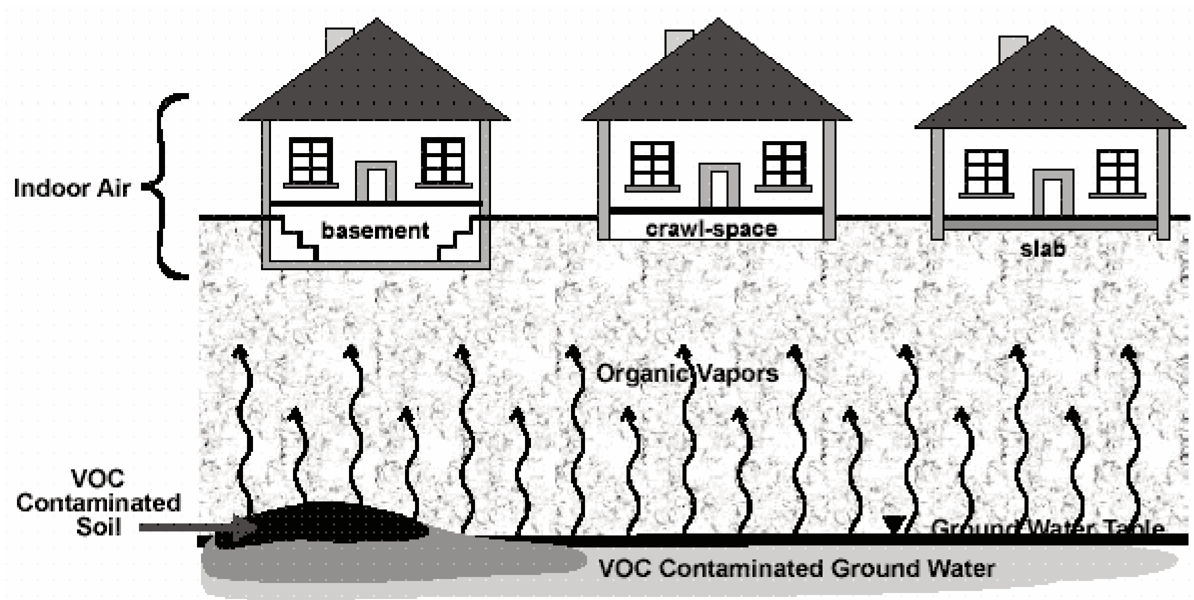
VAPOR INTRUSION GUIDANCE



DIVISION OF WASTE MANAGEMENT

NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY

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TABLE OF CONTENTS

APPENDICES

ABBREVIATION LIST

ATSDR	Agency for Toxic Substances and Disease Registry
BTEX	benzene, toluene, ethylbenzene and xylenes
COC	chemicals of concern
CSM	conceptual site model
DEQ	North Carolina Department of Environmental Quality
DWM	Division of Waste Management
GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
GWSL	Groundwater Screening Level
HVAC	heating, ventilation and air conditioning
IASL	Indoor Air Screening Level
ITRC	Interstate Technology and Regulatory Council
μg/m3	microgram per cubic meter
MTBE	methyl tertiary-butyl ether
NAPL	non-aqueous phase liquid
OSHA	Occupational Safety and Health Administration
ppb	parts per billion
ppbv	parts per billion by volume
PCE	tetrachloroethylene (also called perchloroethylene)
QA/QC	quality assurance/quality control
RSL	Regional Screening Level
SGSL	Soil Gas Screening Level
SSD	Sub-slab depressurization
TCE	trichloroethene
UST	underground storage tank
USEPA	United States Environmental Protection Agency
VI	vapor intrusion
VOC	volatile organic compound(s)

1.0 PURPOSE AND APPLICABILITY

The DWM VI guidance document addresses the evaluation and mitigation of vapor intrusion (VI) issues that may be present at sites under cleanup programs in the Division of Waste Management (DWM). This document primarily addresses VI issues resulting from volatile organic compounds (VOCs). **Separate petroleum vapor intrusion guidance is being developed by the Underground Storage Tank (UST) Section for use at petroleum sites under their jurisdiction. Screening and testing for petroleum vapor intrusion (PVI) risks in adjacent structures associated with UST sites may be addressed as presented in the *Guidelines for Assessment and Corrective Action for UST Releases, [in development]*, based upon the Interstate Technology and Regulatory Council (ITRC) guidance on the topic entitled: *Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management,* dated October 2014 (available at http://www.itrcweb.org/PetroleumVI-Guidance/). If petroleum constituents are comingled with VOCs at a site being managed by a DWM program other than the UST Section, this guidance document should be used.** If site conditions or chemical constituents vary greatly from those discussed in this guidance document, the specific cleanup program within DWM that regulates the site should be consulted on how to proceed with the VI investigation. Individual cleanup programs in DWM may have additional requirements for VI investigations; therefore, the appropriate regulatory cleanup program should always be consulted before performing a VI investigation.

The potential for current and future VI impacts shall be evaluated if volatile contaminated media are present at a site, either in a residential or nonresidential setting. In addition, this evaluation shall be considered for sites where active soil and/or groundwater remediation systems are proposed or being undertaken that may affect the potential for VI to occur.

The evaluation and mitigation of the VI pathway is an evolving science. DWM will attempt to update this document when significant advances regarding VI science occur, including methodologies, analytical procedures and associated analytical reporting limits. DWM intends to modify the screening level tables twice a year (if necessary) based on updates to the USEPA Region 3 Regional Screening (RSL) Tables used in the development of the DWM screening levels.

An excel-based Risk Calculator and User Guide is available for download from the DEQ Risk-Based Remediation website (https://deq.nc.gov/permits-rules/risk-based-remediation/risk-evaluation-resources) to determine health risks from volatile contaminants. Rather than screening individual contaminants against their respective screening level, the Risk Calculator can determine the cumulative health risk of all site contaminants from all environmental pathways, including structural vapor intrusion.

The current document, along with updates to the screening levels and other sections of the document are, or will be, presented on the DWM website at http://deq.nc.gov/about/divisions/waste-management/waste-management-permit-guidance/dwm-vapor-intrusion-guidance or by going to the North Carolina Department of Environmental Quality web site at http://deq.nc.gov and searching for vapor intrusion guidance in the search bar. The Risk Calculator will, in turn, be updated with the most recent screening levels. It is recommended that interested parties refer to the websites to ensure that they are using the most current information in the evaluation of a site.

2.0 INTRODUCTION

This document will present a brief introduction to VI, but assumes that the user will have a more in-depth knowledge of the issues related to VI. It is highly recommended that users of this document also use the following references for background information and to obtain further information regarding VI issues in general. Please note that specific investigative, screening or technical guidance in this DWM guidance document supersedes that in these reference documents.

- *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)* – 2002a – United States Environmental Protection Agency (USEPA)
- *Vapor Intrusion Pathway: A Practical Guideline* – 2007 – Interstate Technology and Regulatory Council (ITRC)

Any VOC-contaminated site has the potential for VI; however, sites contaminated by chlorinated solvents and petroleum releases represent the two most common VI scenarios. VI occurs when volatile chemicals with sufficient volatility (Henry's Law Constant > 10^{-5} atm m^3/mol) and toxicity are present in the subsurface and migrate from contaminated soils and/or groundwater to the indoor air of buildings. VI can occur even when the contaminated groundwater or soil is not directly beneath a building. Contaminated soil gas can travel along preferential pathways in the subsurface, including geologic formations and utility corridors, to reach buildings located away from the subsurface contaminant source. Soil gas can enter buildings new or old, whether on a slab or with a crawl space or basement.

Even if structures are not currently present, contaminated soil and groundwater can present potential VI issues for future structures.

VI is a complicated pathway to evaluate for human exposure. Buildings may have other sources of indoor air contaminants that do not result from vapor intrusion. Examples include common household cleaning products, dry-cleaned clothes, petroleum fuels, hobby supplies, paints, new carpets, and industrial chemicals used in the workplace. Additionally, changing atmospheric conditions such as wind, pressure, temperature and precipitation affect indoor air concentrations, as well as the type of structure, building characteristics, heating/air conditioning type, and other building specific parameters. Outdoor or ambient air commonly has detectable levels of VOCs, which further complicates the evaluation of VI.

2.1 Conceptual Site Model

Buildings with sensitive populations such as residences, child care facilities and schools should be identified early in the investigation and prioritized for VI evaluation

Assessing the potential for VI to indoor air should begin with visualizing a simplified version of the site or physical setting: this simplified idea, picture, or description is a conceptual site model (CSM). The CSM serves to identify currently complete or potentially complete pathways to receptors and the potential for future risks. The CSM should identify potential sources of contamination, types of contaminants and affected media, release mechanisms and potential contaminant pathways, and actual/potential human and environmental receptors.

The vapor intrusion pathway is referred to as 'complete' if three conditions are met:

- a source of hazardous vapors is present beneath a building,
- vapors form and have a pathway to migrate toward the building and,
- entry routes and driving forces for the vapors to enter the building must exist.

Figure 2-1 is an illustration of a simple, preliminary CSM for the VI pathway.

Figures, maps, flow charts, tables and graphs can be used to summarize and illustrate the overall CSM, its various components, and the associated data. These visual aids are often the most effective tools for communicating complex information to interested parties. The narrative should clarify which CSM components are site-specific, measured or known, and which include assumptions or general information. The Interstate Technology & Regulatory Council's (ITRC) document, titled Vapor Intrusion Pathway: A Practical Guideline (January 2007) provides further discussion of the site conceptual model and provides a Conceptual Site Model Checklist (included in Appendix A) that can be used by investigators when developing the CSM.

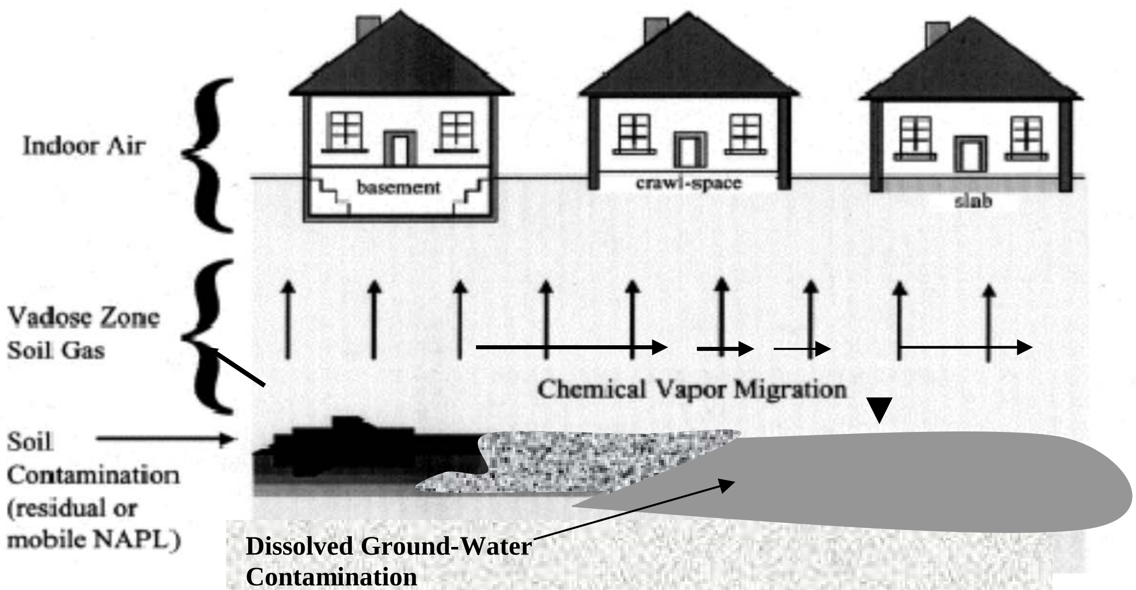

Figure 2-1. General Vapor Intrusion Conceptual Model
Source: USEPA 2002a

2.2 Factors Affecting Vapor Migration

Predicting the extent of vapor intrusion and the potential for human exposure is complicated by various environmental and building factors that can affect vapor migration. The main transport mechanisms by which contaminants can migrate are:

- Diffusion - Diffusion occurs as a result of a concentration gradient between the source and the surrounding area; it can result in the upward, lateral or downward migration of vapors through the vadose zone.

- <u>Advection/convection</u> - The horizontal and vertical movement of vapors located near a building foundation is often affected within an area referred to as the "zone of influence." Chemicals entering this zone are drawn into the building via soil gas advection and convection resulting from building interiors that exhibit a negative pressure relative to the outdoors and the surrounding soil.

  The reasons for this pressure differential include: 1) factors relating to operation of the HVAC system; 2) the use of fireplaces and other combustion sources; 3) the use of exhaust fans in bathrooms and kitchens; and 4) higher temperatures indoors relative to outdoors during the heating season. The combination of these actions/conditions results in a net convective flow of soil gas from the subsurface through the building foundation to the building interior.

- <u>Vapor migration through preferential pathways</u> - Vapors can rapidly migrate from a source to a receptor through natural (e.g. fractured rock) and manmade (e.g. buried utilities) pathways in the subsurface.

Variations in building construction, use, maintenance, site-specific stratigraphy, sub-slab composition and temporal variation in atmospheric pressure, temperature, precipitation, soil moisture, water table elevation, and other factors, combine to create a complex and dynamic system. General aspects of several of these processes and site settings/conditions are described in Tables 2-1 and 2-2.

2.3 Receptors

A receptor is any human or other ecological component which is or may be affected by a contaminant from a contaminated site. The primary VI receptors are the human occupants of enclosed spaces or buildings overlying subsurface volatile contamination. The exposure route of general interest for vapor intrusion is inhalation of contaminated vapors present in indoor air. Vapor intrusion can occur in all types of buildings and any foundation type (e.g. basement, crawl space, slab-on-grade, earthen floor). To account for possible changes in future use, VI is of potential concern in buildings/enclosed spaces whether or not they are currently occupied, including future buildings that may be constructed. Buildings with significant air exchange rates (e.g., commercial garages/spaces with large doors/openings) or significantly limited use (e.g., small utility sheds) should be evaluated on a site-specific basis.

Human exposure typically can take place under a residential (unrestricted use) or nonresidential (restricted use) exposure scenario. Residential settings include single family homes, townhouses, and apartment buildings, and receptors include both adults and children who are expected to spend a greater period of time in a residential setting than those individuals in a nonresidential setting. Other exposure scenarios may be considered residential use based on site-specific factors that should be discussed with DWM if appropriate.

It is DWM policy that day care facilities, schools and any other similar structures where children (under 18) are the primary occupants are evaluated as residential use due to the potentially sensitive nature of the exposed population.

Nonresidential settings include office buildings and commercial/industrial facilities, and receptors consist of adult workers in these buildings or facilities. Nonresidential settings with sensitive populations (e.g., working pregnant women) should be handled on a site-specific basis. Occupational settings that fall under the purview of the Occupational Safety and Health Administration (OSHA) may be handled differently than those not subject to OSHA regulations when indoor air concentrations from normal operating practices cannot be ruled out.

Table 2-1 Environmental factors that may affect VI
(Source: NYSDOH CEH BEEI Soil Vapor Intrusion Guidance 2006)

Environmental Factor	Description
Soil conditions	Generally, dry, coarse-grained soils facilitate the migration of subsurface vapors and wet, fine-grained or highly organic soils retard migration.
Volatile chemical concentrations	The potential for vapor intrusion generally increases with increasing concentrations of volatile chemicals in groundwater or subsurface soils, as well as with the presence of NAPL.
Source location	The potential for vapor intrusion generally decreases with increasing distance between the subsurface source of vapor contamination and overlying buildings. For example, the potential for vapor intrusion associated with contaminated groundwater decreases with increasing depth to groundwater.
Groundwater conditions	Volatile chemicals dissolved in groundwater may off-gas to the vadose zone from the surface of the water table. If contaminated groundwater is overlain by clean water (upper versus lower aquifer systems or significant downward groundwater gradients), then vapor phase migration or partitioning of the volatile chemicals is unlikely. Additionally, fluctuations in the groundwater table may result in contaminant smear zones. The "smear zone" is the area of subsurface soil contamination within the range of depths where the water table fluctuates. Chemicals floating on top of the water table, such as petroleum components, can sorb onto soils within this zone as the water table fluctuates. Sorption of chemicals can influence their gaseous and aqueous phase diffusion in the subsurface, and ultimately the rate at which they migrate.
Surface confining layer	A surface confining layer (e.g., frost layer, pavement or buildings) may temporarily or permanently retard the migration of subsurface vapors to outdoor air. Confining layers can also prevent rainfall from reaching subsurface soils, creating relatively dry soils that further increase the potential for soil vapor migration.
Fractures in bedrock and/or tight clay soils	Fractures in bedrock and desiccation fractures in clay can increase the potential for vapor intrusion beyond that expected for the bulk, unfractured bedrock or clay matrix by facilitating vapor migration (in horizontal and vertical directions) and movement of contaminated groundwater along fractures.
Underground conduits	Underground conduits (e.g., sewer and utility lines, drains or tree roots, septic systems) with highly permeable bedding materials relative to native materials can serve as preferential pathways for vapor migration due to relatively low resistance to flow.
Weather conditions	Wind and barometric pressure changes and thermal differences between air and surrounding soils may induce pressure gradients that affect soil vapor intrusion.
Biodegradation processes	Depending upon environmental conditions (e.g., soil moisture, oxygen levels, pH, mineral nutrients, organic compounds, and temperature), the presence of appropriate microbial populations, and the degradability of the volatile chemical of concern, biodegradation in the subsurface may reduce the potential for vapor intrusion. For example, readily biodegradable chemicals in soil vapor may not migrate a significant distance from a source area while less degradable chemicals may travel farther.

Table 2-2 Building factors that may affect VI
(Source: NYSDOH CEH BEEI Soil Vapor Intrusion Guidance 2006)

Building Factor	**Description**
Operation of HVAC systems, fireplaces, and mechanical equipment (e.g., clothes dryers or exhaust fans/vents)	Operation may create a pressure differential between the building or indoor air and the surrounding soil that induces or retards the migration of vapor-phase contaminants toward and into the building. Vapor intrusion can be enhanced as the air vented outside is replaced.
Heated building	When buildings are closed up and heated, a difference in temperature between the inside and outdoor air induces a stack effect, venting warm air from higher floors to the outside. Vapor intrusion can be enhanced as the air is replaced in the lower parts of the building.
Air exchange rates	The rate at which outdoor air replenishes indoor air may affect vapor migration into a building as well the indoor air quality. For example, newer construction is typically designed to limit the exchange of air with the outside environment. This may result in the accumulation of vapors within a building.
Foundation type	Earthen floors and fieldstone walls may serve as preferential pathways for vapor intrusion.
Foundation integrity	Expansion joints or cold joints, wall cracks, or block wall cavities may serve as preferential pathways for vapor intrusion.
Subsurface features that penetrate the building's foundation	Foundation perforations for subsurface features (e.g., electrical, gas, sewer or water utility pipes, sumps, and drains) may serve as a preferential pathway for vapor intrusion.

