STATE OF DELAWARE

Vapor Intrusion Pathway Guidance

DNREC Division-Wide Investigation, Risk Determination Guidance for Vapor Intrusion

Final
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List of Acronyms

AST- Aboveground Storage Tank

ASTM- American Society for Testing and Materials

COC- Chemical of Concern

COC^{2}- Contaminant of Concern

COPCs- Contaminants of Potential Concern

CSM- Conceptual Site Model

DERBCAP- Delaware Risk-Based Corrective Action Program

EC- Environmental Covenant

EPC- Exposure Point Concentration

FID- Flame Ionization Detector

FPRA- Final Plan of Remedial Action

HHRA- Human Health Risk Assessment

HSCA- Hazardous Substance Cleanup Act

HI- Hazard Index

IDLH- Immediately Dangerous to Life or Health

ITRC- Interstate Technology and Regulatory Council

J&E Model- Johnson & Ettinger Model

LNAPL- Light Non-Aqueous Phase Liquid

LCSM- LNAPL Conceptual Site Model

LTM- Long-Term Monitoring

LTS- Long-Term Stewardship

MLE- Multiple Lines of Evidence

MOC- Maximum Observed Concentration

MPG- Manufactured Petroleum Gas

NAPL- Non-Aqueous Phase Liquid

NJDEP- New Jersey Department of Environmental Protection

PEL- Permissible Exposure Limits

PID- Photoionization Detector

PVI- Petroleum Vapor Intrusion

QA/QC- Quality Assurance/Quality Control

RACR- Remedial Action Completion Report

SSD- Sub-Slab Depressurization

UST- Underground Storage Tank

VI- Vapor Intrusion

VISL- Vapor Intrusion Screening Level Calculator

Definitions

Acute Exposure - Exposure to a chemical or situation for a short period of time (EPA 2007).

Aesthetic Impact- An occurrence of Chemicals of Concern (COC)/Contaminant of Concern (COC^2) at a point of exposure, which is not a potential risk to human health, but may necessitate corrective action because of objectionable odors, taste, vapors, or appearance.

Ambient Air (aka Outside Air)- The terms ambient and outside air are used interchangeably. It refers to the location where air samples are collected.

Chemicals of Potential Concern (COPC) - Chemicals that are potentially site-related and whose data are of sufficient quality for use in the quantitative risk assessment (EPA Risk Assessment Guidance for Superfund, Vol. I Part A, 1989) used in 7 Del.C. Chapter 91.

Chemicals of Concern (COC) – Specific chemical or constituent that is identified for evaluation in the risk assessment process. COCs may include products or constituents of products released to soil and/or groundwater used in 7 Del. C. §74 DE Admin. Code 1351, *Regulations Governing Underground Storage Tank Systems* (the UST Regulations) and 7 Del. C., §74A 7 DE Admin. Code 1352 (*Regulations Governing Aboveground Storage Tank Systems)*.

Contaminants of Concern (COC[2]) Chemicals or contaminants determined to be present at the site in sufficient concentrations to present a health risk (HSCA Guidance 1994) used in 7 Del. C. §74 DE Admin. Code 1351, Regulations Governing Underground Storage Tank Systems.

Exposure Pathway**-** An exposure pathway is one of three risk elements. The pathway provides the route for an exposure. The exposure pathway is the course or route COC/COC[2] take from a contaminant source(s) to a receptor. An exposure pathway describes a unique mechanism by which an individual or population is exposed to COC/COC[2]. Each exposure pathway includes: a source or release from a source; an exposure route; and, a point of exposure. If the exposure point is at a different location from the source, a transport/exposure media (e.g., groundwater) is included. Exposure pathways involve transport of contamination through exposure media (air, groundwater, vapor, and soil) to a receptor.

Exposure Point Concentrations (EPCs)-See the *Guidance for Human Health Assessments (HHRA) under the Hazardous Substance Cleanup Act (HSCA)* for additional details. For vapor intrusion risk, the maximum observed concentration (MOC) in air samples is typically used to represent the EPC.

Hazard Index (HI)- The sum of hazard quotients for toxics that affect the same target organ or organ system. A hazard index (HI) of 1 or lower means toxics are unlikely to cause adverse noncancer health effects over a lifetime of exposure. However, an HI greater than 1 doesn't necessarily mean adverse effects are likely. The more details on this definition can be found at https://www.epa.gov/national-air-toxics-assessment/nata-glossary-terms#hq

Hazard Quotient (HQ)- The ratio of the potential exposure to a substance and the level at which no adverse effects are expected (calculated as the exposure divided by the appropriate chronic or acute value). A hazard quotient of 1 or lower means adverse noncancer effects are unlikely, and thus can be considered to have negligible hazard. For HQs greater than 1, the potential for adverse effects increases, but we do not know by how much. The more details on this definition can be found at https://www.epa.gov/national-air-toxics-assessment/nata-glossary-terms#hq

Human Health Risk Assessment- The analysis of the potential for adverse human health effects caused by contamination. See the DNREC July 2020 or most recent version of the Human Health Risk Assessment Guidance for additional details.

LNAPL**-** Light Non-Aqueous Phase Liquid having a specific gravity less than one and composed of one or more organic compounds that are immiscible or sparingly soluble in water. The term encompasses all potential occurrences of LNAPL including free, mobile, and residual.

- "Mobile LNAPL" means LNAPL that is hydraulically connected in the pore space, exceeds residual saturation, and has the potential to migrate vertically and/or laterally.
- "LNAPL Body" means the 3- dimensional form and distribution of LNAPL in the subsurface existing in any phase.
- "LNAPL Conceptual Site Model" or "LCSM" means a model describing the physical properties, chemical composition, occurrence, and geologic setting of the LNAPL Body from which estimates of flux, risk, and potential Remedial Action can be generated. The

LCSM may be a dynamic, living model that changes through time as a function of natural attenuation or engineered Remedial Action processes, or additional site knowledge.

- "Migrating LNAPL" means Mobile LNAPL that is moving laterally and/or vertically in the environment under prevailing hydraulic conditions. (The result of the LNAPL movement is a net mass flux from one point to another. Not all Mobile LNAPL is Migrating, but all Migrating LNAPL must be Mobile LNAPL.
- "Residual LNAPL" means LNAPL that is hydraulically discontinuous and immobile under prevailing conditions. Residual LNAPL cannot move but is a source for COCs dissolved in groundwater or in the vapor phase in soil gas. Residual LNAPL saturation is a function of the initial or maximum LNAPL saturation and the porous medium.

Multiple Lines of Evidence- All of the data sources including but not limited to groundwater, soil gas, sub-slab soil gas, indoor air, and ambient (outdoor) air, and other factors should be weighed against each other to determine if a complete pathway from the source to indoor air exists.

Preferential Pathway- An increased component of soil gas flow into a building due to natural conditions (e.g. gravel, etc.) or manmade conditions (e.g. utility corridors, sumps, drains, pits or elevator shafts, etc.)

PVI- Petroleum Vapor Intrusion occurs when vapor-phase contaminants migrate from subsurface sources into buildings. One type of vapor intrusion is PVI, in which vapors from petroleum hydrocarbons such as gasoline, diesel, or jet fuel enter a building. The intrusion of contaminant vapors into indoor spaces is of concern due to potential threats to safety (e.g., explosive concentrations of petroleum vapors or methane) and possible adverse health effects from inhalation exposure to toxic chemicals.

