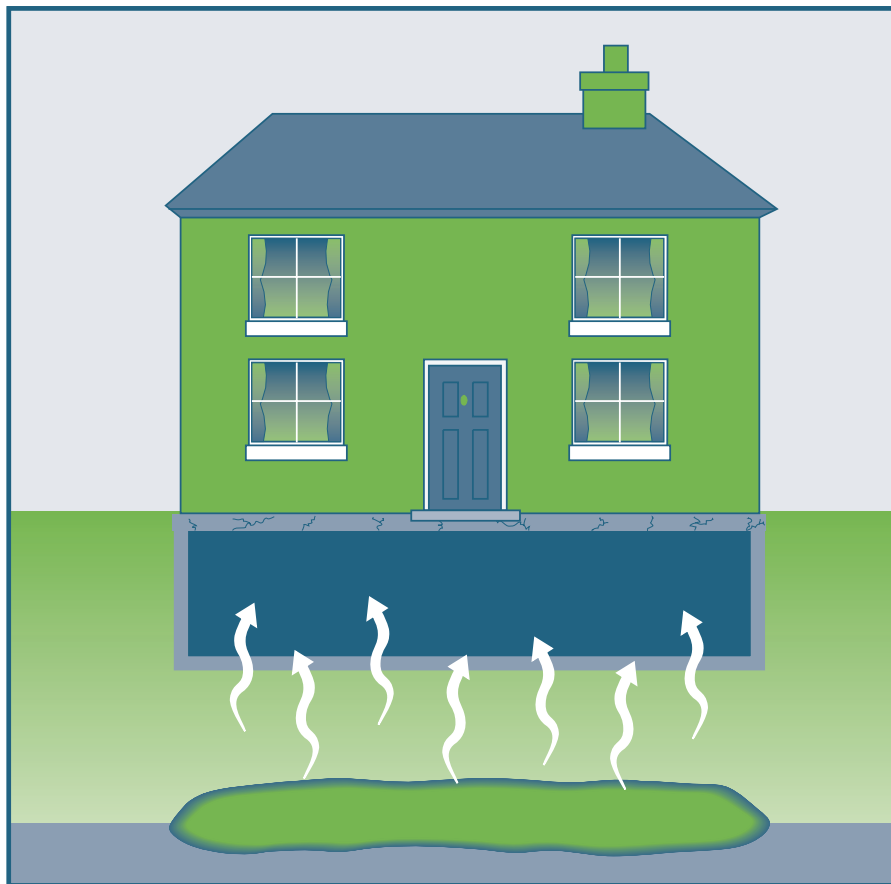




Technical and Regulatory Guidance Supplement

Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios

A Supplement to Vapor Intrusion Pathway: A Practical Guideline



January 2007

Prepared by
The Interstate Technology & Regulatory Council
Vapor Intrusion Team

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EXECUTIVE SUMMARY

This document is not meant to be a stand-alone document—it should be used in conjunction with *Vapor Intrusion Pathway: A Practical Guideline* (ITRC 2007). Appendix A of this document also contains Figure 3-3, “Site Investigation Flowchart,” from that technical and regulatory guidance document.

The ITRC Vapor Intrusion Team comprises of a wide variety of state regulators, federal partners, industry representatives and stakeholders. It was apparent during team discussions that many vapor intrusion scenarios exist, but several seemed to continuously engage the conversation. Since these reoccurring discussions evolved around the same types of sites, the team determined that walking the reader through these common scenarios may assist in the decision-making process for a vapor intrusion investigation.

The scenarios are based on the assumption that these sites start with a “yes” answer to the question in Step 7 of the practical guideline: Does the site require further investigation based on a preliminary assessment? All emergency (acute) exposures, nuisance conditions, and preliminary screening have been completed, and the site has not exited from the vapor intrusion assessment process. For the purposes of the following discussion, the need for further investigation was warranted, though the reasons for the additional investigation may have been different for each scenario.

Innumerable variations of vapor intrusion scenarios are possible, based on the multitude of sources and contaminants of concern, geologic and groundwater conditions, and potentially impacted properties and buildings. Differences in these conditions can lead to numerous investigation issues, constraints, and options, all of which affect the investigation work plan and its implementation. While it is impossible to describe every scenario that could result from varying circumstances, experience has shown that a few situations tend to occur more frequently than others. This document describes six different, yet common, hypothetical vapor intrusion scenarios and the investigation approaches that might be followed. Key decision points and the technical rationale for these decisions are identified in the scenarios. These key points are bolded in the text to assist the reader. Alternative approaches and investigative tools that may be chosen during the various stages are also identified.

Vapor intrusion investigations can be very complex, and the scenarios are tools in themselves. The main theme of each of the scenarios is to highlight the decision process and the reasoning behind the decision, the selection of a specific tool vs. an alternative investigative strategy, and how the tool is used in the hypothetical scenarios.

Review of these hypothetical case histories may help users better understand the nuances of various investigative procedures, particularly if their site is similar to one of the six scenarios, which are as follows.

1. Gas station in residential neighborhood
2. Dry cleaner in strip mall adjacent to neighborhood

3. Large industrial facility with long plume under several hundred buildings
4. Vacant lot with proposed brownfield development over a groundwater plume
5. Vacant large commercial building with warehouse space and office space
6. Apartment building with parking garage over a groundwater plume

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Scenario 1

Residential and Commercial Receptors Located Near an Active Service Station

This scenario illustrates a typical case in the assessment of the vapor intrusion (VI) due to petroleum hydrocarbon vapors.

1.A DESCRIPTION

The Situation

As part of a corporate divesting program, a site investigation was completed on an operating gas station located in a dense residential neighborhood and submitted to the state due to the discovery of petroleum contamination. The site investigation encountered contaminated soils in the vicinity of the existing underground storage tanks (USTs)—a petroleum hydrocarbon dissolved-phase plume and a small light, nonaqueous-phase liquid (LNAPL) plume at the site. The contaminant levels in soil and groundwater and the presence of LNAPL prompted the state UST regulatory agency to require a vapor intrusion investigation to determine whether receptors were at risk.

Conceptual Site Model

A site visit and review of the state UST regulatory agency files allowed the new facility owner's consultant to develop an initial conceptual site model (CSM).

The site, located in a dense residential neighborhood, is mostly paved and includes a convenience store and operating gas station. Groundwater flow direction is generally to the south towards a residence that has a dirt floor crawl space. Another residential property abutting the site to the south has a full concrete basement. During a site visit, odors were noted in the on-site convenience store but not in the residences that abut the site to the south.

The previous site investigation found the top of groundwater at 20 feet below ground surface (bgs). Soil borings consistently indicated sandy soil from ground surface to 30 feet below grade. The previous site investigation delineated an LNAPL plume approximately 70 feet long extending downgradient from the existing USTs. A dissolved plume extended an additional 110 feet downgradient of the LNAPL plume onto a residential property to the south.

The downgradient edge of the LNAPL plume has not left the site property and is approximately 50 feet upgradient from a residential structure (House 1) with the dirt floor crawl space (see Figure 1-1). A monitoring well located at

Site Summary

- Active service station
- Groundwater @ 20 feet bgs
- Soil contamination, LNAPL, and dissolved plume
- Sandy soils present at site
- Two residences downgradient of site, one with crawl space, the other with basement
- High benzene concentrations upgradient of residences
- LNAPL contained on site

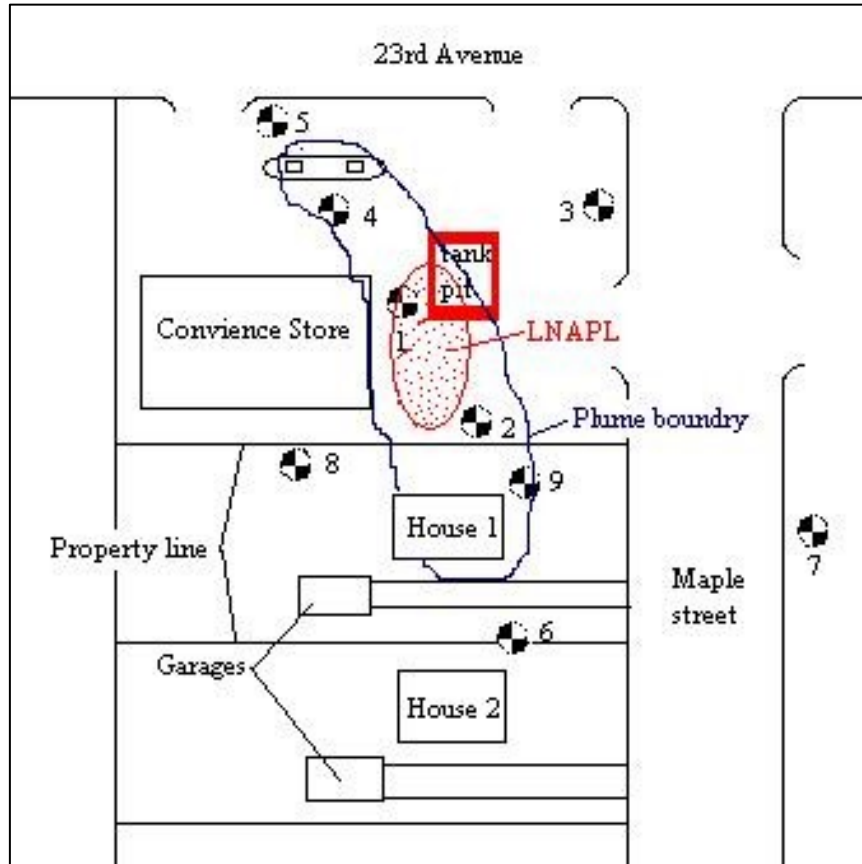


Figure 1-1. Residential neighborhood gas station.

the edge of the LNAPL plume has a benzene concentration of 10,000 $\mu\text{g/L}$. A monitoring well located near House 1 has a benzene concentration of 500 $\mu\text{g/L}$. The most downgradient well—located between House 1 and House 2, which has a full concrete basement—has a benzene concentration of 5 $\mu\text{g/L}$.

Analysis of soil immediately adjacent to the existing USTs detected benzene at 100 mg/kg approximately 10 feet from the on-site convenience store.

1.B VI INVESTIGATION PROCESS

Is vapor intrusion occurring at this site? (Use any existing data to assess whether the pathway is potentially complete).

Benzene is 500 $\mu\text{g/L}$ in the well closest to the residence, exceeding state risk-based groundwater screening levels by several orders of magnitude. The state oversight agency does not have any screening levels for soil phase data, so a soil gas concentration was calculated from the soil phase data using the U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) spreadsheet. The calculated soil gas values exceed state risk-based soil gas screening levels by several orders of magnitude.

Conclusion: There is a need to collect additional data.

Step 8. Choose Investigative Strategy (see Site Investigation Flowchart, Figure 3-1 of the *Practical Guideline* (ITRC 2007), reproduced in the appendix of this document)

There are two known sources of contamination: the groundwater (free-phase product and dissolved) and contaminated soil in the tank area.

Table 1-1 summarizes the pros and cons of the various investigation methods.

