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DEPARTMENT OF NATURAL RESOURCES

ENVIRONMENTAL PROTECTION DIVISION

LAND PROTECTION BRANCH

Hazardous Waste Corrective Action Program

Hazardous Waste Management Program

Response and Remediation Program

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****FINAL****

Guidance for Evaluating the Vapor Intrusion Exposure Pathway

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Technical Guidance Document

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Guidelines for Applicability and Use of this Guidance Document

This document provides technical guidance for evaluating the vapor intrusion exposure pathway when such an evaluation is required under the applicable Georgia statutes and regulations administered by the following programs of the Land Protection Branch:

- Hazardous Waste Corrective Action Program
- Hazardous Waste Management Program
- Response and Remediation Program

This guidance document is intended for use by environmental professionals who have experience in the investigation and remediation of subsurface contamination. The guidance provided within this document includes methods and recommendations that can be used to meet the pathway evaluation requirements of statutes and regulations; however, this document is not a statute or a regulation. This guidance document is intended to be generic in nature, so that it applies to a majority of sites. Using the methods and recommendations in this guidance document will provide for streamlined EPD review of vapor intrusion exposure pathway evaluations. Other approaches, emerging technologies, and new methodologies will be considered given site-specific conditions and can be accepted if they meet the requirements of applicable statutes and regulations. If another approach, technology, and/or method is being considered, EPD recommends discussing that approach with EPD staff involved with the project prior to implementation. This document may be revised in the future based on comments and/or new information. The use of trade names does not constitute endorsement by EPD.

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1. Introduction

This document provides technical guidance for evaluating the vapor intrusion exposure pathway when such an evaluation is required under the applicable Georgia statutes and regulations administered by the following programs of the EPD Land Protection Branch:

- Hazardous Waste Corrective Action Program
- Hazardous Waste Management Program
- Response and Remediation Program

The statutes and regulations administered by these programs include:

- Statutes:
 - Hazardous Site Response Act (OCGA 12-8-90)
 - Georgia Brownfield Act (OCGA 12-8-200)
 - Hazardous Waste Management Act (OCGA 12-8-60)
 - Voluntary Remediation Program Act (OCGA 12-8-100)
- Regulations:
 - Rules for Hazardous Site Response (Chapter 391-3-19)
 - Rules for Hazardous Waste Management (Chapter 391-3-11)

This guidance document is intended to complement broader vapor intrusion guidance from the United States Environmental Protection Agency (USEPA) and the Interstate Technology and Regulatory Council (ITRC), which include:

- Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (USEPA 2015)
- Vapor Intrusion Pathway: A Practical Guideline (ITRC 2007)
- Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management (ITRC 2014)

This document is intended to serve as a guide in evaluating the vapor intrusion of hazardous vapors from contaminated soil or groundwater into the indoor air of residential and non-residential (*e.g.*, commercial, industrial and occupational) structures. This guidance document is not intended to be used to evaluate worker exposure to chemicals used in a workplace setting, which would be regulated by OSHA. If the evaluation of the vapor intrusion pathway is being complicated by chemicals used in a workplace setting regulated by OSHA, it is recommended that the situation be discussed with EPD.

Vapor intrusion occurs when volatile compounds migrate from contaminated groundwater or soil into the indoor air of an overlying or nearby building. A conceptual model of the vapor intrusion exposure pathway is shown in Figure 1.

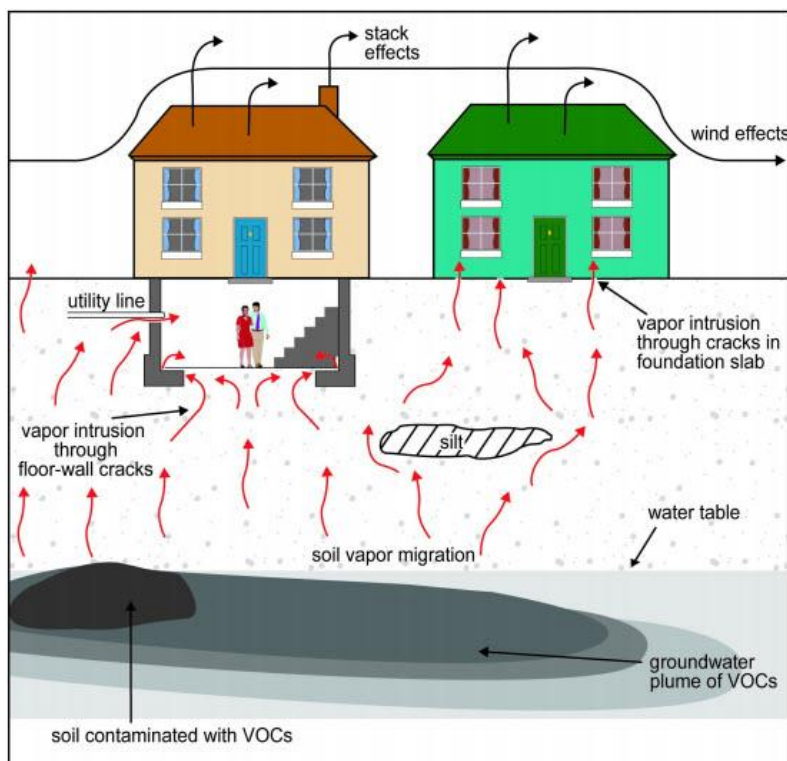


Figure 1: Conceptual Model of the Vapor Intrusion Exposure Pathway. Source: USEPA 2019.

Vapor intrusion can be a potential exposure pathway when buildings are located near a release of volatile substances in the subsurface. “Near” is typically considered within 100 feet laterally for chlorinated or recalcitrant volatile compounds and within 30 feet laterally for petroleum hydrocarbons (USEPA 2015, ITRC 2014). Typical chemicals that are considered sufficiently volatile and toxic to be of concern for vapor intrusion are identified in the USEPA Vapor Intrusion Screening Level Calculator, which is currently available at: www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator.

This guidance document focuses on the evaluation of vapor intrusion from releases of volatile organic compounds (VOCs), except for petroleum hydrocarbons released from underground storage tanks (USTs), to the extent subject to regulation under the above-referenced statutes. Releases of petroleum hydrocarbons subject to EPD UST regulations should be addressed through the EPD UST Management Program and its corrective action framework. It is important to note that petroleum hydrocarbons can undergo greater attenuation in the subsurface than chlorinated VOCs due to aerobic biodegradation (USEPA 2012a), an effect which is not accounted for in this guidance. The ITRC (2014) Petroleum Vapor Intrusion guidance document, which incorporates vertical screening distances to account for biodegradation, can be used in the evaluation of the vapor intrusion pathway for petroleum hydrocarbons.

2. Overview of Assessment Approach

A multiple lines of evidence approach should be used to evaluate the vapor intrusion pathway. Information such as building science [*e.g.*, air exchange rate, air changes per hour (ACH)/heating, ventilating and air conditioning (HVAC) zones, etc.], building construction and condition

(presence of footers, sumps, slab integrity, etc.), geologic, hydrologic and biochemical factors, physics, preferential pathways, etc. should be considered in sampling and evaluating vapor intrusion at a site. The approach outlined in this document involves gathering information to draft a CSM, using the CSM to determine what media to sample and sample locations, characterizing the subsurface vapor source, and either screening out the pathway or continuing the assessment by sampling media closer to potential receptors (i.e., building occupants). Assessing the presence of a vapor source in the subsurface and the associated vapor intrusion risks through groundwater and/or exterior soil gas sampling is generally recommended prior to conducting sampling inside a building, such as sub-slab or indoor air sampling. However, in some cases, it may be appropriate to begin the assessment with sampling inside a building, such as when there is a vapor source located immediately beneath the building or when a significant or imminent risk to indoor air is suspected. The typical assessment approach is outlined below, along with relevant sections of this document:

1. Collect and assemble site information that relates to vapor intrusion to form a Conceptual Site Model (CSM). The CSM for vapor intrusion is discussed in Section 3.
2. Based on the CSM, conduct appropriate media sampling to evaluate the presence and concentrations of volatile compounds in the subsurface. Sampling guidelines are discussed in Section 4.
3. Based on the CSM and media sampling results, calculate potential vapor intrusion risks. Guidelines for calculating potential vapor intrusion risks are discussed in Section 5.1.
4. Based on the potential vapor intrusion risks, determine whether the assessment is complete, or additional assessment or mitigation is appropriate. Guidelines for risk-based decision-making are provided in Section 5.2.
5. For cases where mitigation is implemented, guidelines are provided in Section 6. Note that preemptive mitigation could be considered during the assessment process; however, an understanding of the CSM for vapor intrusion and an assessment of vapor intrusion risks due to subsurface contamination are generally needed to inform mitigation system design.

3. Conceptual Site Model

The CSM is the foundation for evaluating the vapor intrusion pathway using a multiple lines of evidence approach. A CSM for vapor intrusion is a short description and/or depiction of the key characteristics of the site relevant to vapor intrusion. A visual and/or narrative CSM should be developed to support the vapor intrusion evaluation and included in any submittals to EPD. The goal of a CSM is to summarize key information to provide a common understanding of what is known about the vapor intrusion pathway for a given site. For more information on CSMs, please consult USEPA documents *Conceptual Site Scenarios for the Vapor Intrusion Pathway* (USEPA, 2012c) and *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (USEPA, 2015).

The elements of a CSM are threefold: 1) source, 2) pathway, and 3) potential receptor. For the vapor intrusion exposure pathway to be complete at a given building, each of the following elements must be present:

- A source of vapor-forming chemicals is present in soil or groundwater underneath or near one or more buildings;
- Vapors have a route along which to migrate toward a building and the building is susceptible to soil gas entry;
- Vapor-forming chemicals from subsurface sources are present in the indoor environment; and
- Building is occupied when the vapor-forming chemicals are present indoors.

A summary of information to consider in a CSM is provided as a reference in Table 1. These considerations are not all inclusive and some may not be applicable on a site-specific basis. An example CSM write-up for a hypothetical site is provided as Figure 2. An example graphic CSM for a different hypothetical site is provided as Figure 3.

CSMs should identify any significant data gaps where additional information may be warranted or required to complete the evaluation. The CSM is intended to be a dynamic tool that is updated throughout the evaluation as new information is obtained. For sites with on-property and off-property impacts, it may be helpful to develop a separate CSM for each area. Similarly, for large, heterogenic sites, it may be helpful to develop separate CSMs for areas or buildings with common characteristics.