Remedial Action - The containment, contaminant mass or toxicity reduction, isolation, treatment, removal, cleanup, or monitoring of hazardous substances released into the environment, or the taking of such other actions as may be necessary to prevent, minimize, or mitigate harm, or risk of harm to the public health, welfare, or the environment which may result from a release or an imminent threat of a release of hazardous substances (HSCA Regulations).

Vapor Intrusion (VI)- is the migration of volatile chemicals from the subsurface into overlying buildings. Volatile chemicals may include volatile organic compounds (VOCs), select semi-volatile organic compounds (SVOCs), and some inorganic analytes such as mercury and hydrogen sulfide. Methane should be considered where it is appropriate (ITRC 2007).

1.0 Purpose

The Delaware Department of Natural Resources and Environmental Control, Division of Waste & Hazardous Substances (DNREC-DWHS) adopts this guidance to provide consistency in the evaluation of vapor intrusion risk from investigation to remediation. Any variations from this Guidance should be approved in writing by DNREC-RS prior to implementation.

The General Assembly of the State of Delaware enacted the Hazardous Substance Cleanup Act (HSCA), (7 Del. C. Ch.91) in 1990 to eliminate or minimize the risk to public health, welfare, and the environment from the release of hazardous substances. In addition, corrective actions for the release of petroleum related substances are regulated under 7 Del. C. Chapter 60, 7 Del. C. Chapter 74, and DE Admin. Code 1351, State of Delaware *Regulations Governing Underground Storage Tank Systems* (the UST Regulations) and 7 Del. C., Chapter 74A and Delaware's *Regulations Governing Aboveground Storage Tank Systems*. This Guidance document is also intended to be guidance for federal Resource Conservation and Recovery Act (RCRA) facilities in Delaware that treat, store or dispose of hazardous wastes. These facilities are regulated under 7 Del. C. Chapter 60, 7 Del. C. Chapter 63, and DE Admin. Code 1302, State of Delaware *Regulations Governing Hazardous Waste*).

Follow petroleum investigation steps when dealing with a site where **only** petroleum chemicals of concern (COCs) are identified. With DNREC authorization, these steps may be followed at Chapter 91 Sites where **only** petroleum releases have been identified. See Step 2A

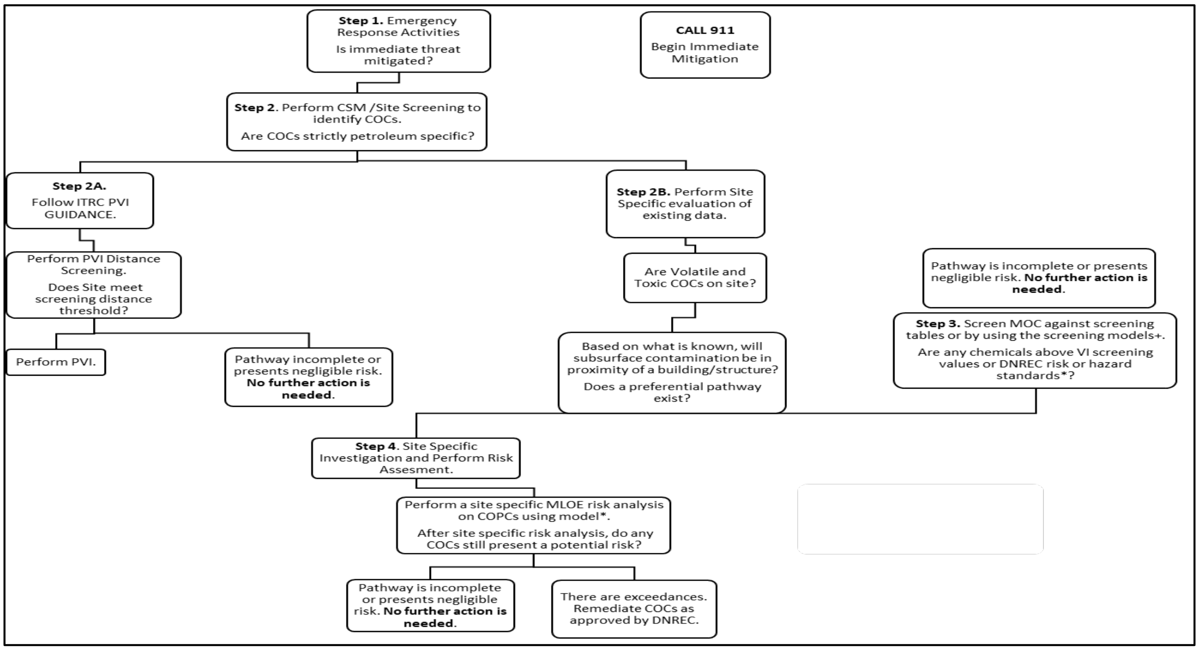
HSCA provided authority to the Department of Natural Resources and Environmental Control (DNREC) to enforce the provisions of HSCA. Media-specific descriptions for the general risk levels used to determine the need for cleanup were specified in the regulations as a cancer risk of 1×10^{-5} or a Hazard Index (HI) value of 1.0 for non-cancer risk.

This Guidance document will:

- Identify VI as a pathway by which humans may be exposed to dangerous levels of toxic vapors.
- Provide a clear pathway to evaluate petroleum vapor and chlorinated solvent vapors or other vapors and evaluate against screening levels.
- Determine when a VI investigation should be conducted.
- Provide procedures which serve to evaluate the VI risk.
- Evaluate remedial option(s).
- Guide Long-Term Stewardship (LTS) Plan development.

The process to determine if a VI risk exists and consider remedial options is detailed in the Sections below. Please follow Steps 1 through 4 as neccesary to evaluate VI. The general process is outlined in the Process Flow Chart in Figure 1 and also found in Appendix I.

Figure 1: VI Process Flow Chart. Larger version found in Appendix I.



2.0 Step 1. Initial Evaluation-Emergency Response Activities

Evaluate if potential acute exposure vapor conditions exist at the Site that require emergency response. Emergency conditions exist if any one of the following is present:

- Odor that may indicate the presence of a hazardous material
- High vapor concentrations (aka acute exposure) of a hazardous material exceeding (OSHA Permissible Exposure Limits (PELs) or Immediately Dangerous to Life or Health (IDLH) levels are being exceeded)
- Explosive levels are present as indicated by a meter
- Physiological effects of vapor intrusion
- Presence of non-aqueous phase liquids (NAPL) in a basement inside a home
- Any other hazardous condition which requires immediate response.

Contact 911 and DNREC Emergency Response Section (DNREC-ERS) at **1-800-662-8802** and take immediate remedial actions as directed by these agencies.

After contacting 911 and DNREC-ERS, DNREC will contact Delaware Department of Health and Social Services (DHSS) for any further coordination that may be required.

For currently operating Sites/facilities, DNREC will follow the USEPA June 2015 OSWER Vapor Intrusion Guidance Section 7.4.3 (EPA 2015). The Guidance states that EPA does not recommend using Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) or Threshold Limit Values (TLVs) for the purposes of assessing human health risk posed to workers from vapor intrusion but recommends following standard EPA risk assessment risk limits.