Table 1-1. Pros and cons of investigative methods for Scenario 1

Alternative	Pros	Cons
Indoor air sampling	⇒ Direct confirmation if benzene in building	⇒ Likely to have contributions from numerous sources, especially store ⇒ Can't differentiate source ⇒ Legal complications at residences ⇒ Public awareness required
Groundwater or soil phase data	⇒ Can search and delineate extent of contamination sources	⇒ Sources already delineated ⇒ Vapor intrusion risk often overestimated from these matrices
Passive soil gas investigation	⇒ Less invasive ⇒ More coverage for cost	⇒ Sources already delineated; values are qualitative ⇒ Depth of sampling is typically 3 feet bgs, and basements are ~8 feet bgs
External soil gas investigation	⇒ Gives actual vapor-phase values and reflects bioattenuation ⇒ More coverage for cost	⇒ Attenuation factor unknown ⇒ Conservative screening levels ⇒ Values may not be same as subslab
Subslab soil gas	⇒ Closest to receptor ⇒ Preferred by many agencies	⇒ Attenuation factor unknown ⇒ Very intrusive; legal issues ⇒ Public awareness required

Decision: External soil gas investigation was chosen.

Rationale: Since hydrocarbons are the contaminant of concern (COC) and bioattenuation in the vadose zone may be reducing the soil gas concentrations, exterior soil gas data will be most representative of the subsurface contamination and be less invasive than subslab sampling. Indoor air was considered not to be a good alternative because of the likely presence of vapors from the active service station. Subslab sampling will be considered depending on the results from the exterior sampling.

Steps 9 and 10. Design and Implement VI Investigative Work Plan

There are three primary receptors: House #1, House #2, and the on-site convenience store. The initial sampling plan was designed to assess the risk to each of these receptors but not to go onto the residents' properties to minimize legal complications.

- For House #1 (located over the dissolved plume), soil gas samples from three locations at 5 feet bgs along the property line adjacent to the house are planned. If values exceeding the risk-based levels are detected, a vertical profile of the soil gas from 5 feet bgs to the surface at the location showing the highest concentration will be conducted to determine whether the contamination is making it to the surface, keeping in mind that this building has a dirt crawl space instead of a slab construction. **The logic for this approach is that if the contamination is not making it to the surface over a higher concentration portion of the plume, then the same will likely be true further downgradient where other houses**

reside. The vertical profile will also test for the presence of any hydrocarbons moving laterally from the station at shallower depths, which can happen if the site is completely paved over.

- For House #2 (not over the groundwater plume), soil gas samples were collected at depth intervals of 3, 8 and 13 feet bgs (5 feet below the basement floor). Three locations along the property line adjacent to the residence toward the source were selected to get the concentration profile at depths corresponding to the basement walls, basement floor, and below the basement floor. **The logic for this approach is that if the contamination levels are not above risk-based levels at depths corresponding to the basement walls and basement floor closer to the source, then the same will likely be true at the house that is farther away from the source.**
- For the on-site convenience store, four soil gas samples are planned on 10-foot spacing on the side of the store towards the tank pit at a depth just below the surface cover (asphalt or cement). **The logic for this approach is that the ground surface at most service stations from the tank pit to the store is typically covered by impervious material, so near-slab soil gas data should reflect subslab soil gas data and be obtainable less intrusively. In addition, the samples will be closer to the source, so they likely will be higher concentrations than subslab samples located farther from the source.** If the near-slab data exceed risk-based levels, then either additional samples will be collected around the store to get a concentration profile around the store's footprint or, if allowed, interior samples below the slab will be collected.

Note: Some states may require different exposures pathways (future use, commercial, etc.) regarding the on-site convenience store.

Having the ability to add sampling locations both spatially and vertically in real time will optimize the field effort, so on-site analysis is planned.

Continuous soil cores may be collected at several locations at the property line and near each residence to get soil physical properties for later use in vapor intrusion modeling. Depending on its acceptance by the oversight agency, modeling might be used to determine site-specific screening values.

Step 11. Evaluate Data

The state oversight agency follows the EPA OSWER guidance for soil gas samples 5 feet below the receptor but uses a different default attenuation factor of 0.01 for subslab samples.

- For the residences, risk-based screening levels for benzene in soil gas at a 1-in-1-million risk level are $150 \mu\text{g}/\text{m}^3$ for soil gas samples collected 5 feet below a receptor and $30 \mu\text{g}/\text{m}^3$ for subslab soil gas samples.
- For the convenience store, screening levels were calculated using the state-allowed subslab attenuation factor for residences of 0.01 adjusted for default exposure times and ventilation rates for commercial settings. For benzene at a 1-in-1-million risk level, the residential risk-

based screening level is $30 \mu\text{g}/\text{m}^3$ using an attenuation factor of 0.01. For commercial settings, assuming an exposure time of 12 hours/day, 250 days a year, and a indoor air exchange rate of 1 per hour, the calculated risk-based screening level is 11 times higher, so a value of $330 \mu\text{g}/\text{m}^3$ will be used as the not to exceed level.

Both EPA test methods 8021 and 8260 can be used for soil gas samples conducted on site and reach detection levels of $30 \mu\text{g}/\text{m}^3$ and $100 \mu\text{g}/\text{m}^3$, respectively. Method 8021 was selected to reach the screening level required at the site.

Since the COC is a hydrocarbon, oxygen and carbon dioxide data will be collected to show bioattenuation and document the presence of highly aerobic soils. These data can be collected using gas chromatography or with a portable field meter such as a Land Tec GEM-2000.

House #1 (above the groundwater plume): The benzene values at the 5-foot collection depth ranged 1000–2000 $\mu\text{g}/\text{m}^3$, which exceeded screening levels by >10 times. To test whether bioattenuation was reducing concentrations in the shallow vadose zone, it was decided to collect additional samples at shallower depths even though more influences from the surface would be expected. A vertical profile in the upper 5 feet gave values of $500 \mu\text{g}/\text{m}^3$ at 3 feet bgs, $150 \mu\text{g}/\text{m}^3$ at 2 feet bgs, and below detection (detection level of $30 \mu\text{g}/\text{m}^3$) at 1 foot bgs. Oxygen levels were 12% at 3' bgs reaching 20% at 1' bgs. The vertical profile indicated that bioattenuation was occurring and that at least 3' of highly aerobic (>10%) soils existed. A sample from the 1' depth was collected for off-site TO-15 analysis to confirm field results.

Note: Groundwater concentrations should be stable prior to making final decisions regarding vapor intrusion. If the plume is expanding, then soil gas concentrations can increase with time.

House #2 (not over the groundwater plume): The vertical profiles at the property line adjacent to this residence showed a rapid decrease in the benzene concentration and increase in the oxygen concentration from depth towards the surface due to bioattenuation. Benzene values 3–8 feet bgs (depth of the basement floor) were below detection ($30 \mu\text{g}/\text{m}^3$ detection level), and oxygen levels exceeded 15%. Benzene values at 13 feet bgs (5 feet below the basement) ranged from below detection to $110 \mu\text{g}/\text{m}^3$, which is below the risk-based screening level. All samples with nondetect benzene values were collected for off-site TO-15 analysis to reach the subslab risk-based detection limit of $30 \mu\text{g}/\text{m}^3$, which would apply if contamination were immediately against the basement walls.

Convenience Store: The benzene concentrations in the four samples ranged 500–2000 $\mu\text{g}/\text{m}^3$, exceeding the calculated risk-based level of $330 \mu\text{g}/\text{m}^3$. Additional samples around the store showed values ranging from $500 \mu\text{g}/\text{m}^3$ closer to the source to below detection on the side away from the source.

Step 12. Is Additional Investigation Warranted?

House #1: Possible risk exists although bioattenuation is apparent in the upper 5 feet of the soil column. Off-site TO-15 (of 1-foot bgs soil gas sample) will document whether benzene is below subslab risk level of $30 \mu\text{g}/\text{m}^3$. The investigator will have to convince the oversight agency that

the shallow (<5-foot bgs) soil gas data at the property line are representative of conditions at the residence and not subject to temporal effects or atmospheric dilution. **More data will likely be required.**

To address the data deficiency, several alternatives are available:

- Monitor the shallow soil gas at the property line to prove the values are representative and not subject to temporal effects or atmospheric dilution. This process might take several sampling events over the seasons. The investigator can make the argument that the same results can be expected at the residence.
- Collect soil gas data near the foundation of the residence to see whether contamination is detected above risk-based levels.
- Collect subslab soil gas samples from within the residence.

Sampling around structures is less intrusive than going inside, especially at residential properties. If near-slab soil gas data collected at a 5-foot depth show benzene levels below the risk-based screening level of $150 \mu\text{g}/\text{m}^3$ and oxygen is greater than 10%, it is very likely that there are adequate oxygen levels under the house and bioattenuation is active as seen on the site property line. Subslab soil gas sampling should not be necessary. If higher concentrations are detected and oxygen levels are low (<10%), then subslab soil gas sampling is likely necessary.

If subslab soil gas sampling is required, the dirt crawl space affords an alternative approach to typical soil gas techniques. Measurement of the crawl space air is not recommended as the currently available research suggests that crawl spaces communicate very effectively with the overlying structure. Hence, the same complications that apply to indoor air sampling (e.g., background sources) would apply to crawl space air sampling. However, flux chambers offer an alternative in this situation. They can be easily emplaced in the dirt crawl space with minimum disruption to the occupants and would measure the actual flux into the crawl space. These data would be more reliable than shallow soil gas since the lack of a slab would raise concerns over the temporal variability and other technical issues related to shallow soil gas data.

House #2: The measured values are below risk-based levels. Even if the off-site TO-15 results show benzene levels at the subslab risk level of $30 \mu\text{g}/\text{m}^3$, the residence is further from the source and it is very likely values near the residence will be lower. **No more data will likely be required.** Seasonal variability is unlikely to differ by more than a factor of two, so it's unlikely to exceed the screening value.

If the regulatory agency is not convinced by the current data, further investigation consistent with the approaches outlined for House #1 may have to be employed.

Convenience Store: Near-slab results exceed risk-based criteria, even for a commercial setting. **More data will likely be required.**

Although the samples were not collected immediately below the store footprint, there is no reason to expect there would be any significant difference under the slab, so subslab sampling is not likely to yield any benefit. Two other types of data might prove more useful for this situation:

- Determination of store ventilation rate—Retail stores such as these have an enormous amount of foot traffic, which increases the ventilation rate of the store with every opening of the door. The risk-based screening levels assume a default ventilation rate of 1 room exchange per hour. The actual rate is likely to be significantly higher. The risk-based screening level increases linearly with the ventilation rate. Ventilation rates are often available from architectural drawings or are easy to determine using tracer gases.
- Determination of a slab-specific attenuation factor—The risk-based screening levels assume a conservative value of the attenuation factor of 0.01. However, many slabs, especially those with floor coverings, have a higher attenuation. A slab-specific attenuation factor can be determined using natural conservative tracers, most commonly radon analyses. The risk-based screening level is inversely proportional to the attenuation factor.

Step 13. Is Mitigation Warranted?

The determination of whether mitigation is warranted at either the residential properties or the convenience store will depend on the investigative results, regulatory agency preferences, the time frame, and numerous legal issues. If time is not a factor, legal complications could hinder sampling on the residential property. The regulatory agency may not be comfortable that the demonstration of bioattenuation on the site applies to the residence based on the SCM. In these situations, mitigation would be a suitable choice.

1.C WHAT WAS UNIQUE ABOUT THIS SCENARIO?

- Vertical profiles were used to document bioattenuation.
- Different sampling strategies were used for different buildings/receptors.
- Supplemental approaches such as flux chambers, radon measurements, and ventilation rates were used.