2.4 Factors Affecting Indoor Air Quality

Many different chemicals are used and found in buildings as part of our everyday lives that contribute to indoor air quality and are not attributable to VI. Cleaning products, glues, paints, cigarette smoke and dry-cleaned clothes are examples of common indoor air contaminants. Volatile chemicals can be found in the outdoor ambient air from sources such as gas stations, dry cleaners and vehicle exhaust that may enter buildings. Commonly found concentrations of these indoor and outdoor chemicals not attributed to VI are referred to as “background levels”. Background sources of contamination are typically determined from the results of samples collected in homes, offices and outdoor areas not known to be affected by external sources of chemicals and are considered when evaluating the results of VI investigations. Table 2-3 contains examples of alternate sources of volatile chemicals in indoor air.

Table 2-3 Alternate sources of volatile chemicals in indoor air

(Source: NYSDOH CEH BEEI Soil Vapor Intrusion Guidance 2006)

Source	Description
Outdoor air	Outdoor sources of pollution can affect indoor air quality due to the exchange of outdoor and indoor air in buildings through natural ventilation, mechanical ventilation or infiltration. Outdoor sources of volatile compounds include automobiles, lawn mowers, oil storage tanks, dry cleaners, gasoline stations, industrial facilities, etc.
Attached or underground garages	Volatile chemicals from sources stored in the garage (e.g., automobiles, lawn mowers, oil storage tanks, gasoline containers, etc.) can affect indoor air quality due to the exchange of air between the garage and indoor space.
Off-gassing	Volatile chemicals may off-gas from building materials (e.g., adhesives or caulk), furnishings (e.g., new carpets or furniture), recently dry-cleaned clothing, or areas (such as floors or walls) contaminated by historical use of volatile chemicals in a building. Volatile chemicals may also off-gas from contaminated groundwater that infiltrates into the basement (e.g., at a sump) or during the use of contaminated domestic well water (e.g., at a tap or in a shower).
Household products	Household products include, but are not limited to, cleaners, mothballs, cigarette smoke, paints, paint strippers and thinners, air fresheners, lubricants, glues, solvents, pesticides, fuel oil storage, and gasoline storage.
Occupant activities	For example, in non-residential settings, the use of volatile chemicals in industrial or commercial processes or in products used for building maintenance. In residential settings, the use of products containing volatile chemicals for hobbies (e.g., glues, paints, etc.) or home businesses. People working at industrial or commercial facilities where volatile chemicals are used may bring the chemicals into their home on their clothing.
Indoor emissions	These include, but are not limited to, combustion products from gas, oil and wood heating systems that are vented outside improperly, as well as emissions from industrial process equipment and operations.

3.0 SCREENING LEVELS

DWM has developed Indoor Air Screening Levels (IASLs), Groundwater Screening Levels (GWSLs), and Soil Gas Screening Levels (SGSLs) for residential and nonresidential exposures to assist in the evaluation of potential VI impacts. Exceedances of the screening levels indicate that VI is possibly a concern and that further evaluation and/or potential remediation of the pathway is necessary.

In addition to screening individual contaminants, health risk associated with vapor intrusion into current and potential future structures can be calculated using the DEQ Risk Calculator to determine whether it is acceptable for the structure’s current or planned use.

To allow for flexibility in updating the tables on a frequent basis, an explanation of how the screening levels were derived and the screening level tables are separate from this document and can be found

on the DWM website at http://portal.ncdenr.org/web/wm/ https://deq.nc.gov/about/divisions/waste-management/waste-management-permit-guidance/dwm-vapor-intrusion-guidance.
It is recommended that users refer to the DWM website directly rather than rely on printed versions of the tables to ensure that the most current information is used.

4.0 INVESTIGATION

When investigating the potential for vapor intrusion, each site should be evaluated on a site-by-site basis since no two sites are exactly alike. The guidance in this section contains general steps and procedures that should be applied in most situations; however, site-specific and building specific conditions should be taken into account. Investigators should also check with the specific DWM cleanup program addressing the site before conducting VI investigations since some programs may have supplemental VI guidance. **A flow chart of steps for conducting a structural vapor intrusion evaluation has been developed for Inactive Hazardous Sites Branch (IHSB) sites and is included in Appendix B.**

DWM recommends a phased approach proceeding in a stepwise manner when investigating the VI pathway. A preliminary assessment should determine if immediate action is required, followed by an investigation phase where existing or new analytical data from groundwater, sub-slab or near slab soil gas, and indoor air are compared to DWM screening levels to further evaluate whether the VI pathway is complete.

4.1 Preliminary Evaluation

For the VI pathway to be complete, there must be a source of hazardous vapors present beneath a building, vapors must form and have a pathway to migrate toward the building, and entry routes and driving forces for the vapors to enter the building must exist. The investigator should first confirm that one or more contaminants of concern represent a potential risk due to VI. Chemicals that are sufficiently volatile (Henry's Law Constant > 10^{-5} atm m^3/mol) to result in potential vapor intrusion and sufficiently toxic to result in potentially unacceptable indoor air inhalation risks should be considered a contaminant of concern. A list of these chemicals can be found in USEPA's *Draft Subsurface Vapor Intrusion Guidance* (2002a).

Certain site conditions may require an immediate VI investigation or implementation of an interim mitigation measure. They include:

- Known contaminant spill in a structure.
- Physiological effects (dizziness, nausea, vomiting, confusion, etc.) reported by occupants (with a known or suspected source nearby).
- Wet basement or sump with contaminated groundwater nearby.
- Odors reported in a structure (with a known or suspected source nearby).
- NAPL at the water table under or immediately adjacent to a structure.
- Indoor air samples exceeding DWM IASLs.

If immediate action is warranted, a workplan should be submitted to DWM for approval, if required. If immediate action is not necessary, but there is a potential VI concern, a VI investigation should be performed.

4.2 General Considerations

4.2.1 Investigation Area

Vapor concentrations are generally expected to decrease with distance from a subsurface vapor source. The distance at which structures will not be threatened by vapor intrusion is a site-specific determination that relies on many factors including preferential pathways, surface cover, geologic setting, biodegradability of contaminant, etc. However, a vapor inclusion zone of 100-feet is generally considered an adequate starting point for looking at buildings that may be threatened by vapor intrusion.

The VI pathway should initially be considered a potential threat for all current or future buildings located within 100 feet horizontally or vertically of a soil or groundwater source area or of a soil vapor or groundwater plume exceeding the DWM screening levels. For landfills that are or could potentially be producing methane, the distance should be extended to 500 feet.

For sites with deeper, larger contaminant sources or where sources are intersected by utilities or other preferential pathways, the distance may need to be increased based on professional judgment. If the depth to the shallowest groundwater exceeds 100 feet, a VI investigation is not required unless vertical preferential pathways exist and the CSM indicates there is a significant VI risk.

The 100-foot distance criterion for investigating the VI pathway does not consider the aerobic biodegradation of petroleum hydrocarbons, particularly the benzene, toluene, ethylbenzene, xylenes (BTEX) compounds. Depending on the site conditions, the criterion is likely to be too conservative for petroleum hydrocarbons when that is the only source of contamination. Typically, an inclusion distance of less than 100-feet is recommended for petroleum hydrocarbon-only VI investigations. Investigators should consult with the appropriate DWM cleanup program addressing the site regarding modifications to this distance criterion in cases involving **only** petroleum hydrocarbon contamination. If NAPL is present or a VOC plume is co-mingled with petroleum hydrocarbons, the 100-foot distance criterion should be used.

The VI investigation should start in the known worst-case area and progress outward as warranted. **It may not be necessary to evaluate soil vapor or indoor air at all structures within 100 feet of known contamination as described above.** Typically, VI sampling should begin near the source areas or 'worst' case areas and move outward to adjacent properties, especially toward the down-gradient side of contamination. However, the investigator should also identify structures within the inclusion zone that may have building-specific characteristics or occupant activities that increase the potential for VI and may require investigation.

4.2.2 Chemicals of Concern

All subsurface contaminants that have the greatest potential to pose a health concern via vapor intrusion, based upon their volatility, should be evaluated. A chemical generally is considered to be 'volatile' if:

- Vapor pressure is greater than 1 millimeter of mercury (mm Hg), or
- Henry's law constant is greater than 10^{-5} atmosphere-meter cubed per mole (atm m^3 mol^{-1})

Aside from typical analytes on a volatile organic compound scan, chemicals of concern (COCs) should include mercury, ammonia, hydrogen sulfide and other semi-volatile compounds if present at the site.

If a COC (present in soil or groundwater) is a chemical currently in use in a place of employment, [e.g. perchloroethylene (PCE) in a dry-cleaner, trichloroethylene (TCE) in a machine shop], the chemical is subject to Occupational Safety and Health Administration (OSHA) regulations. In these cases, OSHA regulatory limits may apply if the employer is in compliance with OSHA regulations governing the chemical's use. It is very difficult to determine how much of the chemical in indoor air is due to use of the chemical in day-to-day operations or from vapor intrusion. There are instances when sampling inside these structures may be conducted to compare to indoor air samples in adjacent spaces or to investigate the downward migration of vapors from a structure into the subsurface.

DWM does not recommend collecting indoor air samples that analyze for a chemical in use at a structure as part of day-to-day operations without DWM approval prior to sampling.

If OSHA standards currently govern the amount of chemical allowed in indoor air, future exposures from subsurface contamination should be evaluated using soil gas to account for changes in use of the building or changes in land use. Land use controls may be used to protect future occupants of the building once OSHA standards no longer apply. Alternatively, remediation of subsurface contamination to SGSLs or GWSLs may be required to prevent future vapor intrusion.

DWM recommends that initial groundwater or soil gas samples be analyzed for the full suite of volatiles based on the approved method. The analyte list may be reduced for further soil gas, crawl space or indoor air testing with the approval of the specific DWM program with oversight of the project. Reducing the analyte list may assist with eliminating or assessing background sources.

4.2.3 Underground Utilities

Many accidents in subsurface investigations are due to encountering subsurface utilities. Prior to mobilizing for any groundwater or soil gas investigation, health and safety concerns must be answered. Of greatest concern would be to locate any underground utilities. NC811 is a free one-call utility location service and can be contacted at 1-800-632-4949 or http://www.nc811.org. They will contact all utility companies in the area that are members of their service. It is the investigator's responsibility to directly contact any utilities that are not affiliated with NC811. Typically, calls must not be made less than 48 hours prior to the planned work.

4.2.4 Landfills and Methane Gas

(This section adapted from New Jersey Department of Environmental Protection's Vapor Intrusion Guidance, 2013)

A landfill gas investigation may be required by the program with jurisdiction when a solid waste landfill is located on or adjacent to a structure. The presence of methane-generating conditions that may cause an explosion will require an investigation. Landfills and the gas generated from them can greatly influence the investigative approach.

A landfill is defined as a solid waste that is deposited on or into the land as fill for the purpose of permanent disposal.

While the concern for the migration of naturally produced or anthropogenic methane and the potential for the concentration of methane to exceed the lower explosion limit in a building are similar, the investigation of these issues requires the consideration of site-specific conditions.

4.2.4.1 Methane

Methane is a flammable, potentially explosive gas that alone is non-toxic and is not a long-term human health risk due to exposure. It is a colorless, odorless hydrocarbon combustible at concentrations of 5-15% by volume in air. A methane investigation is initiated when of methane values of 2% by volume or greater are present in a gas probes/wells. Methane may be generated under natural conditions or from an anthropogenic source. Organic-rich soils, sediments or methane associated with natural petroleum reserves are examples of natural methane-producing conditions.

4.2.4.2 Landfill Gases

Landfill gas (LFG) is the natural by-product of the anaerobic decomposition of biodegradable material that is placed in landfills. The composition of LFG produced under anaerobic conditions is typically in the range of 45-60% methane and 40-60% carbon dioxide. Additional components of LFG include trace amounts of ammonia, hydrogen sulfide and other non-methane organic compounds including VOCs. Nearly 30 organic hazardous air pollutants have been identified in LFG including, but not limited to, benzene, toluene, ethylbenzene, vinyl chloride, chloroform, carbon tetrachloride and trichloroethene (TCE). A useful source of information on this subject is the USEPA publication, Guidance for Evaluating Landfill Gas Emissions for Closed or Abandoned Facilities (USEPA, 2005).

Because of its combustible nature, methane is a product of interest at landfills along with the volatile compounds that are carried along in the LFG plume. It should be noted that collection and venting may be necessary to prevent offsite migration and control the accumulation of any methane gas at any concentration in any building.

4.2.4.3 Landfill Gas Production and Flow

The rate and volume of LFG production depends upon the characteristics of the waste material and the environmental factors. They include the following:

- Waste composition - The greater the amount of biodegradable organic materials present in the waste (typically from municipal waste), the more LFG is produced by bacteria during decomposition. In addition, the more industrial waste that is disposed in the landfill, the higher the levels of non-methane organic compounds that will be produced through volatilization and chemical reactions.

- Age of the waste – Generally waste buried for less than 10 years produces more LFG than older waste. Peak gas production is generally between 5-7 years after the waste is buried. Note that many of the larger (and some smaller) pre-regulatory municipal solid waste landfills have been found to produce methane.
- Presence of oxygen – Methane is produced in anaerobic regions of the landfill and can be consumed in aerobic regions. If the buried waste is disturbed, then conditions may become more aerobic limiting the microbial process until it again becomes oxygen reduced.
- Moisture content – The presence of moisture increases the gas production because it supports and enhances bacterial decomposition. Moisture may also promote chemical reactions that produce LFG.
- Temperature – As temperature increases the rate of bacterial activity will increase, which increases gas production. Increasing temperatures also promote volatilization and increase the rate of chemical reactions.

Migration of LFG may occur because of diffusion or advection. Gas flow due to diffusion is in the direction which the concentration decreases. When LFG concentrations are higher in a landfill than the surrounding area, LFG will tend to move out of the landfill to the surrounding area with a lower gas concentration. Gas flow by advection occurs when a pressure gradient exists; flow is in the direction of decreasing pressure - from high pressure to low pressure.

Factors that influence the flow of LFG in the subsurface include the following:

- Landfill cap – If the landfill is cap constructed of a liner or silts and clays that are impermeable to gas flow; LFG gas will tend to migrate laterally.
- Landfill liners – If the landfill has an impermeable liner system, LFG will not migrate into the surrounding subsurface area by advection.
- Ground water levels – Gas movement is influenced by the movement of the ground water table. As the ground water table rises, it forces the LFG upward.
- Barometric pressure – The difference in the soil gas pressure and the barometric pressure will guide the LFG to move laterally or vertically, depending upon the pressure gradient.
- Preferential pathways – Pathways for the movement of LFG can be either natural or anthropogenic. The geology provides natural pathways such as sand or gravel zones, fractured bedrock and old stream channels. Anthropogenic pathways include buried utilities, drains, trenches and tunnels.
- Seasonal Variations – The time of year (winter, summer) will cause variations in lateral LFG movement due to saturated soils from precipitation acting as a cap for vertical LFG migration and increased LFG production.

It is often difficult to predict the specific patterns and directions of LFG movement due to the many variables for gas flow and generation. LFG can migrate up to 1,000 feet or more in the subsurface from the footprint of the disposed waste (landfill source).

4.2.4.4 Methane Investigations and Analytical Methods

When methane may likely be present (see Section 3.1.4.1), conduct an initial assessment of the buildings identified through the receptor evaluation for fire and explosion hazards. The characterization should focus on below grade floors, ground level floors (when no basement present), crawl spaces, sumps, utility penetrations, utility vaults, and enclosed spaces. If explosive conditions are present, immediate notification of emergency responders is required followed by program notification.

Once the investigator determines that an explosive condition does not currently exist at the building, an evaluation of vapor intrusion (VI) for volatile compounds and non-emergency methane concentrations should follow. The absence of methane does not eliminate the possibility of volatile compounds in a building.

For structures located on or near a landfill, the following methods may be used as part of a LFG assessment.

1. Probes can be installed at several levels in the vadose zone between the structure and the landfill to allow for measurements of subsurface pressure and methane concentrations to evaluate the attenuation and migration potential of methane in the soil column. Install the deepest probe at the approximate depth of the landfill refuse, or at least two feet above the seasonal high-water table and at least five feet below ground surface. The investigator uses professional judgment to determine the number of vertical profiles. Collect readings using a field instrument capable of directly measuring methane (e.g., landfill gas analyzer, combustible gas meter, infrared sensor) can be used. Evaluate preferential pathways that may serve as migration routes to buildings. Based on the results, the investigator can determine if LFG is reaching the structure.
2. Where possible obtain initial information regarding LFG migration from the landfill owner/operators if they were required to monitor for LFG at the perimeter the landfill. Information on the periodic LFG measurements should give an indication of the potential (pressure) and concentrations of LFG migrating away from the landfill. Other factors listed in Section 3.1.4.3 may assist the investigator, including the type and age of the landfill, landfill construction (e.g., cap, liner), and the presence of an active methane gas venting system.

The trigger distances do not necessarily reflect the distance LFG can travel from a landfill, often carrying site-related contaminants of concern.

The investigator should establish a clean zone beyond the limits of LFG contamination; a clean zone would have 0% LEL (or no more than global background).

Consider sources of methane in buildings (sewage systems, natural gas equipment). As previously stated, the measurement of methane from LFG may also indicate the presence of other volatile compounds in the absence of other screening conditions such as dissolved volatile compounds in ground water or volatile compounds in soil.

4.3 Groundwater

In situations where there is urgency regarding a potential human exposure or when NAPL is located close to buildings, it may be necessary to collect sub-slab soil gas and/or indoor air samples prior to acquisition of sufficient groundwater data.

DWM recommends groundwater (in most circumstances) as the first medium to be investigated for the VI pathway. Most site investigations require the characterization and delineation of groundwater contamination; therefore, in most cases, there will be existing groundwater data available to begin evaluation of the VI pathway. If soil gas and/or indoor air data has already been collected, using screening levels for those media are more appropriate, however, groundwater data may still be used to screen other areas of the site that may need to be investigated for potential VI.

There are several factors that should be considered when utilizing groundwater data for VI investigations:

- Clean Water Lens - As groundwater moves away from the source area, infiltrating water (precipitation, irrigation, septic systems, leaking water lines, etc.) that reaches the water table will lie on top of the contaminated groundwater and, gradually, a lens of clean groundwater may form above a contaminant plume. The overlying groundwater can impede or prevent volatiles in deeper groundwater from reaching the unsaturated zone, thus possibly preventing a vapor intrusion situation.

- Depth to Saturated Zone - The water table can be described as the shallowest depth at which groundwater will freely flow into wells, or other groundwater sampling devices. The depth to the regional water table and/or any perched saturated zone(s) needs to be determined in the vicinity of buildings at risk for VI.

- Stratigraphy - A low permeability layer in the unsaturated zone can impede the upward migration of vapors from an underlying source and prevent VI impacts in areas where it might otherwise occur. It is important to have a good understanding of the stratigraphy of a site where VI is being investigated since these features can have a tremendous effect on the presence or absence of VI impacts.

- Fluctuations in Water Table Elevation - A significant drop in water table elevation (e.g., during a prolonged drought) can expose an area of contaminated groundwater previously separated from the vadose zone by a clean water lens resulting in a potential VI situation.