3.0 Step 2. Site Screening to Identify COCs

3.1 Step 2A-Petroleum Specific COCs

Follow these steps when dealing with a site where only petroleum COCs under 7 Del. C. §74 DE Admin. Code 1351, *Regulations Governing Underground Storage Tank Systems* (the UST Regulations) and 7 Del. C., §74A 7 DE Admin. Code 1352 (*Regulations Governing Aboveground Storage Tank Systems* are identified. This Step may be followed at Chapter 91 Sites where **only** petroleum releases have been identified in conjunction with DNREC authorization. Note that Step 2A evaluation is conducted under current conditions, and in the event of redevelopment DNREC may require practitioners to jump to Step 2B to evaluate risks associated with future use. If the contaminants include non-petroleum related COCs[2] covered under Chapter 91, please refer to Step 2B (Section 4.0).

Petroleum vapors emanating from contaminated soil or groundwater that enter buildings may result in indoor air concentrations that pose a risk to occupants. Accumulated vapors may pose an immediate risk of fire or explosion and may create adverse health effects from inhalation of toxic chemicals. Adequate ventilation is a short-term step to provide immediate relief and may be part of an engineered long-term solution.

The first step in evaluating petroleum vapor intrusion at a Site involves utilizing lateral and vertical screening distances (Appendix I). LNAPL release volumes and plume extents may not always correlate with the site type; therefore, a robust conceptual site model (CSM) and professional judgment are needed to select the most appropriate LNAPL vertical screening distance.

The preliminary CSM is developed by collecting soil and groundwater data as part of routine site investigations in accordance with the Delaware Risk Based Corrective Program (DERBCAP) for petroleum facilities. The CSM necessary for PVI screening has the following minimum components:

- site type
- petroleum vapor source (aka subsurface contamination)
- extent of source
- lateral inclusion zone
- vertical separation distance
- precluding factors- preferential pathways (natural and anthropogenic), expanding or advances plumes, fuel types, and soil types

3.2 Petroleum Vapor Source

Source identification can be challenging at locations where LNAPL is present as a residual-phase source in soil or groundwater. LNAPL may not be readily apparent unless there is measurable thickness of LNAPL in a nearby groundwater monitoring well. In these cases, a multiple-lines-of-evidence (MLE) approach may be used for LNAPL identification. The LNAPL indicator criteria and parameter ranges are values reported in the literature (ITRC 2009 a, 2009 b, 2018, 2021). Measurable petroleum hydrocarbon concentrations in groundwater, less than those indicative of LNAPL, are consistent with a dissolved-phase petroleum vapor source. Petroleum hydrocarbon concentrations in soil or groundwater can vary widely depending on the LNAPL type (e.g., gasoline, diesel, jet fuel, etc.) and the degree of weathering.

3.3 Extent of Source

Proper delineation of the petroleum vapor source in soil or groundwater is critical in determining which buildings are within the lateral inclusion zone and the vertical separation distance. There is a higher probability of encountering LNAPL in the vadose zone near and below former or current underground storage tank and above ground storage tank equipment, in known or suspected release areas, along perching lens or low-permeability soil layers, or in a smear zone near the water table. The LNAPL smear zone may extend well above the water table at some sites with large (several feet) water-table fluctuations. Soil sampling and soil screening using a photoionization detector (PID) or flame ionization detector (FID) are recommended for delineating vadose zone sources. For dissolved-phase sources, the edge of the plume should be defined according to the DERBCAP for petroleum sites.

3.4 Utilities in LNAPL Zones

There is a significantly greater risk of PVI from utilities located within LNAPL zones than there is with dissolved phase groundwater plumes. Utilities may create preferential pathways. For more information on investigating preferential pathways, please see Step 4. Site-specific Investigations.

3.5 Evaluate Buildings Vertical screening distances can only be applied in the absence of any precluding factors identified in the preliminary CSM. If precluding factors (natural and anthropogenic, preferential pathways, expanding or advances plumes, fuel types, and soil types, etc.) are present, then further site investigation is necessary. If no precluding factors are present, then determine whether the edge of the building foundation is within the lateral inclusion zone that extends 30 feet from the edge of the petroleum vapor source. If the building is located within the lateral inclusion zone, then vertical screening distances can be applied. Buildings located outside of the lateral inclusion zone require no further PVI evaluation.

3.6 Vertical Separation Distance

The vertical separation distance is measured from the top of the petroleum vapor source to the bottom of the building foundation for each building located within the lateral inclusion zone. Seasonal and long-term fluctuations in groundwater levels should be considered when determining the depth to the LNAPL smear zone or dissolved phase source. Seasonal fluctuations can include tidal fluctuations. A consideration of current and historical land use is recommended for buildings located in the lateral inclusion zone in order to assess the potential for additional (secondary) sources that are not associated with the primary release under investigation. Vertical separation distance should be determined from the top of the source closest to the building foundation where these additional (secondary) sources are identified.

3.7 Lateral Inclusion Zone and Structures

The lateral inclusion zone is defined as the area from the edge of the petroleum vapor source (as determined by the conceptual site model) to the edge of a building foundation. The lateral inclusion zone is used to determine whether a building is close enough to the lateral edge of a petroleum vapor source to be considered for PVI screening.

A 30-foot lateral inclusion distance may be considered as a conservative evaluation to account for uncertainty when direct measurements are not available. If a high degree of confidence exists in the delineation of the lateral edge of the source, it may be appropriate to use the applicable vertical screening distance to define the lateral inclusion zone.

3.8 Vertical Separation Distance Screening

Several empirical studies have defined vertical screening distances for LNAPL and dissolved-phase sources. As previously noted, there is more uncertainty with industrial sites because of the relatively small data set of industrial sites in the empirical study (ITRC Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management (PVI-1, 2014)). Although the values derived for dissolved-phase and LNAPL sources vary slightly among the studies, they can be conservatively defined as:

- 5 feet: dissolved-phase sources
- 15 feet: LNAPL sources
  - Petroleum UST/AST sites generally include facilities used for vehicle fueling (such as gas stations, municipal fleet yards, bus terminals, and fire stations) and commercial/home heating oil tanks. Fuel at these sites is typically stored in USTs but could be stored in similarly sized ASTs.
- 18 feet: LNAPL sources (petroleum industrial sites)
  - Petroleum industrial sites include: (a) bulk fuel terminals; (b) refineries; (c) exploration and production sites; (d) crude oil and product pipelines; and (e) former manufactured petroleum gas plants (MPGs)¸ sources at fuel terminals, refineries, petrochemical (non-UST) sites and any sites not covered by the 15 feet rule.

Determine whether the vertical separation distance between the top of the petroleum vapor source and the bottom of the building foundation exceeds these vertical screening distances.. If so, then no further evaluation of the PVI pathway is necessary. If the location fails the vertical separation distance evaluation, then further site investigation or vapor control and corrective actions are necessary. To evaluate the site COCs see Step 3 of this document, and for site-specific investigation and remedial methods see Step 4.

For additional information and remedial design regarding petroleum specific impacts, refer to the ITRC Petroleum Vapor Intrusion Guidance (Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management (PVI-1, 2014)) and the EPA Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites (EPA 510-R-15-001) https://www.epa.gov/sites/default/files/2015-06/documents/pvi-guide-final-6-10-15.pdf.