1.D LESSONS LEARNED

- Near-slab data can be used to make a decision on the need for subslab data.
- Supplemental tools can be extremely useful, especially for commercial settings.

1.E NEXT STEPS

- If flux chambers show flux into crawl space, how do we mitigate?
- If increased ventilation rate and slab-specific attenuation from radon still do not lower the risk levels above measured levels, then mitigation is required.
- Refer to oversight agency regarding other remediation that may be necessary at the site (e.g., soil removal, groundwater remedy, etc.)

Scenario 2

Dry-Cleaning Operations in a Strip Mall Near a Residential Neighborhood

This scenario illustrates a typical assessment of the vapor intrusion risk to adjoining businesses due to tetrachloroethene contamination emanating from a dry cleaner.

2.A Description

The Situation

This is a typical strip mall site, with a day care center, candy store, dry cleaner, hardware store, and fast food restaurant located in one commercial building with slab-on-grade construction. An odor complaint in the day care center was submitted to the local department of health, which collected an air sample. The department of health determined that the odor was likely due to tetrachloroethene (PCE) and that the levels of PCE were unacceptable but did not exceed acute levels to warrant immediate action. The investigation was addressed ultimately under the state's voluntary cleanup program.

Conceptual Site Model

A preliminary assessment (PA) of the site revealed that the only viable source of PCE was the dry cleaner located several doors down from the day care center. The current owner of the dry cleaner had recently installed new equipment; however, the PA found that the dry cleaner's historical operations likely resulted in a discharge of PCE to the back of the building via a subsurface floor drain. The new dry-cleaning equipment apparently eliminated any waste discharge, so there is no current release of PCE to the subsurface soil environment. The dry cleaner does have an air permit for the equipment.

Preliminary subsurface data developed during geotechnical investigations for the construction of the strip mall indicate that groundwater is approximately 40 feet bgs and that the surficial soil consists primarily of a thick clay layer to the groundwater interface. Construction plans indicate a 6- to 8-inch-thick gravel layer directly under the slab of the building.

An environmental consultant is contracted by the owners of the dry cleaner to determine the extent and severity of the potential exposure of the strip mall tenants to the historical release of PCE.

Site Summary

- Historic release of PCE to subsurface
- No current release
- Air permit for PCE at current drycleaner
- Groundwater \geq 40 feet bgs
- Lithology is 5 feet silty clay with >35-foot-thick clay

2.B VI INVESTIGATION PROCESS

Data must be developed to sufficiently characterize the fate and transport of the PCE release, including whether the release has generated vapors that potentially could affect the other tenants in the strip mall.

Step 8. Choose Investigative Strategy

There are no preexisting data for this site to use in determining the optimal investigation method; however, the location of the source—the dry cleaner—is known. Table 2-1 summarizes the alternatives.

Table 2-1. Pros and cons of investigative methods for Scenario 2

Alternatives	Pros	Cons
Perform passive soil gas investigation around perimeter of building	<ul style="list-style-type: none"> ⇒ Easy to perform; cost-effective to identify areas of additional investigation ⇒ Works well in tight soils 	<ul style="list-style-type: none"> ⇒ Data reported in mass, not concentration ⇒ Two- to three-week delay in results
Sample groundwater underneath the strip mall	<ul style="list-style-type: none"> ⇒ Determine whether secondary source exists that may affect strip mall and surrounding properties 	<ul style="list-style-type: none"> ⇒ Surface source of PCE likely to be in soil and soil vapor before groundwater ⇒ The initial geotechnical data suggest that the clay lenses would inhibit the vertical migration of the PCE to the groundwater
Investigate the subslab soil gas under the entire strip mall area	<ul style="list-style-type: none"> ⇒ Determine whether PCE may be present at concentrations that could affect indoor air quality 	<ul style="list-style-type: none"> ⇒ More intrusive than initial characterization ⇒ May be unnecessary if determined that only portions of subsurface are affected by the release
External soil gas investigation.	<ul style="list-style-type: none"> ⇒ Gives actual vapor phase values ⇒ Less invasive ⇒ More coverage for cost 	<ul style="list-style-type: none"> ⇒ Attenuation factor unknown ⇒ Conservative screening levels
Sample indoor air quality in the tenant buildings	<ul style="list-style-type: none"> ⇒ Direct measurement of potential exposure point concentrations 	<ul style="list-style-type: none"> ⇒ Results may be confounded by other sources of PCE

Decision: External soil gas investigation was chosen.

Rationale: This strategy was considered to offer the most advantages and fewest disadvantages for locating the areas of contamination both spatially and vertically and initially assessing the vapor intrusion pathway.

Steps 9 and 10. Design and Implement VI Investigative Work Plan

Decision: The initial VI investigation was to focus on the characterizing of the subsurface conditions along the perimeter of the strip mall using direct push and sampling for volatile organic compounds (VOCs) in soil gas at depths of 2, 6, and 10 feet. Direct-push borings were located along the front and back of the strip mall (Figure 2-1) approximately 5–15 feet from the building and included a utility location survey.

Rationale: There were no characterization data for the reported release, and the air permit was already issued to control an outdoor air emission source.

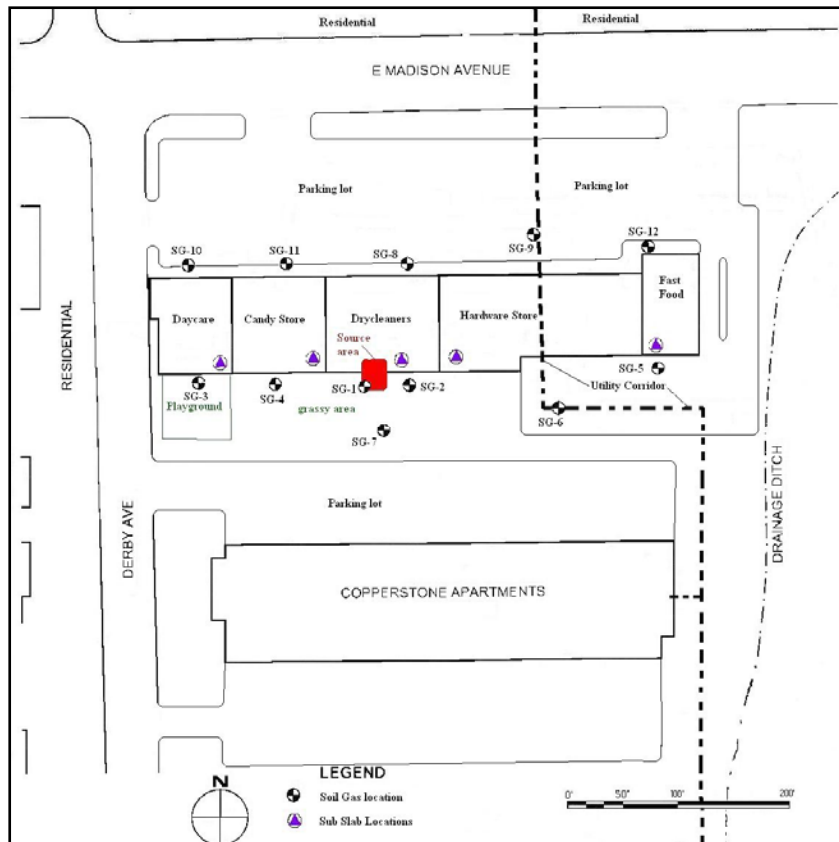


Figure 2-1. Neighborhood strip mall.

Step 11. Evaluate the Data

Results of Sampling: The initial investigations determined the following environmental conditions of the site:

- The source area was identified by soil gas sampling, only in the back area of the strip mall. Table 2-2 shows results of soil gas sampling.
- The vapor plume extends radially from zone of release in back of dry cleaner to the surrounding area in a decreasing gradient to the day care center and fast food tenants.
- Confirmed soil geology in the affected subsurface area is gravel base immediately beneath the strip mall slab to silty gravel with a thick clay layer to the groundwater

Table 2-2. Soil gas sampling results, $\mu\text{g}/\text{m}^3$

Sample	2 feet	6 feet	10 feet
SG-1	100,000	2,000	ND* (50)
SG-2	1,000	75	ND (50)
SG-3	100	ND (50)	ND (50)
SG-4	350	ND (50)	ND (50)
SG-5	ND (50)	ND (50)	ND (50)
SG-6	250	50	ND (50)
SG-7	ND (50)	ND (50)	ND (50)
SG-8	8,000	100	ND (50)
SG-9	100	ND (50)	ND (50)
SG-10	ND (50)	ND (50)	ND (50)
SG-11	75	ND (50)	ND (50)
SG-12	ND (50)	ND (50)	ND (50)

*ND = nondetect with detection limit in parenthesis.

interface.

- The presence of the sewer line may be an additional transport mechanism for the PCE to areas away from the site via the sewer line trench. Additional soil gas sampling of the sewer line to determine the concentration and lateral dispersion of PCE may be needed. Initial data (SG-6, SG-9) indicate some contamination along the trench, but show concentrations rapidly decreasing with distance from the building.

Step 12. Is Additional Investigation Warranted?

Determine whether PCE from normal dry-cleaner air emissions is being recirculated into the adjoining businesses. Check design of the exhaust of the dry cleaner to determine whether the discharge permitted from the dry cleaner could affect air intakes of the other tenants or of any adjacent buildings downwind of the dry cleaner that may have an air intake.

Establish whether the air discharging from the dry cleaner may be contributing to PCE concentrations in the day care and the other tenants of the building at levels below an odor threshold.

Based on the inspection of the dry-cleaner air discharge and the other tenants' air intakes, it is unlikely, based on wind direction and location of intake, that PCE-affected air from dry cleaner is getting to the day care center; however, other tenants may be affected.

Determine whether the concentrations of PCE detected along the back perimeter of the strip mall (landscaped area) are potentially migrating under the slab and potentially affecting indoor air quality. The vertical profiles indicate that the PCE contamination is a surface release, so movement laterally under the slab is a likely mechanism. The 2-foot samples closest to the candy store and day care are below commercial risk exposures but exceed allowed subslab values for a 1-in-1-million residential risk exposure ($40 \mu\text{g}/\text{m}^3$). These values are considered close enough to allowable levels that further assessment is deemed necessary. Conduct subslab and indoor air sampling in following buildings: fast food restaurant, hardware store, dry cleaner, candy store, and day care center. (Note, at the end of strip mall, there is a play area located outside and immediately adjacent to the day care center). Outdoor ambient sampling should be included during this phase of the investigation, and some focus on the outdoor play area may be appropriate. Community outreach with affected parties will be done at this stage, if not already instigated.

Indoor air and subslab samples were taken from the occupants of the strip mall with the exception of the dry cleaner. Indoor air and subslab samples are often coupled together to aid in the determination of vapor intrusion and to enable determination of background. Results (Table 2-3) showed measurable levels in all but the fast food restaurant (indoor) location.

Table 2-3. Subslab and indoor air sampling results, $\mu\text{g}/\text{m}^3$

Location	Subslab	Indoor
Day care	100	5
Candy	1,500	15
Dry cleaner	10,000	NA*
Hardware	1,500	20
Fast food	75	ND (0.2)

*NA = not applicable. ND = nondetect with detection limit in parenthesis.

The dry cleaner had the highest subslab soil gas concentration of PCE at 10,000 $\mu\text{g}/\text{m}^3$, the hardware and candy stores had PCE concentrations at 1,500 $\mu\text{g}/\text{m}^3$, the day care at 100 $\mu\text{g}/\text{m}^3$, and the fast food restaurant at 75 $\mu\text{g}/\text{m}^3$.

