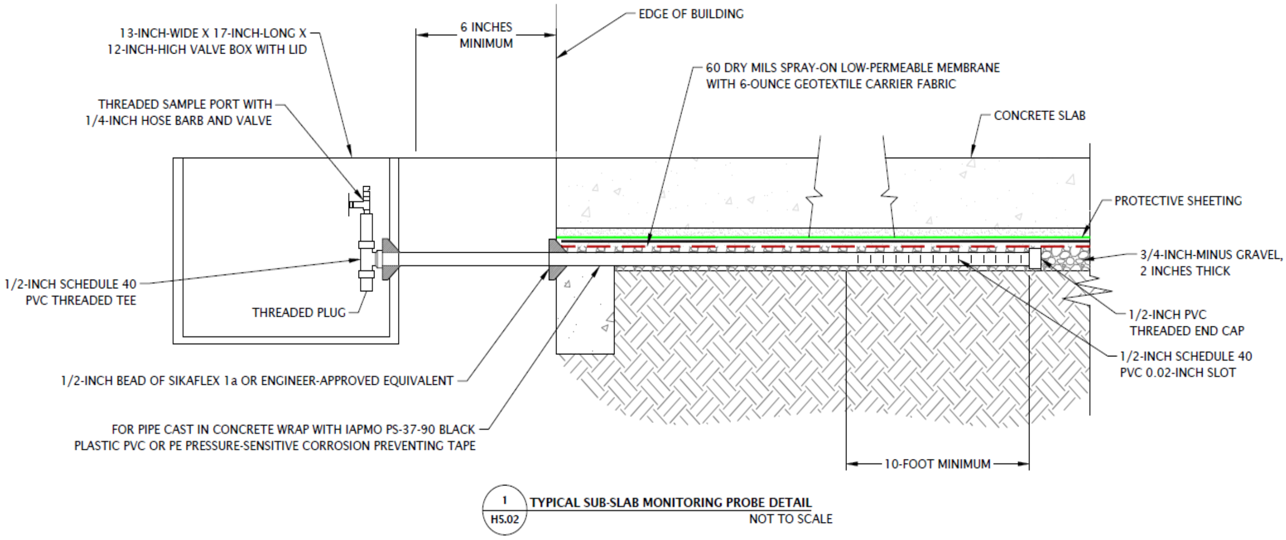


Figure 26. Example Sub-Slab Monitoring Probe Design (Drawing by GeoDesign Inc., a NV5 Company)

Alternative or Modified SSD Design for Existing Buildings. It is not always practical to install a gas collection network across a large area, particular 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 sub-grade permeability properties beyond the “suction” features to reduce sub-slab vapors. Pre-installation testing is necessary to evaluate the suitability of these mitigation strategies to understand sub-slab permeability, slab leakage, and other features effecting flow and/or vacuum propagation (e.g., grade beams, utility conduits, high transmissivity trenches). Common elements include a fan/blower and conduit for vapor to evacuate to the outdoor air (away from the building openings). These systems are commonly used for radon mitigation in existing buildings and performance will highly depend on subgrade permeability and competence of the flooring/sub-slab of the building (e.g., cracks and openings).

In general, sub-slab suction pits or sump collection points (such as vertical pipe or pit or cavity) are installed into the base layer (e.g. twelve inches deep) beneath the slab and a vacuum is applied. For multiple points the suction points are manifolded to a fan which vents to the atmosphere. Designs will vary depending on the granular material beneath the slab and leakage across the slab. If the base layer is permeable, such as crushed gravel, fewer suction pits may be necessary to be effective. Buildings constructed directly on native soil typically require comparatively more suction points to develop 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. Sub-slab permeability should be considered in designing the mitigation system. 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 (but temporary are acceptable) for monitoring performance of the mitigation system (e.g., vacuum across the building sub-slab, demonstrating reduction in sub-slab concentrations, etc.).

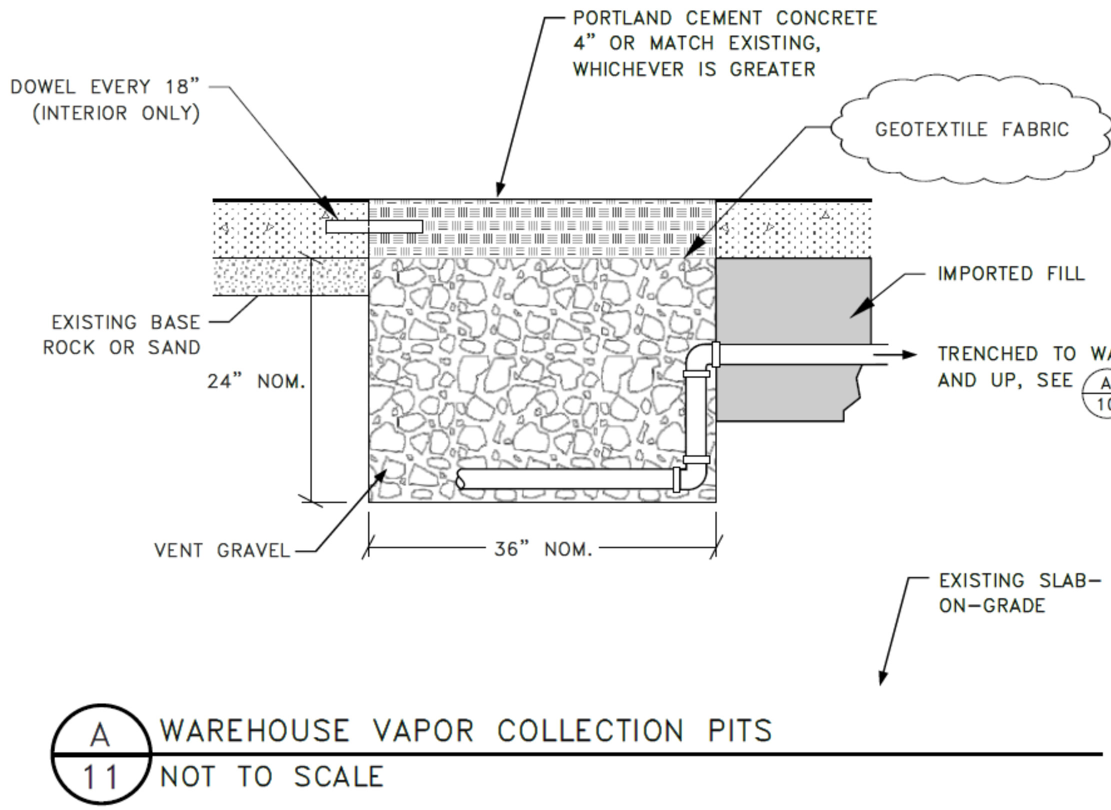


Figure 27. Example Vapor Pit Detail (Drawing by Apex Companies, LLC)

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.

Sub-Slab Ventilation

Sub-slab ventilation (SSV) may be an option in cases where sub-slab concentrations are low, sub-grade 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: 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 discernable flow can be achieved at vacuum levels that may be too low to measure when building sub-grade 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.

Building Pressurization

Building pressurization consists of maintaining a positive indoor pressure relative to the sub-slab. In some buildings the HVAC system can be operated in a manner that over-pressurizes interior spaces forcing indoor air downward through floors and foundations into the underlying subgrade material or soil. This reverses the typical direction of soil vapor transport and acts as a mitigation component. In addition, adjustments to HVAC systems that simply increase fresh air exchange rates can dilute indoor air contaminant concentrations.

HVAC systems are challenging to monitor and maintain as a reliable standalone mitigation technique, particularly in older buildings and over time. Building pressurization at VI sites is generally used in combination with sub-slab mitigation measures. 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-b).

HVAC modifications as a VI mitigation measure is 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. For sites that necessitate a prompt response (discussed above in Section 6.2.1), adjustments to an existing HVAC system can be easy and quick to implement. In general, HVAC performance can be highly variable, requires regular maintenance, is vulnerable to building uses, and can be difficult to monitor which means performance monitoring typically will rely on periodic long-term indoor sampling.

6.3 Performance Monitoring of Vapor Intrusion Mitigation Systems

Monitoring is required following implementation of a remedial action (e.g., soil excavation, soil vapor extraction) including installation of a VI mitigation technology to assess performance and verify conditions are protective for building occupants. While performance monitoring is integral to assess the progress of remediation of sources, the following discussion generally applies to demonstrating adequate 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 (EPA, 2002).

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

- **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 represent relatively short, discrete periods of time. In addition, indoor air is highly variable temporally and spatially due to seasonal variations and the habits of building occupants. Consequently, there are greater challenges in obtaining a defensible indoor air dataset (see Section 4.2.3 regarding temporal variability). Accordingly, additional lines of evidence are valuable to evaluate if VI is sufficiently mitigated.

- **Soil vapor concentrations**

  Another indirect measure of mitigation system performance is the extent to which it reduces contaminant concentrations in sub-slab soil vapor. For this line of evidence, the goal is to reduce levels to below soil vapor RBCs.

- **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 thus 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). Deeper vadose zone or groundwater sources may also lengthen the duration for the subsurface to equilibrate.

It is valuable to have an adequate dataset to develop the understanding of the VI CSM prior to mitigation design, inform the performance sampling strategy, and evaluate the performance of a mitigation system. Development of a monitoring program for a mitigation system should be based on site-specific conditions *and* technology selected to mitigate vapor intrusion risk, current and long-term. Important site-specific 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 source volume, stability, soil vapor concentrations, type of contamination and location left in-place. 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.[27] Monitoring is

[27] When interpreting soil vapor data with respect to rebound and stability, seasonal fluctuations must be factored into the data analysis.

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; and
- Mitigation strategy and performance monitoring results.