Changes in water table elevation may increase or decrease the risk of VI.

- NAPL - Where NAPL reaches the capillary fringe and/or soil is contaminated with residual NAPL in the zone surrounding the capillary fringe, fluctuations in the water table could smear the product vertically and greatly enhance vertical mixing between vapor and dissolved contamination, resulting in much higher volatile concentrations near the water table than in deeper intervals not within the zone of fluctuation.

4.3.1 Groundwater Sampling

Groundwater sampling methods are not discussed in detail because DWM assumes investigators are relatively experienced and trained to collect samples that meet data quality needs. However, DWM has a few recommended guidelines for groundwater sampling as related to vapor intrusion investigations.

Groundwater samples should be collected as close as possible to the structures under investigation.

DWM recommends groundwater samples be taken from wells screened across the top of the water table and samples should be collected as close as possible to the top of the water table. A monitoring well should be considered adequate for evaluating the appropriate depth interval(s) if the screen/open borehole intersects the water table throughout the year (i.e., a water table well), and the thickness of the water column in the well is approximately 10 feet or less.

4.4 Soil Gas

If the GWSLs are exceeded, soil gas testing will need to be conducted in most cases. Three alternative approaches are possible for this initial step, source area soil gas, sub-slab soil gas or exterior soil gas as outlined below. **Site-specific conditions may dictate which approach is appropriate, therefore, please ensure that the DWM program with oversight is consulted regarding the approach chosen and the associated sampling plan.**

Note that underground storage tank sites or where chlorinated solvents are used in buildings may have contamination in the vadose zone solely due to vapor releases. In these cases, soil and groundwater data may not identify the VI source. Soil gas sampling is the preferable investigative tool in these circumstances.

4.4.1 Source Area Soil Gas

Soil gas samples collected within one foot above the capillary fringe in the area of highest groundwater contamination may be an acceptable screening procedure to estimate ‘worst case’ conditions even if the samples are not located on the property with the structures of concern.

4.4.2 Sub-slab Soil Gas

The collection of sub-slab soil gas is an effective investigative tool when assessing the VI pathway, especially combined with concurrent indoor air sampling. When combined with a conservative attenuation factor (as used in the development of the DWM SGSLs), sub-slab soil gas can be used to estimate potential indoor air concentrations. For commercial/industrial buildings, sub-slab soil gas is preferred over exterior soil gas sampling. Typically, sub-slab soil gas samples should be collected at the structure representing the worst-case scenario and move outward. Not all structures must be investigated, but site-specific conditions should be considered when developing a sampling plan.

4.4.2.1 Sampling Considerations

To evaluate potential VI from soil gas, DWM recommends that laboratory analyses for sub-slab soil gas samples be limited to chemicals of concern present in the subsurface, typically in groundwater or other soil gas samples.

When sub-slab samples are collected, DWM recommends that the *Indoor Air Building Survey and Sampling Form* (Appendix C) be completed to document site-specific conditions associated with the sampling. At a minimum, the following information should be collected:

- Building conditions that are pertinent to assessing potential soil gas entry such as conduits, cracks or floor drains, utilities, basements, type of sub-slab backfill, thickness of flooring.
- The location of the HVAC system and outdoor air intake.
- Areas that may create over- or under- pressurization in the building such as vent hoods, fans, attic vents. Note that over-pressurization of a building could cause indoor sources to contribute to subslab soil gas.
- Meterological data such as recent precipitation, changes in barometric pressure, wind speed, temperature, humidity.

4.4.2.2 Number, Location and Frequency of Sampling

Prior to conducting sub-slab sampling, evaluate whether any special conditions exist that should be taken into consideration including, but not limited to:

- The presence of a vapor barrier.
- Underground utilities.
- Cables or rebar in concrete floors.
- If there are entry points for vapors in basements through sidewalls.
- If the water table or capillary fringe extends into the fill material beneath the slab.

Due to spatial variability in sub-slab soil gas concentrations over a slab, DWM generally recommends the collection of one sample per 1000 square feet of first floor building area. However, other site-specific conditions should be considered when determining the number of samples including:

- Multi-family residential units and commercial or retail buildings that may have more than one tenant.
- Subsurface structures that may degrade indoor air quality in one portion of the building and not another such as basements, sumps, elevator pits, earthen floors.
- Past usage such as dry cleaners, underground storage tanks, industrial.
- Different exposure scenarios (e.g., day care, medical facilities) that exist within the building and any sensitive populations that may be exposed.
- Very large or small buildings.

DWM recommends that sub-slab samples be collected towards the center of the slab, at least 5 feet from an outer wall, since concentrations in the center are typically higher than concentrations near the perimeter of the building.

To minimize potential damage to flooring, it may be necessary to select a location in a closet or utility room (where carpeting or tiles are less visible or not present at all). The selected location(s) should be chosen in consultation with the property owner during the building walkthrough.

If sub-slab soil gas samples are being collected as a stand-alone determination of the VI pathway, more than one round of sampling is recommended. Supplemental environmental data (e.g., groundwater, indoor air, or near slab soil gas data) may eliminate the need for multiple rounds of sub-slab soil gas sampling. In addition, DWM may accept a single round of sampling in those cases where the analytical results are an order of magnitude below the appropriate screening level.

4.4.3 Exterior Soil Gas

For the evaluation of structures, it is not always possible to obtain the building occupants and/or owner's approval to drill a hole in the basement/foundation slab or a slab may not be present. In these situations, exterior soil gas sampling is often the best alternative to evaluate whether VI is a concern.

4.4.3.1 Number, Location and Frequency of Sampling

Unless soil gas samples are being collected just above the water table in the area of highest groundwater contamination, soil gas samples should be collected as close as possible to the structures being investigated for potential VI. Soil gas concentrations are typically greater beneath the building than at the same depth adjacent to the building in an open area, especially for shallow soil gas samples. Deeper soil gas samples collected immediately above the source of contamination (groundwater or soil) are likely to be more representative of what may be in contact with the structure's sub-slab, especially for chlorinated hydrocarbons. Samples should be collected on the side of the building closest to the groundwater contaminant plume. For petroleum only investigations, consult with the UST section or other DWM Program providing oversight regarding soil gas collection depths.

For chlorinated hydrocarbons and most VOC releases, DWM recommends the collection of soil gas in the vadose zone at the depth within one foot above the capillary fringe and a minimum of 5 feet below ground surface as close as possible to the structure being investigated.

Vertical profiling and multiple depth soil gas sampling can better clarify the source(s) of VI by evaluating the distribution of chemical concentrations over a defined depth. If a groundwater plume under a structure is the suspected source, soil gas concentrations should typically increase as the depth of the sample collection increases. Deviations from this general assumption may suggest an alternative source, such as preferential pathways, vapor leaks or vadose zone soil contamination.

The investigator should rely on the conceptual site model to determine an appropriate number and location of soil gas sample points. For example, if there are indications that groundwater could have large lateral concentration changes over short distances near a building, then more sample points may be necessary.

Precise sample locations will be dictated by the existing conditions around the building perimeter (e.g., other structures, landscaping, access issues) and the location of the groundwater plume. Generally, samples should be spaced horizontally along the perimeter of the building, at two to three times the depth to groundwater. If two soil gas sample locations have two to three orders of magnitude difference in concentration, it is recommended that at least one additional soil gas sample be collected between the two points.

Due to spatial variability and other uncertainties associated with soil gas and VI, it may be necessary to collect multiple rounds of near-slab soil gas to demonstrate that the concentrations are stable and not increasing, especially when soil gas concentrations are near the SGSLs.

4.4.3.2 Undeveloped Land and Future Use

Undeveloped land without existing structures presents a unique situation for the investigation of the VI pathway. The collection of sub-slab soil gas or indoor air samples is not possible without a structure on the parcel. However, subsurface vapor concentrations may be changed with the construction of a new building, excavation or installation of utilities, garages or subsurface structures.

If contaminated groundwater is located under the undeveloped parcel, the maximum groundwater concentration within the parcel should be compared to the GWSLs. If the groundwater concentration exceeds the GWSL, DWM recommends a soil gas survey be conducted to assess the potential for VI under a future use scenario. If the site is uncapped with concrete or other impervious cover, the soil gas samples should be collected in the vadose zone at the depth within one foot above the capillary fringe and a minimum of 5 feet below ground surface for chlorinated hydrocarbon or VOC releases. For petroleum-only investigations, consult with the UST section or other DWM program providing oversight regarding soil gas collection depths.

A grid sampling approach should be employed across the site and biased towards the highest concentrations within the groundwater plume.

If the soil gas results exceed the SGSLs, remediation of contaminated media to levels that will prevent vapor intrusion in future buildings may be required. Alternatively, the property owner can record appropriate land use restrictions that require evaluation of the VI pathway when buildings are constructed or may include engineering or institutional controls on the property to address future vapor intrusion concerns. In situations where the future use is already restricted by an institutional control, VI investigations may be postponed to some point in the future when development is being considered.

4.4.4 Sampling Procedure

Active soil gas sampling is typically conducted using permanent or temporary sampling points. Permanent sample points with stainless steel, nylon or Teflon tubing are recommended to assess the changing concentration of contaminants of concern over time for long term monitoring of sub-slab soil gas as part of a remedial action or operation of a sub-slab depressurization system. Temporary sample points using Teflon, metal, nylon, PVC or similar tubing are more appropriate during the initial phases of investigation when the VI pathway is being evaluated.

The primary sample container recommended for the collection of soil gas samples is stainless steel canisters. Either 1-Liter or 6-Liter canisters may be employed. The soil gas samples can be analyzed using USEPA Method TO-15 (or other appropriate certified methods). Smaller canisters and sample volumes are permissible with DWM approval.

Sample containers other than stainless steel canisters can be employed when screening or preliminary results are appropriate or with DWM approval. The investigator can utilize a Tedlar® bag for sample collection and analyze the samples with a field gas chromatograph (GC) or mobile laboratory. Alternately, a glass or Teflon® syringe can be used. As with the Tedlar® bags, syringe samples should be analyzed with a field GC or mobile laboratory. It should be noted that the holding time for Tedlar® bags should not exceed 3 hours. USEPA SW-846 Method 8260B and TO-14 are the most common methods utilized for field screening of soil gas samples.

The soil gas sampling points should be installed in such a manner to provide a tight seal around the sampling point and allow for collection of samples which are representative of sub-slab vapor conditions. **Perform leak tests on all soil gas probes and fittings of the sampling train prior to collecting a soil gas sample.** The ITRC document, *Vapor Intrusion Pathway: A Practical Guideline* (2007), Appendix D provides additional information on leak testing.

Whenever possible, DWM recommends on-site field analysis for leak check compounds using a helium tracer. On-site analysis will allow adjustments to be made immediately and may avoid a remobilization to the site for additional sampling. The investigator should discuss leak test methods with the appropriate DWM program with oversight of the project to ensure that specific requirements are being met. DWM recommends the use of helium as the tracer compound introduced through a shroud over the probe and sampling train. With the canister valve closed, collect a soil gas sample using a Tedlar® bag. A leak is considered to occur when the helium concentration is greater than 10% of the concentration within the shroud.

When a Tedlar® bag or syringe is utilized in combination with a field GC or mobile laboratory, the length of time for sample collection should be based on the professional judgment of the investigator but should not exceed 200 milliliters per minute to avoid short circuiting. In addition, a proper seal between the sample point and slab must be established to prevent indoor air from mixing with the soil gas sample.

For stainless steel canisters, typically, the sample flow rate should be a maximum of 200 milliliters per minute, which corresponds to a sample time of five minutes for 1-Liter canisters and 30 minutes for 6-Liter canisters. This maximum flow rate has been established due to the larger volume of stainless steel canisters and the concern over short circuiting. Smaller canisters and sample volumes are permissible with DWM approval.

Prior to attaching the sample container, the vapor probe should be purged by drawing 3.0 volumes through the probe and sampling train. The investigator should use a low purge rate with a maximum of 200-ml per minute.

4.4.5 Passive Sample Collection Methodologies

Passive sample collection includes two general sample collection techniques: the passive collection of contaminants onto sorbent material placed in the vadose zone and, a whole air passive collection technique for collecting vapors emissions from the soil surface using an emission isolation flux chamber.

Since the passive sorbent samplers provide results in mass concentration, their use is limited to field screening only during the investigation of the VI.

Passive sorbent sample collection utilizes diffusion and adsorption for soil gas collection onto a sorbent collection device over time. The soil gas data will delineate the nature and extent of subsurface contamination. The soil gas data at one location can be compared relative to the soil gas data from other sample locations in the survey. The mass levels will show patterns of the spatial distribution indicating areas of greatest subsurface impact. These areas can then be targeted for further investigation.

The flux chamber is an enclosure device used to sample gaseous emissions from a defined surface area. The data can be used to develop emission rates for a given source for predictive modeling of population exposure assessments or emission factors for remedial action designs.

The emission isolation flux chamber is a dome superimposed on a cylinder. This shape provides efficient mixing since no corners are present and thereby minimizing dead spaces. Clean dry sweep air is added to the chamber at a controlled volumetric flow rate. The gaseous emissions are swept through the exit port where the concentration is monitored by a real time or discrete analyzer. Real time measurements are typically performed with portable survey instruments to determine relative measurements of flux chamber steady state operation and areas of high contamination. Discrete samples are taken when absolute measurements are required for steady state concentrations and emission rate levels. The emission rate is calculated based upon the surface area isolated, sweep airflow rate, and the gas concentration. An estimated average emission rate for the source area is calculated based upon statistical or biased sampling of a defined total area. The ITRC document, *Vapor Intrusion Pathway: A Practical Guideline* (2007), in Appendix D provides additional information on flux chamber sampling.

Flux chamber sampling should not be used without first receiving approval from DWM. Justification should be provided as to why the emission isolation flux chamber method is more appropriate for this particular phase of the investigation.

4.5 Building Survey and Pre-Sampling Evaluation

A building survey and pre-sampling evaluation are critical elements of any VI investigation that includes indoor air and/or sub-slab soil gas sampling as an investigative tool. There are several components that should be addressed:

- Detection of potential background sources of volatile organic compounds.
- Determination of the building construction.
- Recognition of points of VI in a structure.
- Identification of possible sample locations.
- Education of the occupants on VI and sampling procedures.

Ideally, the building walkthrough should be conducted at least one week before the actual indoor air or sub-slab soil gas sampling event. This advance timeframe allows the investigator to identify and eliminate (to the extent practical) potential background sources of indoor air contamination. It also permits the investigator to confirm the sample locations with the occupants ahead of the scheduled sampling episode.

If crawl space samples are being collected, it is also important to survey the entire crawl space to identify any potential background sources of contamination. Often, sources of volatiles such as gas cans, small engine equipment, paint, etc. are stored in the crawl space. A survey of the crawl space will also assist in identifying potential VI entry points related to building construction and perforations in the floor.

4.5.1 Detection of Potential Background Sources

The VI pathway is greatly complicated by the impact of background contaminant sources and differentiating the common household sources of poor indoor air quality from those associated with contaminated groundwater or subsurface. DWM recommends the use of the *Indoor Air Building Survey and Sampling Form* (Appendix C) to assist with identifying background sources in the indoor air environment. The survey form allows the investigator to document various information on the building, occupants, and potential sources of indoor air contamination.

Another essential tool for pinpointing background sources of indoor air contaminants is the use of handheld field screening instruments which are now providing parts per billion (ppb) detection, making them appropriate for building walkthroughs and surveys during VI investigations. With a field screening instrument capable of detecting volatiles on a ppb range, areas of high VOC concentrations or individual items, paint or solvent cans for example, can be identified as vapor sources and removed from the building in advance of the sampling event.

When household or background sources of indoor air contamination are identified and removed from a building, it may be necessary to ventilate the rooms affected in advance of the air sampling event. **This ventilation should be completed at least 24 hours before the commencement of the indoor air sampling event.**

4.5.2 Recognition of Points of Vapor Intrusion in a Building

When elevated concentrations of soil gas are present below the foundation of a building, VI can occur through cracks in the walls and floors, sumps, penetrations in the foundation or around the wall/floor juncture of floating floor construction or other breaches in the basement walls or slab. Vulnerability to soil gas entry should be assessed for the building under investigation. Some of the tools that may be used include, but are not limited to:

- Use of a handheld field screening instrument capable of detecting parts per billion by volume (ppbv) levels to survey suspected entry locations.
- Visual inspection for cracks, holes and penetrations in the slabs or basement walls.
- Assess the effects of the HVAC system by monitoring pressure differences between the building and subsurface.
- Inject a tracer element in the subsurface and monitor for its presence in indoor air. Similarly, radon can be monitored in indoor air and compared to outdoor levels as an additional line of evidence.

Collecting relevant information regarding the HVAC system for the building is important for the VI investigation. HVAC systems bring outdoor air into the building, sometimes creating building over-pressurization, especially in commercial buildings. When the building is over-pressurized, the potential for VI is decreased.

It may be useful to evaluate the potential for VI by collecting indoor air samples when HVAC systems are often turned off, typically during the evening

4.5.3 Education of the Occupants on Vapor Intrusion and Sampling Procedures

One of the investigator's responsibilities when collecting samples within a structure is to educate the occupants on the VI pathway. Unlike other environmental matrices (soil, groundwater, surface water, or sediments), indoor air quality can have an immediate and possibly long term affect on human health that is not easily addressed by simple avoidance of the contaminated material.

During the building walkthrough, occupants are likely to raise a number of issues that the investigator should be prepared to answer. Refer to Section 7.0 for a discussion on how to conduct community outreach during the investigation of the VI pathway. In addition, two fact sheets, *What You Should Know About Vapor Intrusion* (Appendix D) and *Subsurface Depressurization Systems* (Appendix E) may provide further assistance.

A one page advisory paper entitled *Instructions for Occupants - Indoor Air Sampling Events* (Appendix F) should be provided to the occupants during the building walkthrough and at least one week prior to the sampling event. This sheet provides the occupants with a list of actions that should be avoided before and during the sampling event. Any deviation from the instructions noted during the sampling event should be documented on the *Indoor Air Building Survey and Sampling Form*.

4.6 Crawl Space

Before collecting indoor air samples, DWM recommends the collection of crawl space samples since it is less intrusive and typically does not involve other indoor air sources. Crawl space sampling results should be compared to the IASLs. For chlorinated hydrocarbons and VOC releases, the collection of crawl space air is often recommended in lieu of or in conjunction with soil gas sampling near buildings. Crawl space samples should be collected following soil gas or indoor air sampling procedures depending on the type of sample to be collected. The crawl space should be inspected for background sources before sampling, just as described for indoor air sampling. If a crawl space does not exist, or if crawl space air results exceed IASLs, indoor air samples should be collected.

When time allows, crawlspace samples should be collected during the time of year the structure is most prone to vapor intrusion. The following conditions should be evaluated when determining the sample collection time period:

- Cold weather: When the exterior of the building is colder than the interior, the heating of the indoor space can produce a chimney effect and cause air below the structure to rise into the structure. Cold weather sample collection should occur when the high temperature for the day will be less than 60 degrees (Fahrenheit). Generally, that means mid-November through mid-March for the mountains and upper piedmont and mid-December through mid-February for the lower piedmont and coastal plain.