The state oversight agency's acceptable indoor air level for PCE for a 1-in-1-million risk exposure for a residential setting is 0.4 $\mu\text{g}/\text{m}^3$. For commercial settings, exposure times are approximately 5 times lower, and the state uses a 1-in-100,000 risk level, so the allowable level is 20 $\mu\text{g}/\text{m}^3$.

Step 13. Is Mitigation Warranted?

Although the measured indoor air concentrations appear to be acceptable, the levels in the subslab soil gas data clearly indicate that PCE from the dry cleaner has migrated underneath the slab and could impact the indoor air of the neighboring businesses. In addition, the day care center is considered a sensitive receptor, which could lead to legal ramifications if the problem is ignored. The choices here are as follows:

- Do not mitigate, but continue to monitor the situation on a regular basis.
- Remove the source of vadose zone contamination. Implement subslab depressurization mitigation measures, and monitor PCE concentration in depressurization discharge on a quarterly basis to determine whether source removal has mitigated the presence of PCE subslab gas and concentrations are decreasing with time.

2.C WHAT WAS UNIQUE ABOUT THIS SCENARIO?

The first issue facing investigators at dry-cleaning sites is to determine whether PCE is currently being used in the process and whether there are any permitted waste streams that may contain PCE. Permitted waste streams that contain PCE must be considered in the relative overall assessment of potential risks from unpermitted releases that may have occurred historically or that may be continual release to the environment.

The second major issue affecting dry-cleaning vapor intrusion sites is the presence of other tenants that may be affected by dry cleaners located in multiuse buildings, such as strip malls or office buildings with commercial use on the first floor.

Another issue to keep in mind in a strip mall scenario is that some buildings and tenants may share heating, ventilating, and air conditioning (HVAC) systems, which can further complicate any VI investigations. There may be contributions to indoor air through the shared HVAC rather than from vapor intrusion.

Finally, dense vapors of chlorinated solvents leaking from surface sources such as washing units can create vapor contamination underneath the slab that moves laterally underneath adjacent businesses. In such cases, groundwater data are likely to have little correlation with soil gas samples collected in the vadose zone.

2.D LESSONS LEARNED

- Permitted discharges from dry-cleaning operations must be considered as a potential secondary source that may affect adjacent buildings via a pathway independent of vapor intrusion through the subsurface.
- Soil gas may follow preferential pathways that lead to confounding sampling results, (e.g., the results from SG-6 seem to indicate that vapors have migrated away from the building into the disturbed soils of the utility trench and may lead to a potential impact to receptors outside the CSM initially developed.

2.E NEXT STEPS

Future activities at the site will include monitoring of the depressurization discharge to determine whether the removal action of the vadose zone source area was successful.

Refer to the oversight agency regarding other remediation that may be necessary at the site (e.g., soil removal, groundwater remedy, etc.).

Scenario 3

Degreasing Solvent Contamination from a Small Industrial Site on an Adjoining Mixed-Use Neighborhood

This scenario illustrates a typical investigation of a large vapor intrusion site due to chlorinated VOCs (CVOCs) contamination of groundwater beneath occupied structures.

3.A DESCRIPTION

The Situation

An industrial facility with a small degreaser contaminated groundwater off site more than 20 years ago, impacting the adjoining mixed-use community. The degreaser created a small zone of high-concentration soil contamination of multiple CVOCs, resulting in a large (several-mile) groundwater plume beneath several hundred structures. The community is primarily residential, with mixed zoning of commercial properties, schools, home day cares, etc., in the area. A legacy evaluation showed that ineffective source control was installed 20 years ago on the facility property. The evaluation has been reopened specifically to evaluate vapor intrusion into structures that overlie the plume. This is a state-led site, and project costs are an issue.

Conceptual Site Model

Reports from the original assessment of this site were reviewed. Nothing in the reports indicated conditions likely to result in vapor impacts to the surrounding community from the soil itself or laterally from the plume. Existing state vapor intrusion guidance follows the EPA OSWER guidance and recommends that all structures within 100 feet laterally of the contamination plume be assessed. Depth to groundwater in the community over the area of the plume varies 15–30 feet. Groundwater is not used as a potable source of water. The report also classified the lithology/geology of the site as alluvial sands with a clay layer at 3–5 feet bgs.

Existing groundwater data and trends were reexamined with the vapor intrusion pathway in mind. Such data were compared to state-approved vapor intrusion screening levels. A definite hot spot in the groundwater was identified where concentrations exceeded screening levels by a factor of 100.

Most of the buildings in the adjacent community are 30–50 years old. Such structures are known to have basements or crawl spaces or were built on slabs on grade. Special populations include grade school, home day care, and several homebound individuals.

Site Summary

- Known CVOc contamination in groundwater
- Groundwater @ 15–30 feet bgs
- Lithology: alluvial soil with clay layer 3–5 feet bgs
- Plume several miles long
- Hundreds of occupied structures above plume
- Structures have basements and crawl spaces; some slab on grade
- Hot-spot concentration 100 times screening levels

3.B VI INVESTIGATION PROCESS

Step 8. Choose Investigative Strategy

Should the investigation encompass the entire area of groundwater contamination or proceed with a more focused approach? There are many factors that go into this decision. It is important to develop a comprehensive work plan and CSM. Table 3-1 summarizes the alternatives.

Table 3-1. Pros and cons of investigative methods for Scenario 3

Alternatives	Pros	Cons
Investigate entire area where groundwater exceeds screening levels to reduce area of VI concern	⇒ Ability to evaluate an entire site ensures that all areas and conditions are considered (most conservative approach)	⇒ Very costly ⇒ May be unnecessary if it is determined there is no VI in hot spot
Statistical selection of structures within contamination area	⇒ Gives a representative mix of sampling locations ⇒ Provides broader coverage than just hot spots	⇒ Can be costly if sample size needs to meet data quality objectives (large sampling size)
Model groundwater data to limit area of VI concern (regulatory agency may not allow modeling)	⇒ Inexpensive ⇒ Can be done with existing data if of sufficient quality and detail	⇒ Although costs can be reduced, the size of the investigation is not necessarily reduced ⇒ Conservative assumptions should be used due to model imprecision and uncertainty
Focus area on hottest part of plume	⇒ Saves cost ⇒ Minimizes disturbance to residents	⇒ May miss some impacted receptors ⇒ Not-included residences may get concerned

Decision: Focus the investigation on the hottest part of the plume.

Rationale: There are sufficient groundwater concentration data to identify the hottest part of plume. Geologic conditions are relatively uniform across the site, such that groundwater concentrations are likely to define the area with the greatest VI potential (in some cases, depth to groundwater, soil type, and building conditions may be as or more important than groundwater concentrations, making selection of a hot spot more difficult). So it is concluded that it is safe to limit the initial VI investigation on this area in the plume.

The hot spot covers approximately five square blocks (~50 structures). Two sensitive populations are located in the hot spot, and one is directly adjacent to the hot spot.

Table 3-2 summarizes the several methods that can determine the presence and/or concentrations of contaminants at various points along the vapor intrusion pathway.

Table 3-2. Pros and cons of investigative methods for Scenario 3 along identified pathway

Alternatives	Pros	Cons
Additional groundwater sampling	⇒ Groundwater concentrations are likely to define the area with the greatest VI potential	⇒ More expensive and slower than soil gas sampling ⇒ May or may not reflect soil gas concentrations under or near receptors
Passive soil gas	⇒ Can be used to focus areas of investigation ⇒ Less invasive, easily installed, greater number of sampling locations for lower costs	⇒ Quantitative testing will still be required to evaluate vapor intrusion potential and risks, if any ⇒ Location of hot spot already known
External soil gas investigation	⇒ Less invasive than subslab sampling ⇒ Faster, less expensive than groundwater sampling	⇒ External soil gas results may not be representative of subslab data in low-permeability, heterogeneous, or fractured materials
Indoor air sampling	⇒ Can obtain actual exposure data; can be cheaper if there is a signature compound (e.g., 1,1-dichloroethene, carbon tetrachloride) ⇒ If geology doesn't warrant soil gas investigation	⇒ Background contaminant issues make it difficult to interpret indoor air results ⇒ Has the potential to be more costly, (multiple sampling events, hardware problems, etc.) ⇒ Must start community relations/communications at this point
Investigate the subslab soil gas under receptors over hot spot	⇒ Gives actual value under receptors	⇒ Very intrusive and more expensive ⇒ Fewer data points

Decision: The alternative of an external soil gas investigation in the hot spot area was chosen.

Rationale: This is the most practical approach based upon consistent geology and the fact that the preexisting data enable identification of the worst case area of the plume. Soil gas sampling allows evaluation of a large area with relatively low impacts to occupants of the structures.

Step 9. Design VI Investigative Work Plan

Determine Target/Screening Levels: Risk-based screening levels for COCs in soil gas at a 1-in-1-million risk level are $\sim 250 \mu\text{g}/\text{m}^3$ for soil gas samples collected 5 feet bgs. Commercial receptors are regulated at 1-in-100,000 risk level, so target levels are at least 10 times higher ($>2,500 \mu\text{g}/\text{m}^3$)

To perform the initial soil gas investigation, samples are to be taken in the rights-of-way along the axis of the plume with multiple transects across the focus area (Figure 3-1). Soil gas samples will be collected at 5-foot intervals, vertical spacing may be different if implants are to be installed, and several vertical soil gas profiles will be taken.

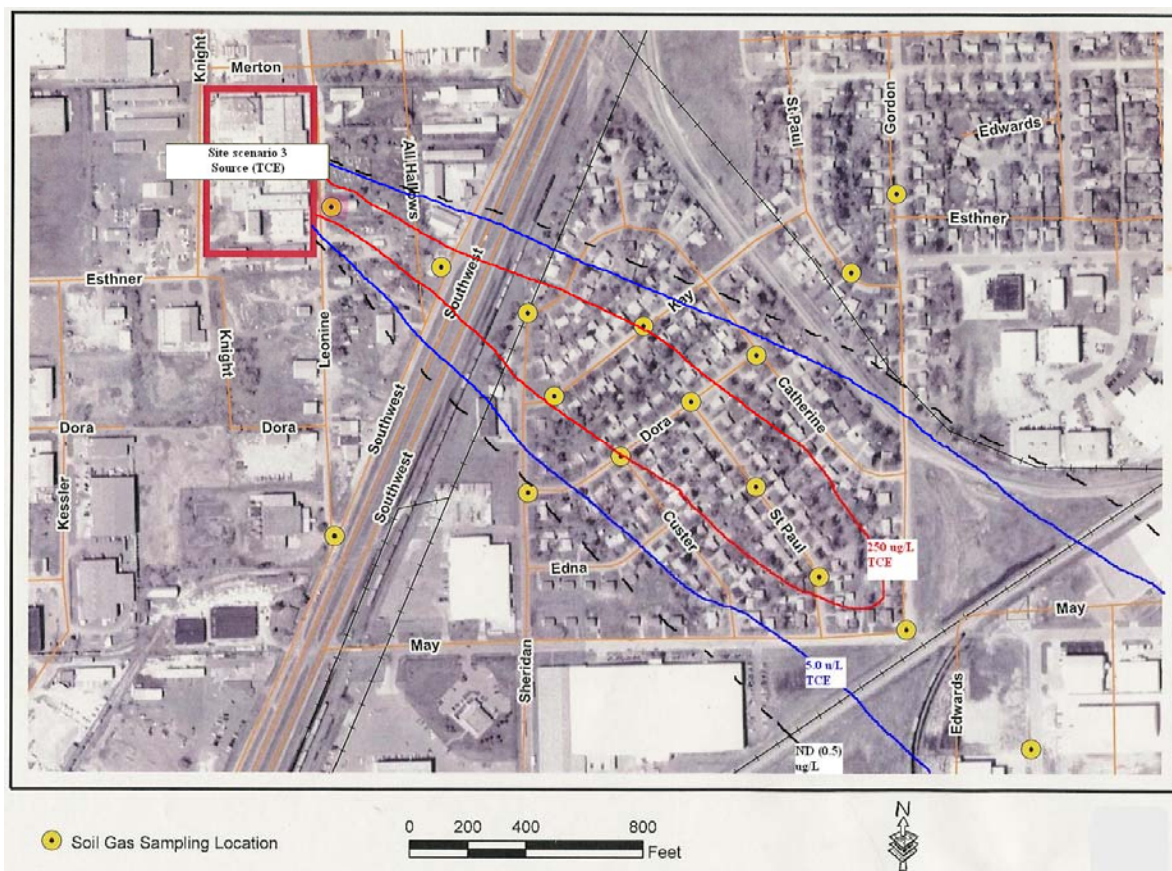


Figure 3-1. Potential locations for soil gas sampling.