4.0 Step 2B-Site-Specific Evaluation of Existing Data

This step is primarily for the evaluation of non-petroleum constituents. However, if there are mixed groundwater plumes [petroleum COCs and/or non-petroleum COPCs (example chlorinated solvents, etc.)], the evaluation should continue with Step 2B. Practitioners may need to follow Step 2B in cases where petroleum compounds are the only COCs but there is a significant change to the petroleum CSM including but not limited to a change from a slab on grade construction to a basement or the proposed site redevelopment will result in a change in use. This determination will be on a case-by-case basis and at DNREC's discretion. The primary goal of Step 2B is to address the following based on existing data:

First, Are volatile and toxic COPCs present on the site?
Second, Is (or will there be) a vapor source in proximity (within approximately 100') to a building/structure?
Third, Do preferential pathway(s) exist?

In the event the answer to any of these questions is 'No,' then the pathway is incomplete or presents negligible risk. As a result, no further action is required. If the answer is 'Yes' for all three questions, then proceed to Step 3. In this step, it is important to determine if the data is of sufficient quality and quantity to determine if vapor intrusion could present a risk. For instance, if only one soil sample has volatile organic chemicals, there is not enough sample population to determine if an unacceptable risk exists at the Site. Further information on answering these questions can be found below.

4.1 Identify if the known contaminants are volatile and toxic.

Screen the list of chemicals of potential concern (COPC) in groundwater against the list of volatile compounds, (listed as "V" in the "Vol" Column) in the most-recent HSCA Screening Level Table. If the COPCs are not identified as Volatile on the HSCA Screening Table, then the site conditions do not pose a risk for vapor intrusion.

4.2 Building and/or Preferential Pathway Location

Are there any current or future buildings within 100 feet of the contamination (groundwater or soil vapor)? Are there any preferential pathways near the contamination which may present a potential risk? Please see Step 4. Site Specific Investigation for information on preferential pathway determination. If no development plan is provided by Site developers, then DNREC will assume residential use within 100 feet of the contamination and continue the screening process. Re-evaluation of VI risk is required when new data or new development plans are provided.

5.0 Step 3. Screen Maximum Observed Concentration (MOC) Against Screening Table

The MOC should be screened against the HSCA Screening Table or models. The values in the screening table are set to a cancer risk of $1X10^{-6}$ and a hazard index of 0.1. If the MOCs are below these values then the risk is negligible, and no further evaluation of risk is required.

5.1 EPA Vapor Intrusion Screening Level (VISL) Calculator

As of the date this guidance is issued, the MOC can also be screened using the VISL or the current Johnson and Ettinger (J&E) Model with updated toxicity values. Other models will be considered on a Site-by-Site basis. The current versions (as of the date of this guidance) of the VISL (web-based) and J&E model (Version 6.0) can be found at https://www.epa.gov/vaporintrusion. Consultants are responsible for ensuring that they are using the most up to date version of the software.

VISL Calculator can be used with groundwater or air data. The MOC of each COPC/COC[2] should be used as the media concentrations in the VISL calculator. For more details on screening and action levels for cancer and non-cancer toxicity, please review DNREC- RS Guidance for Human Health Risk Assessments (HHRA) (DNREC 2020).

If using Groundwater data, then the following non-cancer toxicity, or Hazard Index (HI), and cancer toxicity, or Target Risk, values should be selected. Target risks noted in this Guidance for cancer and HI are cumulative. For more details on cumulative risk, please see Section 6.2 and refer to the HHRA (DNREC 2020).

-Hazard Index=0.1
-Target Risk=10^{-6}

If using Soil gas/Sub-slab/Ambient Air, then select the following:
-Hazard Index=1
-Target Risk=10^{-5}

The VISL Calculator has two exposure scenario options: residential or commercial. Select 'Yes' for "predict indoor air concentrations, and risk, from measured media concentrations," will allow the user to enter site-specific media contaminant concentrations. The appropriate media should then be selected. Besides selecting individual contaminants and inputting the MOC of each COPC/COC[2], no other parameters should be changed without prior written approval from DNREC. Please also select to include all Metadata in the VISL Calculator outputs. If the MOCs are below these values then the risk is negligible, and the evaluation of risk should stop.

5.2 Johnson and Ettinger (J&E) Model

The J&E model uses either groundwater or soil gas data to model vapor migration into buildings. For details on how to use the model, please review "Documentation for EPA'S Implementation of the Johnson and Ettinger Model to Evaluate Site Specific Vapor Intrusion Into Buildings, Version 6.0" or EPA's most current version.

Either groundwater data or the soil gas data can be used for screening. Soil data should not be used as it does not represent soil gas conditions. Generally, as a conservative measure, e.g., MOCs should be used.

The J&E model cannot be used when any of the following conditions are/will be present (EPA 2017):

- Free product is suspected or confirmed.
- Contaminated groundwater sites with large fluctuations in the water table elevation.
- A preferential pathway exists.
- Building foundation is in contact with groundwater
- There are significant openings to the sub-surface including large cracks or sumps. The model will work with an earthen floor or crawlspaces.
- Very small building air exchange rates (e.g., <0.25/hour)
- Very shallow vapor sources (e.g., depths less than 5 ft below foundation level); the model can be used at depth less than 5 feet under the conditions noted in the 2021 NJDEP Vapor Intrusion Technical Guidance Section G.2.1.3.

If the groundwater to indoor air results exceeds cancer risk of $1x\ 10^{-6}$ or hazard index (HI) of 0.1 then proceed to Step 4. If the soil gas to indoor air exceeds a cancer risk of $1x\ 10^{-5}$ or hazard index (HI) of 1 then proceed to Step 4. DNREC may require additional sampling or evaluation if the risk is close to the action level to confirm that risk levels are acceptable. If it does not exceed, then an unacceptable risk does not exist and no further action is required.

6.0 Step 4. Site-Specific Investigation and Risk Assessment

6.1 Site-Specific Investigation

The strategy and goal(s) of the investigation will depend on current and potential future use of the Site.

Details on the sampling procedures and requirements can be found in the DNREC Standard Operating Procedures (SOPs) for Active Soil Gas, Sub-Slab and Indoor Air Sampling on DNREC's website. In addition, please refer to the most appropriate guidance on conducting Remedial Investigations (RI). For petroleum investigation guidance, please see the DERBCAP guidance.

If potential sources of vapor intrusion are known to be present, a VI investigation should be part of the Sampling and Analysis Plan (SAP), which must be submitted and approved by DNREC prior to sample collection.

There may be situations where vapor intrusion sources are discovered after the SAP has been developed such as during the environmental investigation or during redevelopment. In these cases, the CSM should be updated and a revised SAP with additional VI investigations should be submitted to DNREC and investigations conducted after DNREC approves the SAP.

Indoor air samples should not be collected after major building renovations unless a baseline sampling event has occurred previously. The reason is that many products used in the renovation process including caulking, paints, cleaning products, etc. are known to contain VOCs, which could skew the results and lead to a false conclusion of vapor intrusion. The baseline would document any chemical vapors likely to be from a sub-surface source. Renovated buildings that have had a baseline should be aired out at a minimum of 24-hours before indoor air sampling is conducted to allow some of the chemicals used in the renovation to off-gas. Any chemicals stored in the building should be either removed or sealed to prevent indoor air sources from skewing the results.

The previous strategy for VI was a stepwise progression from the source area to the potential receptor. There are a number of reasons why this approach to VI is not considered to be sufficient. In addition to being slower to implement, this strategy does not provide a comprehensive view of the conditions along the exposure pathway.

