Conceptual Site Model (CSM) Development: Vapor

5.1 Introduction

Vapor intrusion (VI) refers to subsurface volatile chemicals that can move through the air-filled pores of vadose zone soils and enter the breathing space of buildings. VI can also occur when contaminated ground water infiltrates buildings and chemicals directly volatilize from the ground water into indoor air of the building. Vapors may move through permeable soils, fractures in bedrock or clay tills, man-made subsurface structures such as utility lines, basement sumps, cracks in the building foundation, or any combination of these pathways.

This section describes some procedures for evaluating VI. In addition to utilizing professional judgment and developing lines of evidence (LOEs), these procedures rely on existing CSM information, and also contribute to further CSM development. The science of VI is evolving rapidly. Other VI investigatory procedures are described in the literature, and IDEM will evaluate the implementation of those procedures consistent with principles addressed in U.S. EPA guidance and literature.

VI investigations typically begin with preliminary screening (Section 5.4), which includes an evaluation of volatile organic compounds (VOCs) in soil and ground water. Sites that meet certain qualifying conditions and have ground water VOC concentrations below applicable VI screening levels screen out of further evaluation of the VI pathway. Ground water stability is assumed during the screening process. If ground water plume stability remains undetermined, or if the ground water plume is expanding, the VI screening process may be iterative. Sites that do not meet these criteria require further evaluation, which typically involves two or more rounds of subslab soil gas (SGss), crawl space air (CSA), and/or indoor air (IA) sampling. However, certain low risk sites (Section 5.4.2) may rely on exterior soil gas (SGe) measurements during further evaluation.

5.2 Applicability

It is appropriate to evaluate both current and potential VI exposures at buildings. Current exposures exist when VI is documented in an occupied building. Potential exposures may be a concern when:

- Vapor phase chemicals exist beneath a building, even if they do not currently affect IA quality,
- Vapor phase chemicals may move into previously unaffected structures,
- A currently unoccupied building has vapor contamination, and/or
- New construction may result in exposure.

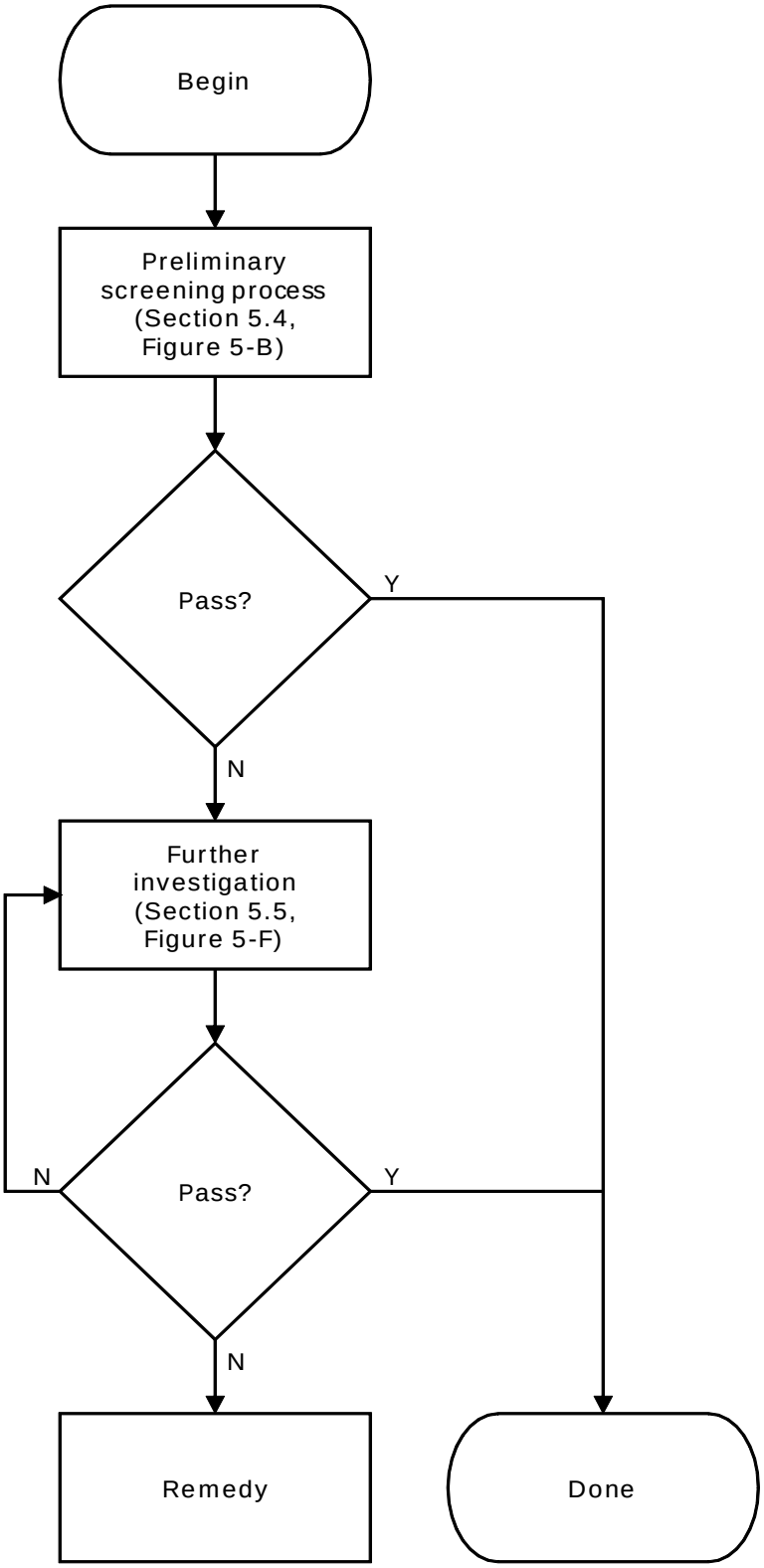
5.3 Process Overview

VI investigations are typically sequential (Figure 5-A), beginning with a preliminary screening process (Section 5.4). Preliminary screening evaluates the CSM to determine whether existing soil and/or ground water chemical concentrations may result in VI. Further investigation is appropriate where that is the case, and may show the need for additional work, or it may show that the VI pathway is incomplete and eligible for closure.

Further investigation (Section 5.5) is necessary for sites that do not screen out during the preliminary screening process. Further investigation typically begins with either SGss or CSA sampling, or paired SGss/CSA and IA sampling of potentially affected structures. SGe sampling may prove useful where interior access is not available or practical. The success of SGe sampling is dependent upon reasonable documentation of the subsurface lithology as it relates to vapor transport, particularly in heterogeneous settings.

Section 10 discusses comparison of sample results with applicable screening levels. An exceedance of the screening levels may indicate the need for further investigation or a remedy. If further investigation shows that VI does not present unacceptable present or future risk, the VI pathway is typically eligible for closure.

Figure 5-A: VI Investigation Process Overview



5.4 Preliminary Screening Process

Preliminary screening (Figure 5-B) determines whether subsurface VOCs exceed screening levels and whether preferential pathways and potentially affected buildings are present. The preliminary screening process relies on information obtained during CSM development. Conversely, the VI investigation will build LOEs useful in updating the CSM and evaluating the VI pathway.