As discussed in previous sections, reliability is an important criterion for selecting a VI mitigation technology given the system will need to consistently prevent VI for potentially long periods of time. Mitigation systems that incorporate redundant controls and mitigate contaminant levels and conditions above and below the slab are more dependable and can provide forewarning of changing conditions or declining system performance. When a mitigation system is anticipated to be less effective to address VI, more intensive monitoring may be warranted in advance and can be integrated into the performance monitoring plan.

Increased adequacy of a mitigation system increases the likelihood of achieving DQOs during performance monitoring and often results in reduced compliance monitoring obligations or may allow for substitution of other lines of evidence (e.g., pressure differentials, sub-slab sampling) once system effectiveness is demonstrated. In contrast, mitigation systems that provide marginal to sporadic performance often will result in extended monitoring periods to compensate for lower confidence in mitigation performance. Marginal to sporadic performance may also warrant additional mitigation measures.

Figure 28 illustrates several site-specific factors that can impact the scope of monitoring in advance, during the performance monitoring stage, and whether institutional controls are needed for long-term risk management, including compliance monitoring. Monitoring needs generally increase for conditions presented on the right and potentially decrease for conditions identified on the left.

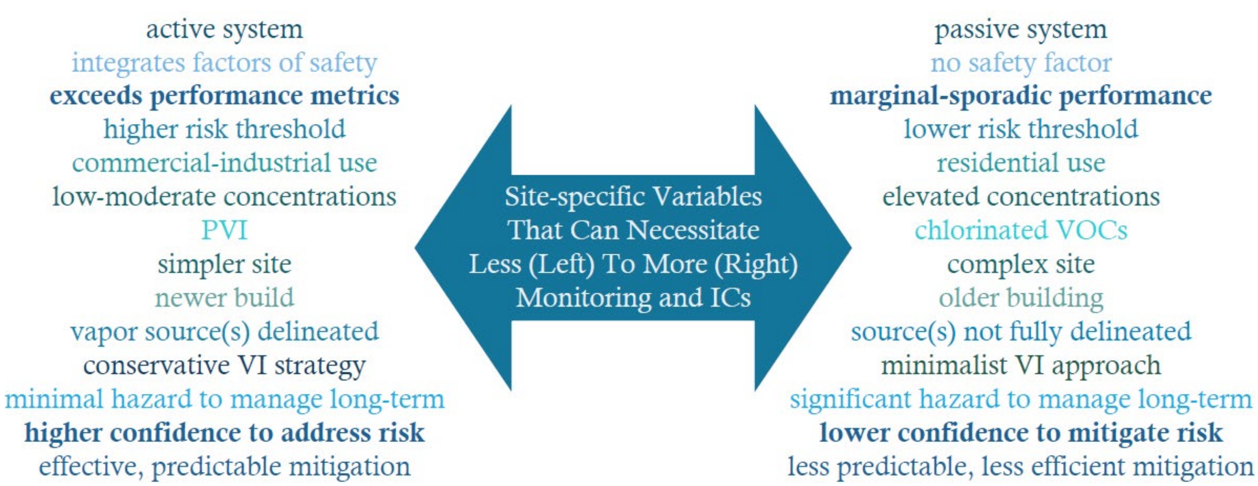


Figure 28. Site-Specific Factors That Can Impact Scope of Monitoring and ICs

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 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 that will serve as the baseline for comparing to post-mitigation data. Note: this may not be possible when immediate active mitigation (e.g., SSD) 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 exposure (RME) 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.
- Negative pressure is sustained across the building slab (or areal extent of vapor plume).
- Soil vapor concentrations beneath buildings are below RBCs.
- Vapor migration is not occurring along preferential pathways.

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

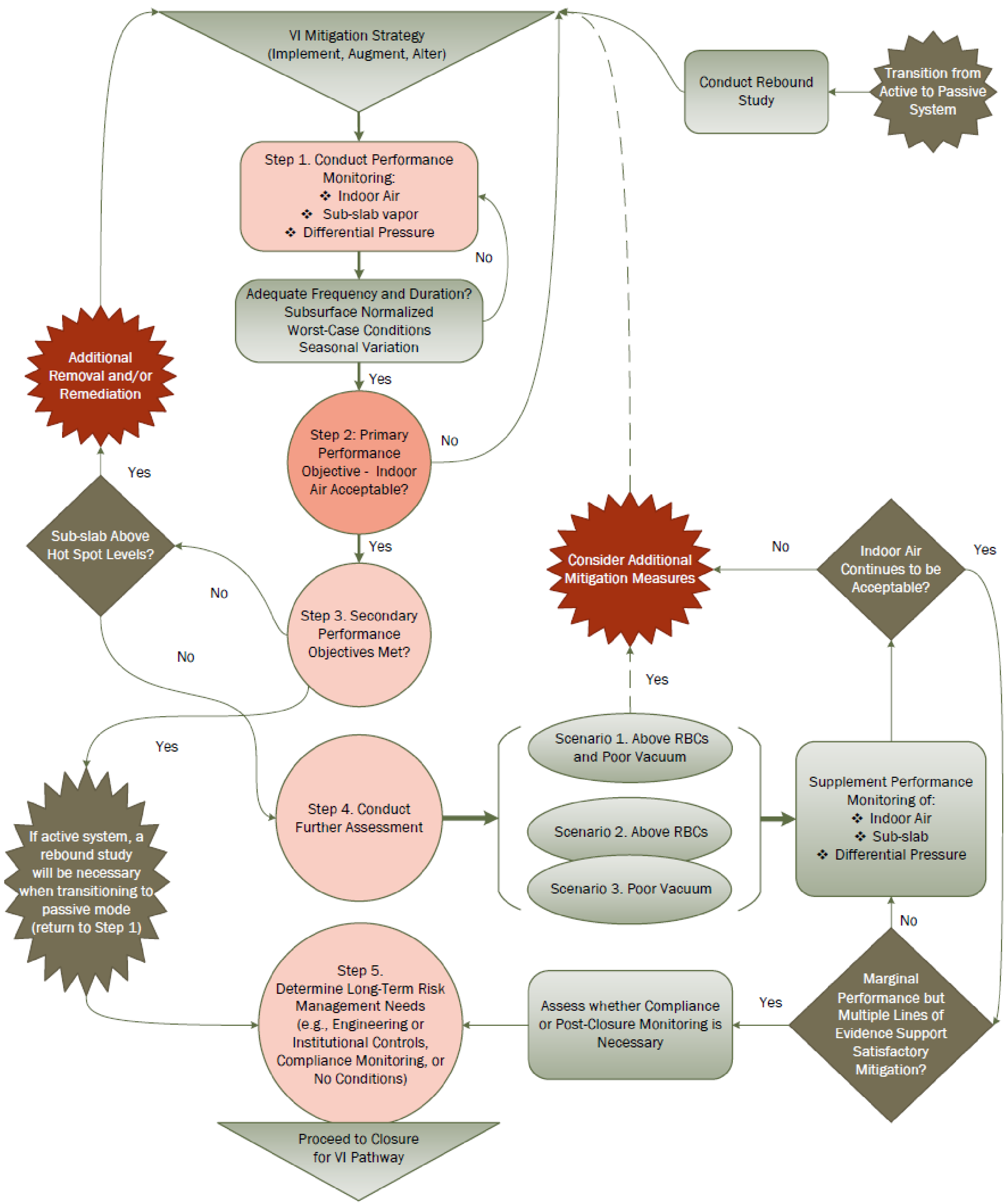


Figure 29. Performance Monitoring Flow Chart

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: 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. See Sections 6.3.2 for recommended methodologies and considerations.

Performance sampling can be scaled up or down as appropriate. Four quarters is a starting point. For example, after confirming indoor air is acceptable, sub-slab vapor sampling may be the preferred monitoring strategy with contingencies that indoor air sampling would be resumed or monitored periodically when sub-slab vapor concentrations peak or remain above RBCs. Once sufficient duration and frequency of sampling has been implemented, proceed to Step 2.

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

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

When indoor air concentrations cannot be immediately achieved or sustained over the performance monitoring period, the VI mitigation strategy will need to be augmented and mitigation performance revaluated. 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: differential pressure is sustained across the sub-slab and reduction in sub-slab vapors below RBCs.

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

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

Other considerations include:

- Removal and remediation options should be evaluated if hot spot levels remain present below the building.
- Augmenting or transitioning to an active mitigation system, specifically if sub-slab concentrations remain 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 additional 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. 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 of site closure.

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.

Generally, project sites that do not meet secondary performance objectives fall under one of three scenarios that are described below. DEQ's recommended responses are included below as well.

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 levels exceeding hot spot levels may require further 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 (e.g., 0.02 inches water) is a strong LOE when RBCs are exceeded below the building. However, if VOCs remain elevated above RBCs by orders of magnitude, 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.

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 for effective mitigation and that sub-slab concentrations are consistently below RBCs. Tools are available to identify when differential reversals occur (see Section 6.3.2: Sampling Methods and Frequency). If supplemental monitoring data indicate sub-slab vapors will remain below RBCs, proceed to Step 5 to develop a compliance monitoring program if necessary.

When a source remains in-place that poses VI risk, for instance sub-slab contaminant concentrations are above RBCs, a compliance or post-closure monitoring program should be developed that requires maintaining engineering controls (e.g., the mitigation system) for the site. The scope of the long-term program will vary depending on the magnitude and extent of contamination left in-place and the certainty in the effectiveness of the mitigation strategy for the duration of the project.

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, represents an unacceptable risk. Examples of ICs are provided in Section 6.5. To the extent practical the engineering control 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 another binding agreement with DEQ.

Compliance monitoring or post-closure monitoring is also recommended as part of the long-term risk management of the site when contamination of concern is left at the site, particularly if concentration exceed sub-slab RBCs and additional assurance is necessary to ensure performance metrics 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 also inform long-term risk management needs and potential restrictions on building use.

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

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 in perpetuity or until it is demonstrated mitigation is no longer necessary.

With that said, 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.