Table 1: Summary of Information to Consider for a CSM for Vapor Intrusion

Topic	Scenario
Source Identification	<input type="checkbox"/> Dry cleaner <input type="checkbox"/> Tank <input type="checkbox"/> Landfill <input type="checkbox"/> Other:
Nature of Contamination	<input type="checkbox"/> Presence of free product (i.e., LNAPL or DNAPL) <input type="checkbox"/> Dissolved contamination in ground water <input type="checkbox"/> Solid or liquid contamination in vadose zone <input type="checkbox"/> Surface spill or release
Primary Pollutants of Interest	<input type="checkbox"/> Gasoline (BTEX) <input type="checkbox"/> Fuel oil or jet fuel <input type="checkbox"/> PCE <input type="checkbox"/> TCE <input type="checkbox"/> Other chlorinated solvents. Specify: <input type="checkbox"/> Other chemicals. Specify:
Analytical Data	<input type="checkbox"/> Groundwater VOC data <input type="checkbox"/> Soil VOC data <input type="checkbox"/> Soil-gas data <input type="checkbox"/> Indoor air data
Other Available Data	<input type="checkbox"/> Tracer testing <input type="checkbox"/> Building pressure control testing
Level of Contamination in Various Media	<input type="checkbox"/> Maximum concentration at site = <input type="checkbox"/> Maximum concentration near building = <input type="checkbox"/> Average concentration at site = <input type="checkbox"/> Average concentration near building = <input type="checkbox"/> Concentration of background sources in indoor and outdoor air =
Limits of Contamination	<input type="checkbox"/> Building(s) directly over contamination; or <input type="checkbox"/> Building(s) not directly over contamination Lateral distance = Number of buildings in each category =
Subsurface Characteristics	<input type="checkbox"/> Depth to groundwater = <input type="checkbox"/> Soil type(s) = <input type="checkbox"/> Air-filled porosity = (e.g., low, medium, high) <input type="checkbox"/> Permeability = (e.g., low, medium, high)
Type of Construction	<input type="checkbox"/> Building with subsurface level(s) <input type="checkbox"/> Slab on grade <input type="checkbox"/> Pier-and-beam Is crawl space vented? Compacted dirt surface in crawl space? <input type="checkbox"/> Mobile home <input type="checkbox"/> Other:

Topic	Scenario
Preferential Pathways	<input type="checkbox"/> Cracks and/or gaps in slab <input type="checkbox"/> Sewer <input type="checkbox"/> Utility tunnel or conduit <input type="checkbox"/> Plumbing <input type="checkbox"/> Elevator Shafts <input type="checkbox"/> Permeable fill around piping, utilities, etc. <input type="checkbox"/> Sumps <input type="checkbox"/> Other:
Exposure Scenario	<input type="checkbox"/> Residential - Single Family Home <input type="checkbox"/> Residential - Multi-family Home <input type="checkbox"/> Warehouse <input type="checkbox"/> School <input type="checkbox"/> Industrial building <input type="checkbox"/> Office building <input type="checkbox"/> Retail building (e.g., strip mall)
Building Ventilation	<input type="checkbox"/> No HVAC system <input type="checkbox"/> <0.5 ACH (e.g., new house) <input type="checkbox"/> 0.5 – 1.0 ACH (e.g., old house) <input type="checkbox"/> 1.0 ACH (e.g., office building) <input type="checkbox"/> >1.5 ACH (e.g., warehouse w/open bay doors) <input type="checkbox"/> Number of HVAC/Air Handling Unit (AHU) zones <input type="checkbox"/> Air exchange rate (measured or assumed?)
Current Use Scenario	<input type="checkbox"/> Building in use. Typical use is ____ hours/week <input type="checkbox"/> Building abandoned or otherwise not in use <input type="checkbox"/> No building – site is undeveloped

To provide a framework for the process of evaluating vapor intrusion into buildings, a conceptual site model (CSM) was developed. The CSM is summarized below. The results of the soil-gas investigation will be compared with the CSM to verify that the results are consistent with the expectations derived from the CSM. If the results differ from expectations, the CSM may require revision.

A chemical release occurred at a dry cleaner in a strip mall. The impacted soils in the immediate vicinity of the release have been removed to the extent feasible. The groundwater impacts extend under the strip mall and may have reached nearby residential buildings. Impacted soil and groundwater are potential sources of vapors at the strip mall and impacted groundwater is a potential source of vapors downgradient. The depth to groundwater is about 12 ft. The surface soils are primarily sandy silts. The occupied buildings in the area are primarily one-story, single-family residences. The houses are relatively small (~1,200 ft²) and date to the 1920's. The lots also are relatively small (e.g., one-sixth acre) with small lawns and flower beds. The buildings appear to be slab-on-grade construction. There may be preferential pathways present in the subsurface (e.g., buried pipelines and utility lines in porous fill) that could affect pollutant transport.

Figure 2: Example Conceptual Site Model Write-Up

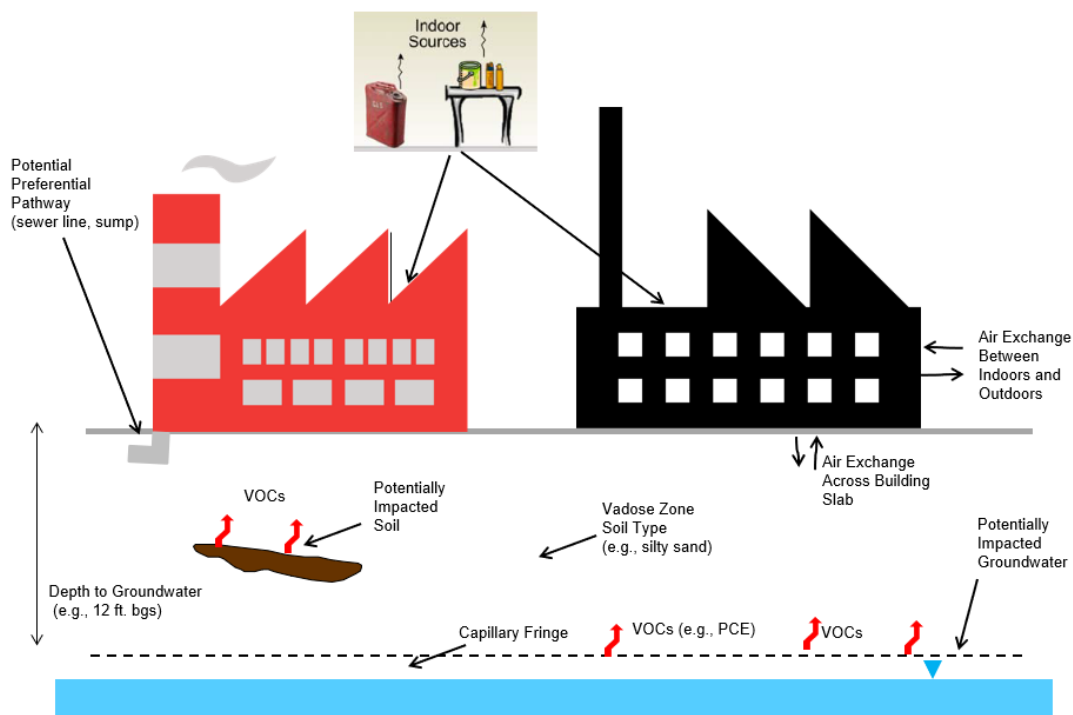


Figure 3: Example Graphic CSM

4. Sampling Guidelines

Multiple lines of evidence are typically used in vapor intrusion assessments. The appropriate types of data to collect will vary based on the CSM, type and number of potential receptors, and property access or other physical constraints. Physical constraints could include property access issues, building access issues, working hour limitations, and geologic limitations. The appropriate number of samples and sampling locations will be based on site-specific conditions. Section 4.2.4 provides guidelines for the minimum number of samples that would typically be needed for existing and proposed structures when soil gas data is used in the evaluation. EPD generally recommends that sampling be conducted in accordance with the most recent USEPA Region 4 Field Branches Quality System and Technical Procedures, which are available at: <https://www.epa.gov/quality/quality-system-and-technical-procedures-lsasd-field-branches>.

Collecting samples of multiple media (e.g., groundwater, soil gas, indoor air, outdoor air, etc.) can provide valuable data to evaluate subsurface vapor sources and whether indoor air concentrations are attributable to subsurface vapor intrusion or other factors. Recommendations for the sampling of various media are provided in Table 2 and in the following subsections, but may vary depending on the specific site and situation involved.

Table 2: Media Sampling Recommendations

Medium	Cases Where Medium Sampling is Recommended	Additional Recommendations
Groundwater	<ul style="list-style-type: none"> • Vapor source in groundwater is present 	<ul style="list-style-type: none"> • Wells screened across water table • See Section 4.1
Exterior Soil Gas	<ul style="list-style-type: none"> • Groundwater screens in¹; • Vapor source in groundwater with significantly fluctuating water table; and/or • Vapor source in vadose zone is present 	<ul style="list-style-type: none"> • Nested probes at different depths • For groundwater source, one above capillary fringe, one several feet below the foundation • Place near building and/or near vapor source • See Sections 4.2.1, 4.2.3, 4.2.4, and 4.2.5
Sub-Slab	<ul style="list-style-type: none"> • Groundwater screens in¹, no exterior soil gas collected; • Exterior soil gas screens in¹; • Vapor source in vadose zone is present under building; and/or • Indoor air sampling conducted 	<ul style="list-style-type: none"> • See Sections 4.2.2, 4.2.3, 4.2.4, and 4.2.5
Indoor Air	<ul style="list-style-type: none"> • Cannot screen out¹ based on other media sampling; • Sub-slab or crawlspace sampling at residence (combine sampling events when possible to limit disruptions to residents); • Sub-slab sampling when other media sampling indicates a higher priority for assessment¹; and/or • Significant or imminent health risk suspected 	<ul style="list-style-type: none"> • Sample indoor air before sub-slab • Sample outdoor air concurrently with indoor air • Consider limiting analysis to constituents present in subsurface (if subsurface contamination is well-characterized) • See Section 4.3

¹see Section 5.2 for definitions of screen out, screen in, and higher priority for assessment

Rapid assessment techniques such as a mobile lab or continuous monitoring may be used to evaluate the VI pathway when applicable QA/QC procedures and protocols are followed.

4.1 Groundwater Sampling Considerations

Groundwater sampling is recommended when a vapor source may be present in groundwater. For vapor intrusion evaluation purposes, groundwater samples collected from the top of the saturated zone are recommended, since the partitioning of chemicals into the vapor phase occurs at this location (the water / air interface). There are various options for sampling from the top of the saturated zone, including screened interval placement across the water table and sampling techniques such as low flow sampling or passive diffusion bags. The presence of clean groundwater above contaminated groundwater (i.e., a clean water lens) can act as a barrier to volatilization of chemicals into the vadose zone. Additional groundwater data can be collected that may add value to the VI assessment, such as depth to groundwater, groundwater elevation trends, vadose zone soil lithology (boring log), soil characteristics at the water table interface (assists with characterizing the capillary fringe), groundwater conditions (e.g., is the water table perched, confined, or submerged), etc. Measurement of groundwater temperature is also recommended since temperature is used to calculate potential vapor intrusion risks from groundwater concentrations. A map of average shallow groundwater temperatures in the United States is provided in Appendix A. Groundwater concentration trends (i.e., stable, decreasing, or increasing) at the locations of interest should also be considered.