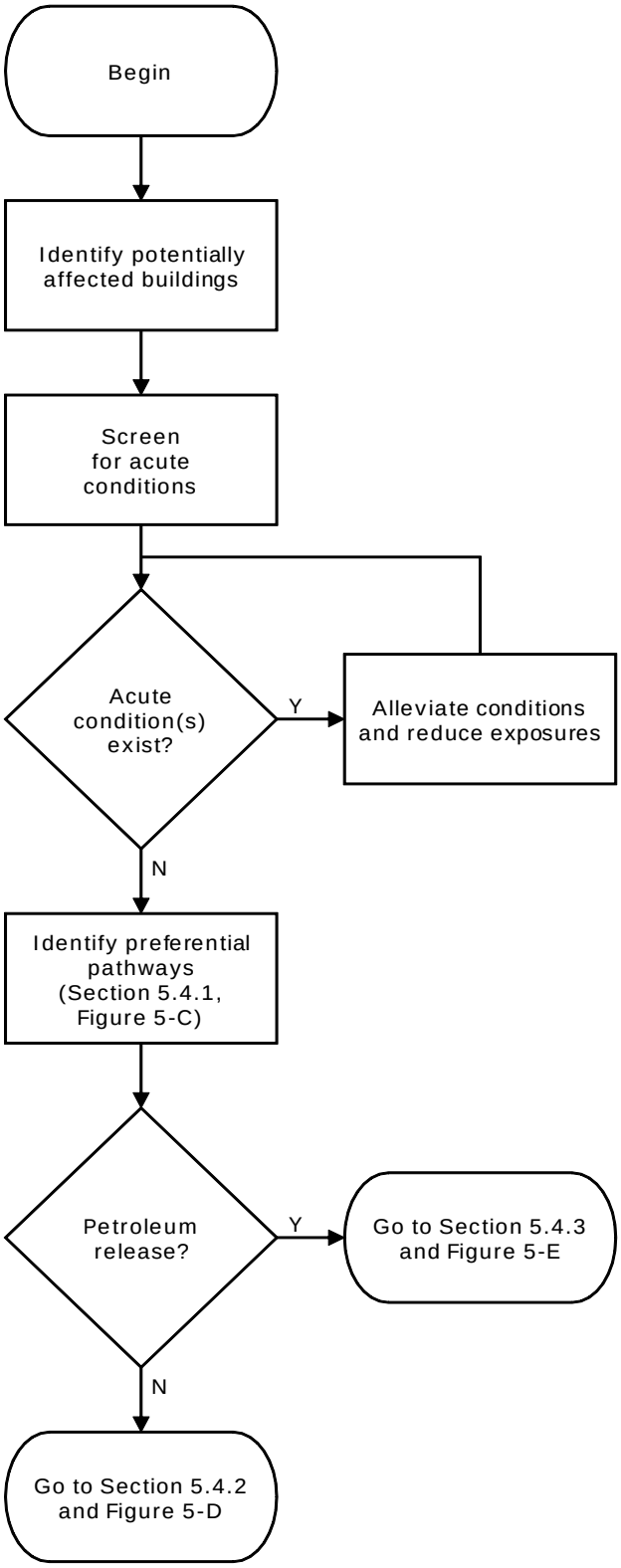
Another component of preliminary screening is the identification of structural characteristics important in vapor transport. These might include: basements (including earthen-floored basements), crawl spaces, crawl space linings, slab-on-grade construction, open sump pits or shallow ground water (less than five feet below the basement, crawl space or slab). Field instruments, such as a photoionization detector (PID) or a flame ionization detector (FID), may be useful for identifying vapor entry points and preferential pathways within a building.

Field instruments may also be useful in verifying the presence or absence of acute, explosive, or imminently dangerous conditions at a site. Where such conditions exist, the initial priority should be the immediate safety of the building occupants. This may require actions such as removal of occupants and/or immediate corrective action to reduce exposure and/or explosive hazards.

Preferential pathways are often important conduits for vapor transport. Section 5.4.1 includes additional guidance on the identification and preliminary screening of preferential pathways.

Chlorinated VOCs (CVOCs) and petroleum-related volatile chemicals generally exhibit different densities and biodegradation potential (Howard 1991; McHugh *et al.* 2010). These properties influence subsurface transport behavior in a manner that justifies preliminary screening procedures specific to each group (U.S. EPA, 2011d). Preliminary screening procedures for CVOC appear in Section 5.4.2, while Section 5.4.3 covers preliminary screening procedures for petroleum chemicals.

Figure 5-B: Preliminary Screening Process



5.4.1 Preliminary Screening Process: Preferential Pathways

In the context of VI, preferential pathways may be thought of as subsurface routes of least resistance for vapors. Vapors typically move from areas of high concentration to low concentration (diffusion), and areas of high pressure to low pressure (advection). Preferential pathways serve as a conduit that facilitates both of these processes. Examples of preferential pathways include: underground conduits and utility corridors (e.g., sewer lines, tile drains), fractured bedrock, karst geology, sump pumps, etc.

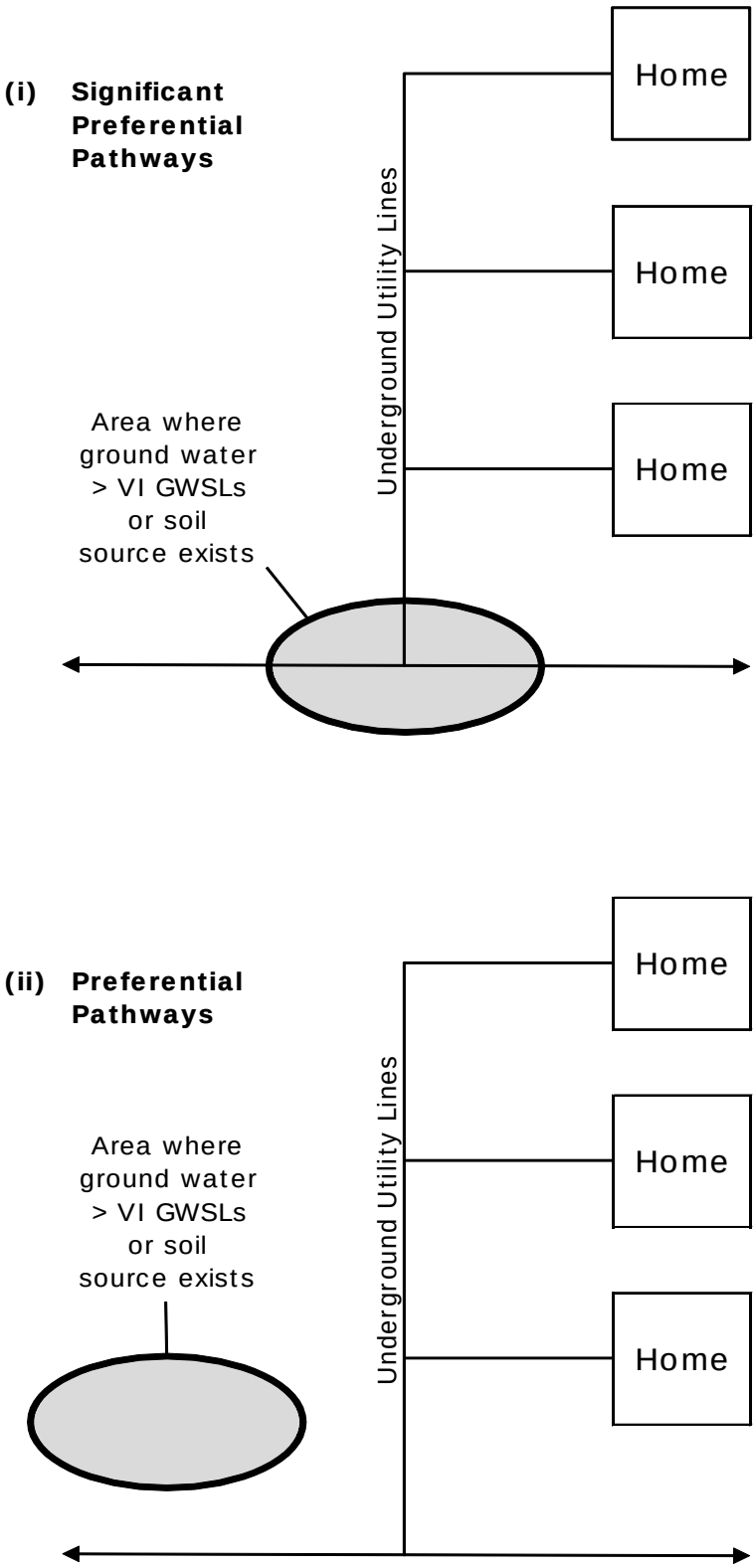
Preliminary screening should include mapping of man-made preferential pathways (e.g., utility conduits, drainage tiles, parking lots, etc.). Mapping man-made preferential pathways provides a sense of where vapors might move and whether preferential pathways may be significant.

For the purpose of VI investigations, IDEM considers a preferential pathway to be significant if it extends through *both* an area where ground water exceeds VI ground water screening levels (GWSLs) *and* a building footprint. This may include utility conduits overlying ground water that exceeds the VI GWSLs. Figure 5-C(i) illustrates a significant preferential pathway that merits further investigation (Section 5.5.1). Figure 5-C(ii) depicts a situation in which further investigation of the preferential pathway may not be necessary.

While VI investigations typically focus on the shallowest ground water interval as the VI source, soil VOC contamination may also act as a source of VI. Evaluation of soil as a vapor source requires professional judgment. LOEs relevant to evaluating the soil matrix as a potential VI source include:

- Distance of a source area from a building
- Contaminant degradation capacity
- Contaminant concentration in the soil (high, medium, low)
- Soil texture

Figure 5-C: Preferential Pathways



5.4.2 Preliminary Screening Process: Chlorinated Chemicals

Preliminary screening for chlorinated vapor intrusion (CVI) builds on the CSM with identification of significant preferential pathways (Section 5.4.1) and an assessment of distance between a CVOC source and a building (Figure 5-D). A CVI site can screen out from further consideration of VI if:

1. Buildings are more than one hundred feet from a CVOC soil source or ground water exceeding VI GWSLs (as measured at the top of the shallowest saturated zone), and
2. No significant preferential pathways are present.