Initial samples will be analyzed on site by EPA Methods 8021/8260 if a mobile lab is available. **(Quality assurance note: ~10%–20% samples collected in canisters for TO-15 off-site analysis.)** **Once work starts in any neighborhood, community relations/communication may be necessary.**

Steps 10 and 11. Collect and Evaluate Data

(These two steps are actually combined for this type of scenario. Since the sampling program is designed to collect data, review data, and make additional decisions regarding step out sampling, it highlights the iterative process of vapor intrusion investigations.)

Soil gas data indicated about 15–20 structures are of higher concern and need additional investigation (the shallow soil gas concentrations in the area are approximately two orders of magnitude over screening levels, the rest of the focus area about one order of magnitude higher). The data suggest additional investigation is needed.

Note: The COC(s) at the site may change the investigative methodology chosen. Certain chemicals are good tracers and do not have the same issues with background (e.g., 1,2-dichloroethene, carbon tetrachloride). Indoor air sampling may be the most appropriate investigative tool in these cases. The oversight agency may also require indoor air sampling as the primary investigative tool.

Alternatives: Conduct additional exterior near-slab sampling around structure or subslab sampling in all structures near high soil gas concentrations.

Decision: Conduct subslab sampling. Community participation/communications are necessary at this point.

Rationale: Exterior soil gas concentrations are very high at shallow depths, and access limitations are not a problem; otherwise, additional exterior near-slab data might have been chosen.

The subslab data exceeded allowable risk-based screening levels at eight structures by a factor of at least 10.

Step 12. Additional Investigation for the Affected Structures

Alternatives: Measure slab-specific attenuation factors using radon, measure indoor ventilation rate, measure pressure gradients, use flux chambers in crawl spaces, measure indoor air.

Decision: Indoor air sampling is selected as next step.

Rationale: COCs were not common household chemicals, so potential for background sources is not considered, and all houses were slab-on-grade with floor coverings.

Six of the eight structures failed indoor air levels by up to factor of 10.

Alternatives: Monitor indoor air or mitigate structures.

Decision: The six structures with high indoor levels were mitigated. At the other two structures, resampling was proposed.

Rationale: Due to the costs associated with indoor air sampling and issues related with sampling, it was determined that installing subslab depressurization systems was more cost-effective than additional sampling at the six homes having high indoor air concentrations.

Since some of the structures over the highest concentration part of the plume clearly had indoor air impacts, additional investigation to the nearby homes is warranted. Alternatives include the following:

- Additional exterior soil gas sampling near and around foundations
- Additional subslab sampling
- Additional indoor air sampling

Decision: Collect additional subslab samples by stepping out two additional structures in all directions from mitigated houses. Continue this sampling protocol until lines of evidence and the two structures show no vapor intrusion impacts.

Rationale: This decision point would depend on the results of the first indoor air sampling event. (That is, for this scenario the levels found within the structures were within an order of magnitude of the allowed risk-based level. Had they been several orders of magnitude, it may have been prudent to step out more than two houses.) This point should be covered in the CSM and work plan, and the regulatory authority will have input. Any community action groups should be notified of this strategy up front as a practical approach.

Once this process is stated, it is practical to continue until there are several clean structures since there has been a continual community involvement effort.

These decision points may be different depending on original course of the investigation.

Step 13. Mitigation to Receptors and Remediation of Groundwater

Decision: Verify clean structures are “clean” and mitigation systems are working properly.

Rationale: An additional indoor sampling event when buildings were closed was performed and verified “clean.” (Community participation/communications have been ongoing at site.)

Depending on the approach selected, it is important to remember that anytime during this process modeling with current data collected at the various phases may be performed to determine whether additional sampling, closure, etc. is/are warranted.

Decision: Institute groundwater—long-term monitoring and closure.

Rationale: Since vapor intrusion has been identified, source control should be considered unless it can be documented that source concentrations will decline within the time frame of the operation and maintenance of the mitigation systems. Monitoring and closure activities will be different from state to state and possibly from structure to structure.

3.C WHAT WAS UNIQUE ABOUT THIS SCENARIO?

Numerous issues are unique to large vapor intrusion sites, including the extensive resources and time required to address them, the need for public communications and outreach, and the logistical challenges associated with investigating and potentially mitigating large numbers of buildings. Other issues faced by most vapor intrusion sites are often exacerbated by the size and complexity of large sites, including variable site conditions, seasonal factors, future land use, and separating the contributions of vapor intrusion from those of background sources.

The first issue facing investigators at large vapor intrusion sites is simply the resources, time, and money required to determine the extent of vapor intrusion impacts, if any, and to address these impacts through mitigation or other actions. As a result, site screening becomes a more critical step to ensure that the costly and involved process triggered by intrusive testing is warranted. Unfortunately, generic screening levels are often set at (or, in some jurisdictions, below)

maximum contaminant levels so that the entire plume area is, by definition, above the generic screening level. Semi-site-specific screening levels may be difficult to apply to large plume areas due to variable depths to groundwater and soil types and may not raise screening levels high enough to eliminate an entire plume. Therefore, selection of worst-case buildings often becomes a critical step for large sites, allowing site-specific testing of a more manageably sized area.

Worst-case building selection can be challenging on its own because of the large number of factors that contribute to the potential for vapor intrusion, including concentrations in groundwater, depth to groundwater, geologic conditions, buildings conditions, and building use. As a result, more than one “worst-case” area may warrant investigation, and more than one building should be investigated in each worst-case area. To be effective, a worst-case area must serve as a surrogate for the entire site; i.e., if no vapor intrusion impacts are found in the worst-case area(s), then no further investigations should be required in the other areas of the site. Additional groundwater and/or soil vapor data may be warranted to better define worst-case areas and buildings.

Delineation of the extent of vapor intrusion impacts, if detected in worst-case buildings, is another issue often faced at large sites. Once again, because of the costs and time associated with testing a large number of buildings, large sites require efficient decision-making strategies to limit unnecessary tests. Delineation is commonly accomplished by a “step-out” process, with a methodical set of rules for selecting buildings for testing (and for stopping testing) around worst-case or other buildings found to have vapor intrusion impacts. Issues that investigators face when designing step-out testing programs include the following:

- How many buildings do you test beyond a building with impacts, and in what directions?
- Where do you not test (e.g., when requests for testing are received)?
- When do you stop testing? What are the criteria? A certain distance (e.g., 100 feet) beyond the edge of the groundwater plume? A certain number of unimpacted buildings?
- What kind of tests do you conduct? The same tests in all buildings or different types of test depending on concentrations, proximity to the edge of the plume, etc.?
- Can you make reliable decisions based on fewer tests per building (compared to a single building case), based on the knowledge gained from testing many buildings in the same area?
- Do you make preemptive risk-management decisions without testing all buildings (e.g., blanket mitigation)?

The second major issue affecting large vapor intrusion sites is public communications and outreach. Smaller sites may involve only the responsible party’s own site, their lessees, or a small number of adjacent landowners. Large sites may involve hundreds of different landowners with different types of buildings and issues, including single-family homes, multifamily buildings, commercial operations with employees and customers, schools, churches, day care operations, and public institutions such as libraries. A comprehensive public communications program will be essential to educate the public and put risks into perspective, gain access to properties and/or buildings for testing, schedule tests, report results, and install mitigation systems, if necessary. In addition, community leaders, government representatives, other regulatory agencies, realtors, and other members of the public may be indirectly affected by the investigation and require timely information. Finally, the media will need to be informed to

minimize miscommunication of information to the public. A key issue facing investigators and regulators of large sites is to determine when public outreach should begin so as to provide timely notice of potential concerns and investigation activities without creating unnecessary alarm.

The third major issue affecting both investigators and regulators at large sites is the logistical challenge associated with investigating and potentially mitigating a large number of buildings in a relatively short period of time. Investigators must be prepared, often with little advanced warning, to coordinate access and schedule tests with a large number of property owners; to obtain, store, and ship large numbers of samples (potentially bulky Summa canisters); to manage and report large quantities of data to both agencies and property owners on a continual and relatively rapid turnaround basis; and to coordinate the installation, monitoring, and operation and maintenance of a large number of mitigation systems. With most of the contamination being off site, institutional controls may not be applicable in this scenario, so long-term monitoring of the systems needs to be considered. Regulators may be contacted by a large number of interested parties asking for information over an extended time period and may be under a great deal of pressure to make a large number of risk-management decisions in short time frames.

Finally, issues potentially affecting all vapor intrusion sites regardless of size are often exacerbated at large sites. Geologic, groundwater, and building conditions are likely to vary to greater degrees across larger sites. Each building at a large site may also have unique materials and occupant activities creating potential background sources. At the same time, it is impractical to study each building and property at a large site to the degree of detail feasible at smaller sites. Therefore, building-specific decisions have to be made using less information than typically available at smaller sites. On the other hand, the database of information provided by testing at numerous buildings may provide different tools for evaluating vapor intrusion impacts that are not available at smaller sites. For example, spatial patterns and correlations with other site factors based on testing at other properties may aid interpretation of individual test results.

3.D LESSONS LEARNED

- There are an infinite number of investigative strategies to handle large vapor intrusion sites. There is no cookie-cutter approach to their investigation. The process must start with the CSM and proceed from there.
- Expect surprises, especially additional sources when dealing with large plumes.

Lessons Learned from Redfields

- Very low levels of groundwater contamination can cause vapor intrusion.
- If using soil gas sampling for screening large site, make sure to use state-of-the-art techniques, including the use of vapor implants and tracer compounds to ensure that the results are the subsurface soil gas and not ambient air.
- Subslab sampling is likely to be a better indicator of vapor intrusion potential than soil gas sampling remote from the building (e.g., in public areas) or even adjacent to the structure.
- There can be many complications with sampling indoors due to background chemicals in the structure. Indoor product inventory is essential to demonstrate that contributions to indoor air concentrations are not due to vapor intrusion. However, inventories may not identify all sources, particularly if the compound is not indicated on the container or is present in building materials.
- Large sites will be very costly no matter what type of investigation strategy is used.
- External drivers that dramatically affect the cost of mitigation include asbestos, dry-layered foundation walls, and multiple foundations (grade beams, etc.).