VI can be influenced by several factors including temperature, rainfall, and barometric pressure. These factors change seasonally, daily, and sometimes hourly. The goal is to collect all the necessary samples at the same time to capture a single snapshot of conditions. For this reason, VI investigations should include the following samples collected during the same day or as close to the same day as possible. The best time to collect air samples may be during strong winds or prior to storms as these would be most representative of the worst-case scenario. Please see the discussion on stack effects in the text below.

-Soil gas samples at the source area
-Soil gas samples along the potential pathway to the receptor
-Sub-slab soil gas samples,
-Indoor air and outdoor air (ambient air)

It will also be important to document temperature conditions, indoor and outdoor pressure, and general weather conditions. With regard to soil gas samples collected at the source area; it is anticipated that the sample will be collected no shallower than one to two feet above the source. For example, when the source is in or on the groundwater, the sample should be collected within one to two feet above the water table. This allows for evaluation of the worst-case scenario.

In situations where groundwater is at or less than 3 feet deep, it may be difficult to install an active soil gas vapor point according to the Active Soil Gas standard operating procedures (SOPs) without short-circuiting occurring or introducing groundwater into the air samples. Both conditions would invalidate the sample. The SOPs require that vapor point screens be constructed a minimum distance of 3 feet below the ground surface. Short-circuiting occurs when surface air enters the vapor point due to shallow conditions or incorrect vapor point construction. Please refer to the Active Soil Gas SOPs for more details.

In the situation noted above where groundwater is demonstrated to be less than 3 feet below ground surface and the consultant has been unsuccessful in collecting/installing soil gas points, DNREC will allow groundwater data modeled through the current J&E model to be used to calculate risk. DNREC will not require soil gas samples to be collected.

Shallower samples may be used on a site-by-site basis with prior written DNREC approval. In addition, soil gas samples should be collected at the depth of anticipated utility corridors. These corridors can provide a preferential pathway to an occupied building.

The VI investigation should be conducted as a Multiple Lines of Evidence (MLE) approach, where as many different pieces or lines of evidence are collected and compiled together such that a determination can be made that the vapor pathway is complete or not complete. The sampler has to consider if they have enough information for each line of evidence to make a determination concerning the pathway. For the air sampling, the sampler should consider if they have sufficient number and location for each type of air sample (soil gas, sub-slab, indoor air, and outdoor air) to determine if those samples support a determination that a pathway does or does not exist.

If preferential pathways are determined to exist, these need to be included in the field investigation. Preferential pathways should be considered whenever an existing utility may pass through contaminated groundwater. In a number of states, sewer lines have been demonstrated to be significant pathways for VI into buildings. A number of states have developed guidance to investigate sewer lines and other preferential pathways including Wisconsin Department of Natural Resources (Wisconsin 2021). A complete description of how to conduct the preferential pathway investigation is beyond the scope of this document. Please review the Wisconsin guidance document noted above for information on how to investigate preferential pathways.

Prior to sampling, conduct a detailed survey of the interior of the building and remove or otherwise isolate any VOC containing products. Many commercially available items contain VOCs at levels sufficient to cause a background issue. It must be determined if the source is from household products or from the subsurface. To assist with this assessment, building survey forms may be found in the attachments of the SOPs. Depending on Site conditions, it may be necessary to use a portable gas chromatograph/mass spectrometer (GC/MS) to identify sources to be removed and/or identify significant pathways for vapor into the building that need to be sealed.

During evaluation of a pathway, sub-slab soil gas and indoor air samples should be paired and co-located to create collective picture of assessment. The indoor air sample should be collected at the breathing zone for an adult typically 3-5 feet above the floor. Depending on the number of samples, it may not be necessary to have a paired sample for each location.

A 24-hour air sample is required for indoor, outdoor, and sub-slab samples to evaluate risk and assess data variability in all site use scenarios (commercial or residential). A soil gas sample may be collected for 30-minute sample duration. Length of sample time may depend on site-specific conditions.

If no building is present, but the location and/or footprint of the building is known, soil gas samples can be collected based on the proposed footprint of the building and used in lieu of sub-slab samples. If the size and/or location is unknown, DNREC will allow soil gas samples to be collected above the source area as if the building were going to be built over the source area to simulate a worse-case scenario.

During the winter when heating systems are in use and/or strong winds are blowing over the top of a house's chimney/commercial building roof, these cause a reduction of the internal air pressure and create a vacuum effect that enhances advective flow from underlying soils and/or groundwater into buildings (ITRC 2007). This is known as the stack effect. For this reason, collecting sub-slab samples and indoor air during the winter is generally considered to be representative of the worse-case scenario for VI into buildings. However, at DNREC's discretion several rounds of air samples may be required to determine if there is a VI risk.

For residential buildings, the minimum number of sub-slab vapor points is four (4). For larger residential buildings or commercial structures, please see Table 1 (NJDEP, 2021). Table 1 is intended to act as a guide to selecting the number of samples. The number of samples may be more or less depending on Site specific conditions as noted in the text below. The number of samples for indoor air may also depend on the use of the interior of the building as a reflection of risk scenarios or the presence of sensitive receptors such as children in a daycare. For instance, a building exclusively operating as a storage facility may not require as many samples as a building which has a daycare, office space, gym, and a warehouse even through the square footage is the same for both buildings.

For multiple story buildings, it may be necessary to collect indoor air samples on the upper floors (above the 1st floor) if the 1st floor indoor air samples indicate a vapor intrusion risk above standards. As detailed in the HHRA, for buildings with retail/commercial on the first floor and residents on the upper floors, DNREC requires the building to pass residential standards on all floors or a remedy is required (DNREC, 2020).

Table 1

Square Footage of Building/Proposed Building	Recommended Number of Soil Gas/Sub-Slab Soil Gas or Indoor Air Samples
1,500	1-2
1,501 to 5,000	2
5,001 to 10,000	3
10,001 to 20,000	4
20,001 to 50,000	5
50,001 to 250,000	6
250,001 to 1,000,000	7
>1,000,000	9+

6.2 Risk Assessment

Ideally, multiple types of air samples have been collected (e.g., soil gas, sub-slab soil gas, indoor air, and outdoor (ambient) air) simultaneously during the investigation. In these cases, risk should be calculated for soil gas, sub-slab soil gas, and indoor air.

The maximum concentration of a COPC for a media should be used as the Exposure Point Concentrations (EPCs) when calculating risk. DNREC may consider, other EPCs on a Site-by-Site basis, as appropriate, according to the Guidance for Human Health Risk Assessment (HHRA) under the Hazardous Substance Cleanup Act (HSCA).

The outdoor air results can be important to determine if potentially elevated indoor air results are due to sub-surface contamination or due to a regional/local air issues such as automobile exhaust. For example, if benzene is detected in the indoor air at 8 ug/m3 but the ambient air is detected at 13 ug/m3, the likely conclusion would be that the indoor air contamination is likely from outdoor air. However, it is possible that even if the contamination is found in both ambient (outdoor) air and subsurface air and/or indoor air that the cause is a subsurface source. In cases where this is possible, it is important to follow the multiple lines of evidence approach which is described in the paragraphs below.