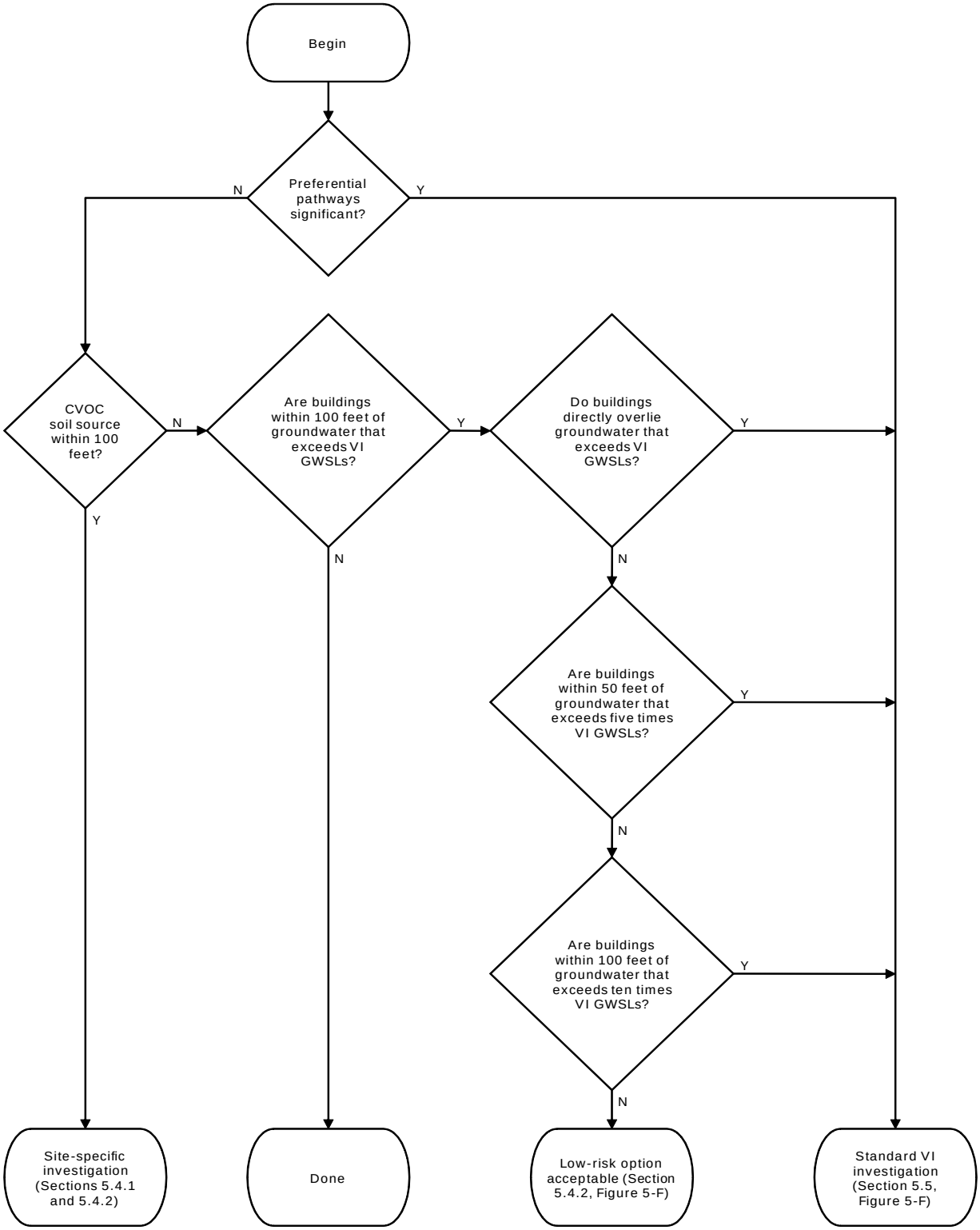
Note that soil source contamination directly underneath or near a building can indicate a higher potential for VI to occur (see Section 5.4.1 regarding LOEs). Where soil source contamination exists, work with the assigned project manager to determine whether a soil source VI investigation plan may be appropriate.

If the two screening criteria above are not satisfied, then the site can be further screened to determine if potentially affected buildings may be characterized as low risk for VI. Low risk building evaluation compares ground water contaminant measurements (measured at the top of the shallowest saturated zone) with distance-based VI GWSLs. IDEM considers a building to be low risk for VI if it satisfies the following criteria:

1. Directly beneath the building, there are no ground water CVOCs present at concentrations greater than VI GWSLs.
2. Within fifty feet of the building, there are no ground water CVOCs present at concentrations greater than five times VI GWSLs.
3. Within one hundred feet of the building, there are no ground water CVOCs present at concentrations greater than ten times VI GWSLs.
4. Any significant preferential pathways and soil source that may be present have been evaluated.

Low risk building investigation may employ SGe samples in lieu of SGss or CSA samples. However, due to the uncertainties associated with soil gas investigations, SGe sampling is only appropriate as a *stand-alone* screening tool when a building is at low risk for VI.

Figure 5-D: Preliminary Screening Process: CVOCs



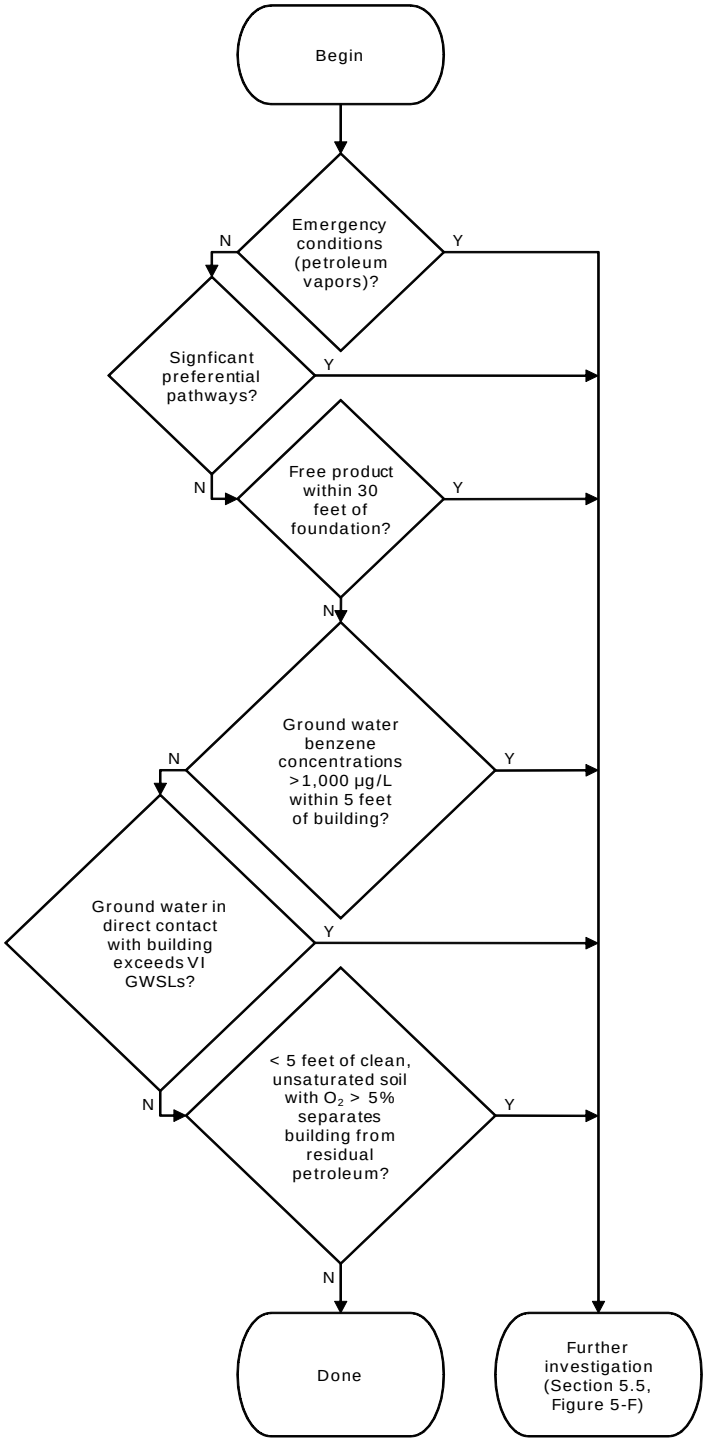
5.4.3 Preliminary Screening Process: Petroleum Chemicals

Figure 5-E illustrates a preliminary VI screening process for sites with petroleum hydrocarbon releases. Petroleum hydrocarbon vapor plumes are typically less extensive than CVOC vapor plumes. VI of benzene and other petroleum constituents occurs most often where contaminated ground water is inside a building or in contact with a building foundation, or light non-aqueous phase liquid (NAPL) is located near a building foundation. Benzene, the petroleum constituent that drives the risk at VI sites, readily degrades in unsaturated, oxygenated soils (U.S. EPA, 2011d).