- Soil gas investigations may be the preferred method of screening a large vapor intrusion site if subsurface conditions are suitable and conservative assumptions (i.e., attenuation factors or modeling assumptions) are applied, but they may not be adequate to close out a site.
- Community involvement is paramount at all sites, more so at large sites. It can greatly influence how well the investigation proceeds. Significant resources are required for gaining access to buildings, scheduling tests, and communicating with building owners and occupants.
- While mitigation of typical residences is straightforward and in many cases less expensive than resampling multiple times, there will be exceptions.
- Ongoing monitoring of both mitigated and unmitigated buildings can be very expensive, depending on the number of homes selected for monitoring and the testing frequency.

3.E NEXT STEPS

- Future activities at the site will include groundwater and soil gas monitoring, maintenance, and performance testing of the vapor intrusion mitigation systems.
- Groundwater, soil gas, and indoor air monitoring will occur for the foreseeable future.
- Groundwater movement may create vapor intrusion issues within structures that are not currently impacted. An effective groundwater/soil gas monitoring network will be established and sampled at appropriate intervals.
- Existing mitigation systems will be inspected on a regular basis. A work plan should be created that details the inspection procedures, frequency, and termination procedure.
- A groundwater or vadose zone source control remedy may be implemented to reduce subsurface vapor concentrations. The remedy will need to be coordinated with the vapor intrusion investigation.
- Data collected from the subsurface and indoor air sampling will be analyzed to develop site-specific attenuation factors. The attenuation factors may be useful as a screening tool. When used in conjunction with the soil gas data from the monitoring wells, vapor intrusion problem spots may be identified. However, it should be noted that even site-specific attenuation factors may span several orders of magnitude; therefore, application of the most conservative attenuation factor (generally necessary unless attenuation factors can be correlated with other parameters, such as depth to groundwater or soil type) will still result in a significant number of false positives.
- Community involvement will be an ongoing activity at the site. The vapor intrusion mitigation systems and source control are long-term actions that will require community input. A community involvement plan will be developed.
- Refer to the oversight agency regarding other remediation that may be necessary at the site (e.g., soil removal, groundwater remedy, etc.).

Scenario 4

Brownfield Redevelopment Site (Vacant Land)

This scenario illustrates a typical vapor intrusion investigation at a vacant brownfield site slated for future development.

4.A DESCRIPTION

The Situation

A 20-acre brownfield site is being sold for redevelopment. The proposed redevelopment plan consists of converting an old abandoned factory into apartments and the remaining 15 acres into mixed commercial and residential uses. A Phase 1 evaluation indicated that the old factory contained a degreaser and parts-washing operation using chlorinated solvents and that the undeveloped area was used for fire training by the local fire departments. Records indicate that the fire training operation used pits for fuel oil, but historical aerial photographs did not show evidence of the locations of the pits.

Conceptual Site Model

The site consists of uniform stratigraphy, primarily silty sand with some fill material near the old factory. Depth to groundwater is approximately 20 feet across the site. No groundwater wells exist on the property, so the gradient is unknown. From neighboring properties, it is expected that the factory is downgradient of the area containing the training pits.

A limited Phase 2 investigation found soil contamination in defined areas to 10-foot depths within the fire training areas believed to be the former pits. Free product was detected on the groundwater in the vicinity of the former pits and lies about 500 feet from the factory. A limited number of discrete water samples were collected near the factory, and no evidence of chlorinated solvent contamination was detected in the groundwater. Discrete groundwater samples were also collected at one location on each border of the property, and no contamination was found. Since there are no occupied buildings currently on the property, no further work was done pending future development.

Since there are no receptors currently of concern, the issue is whether there might be potential vapor intrusion risk to future buildings. Fuel oil does not contain high concentrations of benzene but does contain naphthalene and a mix of alkanes that are of concern to some regulatory agencies. The factory used chlorinated solvents that might have left contamination, regardless of the previous groundwater data showing little contamination. In this case, the available data are too limited to answer

Site Summary

- Phase 2 found soil contamination in fire pits
- Free product found in pit area
- Limited water samples found no groundwater contamination
- No additional work done, awaiting property redevelopment
- No current receptors—"Future Use"
- Very little data to work with

whether vapor intrusion may be a concern to future buildings. Since little is known about the site and proposed redevelopment covers most of the site, the entire parcel needs to be investigated.

Conclusion: Sufficient data do not exist to close VI pathway. Need to collect additional data.

4.B VI INVESTIGATION PROCESS

Step 8. Choose Investigatory Strategy

There are two known sources of contamination:

- The fuel oil in the training area
- Chlorinated hydrocarbons near the factory building

Table 4-1 summarizes the pros and cons of the various applicable methods.

Table 4-1. Pros and cons of investigative methods for Scenario 4

Alternative	Pros	Cons
Groundwater or soil phase data	⇒ Can search and delineate extent of contamination sources	⇒ Vapor intrusion risk is often overestimated from these matrices ⇒ Expensive for a large site ⇒ Soil phase data unreliable for vapor intrusion
Active soil gas investigation	⇒ Will reflect soil and groundwater contamination ⇒ Less expensive than soil and groundwater data ⇒ Gives quantitative vapor-phase values	⇒ Not as easy or inexpensive for a large site
Passive soil gas investigation	⇒ Identifies areas that may need further investigation ⇒ Easy to install ⇒ Gives best coverage for least cost	⇒ Data may require follow-up quantitative sampling

Decision: A combined passive soil gas and active soil gas program was considered to offer the most advantages for this site.

Rationale: The passive soil gas survey would be used to determine areas where VOC contamination exists on the site to be followed by an active soil gas program in the identified contamination areas.

Step 9. Design VI Investigative Work Plan

To determine target/screening levels, the state oversight agency has its own guidance, which allows risk-based screening values to be determined from modeling. Version 3.1 of the Johnson-Ettinger soil gas screening spreadsheet was used. The scenario modeled was slab-on-grade construction, silty vadose zone, and default values for all other parameters. Since residences are

planned in several portions of the site, residential screening levels apply. Subslab screening levels were obtained from the same spreadsheet using a 2-foot depth below the slab. The allowable indoor air concentrations at a 1-in-1-million risk level or a hazard index of 1 from the state guidance for TCE, 1,1,1-TCA, and naphthalene are $0.022 \mu\text{g}/\text{m}^3$, $2,200 \mu\text{g}/\text{m}^3$, and $3.0 \mu\text{g}/\text{m}^3$, respectively. Table 4-2 shows the risk-based screening levels derived from the model compared to generic screening values in the EPA OSWER guidance using default attenuation factors. Also included are the dilution factors for soil gas to indoor air defined as the inverse of the attenuation factor. Comparison of the generic screening values to the site-specific values derived from the model show that the generic values are about 30 times more conservative for the subslab values, but very similar for the 5-foot depth.

Table 4-2. Risk-based screening levels derived from J&E Model versus generic values from EPA OSWER guidance

Location	TCE		1,1,1-TCA		Naphthalene	
	Generic	Modeled	Generic	Modeled	Generic	Modeled
Subslab, $\mu\text{g}/\text{m}^3$	0.22	6.7	22,000	680,000	30	1,000
Dilution factor	10	306	10	308	10	341
5 feet, $\mu\text{g}/\text{m}^3$	11.0	11.2	1,100,000	1,100,000	1,500	2,000
Dilution factor	500	510	500	510	500	613

Since fuel hydrocarbons are present, EPA test method 8021 may be subject to interferences and false positives. Method 8260 (GC/MS) is not subject to interferences, can be conducted on site, and reaches detection levels except for subslab naphthalene detection levels. Method 8260 will be used with a subset of subslab samples collected for off-site analysis for naphthalene by method TO-15 or TO-17 if the 8260 analysis is nondetect.

On-site analysis for total alkanes will be done by method 8015 modified (GC–flame ionization detector). This method gives a detection limit of approximately $50 \mu\text{g}/\text{L}$ for C10 to C20 hydrocarbons. If nondetect, a sample will be collected for off-site analysis by method TO-15 or TO-3.

Methane will be measured by EPA method 8015 modified, and oxygen and carbon dioxide with a portable field meter (e.g., Land Tec GEM-2000, etc.).

Step 10. Collect Data

Passive Soil Gas Program: Based on the Phase 2 assessment, passive soil gas samples were collected on a regularly spaced grid of 100-foot centers in the undeveloped areas. The suspected fire pit areas, degreaser location, and the old factory were subjected to a more dense sampling grid of 50-foot centers. The sorbent-based samplers were placed 2–3 feet bgs and were analyzed by gas chromatography (GC)/mass spectroscopy (MS) (8260/8270 or TO-15) for fuel-related and chlorinated compounds.

Results from the Passive Soil Gas Survey:

Factory: High levels of trichloroethene (TCE) were found in the area containing the degreaser and adjacent to this location beneath the factory slab (Figure 4-1).

Fire Training Area: Numerous detections of hydrocarbons out into the C20 range and naphthalene, were detected in the area measuring roughly 100 feet in diameter (fire pits, Figure 4-2).

The remainder of the site was expected to be contaminant-free; however, an area of 1,1,1-trichloroethane (TCA) was detected northwest of the factory (Figure 4-3).

Property Borders: No VOCs were detected in the samples collected along the property borders, indicating that the VOC contamination is primarily limited to the interior of the site.

Active Soil Gas Program: Based on the passive soil gas data, 35 initial soil gas sample locations were selected as follows (Figure 4-4):

- Five vertical profiles (3-, 5- and 10-foot sample depths) were taken in the fire pit training area, one from the 1,1,1-TCA hot spot, and another near the former degreaser.
- Soil gas samples at a 5-foot sample depth were located around the factory and along and across the axes of the naphthalene and 1,1,1-TCA soil gas plumes.
- Five subslab soil gas samples were collected from underneath the factory slab.
- Samples were collected across the remainder of the site at 5-foot sample depths to test for background concentrations of VOCs and for the possible presence of methane gas that could not be detected by the passive survey).

Soil gas samples were analyzed for VOCs including naphthalene, hydrocarbons ranging from C10 to C20, methane, and fixed gases (oxygen and carbon dioxide).