4.2 Soil Gas Sampling Considerations

Soil gas samples can be collected from various depths within the vadose zone (deep soil gas and near-slab/shallow soil gas) as well as directly below the concrete slab of a building (sub-slab soil gas). Soil gas samples can be useful to characterize vapor sources, estimate attenuation factors, and define the extent of potential vapor impact. When an appropriate attenuation factor is applied, soil gas samples can be used to estimate potential indoor air concentrations. Soil gas samples should be considered grab samples and not time-integrated samples like indoor air or ambient air samples.

Equilibration time following soil gas implant installation, leak testing, and purging are important sampling considerations. A proper amount of equilibration time should be allowed between soil gas implant installation and sample collection (see Section 4.2.3). A proper leak test should be conducted prior to sample collection (see Section 4.2.5). The void volume of the system (including sand placed around a probe) should be calculated. A minimum of three purge volumes should be removed prior to sampling. The vacuum induced during purging should be noted. If the formation is too tight to purge, no soil gas sample can be collected. Other purging methods such as screening soil gas while purging until readings are stable will be considered on a case-by-case basis.

Typically, soil gas samples are collected in evacuated Summa canisters of 1.4 liter or smaller size. However, larger canisters may be advantageous if multiple analytical methods are to be employed. Other collection media such as Tedlar bags or glass syringes may be acceptable if special conditions exist (e.g., mobile laboratory onsite). Caution should be used when collecting samples in a Tedlar bag as they have a limited holding time prior to analysis (typically 24 to 72 hours). Passive vapor sampling methods may also be used (see Section 4.5).

4.2.1 Exterior Soil Gas Sampling

Exterior soil gas sampling is generally recommended when there is a vapor source in the vadose zone or when a groundwater vapor source cannot be screened-out based on groundwater data. Other site-specific conditions, such as a vapor source in groundwater with a significantly fluctuating water table, may also indicate the need for exterior soil gas sampling. When using the Data Evaluation Guidelines in Section 5, exterior soil gas samples should be collected near the vapor source or from locations that are otherwise representative of soil gas concentrations beneath the building foundation. When vapor sources are present deeper in the subsurface, such as in groundwater, exterior soil gas samples may need to be collected several feet below the foundation to be representative of sub-slab concentrations (ITRC 2007, USEPA 2012c). When vapor sources are present immediately beneath a building foundation, sub-slab sampling is typically needed.

When conducting soil gas sampling to evaluate the vapor intrusion pathway for a potential future building, near-source soil gas sampling is recommended to provide a conservative estimate of vapor intrusion risk. Uncertainties associated with future construction that could affect the vapor intrusion pathway include building footprint location and foundation depth relative to a vapor source. Additionally, changes in impermeable ground cover may affect soil gas concentration profiles (USEPA 2012c).

4.2.1.1 Deep Soil Gas

Deeper soil gas samples [> 5 feet below ground surface (bgs)] are useful to help determine the source of any soil vapor and for evaluating buildings with basements. Samples collected close to the groundwater (generally stay at least 5 feet above the water table) provide evidence of the soil gas concentrations being off-gassed by the groundwater. Soil gas samples collected between the deeper soil gas and the shallow soil gas (or near slab soil gas) provide information regarding the contribution of any soil contamination to the total vapor phase contamination. A comparison of the deeper soil gas and the shallower soil gas samples can help determine the source of the vapor phase contamination and provide insight regarding vapor attenuation in the subsurface.

Deep soil gas samples are typically installed as either temporary or permanent vapor implants. Other methods such as Post Run Tubing (PRT) sampling through direct push rods or other methods can be used. Regardless of the method chosen to collect the sample, a proper leak test should be conducted (see Section 4.2.5).

4.2.1.2 Near Slab or Shallow Soil Gas

The industry standard for shallow soil gas probes is five (5) ft. bgs, but soil gas samples collected from depths as shallow as 2.5 feet bgs can provide useful data regarding potential vapor concentrations near the foundation of a structure. Near-slab samples are typically defined as being collected within 10 feet laterally of an existing structure. Shallow soil gas or near-slab samples are typically collected from either a temporary or permanent soil gas implant or soil gas samples collected through a small diameter steel rod (either hand driven or advanced by direct push).

4.2.2 Sub-Slab Soil Gas Sampling

Sub-slab soil gas samples are collected from immediately below the lowest floor slab/foundation of a building. These samples are useful to characterize the levels of chemicals that can enter the building via vapor intrusion. For sub-slab sampling points, care should be taken to ensure the entire thickness of the concrete slab around the sampling point is sealed with impervious material and that the intake point is below (but generally not more than 3 inches below) the bottom of the concrete slab. A high degree of spatial variability is associated with sub-slab samples; therefore, more than one sample generally should be collected. The Pre-Sampling Building Survey discussed in Section 4.3.1 should also be considered prior to conducting sub-slab sampling.

4.2.3 Equilibration Time

The following minimum equilibration times are recommended prior to sampling a newly installed soil vapor implant (ADEQ 2017, CalEPA 2015, MDEQ 2013, WDNR 2014). If logistical constraints prevent meeting the recommended minimum equilibration time, additional purging may be sufficient to ensure representative data. In that case, records of concentration versus purge volume/time should be made. Alternatively, soil gas can be screened for oxygen, carbon dioxide and organic vapors during purging to determine when equilibrium has occurred. Once screening parameters have stabilized, sampling can commence. However, the purge and screen method should only be used after sufficient time has elapsed between probe construction and sampling to allow cements to cure or bentonite seals to hydrate according to manufacturers' recommendations.

Table 3: Recommended Minimum Equilibration Times for Soil Vapor Implants

Sample Type	Installation Method	Minimum Equilibration Time
Sub-slab	Hammer drill	2 hours
Shallow or deep soil gas implant	Hand Auger or hollow stem auger	48 hours
Shallow or deep soil gas implant	Direct push rig or hand driven tooling	8 hours
Shallow or deep soil gas sample	Direct push PRT method	2 hours
Shallow or deep soil gas sample	Direct push or hand driven with tubing attached prior to advancing the tool string	1 hour

4.2.4 Soil Gas Sample Collection Density

The appropriate number of samples and rounds of sampling should be determined based on site-specific conditions. If only one round of sampling is being proposed, the number of samples collected (density of samples) may need to be greater than if multiple rounds of sampling are planned. However, Table 4 provides general guidelines for the minimum number of samples to consider in assessing the presence of soil vapor contamination underlying current or proposed

buildings. These guidelines are based on a review of guidance from other states (Fineis 2018), including New Jersey (2018), and are intended to serve as a starting point for developing sampling plans. For larger existing buildings, High Volume Sampling may be useful to identify areas to investigate with traditional sub-slab sampling methods (Knight 2019). The number of samples needed for a particular site should be based on the conceptual site model (including building features / uses) and professional judgement.

Table 4: Recommended Minimum Number of Sub-Slab or Soil Gas Samples for an Existing or Proposed Building

Building Footprint (ft ²)	Recommended Minimum Number of Samples
0 to 1,500	2*
1,501 to 5,000	3
5,001 to 10,000	4
10,001 to 20,000	5
>20,000	6 or more

* One centrally-located sub-slab sampling point may be acceptable for residential buildings with footprints less than 1,500 square feet, provided that indoor air sampling is also conducted and that more than one sampling event is conducted.

4.2.5 Leak Test Methods

Regardless of the type of soil vapor sample collected, an appropriate leak test should be conducted to document the proper construction of the implant or the proper use of the sampling apparatus (PRT or hand driven). Table 5 summarizes leak check considerations.

Table 5: Leak Check Considerations

Leak Check Type	Considerations
Vacuum leak check	To be performed for every sampling train (canister, any flow controller, and associated fittings).*
Gaseous Leak Test (Helium, etc.)	No more than 10% of shroud concentration
Liquid (IPA, 11, DFA, etc.)	Liquid tracers may be used only in conjunction with a mobile lab.
Water Barrier (permanent sub-slab)	Not recommended**
Water Barrier (temporary sub-slab only)	Acceptable**

* For a description of the vacuum leak check, see Section V.B. “Vacuum Testing” of the State of Tennessee Department of Environment and Conservation, Division of Underground Storage Tanks, Technical Guidance Document – 018, Requirements for Conducting Soil Gas Surveys, effective January 1, 2008, https://www.tn.gov/content/dam/tn/environment/underground-storage-tanks/documents/tgds/ust_guidance_tgd-018.pdf

** A water barrier should only be used during the sampling of vapor from temporary sub-slab probes installed on a solid impermeable floor such as concrete and if used in conjunction with a vacuum test for the above ground sampling train. The water barrier should remain in place throughout vapor sampling until the summa cannister has been filled. A water barrier may be used as a physical barrier to prevent ambient air intrusion into a sub-slab point or sub-slab vapor to escape into the indoor air, but it should not be considered a leak test method because it does not inform you as to whether the area around the probe is leaking once the water barrier is removed. If you believe that the water barrier may be used while sampling permanent sub-slab probes at your site, please discuss with EPD prior to sampling.

4.3 Air Sampling Considerations

4.3.1 Pre-Sampling Building Survey

Prior to sub-slab or indoor air sampling in a building, the building occupant and/or owner should be contacted to schedule a building survey prior to the sampling event. One purpose of the building survey is to identify and discuss the potential products present in the building that could emit VOCs. Additionally, a questionnaire should be completed in coordination with the owner or user of the building to collect pertinent information related to the building design, construction, and operation that could affect the sampling results. A sketch of each building planned for sampling should be prepared in the field to identify sample locations. An example of a questionnaire is provided in Appendix G of the ITRC (2007) *Vapor Intrusion Pathway: A Practical Guideline* guidance document.

It is recommended that potential indoor sources of VOCs, such as chemical products, be removed at least 24 hours prior to sampling. In some cases, it may not be practical to remove all potential indoor sources of VOCs. In the event items cannot readily be removed, potential sources of VOCs present during sampling should be documented. The use of VOC-containing products during sampling should be avoided, as they could affect sampling results.

4.3.2 Indoor Air Sampling

Indoor air sampling is a valuable line of evidence, as it provides a direct measurement of indoor air quality for the point and time of collection; however, care must be taken to ensure that indoor sources of volatile vapors do not cause misleading results. Indoor air samples are not typically collected as the first line of evidence for evaluating vapor intrusion, as the resulting data prove difficult to interpret in the absence of other lines of evidence (e.g., groundwater, exterior soil gas, sub-slab soil gas, building survey, etc.). Indoor background sources (e.g., consumer products, tobacco smoke, etc.) can contribute to indoor air contaminant concentrations or interfere with indoor air result analysis and interpretation. Completing an indoor air questionnaire can assist you with determining what background sources may be present. Per Section 4.3.1, prior to collecting indoor air samples from a residence, an attempt to remove all chemical products from the residence should be made. After the removal of all chemical products, a minimum of 24 hours should elapse prior to the start of indoor air sampling. If chemical product removal is not practical or is not allowed by the homeowner, a detailed chemical inventory should be made. Removal of all chemical products from a non-residential property is not typically practical, so a detailed and thorough chemical inventory should be made. In either case, sampling may be limited to a site-specific indoor air analyte list based on chemicals that are known or suspected to be present in the subsurface.