When a mitigation system has been demonstrated to address current and long-term VI risk and includes maintaining engineering controls and other agreed upon institution controls, project closure can proceed with conditions for the VI pathway. If the site still has other risk pathways to address, satisfactory mitigation and long-term risk management strategy can be documented for the project administrative file until all applicable exposure pathways have been addressed to receive a conditional no further action.

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, following successful source remediation when (e.g., soil vapor levels have reliably declined below applicable RBCs)

Termination of engineering controls (e.g., mitigation system) or ICs requires approval by DEQ. It is recommended to coordinate with DEQ on the appropriate steps, which may include additional data collection to demonstrate site controls are no longer necessary to address VI risk.

Closure steps may entail a public comment period and, when conditions are still required to address risk, recording site restrictions and/or long-term obligations as an Easement and Equitable Servitudes.

6.3.2 Sampling Methods and Frequency

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 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, fill in data gaps, identify 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 control 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. Modifications to the mitigation system and/or additional monitoring will be necessary if initial performance monitoring does not clearly demonstrate effective mitigation. Following a successful demonstration of effectiveness, periodic monitoring or compliance monitoring may be necessary to verify the performance is sustained.

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 gas collection piping and exterior walls. Similarly, 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 taking 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 Guidelines. Sub-slab sampling locations should be proposed before and installed during mitigation design and construction (see Section 6.2.2 for further details and considerations). The following is recommended when conducting indoor air and sub-slab vapor sampling:

- Longer duration passive samplers are preferred for indoor air monitoring (see Section 4.2: Indoor Air Sampling). Longer sampling timeframes or more likely to capture VI events and more accurately estimate chronic exposure levels. Analytical testing of indoor air using summa 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 summa 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).
- PID/FID can be used to supplement analytical data to assess concentration trends over time (see Section 4.1.1.2: Field Screening for VOCs with a PID/FID).
- Continuous logging differential pressure measurements for different months of the year or longer, which can identify potential reversals between the sub-slab and indoor air.
- 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.

There are numerous methods to evaluate the VI pathway. Continuous differential monitoring can be one valuable tool to understand site-specific conditions through collection of frequent, real-time data to better understand temporal variability or trends over longer periods.

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, nevertheless, warrants consideration, since indoor air data can provide direct confirmation that the system is reducing exposure levels of vapor-forming chemicals and because depressurization technologies can be expected to alter the distribution of vapors in the vadose zone and available for soil vapor entry, if any (EPA, 2015a).

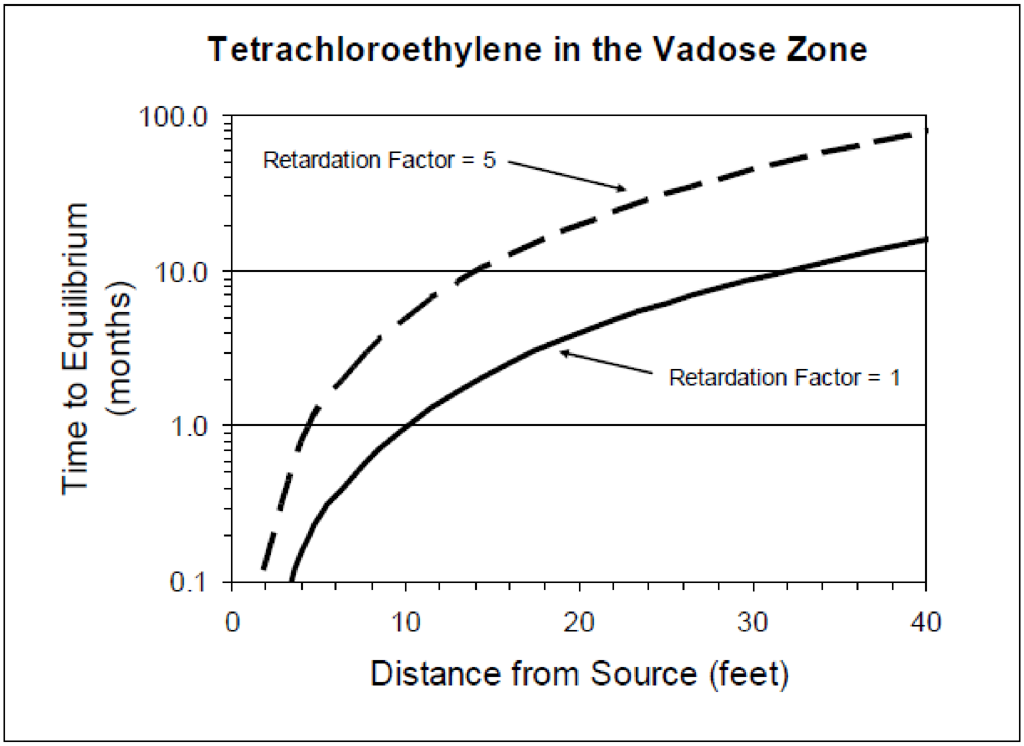
The monitoring plan should also consider an exit strategy including mapping out when/how to demonstrate mitigation is no longer necessary. If planning on a shutdown of "active" mitigation in coordination with DEQ, an adequate period of assessment should be anticipated in "passive" mode to assess potential rebound in sub-slab concentrations and demonstrate concentrations remain below RBCs (see following section for more detail).

6.3.3 Assessment of Rebound

Rebound is assessed following completion of a removal or remediation of a source area, including after shutdown of a SVE system. Rebound occurs when a source has not been sufficiently removed or controlled. California EPA guidance presents methods from Johnson and others (1999) to estimate time to reach steady-state conditions including the following figure which contains an example of timeframes for approaching steady-state vapor concentrations for a hypothetical site (CalEPA, 2011a). The 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. Note: in this context "equilibrium" is a form of dynamic equilibrium that has long-term stability but includes seasonal variability in concentrations. 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 30. Example of Timeframe to Reach Steady-State Conditions

VI mitigation on the other hand does not treat or effectively remove a source but instead disrupts the pathway at the interface of the building slab and underlying soil. 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 are typically 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 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. Using data collected since startup of a SVE system, mass removal rates can be calculated and extrapolated to predict when and whether the system has reached asymptotic or plateau conditions. Figure 31 presents data collected for a SVE system after startup and an example of approaching asymptotic conditions over the life of the project. If measurable mass removal continues, the system still functions to a certain extent but less effective in terms of mass removal. At this stage, system operations can be modified through "pulsing" methods, which consist of on and off operational periods. Duration of on and off periods can be extended as mass removal rates decline or as concentrations take longer to rebound following a shutdown period. During pulsing and following complete shutdown, rebound of subsurface vapor should be monitored. If concentrations rebound above risk-based concentrations, additional pulsing is recommended. If rebound persists and minimal to no discernible mass removal is measurable, alternative VI mitigation measures can be evaluated and proposed for DEQ approval.

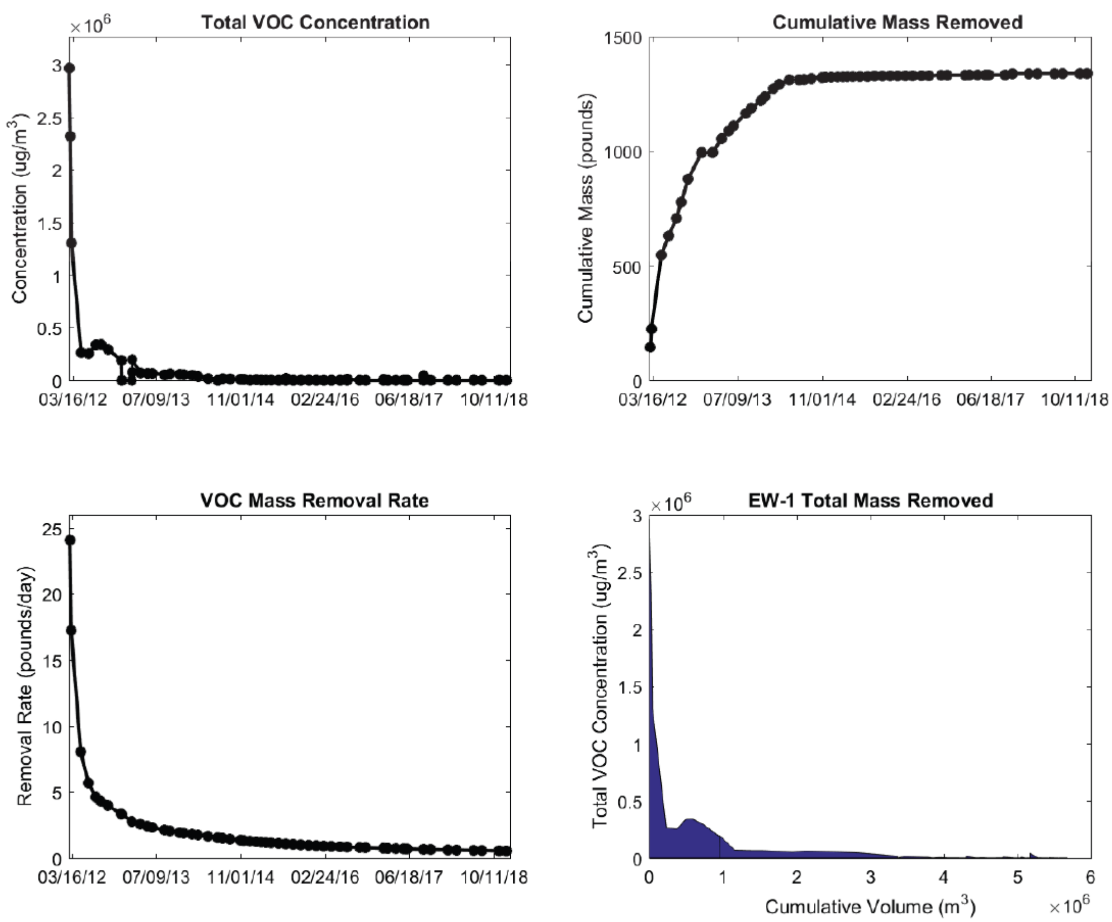


Figure 31. Example of SVE System Approaching Asymptotic Conditions

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 under a different type of operation. In contrast to a removal or 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 to a passive mode is most appropriate when sub-slab vapor concentrations are below RBCs. Rebound has a lower likelihood to occur in a passive mode when concentrations observed in active status are below risk-based levels or at discernible levels for some time. A rebound period should also capture seasonal variability and reasonable maximum conditions. Accordingly, a few quarters or more of monitoring may be necessary (quarterly for a year is typical) to document an absence of rebound. Some rebound may not pose a vapor intrusion risk to indoor air, which can be verified through the additional monitoring and general confidence in the robustness of the mitigation system, such as presence of a competent vapor barrier. If sub-slab concentrations rebound above RBCs, a mitigation system should resume active mode, unless it can be demonstrated that rebound conditions in the sub-slab will not impact indoor air conditions while continuing in passive mode.