- During seasonal high-water table: For areas with shallow water tables, sampling during the time of the seasonal high-water table should also be conducted.

- Positive pressure HVAC off: During the fair-weather periods of the year, an HVAC system may not cycle or will cycle less. If windows are opened, there will be more fresh air exchange. If windows remain closed, the structure may not be under positive pressure conditions, allowing vapors to enter from the subsurface. This for structures with positive pressure HVAC systems, periods of milder weather may allow more vapor intrusion than during the summer and winter months when the system is running more frequently.

- High concentrations initially detected may call for immediate retesting with another sample to follow during worst case conditions.

4.7 Indoor Air

If groundwater and/or soil gas concentrations exceed the screening levels, typically, the next step should be the collection of crawl space or indoor air samples. Site-specific conditions may warrant the collection of indoor air samples prior to characterizing groundwater, sub-slab gas or soil gas if immediate health hazards exist. Indoor air sampling results can be used to assess risk to human health by comparing the concentrations to the IASLs which are based upon EPA derived screening levels. The results can also be used alone or in conjunction with other lines of evidence such as groundwater and soil gas concentrations to determine if VI is occurring.

Indoor air sampling is generally the last investigative step in the evaluation of the VI pathway. Indoor air samples should typically be collected after other types of sampling, including groundwater, sub-slab gas, soil gas and crawl space air have indicated that there is a potential VI impact to a structure. Data from soil gas sampling employs an attenuation factor that can **estimate** indoor air concentrations resulting from VI; however, these procedures do not provide actual analytical data on the indoor air quality.

Indoor air quality is affected by a multitude of sources that originate both inside and outside any building that are not associated with VI. This complication may be unavoidable especially when products containing the same volatile chemicals that are under investigation can be found in the building under investigation. Therefore, it is important to develop multiple lines of evidence to evaluate indoor air.

DWM recommends that indoor air samples are collected concurrently with sub-slab soil gas samples. Sub-slab gas sampling results are used in conjunction with indoor air sampling results when evaluating human exposures, determining site-specific attenuation factors and evaluating potential indoor air background sources. Concurrent measurement of sub-slab and indoor air radon gas concentrations may be used in order to estimate building specific sub-slab to indoor air attenuation factors with the approval of the DWM program with oversight of the project (see Appendix G). Radon measurement may be particularly useful where indoor sources of contaminants of concern make it difficult to determine the proportion of indoor air contamination that is attributable to vapor intrusion. A radon-derived attenuation factor should be used as an additional line of evidence and not as the sole factor in determining if vapor intrusion is occurring.

When collecting indoor air and sub-slab soil gas concurrently, collect the indoor air samples prior to the sub-slab gas samples to prevent the sub-slab soil gas sampling from potentially affecting the indoor air samples.

4.7.1 Background Indoor Air Sources

Sources of background indoor air contamination can be broken down into several categories – household activities, consumer products, building materials and furnishings, and ambient air pollution. Smoking tobacco products, parking a car in an attached garage, using a kerosene heater, burning scented candles, dry cleaning clothes - all these household activities contribute to potentially unhealthful contaminant concentrations in the indoor air. The searchable household products database found at http://householdproducts.nlm.nih.gov can help identify potential indoor air sources.

Consumer products represent a second source of indoor air contamination that should be evaluated when assessing the contribution from VI. Mothballs (1,4-dichlorobenzene), nail polish remover (acetone), rug spot cleaner (tetrachloroethene), floor polish (xylenes), drain cleaner (1,1,1-trichloroethane), and gasoline (benzene, toluene, ethylbenzene, and xylenes) are just a few of the examples. (Refer to Table 2-3 for additional information). With the proprietary nature of consumer products today, it is often impossible to determine what chemicals are contained in most products. Either the labels do not list the ingredients or they will refer to some generic constituent, such as "petroleum products."

Building materials and furnishings are another source of indoor air contamination, particularly when they are new. Whether it's carpeting, shower curtains, fabrics and draperies, furniture, building insulation, or pressed wood products (particleboard, hardwood plywood, and medium density fiberboard), indoor air quality can be significantly affected by volatile organic compounds and formaldehyde emanating from these products.

DWM relies on a multiple lines of evidence approach when assessing potential background sources of indoor air contamination. Some of the tools that can be used to assist in differentiating or eliminating potential background sources include, but are limited to:

- Having a well-delineated groundwater plume (or subsurface soil contamination) with identified chemical contaminants including potential degradation products.
- Collecting sub-slab soil gas samples. When sub-slab sampling is not possible, the collection of exterior soil gas may be useful.
- Identification of preferential pathways.
- Collecting an outdoor air sample when conducting indoor air sampling to identify any outdoor influences.
- Use of the *Indoor Air Building Survey and Sampling Form* (Appendix C) when collecting sub-slab soil gas and indoor air samples to identify building characteristics, indoor

contaminant sources, miscellaneous items (such as "do you smoke or dry clean clothes?"), sampling information, and weather conditions.

- Providing occupants, the *Instructions for Occupants - Indoor Air Sampling Events*, found in Appendix F to possibly eliminate potential background sources.
- Utilization of local, regional, national, or international indoor air background. The USEPA's document Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion (USEPA 2011) is one resource for determining typical background concentrations in buildings.

If contaminants are detected that are not associated with the chemicals of concern under investigation at the site and are present in local ambient air or associated with activities or products in use in the building, they will not be included when determining whether final risk levels are met. Background determinations are made on a site-specific basis in consultation with DWM and as part of the overall multiple lines of evidence approach. A DWM toxicologist may advise the occupants of a building, as part of a health risk evaluation, of the additional risk posed by background sources and other detected contaminants that are not associated with the chemicals of concern under investigation at the site.

DWM recommends that indoor air sample analyses be limited to the chemicals of concern found or expected to be found in the subsurface to eliminate potential background sources. For example, if benzene was not found in groundwater or soil gas, it may be eliminated from indoor air sampling since it could originate indoors from other sources such as gasoline, cigarette smoke or adhesives.

4.7.1.1 Outdoor Air

An outdoor ambient air sample provides background concentrations outside of the building being investigated at the time of the indoor air sampling event. The investigator should clearly designate where the sample is collected and the site conditions at the time of sampling. The investigator also should be aware of the weather conditions during the sampling event. It is highly recommended that the sampling device be placed in a secure outside location and not in front of a building. Ambient air samples should be taken upwind of the building being investigated, at breathing zone height and as far from auto traffic or other potential sources as possible.

The ambient air sample should have the same sample collection time and be analyzed in the same manner as the interior sample.

The recommended number of ambient samples is one per sampling event. DWM may determine that subsequent sampling events do not require additional ambient sampling. If the sampling event occurs over multiple days, additional ambient samples may be recommended at the discretion of DWM. If the spatial arrangement of the sampling points is dispersed and background cannot be easily defined, additional ambient samples may be recommended.

It is highly recommended that suitable precautions be taken whenever VI investigations include outside air sampling. The sampling equipment (e.g., stainless steel canisters) and related devices are not familiar to most individuals and may be misinterpreted as a safety concern; therefore, the investigator may consider notifying the local police and fire departments, in addition to the municipal officials. It may be necessary to demonstrate the operations of the sampling equipment to these officials. A label should be affixed to the sampling device explaining the nature of the equipment and all appropriate contact information in case there are further questions. The individuals collecting the indoor air samples should be prepared to provide proper identification to the building occupants.

4.7.2 Sampling Considerations

In situations where ambient indoor levels for contaminants of concern are expected to be elevated based on the nature of the commercial/industrial/retail operation, the investigator should consider avoiding the collection of indoor air samples. For example, at active dry-cleaners, if groundwater contaminant concentrations exceed the GWSL, DWM recommends the collection of sub-slab soil gas samples where possible in lieu of indoor air samples.

When sampling indoor air or sub-slab soil gas, DWM recommends removing potential indoor air sources that may contain similar chemicals to those being investigated if possible. It may not be possible to remove all sources, especially in an industrial setting. An attempt to remove any potential indoor air sources will help ensure that indoor air results will be more indicative of VI than indoor air sources. After removal of any indoor air sources, DWM typically recommends that the investigator wait 24-72 hours before collecting indoor air samples.

4.7.3 Number, Location, Duration and Frequency of Sampling

For a typical residential or non-residential building, DWM recommends a one time-integrated sample per 1500 square feet directly above the floor or crawl space. In general, samples should be collected from the breathing level zone of the most sensitive occupant population. The investigator should determine the appropriate number of sample locations based on several factors including, but not limited to:

- Very large or small buildings.
- Subsurface structures. For example, it may be appropriate to collect an indoor air sample from a basement or elevator pit in addition to the first floor.
- Buildings with multiple uses. For example, a commercial building may also have a day care center, and it would be appropriate to collect indoor air samples from both areas of the building.
- Buildings with different tenants separated by wall partitions. Some tenant spaces may share the same HVAC air space and have a false ceiling.
- Areas of the building may have cracks or perforations in the floor that make that area more susceptible to VI.

Indoor air samples are generally collected from the lowest floor in the building. Samples may also be collected from more than one floor within a structure to address varying exposures and as part of the process to distinguish contaminants related to VI from background sources. Thus, the location and position of the sample container will vary depending on which floor the sampling event takes place. Ground floor (living space) samples should be located to approximate human exposure. These indoor air samples are generally placed at breathing zone height (3-5'). Consideration should also be given on a case specific basis to those situations (such as a day care facility) where a different sampling height may be appropriate to evaluate a unique setting or population. The basement sample(s) are primarily designed to investigate "worst case" situations within a building. Therefore, basement samples should be positioned as close as possible to the source area (e.g., sumps, major cracks in foundation).

The use of passive samplers allows the collection of indoor air samples over a longer time, up to 30 days, thereby providing an average indoor air concentration over a longer exposure period.

Sample duration should be determined by the potential receptors and the detection limits necessary to reach the IASLs. Typically, for residential exposure, a minimum 24-hour sample is required since residents are in the home 24 hours a day. For nonresidential exposure, a minimum 8-hour sample is required since workers typically have an 8-hour work day. Depending on the sample type, it may be necessary to collect samples over longer periods of time to reach the IASLs.

Indoor air samples should be collected concurrently with ambient air and sub-slab soil gas samples. The analytical results are useful in the differentiation of background contamination in indoor air. By comparing the site-specific contaminants of concern detected in the soil gas sample with the indoor air and ambient air results, the investigator can validate the designation of background contaminants and thus limit any remedial action.

It may be necessary to collect several rounds of indoor air samples based upon the season and operation of the HVAC system.

Depending on the site conditions, the volatile concentrations in groundwater, and seasonal variability, one round of indoor air samples will likely not be sufficient to verify the presence/absence of the VI pathway. A second (or confirmation) round of indoor air samples may be appropriate. At a minimum, a confirmation sample is necessary to eliminate the VI pathway when the initial sample is collected outside the winter or summer timeframe when structures can be expected to be closed up with the HVAC running. Additionally, higher indoor air concentrations might be expected when a building is sealed up and the HVAC is not running. **A single round of sampling is acceptable (irrespective of the seasonal timing of the sampling event) when the results are an order of magnitude below the appropriate IASL.** Modifications to this provision may be appropriate based on site-specific information and with DWM approval.

4.7.3.1 Co-Located Properties

Often, indoor air samples are collected where other residential or nonresidential spaces are co-located with the site being investigated (e.g. strip centers, duplexes, mixed-use developments). If indoor air samples are collected in one building space and the results exceed IASLs for the appropriate setting (residential or nonresidential), indoor air and concurrent sub-slab soil gas samples (if on a ground floor) should immediately be collected in the immediately adjacent building spaces. When indoor air results exceed IASLs at a site being investigated on a ground floor and separate building spaces are located above the site, indoor air samples should be collected from the spaces above and adjacent to the site. Based upon the results from the adjacent building spaces, the investigation should continue outward as necessary.

4.7.4 Sampling Procedures

Time-integrated sampling methods are generally recommended for indoor air to account for variability.

Analytical method TO-15 employs stainless steel canisters to collect whole air samples. Volatile organic compounds (both polar and non-polar) are concentrated on a solid multisorbent trap, refocused on a second trap, separated on a gas chromatograph column, and passed to a mass spectrometer for identification and quantitation. TO-15 is the principal method used for indoor air samples primarily due to the ease of use for the investigator and the limited obstruction for the occupants of the building (compared to other sampling equipment).

Method TO-17 uses adsorbent tubes for the collection of air samples in the field. There is a large selection of sorbents that can be matched to the contaminants of concern. The tubes are thermally desorbed into a gas chromatogram/mass spectrometer instrument system. The method requires specific collection procedures and states that after desorption on to the column the samples are to be analyzed in accordance with USEPA Method TO-15.

4.7.4.1 Passive Samplers

In recent years, a variety of passive diffusion samplers have been gaining popularity for indoor air sampling since they provide some advantages over traditional canister sampling, especially for screening purposes. They are typically small, easy to deploy and can be used for various sampling periods up to 30 days. Previous experience has shown that occupants are more likely to allow deployment of passive samplers rather than a canister, due to its appearance and the ability to place them in a less conspicuous location. Using passive samplers avoids the problems associated with leak testing and flow regulators that often accompany canister sampling.

Before using passive samplers, the investigator should understand the limitations of the sampler and ensure that proper detection limits can be obtained. There are different reporting limits for different sampling times. The reporting limits should be low enough for adequate comparison to the IASLs. Additionally, passive samplers should be appropriate for the chemicals of concern be investigated since some compounds are less reliably detected with passive samplers due to unknown uptake rates.

If using passive samplers, it is recommended that the first sampling event be conducted with both passive samplers and traditional canister methods to compare results and determine if there is acceptable correlation between the results. The chemicals of concern may dictate the sampling type since passive samplers are not capable of quantifying certain chemicals. Passive samplers may be used with prior approval from DWM.

4.8 Quality Assurance/Quality Control

Detailed Quality Assurance/Quality Control (QA/QC) procedures are not provided in this guidance document. The investigator should be familiar with sampling procedures, analytical methods and QA/QC requirements prior to conducting any sampling event. Standard operating procedures for the collection of samples should be included with any reports or sample results documentation submitted to DWM.

Analyses should be performed by an accredited laboratory that has demonstrated competence and compliance with the methods for the matrix being analyzed. The investigator should have confidence in the QA/QC requirements enforced at the accredited laboratory being utilized. The investigator should verify the vacuum when using stainless steel canisters, before and after the sample collection. The investigator should verify the canister's initial vacuum prior to collecting a sample. If the initial vacuum prior to sampling is in excess of 10% lower than the vacuum documented by the laboratory upon shipment, the canister should not be used. The post-sampling vacuum in the canister should be recorded. A residual vacuum of up to -5 inches mercury must exist in the canister upon completion of the sampling event and laboratories should report the received vacuum. Since the sample is designed to be collected over a specified period of time (i.e., 8 to 24 hours), the residual vacuum ensures that the sample was collected over that time period and ensures that the samples are not damaged or altered during transport. If no vacuum remains, the validity of the data is questionable.

For soil gas and indoor air samples collected via Summa canister, a particulate filter should be used over the probe to avoid clogging. Summa canisters can be batch or individually certified for specific needs. The certification process ensures the canisters are first cleaned then evacuated to achieve the appropriate negative pressure. A batch certification process is appropriate for routine ambient air application, soil vapor and landfill gas monitoring, but canisters should be individually certified for indoor air testing. Analytical labs should be contacted in advance to be sure that canisters are available and appropriately certified for the type of sampling and potential contaminants that may be atypical or unusual. VI evaluation reports should include a summary of the lab procedures used to decontaminate and certify equipment.

5.0 DATA EVALUATION AND SCREENING

DWM recommends a multiple lines of evidence approach for determining whether the VI pathway is complete or incomplete, whether levels of contaminants in indoor air are likely caused by VI versus an indoor or ambient air source, whether indoor air concentrations pose an unacceptable health risk, and whether an interim response is needed to mitigate VI. The vapor intrusion pathway should be evaluated using multiple lines of evidence that may include, but are not limited to:

- Presence of contamination in the subsurface that could be a source of VI.
- Potential for vapors to migrate from the source to current or future buildings.
- Groundwater data and comparison to the GWSLs.
- Soil gas data and comparison to the SGSLs.
- Data on site geology and hydrology that supports groundwater and soil gas migration.
- Preferential pathways for subsurface vapor migration.
- Building conditions that demonstrate susceptibility for soil gas entry.
- Pressure data to demonstrate the driving force for soil gas entry.
- Crawl space or indoor air data and comparison to the IASLs.
- Comparison of soil gas and indoor air data, including evaluation of attenuation factors.
- Background indoor air sources of contamination.
- Outdoor air data to assess potential ambient air contributions to indoor air data.
- Indoor air results comparing when HVAC is operational and non-operational.
- Evaluation of tracer elements or naturally occurring radon.

Ideally, the investigator will have enough lines of evidence to support a decision regarding the VI pathway. Not all lines of evidence will be definitive. The investigator must use scientific and professional judgment to determine when the VI pathway is complete or incomplete. In general, when lines of evidence are inconsistent, DWM recommends collecting a new line of evidence or collecting additional data to add weight to the existing evidence.

When evaluating sampling results to assess the VI pathway, it is important to first determine that the samples were collected appropriately. After verification, the sample results can be compared to the appropriate medium-specific DWM screening levels. Risk-based screening is used to identify sites or buildings likely to pose a health concern, to identify buildings that may warrant immediate action, to help focus site-specific investigation activities or to provide support for building mitigation and other risk management options including remediation.

Generally, if all sample results for a given building or area are below the respective screening levels, then VI is less likely to pose an unacceptable health risk to occupants. When sample results exceed the screening levels, additional evaluation, assessment or mitigation are warranted. However, if any individual sampling result exceeds the screening level, that does not mean VI will pose an unacceptable health risk. Sample results can be expected to be variable spatially and temporally, and the DWM screening levels are very conservative and assume a long period of exposure at that level. The Risk Calculator can be used to directly calculate risk associated with multiple chemicals either using groundwater, soil gas, crawl space <u>or</u> indoor air data.

The following sections discuss medium-specific data evaluation considerations and screening procedures.

5.1 Groundwater

The investigator should compare the highest groundwater concentration present within 100 feet of any structure to the appropriate GWSLs (residential or nonresidential). If a particular chemical is not found on the GWSL tables, contact the appropriate DWM cleanup program about developing a screening number for that chemical.

If the groundwater concentrations do **NOT EXCEED** the GWSLs, typically no further VI investigation is necessary unless the investigator has knowledge of site-specific conditions (i.e. preferential pathways, structural features, etc.) that may warrant further investigation. If the groundwater concentrations do **NOT EXCEED** the GWSLs (or calculated risk) but there is near-slab soil gas that exceeds the SGSLs, the VI investigation should proceed with additional soil gas, crawl space or indoor air sampling.