Samples are typically collected in 6-liter individually certified evacuated Summa canisters, although batch certification may be sufficient in many circumstances. The use of passive vapor samplers can be an acceptable alternative to Summa canisters, especially if longer sampling timeframes (e.g., >24 hours) are needed. Samples collected from residential structures are typically collected for a period of 24 hours. Samples collected from non-residential structures are typically collected for a period that is representative of daily non-residential building occupation time, but generally not less than 8 hours. Depending on site-specific conditions, alternative methods of sample collection such as continuous monitoring or the use of passive vapor samplers may be appropriate. For longer-duration passive sampling, collection durations such as 7 days, 14 days, and longer have been discussed in the literature (USEPA 2015, USEPA 2012d). The duration for passive sampling should be determined on a site-specific basis, as considerations can include accounting for temporal variability, manufacturer or laboratory recommendations for the type of passive sampler being used, potential contributions from background sources during the sampling duration, the laboratory reporting limits needed, and the timeframe in which sampling results are needed (USEPA, 2014).

Per Table 4, the appropriate number of samples to collect will depend on the size and type of the structure. For residences, one indoor air sample per 1,000 square feet on the lowest living space is considered adequate. For small, non-residential structures, a similar density would be acceptable. For larger industrial buildings, the density can be adjusted on a site-specific basis, depending upon the CSM, building use, and size. For residential buildings, more than one round

of sampling is generally recommended to account for seasonal variations. For commercial buildings, one round of sampling may be acceptable depending on site-specific conditions.

4.3.3 Ambient Air Samples

Ambient (i.e., outdoor) air samples are helpful to identify potential contributions to indoor air concentrations from building air exchange with outdoor air and should be collected any time indoor air samples are collected. Locations for ambient air samples should be upwind of the structure being evaluated for vapor intrusion and avoid local emission sources to the extent feasible. Ambient air samples should be collected concurrently with indoor air samples and over a similar duration. USEPA (2015) recommends beginning ambient air sampling prior to (e.g., approximately 2 hours before) indoor air sampling to account for building air exchange rates.

4.3.4 Crawl Space Air Samples

Structures that do not have slab on grade construction may have a crawl space between the ground surface and the floor of the structure. If a crawl space is present, an air sample from the crawl space should be collected over the same duration as indoor air sample collection and paired with ambient air samples. Prior to collecting crawl space samples, removal of all materials from the crawl space should occur. If removal is not possible, a detailed inventory of materials in the crawl space should be made. If the crawl space does not have a continuous dirt floor, this should be noted. A site-specific analyte list may be prepared based on chemicals that are known or suspected to be present in the subsurface. Crawl space air samples should be taken from a location that is at least six (6) feet away from any crawl space vents.

4.4 Analytical Methods

Soil gas and air samples collected during a vapor intrusion assessment are analyzed using a variety of USEPA Methods. USEPA Method TO-15 is the most commonly used method for analyzing samples collected in canisters; however, USEPA Method 8260 may also be used for soil gas samples or mobile labs. USEPA Method TO-17 is used to analyze VOCs from sorbent tubes or passive samplers. A site-specific analyte list may be utilized based on chemicals that are known or suspected to be present in the subsurface. A summary table of analytical methods for soil gas, indoor and ambient air samples can be found in Appendix D, Table D-3 of the ITRC (2007) *Vapor Intrusion Pathway: A Practical Guideline* guidance document. A table of common analytical methods used in vapor intrusion investigations is presented in Appendix E.

Existing site conditions can inhibit the ability to achieve low reporting limits. Analysis at sites with high concentrations of background compounds may require dilutions, leading to higher reporting limits; in such situations, alternative methods should be considered. If a site has shallow water or tight lithology, collecting samples in larger Summa canisters could raise the reporting limits for the sample. If only a small amount of sample is collected (change of less than 5 inHg of canister pressure), reporting limits may be elevated and the sample may not provide a good representation of in-situ conditions. It is important to have a discussion with your selected laboratory prior to beginning the collection of any vapor samples. Conditions encountered in the field (low permeability, high moisture, etc) may reduce the amount of vapor available for collection. Having knowledge of the minimum volume of vapor required for collection to achieve

the necessary detection limits is advisable. The use of smaller volume summa canisters (400 ml, 450ml or 1 liter) can also be beneficial in time where limiting conditions are encountered.

Again, consultation with your analytical laboratory is recommended to discuss the analytes of interest for the project and analytical methods, and to determine the appropriate volume of sample necessary to meet your required detection limits relative to your site-specific screening values. Analysis should be conducted by a certified laboratory approved by EPD.

4.5 Passive Vapor Sampling

A passive vapor sampler is a device that contains a sorbent in an inert container that allows for vapors to pass through at a steady uptake rate based on the sorbent material. In general, passive samplers provide semi-quantitative results and the data is used to guide further active soil gas or indoor air sampling. Passive samplers can be used to collect longer duration time-integrated samples (e.g., weeks) compared to canister samples that generally use maximum sample durations of 24 hours.

Section 4.3.2 introduces generally acceptable practices for the use of passive sampling devices for indoor air. Care should be taken when selecting the appropriate passive sampling method(s) for a site and consider target compound sensitivity, retention, recovery and calibration. EPD encourages verification of passive sampling results using co-located samples via an alternative method for a subset of samples during a minimum of a single sample event.

For soil gas sampling, passive samplers can be useful in low permeability soils where the use of active soil gas methods is not effective due to permeability issues, and provide the option of additional analytical methods that allow for some chemical compounds that are not available in USEPA Method TO-15. It is recommended that plans for passive sampling be discussed with EPD prior to use.

For more information on passive vapor samplers, see USEPA's Engineering Paper entitled *Passive Samplers for Investigations of Air Quality: Method Description, Implementation, and Comparison to Alternative Sampling Methods* (USEPA, December 2014).

5. Data Evaluation Guidelines

This section presents guidelines for risk-based decision-making when evaluating the vapor intrusion pathway. These guidelines are based on a cumulative risk comparison to a cancer risk of 1E-5 and/or a hazard index of 1 under reasonable maximum exposure conditions. The use of cumulative risk allows for greater flexibility relative to individual screening level concentrations and ensures that the effects of multiple chemicals are considered. Considering the magnitude of risk relative to these thresholds can also be helpful to inform decision-making. The use of risk-based ranges to inform decision-making for vapor intrusion evaluations has been described by other environmental regulatory and policy organizations (NYSDOH 2006, CalEPA 2011, CRC CARE 2013, IDEM 2019). Risk calculation is discussed in Section 5.1 and risk-based decision guidelines are presented in matrices according to medium (e.g., groundwater, soil gas, and paired indoor air – sub-slab) in Section 5.2. Alternatively, vapor intrusion can also be evaluated using screening levels for individual chemicals, set at a cancer risk of 1E-06 and an HQ of 0.1 when there are ten (10) or less chemicals detected at a site.

5.1 Calculating Risk Using the Vapor Intrusion Screening Level Calculator

Risk assessment is a scientific process used to characterize the nature and magnitude of health risks to humans from chemicals that may be present in the environment. Calculated risk from indoor air exposure to chemicals via the vapor intrusion pathway is a function of the chemical concentration, chemical toxicity, and the exposure scenario (e.g., frequency and duration of exposure). The human health risk assessment framework developed by USEPA, and utilized by EPD, separates the adverse health effects associated with chemicals into two broad categories: i) cancer and ii) systemic health effects (also referred to as non-cancer effects). As discussed below, two different types of chemical-specific “toxicity values” are used to quantify these health effects. Chemicals that are believed to be carcinogenic are also capable of producing non-cancer health effects, although usually at higher doses. For such chemicals, risks for each type of endpoint are evaluated independently.

Carcinogenic effects associated with inhalation exposure to a chemical via the vapor intrusion pathway are characterized using the inhalation unit risk (IUR), which represents the increased probability of an individual developing cancer as a result of continuous exposure to a chemical at a concentration of $1 \mu\text{g}/\text{m}^3$ over a lifetime. Cancer risk associated with exposure to a chemical carcinogen is expressed as an excess lifetime cancer risk, which represents the increased probability of developing cancer above the background cancer rate. For each chemical with an IUR, cancer risk is calculated by multiplying the lifetime average daily exposure concentration (chronic daily intake) by the IUR for that chemical. If multiple chemical carcinogens have been detected, the cumulative risk to a receptor is calculated as the sum of the risks for each carcinogen. Calculated cancer risks are used in the decision matrices discussed in Section 5.2.

Non-carcinogenic effects associated with inhalation exposure to a chemical via the vapor intrusion pathway are characterized using the reference concentration (RfC), which represents a chemical concentration to which humans (including sensitive individuals) may have continuous inhalation exposure over a lifetime without deleterious effects. A hazard quotient (HQ) is calculated by dividing the average daily exposure concentration (chronic daily intake) by the RfC. If multiple chemicals that share one or more common target organs have been detected, the chemical-specific hazard quotients are summed to obtain a hazard index (HI) for each common target organ. Calculated hazard indices are used in the decision matrices discussed in Section 5.2.

For soil gas and groundwater, estimated risk is also a function of the attenuation factor, which is used to predict an indoor air concentration based on the chemical concentration in groundwater or soil gas. Table 6 summarizes key factors that affect calculated risk for each medium.

Table 6: Factors Affecting Calculated Risk

Medium	Factors Affecting Calculated Risk
Groundwater	<ul style="list-style-type: none"> • Chemical-specific parameters (e.g., toxicity) • Exposure Scenario (e.g., residential) • Chemical concentration in medium • Attenuation Factor • Groundwater temperature
Soil gas (exterior or sub-slab)	<ul style="list-style-type: none"> • Chemical-specific parameters (e.g., toxicity) • Exposure Scenario • Chemical concentration in medium • Attenuation Factor
Indoor Air	<ul style="list-style-type: none"> • Chemical-specific parameters (e.g., toxicity) • Exposure Scenario • Chemical concentration in medium

The recommended method for calculating risk is the most recent version of the USEPA Vapor Intrusion Screening Level (VISL) Calculator, which is currently available at: <https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-level-calculator>.

Note that both cancer risk and HQ/HI values may be rounded to one significant figure for decision-making purposes (USEPA 2018). If the total HI for all analytes of interest exceeds 1, more specific HIs can be developed for each target organ/system. Appendix B lists the target organ/system for some of the more common substances detected in vapor intrusion assessments.