6.3.4 Compliance Monitoring

Compliance monitoring may be required to demonstrate that 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 a concern of elevated vapors below the building. Depending on the nature and extent of contamination left in-place and reliability of the remedy 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 than performance or rebound monitoring. When appropriate monitoring can 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 reasonable following subsequent phases, upon approval by DEQ. Proposals for less frequent monitoring, transitioning to passive modes or shutdown of active systems, and requests for closure 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, DEQ will request proposals of work (e.g., work plans, studies, and summary reports) for review and concurrence until the site is restored to protective conditions and DEQ determines no further action is needed. Note: 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 licensed in the State of Oregon (Section 6.6). 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 typical chronological order from evaluation of remedial options to implementation.

- Corrective action plan or equivalent document presenting an evaluation of viable VI remedial alternatives and/or mitigation technologies and recommended VI strategy to support remedy selection. Assessment and recommendations of engineering controls are prepared/stamped by an Oregon P.E.
- Design plans by an Oregon P.E. with proposed construction details of the selected remedial action for DEQ 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: it is unnecessary to submit the entire engineering drawing set for new

construction, such as that required by local planning, development and review departments. The DEQ Cleanup Program only requires the VI related construction specifications and drawings.

- Supervision by Oregon P.E. during construction of approved engineering design plans. Following construction, submittal of constructed remedial VI system as-built and related documentation in the form of a construction completion report or equivalent document.
- 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 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.
- Operations and maintenance plan, if applicable, for DEQ approval and implementation.
- Project schedules and updated as needed.
- Required engineering and institutional controls documented with the property, such as by an EES, to ensure the remedy remains protective. Controls may be integrated into conditions for project closure, such as a "conditional" no further action determination.

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 removals or remedial actions for VI, and may include soil vapor extraction systems, sub-slab depressurization systems, vapor venting systems, or HVAC or other building modifications.

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 preventing residential uses when VI levels exceed residential RBCs but do not pose unacceptable risks in a commercial/industrial scenario.

Institutional controls are often necessary to ensure the continued integrity of the cleanup and/or mitigation system remains protective of 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.

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, maintaining building sub-slab or first floor flooring (e.g., above a crawlspace/basement), etc.
- Potentially restrictions on building modifications; however, tedious restrictions or conditions that are difficult to manage should be avoided.
- Maintaining building pressurization, for example by HVAC operation. As noted previously, HVAC systems generally should not be used as a stand-alone long-term mitigation strategy because HVAC performance can vary, particularly for older buildings, vulnerable to building uses, and difficult to monitor without out periodic sampling.
- 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 monitoring if applicable.
- If applicable, periodic compliance or post-closure monitoring to verify long-term protectiveness of site occupants.
- If applicable, restrictions on site uses (e.g., residential) or until a vapor source is remediated sufficiently to allow for expanded uses. Proposed changes to restricted uses will need to be coordinated with DEQ and submittal of appropriate plans for DEQ-approval to ensure protective conditions for planned uses.
- While not directly related to VI mitigation, 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 deed (e.g., EES), but other appropriate mechanisms are used on a site-specific basis, until it is demonstrated to DEQ that the controls are no longer necessary. Note: a recorded EES is retained on the deed in perpetuity; however, if a restriction has changed or been deemed unnecessary, a revised EES or notice of release can be recorded over it.

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* (a copy is 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

At VI sites, it is critical to effectively communicate results of vapor intrusion risk to impacted parties (EPA, 2015a; ITRC, 2007a, ITRC, 2014, WADOE, 2022). DEQ recommends proactive public outreach and effectively engaging communities impacted by VI risks early on and throughout the process of evaluating and mitigating potential risks. VI risks can be imminently concerning to impacted parties. Clear and open communication, such as explaining what to expect, openly answering questions, and responding to concerns is key to establishing trust and collaborative working relationships. Developing a Community Involvement Plan and using established risk communication techniques are important to support proactive community engagement and effective risk communication. 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:

- Chapter 5, "Public Involvement", *Guidance for Evaluating Vapor Intrusion in Washington State*. Washington Department of Ecology, March 2022. https://apps.ecology.wa.gov/publications/SummaryPages/0909047.html.
- Appendix A, "Community Stakeholder Concerns", ITRC, 2007a. *Vapor Intrusion Pathway: A Practical Guideline*. Washington, DC: Interstate Technology & Regulatory Council, 2007. https://itrcweb.org/teams/projects/vapor-intrusion.
- Section 7, "Community Engagement", ITRC, 2014. *Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management*. Washington, DC: Interstate Technology & Regulatory Council, 2014. https://itrcweb.org/teams/training/petroleum-vapor-intrusion.
- Section 9, "Planning for Community Involvement", EPA, 2015a. *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*. EPA Office of Solid Waste and Emergency Response, 9200.2-154, June 2015. https://www.epa.gov/vaporintrusion/technical-guide-assessing-and-mitigating-vapor-intrusion-pathway-subsurface-vapor.
- Section 4, "Community Engagement", EPA, 2020. *Vapor Intrusion Handbook*. EPA Region 5 Superfund and Emergency Management Division, https://www.epa.gov/vaporintrusion/region-5-vapor-intrusion-guidebook.

Some key takeaways from the above guidance documents are summarized below:

- The vapor intrusion pathway is one of the most often complete exposure pathways and can represent imminent risk to human health. Further, vapor intrusion risks in residential spaces can represent extended exposures that are very personal to those affected. Because of this, carefully planning for community engagement and proactive risk communication with impacted parties is extremely important.

- Communication with the public is particularly important when VOCs are detected near or within occupied buildings. Learning that there might be risks to human health and sampling in and around buildings may be concerning and disruptive to building occupants. It is important to build trust with impacted parties and tailor communication strategies to the specific audiences involved. 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.
- Building trust with impacted parties is critical in order to effectively communicate about health risks with individuals potentially exposed to VI contamination. Seeking to proactively understand the community who is impacted is an important component of building trust with them. Communicating clearly, openly, and consistently throughout the VI evaluation and mitigation process is also key to establishing trust with impacted parties. Setting clear expectations, openly answering questions and responding to concerns are all key to establishing trust and collaborative working relationships with impacted parties.
- Best practices 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. A successful approach incorporates a mix of communications tools that are accessible to the impacted community.

DEQ recommends reviewing and drawing from these resources to support proactively and effectively communicating about potential or confirmed vapor intrusion exposures and/or risks.

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Appendix A

Vapor Intrusion Response Matrix for Indoor Air

Indoor air response action levels are provided in the following table. Note: compare results to acute and chronic RBCs. Also use lines of evidence (LOEs) 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 ≤ 3 x acute RBCair[e]**	**> 3 x 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:** **> 10 x 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 the following with additional detail provided in Section 6:

- 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 (OHA) 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

Table of Contents

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 the 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 were 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 DEQs 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 number regularly (twice a year in 2023), and in response DEQs RBCs will change over time. Service providers should check DEQs 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 (sub-slab) **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 and 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 become available and the contamination plume(s) is (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 / crawlspace;
- The location and depths of all underground utility corridors (preferential pathways);
- The location and depth of all samples collected;
- The extent of the contaminated soil (TPH Dx > 500 ppm);
- The extent of contaminated groundwater, if present; and
- A summary of key laboratory results at each sample location.

B.2.2 Characterization / 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.

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.