Each line of evidence is weighed against the other lines of evidence. Although individual results may indicate a risk to the receptor, the weight of evidence may indicate that the pathway is incomplete. If the preponderance of evidence indicates that VI is occurring, then the COPCs are retained for further evaluation within the risk assessment. However, if the evidence does not indicate that VI is occurring, then these chemicals are screened out of the risk assessment process. See the HSCA Guidance for Human Health Assessments for additional details.

Example: Groundwater data is evaluated at a Site using the J&E Model and indicates a VI risk, indicating the 1st line of evidence. Soil gas data is also evaluated at the Site using the J&E Model and indicates a VI risk. This is a second line of evidence. The sub-slab soil gas data is evaluated at the Site using the J&E model and **does not** indicate a VI risk. This is the third line of evidence. The indoor air is compared to the EPA RSLs and **does not** indicate a VI Risk. This is the fourth line of evidence. A potential preferential pathway is sampled and **does not** indicate a VI Risk. This is a fifth line of evidence. Since two of the lines of evidence show a risk but three of lines show no risk, the weight of the evidence is that VI pathway is not complete and there is not a risk. Please note, the lines of evidence presented in this example are not the only possible lines of evidence that can be used at a Site.

However, just because a multiple line of evidence approach as demonstrated in the paragraph above indicates that VI is not currently occurring does not mean that the VI pathway will not have to be evaluated at a later date due to a change in building conditions, a change from commercial to residential use, or other site-specific conditions. For example, if there is a risk for VI from groundwater and soil gas and sub-slab soil gas but indoor air was below standards, DNREC may determine that additional sampling is required to demonstrate that this condition is present over a longer time period. This paragraph and the guidance document in general is not intended to document all scenarios where additional VI sampling may be required. DNREC will always evaluate VI conditions on a site-by-site basis.

Indoor air results are considered to be the most straight-forward (as compared to indoor air concentrations which must be extrapolated from groundwater or soil gas) and the best estimator of risk because people are directly breathing this air. However, if there is an indoor or outdoor air source of contamination, the interpretation of the risk results can be difficult. In this case, the sub-slab or soil gas (if sub-slab data is not available) is the best estimator of risk. In many cases, a relative comparison of the calculated risk from all the air samples will be the most useful to interpret the risk.

Evaluate the MOC soil gas and/or sub-slab risk to the Site with Site-specific information using the J&E model with updated toxicity values, VISL model, or other DNREC-approved models to determine risk.

Site-specific parameters should be used in the J&E model, and other models. These parameters may include slab thickness, indoor air exchange rates, building size, ceiling height, depth to groundwater, groundwater temperature, soil types, and updated toxicity values. DNREC will consider changing model parameters on a site-by-site basis with sufficient data and/or documentation to support the change. Risk should be calculated for both residential and commercial use unless deed restrictions prohibiting residential use are already present on the property.

DNREC requires site-specific input values, model name and version number, documentation, and model output documentation.

6.2.1 Evaluate the Risk Results

The evaluation of risk at a site should follow a MLE approach. All data sources, including but not limited to, concentrations and/or risk from groundwater, soil gas, sub-slab soil gas, indoor air, and ambient (outdoor) air should be weighed against each other to determine if a complete pathway from the source to indoor air exists. Although individual results may indicate a risk to the receptor, the weight of evidence may indicate that the pathway is incomplete. Please see the most recent version of the Guidance for HHRA for additional details. If the cumulative cancer risk using the MOC from sub-slab air sample results or indoor air sample results are below 1x 10^{-5} or HI of 1.0, risk is negligible. As noted in Section 4.1, groundwater to indoor air VI risk is evaluated at a cancer risk of 1x 10^{-6} and HI=0.1. No further action is needed. Once a COPC exceeds a risk level at this step, it is considered a COC.

If the cumulative cancer risk exceeds 1x 10^{-5} or HI of 1.0 risk then a remedial action is needed. Proceed to the Section below to evaluate the remedial options.

7.0 Evaluate the Remedial Options

There are several guidance documents that relate to vapor intrusion remedies. DNREC is developing a Feasibility Study Guidance related to remedy selection process. DNREC has also developed a Vapor Barrier Design Checklist (DNREC, 2021).

As noted in the 2015 OSWER Guide Section 3.3, EPA's preference is to directly address the source of the contamination rather than only address the vapors emanating from the source. As a result, when DNREC considers remedies for addressing vapor intrusion, preference will be given to the remedy that addresses both the source and vapor intrusion. Remedies that only address vapor intrusion will be considered partial remedies or interim actions.

There are a limited number of partial remedies to address vapor intrusion, which are listed below:

- Sub-slab Depressurization (SSD)
- Vapor Barrier with passive venting
- Vapor Barrier with active venting

Other remedial options may be considered on a case-by-case basis.

7.1 Vapor Intrusion Remedy Design

If it is determined a vapor barrier is needed, a completed Vapor Barrier Checklist with all appropriate documentation attached is required. The Checklist can be part of a Remedial Action Work Plan (RAWP) if other remedial actions are required. Please refer to the Vapor Barrier Checklist for additional details. An environmental covenant (EC) and long-term monitoring (LTM) should be considered as part of the remedy if a vapor barrier or SSD is the selected remedy.

A vapor barrier must consist of a barrier material and passive venting system (including but not limited to perforated piping under the slab and piping to the roof vents). The gas, or vapors, diffuses into the piping of the venting system and because of it being lighter than air, the gas rises out of the vent pipes to discharge above the roofline. Studies have shown that most vapor mitigation systems will not effectively prevent vapor intrusion without a venting system (ITRC, 2007). Passive venting will prevent vapors from collecting under the building. In addition, in the event that a passive venting system is deemed ineffective, a small fan or fans can be attached to change the system to an active venting system.

DNREC will determine whether a passive system is ineffective on a by case basis (generally when periodic indoor sampling results indicates a risk above $1*10^{-5}$ still exists in the building, even with passive venting).

Vapor barrier design will not be considered complete without a venting system. Air permitting requirements from the DNREC Division of Air Quality (DNREC-DAQ) are as follows:

- Less than 0.2 lbs/day-No permit
- 0.2 to 10lbs/day- Self permit
- 10 lbs/day-permit required

However, as regulations may change, please contact the DNREC-DAQ to confirm these standards are applicable and that permits will not be required. DNREC requires a letter or email from DNREC-DAQ approving the air permit or confirming no permit is required before DNREC-RS can approve the vapor barrier design. This information should be included with the Vapor Barrier Checklist.

The design for the vapor mitigation system must be approved by DNREC prior to installation. The design must be certified by a Delaware Professional Engineer or certified radon installer. DNREC will accept a material as being a vapor barrier, if it has been previously approved to be from certified manufacturer of vapor barriers. DNREC may also accept other materials as vapor barriers provided that they meet the criteria outlined in the most current Vapor Barrier Checklist.

7.2 Petroleum Specific COCs

If a Site has failed the vertical and horizontal screening distances, follow these steps under 7 Del. C. §74 DE Admin. Code 1351, *Regulations Governing Underground Storage Tank Systems* (the UST Regulations) and 7 Del. C., §74A 7 DE Admin. Code 1352 (*Regulations Governing Aboveground Storage Tank Systems.* You must submit a submit a Remedial Action work plan (RAWP) to the Department.