Risk is typically calculated using both default and site-specific inputs. Sources for VISL Calculator inputs are summarized in Table 7.

Table 7: Sources for VISL Calculator Inputs

VISL Calculator Input	Source
Chemical-specific parameters	VISL Calculator defaults
Exposure Scenario	VISL Calculator defaults based on site use (residential or commercial)
Attenuation Factor	See Section 5.1.1 of this guidance
Groundwater temperature	VISL Calculator default, site-specific measurements, or the USEPA shallow groundwater temperature map (see Appendix A of this guidance)
*Chemical concentration in medium	Based on measured concentrations near or inside a building. Typically, maximum measured concentrations are used. Other representative concentrations, such as a 95% Upper Confidence Limit (95% UCL) of the mean, may be considered for larger commercial buildings based on the dataset.

*Note: Scenarios involving a single-family residence or smaller commercial building would typically warrant using the maximum concentration of each analyte among all sampling locations in or near the building to evaluate a reasonable worst-case scenario. For larger multi-family or commercial buildings, evaluating the analyte concentrations from individual sample locations may be applicable in situations where a structure footprint is of sufficient size that sample locations used in VISL modeling are greater than 150 feet apart (150% of a typical buffer distance) or the building is greater than 16,146 square feet [1,500 m², median value for commercial buildings (USEPA 2017)]. For larger commercial buildings with at least 10 sample locations, a 95% UCL of the mean analyte concentration may be considered if a sufficient dataset is available to characterize exposure units within the buildings (e.g., office vs. warehouse space). EPD recommends discussing the 95% UCL of the mean approach with the EPD project officer prior to implementation.

5.1.1 Recommended Attenuation Factors

Conservative attenuation factors are used to estimate upper-bound indoor air concentrations that may be present due to chemical concentrations in subsurface media. For the purpose of calculating risk for use with these decision matrices, recommended attenuation factors and supporting information needed are provided in Table 8 and Table 9

Table 9. These tables include minimum recommended attenuation factors for use with commercial buildings without validation sampling from other media. For example, if a tracer-supported sub-slab attenuation factor of less than 0.006 is being relied on for decision-making, indoor air sampling for vapor intrusion constituents of concern should be conducted to validate the attenuation factor.

Table 8: Groundwater Attenuation Factors

Attenuation Factor	Comment	Supporting Info Needed
0.001	USEPA default	<ul style="list-style-type: none"> • Water table > 5 feet below foundation • Significant openings to subsurface or significant routes for preferential subsurface vapor migration not present
0.0005	USEPA default for fine soil type ¹	<ul style="list-style-type: none"> • Same info for default • Soil classification based on laboratory grain size distribution • 50% or more passing No. 200 sieve
< 0.0005 and ≥ 0.0002	Model-supported value for commercial building	<ul style="list-style-type: none"> • Same info for default • Soil classification based on laboratory grain size distribution • Model results
< 0.0002		<ul style="list-style-type: none"> • Same as above plus validation sampling

¹EPD will consider “fine soil type” to be soil with 50% or more passing the No. 200 (0.075 mm) sieve, consistent with the Unified Soil Classification System definition for fine-grained soil.

Table 9: Soil Gas or Sub-Slab Attenuation Factors

Attenuation Factor	Comment	Supporting Info Needed
0.03	USEPA default	<ul style="list-style-type: none"> • Significant openings to subsurface or significant routes for preferential subsurface vapor migration not present
0.01	Slab-on-grade default for commercial building ¹	<ul style="list-style-type: none"> • Same info for default • Commercial building • Slab on grade foundation
< 0.01 and ≥ 0.006	Model or tracer-supported value for commercial building	<ul style="list-style-type: none"> • Same info for default • Soil classification based on laboratory grain size distribution analysis • Model or tracer results
< 0.006		<ul style="list-style-type: none"> • Same as above plus validation sampling

¹NCDEQ (2014)

5.1.2 Use of Modeling

EPD will accept vapor intrusion models as part of a multiple lines of evidence approach. The most commonly-used model is the USEPA implementation of the Johnson and Ettinger (J&E) Model, which is currently available at: <https://www.epa.gov/vaporintrusion/epa-spreadsheet-modeling-subsurface-vapor-intrusion#model>.

The J&E model calculates an estimated attenuation factor based on subsurface and building parameters (USEPA 2017). USEPA default input parameters are provided, and any deviation from default values should be explained. For petroleum hydrocarbons and other compounds amenable to aerobic biodegradation (e.g., vinyl chloride), other models that account for biodegradation (e.g., BioVapor) may be appropriate.

Mathematical modeling can be used in a variety of ways, such as identifying conditions where buildings may be more susceptible to vapor intrusion and comparing paired field measurements (such as groundwater and indoor air concentrations) to model predictions that represent theoretical subsurface vapor transport. Modeling can also be used to support the use of site-specific attenuation factors. When modeling is used to support site-specific attenuation factors, the following are recommended:

- Modeling should be limited to commercial buildings that may not be well-represented by the USEPA (2012b) attenuation factor database, which is primarily based on residential buildings. Attenuation factors based on the USEPA database are recommended for residential buildings. See Section 5.1.1 of this guidance for a summary of recommended attenuation factors.
- Using modeling to calculate attenuation factors for residential buildings is not recommended because residential building construction varies, as does heating, ventilation and air conditioning (HVAC) systems, and air exchange rates. Additionally, preferential pathways (sumps, water supply and sewer lines), which are likely to present at residential buildings and have more influence on smaller footprint buildings, precludes the use of the J&E model.
- Modeling should be limited to buildings with either slab-on-grade, basement with slab, or crawlspace with slab foundations. Modeling to develop site-specific attenuation factors for buildings with dirt floors in a basement or crawlspace is not recommended.
- The use of a site-specific soil type should be supported by laboratory grain-size distribution analysis. More than one grain-size distribution analysis may be needed for a borehole, especially for soils with greater variability at depth; otherwise, one grain-size distribution analysis may not be representative of the heterogeneous nature of the soil within the entire soil column. In the USEPA implementation of the J&E Model, model-provided soil properties (e.g., porosity, bulk density, etc.) based on soil type should be used. The use of other site-specific parameters should be supported by field measurements.
- Validation sampling of model-predicted media concentrations (i.e., sub-slab and/or indoor air concentrations) is recommended if relying on a calculated groundwater attenuation factor of less than 0.0002 or a calculated sub-slab/soil gas attenuation factor of less than 0.006, which are approximately 75th percentile values from the USEPA database and are a reduction by a factor of 5 from default attenuation factors. For example, the USEPA implementation of the J&E Model provides a predicted indoor air concentration and a predicted vapor concentration beneath the foundation when modeling a groundwater or exterior soil gas vapor source. In these cases, validation sampling could consist of indoor air and/or sub-slab sampling to verify that field-measured vapor concentrations do not exceed model predictions. An appropriate amount of validation sampling will depend on site-specific considerations, with more validation sampling generally being appropriate if proposed site-specific attenuation factors are significantly lower (e.g., more than an order of magnitude) than default values. Note that a more conservative attenuation factor can be utilized even if a lower attenuation factor is supported by modeling. For example, a groundwater attenuation factor of 0.0002 could be utilized for a commercial building without the need for validation sampling, provided that appropriate modeling supported the use of an attenuation factor of 0.0002 or lower.
- Although some models (such as the USEPA implementation of the J&E Model) may provide risk calculations, it is recommended that an appropriate site-specific attenuation factor be used in the VISL Calculator for conducting risk calculations. This helps ensure

that risk calculations are based on current methods, exposure factors, toxicity values, and chemical parameters.

It is recommended that any modeling approach that does not follow the above recommendations be discussed with EPD staff prior to conducting said modeling. For further discussion of modeling, see Section 6.6 “General Principles and Recommendations for Mathematical Modeling” from the *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* (USEPA 2015).

5.1.3 Use of Tracers

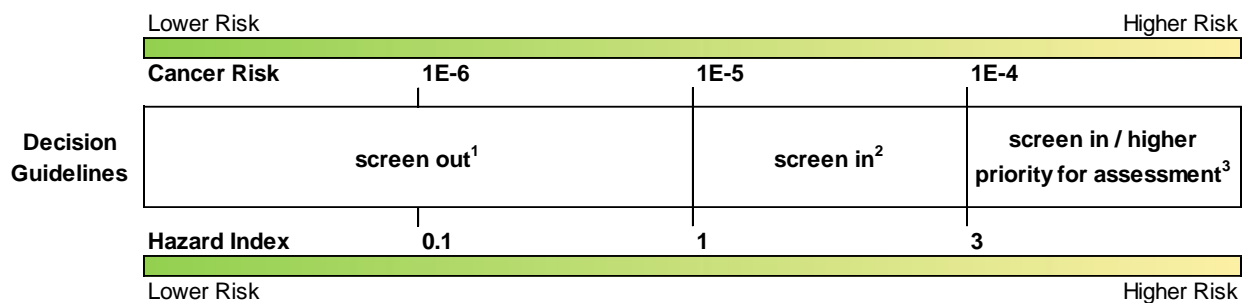
Tracers are substances that are either naturally occurring (such as radon) or not typically found in indoor air from background sources. When tracers are present in the subsurface and in indoor air, they provide a line of evidence that vapor intrusion is occurring. VOCs that are not typically detected in background indoor air include vinyl chloride, 1,1-dichloroethylene, cis-1,2-dichloroethylene, and 1,1-dichloroethane (USEPA 2011).

Tracers can be used to calculate site-specific sub-slab attenuation factors by sampling both sub-slab and indoor air and dividing the indoor air concentration by the sub-slab concentration. However, there is some uncertainty associated with the exact correlation between the tracer attenuation factor and the attenuation factor for other constituents of concern. Therefore, it is recommended that the use of tracer attenuation factors be limited to commercial buildings that may not be well-represented by the USEPA (2012b) attenuation factor database. Indoor air sampling validation of predicted indoor air concentrations from tracer attenuation factors is recommended if relying on a tracer attenuation factor of less than 0.006, which is the approximate 75th percentile value from the USEPA database and a reduction by a factor of 5 from the default attenuation factor of 0.03.

5.2 Decision Matrices

The decision matrices shown in Figure 4, Figure 5 and Figure 6 are intended to inform decision making by environmental professionals experienced in the evaluation of vapor intrusion. Both cancer and non-cancer cumulative risks are incorporated into the matrices. The most conservative decision guideline regarding both risks should be considered. For instance, if cancer risk indicates a “screen out” decision, but non-cancer risk indicates a “screen in” decision, the overall decision would be “screen in.” The definitions for each decision guideline are provided below the matrix. Examples using the decision matrices are provided in Appendix C. An example of a decision matrix expressed in terms of concentration for a single chemical is provided in Appendix D.