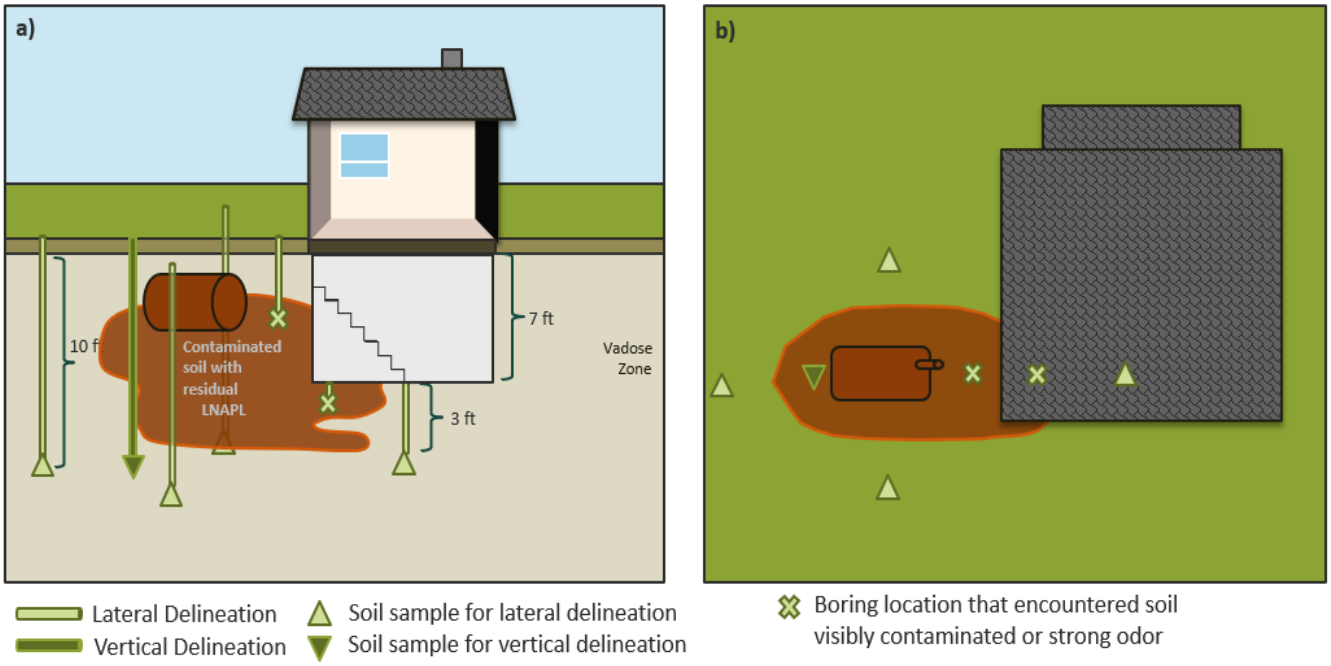

Figure B.1: (a) Cross-sectional view and (b) plan view of soil sample locations to laterally and vertically delineated contaminated soil. All soil samples are collected from the same distance below the tank bottom (10 feet below ground surface). *Figure shows offset samples in an attempt to show dimensionality.*

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 nature, 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 2.2.2: Vapor Attenuation in the Subsurface of the main VI guidance and from ITRC (https://projects.itrcweb.org/PetroleumVI-Guidance) and EPA (EPA, 2014).

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**.

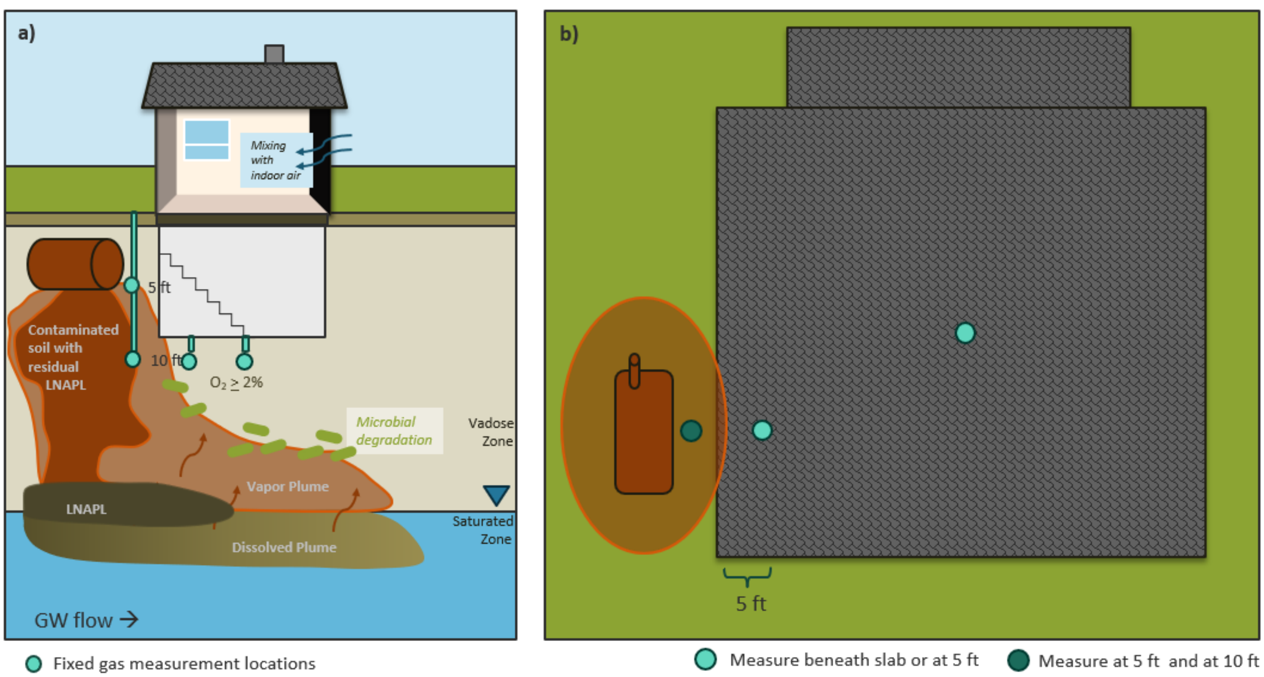

Figure B.2: (a) Cross-sectional view and (b) plan view of fixed gas measurement locations to establish whether biodegradation conditions are present. Measurements beneath the building should be collected at least 5 feet in from the foundation wall. Contaminated soils vary in distance from the building;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

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 following conditions are met: The crawlspace area must be 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 three-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 is (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 4.1.4: Soil Vapor Sampling copied below for your convenience.

Advisory - Active Soil Gas Investigations. California DTSC, July 2015
https://dtsc.ca.gov/wp-content/uploads/sites/31/2021/11/VI_ActiveSoilGasAdvisory_FINAL_a.pdf

Soil Gas Sampling. EPA Region 4, April 2023.
https://www.epa.gov/sites/default/files/2015-06/documents/Soil-Gas-Sampling.pdf

Sub-Slab Vapor Sampling Procedures. Wisconsin DNR, July 2014.
https://dnr.wisconsin.gov/topic/Brownfields/Vapor.html

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. 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 great 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 4.1.4.5: Characterizing Seasonal Variability and Section 4.2.3: Temporal Variability in Vapor Intrusion 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 this document 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 4.2 of the main guidance describes indoor air sampling. See also: https://www.epa.gov/sites/default/files/2017-01/documents/sample_collection_procedures_sow1.pdf

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 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 chosen 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 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

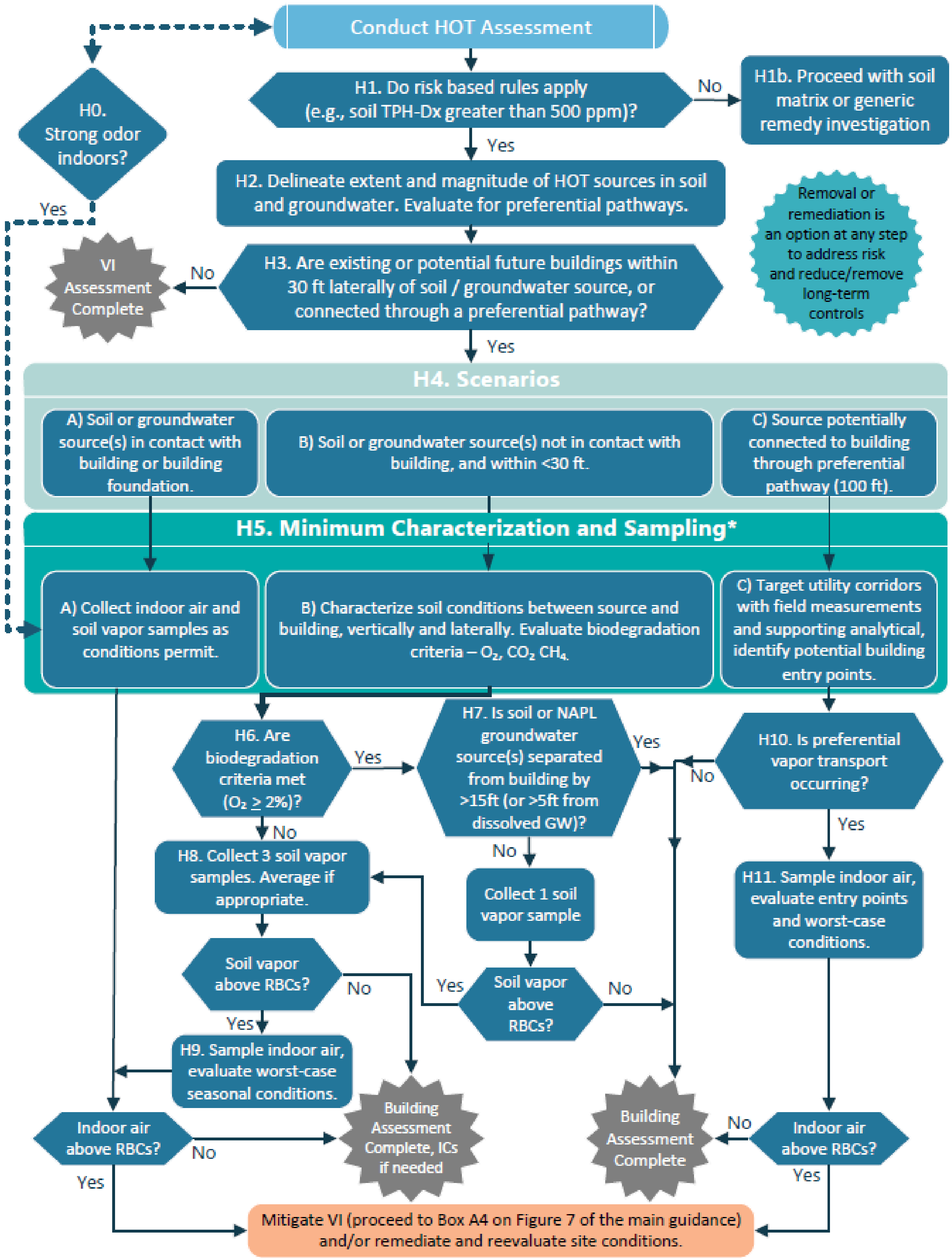

Figure B.3 Flow Chart to Evaluate the VI Pathway for Heating Oil Tank Sites

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 (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, (ii) HOT Generic Remedy, and (iii) risk-based closure. 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 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 and 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 are much more likely to have indoor air impacts. Additionally, soil vapor samples 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 / 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 here: [ITRC PVI-1 (https://projects.itrcweb.org/PetroleumVI-Guidance)](https://projects.itrcweb.org/PetroleumVI-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.