If the groundwater concentrations **EXCEED** the GWSLs (or calculated risk), further investigation should proceed in a step-wise fashion, typically with the collection of soil gas samples. However, it should not be assumed that elevated groundwater concentrations automatically indicate that unacceptable levels of vapors are currently entering the structure. Groundwater concentrations that are slightly above the GWSLs or are fluctuating above/below the GWSLs may warrant further monitoring before proceeding with additional sample collection. **Soil gas may be collected immediately above the water table near the highest groundwater concentration and compared to the SGSLs to demonstrate that groundwater concentrations do not pose a potential for vapor intrusion.**

The plume should be shown to be stable or shrinking to indicate that the potential for VI will not increase in the future.

The groundwater data shall be evaluated to determine whether the contaminant plume has been delineated to the extent needed to assess the VI pathway. If it is determined that the plume has not been sufficiently delineated, additional groundwater samples will be required to complete the delineation as it pertains to this pathway. Any newly obtained groundwater data within 100 feet of structures should be compared to the appropriate GWSLs. Depending on the soil type, the presence of preferential pathways, and/or certain hydrogeologic features, the distance criteria may have to be modified. The results of this effort will highlight those structures that will necessitate further investigation for the VI pathway.

In cases where soil contamination represents a potential source of VI, the use of groundwater data and the GWSL alone are NOT appropriate. The investigator should employ soil gas and/or indoor air samples to assess whether soil contamination is a source of VI.

5.2 Soil Gas

The analytical results from exterior soil gas samples should be compared to the SGSLs. If exterior soil gas results **EXCEED** the SGSLs (or calculated risk), typically it is recommended that sub-slab soil gas samples be collected, if possible, before proceeding to the collection of indoor air samples. If soil gas results **EXCEED** the SGSLs (or calculated risk), crawl space or indoor air samples should be collected (except at operating facilities where the chemical of concern is in use). The investigator may propose a site-specific approach involving the use of alternative attenuation factors that may be acceptable to DWM in lieu of crawl space or indoor air sampling. Based on the soil gas results and professional judgment, a determination may be made that implementing an interim or permanent mitigation measure may be the most cost-effective and proactive approach prior to proceeding with further sampling.

DWM does not typically allow the results of the soil gas samples to be averaged across a slab or the subsurface around a building. Individual results should be compared to the SGSLs.

Passive soil gas sampling is often useful in the preliminary delineation of the groundwater plume or as a screening tool to direct active soil gas investigations. Passive soil gas results should **NOT** be compared to SGSLs.

If soil gas concentrations do **NOT EXCEED** the SGSLs (or calculated risk), typically no further investigation is necessary and the VI pathway may be considered incomplete if the investigator is confident in the CSM and the data collected are adequate to evaluate the VI pathway. The SGSLs are expected to be conservative due to a generic default attenuation factor. Additionally, soil gas samples are expected to be highly variable spatially and temporally and the SGSLs assume exposure to a conservative concentration over long periods of time.

In those situations where the soil gas results do <u>not</u> exceed the SGSLs (or calculated risk) but groundwater concentrations exceed the GWSL, a site-specific determination can potentially be made that no additional VI investigation is needed. This determination should be based on an accurate CSM and representative groundwater data which indicates:

- The shallow groundwater plume is stable or shrinking,
- NAPL is not present,

- Other site conditions at the time of sampling (e.g., soil moisture, % oxygen in vadose zone) are unlikely to change enough to result in higher soil gas volatile levels.

Analytical data from soil gas samples should be assessed to identify any patterns in particular chemicals, groups of chemicals, and/or their concentrations (both individually and collectively). When combined with data from other matrices (e.g., groundwater, indoor air, and ambient air), these patterns may assist in distinguishing likely sources of indoor air contaminants and their pathways. This is important when background sources located within the structure generate the same volatile organic compounds identified as contaminants of concern associated with the site investigation. **By comparing the specific chemicals detected in the soil gas sample with the groundwater or soil contaminants associated with the site investigation, a verification of the contaminants of concern can be made. The compounds should be similar. If additional compounds are seen in the soil gas results, a background indoor air source may be present.**
This determination validates the designation of background contaminants and thus limits any remedial action to site related contaminants.

The presence of elevated contaminant vapors in the sub-slab soil gas is generally a positive indicator of VI when applying an attenuation factor. However, the reverse circumstances (low contaminant levels in the sub-slab soil gas) do not automatically imply that the vapor pathway is incomplete. Site-specific conditions, such as distance from any vadose zone sources and depth of those sources should be evaluated before reaching any conclusions on the VI pathway.

With soil gas sampling, it is important to understand the stratigraphy in the area of the building. Low permeability layers under buildings (either natural or as part of construction) may act as an impediment to significant vertical vapor migration from the groundwater contamination. The presence of such a layer may explain why random or irregular soil gas results occur when comparing data from several sample locations around a building or why clean sub-slab samples can occur even though underlying groundwater is contaminated. Soil gas results may not be consistent with the concentrations found in the underlying groundwater plume. Soil gas may still enter the building through utility trenches or other preferential pathways if they bisect or circumvent the low permeability layer.

5.3 Crawl Space

The analytical results from crawl space air samples should be compared to the IASLs since DWM recognizes NO attenuation between crawl space and indoor air. If the crawl space air results exceed the applicable IASL, additional investigation of the VI pathway is necessary to confirm the results. Typically, indoor air samples should then be collected with confirmation soil gas and/or crawl space samples.

5.4 Indoor Air

All indoor air concentrations should be compared to the IASLs (or cumulative risk can be directly calculated with the Risk Calculator). The investigator should check with the appropriate DWM cleanup program to determine the applicable IASL. Various DWM programs use IASLs at different target risk levels ranging from $1x10^{-4}$ to $1x10^{-6}$ and a Hazard Index of 1. DWM does not subtract ambient (outdoor) air or background concentrations before comparison to the IASLs.

DWM does not accept averaging of the results of the indoor air samples within a building. Therefore, each data point should be evaluated independently of each other.

Indoor air sampling results exceed the IASL (or calculated risk) for a cumulative target risk of 1E-04 or Hazard Index of 1 - a confirmation sample should be collected immediately. Based upon the degree of indoor air contamination, mitigation may be initiated before obtaining the results of the confirmation sample. If the confirmation sample exceeds the IASL (target risk 1E-04 or Hazard Index of 1), mitigation and/or remediation of the VI source is required.

For all DWM programs, a confirmed exceedance of a cumulative risk of $1x10^{-4}$ or Hazard Index of 1 will require mitigation and/or remediation of the VI source.

Indoor air sampling results between the IASL for a target risk of 1E-04 and 1E-06 and Hazard Index less than 1 - at least one additional confirmation sample is required. DWM recommends that one of the samples be collected in winter or summer conditions, typically when it would be expected that the structure would be closed up and the HVAC system operating. However, worst case conditions may also be considered when the building is closed up and the HVAC system is not running. It may be necessary to collect samples under different HVAC operation scenarios for comparison. If the results of the confirmation sampling during worst case conditions confirm the results of the first sample, typically, no further sampling is required. If the confirmation sample indicates indoor air concentrations that exceed the IASL for a target risk of 1E-04 or Hazard Index of 1, additional sampling and mitigation should be conducted.

Indoor air sampling results are below the IASL (or calculated risk) for a target risk of 1E-06 and Hazard Index of 1 - no further sampling is required.

Multiple Sampling Locations on the Same Floor - If multiple samples were collected from different locations on the same floor of a building, the results may identify probable background sources when combined with a building walkthrough and survey. Compare the locations of suspect consumer products (e.g., paints, thinners) or household activities (e.g., hobbies, smoking) with the indoor air sample results. Evaluate whether particular volatile organic compounds are higher or lower in certain portions of a building and if they correlate with identified background sources. In addition, compare the analytical results with potential VI routes through the building slab or foundation (e.g., sumps, utility lines, major cracks). Depending on the ventilation system in the basement or crawl space, differences in concentrations of site-specific contaminants of concern between multiple sample points may be related to their relative position near VI points (and not background sources).

Compare the results for individual compounds on each floor. In general, the concentrations should decrease as you move away from the source.

Sampling Locations on Multiple Floors - If indoor air samples were collected from at least two separate floors within a structure, preferably the basement (or lowest floor) and the level immediately above it, the results may assist in the assessment of potential background contaminant sources. This is critical in situations where sub-slab soil gas samples are not collected. **If VI from contaminated groundwater or subsurface soil is the main source, the highest concentrations should be in the basement (or lowest floor) and decrease as you move up to the first or second floor.** Conversely, if the higher concentrations are found in the upper floors (when compared to the basement results), a background source unrelated to the site is probably located within the building on the floor with the highest concentrations. Deviations from this general understanding of vapor movement may exist in situations where a vertical pathway allows vapors to move quickly from one floor to the next (e.g., elevator shafts, laundry chutes).

Co-Located Spaces - When the site under investigation is co-located with other businesses or separate building spaces, it is often necessary to collect sub-slab and/or indoor air samples from the adjacent spaces. DWM recommends that a step-wise approach be utilized. **If IASLs are exceeded in any co-located building space, then sub-slab sample and indoor air samples should be collected from the immediately adjacent building spaces.** If samples from the immediately adjacent building spaces exceed the IASLs, then the next building spaces should be sampled and so on.

Indoor air contaminants from a site may impact adjacent building spaces due to building construction, environmental factors and business practices. In nonresidential buildings such as strip centers, businesses often share HVAC systems, common walls with perforations for piping, conduit, etc. and drop ceilings that allow air flow over walls. Some businesses, for example dry-cleaners, may leave doors open and run fans during the summer, pushing indoor air into adjacent spaces. **The investigator should document business practices, building construction details and any other factors that may be important to evaluate if indoor air contaminants from a site are impacting adjacent spaces.**

Typically, if vapor intrusion is impacting adjacent spaces, evidence can be found by examining the ratio of sub-slab gas to indoor air.

The results from all sub-slab soil gas and indoor air sampling should be evaluated to determine if vapor intrusion is occurring in adjacent spaces. Some of the indications that vapor intrusion is **NOT** occurring and indoor air contaminants are from other indoor sources are: decreasing indoor air concentrations further away from the investigation site and low sub-slab concentrations and high indoor air concentrations in the adjacent space.

In some cases, it has been observed that the investigation site will have low sub-slab concentrations and indoor air concentrations, but the adjacent building space will have higher sub-slab and indoor air concentrations. In these instances, additional source areas have been found that extend under shared walls, creating a greater vapor intrusion concern in the adjacent building space.

5.5 Comparing Indoor Air and Sub-Slab Soil Gas Samples

DWM recommends that the collection of indoor air and sub-slab soil gas samples be conducted concurrently during the investigation of the VI pathway whenever possible. The combination of indoor air and sub-slab soil gas results will assist in identifying likely background indoor air sources and verify whether a VI source exists below the building (instead of extrapolating contaminated groundwater or subsurface soil results from indoor air).

Compare the indoor air and soil gas sample results to see if the same chemicals of concern are found in both samples. If the same contaminants are found in indoor air at lower levels than they are present in soil gas, this is an indication that VI may be occurring if background sources are not contributing to indoor air.

Frequently, contaminants will be found in the indoor air, but not the sub-slab soil gas samples. The compounds are likely originating from background sources unrelated to VI (especially if they are not site-specific contaminants of concern). In these cases, the investigator should evaluate vadose zone (soil) contamination and preferential pathways as potential contributors to indoor air contamination that might not be detected in the subsurface soil gas results. Once it is established that VI is not contributing to the indoor air contamination, no further action is necessary for this pathway.

When the indoor air concentrations are below the IASLs, but the sub-slab soil gas results are elevated, this could indicate a potential source in the subsurface. In these situations, DWM recommends the following:

- For sub-slab soil gas results that are 10 times or less the SGSL, the options are no further action or continued monitoring.
- If the sub-slab soil gas results are greater than 10 times the SGSL, continued monitoring of sub-slab soil gas can be implemented or a remedial action investigated. Changes in site conditions may create the potential for vapor intrusion in the future if the soil gas concentrations or source are not addressed.

The investigator should use professional judgment when determining if continued monitoring or remedial action is appropriate. Factors to be considered include:

- The relative exceedance of the screening level,
- The ratio of the sub-slab soil gas and indoor air results,
- The current building construction (e.g., 1^{st} floor garages, sub-slab vapor barriers, etc.),
- Possible effects of background sources of contamination, and
- Sampling errors.

In many situations, both the sub-slab soil gas and the indoor air results will exceed the applicable screening levels (or calculated risk). In this case, it is likely that the VI pathway is complete and appropriate mitigation or remedial action is required.

Frequently, contaminants will be found in the indoor air, but not the sub-slab samples. In these cases, the compounds are likely originating from background sources unrelated to VI. The occupants will be directed to consult with the local health department on ways to reduce background contamination.

A concentration gradient between the sub-slab and indoor air samples (greater than 20x higher in the sub-slab) strongly suggests that the VI pathway is complete. Conversely, higher concentrations within the structure (when compared to sub-slab results) would indicate that a secondary background source is likely present inside. This scenario, however, doesn't eliminate the fact that the VI pathway may still be contributing to the poor indoor air quality within the structure.

5.6 Official Notification

Although investigators may elect to forward results (or be bound to do so by property access agreements), it is DWM's policy to officially notify property owners and tenants about their indoor air and/or soil gas analytical results. However, it is ultimately the property owner's responsibility to ensure that all potentially impacted current and future building occupants are informed. The notification from DWM will consist of a cover letter explaining the findings and summary of the analytical results.

In cases where the compounds are concluded to be originating from background sources unrelated to VI, the occupants will be directed to consult with the local health department on ways to reduce background contamination.

5.7 Report Requirements

The results of the VI investigation are typically documented in a report that should, at a minimum include the following:

1. Copies of the Indoor Air Building Survey and Sampling form.
2. Scaled site maps identifying the site, adjacent streets, buildings sampled (soil gas/indoor air), ambient air sample locations.
3. Photographs of sample locations (as appropriate) or other pertinent site features.
4. Readings from field instrumentation.
5. Laboratory analytical results.
6. Sampling procedures.
7. Names and addresses of all property owners and current tenants to be notified of results.
8. Any documentation, including scaled maps, on the assessment of preferential pathways.
9. Scaled floor plans that note location of indoor air and sub-slab soil gas samples, observed stains and major cracks in slabs/foundations, sumps, French drains, existing radon systems, chemical storage areas (or other potential background sources), HVAC systems, utility entrances into buildings, etc.

6.0 REMEDIATION AND MITIGATION

Ultimately, the DWM's primary goal is to remediate the source of the vapor contamination (groundwater and/or subsurface soil) such that the risk of VI is eliminated. Excavation and/or treatment of soil sources and groundwater remediation have proven effective in reducing contaminant levels associated with VI. However, it is often not technically possible or feasible to complete such remediation in a timely manner. Therefore, appropriate preventative or mitigation measures may be necessary.

One preventative measure that may be considered is an institutional control, such as deed restrictions or zoning, that may eliminate the potential for VI to occur under current or future conditions. Restrictions may incorporate measures to be taken for new building construction that can address any potential VI issues or specify engineering controls that may be required to mitigate current or future VI potential.

Mitigation needs to be considered when it is determined that the VI pathway is complete and may adversely impact human health. **When the indoor air concentrations are confirmed and exceed the IASLs at a target risk of 1 x 10^{-4} or Hazard Index of 1, mitigation is required.** The objective of these mitigation techniques is to eliminate the pathway between the source (contaminated groundwater and/or subsurface soils) and the receptors (building occupants).

In some circumstances, monitoring only may be appropriate in lieu of active mitigation. For example, when sub-slab soil gas results exceed the SGSLs but the indoor air results are below IASLs, it may be more appropriate to collect indoor air samples on a semi-annual or annual basis to ensure that indoor air levels are still below IASLs.

If mitigation is required by the Brownfields Program, or if pre-emptive mitigation is chosen by the Prospective Developer, all design submittals must adhere to the format outlined in the *Vapor Intrusion Mitigation System (VIMS) Design Submittal New Construction Minimum Requirements Checklist* found in Appendix H.

Since there are many documents regarding mitigation, this section only briefly discusses the various mitigation actions appropriate for VI and the operations, monitoring and maintenance provisions associated with these remedial actions.

It is highly recommended that investigators refer to the following documents for more detailed information regarding mitigation:

ITRC document titled Vapor Intrusion Pathway: A Practical Guideline (January 2007) (http://www.itrcweb.org/Documents/VI-1.pdf)

USEPA's Radon Reduction Techniques for Existing Detached Houses - Technical Guidance (http://epa.gov/radon/pubs)

6.1 Mitigation Methods

While remedial investigation and remedial action of the vapor source are ongoing, mitigation techniques should be implemented to prevent VI. DWM generally does not review engineering design specifications for VI remedial systems. The investigator or entities responsible for implementing the VI remedial system shall demonstrate the effectiveness of the remedial action by collecting verification samples. Some mitigation methods are listed below; the first three of which are typically implemented at a minimum:

- Sealing openings and cracks with caulk or expanding foam (preferably volatile-free).
- Repairing compromised areas of the slab or foundation.
- Covering and sealing exposed earth and sump pits.
- Installing a sealed vapor barrier (e.g., plastic sheeting, liquid membrane) over earthen, gravel, etc. floors or crawlspaces.

- Utilizing natural ventilation.
- Installing a subsurface depressurization system.
- Adjusting HVAC systems/air exchange rates.
- Utilizing house pressurization.
- Installing a soil vapor extraction system.

Certain field instruments may be useful in detecting locations where VI is occurring to further identify cracks and openings that need to be sealed. Subsurface depressurization systems are the most common mitigation method and are discussed below.

6.1.1 Subsurface Depressurization Systems

The objective of the subsurface depressurization system is to apply a negative pressure field or vacuum beneath and/or around the building of concern, thereby preventing VI into the building. Subsurface depressurization systems can be either passive or active. A fact sheet regarding sub-slab depressurization can be found in Appendix E.

Sub-Slab Depressurization (SSD) - can be used when a building has a slab (e.g., concrete) floor. Typically, piping and/or suction points are installed in the subsurface beneath the slab and a fan is used to create a negative pressure field in the sub-slab area and discharge any vapor outside the building. Depending on the size of the slab and the characteristics of the sub-slab material, piping may have to be installed beneath the slab in multiple locations in order to create a negative pressure field across the entire sub-slab area.

Sub-Membrane Depressurization (SMD) - can be used when a building has an earthen (or gravel, etc.) floor or crawlspace, as opposed to a slab. A membrane such as plastic sheeting is used to cover the earthen floor or crawlspace area and, similar to SSD, a negative pressure field is created beneath the membrane thereby preventing VI across the membrane. The membrane needs to be properly sealed to the building walls, etc. and kept intact in order to maintain the negative pressure field.

Block-Wall Depressurization - can be utilized when a building has a block wall foundation. In this scenario the negative pressure field is typically created via piping inserted through the voids in the block wall. Any openings in the top of the block wall and all openings or cracks on the interior surface of the wall should be sealed. This technique is typically used in conjunction with one of the other depressurization techniques.