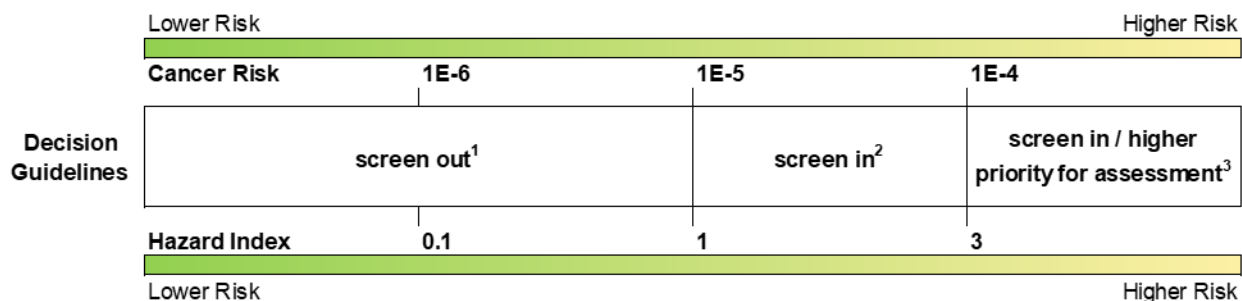
Figure 4: Groundwater Decision Matrix



Notes:

1. **screen out**: No further assessment of the pathway is necessary based on the VISL Calculator input parameters. Consider observed / expected groundwater concentration trends when making a screen out determination.
2. **screen in**: Further assessment of the pathway is recommended. Consider refinement of VISL Calculator input parameters or additional media sampling (e.g., soil gas).
3. **screen in / higher priority for assessment**: Further assessment of the pathway is recommended. Consider refinement of VISL Calculator input parameters or additional media sampling (e.g., soil gas). Consider prioritizing assessment where potential risks exceed CR=1E-4 or HI=3 based on appropriate VISL Calculator input parameters.

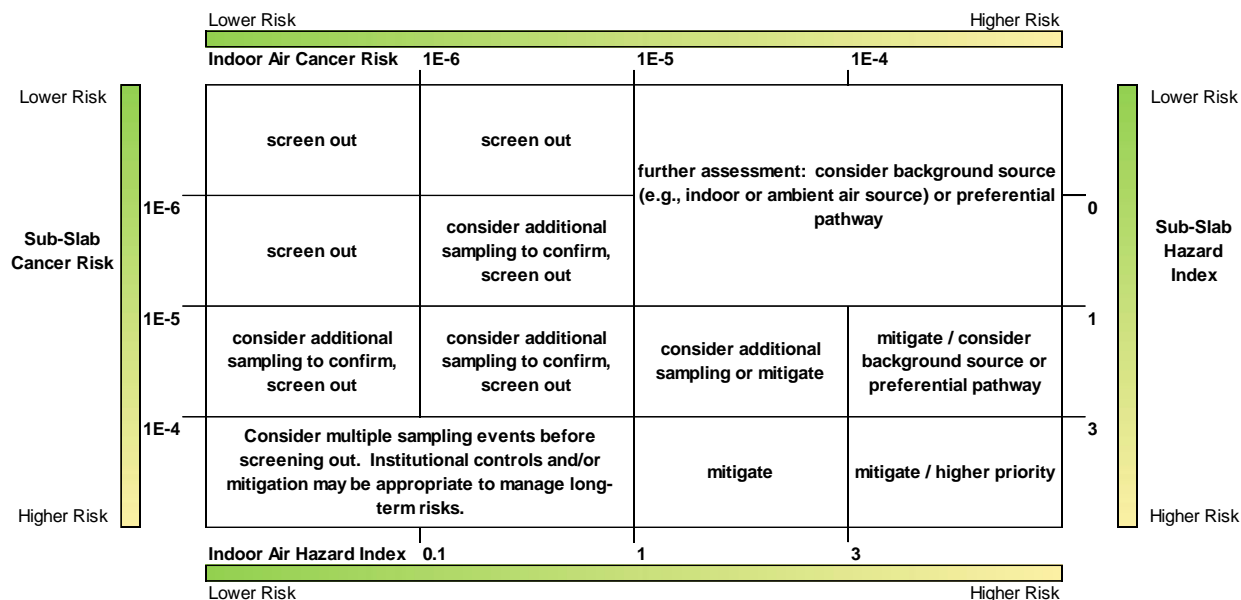
Figure 5: Soil Gas Decision Matrix



Notes:

1. **screen out**: No further assessment of the pathway is necessary based on the VISL Calculator input parameters. Consider the need for additional soil gas sampling to confirm results based on site-specific factors (source strength, data variability, etc.).
2. **screen in**: Further assessment of the pathway is recommended. Consider refinement of VISL Calculator input parameters or additional media sampling (e.g., sub-slab).
3. **screen in / higher priority for assessment**: Further assessment of the pathway is recommended. Consider refinement of VISL Calculator input parameters or additional media sampling (e.g., sub-slab). Consider prioritizing assessment where potential risks exceed CR=1E-4 or HI=3 based on appropriate VISL Calculator input parameters.

Figure 6: Paired Sub-Slab – Indoor Air Decision Matrix



5.3 Chemical-Specific Considerations

5.3.1 Chloroform

When chloroform is present in the subsurface, it may be difficult to attribute any chloroform in indoor air to vapor intrusion. Chloroform forms in tap water from chlorination and can be detected in groundwater due to leaks in water supply or sewer lines. Chloroform is also commonly detected in background indoor air (USEPA 2011). When chloroform is detected in indoor air, please note that it may originate from the indoor use of tap water, especially in areas where tap water is heated such as near water heaters, washing machines, or kitchens. Additionally, chloroform may be present in soil gas if the sample was obtained near a water line. A line of evidence approach to determine the origin of the chloroform vapors, which may include additional sampling and evaluation, may be needed. If a potential mitigation decision is being driven by risk due to chloroform, it is recommended that the situation be discussed with EPD. Mitigation will generally not be necessary for chloroform present in groundwater from nonpoint sources at concentrations less than the Maximum Contaminant Level of 0.08 mg/L.

5.3.2 Naphthalene

Naphthalene can also be a problematic compound when evaluating vapor intrusion. Naphthalene is present in moth balls and may have been sprayed around building foundations as an insect repellent. Therefore, it is a common compound found in indoor air, crawlspace air and soil gas near structure walls and underneath structures. If naphthalene is found in soil gas, crawl space air or indoor air, but is not found in groundwater, it may be from one of these sources. A line of evidence approach, which may include additional sampling, should be used to determine the origin of the naphthalene vapors.

5.3.3 Trichloroethene

EPD recognizes the lack of regulatory and scientific consensus related to short-term inhalation exposure of pregnant women to elevated concentrations of trichloroethene (TCE) and the potential correlation with fetal cardiac development. EPD will evaluate the need for any accelerated response actions due to TCE on a site-specific basis.

5.3.4 Use of Surrogate Toxicity Values

Surrogate toxicity values may be used for volatile compounds without inhalation toxicity values where applicable. Contact the EPD Risk Assessment Program for current information regarding the use of surrogate toxicity values.

6. Mitigation Guidelines

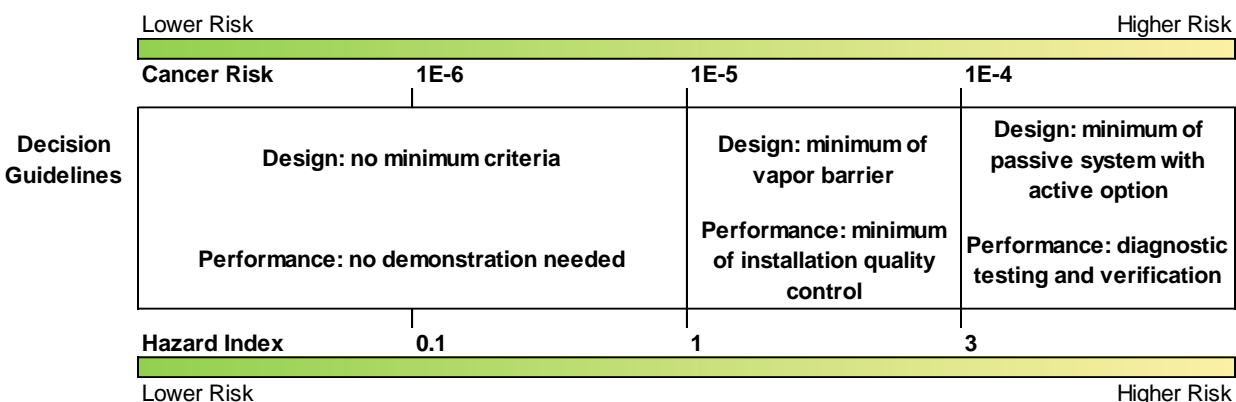
The objective of vapor intrusion mitigation is to interrupt the pathway between a subsurface vapor source and potential receptors (i.e., building occupants). While vapor intrusion mitigation is not typically considered a remediation approach, design and implementation of vapor mitigation systems (VMS) should complement remediation where appropriate. Selection and design of a VMS should consider aspects of the CSM (e.g., building construction, building use, etc.) and the chemical concentrations or risks that need to be mitigated. Generally, more robust VMS design, performance verification, and monitoring/maintenance should be considered where higher risks are indicated. Mitigation components should be installed according to the manufacturer's specifications. EPD recommends that installed VMS should reduce indoor air risks from subsurface contamination to at least a cumulative cancer risk of 1E-5 and a Hazard Index of 1.

A review of mitigation strategies and best practices can be found in Chapter 4 of the ITRC guidance document, *Vapor Intrusion Pathway: A Practical Guide* (ITRC 2007) and ITRC Vapor Intrusion Mitigation Guidance and Training (ITRC 2021). Use of alternative mitigation technologies not specified in this guidance or references should be discussed with EPD and may need to include post-mitigation performance verification (see Diagnostic Testing and Verification).

6.1 New Construction

New construction mitigation design is typically based on groundwater or soil gas sampling at or near the location of a future building. Vapor-mitigating design is generally encouraged as it provides current and future benefits for reducing exposure to soil vapor from subsurface contamination and radon. Additionally, mitigation systems incorporated into new construction are typically more cost-effective than VMS for existing buildings as the former can be integrated into building design. New construction mitigation systems may include geomembrane or spray-applied barriers, passive venting, active sub-slab depressurization, and building design features (parking deck, elevated floor). For new construction utilizing passive mitigation, consider installing the system in a way that preserves the option of converting it to an active VMS if needed. VMS design and performance guidelines for new construction based on vapor intrusion risk (cumulative risks calculated as described in Section 5) from groundwater or soil gas are presented in Figure 7.

Figure 7: Mitigation System Design and Performance Guidelines for New Construction Based on Vapor Intrusion Risk from Groundwater or Soil Gas



Note: Installation quality control would include items such as documentation regarding proper installation and sealing seams.