Petroleum specific sites often are restricted from using VI barrier as mitigation due to existing infrastructure and building foundations. The following are common methods of remediation at petroleum sites:

- Active and passive ventilation
- Fan venting
- Open air
- Depressurization systems
- Air monitoring
- Vapor sampling

8.0 Remedy Completion

8.1 HSCA Remedy Completion Documentation

Upon completion of the vapor barrier or other remedial actions as required in the Site's Final Plan of Remedial Action (FPRA); the consultant should submit a Remedial Action Completion Report (RACR). The RACR, should be completed in accordance with Section 12 of the Regulations and should include Site information, photos of the installation process, description, and documentation that all appropriate quality assurance/ quality control (QA/QC) tests were passed, and as-builts.

In order to protect the remedy, an EC for the Site should be recorded. The EC should include language that DNREC be contacted prior to any building renovation or demolition that may impact the vapor mitigation system(s). Any repairs to the VI remedy caused by the renovation (such as cutting through the floor) or demolition must be corrected immediately.

8.2 Petroleum Remedy Completion Documentation

When analytical results indicate residual contamination at the site poses no threat to human health and safety, or the environment, the site may be considered for no further action (NFA).

8.3 RCRA Remedy Completion Documentation

Upon completion of the vapor barrier or other remedial actions as required in the Site's Final Decision and Response to Comments (FDRTC), the consultant should submit a Corrective Measures Implementation (CMI) Report. The CMI should be completed in accordance with **Part 264 of** *Delaware's Regulations Governing Hazardous Waste* (DRGHW) and should include Site information, photos of the installation process, description, and documentation that all appropriate quality assurance/ quality control (QA/QC) tests were passed, and as-builts.

In order to protect the remedy, an EC for the Site should be recorded. The EC should include language that DNREC be contacted prior to any building renovation or demolition that may impact the vapor mitigation system(s). Any repairs to the VI remedy caused by the renovation (such as cutting through the floor) or demolition must be corrected immediately.

8.4 Long-Term Stewardship Plan

Since vapor barriers are continuously protecting human health, a Long-Term Stewardship (LTS) plan is required to ensure the long-term effectiveness and protectiveness to human health remains for the duration that the remedy needs to remain operational. The LTS plan should detail the type and frequency of periodic sampling to occur, remedial goals to be achieved, and the vapor barrier repair/maintenance process. If it has been demonstrated to DNREC's satisfaction that no risk is present, LTS may be discontinued with DNREC's written approval.

Please refer to ASTM Standard D8408-21, and ITRC Vapor Mitigation Guidance for more details on LTS plans.

9.0 REFERENCES

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ASTM E2856-13(2021), Standard Guide for Estimation of LNAPL Transmissivity, ASTM International, West Conshohocken, PA, 2021, www.astm.org

DNREC. June 2021. Vapor Barrier Design Checklist. https://documents.dnrec.delaware.gov/dwhs/remediation/Vapor-Barrier-Checklist.pdf

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ITRC. 2020. Vapor Mitigation Guidance. Washington, D.C.: Interstate Technology & Regulatory Council.

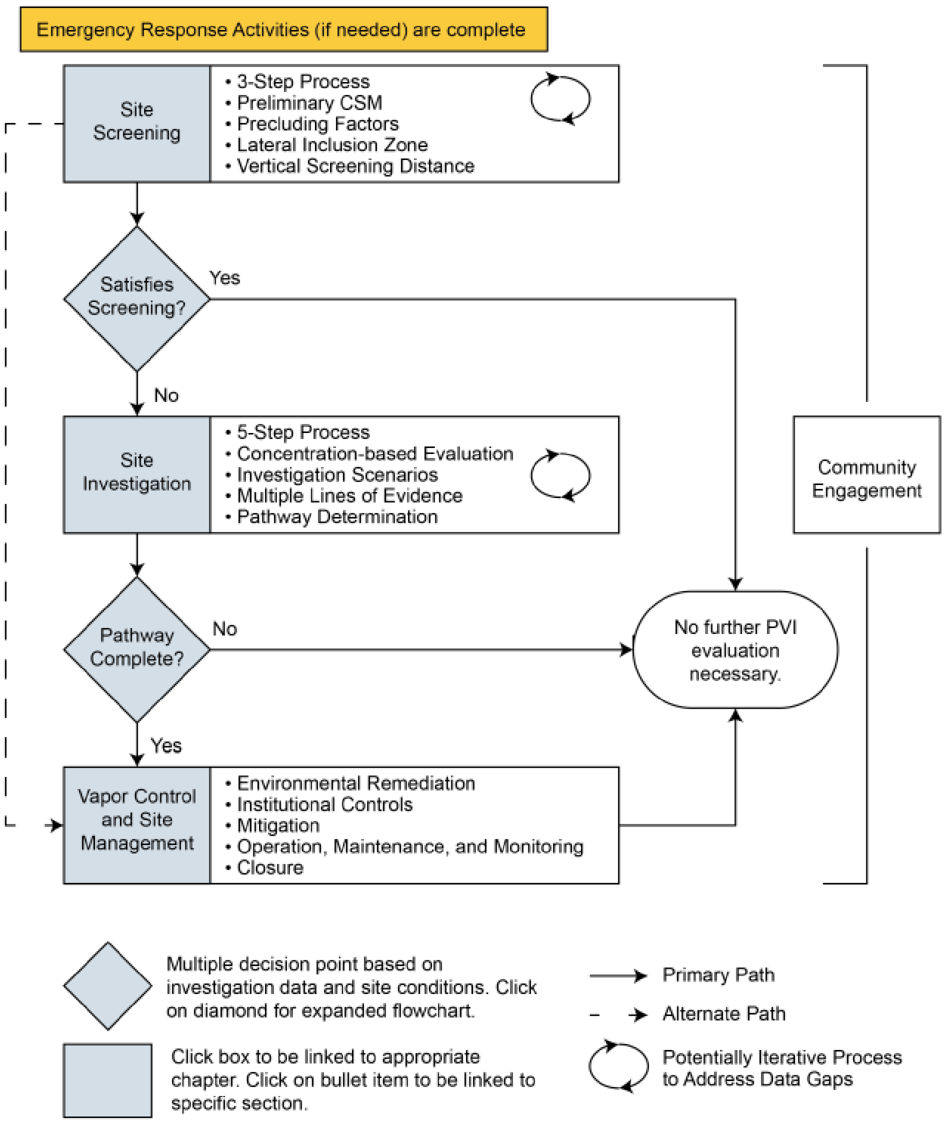
New Jersey Department of Environmental Protection, (NJDEP) Site Remediation & Waste Management Program. May 2021 *Vapor Intrusion Technical Guidance*. Section G.2.1.3, Table 3-2 and Table 3-3.