Drain Tile Depressurization - can be utilized when a building has a loop of perforated drain tiles (piping) adjacent to the building footers for water drainage. If the drain tiles discharge to a sump pit, the sump pit is sealed and the negative pressure field is applied to the sump pit. If the drain tiles discharge to an outdoor location the negative pressure field is applied to the drain tile loop at an outdoor location.

Passive Mitigation Methods - examples include vapor barriers, perforated piping to collect vapors and exhaust piping through a building discharging above the roof. Passive mitigation methods do not use a fan or blower to move air from the subsurface. Passive techniques often work by utilizing pressure gradients, wind and thermal effects to develop a natural vacuum effect. These systems are not as effective as active subsurface depressurization systems and are not recommended for existing buildings. **Typically, passive methods are best applied to new building construction or in**

existing buildings where it has been demonstrated that site-specific conditions exist that will allow a passive system to be as effective as an active system.

6.1.2 Other Mitigation Methods

The use of any mitigation method must be approved by the appropriate DWM cleanup program overseeing the remediation of the site. When subsurface depressurization systems are not appropriate based on-site conditions or technical considerations, other alternative mitigation approaches may include:

- Flooring systems such as Cupolex® that create voids beneath the slab for ventilating vapors.
- HVAC modifications.
- Source removal.
- Sub-slab pressurization.
- Soil vapor extraction systems.
- Limiting access to the affected building(s).

6.2 Mitigation Design and Implementation

6.2.1 Pre-Construction Considerations

DWM's primary goal is to remediate the source of the vapor contamination (groundwater and/or subsurface soil) such that the risk of VI is eliminated. However, it is often not technically possible or feasible to complete such remediation in a timely manner. **Therefore, if a property designated for development has a potential for vapor intrusion risk, DWM recommends that proactive measures (vapor barrier, vapor barrier with passive depressurization system, active depressurization system, etc.) be designed into the building.** These proactive measures are relatively inexpensive, especially compared to the cost of retrofitting them after the building is constructed.

The ITRC document titled, Vapor Intrusion Issues at Brownfield Sites (December 2003) (http://www.itrcweb.org/Documents/BRNFLD-1.pdf) provides a discussion regarding redevelopment of property and ways to prevent vapor intrusion in new construction.

6.2.2 Design Considerations

The installer of any mitigation system should visually inspect the site where the system will be installed prior to installation to assess any impediments or unusual circumstances that may affect the installation and to determine the best location for the system.

Cracks or openings in the slab should typically be sealed prior to system installation. Some areas that are commonly sealed are openings in walls or the slab where pipes or utility lines exist, floor drains, areas around sumps and any portions of the floor that are not covered by the slab.

The subsurface depressurization system should be designed to prevent backdrafting of combustion products into a structure. As a safety precaution, the depressurization system fan should be located outside of the building as the fan housing is the most likely location for a leak to occur in the system. DWM recommends subsurface depressurization systems contain the following:

- A pressure gauge (u-tube manometer) for determining operational efficiency.
- An alarm that informs building occupants in case the system malfunctions.
- Labeling that indicates the purpose of the system along with the name, address and telephone number of the entity to contact for questions, repairs, etc.

Diagnostic testing should be performed prior to, during and/or after installation to make sure that there are sufficient suction points to achieve the required vacuum levels over the entire slab. Also, a communication test is recommended to determine the number and locations of the suction points and fan size. Suction fields beneath the slab can be interrupted by subsurface features such as foundation walls, footings, or other man-made features.

6.3 Operation, Monitoring and Maintenance

6.3.1 Institutional and Engineering Controls

Mitigation actions (or interim remedial measures) that involve the installation of subsurface systems, vapor barriers, or other similar devices or engineering controls may require an institutional control to ensure that the protection remains in place, if necessary. DWM or the responsible party may be accountable for the system verification sampling, monitoring and maintenance requirements described below. **The appropriate DWM cleanup program should be consulted regarding the use of institutional or engineering controls.**

For undeveloped properties/parcels that contain source concentrations above the screening levels (GWSL or SGSL), official notification of the property owner is required and institutional controls are typically necessary prior to closure to ensure that vapor intrusion will not occur for future exposures.

If nonresidential screening levels (SGSL or IASL) or OSHA values are used, an institutional control may be necessary to address future modifications in the land use (e.g., conversions to residential use).

Nonresidential properties may require institutional controls when future use may differ from the current use under which closure was issued. For example, a property used for dry-cleaning may be issued a no further action letter based on current conditions, but depending on remaining contaminant levels, an institutional control may be required to prevent vapor intrusion if the property is used for anything other than dry-cleaning in the future.

If site-specific building parameters (e.g., ventilation rate changes, building size modifications, positive pressure controls) are used to address VI concerns, an institutional control may be necessary to ensure that the property owner maintains these building controls at the affected structure/property and allows periodic monitoring.

Depending on the type of institutional control employed, the responsible party may have to monitor change in ownership and building conditions annually and inform DWM of these observations through an annual certification. This is critical in situations where nonresidential screening levels or site-specific building parameters are utilized.

6.3.2 System Verification Sampling, Monitoring and Maintenance

6.3.2.1 Verification Procedures

Samples should be analyzed for the site-specific COCs and their breakdown products – analysis for the full suite of chemicals is not necessary.

After the mitigation system is operational, confirmation indoor air sampling should be conducted. Indoor air sampling should be conducted approximately two to four weeks after the system is operational to verify its effectiveness. Indoor air sampling events that do not occur during the winter or summer months when the structure is closed with the HVAC running should necessitate a second round of indoor air sampling during this timeframe. However, DWM will accept a single round of sampling (irrespective of the seasonal timing of the sample event) in those cases where the results are an order of magnitude below the appropriate screening level.

If the indoor sampling data for the contaminants of concern are above the IASLs (with consideration of background sources), modifications or supplementation to the existing mitigation system will be required. Additional indoor air sampling will be necessary to verify the effectiveness of the system if it has been modified. Once indoor air data collected during the winter or summer (if previously shown to have higher indoor air concentrations) are below the IASLs (or site-specific background concentrations), additional indoor air sampling may not be necessary until system termination sampling takes place.

If subsurface depressurization systems are chosen for mitigation, immediately after system startup, indoor air sampling should be conducted and it should be demonstrated that a negative pressure field exists beneath the building. These diagnostic provisions should be incorporated into the original design of the subsurface depressurization system to avoid modifications to the system after installation.

6.3.2.2 Monitoring and Maintenance

A monitoring and maintenance plan shall be submitted for DWM review and approval. **For subsurface depressurization systems, inspection of the system and pressure gauge (typically a U-tube manometer) is recommended quarterly for the first year.** Additional sub-slab pressure monitoring may be necessary. A reduced monitoring frequency, typically annual monitoring, may be appropriate after one year of successful operation of the mitigation system. If the pressure gauge indicates the system is not operating efficiently the system should be diagnosed and repaired. The pressure gauge measurements should be recorded over time in tabular format and updated with each submittal to DWM.

For passive subsurface depressurization systems, an inspection should be conducted semiannually to determine if any new or existing areas (e.g., cracks, holes, sump pit covers, earthen crawlspaces) need to be sealed, caulked, and/or covered, etc. If repairs are necessary they should be conducted and documented in the next submission to DWM. A reduced inspection frequency may be appropriate after one year.

The investigator should consult with the appropriate DWM cleanup program regarding requirements for any additional indoor air or sub-slab monitoring after the mitigation system has been verified to be operating effectively.

6.3.2.3 System Termination Sampling

Once the investigator concludes that the VI source (groundwater, soil gas, etc.) has been properly remediated to the point where the VI pathway is not complete, a proposal may be submitted to DWM to cease operation of the VI remedial system. Upon approval from DWM, system termination sampling of indoor air and sub-slab soil gas should be conducted. The system termination sampling should occur during the winter and summer months when the structure could be expected to be closed up with the HVAC running. The system termination indoor air and sub-slab analytical results should be submitted for DWM review. Note subsequent sampling rounds may be required on a case by case basis to verify the appropriateness of system termination. Analytical parameters for the system termination samples should include the contaminants of concern analyzed after the initial startup of the mitigation system. However, additional analytical parameters may be required on a case by case basis.

7.0 COMMUNITY OUTREACH FOR VAPOR INTRUSION SITES

7.1 Why Do Community Outreach?

Early, two-way communication with residents, business owners and local officials affected by a contaminated property can be critical to a successful investigation and cleanup. When citizens are well-informed about the issues surrounding a site, their questions and concerns can be more easily addressed. This builds trust and credibility and allows the remedial process to proceed most efficiently.

An effective outreach strategy that anticipates the needs and concerns of the community will be particularly important to a VI investigation. In most cases, the parties conducting the investigation will need to arrange sampling appointments with residents/property owners, collect indoor air and soil gas samples, and report the findings. At some properties, sub-surface depressurization systems may be required. Information sessions may be necessary to ensure the general public is properly informed about the investigation and remedial actions. Those involved in a VI investigation will want to develop their community outreach strategy before the actual work begins to ensure the most successful outcome.

DWM strongly recommends that parties investigating VI sites familiarize themselves with the concepts in USEPA's guidance, The Seven Cardinal Rules of Risk Communication (www.epa.gov/superfund/tools/pdfs/37riskcom.pdf), when preparing their community outreach activities for VI sites.

7.2 Communicating with the Public about Vapor Intrusion

When initiating a VI investigation and during an investigation, there are different key groups of people that may be involved at varying points in the investigation. Typically, local officials and the general public are not notified when soil gas or indoor air testing is being conducted as part of the site investigation unless they are directly involved and must give access for sampling. **In large, high profile cases, it is often beneficial to notify local officials and the general public prior to conducting the VI investigation.** The media may emerge as a third group if the site becomes high profile. Below are some tips on how and when to communicate with parties for maximum effectiveness.

The DWM Public Information Officer should be consulted when preparing to hold a public meeting or interacting with the media.

7.2.1 General Public

When communicating with the general public about the investigation, remember that the nature of VI, how it is evaluated, sources of background contamination, possible health effects and potential remedies will likely be unfamiliar concepts. Expect to expend significant effort educating residents/property owners and local officials about these topics during and sometimes before conducting an indoor air investigation. **If there is a large population of sensitive individuals (e.g., small children in school or daycare) in the area being investigated, or if there has already been significant media attention or community interest focused on the site, it may be helpful to hold an information session before the VI investigation work begins.**

7.2.1.1 Information Sessions with the Public

Information sessions can be useful forums for disseminating information and answering questions. These sessions are usually held in coordination with DWM at a municipal building, school, church or other public building in the area near the site. Consult with interested parties to determine the best day and time and give the public several weeks' notice of the session date. Weekday evenings are usually the most convenient times for such sessions. After a date and time has been selected, mail notices of the session to interested parties, property owners and occupants near the site. DWM recommends notification of the local health department when health and risk issues are likely to be discussed.

The informational session may include a short presentation regarding the site history and investigation and a question-and-answer period. Typically, these sessions take place in an informal setting and allow the public to speak one-to-one with the professionals involved in the investigation in a relatively private setting.

When presenting data about the site to the public, remember that confidentiality may be an issue for some residents/property owners. For this reason, maps or other documents identifying specific homes with indoor air contamination may not be suitable presentation materials.

During the session, note concerns and issues raised by the public and local officials that cannot be answered or addressed immediately. Provide responses to these concerns and issues as quickly as possible once the session is over. In the weeks and months following the session, continue to periodically update the residents and local officials on the VI investigation and any remedial actions through fact sheets, letters and telephone calls.

When discussing VI, be sure to define technical jargon and explain complex concepts in a manner that can be easily understood. Provide supplemental literature, such as fact sheets, or identify a website they can go to for more information about the site. A generic fact sheet, *What You Should*

Know About Vapor Intrusion can be found in Appendix D. Ask for feedback to ensure the public understands the information. In addition, find out how they would like to be notified about developments in the future. Since people living in indoor air contamination areas are directly affected by the site, the investigator should be prepared to engage in frequent contact with the residents/property owners (phone calls, letters, meetings, etc.).

7.2.2 Local Officials

In some cases, it may be beneficial to notify the municipal officials (e.g., municipal clerk, township administrator, mayor) and the local health officer that indoor air and/or soil gas sampling is going to be conducted in their area and why it is being done. **When performing notifications of officials, always work with the appropriate DWM cleanup program overseeing work at the site and the DWM public information officer.** As the elected or appointed leaders of the community, the media or residents will likely contact them for information. (If site activities include going door-to-door to collect information from residents or any other type of canvassing, the local police department should also be notified.)

Establish a working relationship with local officials early in the process so they can be involved as needed later on. Provide local officials with copies of the *What You Should Know About Vapor Intrusion* fact sheets in Appendix D and inform them of the availability of this guidance document on DWM's web site, http://portal.ncdenr.org/web/wm/. Let them know that you may be copying them on correspondence to residents regarding the VI investigation.

7.2.3 Media

A site does not have to be particularly large or complex to garner attention from local newspapers, television stations, or other media outlets. In cases where the media have focused on the VI investigation, it is always advisable to make background material available (if the confidentiality of individual test results is maintained).

The DWM Public Information Officer should be made aware of any media inquiries regarding activities at a site.

7.3 Arranging Sample Appointments

DWM recommends a two-step approach when initially contacting residents/property owners to obtain permission to conduct a VI investigation at their buildings. First, send an introductory letter to the residents/property owners to inform them of the proposed VI investigation at their buildings. The DWM Public Information Officer should be allowed to review the letter prior to sending it out whenever possible. Follow up with phone calls to the residents to arrange sampling appointments. Often, face-to-face meetings with residents/property owners offer a better opportunity to explain the investigation and what the sample results may mean.

Send the introductory letters several weeks ahead of the sampling event. For rental properties, send the letters to both the property owners and tenants. Write the letters in non-technical terms and include the following information:

- An explanation for the reason for the sampling.
- The name of the contaminant(s) of concern.

- The anticipated sampling date (or approximate timeframe).
- Who will be doing the sampling.
- What the sampling will involve.
- The phone numbers of DWM project manager.

Also include the following attachments, which are available from this guidance document and on the DWM web (http://portal.ncdenr.org/web/wm/):

- *Indoor Air Building Survey and Sampling Form* (Appendix C)
- *What You Should Know About Vapor Intrusion* (Appendix D)
- *Instructions for Occupants – Indoor Air Sampling Events* (Appendix F)

It may also be helpful to enclose specific information about the contaminant(s) of concern, such as ToxFAQ^{TM} fact sheet(s) about the chemical(s) from the Agency for Toxic Substance and Disease Registry (ASTDR) web page [http://www.atsdr.cdc.gov/atsdrhome.html].

Finally, if plans include collecting soil gas or crawl space/indoor air samples, attach an access agreement for the recipient to sign and return. For rental properties, the access agreement need only be attached to the letter to the property owner.

Note: If working with local officials, it is important to keep them apprised of your activities at this stage. Provide them with a sample introductory letter and a list of the names and addresses of the residents/property owners that have been contacted to request an indoor air investigation.

After sending the introductory letters, call the occupants of the buildings to arrange the sampling appointments at least one to two weeks prior to the scheduled sampling event. Ask local contacts to help get in touch with occupants that are not available or responsive. When calling to arrange the appointments, be prepared to discuss the following:

- The contaminant(s) of concern.
- General health issues - direct specific health questions to the local health department.
- How the sample(s) will be collected and analyzed.
- When the analytical results will be available and possible remedial actions.
- How to prepare for the sampling and what to avoid when sampling is being conducted, as outlined in *Instructions for Occupants – Indoor Air Sampling Events* (Appendix F).

In addition, discuss the *Indoor Air Building Survey and Sampling Form* Appendix C with the occupant. Inform the occupant that someone knowledgeable about the property should be available on the day of sampling to help the sampling team to fill out the form. If that is not possible, try to fill out the form over the phone with the occupant.

When arranging follow-up indoor testing appointments (such as confirmation sampling or sampling to check the effectiveness of a remedial action), it is only necessary to contact the residents/property owners by telephone. As a courtesy, try to give residents/property owners at least two weeks notice of the planned sampling. When scheduling follow-up appointments, always review the recommendations outlined in *Instructions for Occupants – Indoor Air Sampling Events* Appendix F with the residents/property owners to remind them about how to prepare for the sampling and what to avoid while the sampling is being conducted.

7.4 Collecting Samples

When entering homes and other private buildings to conduct air sampling, DWM recommends sending a team of two people. Each sampling team member should bring identification for verification by the residents should it be requested. The sampling team should be prepared to provide the occupants with the name and telephone number of a DWM contact person to whom they can direct questions.

Note: It is highly recommended that precautions be taken whenever the VI investigation includes outside air sampling. If using stainless steel canisters (i.e. Summas), the sampling equipment and related devices are not familiar to most people and may be misinterpreted as a safety concern. Therefore, the local police and fire departments should be notified of the sampling event in addition to the municipal officials. It may be useful to demonstrate the operation of the sampling equipment to these officials. A label should be affixed to the sampling device explaining the nature of the equipment and contact information in case there are further questions.

7.5 Reporting Sample Results

Although investigators may elect to forward results (or be bound to do so by an access agreement), DWM is responsible for officially notifying property owners/occupants about their sampling results.

In addition to written results, the DWM may first call the residents/property owners to report results under the following scenarios:

- The analytical results indicate that VI is causing one or more contaminants of concern to exceed the DWM IASLs. This will give the occupant/property owner the opportunity to discuss the results as soon as they become aware of them.
- Very high levels of background contaminants are found in the indoor air. This may allow the resident/property owner to take immediate measures to reduce their exposure to these contaminants by addressing the source. Occupants/property owners should be referred to their local health department if they have specific health questions about non-site related contaminants.
- A significant period of time has elapsed (more than eight weeks) since the testing was conducted. Residents who are anxious about their results will appreciate receiving them verbally if it speeds the process.

Verbal Reports - When reporting indoor air results verbally, DWM will provide the results directly to the property owner, resident and/or tenant, since leaving the information on an answering machine or with another person can lead to a misunderstanding of the findings and/or breach confidentiality.

Once property owners/residents/tenants know their indoor air testing results, DWM will explain the next action, if any, and when they can expect to receive written copies of their results. DWM will also provide the name and phone number of a DWM contact person in case the resident/property owner has follow-up questions.

Written Reports - The written reports from DWM should consist of a cover letter explaining the findings and a summary of the analytical results. The purpose of the cover letter is to put the results in a context that the property owner, resident and/or tenant can easily understand. In the case of rental properties, the findings should be reported in writing to both the tenant and the property owner. If local officials or local health officers have been involved, they should also be copied on all letters.

The cover letter should be written in non-technical terms and include the information listed below.

- The date the sampling was conducted.
- Who conducted the sampling (e.g., name of government agency or private contractor).
- The site for which the sampling was conducted (if applicable).
- The sample location/address.
- An explanation of the findings with the contaminant(s) of concern highlighted.
- The next action, if any, for the property (e.g., another round of sampling or a remedial action).
- A brief discussion of the indoor air contaminants detected that are not related to the site. (Refer the property owner/resident/tenant to their local health department if they have questions about non-site related indoor air contaminants.)
- Name and telephone number of a DWM contact person.

Also attach a copy of the *Subsurface Depressurization Systems* fact sheet (Appendix E), if applicable.