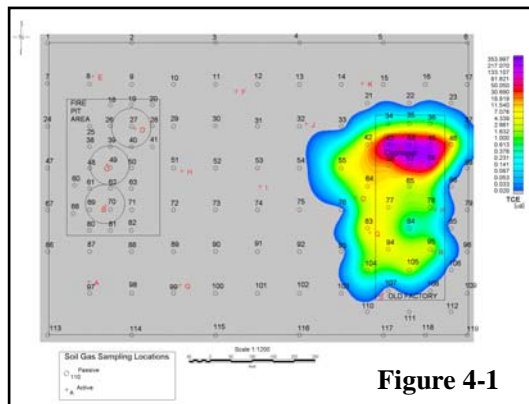


Figure 4-1

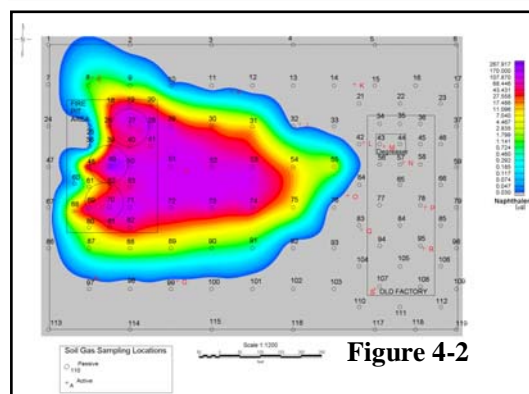


Figure 4-2

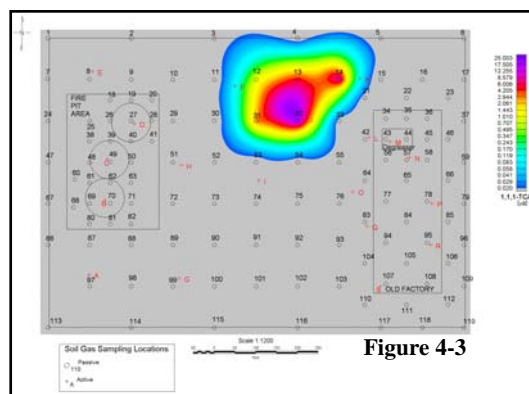


Figure 4-3

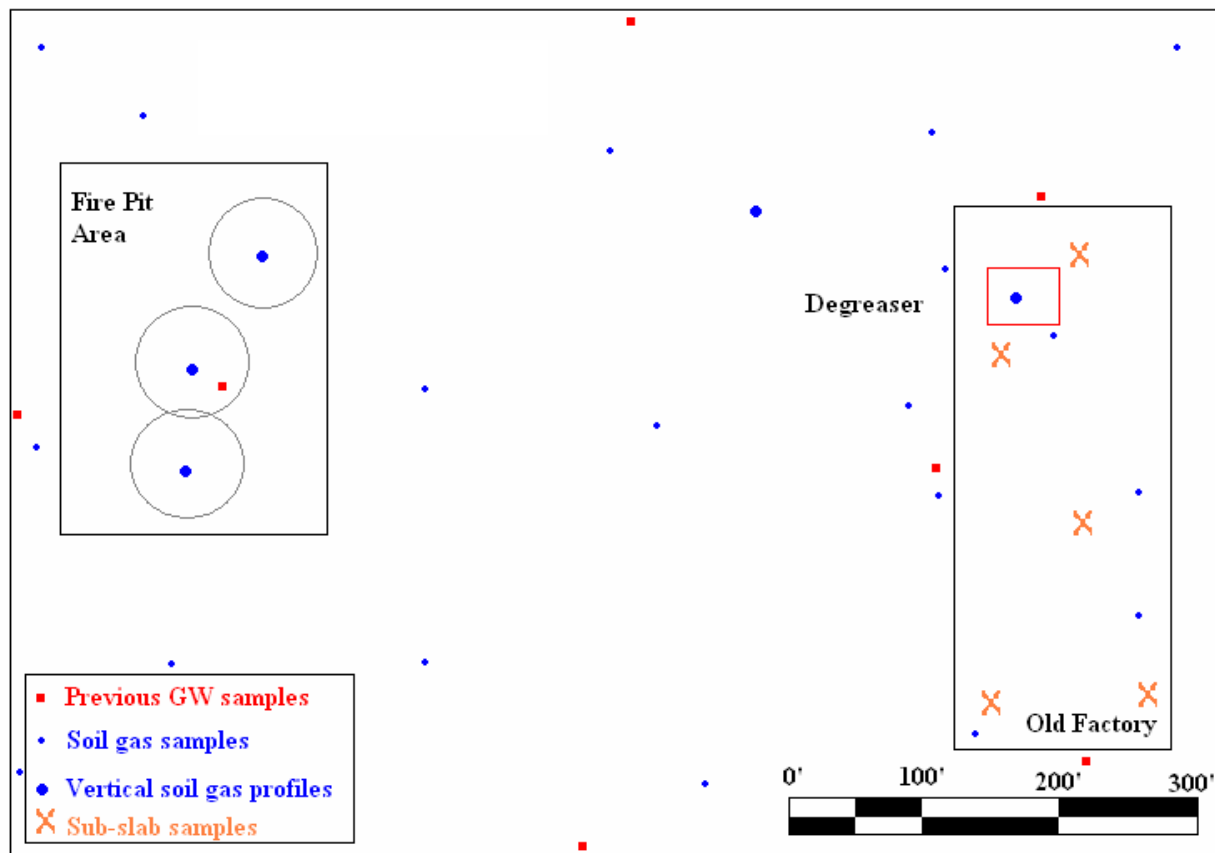


Figure 4-4. Initial soil gas sample locations.

Having the ability to add sampling locations both spatially and vertically in real time was considered useful to optimize the field effort, so on-site analysis was planned.

Continuous soil cores were collected from 10 locations across the site to get soil physical properties for later use in vapor intrusion modeling.

Step 11. Evaluate Data

Fire Training Area:

- The vertical profiles showed a consistent trend in all three locations. Total hydrocarbons were high at the deepest depth (>500 $\mu\text{g/L}$), decreasing to below detection at the 3 feet. Oxygen was near atmospheric levels to 3-foot depths and then decreased rapidly to only a few percent at depth. Carbon dioxide also increased with depth to percent levels.
- Methane values exceeded 10% in all locations at 5- to 10-foot sampling depths but decreased to 500–1000 parts per million by volume (ppmv) at the 3-foot depths.

Area Around and Underneath Factory: TCE values at the 5-foot collection depth ranged from nondetect to 10,000 $\mu\text{g/m}^3$, which exceeded screening levels by 20 times. Subslab samples had TCE at concentrations ranging 50,000–100,000 $\mu\text{g/m}^3$, exceeding screening levels by many

orders of magnitude. The highest values were in the northwest portion of the factory building coincident with the location of the former degreasers.

Background Areas

- 1,1,1-TCA values were determined to be below the regulatory action level for residential scenarios.
- No VOCs were detected, and only modest quantities of methane (<500 ppmv) with high oxygen was detected at all of the locations.

Conclusions from Field Work:

Fire Training Area: The vertical profiles are indicative of active bioattenuation of the fuel oil hydrocarbons. High oxygen levels at 3 feet indicate that the upper 3 feet of vadose zone is highly aerobic and will act as a barrier to methane migration. **Data to confirm there is no risk of methane migration is likely to be required. Removal of soil contamination is recommended prior to further development.**

Former Factory: Higher concentrations below the slab with lower concentrations at the 5-foot depth indicate a surface source, most likely a vapor-phase source (vapor cloud) from the former degreaser. Concentrations are orders of magnitude above risk-based levels, indicating that the vapor pathway is complete and mitigation is necessary. Subsequent soil phase data might be helpful to determine whether soil contamination does exist, but soil vapor extraction is likely necessary. **Mitigation is required. Any development of the factory should be done with caution and monitored to ensure remedial measures are effective.**

Undeveloped Area: Levels of 1,1,1-TCA were not a concern.

Background Areas: Methane values were low and oxygen high, indicating little threat for migration out of the subsurface. **No further data required.**

What Other Tools or Data Can We Collect?

Fire Training Area: Flux chambers at the surface would be a good approach to see whether methane is escaping through the upper 3 feet of section. However, even if not, the soil contamination might be more of a problem if a future building restricts oxygen replenishment into the subsurface.

Former Factory: The levels of TCE are so high that no other types of data could change the conclusion that the vapor intrusion pathway is complete.

4.C WHAT WAS UNIQUE ABOUT THIS SCENARIO?

- Mixed sources (solvents and fuels)
- Little knowledge of site history, requiring a screening step to determine zones of contamination

- Use of vertical profiles to document bioattenuation
- Unexpected presence of methane gas and an approach to see if it represents a risk
- Finding unexpected source areas
- Institutional controls and the problems with implementing them long term

4.D LESSONS LEARNED

- Passive soil gas is an effective screening tool (located additional unknown source area). It reduced overall investigation costs substantially (fewer active soil gas samples taken).
- Bioattenuation of hydrocarbons is likely when oxygen is present.
- Vapor phase contamination (vapor clouds) can exist with no associated soil phase or groundwater contamination.

4.E NEXT STEPS

- Validation tests (flux chambers) can ensure shallow methane is not a problem.
- Soil removal in the fire training area should be completed to remove contamination, and any buildings erected in this area should have integral mitigation systems built in.
- Mitigation of the TCE plume under the factory should be done prior to any redevelopment and subsequent sampling performed to ensure that vapor intrusion is not occurring after redevelopment.
- Groundwater monitoring of the plume should continue to document contaminate migration and/or plume stability.
- Refer to the oversight agency regarding other remediation that may be necessary at the site (e.g., soil removal, groundwater remedy, etc.).

Scenario 5

Large Industrial Building Undergoing Redevelopment

This scenario illustrates a typical vapor intrusion investigation of an existing structure located at a former industrial site.

5.A DESCRIPTION

The Situation

A large industrial facility with warehouse and offices under one roof is being sold. An environmental assessment is conducted at the site and contamination is found. Previous shallow soil data from hand borings indicated a suite of CVOCs directly below a portion of the building. Building construction is slab on grade and divided into three distinct ventilation areas—open warehouse, warehouse rooms, and attached offices. Low-level contamination is found outside the building footprint in one area, but it is suspected that higher concentrations still exist directly under the building. Soil type in the area is likely to be a tight clay soil matrix, and it is assumed there is a coarse-grain material directly beneath the slab. The seller (Principal Responsible Party) applies to state voluntary cleanup program for assistance and is trying to lease building in the interim. The regulatory agency determines that VI needs to be investigated.

Conceptual Site Model

The building plans, historical uses of the facility, and the environmental assessment of this site were reviewed. Nothing in the review indicated conditions likely to result in vapor impacts to the surrounding community. Minimal contamination was detected outside the building footprint. Therefore, the only potential vapor impacts would be the existing building above the contamination. Groundwater at the site varies 15–30 feet bgs and is not impacted.

After the review, several areas of additional investigation are identified, including an old degreaser, former drum storage area, and several floor drains and sump pits. All of these are identified as potential pathways of contaminants to the subsurface.

Site Summary

- Former industrial facility
- CVOCs found directly below building
- Contamination contained in building footprint
- Several areas of concern identified
- Site owner applies to state Voluntary Cleanup Program
- Regulatory agency requests VI assessment

5.B VI INVESTIGATIVE PROCESS

Step 8. Choose Investigatory Strategy

See Table 5-1.

Table 5-1. Pros and cons of investigative methods for Scenario 5

Alternatives	Pros	Cons
Collect indoor air samples	⇒ Direct measure of VI	⇒ High chances of background sources from materials in warehouse
Collect soil samples around or under building	⇒ Familiar method	⇒ Soil data generally considered not representative of vapor concentrations
External soil gas investigation around the perimeter of the building	⇒ Do not have to drill through the slab inside building	⇒ External soil gas results may not be representative of subslab data
Perform an investigation under the building (subslab and vertical soil gas samples)	⇒ Closest point to receptor	⇒ More intrusive ⇒ Conservative screening levels

Decision: Collect internal soil gas and subslab gas samples.

Rationale: Access is not a problem, and contaminant source zone lies directly underneath structure.

Step 9. Design VI Investigative Work Plan

Subslab soil gas samples are to be collected at the following locations (Figure 5-1):

- Near the location of the former degreaser
- Near the floor drains and sumps
- Near the former drum storage area
- Along the edges of the building slab

Vertical profiles of the soil gas are proposed in the hottest locations to ensure no threat to groundwater.

A second subslab sample will be collected from several points for radon analysis to determine an average building-specific attenuation factor.