Wisconsin Department of Natural Resources. 2021. *Guidance for Documenting the Investigation of Human-made Preferential Pathways Including Utility Corridors*. RR-649. https://dnr.wisconsin.gov/topic/Brownfields/Vapor.html

Appendix I

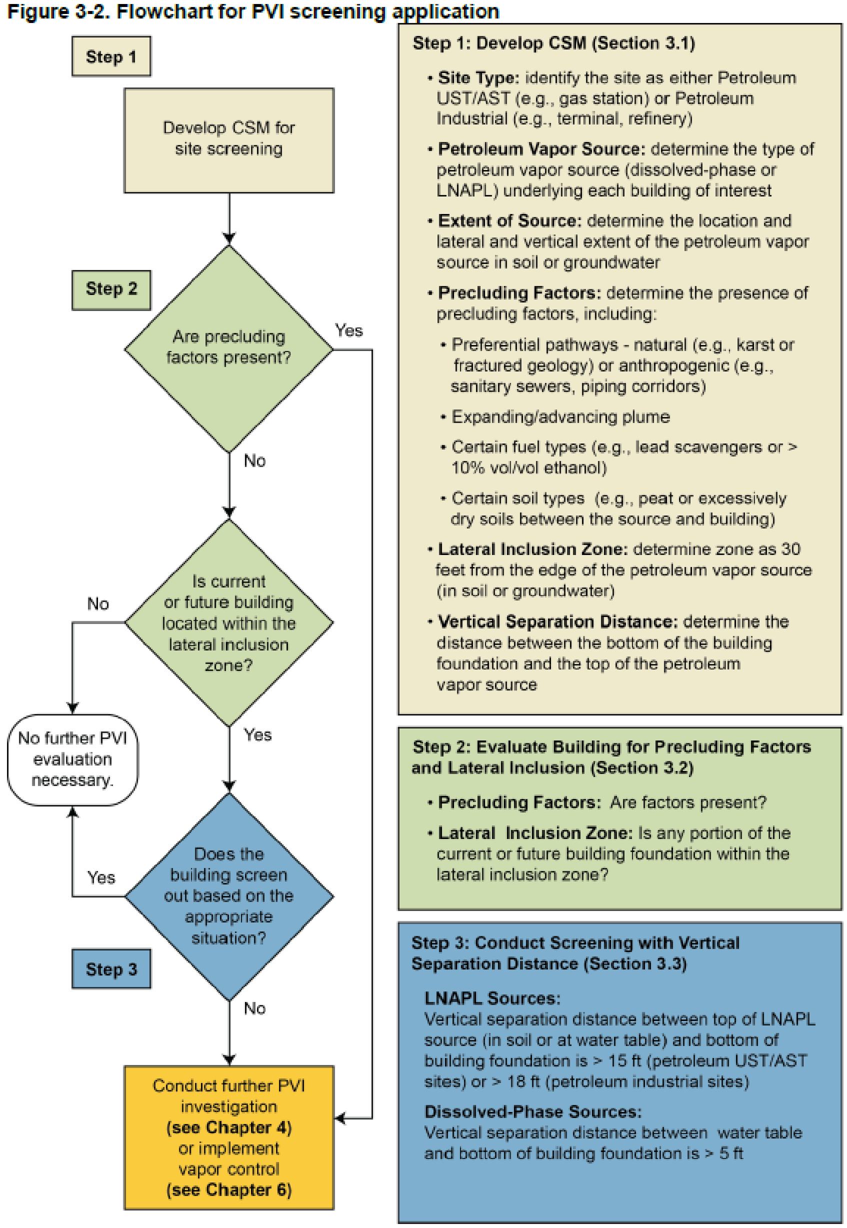
Appendix I: PVI Flow Chart: https://clu-in.org/conf/itrc/PVI/ITRC-PVI-FlowCharts.pdf

Figure 1-2. PVI strategy flowchart



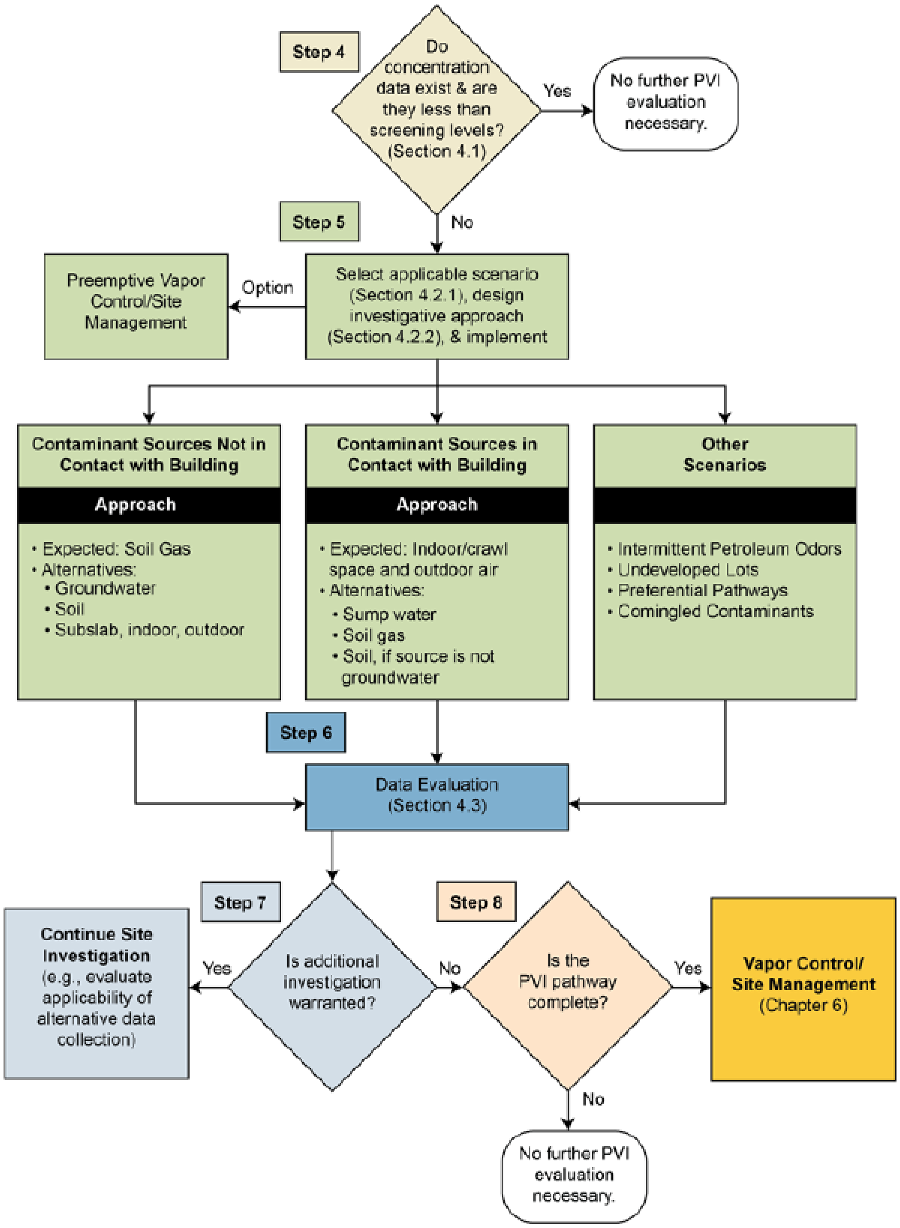
From ITRC Petroleum Vapor Intrusion (PVI) Technical and Regulatory Guidance Web-Based Document (PVI-1, 2014) at www.itrcweb.org/PetroleumVI-Guidance

Figure 3-2. Flowchart for PVI screening application



From ITRC Petroleum Vapor Intrusion (PVI) Technical and Regulatory Guidance Web-Based Document (PVI-1, 2014) at www.itrcweb.org/PetroleumVI-Guidance

Figure 4-1. Site investigation approach flow chart



From ITRC Petroleum Vapor Intrusion (PVI) Technical and Regulatory Guidance Web-Based Document (PVI-1, 2014) at www.itrcweb.org/PetroleumVI-Guidance

Process Flow Chart