The presence of five feet (in the horizontal and vertical directions) of clean, unsaturated soil with an oxygen content greater than five percent between the petroleum contamination and the building generally rules out petroleum vapor intrusion (PVI) (Davis, 2009; Luo *et al*., 2009). Soils in Indiana are generally sufficiently aerated if they are unsaturated and free of contamination. Therefore, further investigation of the PVI pathway is appropriate in situations where less than five feet of clean aerated soils are present, or where any of the following conditions exist:

- Emergency conditions (e.g., reports of petroleum vapors in the building)
- Significant preferential pathways
- LNAPL underlies a building or is within 30 feet, horizontally or vertically, of a building foundation
- The concentration of benzene in the shallowest ground water interval underlying a building exceeds 1,000 µg/L, or ground water in direct contact with a building exceeds VI GWSLs. Direct contact may lead to contaminant vapor migration through the foundation or actual penetration of contaminated water or LNAPL into the building. For example, a basement sump may draw contaminated ground water into the building, resulting in petroleum hydrocarbon vapor impacts to IA.

Figure 5-E: Preliminary Screening Process: Petroleum Chemicals



5.5 Further Investigation

Further investigation (Figure 5-F) is necessary at any site that does not screen out during the preliminary screening process. There are many possible approaches to further investigation of the VI pathway. The optimal approach will depend on circumstances and may change as the investigation proceeds. The RCG describes standard VI investigation procedures but allows for other site-specific investigation procedures to be proposed based on the CSM. The conclusions of a VI investigation are typically based upon relatively limited data collection to interpret a vapor flux dynamic that exhibits a high degree of variability. In most cases, a minimum of two rounds of vapor sampling is necessary to rule out the VI pathway once it has failed a screening procedure. Installation of a mitigation system in lieu of multiple sampling events is also an acceptable option, and may prove more cost effective at some sites.

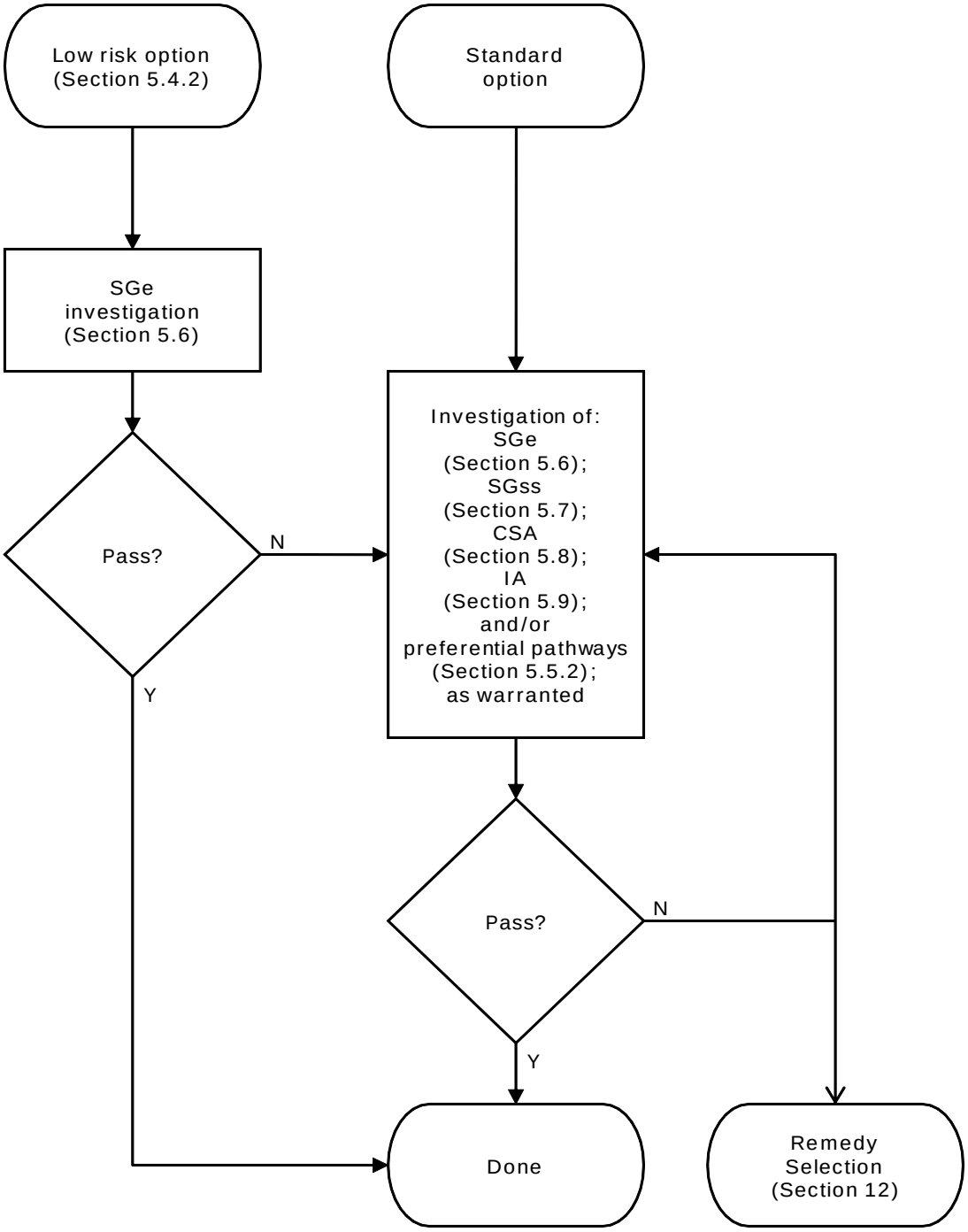
SGe sampling (Section 5.6) for stand-alone evaluation of VI risk is generally only appropriate for sites that qualify as low risk (Section 5.4.2), further investigation of undeveloped properties with potential VI issues, or preferential pathway investigations. Otherwise, IDEM recommends that further investigation begin with either SGss (Section 5.7) or CSA sampling (Section 5.8), or paired SGss/CSA and IA sampling (Section 5.9) of potentially affected buildings. If the building owner does not grant access for SGss or CSA sampling, IDEM recommends SGe or paired SGe/IA sampling.

Paired IA and SGss or CSA sampling helps establish the relationship between subsurface vapor and IA. It is a strong LOE that also helps to interpret potential sources of background contamination within the building. Other potential advantages of the paired approach include fewer SGss samples, less extensive preferential pathway evaluation, and less disturbance to building occupants.

Though paired sampling provides better information, SGss and CSA sampling may be acceptable as a stand-alone investigative tool. The stand-alone approach requires a sufficient number of samples to adequately characterize the spatial variability within the building footprint. Preferential pathways may provide a conduit for subsurface vapors to contaminate IA without significantly affecting the subsurface beneath the building (non-uniform horizontal distribution). Depending on the SGss sampling density, SGss sample results that are not paired with IA may not be sufficient to rule out VI. Preferential pathway investigations (Section 5.5.2) should include SGe evaluation wherever SGss sampling occurs without IA sampling. IDEM does not recommend sampling only IA due to inherent interpretation difficulties.

Section 10 discusses comparison of CSA, SGss, SGe, and/or IA sample results to applicable screening levels. A screening level exceedance may indicate the need for further investigation, remediation or mitigation.

Figure 5-F: Further Investigation



5.5.1 Further Investigation: Significant Preferential Pathways

Further investigation should include, where appropriate, an evaluation of significant preferential pathways. Digging or trenching (e.g., when installing underground utilities) destroys the native soil structure, and soil settlement may result in greater permeability than occurs in undisturbed natural soil. This is a special concern at sites where native soils exhibit lower permeability than backfill or bedding materials. The nature of significant preferential pathways investigations will vary according to the characteristics of the site and the sampling procedures used to evaluate VI in potentially affected buildings.

Evaluation of significant preferential pathways is critical when a building cannot be accessed for SGss, CSA, and IA sampling. Significant preferential pathway investigation can identify specific buildings within a neighborhood that warrant further VI evaluation, and may reveal how source vapors enter buildings. A significant preferential pathway investigation can also improve the placement of SGss sampling ports. Preferential pathway sampling may entail soil gas monitoring in and/or near the pathway. If a buried gas or electrical utility line is a significant preferential pathway, SGe sampling near the backfill material, rather than within the backfill material, is appropriate for safety reasons. When explosive vapors accumulate within a sewer at concentrations that could exceed the lower explosive limit, monitor vapor within the sewer and associated manholes.

Contamination in a preferential pathway is an indicator of likely VI. Any exceedance of SGss criteria in a preferential pathway may warrant further investigation.

5.5.2 Further Investigation: Sampling Procedures

Appropriate vapor sample collection procedures may vary by site and scenario. However, some procedures apply in most situations. This section describes certain sampling procedures or concepts that apply at most sites.