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.

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.

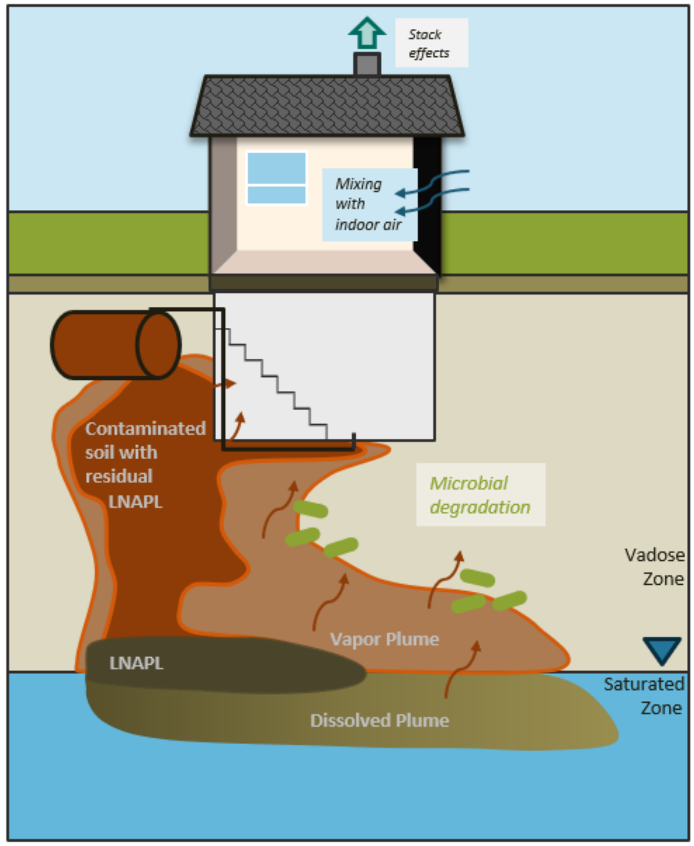

Figure B.4: Scenario A: Soil sources in contact with building. Line leaks are also of particular concern as they can produce strong VI impacts.

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 3 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, then the collection and testing of soil vapor samples is not required. The building assessment is complete. Note: groundwater concentrations of TPH-Dx above 6,800 ppb are considered indicative of NAPL (DEQ, 2003).

If the structure is separated from the 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 Figure B.6b for more information. Proceed to Box H8.

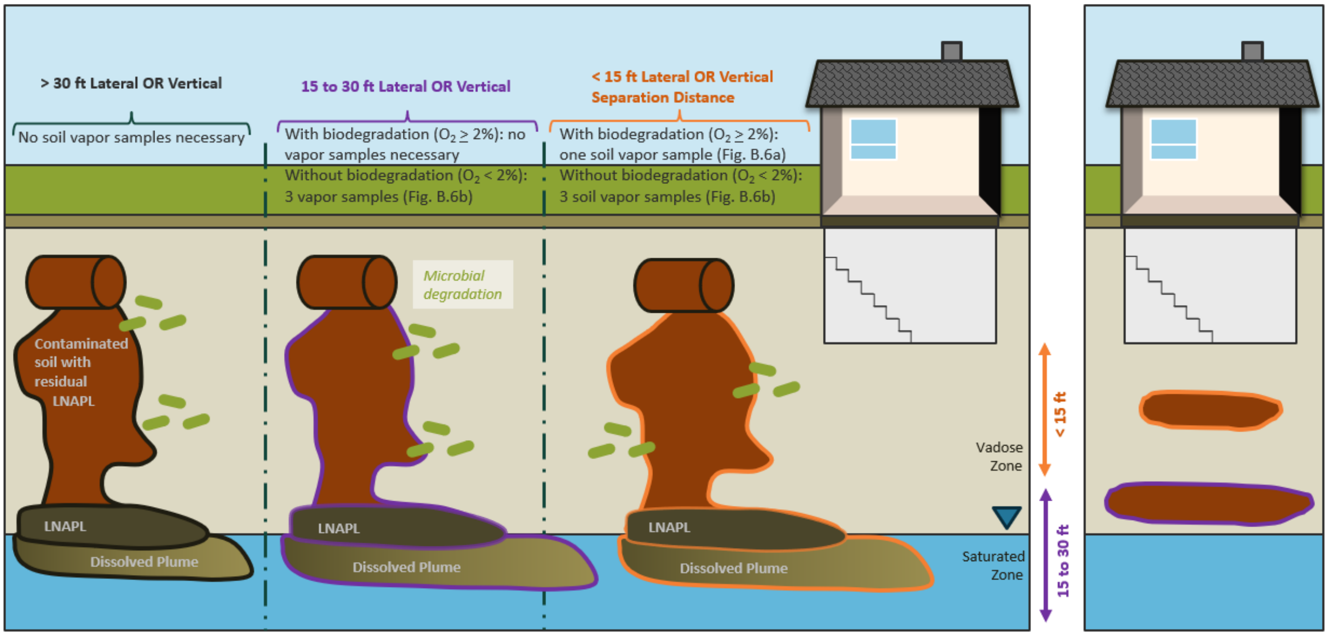

Figure B.5a Soil vapor sampling with lateral distance for a soil source

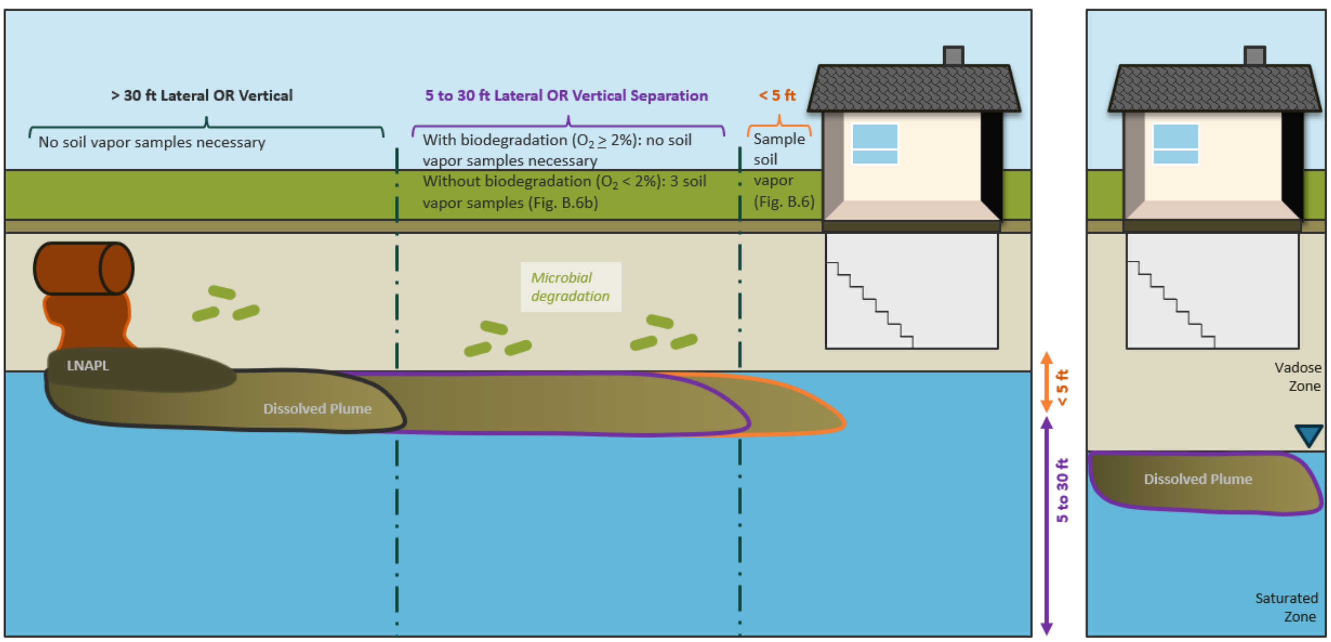

Figure B.5b Soil vapor sampling with lateral distance for a dissolved groundwater source. Groundwater concentrations of TPH-Dx above 6,800 ppb are considered indicative of NAPL (DEQ, 2003).

Box H8. Collect 3 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 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.

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.