6.2 Existing Buildings

Existing building VMS design involves retrofitting a mitigation system to an existing building. Although preemptive or precautionary mitigation is not discouraged, existing building vapor mitigation is typically conducted in response to a demonstrated need based on environmental sampling (soil gas, sub-slab, and/or indoor air sampling). Typically, a VMS for an existing building will involve passive or active sub-slab depressurization and sealing significant cracks and conduits for soil gas entry into the building. Other VMS may include aerated floors or floor coatings. Modification of HVAC operation to reduce indoor air concentrations may improve conditions but is not considered a mitigation strategy without confirmation of effectiveness.

6.3 Mitigation System Design, Diagnostic Testing and Verification

Active depressurization system design should include conducting a pilot test to ensure the system is capable of interrupting the vapor intrusion pathway. Pre-emptive mitigation or VMS installation where the conceptual site model is incomplete or being developed may warrant system design to meet higher risk situations. Intrinsically safe blowers (or a passive design) should be used where appropriate (situations where petroleum hydrocarbons or methane may be present) as determined by a qualified professional. At a minimum, a vacuum of -0.004” of water column (WC) should be achieved throughout the area targeted for mitigation under worst-case, seasonal conditions. Sub-membrane Depressurization Systems (SMDS) are typically used for structures with crawl spaces. Membrane barriers should be designed and manufactured for use in VOC mitigation and installed according to manufacturer instructions. A minimum single sheet thickness of 30 mil is recommended for membrane barriers used in new construction or where the membrane could be damaged during installation (USEPA 2008) (or comparable material designed for VI mitigation which can stand up to construction/installation stresses), with thinner membranes such as 12 mil (0.012 inches) being potentially acceptable for existing crawl spaces. Membrane installation should include sealing the membrane barrier at seams and penetrations. Heavier gauge sheeting or a means for protecting the membrane should be employed when crawl spaces are used for storage or frequent entry is needed for maintenance of utilities or equipment. Mitigation design

and installation should be reviewed by an environmental professional sufficiently experienced with VMS. Documentation of construction completion and performance testing is recommended.

Once a vapor mitigation system is installed, diagnostic testing and/or verification sampling should be conducted. Diagnostic testing is needed to verify that the system meets its performance specifications and to establish an operational baseline. Diagnostic testing should include:

- Visual inspection of the mitigation system;
- Documentation of baseline system performance measurements (e.g. manometer, gauge, or other appropriate measurement); and
- Determining whether alterations or augmentations to the system are needed.

Following installation of a vapor mitigation system, EPD recommends one or more of the following:

- Pressure Testing - demonstrate that a negative pressure differential exists between the sub-slab and indoor air.
- Indoor Air Sampling - one round of indoor air sampling at least 30 days after system installation or during worst-case conditions.

Testing of the mass emission rate from the exhaust of the mitigation system can also be useful for tracking performance over time. Mitigation systems should be maintained, and effectiveness verified regularly or if a significant modification is made. Where appropriate, remote monitoring is recommended and is a suitable ongoing verification method once the initial diagnostic testing and system effectiveness verification has been completed. Monitoring and maintenance of the VMS should be conducted at a sufficient frequency to detect problems. Termination of monitoring/maintenance or VMS decommissioning may be considered if it is demonstrated that mitigation is no longer needed. A multiple lines of evidence approach should be used to substantiate any requests to terminate effectiveness monitoring, or shut down the VMS. Multiple lines of evidence may include indoor air testing, a significant decrease in groundwater/sub-slab soil gas concentrations, differential pressure readings between sub-slab and indoor air under advective flux conditions, etc.

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Appendix A: Map of Average Shallow Groundwater Temperature

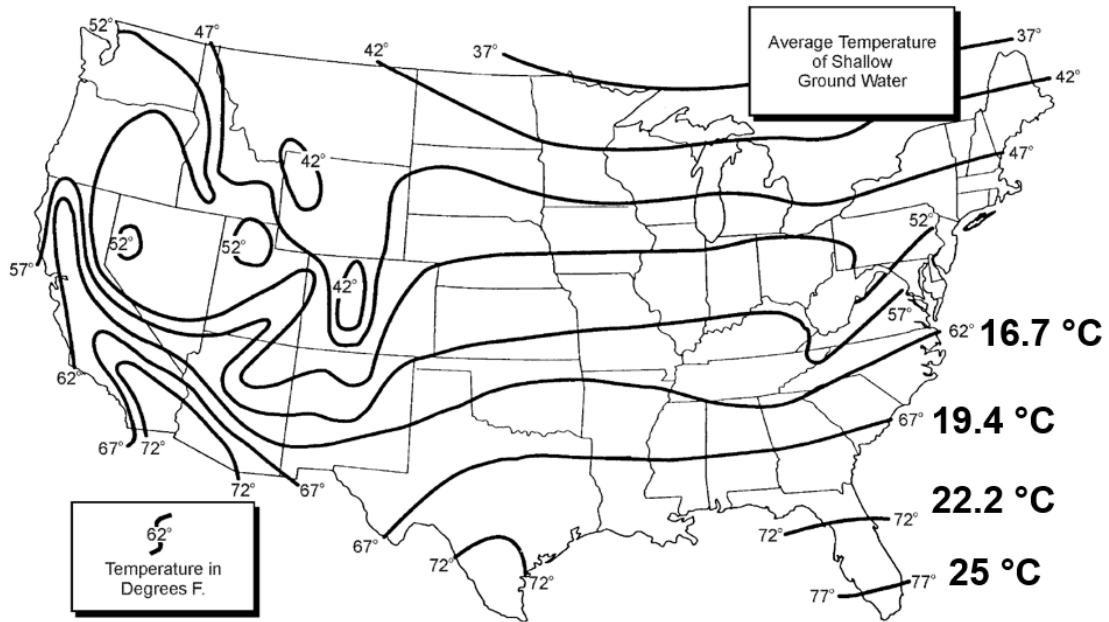


Figure 8: Average Temperature of Shallow Groundwater. Adapted from USEPA 2001.

Appendix B: Table of Non-Cancer Target Organ Effects for Selected Chemicals

<i>Chemical</i>	<i>Target System/Organ</i>
<i>Acetone</i>	Neurological
<i>Benzene</i>	Blood
<i>Carbon Disulfide</i>	Neurological
<i>Carbon Tetrachloride</i>	Liver
<i>Chlorobenzene</i>	Liver; Kidney
<i>Chloroform</i>	Hepatic
<i>1,2-dichlorobenzene</i>	Whole body
<i>1,4-dichlorobenzene</i>	Liver
<i>1,2-dichloroethane</i>	Neurological
<i>1,1-dichloroethylene</i>	Liver
<i>Ethylbenzene</i>	Developmental
<i>2-hexanone</i>	Nervous
<i>Methyl ethyl ketone</i>	Developmental
<i>Methyl isobutyl ketone</i>	Developmental
<i>Methylene Chloride</i>	Liver
<i>Naphthalene</i>	Nervous; Respiratory
<i>Tetrachloroethylene</i>	Nervous
<i>Toluene</i>	Neurological
<i>Trichloroethylene</i>	Thymus
<i>Vinyl Chloride</i>	Liver
<i>Xylenes</i>	Nervous

Source: USEPA VISL Calculator, Inhalation Chronic Toxicity Metadata, Inhalation Chronic Reference Concentration Target Organ

Appendix C: Examples Using Data Evaluation Guidelines

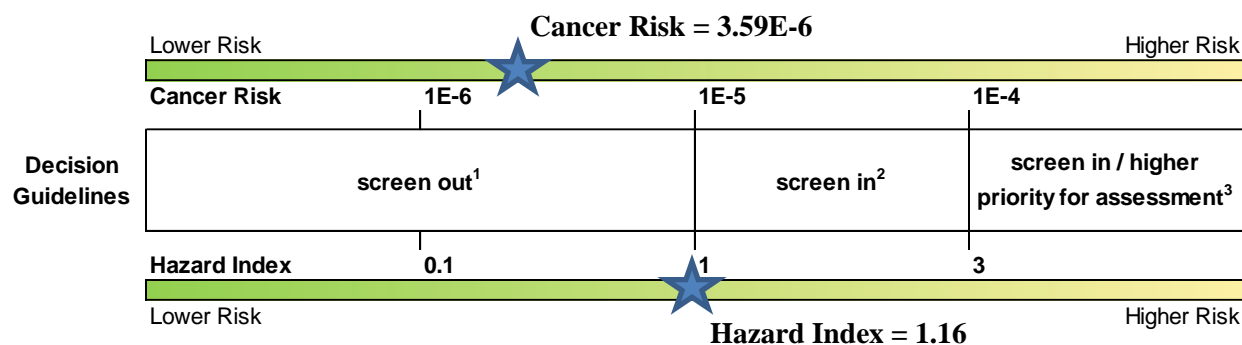
Example 1:

- Commercial scenario, slab on grade foundation
- Tetrachloroethylene groundwater concentration = 150 ug/L
- Trichloroethylene groundwater concentration = 50 ug/L
- Groundwater temperature = 20°C
- Groundwater depth = 20 feet, fine soil type (use attenuation factor = 0.0005)
- No vapor source in the vadose zone, no preferential pathways

VISL Calculator Output:

Chemical	CAS Number	Site Groundwater Concentration C_{gw} ($\mu\text{g/L}$)	Site Indoor Air Concentration $C_{i,a}$ ($\mu\text{g/m}^3$)	VI Carcinogenic Risk CDI ($\mu\text{g/m}^3$)	VI Carcinogenic Risk CR	VI Hazard CDI (mg/m^3)	VI Hazard HQ
Tetrachloroethylene	127-18-4	150	4.20E+01	3.43E+00	8.91E-07	9.60E-03	2.40E-01
Trichloroethylene	79-01-6	50	8.07E+00	6.58E-01	2.70E-06	1.84E-03	9.21E-01
*Sum					3.59E-06		1.16E+00

Groundwater Decision Matrix:



Summary:

In this example, the cumulative cancer risk is within the “screen out” range. The hazard index is at the border of the “screen out” / “screen in” ranges. Note that for decision-making purposes, the hazard index may be rounded to one significant figure, or HI=1. The overall decision would be “screen out” based on the input values and VISL Calculator output. Note that in making a “screen out” determination, observed / expected groundwater concentration trends should be considered. Another option for evaluating the hazard index would be to separate risks based on target organ effects. As shown in Appendix B, tetrachloroethylene and trichloroethylene have different target organ effects. Therefore, the trichloroethylene hazard quotient of 0.9 could be used for decision-making purposes.