IDEM recommends use of summa-type canisters for vapor investigation. IDEM will evaluate alternative sampling devices and techniques on a site-specific basis. Tedlar® bags offer advantages when used with some specific sampling and analysis procedures. However, concerns over leaks, pressure changes during transport, cleanliness certification, and very short holding times (two to three hours) prevent acceptance of Tedlar® bags for general use in vapor investigations. Canisters should be batch-certified clean[37] and usually arrive from the laboratory equipped with flow regulators and a vacuum gauge. Laboratories typically pre-set flow regulators, so it is important to determine appropriate flow rates prior to delivery.

If the purpose of sampling is a stand-alone assessment of the VI pathway, IDEM recommends use of a fixed laboratory for sample analysis and U.S. EPA Methods TO-14A, TO-15, or TO-15 SIM (all canister-based methods). However, where use of an alternative sampling device or analytical procedure provides results of comparable quality to results using summa-type canisters and U.S. EPA methods, IDEM will consider approving such devices and techniques on a site-specific basis.

[37] A percentage of batch-certified clean canisters have been tested by the laboratory supplying them, and this certification is acceptable for routine air sampling and high concentration applications such as soil gas. Canisters that are individually certified clean have been separately checked by the laboratory, and are typically only needed for indoor air samples requiring high sensitivity (parts per trillion by volume).

Sorbent-type sampling devices used in active mode (air is mechanically drawn through the sorbent) with U.S. EPA Method TO-17 are generally acceptable for IA sampling (and potentially for CSA, SGss or SGe sampling) in many cases. However, due to variations in procedures and sorbent materials used, and potential site-specific complications, use of such devices should be discussed with IDEM prior to sampling.

Field duplicate samples provide information on the precision of collection procedures. Section 3.1 of U.S. EPA (2006a) provides general guidelines for collecting field duplicates. Most project sampling objectives do not require field duplicates. Where required, collect one field duplicate for every twenty samples per matrix for each method and analyze it as an independent sample.

Field blank samples provide information about sample contamination resulting from sampling equipment, sample containers, and the handling and transportation of samples. Field blanks typically consist of empty, clean, summa-type canisters, filled on-site with humidified, ultra-high purity nitrogen (or similar) gas, and then delivered to the laboratory with the other samples. Most project objectives do not require field blank analysis. However, if required, collect one field blank for every twenty samples and analyze it as an independent sample.

Where possible, avoid activities (e.g., smoking, solvent use) that may compromise analytical results. If such activities are reported during the sampling period, document them. Sample event documentation should include certification of canister cleanliness, records of regulator calibration, and evidence of appropriate chain of custody procedures. Section 3.9.1 lists appropriate analytical documentation elements.

Avoid collecting IA samples when subslab ports are being installed or opened for sampling, as doing so may bias the IA samples. Collect paired IA and SGss samples concurrently or sequentially within the same general time frame if this potential impact to IA samples is a concern.

5.6 Exterior Soil Gas (SGe) Sampling

SGe samples are whole air samples collected from within the soil or backfill matrix at locations outside the slab or footprint of a building. SGe sampling requires a borehole, usually advanced using a hand auger, hollow stem auger, or direct-push methods. IDEM prefers small-diameter (less than two inches) direct-push methods, as there is less disturbance of surrounding soils. Following installation of permanent or temporary sampling tubes in the boreholes, summa-type canisters are attached to the tubes and used to collect the SGe samples.

SGe sampling in combination with other LOEs is useful when evaluating preferential pathways, screening low risk buildings, identifying and delineating a contamination source, or estimating VI potential on undeveloped property. It is also useful when a property owner allows access for IA sampling but will not allow a hole to be drilled in the floor for collection of SGss samples. In this instance, it is better to pair the IA data with SGe data than nothing at all. Although SGe data provide important information, generally SGe sampling should not be used to estimate IA levels of contaminants, and is suitable as a *stand alone* tool for predicting IA concentrations *only* when a building meets the low risk criteria (Section 5.4.2).

5.6.1 SGe Sampling: Appropriate Conditions

Soil moisture content strongly affects migration of contaminant vapors through the subsurface (Tillman and Weaver, 2007). Wetting fronts moving downward though the unsaturated zone can cause underestimation of contaminant concentrations in SGe samples. Therefore, IDEM generally recommends waiting at least 72 hours after a significant precipitation event before collecting SGe samples. The actual amount of precipitation required to affect the movement of vapors will depend on a number of factors, including soil type, the soil moisture conditions prior to the precipitation, ground cover, and other factors that influence infiltration. Because of this, IDEM relies on the professional judgment of the consulting geologist to determine when sampling conditions are appropriate. The effect of significant precipitation can be recognized by observing high vacuum readings, extended sample collection time, and visible moisture droplets within the sampling train during sample collection. Detailed soil borings that take note of soil moisture conditions should be submitted for each soil gas sampling port installed at a site. As a general rule of thumb, for the purposes of SGe sampling, IDEM defines significant precipitation as an event yielding greater than one inch of precipitation. When evaluating the effect of water table fluctuations on VI, collect samples during a period when the water table is high and during a period when the water table is low.

5.6.2 SGe Sampling: Sample Number and Placement

IDEM recommends collecting SGe samples as close as possible to the target building (typically within five feet). This minimizes potential differences in the vapor environments beneath the building and beyond the building footprint.

Collect SGe samples from two locations near residential buildings: the side of the building closest to the ground water contamination, and the upgradient side of the building. If these two locations happen to be on the same side of the building, collect two SGe samples from separate locations on that side of the building. Given the variability involved with SGe sampling, the second location will provide additional confidence in the sample results. Professional judgment may suggest adjusting the location of the second sample to the side of the building most likely to be affected by VI, based on heterogeneities in the subsurface, building construction, etc. For large commercial buildings, a single SGe sample per side of the building is generally insufficient

to properly characterize vapor conditions in the subsurface, and additional SGe sampling locations will be necessary along multiple sides of the building.

Appropriate sample depth will depend on the vapor migration component of the CSM and the geologic material at that location. Unless site conditions dictate otherwise, IDEM generally recommends collecting SGe samples approximately five feet below the depth of the basement or building slab. SGe samples collected from depths less than five feet risk drawing ambient air (AA) from the surface into the sample, thereby biasing the results.

Sampling at multiple depths can provide important information about the movement and attenuation or degradation of vapors through the subsurface, particularly for petroleum chemicals. Deeper samples are often appropriate if the subsurface geology is complex. In these situations, IDEM recommends collecting SGe samples from multiple depths at each location, from the material most likely to transmit, or accumulate, the highest concentration of vapors.

5.6.3 SGe Sampling: Sampling Frequency and Duration

It will be necessary to collect SGe samples during appropriate conditions, in at least two distinct seasons, before an occupied building can be screened out by SGe sampling alone. If the results of the first two sampling events are contradictory or inconclusive, IDEM may request additional sampling.

Low vacuum and a low sample collection rate will minimize short-circuiting of vapors from outside the area of interest. IDEM recommends a sampling rate of 100 to 200 milliliters per minute (mL/minute) (CalDTSC/RWQCB, 2003). Approximate minimum fill times are five minutes for a one liter summa-type canister.

5.6.4 SGe Sampling: Procedures

To reduce the need for purging, SGe sampling equipment should have the smallest possible internal volume. Minimal purging reduces the risk of inducing air flow from outside the area of interest, and helps preserve sample integrity. IDEM recommends small-volume summa-type canisters (one liter) for SGe sample collection. All connections or fittings in the sampling equipment need to be tight, so no air leakage into the sample collection container occurs.

IDEM recommends installing permanent sampling ports, as this will improve the reproducibility of sample results. Calculate the volume of air in the sand pack after installing the sampling port, and use a large graduated syringe or hand-operated vacuum pump to slowly purge approximately three times the calculated volume of air immediately after installing and sealing the sampling port.[38] Avoid sampling for 24 to 48 hours after sampling port installation and sand pack purging, as this allows subsurface vapors to equilibrate. The SGe sampling event report should include purge volumes.

Prior to sample collection, determine the internal volume of the sampling apparatus, including the implant screen, and the tubing, but excluding the sample container volume and the sand pack volume. This dead volume of air in the sampling apparatus requires purging prior to sample collection. Slowly purge approximately three times the dead volume prior to sampling (DiGiulio, 2006). Measure and record purge volumes, which should remain consistent between sample locations.

[38] This should not be a large volume, assuming a small diameter borehole, a sand pack height of one foot or less, and a porosity of about thirty percent for the sand pack (DiGiulio, 2006).