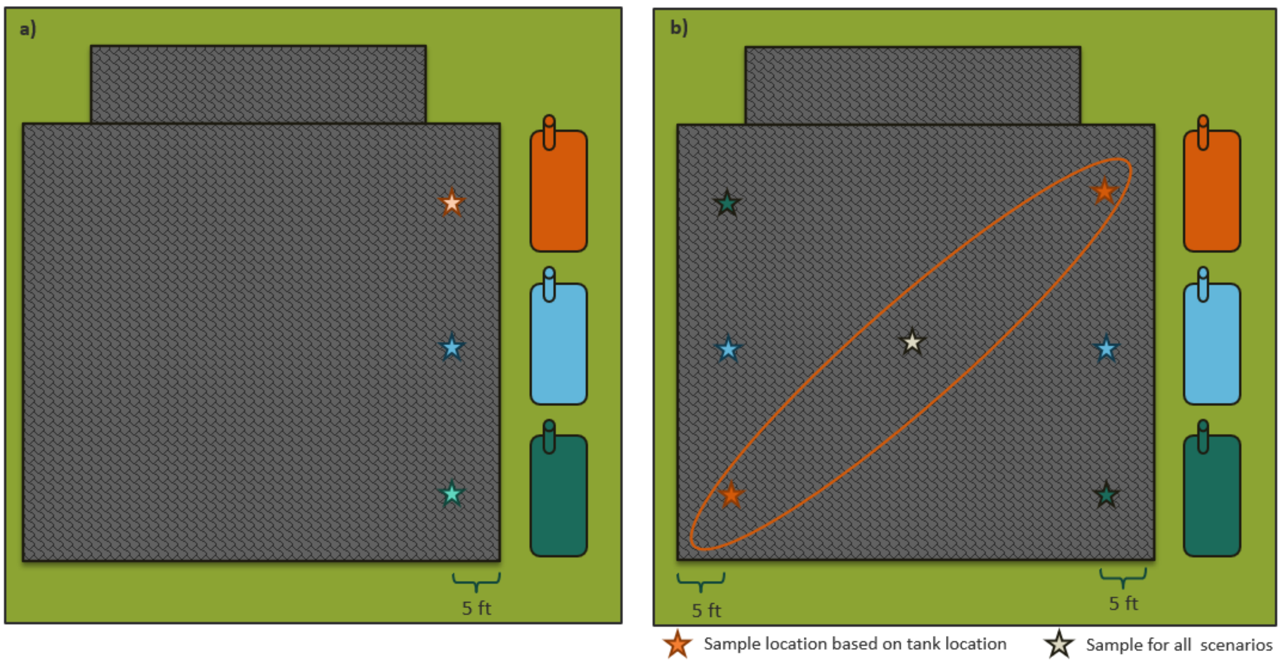

Figure B.6: Plan view / map view of **(a)** single sampling location and **(b)** three sample locations based on tank location. Soil vapor samples should be collected from beneath the building at least 5 feet in from the foundation wall.

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, utility trench backfill, and potentially the lines themselves 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: 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) :

Preferential pathway scenarios are very site specific; the best way to make sure your soil vapor investigation plan addresses risk is to reach out to a HOT project manager.

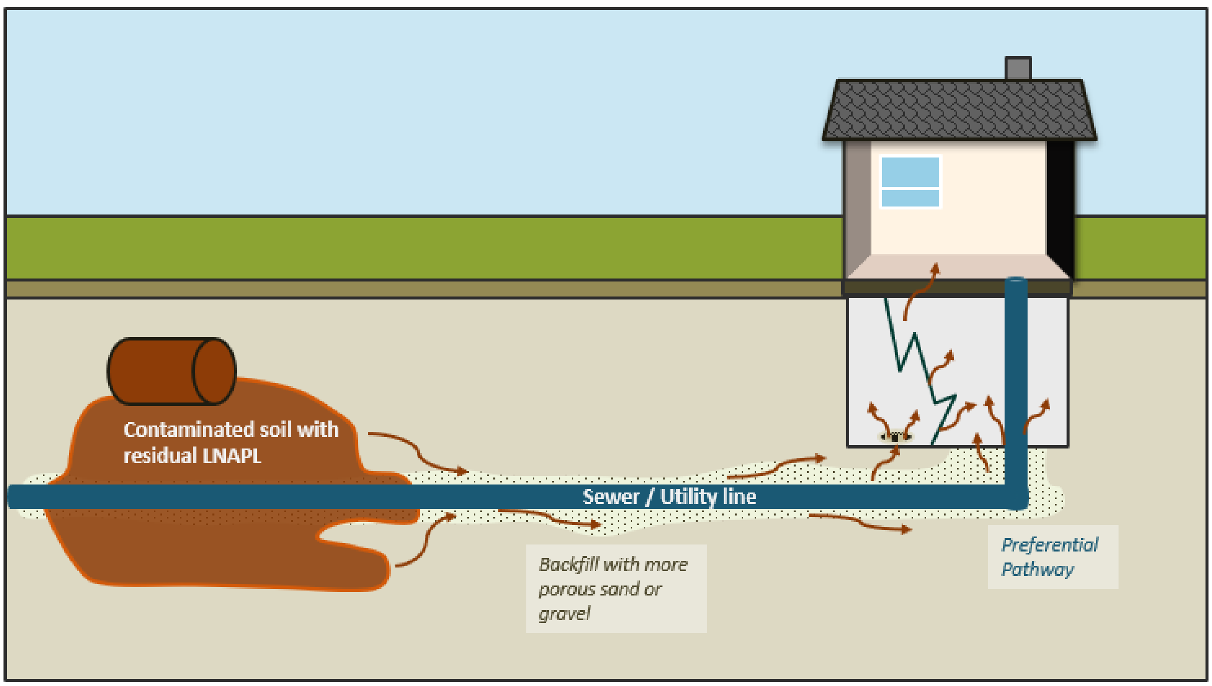

Figure B.7: Cross-sectional view of preferential pathways that facilitate vapor transport along greater distances to enter the structure. Examples shown include a basement drywell drain or unsealed sump pump, a sewer line that transects the contaminated soil, and a large crack in the foundation wall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

For all scenarios:

Box H9 and H11. Indoor Air samples.

Refer to Section B.2.9 Indoor Air Sampling and Section 4.2: Indoor Air Sampling of the main guidance 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.

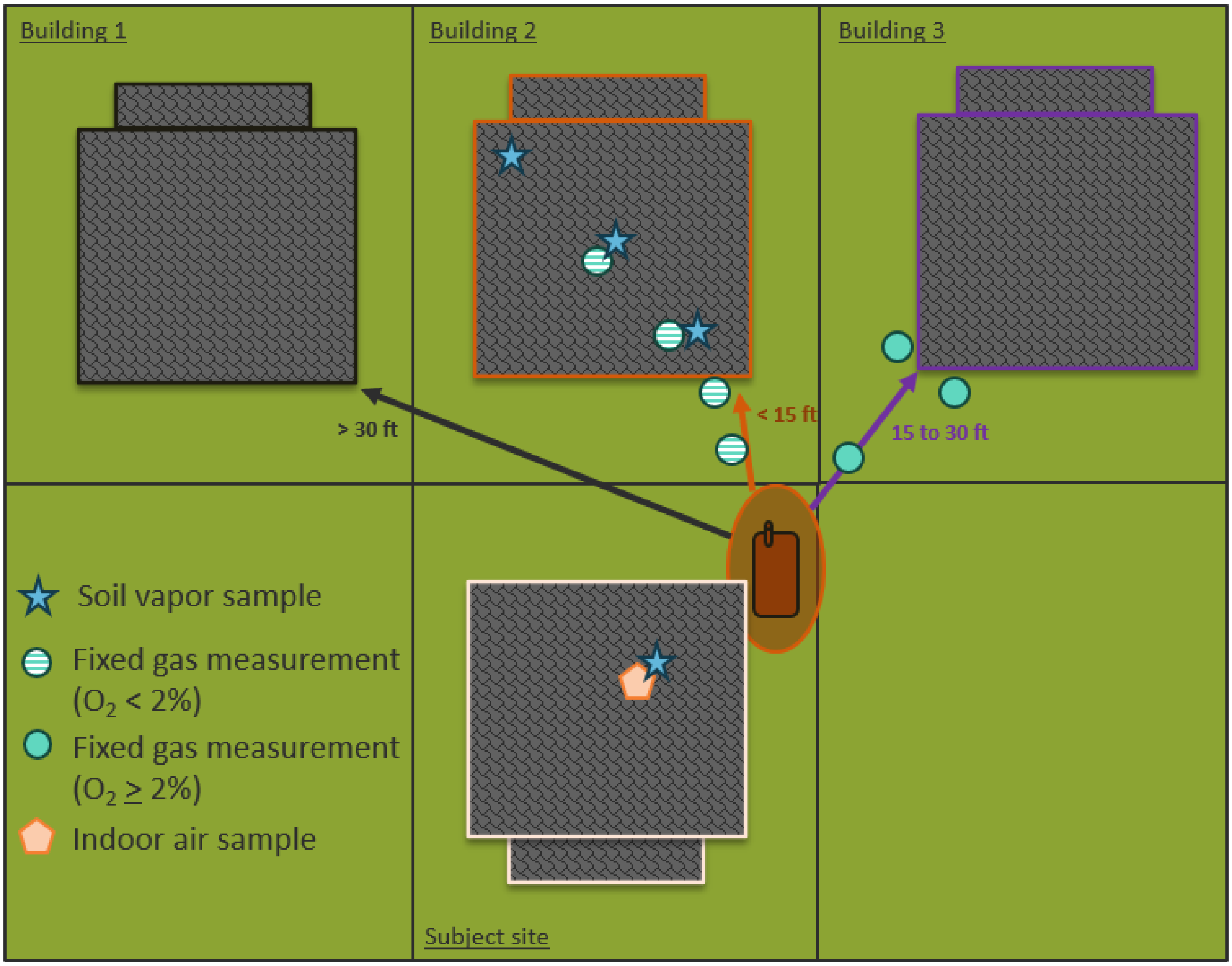

Figure B.8: Sampling at neighboring properties. Structures on neighboring properties may need to be sampled depending on distance from contaminated soil and whether or not biodegradation criteria can be established. Note: requesting access to a neighbor's property may take additional time. This figure 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 to 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 Checklist for HOT Program Vapor Intrusion Evaluation

This checklist is 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

- ☐ 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: 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, and 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

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

Fixed Gas Percentages (as applicable)

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

B.5.4 Soil Vapor Sampling (Oxygen 2% or greater): if oxygen is less than 2% beneath structure proceed to B.5.5

- ☐ 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. Samples collected can either be 6 inches sub-slab or 5 feet deep soil vapor depending on whether the structure has a basement or a crawlspace.
- ☐ Use checklist B.5.6 for sample collection.
- ☐ Photo of the sample point and the collection setup taken.
- ☐ Consider neighboring structures (see Fig. 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.