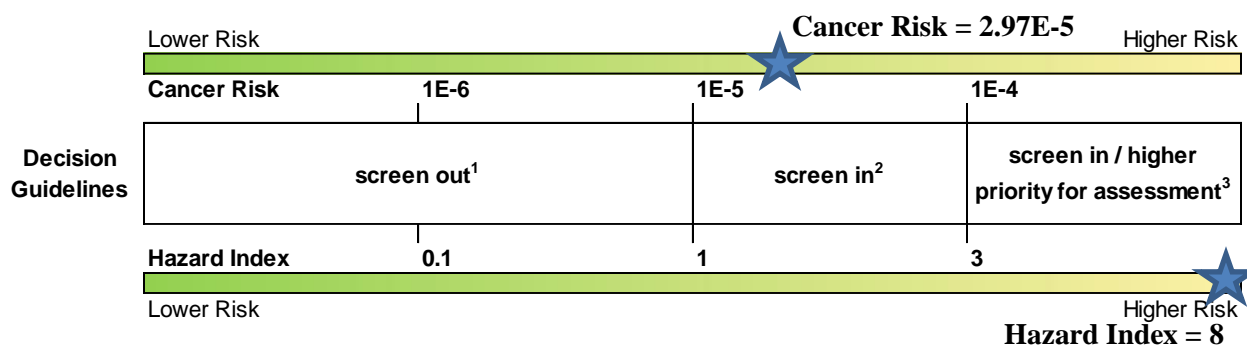
Example 2:

- Commercial scenario, slab on grade foundation
- Tetrachloroethylene groundwater concentration = 5,000 ug/L
- Groundwater temperature = 20°C
- Groundwater depth = 20 feet, fine soil type (use attenuation factor = 0.0005)
- No vapor source in the vadose zone, no preferential pathways

VISL Calculator Output:

Chemical	CAS Number	Site Groundwater Concentration C_{gw} ($\mu\text{g/L}$)	Site Indoor Air Concentration $C_{i,a}$ ($\mu\text{g/m}^3$)	VI Carcinogenic Risk CDI ($\mu\text{g/m}^3$)	VI Carcinogenic Risk CR	VI Hazard CDI (mg/m^3)	VI Hazard HQ
Tetrachloroethylene	127-18-4	5000	1.40E+03	1.14E+02	2.97E-05	3.20E-01	8.00E+00
*Sum					2.97E-05		8.00E+00

Groundwater Decision Matrix:



Summary:

In this example, the cancer risk is within the “screen in” range and the hazard index of 8 is well above the “screen in / higher priority for assessment” threshold of 3. The overall decision would be “screen in / higher priority for assessment”, indicating that further assessment is recommended with consideration for prioritizing the vapor intrusion pathway evaluation.

Example 3:

- Residential scenario
- Vinyl Chloride sub-slab concentration = 54 $\mu\text{g}/\text{m}^3$
- Vinyl Chloride indoor air concentration = 0.09 $\mu\text{g}/\text{m}^3$
- Slab on grade foundation (use attenuation factor = 0.03)

Sub-Slab Soil Gas VISL Calculator Output:

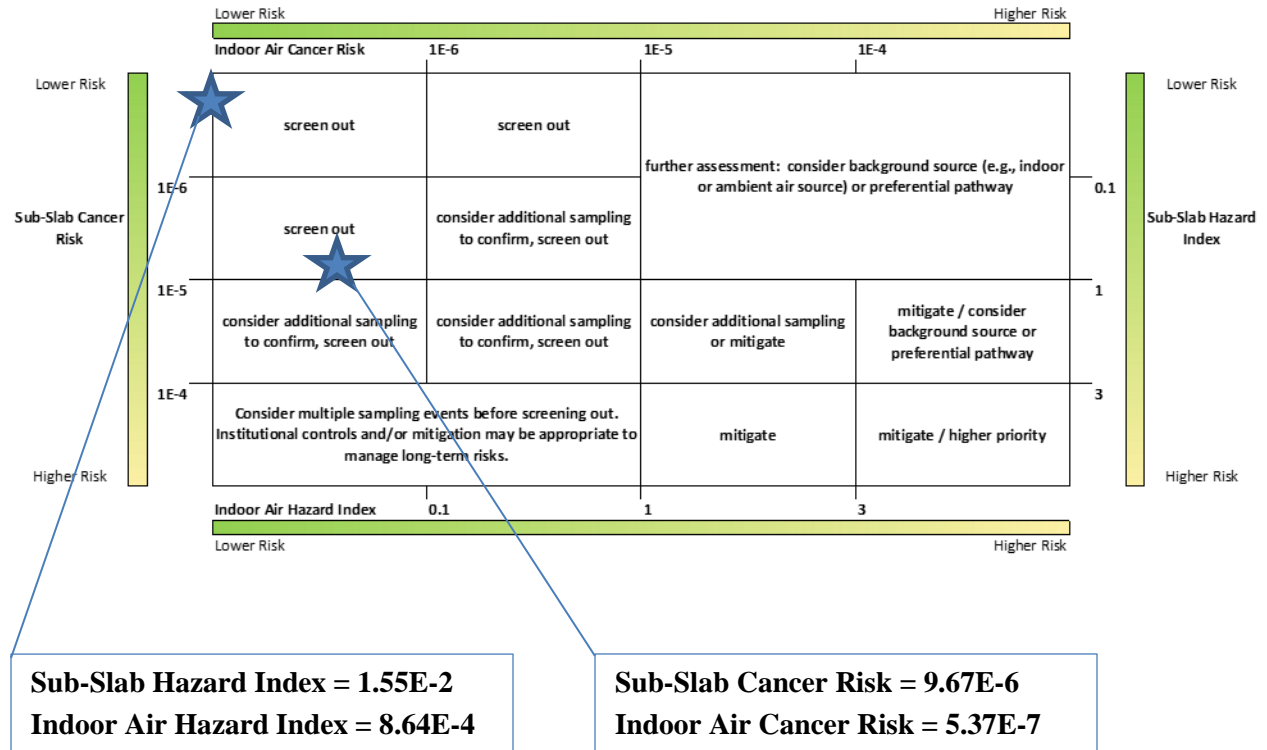
Chemical	CAS Number	Site Sub-Slab and Exterior Soil Gas Concentration C_{sg} ($\mu\text{g}/\text{m}^3$)	Site Indoor Air Concentration $C_{i,a}$ ($\mu\text{g}/\text{m}^3$)	VI Carcinogenic Risk CDI ($\mu\text{g}/\text{m}^3$)	VI Carcinogenic Risk CR	VI Hazard CDI (mg/m^3)	VI Hazard HQ
Vinyl Chloride	75-01-4	54	1.62E+00	2.20E+00	9.67E-06	1.55E-03	1.55E-02
*Sum					9.67E-06		1.55E-02

Indoor Air VISL Calculator Output:

Chemical	CAS Number	Site Indoor Air Concentration $C_{i,a}$ ($\mu\text{g}/\text{m}^3$)	VI Carcinogenic Risk CDI ($\mu\text{g}/\text{m}^3$)	VI Carcinogenic Risk CR	VI Hazard CDI (mg/m^3)	VI Hazard HQ
Vinyl Chloride	75-01-4	9.00E-02	1.22E-01	5.37E-07	8.63E-05	8.63E-04
*Sum				5.37E-07		8.63E-04

Summary:

Paired sub-slab soil gas / indoor air cancer risks and hazard indices are plotted on the decision matrix below. In this example, both the cancer risks and the hazard indices are within the “screen out” range, with the cancer risks resulting in the most conservative decision guideline. The overall decision would be “screen out”. Note that when conducting indoor air sampling for residential buildings, more than one round of sampling is generally recommended to account for seasonal variations (see Section 4.3.2 of this guidance).



Appendix D: Example of a Decision Matrix Expressed in Terms of Concentration

- Tetrachloroethylene (PCE) in groundwater
- Commercial Scenario, slab on grade foundation
- Groundwater temperature = 20°C
- Groundwater depth = 20 feet, fine soil type (use attenuation factor = 0.0005)
- No vapor source in the vadose zone, no preferential pathways
- PCE groundwater concentrations presented are the lower based on CR=1E-6 or HQ=0.1, CR=1E-5 or HQ=1, and CR=1E-4 or HQ=3. In all cases, the HQ-based concentrations control (are the lowest of the two) for this example.

		Lower Risk	Higher Risk	
		62.5 ug/L (HQ=0.1)	625 ug/L (HQ=1)	1,880 ug/L (HQ=3)
Decision Guidelines	PCE GW Conc.	screen out ¹	screen in ²	screen in / higher priority for assessment ³

Notes:

1. **screen out**: No further assessment of the pathway is necessary based on the VISL Calculator input parameters. Consider observed / expected groundwater concentration trends when making a screen out determination.
2. **screen in**: Further assessment of the pathway is recommended. Consider refinement of VISL Calculator input parameters or additional media sampling (e.g., soil gas).
3. **screen in / higher priority for assessment**: Further assessment of the pathway is recommended. Consider refinement of VISL Calculator input parameters or additional media sampling (e.g., soil gas). Consider prioritizing assessment where potential risks exceed CR=1E-4 or HI=3 based on appropriate VISL Calculator input parameters.

Appendix E: Common Analytical Methods for Vapor Intrusion Investigations

Category	Sample Type	Method	Approach	Comments
Individual VOCs	Indoor air or soil vapor	USEPA Method TO-15 (full-scan)	Canister sample analyzed by GC/MS	Method lists about 40 analytes but most labs have an extended list
	Indoor air	USEPA Method TO-15 (SIM)	Canister sample analyzed by GC/MS. Canister requires specialized cleaning and individual certification	Selective ion mode (SIM) has very low detection limits. Not suitable for soil vapor samples.
	Indoor air	USEPA Method TO-17	Sorbent sampler analyzed by GC/MS	Examples of samplers include Radiello, WMS
Individual VOCs and SVOCs	Soil vapor	USEPA Method TO-17	Solid adsorbent tube sample analyzed by GC/MS	Provides data for naphthalene and heavier hydrocarbons in addition to VOCs
Hydrocarbon Fractions	Indoor Air or soil vapor	USEPA Method TO-3	Canister sample analyzed by GC-FID	Total non-methane hydrocarbons (TNMHC) in sample
		USEPA Method TO-12		
		Modified USEPA Method TO-15	Canister sample analyzed by GC/MS for TPH-g	Sum of individual hydrocarbon values
		Modified USEPA Method TO-15 or Massachusetts APH Method	Canister sample analyzed by GC/MS for various hydrocarbon fractions	Sum of instrument response for aliphatic and aromatic fractions (e.g., >C ₆ -C ₈ , >C ₈ -C ₁₀ , >C ₁₀ -C ₁₂)
Fixed Gases	Soil vapor	ASTM D1945	Canister sample analyzed by GC-FID	Typically used for oxygen (O ₂), carbon dioxide (CO ₂), and methane (CH ₄). Can also be used for helium and ethane (C ₂). D1945 has additional light hydrocarbons (C ₃ -C ₅) on the compound list.
		ASTM D1946		