To ensure that SGe samples are high quality and representative of subsurface conditions, perform a leak test prior to collecting each SGe sample. AA entering into the sample through leaks in the sampling train can ultimately bias the SGe results. Common tracers used during leak checks include: helium, propane, isopropanol, pentane, and butane. Choose a tracer that will not interfere with the analytical method for the sample. Document leak testing procedures and results in the report submitted to IDEM. See Hartman (2006), NYDoH (2006) and CalDTSC/RWQCB (2003) for detailed guidance on leak testing.

Vacuum during sampling should be as low as possible, less than or equal to 10 inches of water, and should not exceed 50 inches of water. A very slow draw rate will improve results where wet or fine-grained soils necessitate high vacuum. The SGe sampling report should include sample collection rate and vacuum readings.

5.7 Subslab Soil Gas (SGss) Sampling

SGss sampling means collection of air samples from immediately below the basement or slab of a building. The process involves drilling one or more holes through the concrete floor, placing a sleeve or probe through the concrete, and then collecting an air sample into an evacuated summa-type canister. SGss ports may be permanent or temporary, depending on the installation procedures and materials used.

IDEM considers paired SGss and IA samples best for evaluating VI potential into IA. Paired samples allow quantification of the actual increased risk from VI, while reducing concerns about potential sources of background contamination within the building. However, SGss sampling is acceptable as a stand-alone screening tool, provided there is an adequate investigation of preferential pathways and subslab spatial variability. In instances where subslab sampling is conducted without IA sampling, IDEM recommends a more structured preferential pathway investigation at each building location (e.g., one SGe sample per residence within the potential preferential pathway).

5.7.1 SGss Sampling: Appropriate Conditions

IDEM recommends collecting SGss samples during at least two different time periods to account for worst case conditions related to seasonal variability. One round of SGss samples should be collected during the winter heating season (approximately mid-November through March), when the indoor temperature is typically at least ten degrees higher than the outdoor temperature. Winter heating season SGss samples should be collected with building windows and doors closed and the building heating system in operation. Historically, the winter heating season has been considered the worst case sampling scenario for VI, because there is normally less external ventilation and building heating systems can create a pressure differential that pulls gases up from the subsurface.

A second round of SGss samples should be collected during the dry summer season. Soil moisture content and water table fluctuation may have a more significant impact on VI than winter heating season conditions. Some recent studies and professional experience show the highest transfer rates for VOCs from ground water to soil gas occur during falling water table conditions (McHugh, 2009). Generally, the water table is falling during the hot, dry summer months in Indiana (typically July through mid-September). Additionally, buildings equipped with cooling systems will have the windows and doors closed.

SGss sampling during both the winter heating and dry summer seasons accounts for seasonal variability and provides the best opportunity to capture worst case conditions. Most indoor air measurements represent a narrow “snapshot in time” because of problems with getting repeat access and uncertainty over seasonal and building variations. Due to these uncertainties and limited sampling data, IDEM recommends sampling during “worst case” conditions. Sampling during worst-case conditions provides limited exposure data that are likely to be biased high. This bias may be considered when evaluating the need for action if indoor air sampling can be conducted at a frequency that addresses seasonal and building variability. IDEM will consider alternative SGss sampling schedules, especially where sampling needs are urgent, seasonal variation is insignificant, or where building conditions, weather conditions, or other factors suggest that worst case conditions occur outside of the winter heating and dry summer seasons.

Differential pressure measurements are another LOE for evaluating VI. The difference in pressure between the IA and SGss provides a primary advective force for VI. VI will occur when

the pressure inside a building is lower than the pressure in soil gas below the building. If the pressure inside is positive compared to the subslab, there should be little or no VI potential. Cost-effective instrumentation is available to meaure and log pressure differential over hours, days, or weeks using small diameter subslab sampling ports or pressure taps. These measurements can be used as an LOE to demonstrate whether worst case conditions exist during a sampling event.

5.7.2 SGss Sampling: Sample Number and Placement

Investigative goals, utility locations, owner preferences, and other practical considerations will affect the number and locations of SGss samples. Monitoring points should be installed at locations with minimal potential for AA infiltration via floor penetration (e.g., cracks, floor drains, utility perforations, sumps, etc.)

One centrally-located SGss sampling point is acceptable for most residential buildings when paired with IA sampling. Additional SGss sample locations may be necessary if the ratio of the IA to SGss results is unusually high and the data from a particular building does not compare well with data from neighboring buildings. To account for spatial variability, when collecting SGss samples with no corresponding IA samples, IDEM recommends a minimum of two SGss locations, one in the center of the building and the second near the edge of the building closest to the highest subsurface contamination.

IDEM recommends collecting three SGss samples at commercial/industrial buildings with a footprint less than 5,000 square feet, with another SGss sample added to the sampling plan for each additional 2,000 square feet. Other approaches may be necessary at large commercial/ industrial buildings where this sampling density is unworkable. Alternative sampling plans should include:

- Collection of SGss samples in areas above the highest subsurface contamination
- Collection of SGss samples in areas where exposure to occupants is most likely (e.g., work areas, not closets or hallways)
- Collection of SGss samples from each building unit operating on a separate heating, ventilation, and cooling (HVAC) system

5.7.3 SGss Sampling: Frequency and Duration

Assessing the risk posed from the VI pathway through the subslab of a building generally requires at least two rounds of SGss sampling (one during the winter heating season and one during the dry summer season). Collect the second round of SGss samples from the same locations as the first. The second sampling event is especially important when confirming SGss results used as a stand-alone determination of the VI pathway. If the results of the first two SGss sampling events are contradictory or inconclusive, IDEM may request additional sampling.

In order to minimize air infiltration, maximum flow rates through the SGss probe and related tubing should not exceed 200 mL/min during purging and sampling. Approximate minimum fill times are five minutes for a one liter summa-type canister and thirty minutes for a six liter canister. Alternative canister fill rates are possible depending on project objectives. For example, fill rates may be set to collect the SGss samples over eight or 24-hour periods, especially during concurrent collection of IA samples.

5.7.4 SGss Sampling: Procedures

While SGss sampling is conceptually simple, the actual process has numerous pitfalls and nuances that need to be addressed. U.S. EPA (2006a) is a general reference for conducting SGss sampling, suitable for use at Indiana sites, and is summarized in the following paragraphs.

IDEM recommends installing permanent SGss sampling ports to improve the reproducibility of SGss sample results at each location. U.S. EPA (2006a, Section 3.4) provides detailed guidance on construction and installation of permanent SGss monitoring ports. Materials chosen for SGss monitoring ports should be durable enough to last through multiple sampling events. Fittings should be compatible the SGss collection equipment. Minimize the number of fittings and tighten them as necessary to avoid system leaks.

Avoid sampling until the soil gas has equilibrated within the port (typically two hours). IDEM recommends one or six liter summa-type canisters for SGss sample collection.

U.S. EPA (2006a, Section 3.5) describes a procedure for collecting SGss grab samples in six liter summa-type canisters. Adjust this procedure as necessary to meet site-specific data quality objectives and to address the following recommendations:

- During colder months, building occupants should operate heating systems to maintain normal temperatures of 65-75˚F for at least 24 hours prior to and during sampling.
- Purge three volumes of the sample probe and tubing immediately prior to sampling. Use a large graduated syringe or hand-operated vacuum pump to purge the sampling point. Avoid exceeding a maximum flow rate of 200 mL/min during purging and sampling in order to minimize air infiltration. Record purge volumes and include them in the SGss sampling event report.
- Document SGss sampling procedures using the guidelines outlined in Section 3.9 of U.S. EPA (2006).
- When SGss sampling is no longer needed at a particular building, remove the monitoring ports and seal the remaining holes to prevent migration of vapors through the slab.

To ensure that SGss samples are high quality and representative of subsurface conditions, perform a leak test prior to collecting each SGss sample. AA entering into the sample through leaks in the sampling train can bias the sample results and lead to artificially high or low contaminant concentrations in the sample. Common tracers used during leak checks include: helium, propane, isopropanol, pentane, and butane. Choose a tracer that will not interfere with the analytical method for the sample. Document leak testing procedures and results in the report submitted to IDEM. See Hartman (2006), NYDoH (2006) and CalDTSC/RWQCB (2003) for detailed guidance on leak testing.

IDEM is evaluating sorbent-type sampling devices for use in SGss sampling. Where such devices can provide results of comparable quality to results obtained using summa-type canisters and U.S. EPA analytical methods, TO-15 or similar, IDEM will consider approving the use of such devices and techniques on a site-specific basis.

5.8 Crawl Space Air (CSA) Sampling

SGss samples are not an option in buildings constructed over a crawl space. Such buildings will require collection of SGe or CSA samples, preferably in conjunction with IA samples and/or SGss samples (if there is a partial basement or slab). However, CSA samples may suffice in certain situations as a stand-alone method for investigating VI.