B.5.5 Soil Vapor Sampling (Oxygen less than 2%)

- ☐ Contaminated media not in contact with the structure?
- ☐ Appropriate sample locations for soil vapor sampling for laboratory analysis (6" 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 Fig. 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.5.6 Sampling method

- ☐ 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)
  - Summa Canister (TO-15)
  - Sorbent Tube (TO-17)
- ☐ Appropriate tubing?
  - PEEK™
  - Teflon®
  - 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: five feet below the ground surface within 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 10% 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.

Indoor Air Sampling Checklist

Indoor Air Sampling (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 (Appendix G of the 2007 ITRC Vapor Intrusion Guidance Document presents an example: http://www.itrcweb.org/Documents/VI-1.pdf)
- ☐ 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 4.2: 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 DEQ can be used by the Cleanup Program either directly or with some modification. These includes 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, urban residents, and workers. DEQ's CAO program specifies air RBCs for residents, non-residential children (e.g., schools, daycare), workers, and acute. 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 (RSLs) (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 RBC table. For these reasons, DEQ's Cleanup Program is now incorporating EPA air RSLs directly as DEQ air RBCs for chronic screening. DEQ directly integrated EPA default residential and worker RSLs. Chronic air RBCs are provided 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

Current Cleanup Program default RBCs were developed for chronic exposure, and we also provide 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 do 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. 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. The same assumption is appropriate for urban residential exposure. 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 / 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 Department of Toxic Substances Control (DTSC, 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

Guidance for Managing Hazardous Substance Air Discharges from Remedial Systems

January 2006 – Original publication

September 2017 – Updated contact information and links

March 2024 – Updated

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
SVOC	Semi-Volatile Organic Compounds
SVE	Soil Vapor Extraction
TPH	Total Petroleum Hydrocarbons
UST	Underground Storage Tank
VIM	Vapor Intrusion Mitigation
VOCs	Volatile Organic Compounds

1. Introduction

Cleanup of sites contaminated with volatile chemicals, such as gasoline and solvents, often require purging or extraction 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 not only the effectiveness of a proposed site remedy but also the potential risks posed by implementation of 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 (e.g., remediation and/or vapor intrusion mitigation) is necessary prior to discharge to the atmosphere. This document provides information on assessment methods, compliance point locations, and 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 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 (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 via a stack (or riser pipe) at 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. Note: 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 air toxics 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]

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[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 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,

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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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. Evaluate Vapor Discharge from Remedial Systems

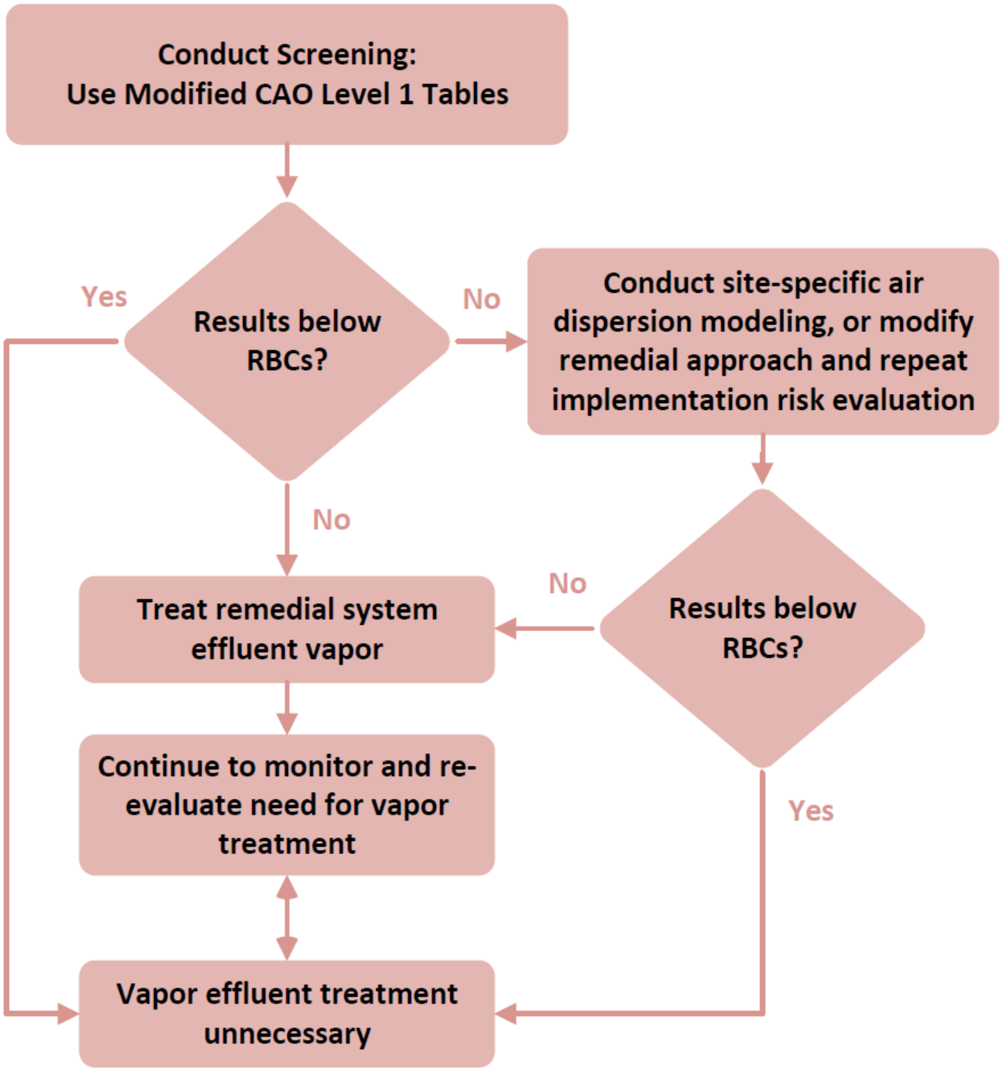

Figure E.1: Flow chart of Effluent Vapor Discharge Management Process

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]

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[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 COIs would be identified based on the preliminary CSM.

- 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. 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. CAO has developed a modeling protocol representative of air dispersion modeling and the exposure scenarios are risk-based. This guidance incorporates this modeling protocol with modifications as the default screening approach to assess remedial system emissions.
Therefore, 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: https://www.oregon.gov/deq/aq/cao/Pages/CAO-Risk-Assessment-Resources.aspx

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). Note: in advance, site-specific modeling may be the preferred approach, such as to support remedial design and therefore the initial screening step is skipped. DEQ recommends that projects coordinate with DEQ regarding the preferred implementation risk evaluation approach and modeling protocol, such as part of the site 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. Note: it is anticipated results will 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 website at the following link: https://www.oregon.gov/deq/hazards-and-cleanup/env-cleanup/pages/risk-based-decision-making.aspx. Typically, remedial systems are intended to treat or mitigate chlorinated solvents or petroleum hydrocarbons and therefore these chemicals are included in the example tables. Additional site-specific chemicals of interest will need to be added, if applicable.

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 general instructions.

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) based on annual exposure (Table 3A) or acute exposure (Table 3B) in addition to stack height and distance from the stack to the nearest exposure location. The dispersion factor needs to be manually entered into Table E-1 and then will 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. The example table allows for more than one emission unit.

Table E-2: Calculation of Air Concentrations. Site-specific annual and daily emission rates are calculated based on site data, pilot testing, and/or remedial system design specifications and entered into Table E-2 (replacing examples provided). Dispersion factors are automatically copied from Table E-1. The average annual concentration and the maximum daily concentration is automatically calculated from the emission rates and dispersion factors.

Table E-3 CAO: CAO Program Risk Calculations. No entries are necessary but note when additional chemicals are added to the list of chemicals, their CAS numbers must match those in Table E-2. Annual and daily concentrations are automatically updated from Table E-2. RBCs will be automatically identified and copied from the CAO RBC tab. 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.

Table E-3 CU: Cleanup Program Risk Calculations. As with Table E-3 CAO, the list of chemicals with their CAS numbers must match those in Table E-2, and annual and daily concentrations will be automatically copied from Table E-2. However, Cleanup Program RBCs currently must be entered into the table manually. Check DEQ's website for current RBCs. 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).

Additional supporting tables included in subsequent tabs:

- CAO RBC Table: OAR 340-245-8010 Table 2 chronic and acute RBCs for CAO Program.
- CU Acute RBC Table: Cleanup Program acute RBCs modified from CAO acute RBCs.
- OAR Table 3 Stack: OAR 340-245-8010 Table 3 for stack emissions from CAO Program and used to look up dispersion factors to be entered into Table E-1.
- OAR Table 3 Fugitive: OAR 340-245-8010 Table 3 for fugitive emissions from CAO Program, provided for completeness only. This table is unlikely to be needed for vapor treatment systems.

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 concentration 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.

When vapor treatment is proactively incorporated in advance, an implementation risk assessment for the effluent vapor discharge pathway is unnecessary but may be warranted prior to discontinuing vapor treatment.

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. Note: DEQ will evaluate the need for treatment of emissions during pilot testing, depending on the anticipated hazardous substance discharge, pilot test length, and the proximity to people.

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.

Pilot Test Guidelines

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, into either Tedlar bags or Summa canisters. 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.

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

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. The results, included methods and populated spreadsheets, should be presented to DEQ including recommendations.

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.

[5] DEQ's Tanks and Cleanup Programs generally require the use of analytical methods from *Test Methods for Evaluating Solid Waste*, SW-846 (EPA).

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 a Level 1 screening results indicate potential risk due 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 website at: https://www.epa.gov/scram/air-quality-dispersion-modeling-screening-models. 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. 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).

<u>Regular sampling should occur whether or not the remedial system includes vapor treatment</u>. 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.

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Appendix F

Engineering Review of Vapor Intrusion Mitigation Systems

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.

Memorandum

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.

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DEQ is a leader in restoring, maintaining and enhancing the quality of Oregon's air, land and water.

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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