The summary of analytical results should be in a format that is easy to understand. Enclosing the summary tables from the laboratory analytical data package is **NOT** recommended, as these are often very technical. It is recommended that a separate table be constructed to include the concentration of each compound that was detected during the indoor air sampling and the IASL for each compound (both reported in $\mu g/m^3$).

7.6 Community Outreach during Mitigation

Most of the community outreach conducted during the mitigation phase will entail acting as a point of contact between the occupant/property owner and the contractor or state regulators. This can include scheduling the installation of the mitigation system, relaying the property owner's concerns to the appropriate individuals, and ensuring that every effort is made to resolve issues or concerns related to the remedial action.

As stated earlier, some people may feel that owning a home with vapor intrusion carries a stigma. Before beginning the mitigation work, make sure the occupant/property owner is comfortable with the final design. In all cases, the finished mitigation system should be as inconspicuous as possible.

Finally, as part of the community outreach for a VI investigation/remedial action, measures should be taken to ensure that the property owner understands that it is his responsibility to inform current and future occupants of the building about the vapor intrusion issues at the property.

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APPENDIX A

ITRC Conceptual Site Model Checklist

CONCEPTUAL SITE MODEL CHECKLIST

The information included in this checklist may be useful for developing a site-specific conceptual migration model and in planning soil gas sampling. The investigator may use this checklist to compile information for each site.

Utilities and Process Piping

- ☐ Locate and map out all underground utilities near the soil or groundwater impacts. Pay particular attention to utilities that connect impacted areas to occupied buildings.

- ☐ Locate and map out all underground process piping near the soil or groundwater impacts.

Buildings (Receptors)

- ☐ Locate and map out existing and potential future buildings.

- ☐ Identify the occupancy and use of the buildings (e.g., residential, commercial). You may need to interview occupants to obtain this information.

- ☐ Describe the construction of the building including materials (e.g., wood frame, block), openings (e.g., windows, doors), and height (e.g., one story, two story, multistory). Determine whether there is an elevator shaft in the building.

- ☐ Describe the foundation construction:
  - Type (e.g., basement, crawl space, slab on grade)
  - Floor construction (e.g., concrete, dirt)
  - Depth below grade

- ☐ Describe the HVAC system in the building:
  - Type (e.g., forced air, radiant)
  - Equipment location (e.g., basement, crawl space, utility closet, attic, roof)
  - Source of return air (e.g., inside air, outside air, combination)
  - System design considerations relating to indoor air pressure (e.g., positive pressure is often the case for commercial buildings)

- ☐ Describe subslab ventilation systems or moisture barriers present on existing buildings, or identify building- and fire-code requirements for subslab ventilation systems (e.g., for methane) or moisture barriers below foundations.

Source Area

- ☐ Locate and map out the source area for the vapor-phase contaminants related to the subsurface vapor intrusion pathway.

- ☐ Describe the presence, distribution, and composition of any NAPL at the site.

- ☐ Identify the vapor-phase contaminants that are to be considered for the subsurface vapor intrusion pathway.

- ☐ Describe the status and results for the delineation of contamination in environmental media, specifically soil and groundwater, between the source area and the potential impacted buildings.

- ☐ Describe the environmental media (e.g., soil, groundwater, both) containing contaminants.

- ☐ Describe the depth to source area.

- ☐ Describe the potential migration characteristics (e.g., stable, increasing, decreasing) for the distribution of contaminants.

Geology/Hydrogeology

- ☐ Review all boring logs, monitoring well construction, and soil sampling data to understand the following:

    - Heterogeneity/homogeneity of soils and the lithologic units encountered and the expected/observed contaminant migration:

        - Depth and lateral continuity of any confining units that may impede contaminant migration

        - Depth and lateral continuity of any highly transmissive units that may enhance contaminant migration

    - Depth of vadose (unsaturated) zone, capillary fringe, and phreatic (saturated) zone:

        - Note any seasonal water table fluctuations and seasonal flow direction changes (hydraulic gradient).

        - Note the depth interval between the vapor source and the ground surface.

- o Note the presence of any perched aquifers.
- o Note where the water table intersects the well screen interval or the presence of submerged screen.

☐ Describe distinct strata (soil type and moisture content, e.g., moist, wet, dry) and the depth intervals between the vapor source and ground surface.

☐ Describe the depth to groundwater.

☐ Describe groundwater characteristics (e.g., seasonal fluctuation, hydraulic gradient).

Site Characteristics

☐ Estimate the distance from edge of groundwater plume to building.

☐ Determine nearby potential sources.

☐ Estimate the distance from vapor source area to building.

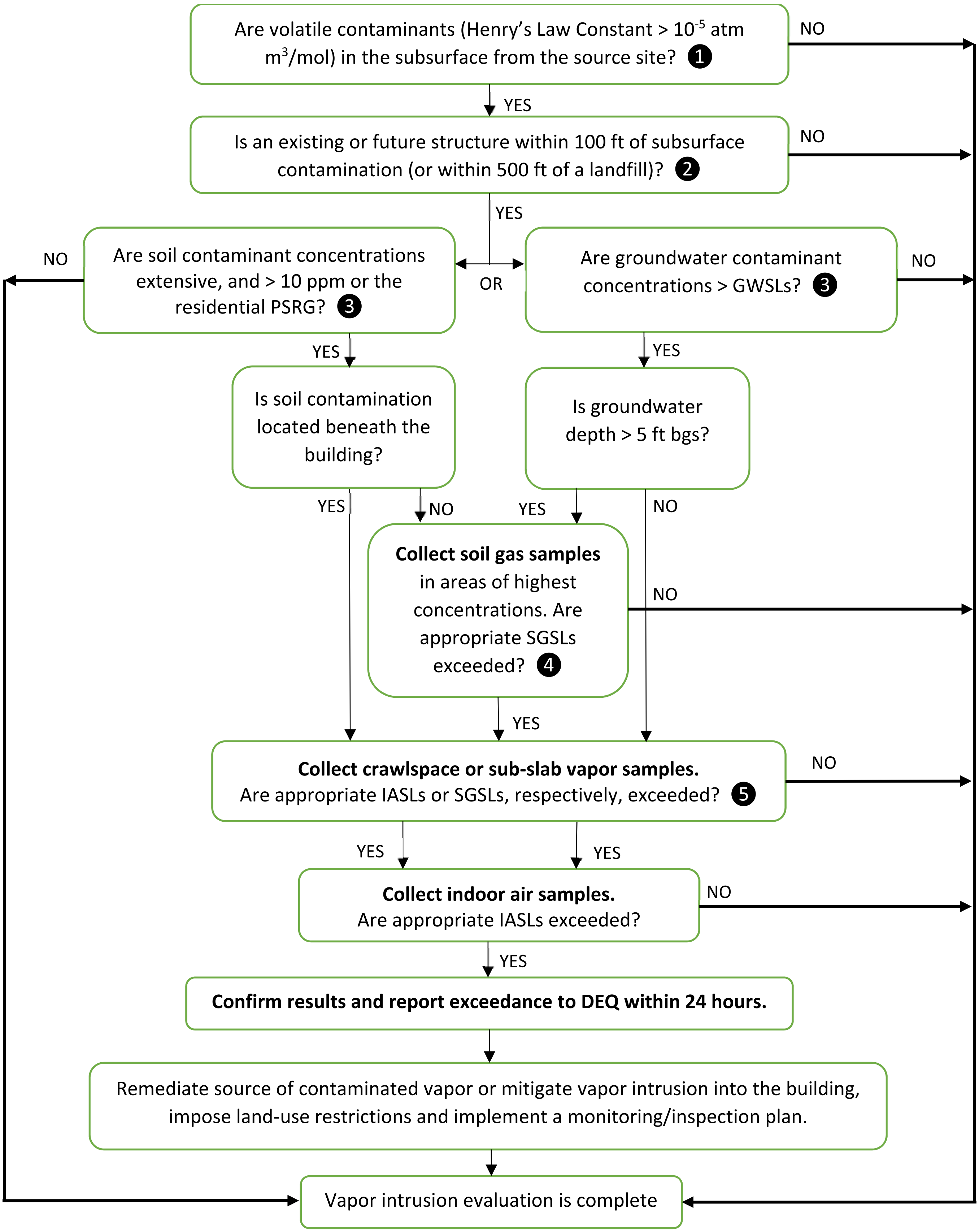
☐ Describe the surface cover between the vapor source area and the potentially impacted building.

APPENDIX B

IHSB Structural Vapor Intrusion Evaluation Steps

IHSB FLOWCHART OF STRUCTURAL VAPOR INTRUSION EVALUATION STEPS

An understanding of extent of contamination and groundwater flow patterns is needed prior to planning a vapor intrusion evaluation



1 See notes on following page.

FLOWCHART NOTES

❶ Contaminants of concern may include not only the typical analytes on a volatile organic scan, but also mercury, hydrogen sulfide, ammonia and some semivolatile compounds.

❷ Existing and future structures located outside the contaminated areas could also be affected because contaminated soil gas can travel along preferential pathways in the subsurface caused by geologic formations, fractures, lithologic lenses and utility corridors.

❸ All child-occupied spaces such as schools and day care facilities should be screened using the residential screening values.

❹ Consider both current buildings and potential future development (see note 2 above).

- For deeper soil contamination (> 5 ft bgs), sample depth with max concentrations and 5 ft depth.
- For shallow soil contamination (< 5 ft bgs), passive sampler emplacement or other method may be needed.
- For groundwater contamination, collect soil gas samples close to the building and just above the water table or between 5-10 ft bgs.

Where soil gas testing fails to meet SGSLs at a vacant lot or any portion of an affected property planned for development, contamination must be reduced to levels that pose no risk for the planned use of the property, and/or land-use restrictions will be required to prevent exposure from potential vapor intrusion into future structures.

❺ Time-integrated, passive sampling methods can provide an average soil gas or indoor air concentration over a longer exposure period (e.g., several days to several weeks) to account for variability. Passive sampling methods have proven to be less intrusive to building occupants and often more convenient to implement. It is recommended that at a minimum the first sampling event include traditional canister methods for comparison and correlation of results.

DEFINITIONS

ft bgs feet below ground surface

PSRG Preliminary Soil Remediation Goals

GWSL Groundwater Screening Level

SGSL Soil Gas Screening Level

IASL Indoor Air Screening Level

APPENDIX C

Indoor Air Building Survey and Sampling Form

INDOOR AIR BUILDING SURVEY
and SAMPLING FORM

Site Name: ___________________________________ ID#: ______________________

Preparer's name: _______________________________ Date: __________________________

Preparer's affiliation: ___________________________ Phone #: _______________________

Part I - Occupants

Building Address: ____

Property Contact: ______________________________ Owner / Renter / other: ______________

Contact's Phone: home ( )__________ work ( )_____________ cell ( )____________

# of Building occupants: Children under age 13 _____ Children age 13-18 ______ Adults _____

Part II – Building Characteristics

Building type: residential / multi-family residential / office / strip mall / commercial / industrial

Describe building: ____ Year constructed: _________

Sensitive population: day care / nursing home / hospital / school / other (specify): _______________

Number of floors below grade: ______ (full basement / crawl space / slab on grade)

Number of floors at or above grade: ______

Depth of basement below grade surface: ______ ft. Basement size: _______ ft^2

Basement floor construction: concrete / dirt / floating / stone / other (specify): ________________

Foundation walls: poured concrete / cinder blocks / stone / other (specify) ________________

Basement sump present? *Yes / No* Sump pump? *Yes / No* Water in sump? *Yes / No*

Type of heating system (circle all that apply):

hot air circulation	hot air radiation	wood	steam radiation
heat pump	hot water radiation	kerosene heater	electric baseboard

other (specify): ________________________

Type of ventilation system (circle all that apply):

central air conditioning	mechanical fans	bathroom ventilation fans
individual air conditioning units	kitchen range hood fan	outside air intake

other (specify): ___________________

Type of fuel utilized (circle all that apply):

Natural gas / electric / fuel oil / wood / coal / solar / kerosene

Are the basement walls or floor sealed with waterproof paint or epoxy coatings? *Yes / No*

Is there a whole house fan? *Yes / No*

Septic system? *Yes / Yes (but not used) / No*

Irrigation/private well? *Yes / Yes (but not used) / No*

Type of ground cover outside of building: grass / concrete / asphalt / other (specify) _______________

Existing subsurface depressurization (radon) system in place? *Yes / No* *active / passive*

Sub-slab vapor/moisture barrier in place? *Yes / No*
Type of barrier: ______________________________

Part III - Outside Contaminant Sources

Other stationary sources nearby (gas stations, emission stacks, etc.): ________________________________

Heavy vehicular traffic nearby (or other mobile sources): ____

Part IV – Indoor Contaminant Sources

Identify all potential indoor sources found in the building (including attached garages) and crawlspace (if present), the location of the source (floor and room), and whether the item was removed from the building 48 hours prior to indoor air sampling event. Any ventilation implemented after removal of the items should be completed at least 24 hours prior to the commencement of the indoor air sampling event.

Potential Sources	**Location(s)**	**Removed** **(Yes / No / NA)**
Gasoline storage cans		
Gas-powered equipment		
Kerosene storage cans		
Paints / thinners / strippers		
Cleaning solvents		
Oven cleaners		
Carpet / upholstery cleaners		
Other house cleaning products		
Moth balls		
Polishes / waxes		
Insecticides		
Furniture / floor polish		
Nail polish / polish remover		
Hairspray		
Cologne / perfume		
Air fresheners		
Fuel tank (inside building)		NA
Wood stove or fireplace		NA
New furniture / upholstery		
New carpeting / flooring		NA
Hobbies - glues, paints, etc.		

Part V – Miscellaneous Items

Do any occupants of the building smoke? *Yes / No* How often? ______________

Last time someone smoked in the building? ____________ hours */ days ago*

Does the building have an attached garage directly connected to living space? *Yes / No*

If so, is a car usually parked in the garage? *Yes / No*

Are gas-powered equipment or cans of gasoline/fuels stored in the garage? *Yes / No*

Do the occupants of the building have their clothes dry cleaned? *Yes / No*

If yes, how often? weekly / monthly / 3-4 times a year

Do any of the occupants use solvents in work? *Yes / No*

If yes, what types of solvents are used? ____

If yes, are their clothes washed at work? *Yes / No*

Have any pesticides/herbicides been applied around the building or in the yard? *Yes* / No

If so, when and which chemicals? ____

Has there ever been a fire in the building? *Yes / No* If yes, when? _____________

Has painting or staining been done in the building in the last 6 months? *Yes / No*

If yes, when __________________ and where? ____________________________

Part VI – Sampling Information

Sample Technician: ____________________________ Phone number: ( ) _______ - __________

Sample Source: Indoor Air / Crawlspace Air / Sub-Slab / Near Slab Soil Gas / Exterior Soil Gas

Sampler Type: Tedlar bag / Sorbent / Stainless Steel Canister / Other (specify): _________________

Analytical Method: TO-15 / TO-17 / other: _________ Cert. Laboratory: _________________

Sample locations (floor, room):

Field ID # _____ - ________________________ Field ID # _____ - __________________________

Field ID # _____ - ________________________ Field ID # _____ - __________________________

Were "Instructions for Occupants" followed? Y*es / No*

If not, describe modifications: ____

Provide Drawing of Sample Location(s) in Building

Part VII - Meteorological Conditions

Was there significant precipitation within 12 hours prior to (or during) the sampling event? *Yes / No*

Describe the general weather conditions: ____

____

Part VIII – General Observations

Provide any information that may be pertinent to the sampling event and may assist in the data interpretation process (e.g., observed that drycleaner operated with door or windows propped open for ventilation).

____

____

____

(Adapted from the NJDEP Vapor Intrusion Guidance, October 2005)

APPENDIX D

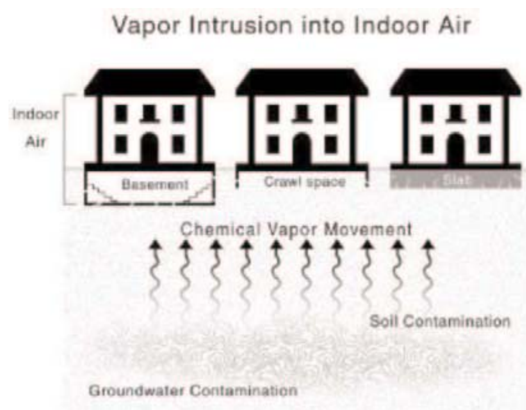
What You Should Know About Vapor Intrusion Fact Sheet

What You Should Know About Vapor Intrusion

EPA has developed this fact sheet to answer some of the most commonly asked questions about an important health issue called vapor intrusion. Vapors and gases from contaminated groundwater and soil have the potential to seep into indoor spaces and cause health problems.

What is vapor intrusion?

When chemicals or petroleum products are spilled on the ground or leak from underground storage tanks, they can give off gases, or vapors that can get inside buildings. Common products that can cause vapor intrusion are gasoline or diesel fuel, dry cleaning solvents and industrial de-greasers. The vapors move through the soil and seep through cracks in basements, foundations, sewer lines and other openings. Vapor intrusion is a concern because vapors can build up to a point where the health of residents or workers in those buildings could be at risk. Some vapors such as those associated with petroleum products have a gasoline odor, others are odor-free.



Can vapors in my home come from household sources?

Common household products can be a source of indoor air problems. Vapors and gases can come from: paints; paint strippers or thinners; moth balls; new carpeting and furniture; stored fuel; air fresheners; cleaning products; dry cleaned clothing and even cigarette smoke.

What are the health concerns related to vapor intrusion?

When vapor intrusion does occur, the health risk will vary based on the type of chemicals, the levels of the chemical found, the length of exposure and the health of exposed individuals. Some people may experience eye and respiratory irritation, headaches and/or nausea. These symptoms are temporary and should go away when the vapors are addressed. Low-level chemical exposures over many years may raise the lifetime risk of cancer or chronic disease.

How is vapor intrusion discovered?

Samples of gas in the soil or groundwater are first collected near a contaminated site. If no contamination is found near a site, then vapor intrusion should not be a problem. If contamination is found, depending on the type, the search may be widened to include samples closer to or on individual properties. The next step is to take vapor samples from the soil under the home’s foundation; these are called slab, or sub-slab samples. EPA does not generally recommend indoor air sampling before slab or sub-slab sampling, because indoor air quality varies widely day to day. Also, household products may interfere with sampling results.

What happens if a problem is found?

The most common solution is to install systems often used to reduce naturally occurring radon that seeps into homes in some geographic areas. These systems, called radon mitigation systems, remove soil vapors from below basements or foundations before they enter homes. Vapors are vented outside of the homes where they become dispersed and harmless. These systems use minimal electricity and do not affect heating and cooling efficiency. They also prevent radon from entering homes – an added health benefit especially in radon prone areas. Once the source of the vapors is eliminated, the systems should no longer be needed.

Vapor Intrusion: Tightly seal common household products after use and seal them in an area that is well ventilated to avoid the release of vapors

What can I do to improve indoor air quality?