5.8.1 CSA Sampling: Appropriate Conditions

CSA samples should be collected during at least two different time periods to account for seasonal variability. Samples should be collected under the worst case conditions and time periods described in Section 5.7.1. The crawl space vents should be closed during all sampling events. IDEM will consider alternative sampling schedules, especially where sampling needs are urgent, seasonal variation is insignificant, or where building conditions, weather conditions, or other factors suggest that worst case conditions occur outside of the winter heating and dry summer seasons.

5.8.2 CSA Sampling: Sample Number and Placement

One centrally-located CSA sampling point is typically sufficient for most residential buildings. Crawl spaces are rare in commercial/industrial buildings. Such structures will require a site-specific sampling plan that includes enough samples to adequately characterize CSA concentrations. Placement of samples should take into consideration the location of the highest subsurface contaminant concentrations.

IDEM recommends collecting an AA background sample in conjunction with CSA sampling to determine whether an AA background source may be contributing to contaminant concentrations in the CSA. Measured AA concentrations should be used as a qualitative LOE, *not* directly subtracted from the measured CSA concentrations.

5.8.3 CSA Sampling: Frequency and Duration

Assessing the risk posed from the VI pathway within a building over a crawl space requires collection of at least two sets of CSA samples, with the second set of samples collected from the same locations as the first. Additional sampling may be necessary if the results of the first two sampling events are contradictory or inconclusive.

IDEM recommends collecting CSA samples over a 24-hour period in residential buildings and over an eight-hour period in commercial/industrial buildings. However, project objectives may dictate alternative canister fill rates.

The sample duration for commercial/industrial sites should capture normal working conditions. For example, if shifts are a twelve hour period, then the samples should be collected for a twelve hour period. Alternatively, if multiple shifts occur it may be necessary to collect one 24-hour sample or two eight-hour samples.

5.8.4 CSAir Sampling: Procedures

IA sample collection procedures (Section 5.9.4) are suitable for CSA sampling.

5.9 Indoor Air (IA) Sampling

IA sampling and results interpretation are inherently problematic. For instance, it is easy to locate a sample in an area where the IA is not representative, such as where air is diluted by vents or air ducts. It is also easy to encounter elevated indoor air background (IAb) levels of the contaminant of interest. Therefore, it is often advisable to sample under conditions where exceedances of indoor air screening levels (IASLs) are most likely, and to simultaneously investigate contaminant vapor directly beneath the building. If sampling is conducted under these worst case conditions and IASLs are not exceeded, then one can be reasonably sure that there is not an IA VI problem. However, an exceedance of the IASLs under worst case conditions does not necessarily indicate a VI problem. Interpretation of IA data must also consider IAb levels and contaminant vapor concentrations beneath the building.

5.9.1 IA Sampling: Appropriate Conditions

IA samples should be collected during at least two different seasons to account for source and pressure differences associated with seasonal change. One round of IA samples should be collected during the winter heating season when building windows and doors are closed and the building heating system is in operation (approximately mid-November through March, when the indoor temperature is typically at least ten degrees higher than the outdoor temperature). Historically, the winter heating season has been considered the worst case period for VI, because there is less external ventilation (due to doors and windows being closed) and the building heating system creates a pressure differential that pulls gases up from the subsurface.

A second round of IA samples should be collected during the dry summer season. Soil moisture content and water table fluctuations may have a more significant impact on VI than winter heating season conditions. Some recent studies and professional experience show the highest transfer rates for VOCs from ground water to soil gas occur during falling water table conditions (McHugh, 2009). Generally, the water table is falling during the drier summer months in Indiana (typically July through mid-September). Additionally, buildings equipped with cooling systems will have the windows and doors closed.

IA sampling during the winter heating and dry summer seasons will account for seasonal variability and will also provide the best opportunities to capture worst case conditions. Alternative proposals should show that the effect of seasonal fluctuations is not significant, or that there is an immediate need to characterize IA conditions and evaluate current human exposures.

Differential pressure measurements are another LOE for evaluating VI. The difference in pressure between the indoor air and the soil gas in the subslab region provides a primary advective force for VI. VI will occur when the pressure inside a building is lower than the pressure in soil gas below the building. If the pressure inside is positive compared to the subslab, there should be little or no VI potential. Cost-effective instrumentation is available to measure and log pressure differential over hours, days, or weeks, using small diameter subslab sampling points or pressure taps. These measurements can be used as an LOE to demonstrate whether worst case conditions exist during a sampling event.

5.9.2 IA Sampling: Sample Number and Placement

For residential buildings, worst case IA samples are generally located in the basement or area where vapors first enter the building. Generally, IDEM recommends at least three 24-hour samples: one IA sample in the basement or assumed worst case location, one IA sample in the general living area, and one AA background sample. If the building has multiple levels, IDEM recommends one IA sample from each floor. Place summa-type canisters within the breathing zone (three to five feet above the floor) and collect the AA background sample upwind of the building.

Site-specific IA sampling plans are necessary for larger commercial/industrial buildings. When planning IA sample locations in commercial/industrial buildings, consider the following:

- Individual offices within a building.
- Individual retail spaces within a larger commercial/industrial complex.
- Areas operating under separate HVAC systems.
- Areas with higher exposure potential (where occupants spend most of their time).
- Areas above the highest subsurface contaminant concentrations.
- Areas with utility inlets.

Illustrate the location of the sample containers on a building floor plan diagram.

5.9.3 IA Sampling: Frequency and Duration

Assessing the risk posed from the VI pathway requires the collection of at least two rounds of IA samples. To minimize the variability between IA samples collected over time, collect the second round of IA samples from the same locations as the first. Pairing IA samples with SGss samples can help assess IAb issues. If the results of the first two sampling events are contradictory or inconclusive, IDEM may request additional sampling.

IDEM recommends completing IA sample collection over a 24-hour period for residential buildings and an 8-hour period for commercial/industrial buildings. Alternative canister fill rates are possible depending on project objectives. However, the fill rate must be established prior to obtaining canisters from the laboratory, since the pre-set flow regulators for the canisters are typically supplied by the laboratory.

5.9.4 IA Sampling: Procedures

To minimize the impact of IAb on IA sampling, building occupants should suspend (where practical) activities such as smoking, dry cleaning, painting, mowing, pesticide application, and the use of sprays, cleaners, and solvents, etc. prior to IA sampling. Note exceptions observed during sampling. U.S. EPA (2011c) and Commonwealth of Massachusetts (2002) contain discussions of background levels.

Pre-Sampling Activities: It is important to complete an Indoor Air Building Survey Checklist[39] at least 24 hours prior to IA sampling. Inspect each room and floor of the building for potential interference from background sources as well as preferential pathways. If feasible, remove possible contaminants prior to sampling. Interview occupants to gather pertinent information that may not be obvious from a building walkthrough or inspection, such as: occupation, hobbies, or activities of the occupants, or any recent home improvements.

Sample Containers: Use six-liter summa-type canisters that are either batch or individually certified clean to collect IA samples. The summa-type canisters should be equipped with flow regulators and a vacuum gauge. The flow regulator should be set to collect the air sample over the appropriate period.

Assemble and operate canisters and flow regulators according to directions provided by the laboratory performing the analysis. The following documentation must be completed as part of sample collection:

- Field records of the initial and final canister pressures, start and stop times for canister filling, and approximate fill rates.
- Records of any field measurements (ambient temperature and pressure; screening instrument results, etc.).
- Records of any leak tests.
- Documentation of canister cleaning (batch or individual certifications).

Begin Collection of AA Samples: Collect an AA sample along with IA samples to evaluate the potential impact of outdoor air on IA. Collect at least one AA sample upwind from the building(s) being sampled. Collect AA samples at least one hour prior to collecting IA samples (and SGss if collected in conjunction with IA samples). Measured AA concentrations should be used as a qualitative LOE. AA concentrations should not be subtracted from measured IA concentrations.

Quality Checks on Sampling: Follow general precautions (avoid smoking or the use of solvents, provide documentation that equipment is clean and calibrated, provide documentation of storage and transport of equipment, etc).

IA Sample Analysis: If the purpose of sampling is a stand-alone assessment of the VI pathway, use a fixed laboratory to analyze IA samples, and U.S. EPA Methods TO-14A, TO-15, or TO-15 SIM (all canister-based methods). Field laboratories and portable analytical instruments may be acceptable for the purpose of screening only on a site-specific basis.

[39] http://www.in.gov/idem/files/la-073-gg.pdf

5.9.5 Sorbent-Type IA Sampling

Sorbent-type sampling devices are being investigated for use in IA sampling. Such devices may be used in active mode (air is mechanically drawn through the sorbent) or passive mode (sorbent exposed to ambient flow). If the investigator is able to demonstrate that the use of a particular sorbent-type sampling device, along with U.S. EPA Method TO-17 or similar analytical procedure, can provide results of comparable quality to results using summa-type canisters and Method TO-15 or similar, then IDEM will consider approving the use of such devices and techniques on a site-specific basis. Sorbent-type sampling devices can be used in conjunction with summa-type canisters to gather additional data over an exposure duration suitable for each device.