- Don't buy more chemicals than you need.
- Store unused chemicals in appropriate tightly-sealed containers.
- Don't make your home too air tight. Fresh air helps prevent chemical build-up and mold growth.
- Fix all leaks promptly, as well as other moisture problems that encourage mold.
- Check all appliances and fireplaces annually.
- Test your home for radon. Test kits are available at hardware and home improvement stores or you can call the Radon Hotline at 800-458-1158 in New York State, or 800-648-0394 in New Jersey.
- Install carbon monoxide detectors in your home. They are available at hardware and home improvement stores.

Sub-slab mitigation system: This system draws radon and other vapors out of the soil and vents them outside

For more information:

- For health related questions regarding vapor intrusion, contact your local health department or the federal Agency for Toxic Substances and Disease Registry at:
  1-888-422-8737 or visit their Web site at www.atdsr.cdc.gov

- For more detailed information on EPA's vapor intrusion sampling, visit the EPA's Web site at: www.epa.gov/correctiveaction/eis/vapor/guidance.pdf

- For more information on indoor air quality, visit EPA's Web site at: www.epa.gov/air/topics/comoria.html or call the indoor air Quality Information hotline at 1-800-438-4318

APPENDIX E

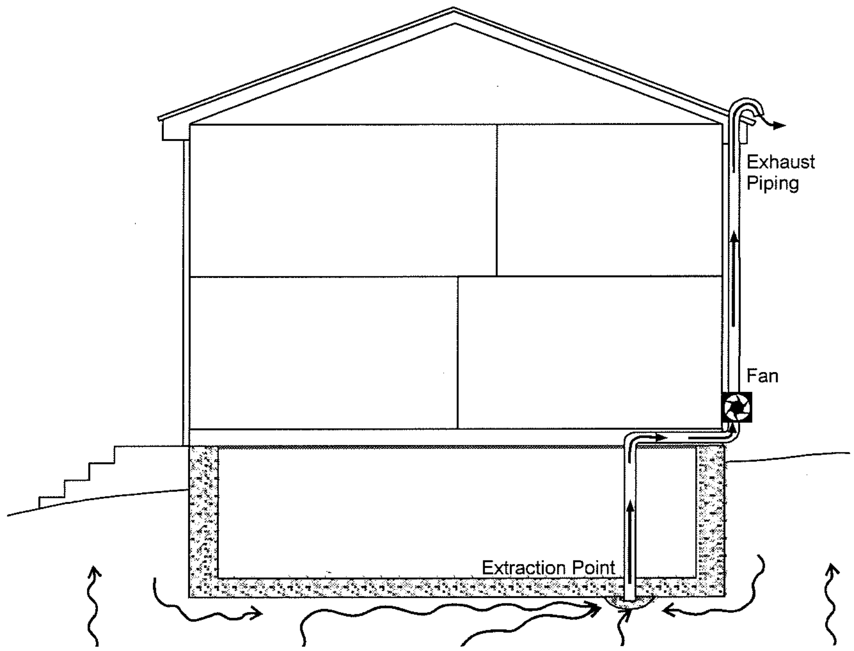
Subsurface Depressurization Systems Fact Sheet

Fact Sheet

Subsurface Depressurization Systems

Vapor intrusion occurs when vapors from volatile organic contamination in soil or ground water enter nearby buildings through cracks and holes in the foundations or slabs or via crawl spaces. In general, the goal at these sites is to remove the source of the vapors by cleaning up the contaminated soil or ground water. Since this can be a lengthy process, interim measures are often needed to protect occupants of the buildings from breathing the vapors while the cleanup is underway.

An effective method to prevent vapor intrusion during the cleanup process is to install subsurface depressurization systems at the affected buildings. The two most common types are the **sub-slab depressurization system** and the **sub-membrane depressurization system.**



A subsurface depressurization system prevents vapor intrusion by directing hazardous vapors in the soil to the exterior of the building.

A subsurface depressurization system fan on the exterior of a building.

Sub-slab depressurization systems are installed in buildings with slab (concrete) floors. Sub-membrane depressurization systems are installed at buildings with earthen or gravel crawl spaces or floors instead of slabs.

A sub-slab depressurization system consists of PVC piping installed through the slab floor and a fan connected with the piping. When the system is on, the fan applies a vacuum beneath the slab and the vapors in the soil beneath the building are directed outside, as shown above.

With sub-membrane depressurization systems, an impermeable membrane (such as plastic sheeting) is placed over the earthen or gravel area and the ventilation piping is installed through the membrane.

Subsurface depressurization systems are also used throughout the country to prevent naturally occurring radon gas from entering buildings.

Sub-slab and sub-membrane depressurization systems must operate continuously to be effective. They use little electricity, are relatively quiet and require little maintenance. A professional contractor should periodically check your system to ensure it is working properly.

(From New Jersey Department of Environmental Protection, Vapor Intrusion Guidance, 2005)

APPENDIX F

Instructions for Occupants – Indoor Air Sampling Events (English and Spanish)

Instructions for Occupants
Indoor Air Sampling Events

In order to collect an indoor air sample in your structure that is both representative of indoor conditions and avoids the common sources of background air contamination associated with household activities and consumer products, the Division of Waste Management (DWM) requests your assistance.

To the extent possible, please follow the instructions below starting at least 48 hours prior to and during the indoor air sampling event:

- Operate your heating and/or whole-house air conditioner as appropriate for the current weather conditions
- Do not use wood stoves, fireplaces or auxiliary heating equipment
- Do not open windows or keep doors open
- Avoid using window air conditioners, fans or vents
- Do not smoke in the building
- Do not use air fresheners or odor eliminators
- Do not use paints or varnishes (up to a week in advance, if possible)
- Do not use cleaning products (e.g., bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners)
- Do not use cosmetics, including hair spray, nail polish remover, perfume, etc.
- Avoid bringing freshly dry-cleaned clothes into the building
- Do not engage in indoor hobbies involving the use of solvents
- Do not apply pesticides
- Do not store containers of gasoline, oil or petroleum-based or other solvents within the building or attached garages (exception: fuel oil tanks)
- Do not operate or store automobiles in an attached garage
- Do not operate gasoline-powered equipment within the building, attached garage or around the immediate perimeter of the building

You will be asked a series of questions about the structure, consumer products you store in your building, and household activities typically occurring in the building. These questions are designed to identify "background" sources of indoor air contamination. While this investigation is looking for a select number of chemicals related to the subsurface contamination, the laboratory may be analyzing the indoor air samples for a wide variety of chemicals. Thus, tetrachloroethene used in dry cleaning or acetone found in nail polish remover might be found in your sample results.

Typical air sampling equipment

Your cooperation is greatly appreciated.
If you have any questions about these instructions, please feel free to contact:

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(Adapted from NJDEP Vapor Intrusion Guidance, October 2005)

Instrucciones Para Habitantes
Con Respecto al Muestreo del Aire Ambiental

Quicieramos que las muestra del aire ambiental del interior de su edificio sea a la vez representativa de las condiciones del interior y eviten las fuentes comunes de antecedentes de contaminación de aire asociado con actividades de la casa y productos de consumo.

Por favor siga las instrucciones abajo mencionadas comenzando por lo menos 48 horas antes de y durante el evento de muestreo:

- Opere su horno y el aire acondicionado de toda la casa apropiadamente a las actuales condiciones del tiempo
- No use estufas de leña, chimeneas o equipos auxiliares de calefacción.
- No abrir las ventanas o mantener las puertas abiertas.
- Evite usar aires acondicionados, abanicos o ventiladores de ventanas
- No fume dentro del edificio
- No use refrescantes de aire o eliminadores de olor
- No use pinturas o barniz (hasta una semana por adelantado, si es posible)
- No use productos de limpieza (ej. Limpiadores de baño, cera para muebles, limpiadores de aparatos electrodomésticos, limpiadores para “todo propósito”, limpiadores del piso)
- No use cosméticos, incluyendo fijador del cabello, removedor de esmalte de uñas, perfume
- Evite traer ropa recientemente limpiada en seco (de la tintorería) al edificio
- No participe en pasatiempos en el interior del edificio que usen solventes
- No aplique pesticidas
- No almacene envases de gasolina, aceite o derivados de petróleo u otros solventes dentro del edificio o garajes adjuntos (con exepción de tanques de aceite de combustible -“fuel oil”)
- No opere o almacene automoviles en un garaje adjunto
- No opere equipos impulsados por gasolina dentro del edificio, garaje adjunto o alrededor de los perímetros inmediatos del edificio

Equipo típica para muestreo de aire

Se le hara una serie de preguntas acerca de la estructura, productos de consumo que usted almacena en su edificio, y actividades de la casa típicamente ocurriendo dentro del edificio. Esas preguntas son diseñadas para identificar “antecedentes” de fuentes de contaminación de aire dentro del edificio. Mientras esta investigación esta buscando unos químicos selectos y relacionados a la contaminación de la sub-superficie, el laboratorio estará analizando las muestras de aire del interior por una variedad de químicos. Así, “tetrachloroethene” usado en tintorerías o acetona encontrada en el removedor de esmalte de uñas podría ser encontrado en los resultados de su muestra.

Su cooperación es grandemente apreciada. Si usted tiene alguna pregunta acerca de estas instrucciones, por favor de contactar a:

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(Adaptado de NJDEP Vapor Intrusion Guidance, October 2005)

APPENDIX G

Radon Sampling for Attenuation Factor

Radon Sampling to Estimate Sub-Slab to Indoor Air Attenuation Factors

Concurrent measurement of sub-slab and indoor air radon gas concentrations may be used in order to estimate building specific sub-slab to indoor air attenuation factors. Radon measurement may be particularly useful where indoor sources of contaminants of concern make it difficult to determine the proportion of indoor air contamination that is attributable to vapor intrusion.

The following procedures should be followed when using radon concentrations to estimate a building specific sub-slab to indoor air attenuation factor.

- Sub-slab sample procedures outlined Sections 5.4 of this document should be followed for preparation of the sub-slab sampling point when preparing to collect sub-slab radon gas samples.
- Sub-slab radon gas samples should be collected using "Pump/Collapsible Bag Devices" protocols described in section 2.6.3.2 of "Indoor Radon and Radon Decay Product Measurement Device Protocols". [1]
- Grab sampling should be used for sub-slab radon sampling. Sorbent samples should not be used for sub-slab radon sampling.
- Indoor air sampling procedures outlined in Section 5.6 of this document should be followed when collecting indoor air radon samples.
- In order to account for variability in indoor radon concentrations caused by building use and ventilation operations changes in the building, and in order to provide a conservative attenuation factor estimate, indoor radon sampling should be conducted under conditions that approximate worst case conditions for radon and vapor intrusion into the building.
- Indoor and sub-slab sampling radon should be conducted concurrently.
- The number and location of sub-slab samples should be chosen on the basis of site-specific parameters and objectives. Sub-slab samples should generally be collected from locations where there is exposure concern (e.g., occupied spaces), and in proximity to the spatial extent of groundwater or soil contamination.
- The mean of sub-slab radon concentrations should be divided by the mean of indoor radon concentrations in order to estimate the sub-slab to indoor air attenuation factor.
- The results of sub-slab VOC results may be multiplied by the attenuation factor in order to estimate an indoor air concentration resulting from vapor intrusion. Individual sub-slab vapor concentration results should be multiplied by the slab attenuation factor in order to obtain an estimated indoor vapor concentration resulting from vapor intrusion.
- If indoor vapor concentrations estimated using a radon derived attenuation factor, are less than indoor screening limits at the 1.0E-06 target cancer risk or Hazard Quotient =1, and if DENR is satisfied with the sampling conditions and methods, then the vapor intrusion pathway may be considered incomplete.

REFERENCES

1. USEPA, EPA 402-R-92-004, July 1992. Office of Air and Radiation: "Indoor Radon and Radon Decay Product Measurement Device Protocols ". http://www.epa.gov/radon/pubs/devprot3.html#2.6

APPENDIX H

Brownfields Program Vapor Intrusion Mitigation System (VIMS) Design Submittal New Construction Minimum Requirements Checklist

Vapor Intrusion Mitigation System (VIMS) Design Submittal New Construction Minimum Requirements Checklist

NCDEQ Brownfields Program – March 2018

If required by the Brownfields Program, or if pre-emptive mitigation is chosen by the Prospective Developer (PD), all Vapor Intrusion Mitigation System (VIMS) design submittals must adhere to the following format and to the NCDEQ Vapor Intrusion (VI) Guidance Document (March 2018). Note that this document is intended for submittals of a VIMS design for new construction; design submittals for retrofitting existing structures have different considerations and requirements based on site-specific factors such as the presence of gravel or clay below the existing slab, interior sources of contamination, damaged utilities, etc. and should be discussed with the Brownfields Project Manager. In order to avoid construction schedule delays, designs should be submitted to the Project Manager on a schedule that allows for adequate review/revision time. Following review and revisions of the VIMS design submittal, a N.C. licensed Professional Engineer (P.E.) must sign and seal the design document prior to installation. Close coordination and consultation with the Brownfields Program must be established and maintained between the PD, VIMS contractors, and all general contractors for the Brownfields Property to avoid installation issues or construction delays. Also note that testing of the VIMS is a key component of the design that must also be reviewed.

____Section 1. Introduction

Provide a brief background of the Brownfields Property and basis for installing a VIMS (e.g. off-site migration of contaminants, on-site releases, chlorinated solvents, etc.). Document the type of foundation design required by construction plans (e.g. waffled construction, ground floor post-tension cabling, build-to-suit construction, or other unique construction plans).

Note: if a VIMS is not installed for certain portions of a Brownfields Property due to open-air 'podium' construction or parking decks, a VIMS may still be required for features such as elevator shafts, stairwells, and areas with utility penetrations that exchange air with occupied areas.

____Section 2. Design Basis

Specify which type(s) of VIMS is intended for the planned structures:

Passive System. Develop a 'trigger' by which the system will be made active, which may include pressure measurements, soil gas and/or indoor air sampling, or changes in site conditions. Note that a passive system should be designed and installed such that the passive system is as effective as an active system at preventing vapor intrusion.

Active System. A pressure differential resulting in depressurization below the slab of 4 pascals or greater at remote extents of each VIMS area is considered sufficiently depressurized (perhaps as low as 1 to 2 pascals if employed with continuous pressure measurement during varied HVAC situations, weather events, and climate for winter and summer months). An alarm that informs building occupants in case the system malfunctions should be included.

For passive and active systems, both of the following design specifications must be included as exhibits:

Sub-slab Venting Construction Materials and Installation. Design specifications must be included as an exhibit (Section 8). All accessible piping must be labeled (at internals no greater than 10 linear feet) stating the purpose of the system along with contact information for questions or repairs.

Membrane Vapor Barrier Construction Materials and Installation. Design specifications must be included as an exhibit (Section 8). Particular attention should be paid to the design and diagrams for sealing barriers at slab penetrations and edges.

Note: Brownfields Property contaminants of concern (COC) must not be present in building materials.

____Section 3. Quality Assurance / Quality Control

Inspections are **required** for all gravel & piping prior to installing the vapor barrier, and are **required** for all sections of the vapor barrier prior to pouring the slab. These inspections must be conducted by qualified personnel under the supervision of the design P.E. and include field logs and photographs. Provide a minimum of 48 business hours advance notification to the Brownfields Program prior to inspections.

Smoke Testing and/or Thickness (Coupon) Measurements are recommended (and may be required by the manufacturer of certain vapor barrier systems).

____Section 4. Post-Construction / Pre-Occupancy System Effectiveness Testing

Pilot/Influence Testing is **required for passive and active systems prior to occupancy** with the objective to document that all areas below the slab can be effectively influenced by the current piping network. Pressure monitoring points should be placed at locations remotely distant from where each suction point transitions to below the slab in addition to locations near each suction point and associated horizontal piping. Based on pilot testing results and review by the Brownfields Program, the number of pressure monitoring points installed for pilot testing may ultimately reduce the number of permanent pressure monitoring points. As noted below in bold, results of the pilot/influence testing must be submitted to the Brownfields Program for conditional occupancy consideration as per our standard VI provisions.

Soil Gas and/or Indoor Air Sampling may be required based on site conditions (regardless of whether a passive or active VIMS is installed) as part of reviewing compliance with the Brownfields Agreement with regards to occupancy under our standard VI provisions.

Note: These two items (Pilot/Influence Testing & Soil Gas and/or Indoor Air Sampling) must be submitted to the Brownfields Program for conditional occupancy consideration as per our standard VI provisions.

____Section 5. Post-Occupancy Testing – Should be specified with the design submittal and not at a later date.

Pressure Testing is **required for active systems** (and may be required for passive systems) to be conducted on a monthly basis for the first year with collected information submitted to the Brownfields Project Manager on a quarterly basis. Based on the first year of pressure readings, and with approval of the Brownfields Program, pressure testing may be collected quarterly and data would be submitted with the annual Land Use Restriction Update (LURU). Note that the Brownfields Program utilizes a 'sliding scale' of pressure reading collection frequency vs. the stated depressurization goal or observed depressurization (e.g., if a VIMS is designed (or observed) to obtain a pressure differential less than 4 pascals, more frequent depressurization measurements will be necessary and may include continuous data logging).

Note: Pressure monitoring points should be placed at locations remotely distant from where each suction point transitions to below the slab in addition to locations near each suction point and associated horizontal piping.

Soil Gas and/or Indoor Air Sampling may be required by the Brownfields Project Manager as part of long-term post-occupancy testing based on site conditions regardless of whether a passive or active VIMS is installed.

____Section 6. Future Tenants & Building Uses

This section must address plans to prevent future tenants or occupants from exposing/damaging the VIMS without the oversight of a qualified P.E. Note that if the VIMS is exposed (for installation of new utilities, etc.), the same inspection requirements and reporting from initial installation is required.

____Section 7. Reporting

Upon completion of post-construction testing, a report must be prepared and submitted to the Brownfields Program under a N.C. licensed P.E. seal for review and approval. The report must summarize the installation, QA/QC measures, post-construction/pre-occupancy system effectiveness testing, and provide an opinion of whether the VIMS was delivered in a condition consistent with the VIMS design and objectives. Certain components of these reporting requirements including pressure measurements, soil gas sampling, and indoor air sampling can be conducted and reported under a N.C. licensed Professional Geologist seal. In the appendix section, the report must include as-built drawings, all inspection logs including photographs and field logs, and safety data sheets for materials used during construction that could contribute to background indoor air contamination. Note that the inspection logs do not need to be addressed in the text of the report unless information pertinent to the operation of the VIMS was discovered.

____Section 8. Design Submittal Exhibits

Drawings: Site Map; System layout including piping network and proposed monitoring point locations; Cross-section details

Design Specifications: Sub-Slab Venting Construction Materials and Installation; Membrane Vapor Barrier Construction Materials and Installation

Materials Sheets for all items associated with the VIMS (vapor barrier, piping, mastic, tape, sealants, cleaners, etc.)

Useful Reference(s):

ANSI/AARST CC-1000, "Soil Gas Control Systems in New Construction of Buildings".

Note: CC-1000 includes companion guidance that is not part of the ANSI/AARST American National Standard (ANS) and may contain material that has not been subjected to public review or a consensus process.