Due to the variety of site-specific conditions and objectives typical of VI investigations, a broader approval of a particular, alternative sampling device or analytical technique is not possible at this time.

5.10 Indoor Air Background (IAb)

Atmospheric and indoor chemical sources may complicate interpretation of IA sample results. Many VOCs common to environmental investigations are present in tobacco smoke, cleaning supplies, craft and hobby supplies, stored fuels, and other common household products, and may exceed chronic screening levels for chemicals such as benzene, carbon tetrachloride, chloroform, methylene chloride, and PCE. For this reason, it is important to assess IAb sources and concentrations at a site when evaluating the VI to IA pathway. For more information, see the U. S. Department of Health and Human Services Household Products Database.[40]

The following LOEs are useful when determining whether IA chemicals are attributable to background sources or subsurface contamination:

- Indoor Air Building Survey Checklist[41]
- AA samples
- Concentration gradients within a building
- SGss to IA concentration ratios
- Individual contaminant ratios across media
- Presence of indicator chemicals
- Use of radon as a tracer gas to determine a site-specific attenuation factor

Indoor Air Building Survey Checklist

Before sampling IA, conduct a detailed inspection of the building's contents and survey occupant activities. Identify the presence of common household items (e.g., cleaning supplies, craft and hobby supplies, and fuels) that contain VOCs common to the release, as well as recent activities such as dry cleaning, or home improvements (e.g., painting or new carpet) that may contribute to exposures. See IDEM's Indoor Air Building Survey Checklist[41] (Appendix IV) or U.S. EPA (2002a) for examples of building surveys.

AA Samples

AA sources (e.g., nearby manufacturing plants, dry cleaning facilities, etc.) may contribute to IA concentrations. When evaluating this possibility, collect at least one outdoor upwind AA sample, concurrent with the IA samples. The AA sample can serve as a reference for background conditions and allow comparison to IA results. Measured AA sample concentrations should be used as a qualitative LOE. AA sample concentrations should not be directly subtracted from the measured IA concentrations.

Concentration Gradients within a Building

Sampling may reveal contaminant concentration gradients or hot spots within a building. Concentration gradients between floors inside a building with higher concentrations in basements or lower levels may be consistent with subsurface VI or a preferential pathway; gradients with higher concentrations on upper floors may suggest an interior source.

[40] http://householdproducts.nlm.nih.gov/
[41] http://www.in.gov/idem/files/la-073-gg.pdf

SGss to IA Concentration Ratios

SGss to IA concentration ratios can be used to characterize potential VOC migration and attenuation from SGss to IA. This comparison may help determine whether IA VOCs originate in the subsurface or may be the result of indoor and/or ambient sources.

Most completed VI pathway conditions are characterized by VOC concentrations that are higher in SGss vapors than in IA. When IA VOC concentrations are higher than SGss VOC concentrations, there may be a background (indoor and/or ambient) source. Alternately, this could indicate the effect of a preferential pathway that is not properly represented by the SGss sample location(s).

Individual CVOC Ratios Across Media

Evaluating the ratio between ground water, SGss, and IA CVOC concentrations may distinguish between VI contributions and background sources. The primary CVOCs (tetrachloroethene and/or its degradation products) have similar properties related to the physical transport process. The individual CVOCs that comprise a gas mixture in SGss should enter a building at similar rates, and therefore be present at roughly the same ratios in IA as in the SGss. A notable difference in the CVOC ratios between SGss and IA may be attributable to IAb sources. Conversely, if the ratios of contaminants in the IA samples are similar to the ratios observed in the SGss samples, it can be presumed that the two are linked and there is a direct contribution from the subsurface source. Even if the ratio analysis suggests that indoor or ambient sources are likely responsible for some contribution to IA CVOCs, subsurface sources may also be contributing CVOCs to IA concentrations, especially if the SGss concentrations are much higher than concentrations in IA. In that case, the need for further investigation of background contributions should be determined through a balanced assessment of available LOEs.

Comparing contaminant ratios in ground water to IA may be a LOE; however, the value of this LOE depends on:

- Chemical-specific adjustment of relative volatility ratios using Henry's Law constants
- Adequate understanding of the ground water plume in the building vicinity
- Adequate investigation of preferential pathways
- Chemical-specific diffusion rates through the vadose zone
- Biodegradation

Indicator Chemicals

An indicator chemical is a substance that is associated with the subsurface contamination, but not background sources. *Cis*-1,2-dichloroethene, *trans*-1,2-dichloroethene, 1,1-dichloroethene, and 1,1-dichloroethane are common chlorinated break down products that are rarely found in background sources (U.S. EPA, 2011c).

The presence of indicator chemicals in IA samples is a good indication that infiltration is occurring and that SGss is the source of the observed contaminants. The opposite may also be true. The absence of an indicator chemical in IA that is present in SGss may indicate that little contamination is coming from the subsurface, suggesting that any air contaminants observed are from background sources.

Use of Radon as a Tracer Gas to Establish a Site-Specific Attenuation Factor

Some literature supports the use of radon as a tracer gas to estimate attenuation rates of SGss to IA. If IAb sources are suspected of contributing to IA sample concentrations, SGss and IA radon measurements can be taken to predict building-specific SGss to IA attenuation factors. The site-specific attenuation factor calculated by the radon measurements can be compared to the site-specific attenuation factor calculated by the VOC measurements. A good correlation of the two site-specific attenuation factors indicates that subsurface contamination is contributing to the IA concentrations. If the two site-specific attenuation factors do not correlate well, this may indicate that background sources are contributing to the IA concentrations.

5.11 Investigating Properties without Existing Structures

Properties with residual soil and/or ground water contamination may pose a threat of vapor exposure if buildings are constructed in the future. The potential for future exposure can be assessed through methods such as SGe sampling, ground water sampling, and flux chambers measurements. If may be appropriate to address the potential for vapor migration at a property without a building by incorporating vapor controls into the new building design, such as a vapor barrier with passive or active venting. In many cases, IDEM's closure conditions will include an Environmental Restrictive Covenant (Section 12) that requires including vapor control measures in the new building design. If the building will be constructed at some point in the distant future, the property owner may conduct further evaluation of the VI pathway at that time to determine if building control measures are needed.

5.12 Key Elements

VI evaluations should include information on the following as appropriate:

1. Source Area
   a) VOC contaminated environmental media (e.g., soil, ground water, both)
   b) Potential migration characteristics (e.g., stable, increasing, decreasing) of contaminants
2. Geology/Hydrogeology
   a) Heterogeneity/homogeneity of soils and the lithologic units encountered and the expected/observed contaminant migration, including depth and lateral continuity of any confining units that may impede contaminant migration and/or highly transmissive units that may enhance contaminant migration
   b) Distinct strata (soil type and moisture content, e.g., moist, wet, dry) and the distance between the vapor source and ground surface
   c) Depth of vadose zone, capillary fringe, and phreatic (saturated) zone
   d) Ground water characteristics (e.g., seasonal fluctuation, hydraulic gradient), including the relationship between the water table and well screening intervals, presence of any lens of clean ground water overlying contaminated ground water, or presence of a lens of clean ground water overlying ground water showing contamination that exceeds VI GWSLs.
3. Site Characteristics
   a) Potential contaminant sources
   b) Distance from the edge of ground water plume or other source to building
   c) Surface cover between the vapor source area and the potentially impacted building
4. Preferential Pathways
   a) Presence of fractured bedrock or karst geology in the area
   b) Map showing the location of any underground utilities, underground process piping near contaminated soil or ground water, with particular emphasis on utilities or process piping that connect(s) contaminated areas to occupied buildings.
5. Buildings (Potential Receptors)
   a) Map of existing and potential future buildings
   b) Occupancy and use of existing buildings (e.g., residential, commercial/industrial). Interviews may be necessary to obtain this information
   c) Building construction details, including:
      i. Materials (e.g., wood frame, block)
      ii. Openings (e.g., windows, doors)
      iii. Elevator shafts (if any)
      iv. Height (e.g., one story, two story, multistory)
   d) Foundation construction details, including:
      i. Type (e.g., basement, crawl space, slab on grade)
      ii. Floor construction (e.g., concrete, dirt)
      iii. Depth below grade

iv. Any vulnerable characteristics of potentially affected buildings, such as earthen-floored basements, unlined crawlspaces, open sump pits or shallow ground water (less than five feet below the basement, crawlspace, or slab)

e) HVAC system construction details, including:

i. Type (e.g., forced air, radiant)

ii. Equipment location (e.g., basement, crawl space, utility closet, attic, roof)

iii. Source of return air (e.g., inside air, outside air, combination)

iv. System design considerations relating to IA pressure (e.g., positive pressure is often the case for commercial buildings)

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