Determine Screening Levels and Test Method: The state oversight agency has developed its own screening levels for vapor intrusion investigations. The state agency has developed risk-based screening levels and applies conservative attenuation factors for subslab, soil gas, and groundwater of 0.1, 0.01, 0.001, respectively. Commercial (non-Occupational Safety and Health Administration) screening levels apply. Risk-based screening levels for PCE, TCE, and 1,1,1-TCA in subslab soil gas at a 1-in-100,000 risk level are 700, 225, and 14,500 $\mu\text{g}/\text{m}^3$, respectively.

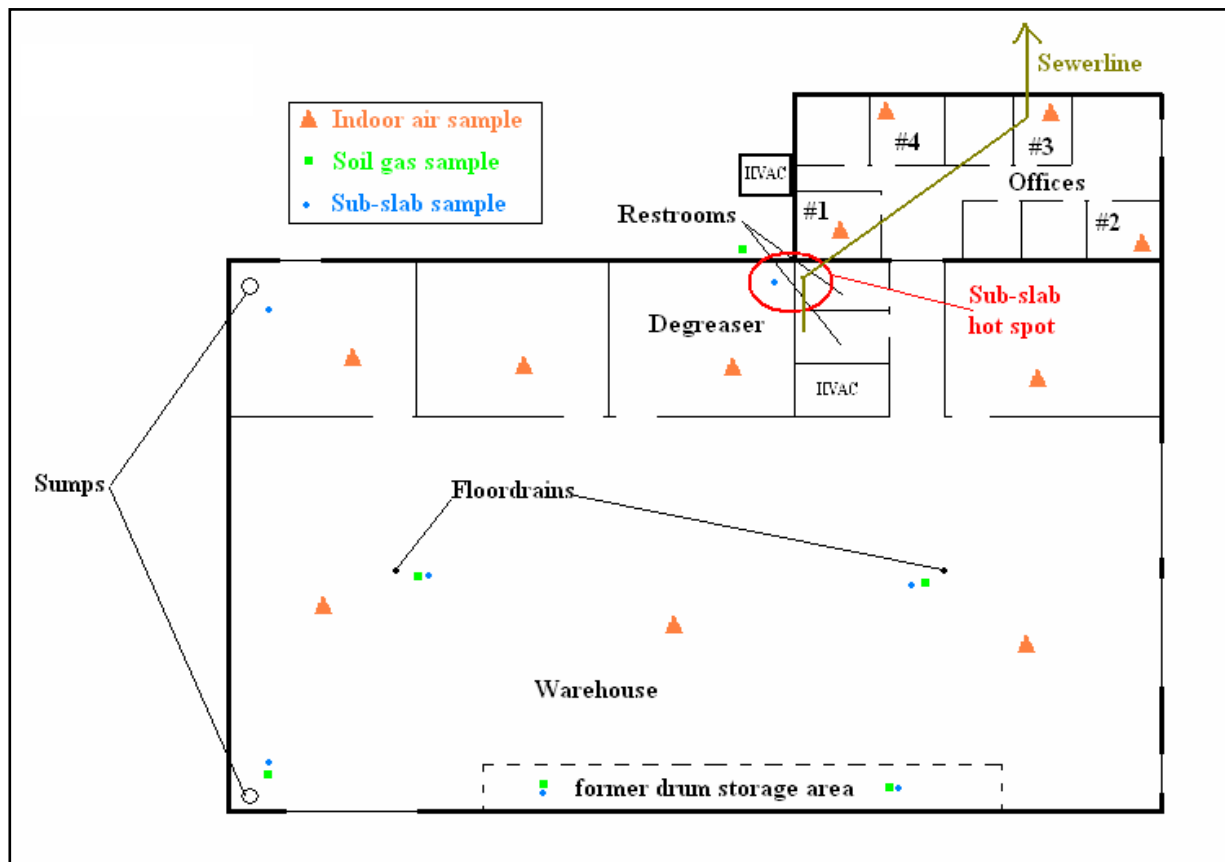


Figure 5-1. Subsurface soil gas sampling sites.

EPA test methods 8021, 8260, and TO-15 can be used for soil gas samples and reach detection levels suitable for these screening levels. On-site analysis is not available, high concentrations are anticipated, and a mixture of compounds are present, so method 8260 is chosen, with approximately 10 of the samples to be confirmed by TO-15.

Step 10. Implement Work Plan

The results of the investigation show various levels of soil gas contamination under the structure footprint. One hot spot near the former degreaser and the offices was identified with subslab concentrations (for PCE and TCE) approximately 100 times higher than the screening levels. The hot spot was contained to a very small area; soil gas concentrations decrease laterally away from the hot spot. A vertical profile at the highest subslab location indicates the contamination decreases with depth and is below detection at 10 feet bgs.

Step 11. Evaluate Data

Warehouse Area: The radon data show a slab-specific attenuation of 0.005, which is 20 times lower than default values used to determine screening levels. Using this attenuation factor, detected subslab values are now slightly above screening levels. Since large warehouse areas will generally have large doors and usually have more air exchanges per hour, it is concluded that there is little risk to the warehouse workers. **No more data required.**

Office Area: Since ventilation rates are lower in the offices, it is possible that the subslab values might represent a risk to the office workers. **Additional data are needed.**

Step 12. Additional Investigation Warranted?

See Table 5-2.

Table 5-2. Pros and cons of investigative methods for Scenario 5

Alternatives	Pros	Cons
Collect indoor air	⇒ Direct measure in room	⇒ Background sources can complicate interpretation
Model indoor air concentrations based on soil gas and subslab concentrations	⇒ Can be inexpensive ⇒ Eliminates any background interferences	⇒ Regulatory agency may not allow just modeling the data
Pressure measurements	⇒ Provide evidence if subslab contaminants entering building	⇒ Data may be variable
Continuous monitoring		⇒ Data may be variable

Decision: Collect indoor air samples in offices and warehouse.

Rationale: Sampling indoors was chosen for a couple of reasons. First, it is believed that background interferences will be negligent. Second, we want to see actual indoor air concentrations. Main focus is the offices; however, indoor air sampling in the warehouse space is conducted at the request of the oversight agency to ensure site specific attenuation factors are applicable.

Take representative samples from various area of the building, including 8-hour summa cans collected during normal business hours.

Office results: Office #1, nearest the hot spot, is below commercial risk levels; however, Offices #2 and #3, away from the hot spot, show elevated levels (Table 5-3). Office #3 is above commercial standards. Office #2 is below the commercial risk level but above residential standards. **It is determined from a former employee that Office #2 was a printing supply room**, so background contamination may be responsible for elevated levels. **Remove background contamination and resample. Blueprints were used to identify a sewer line under the offices, and additional investigation confirms leaking sewer line below the Office #3 accounting for the indoor air impacts. [Matching current data with historic blueprints and past uses enabled identifying background contributions and additional source(s) missed during original investigation.]**

Table 5-3. Office sampling results, $\mu\text{g}/\text{m}^3$

Chemical	Office #1	Office #2	Office #3
PCE	ND (10)	ND (50)	75.0
TCE	ND (2.5)	17.0	30.0
1,1,1-TCA	ND (10)	500	850

Warehouse results: Main open spaces were below commercial risk levels; several smaller warehouse rooms were moderately above commercial risk level.

Decision: Retest after the source remedy.

Rationale: Since a remedy is going to be installed to remediate soils under the building, waiting until after the remedy seemed to be appropriate.

Table 5-4. Pros and cons of investigative methods the Scenario 5 warehouse

Alternatives	Pros	Cons
Perform mitigation steps to eliminate risks to smaller warehouse rooms, then resample	⇒ If source remedy not a priority, then this would be the only route to take	⇒ May not be needed if source control measures are adequate to reduce subsurface concentrations

Step 13. Is Mitigation Warranted

Remedy #1: Use soil vapor extraction (SVE) in the source area to meet soil cleanup goals, with an additional SVE leg to the subslab of Office #3 above the leaky sewer pipe. It is hoped that levels in warehouse spaces will be reduced with the installation of the SVE system. Once installation of remedial system is completed, resampling should occur in the smaller warehouse rooms and offices.

Results from the samples show the two warehouse rooms are still slightly above commercial risk levels. All other samples are nondetect for the COCs. It is determined that a second remedy is warranted.

Remedy #2: Adjust that HVAC system for the smaller warehouse rooms until source remedies are more effective. An operation, maintenance, and monitoring plan for the SVE system and HVAC system adjustments is put into place. Confirmation sampling at a later date is requested by regulatory agency to obtain clean closure.

5.C WHAT WAS UNIQUE ABOUT THIS SCENARIO?

This scenario is different from the others because the potential source of vapor intrusion impacts is in the vadose zone soil directly beneath the building. Therefore, investigations had to focus on the vadose zone rather than groundwater. In addition, investigations had to be conducted inside the building and had to consider how foundation infrastructure might impact both source and vapor distributions. This scenario also demonstrates how multiple sources of vapor intrusion impacts may be located under the same building.

Another issue associated with this scenario was the need for a rapid solution so that the building could be put back into productive use and generate revenue, even while remediation was under way.

Although this scenario has only one building, variations in room size, ventilation rates, and location with respect to the source zone resulted in varying potentials for vapor intrusion impacts across the building. Therefore, testing strategies had to account for each of the subregions within the building. For example, areas closer to the source area may have been subject to higher

subslab vapor concentrations. On the other hand, the floor slabs were likely thicker and more robust in former manufacturing and warehouse areas, compared to the office space. In addition, the large warehouse rooms had larger volumes for mixing of vapors and may have had higher air exchange rates than the office space. Ventilation systems may also have distributed air from impacted areas to otherwise unimpacted areas of the building.

Another issue was operation of the HVAC system during indoor air testing. Because HVAC operations can control vapor intrusion impacts in large buildings, the decision was made to test with the HVAC system operating normally. In other situations—for example, where future operation of the HVAC system cannot be relied on—it may be better to turn off the HVAC system before conducting indoor air tests.

Finally, this scenario presented the need and opportunity for flexible approaches to mitigation. The nature of the impacted space, the proximity to the source zone, and the opportunity to use existing remediation and HVAC equipment varied in different portions of the building. No single approach was best for the entire building, and the vapor intrusion mitigation strategy also varied over time as the source zone soils were remediated.

5.D LESSONS LEARNED

- In a step-wise, structured assessment protocol, the extent and concentration of the contaminant(s) under the building would normally be delineated before collecting soil vapor samples, which would then focus primarily on the hot spots. However, in this instance it was relatively easy and more economical to collect the subslab vapor samples while the direct-push sampling equipment was at the site and holes were cored through the slab. The extra expense of analyzing the extra soil vapor samples (from areas away from the hot spots) is easily justified in light of the cost of remobilizing the equipment to the site and personnel labor rates.
- There may be considerable spatial distribution and variation in the contaminant concentrations under large buildings. While some of the individual concentrations may exceed threshold action levels, the overall average concentration under the building is a more reliable indicator of whether remedial action may be required. (Note: Unless the sampling has been conducted on a statistical grid, it may be more prudent to use the third quartile as the concentration on which to base decisions, thus biasing the data “high” without being as overly conservative as using strictly the highest concentration.)
- Indoor air sampling in the two offices near the subslab hot spot (degreasing area) did not detect significant levels. This finding illustrates that vapor migration into interior spaces is not an absolute “given” because of the tremendous variations that can occur in building characteristics and interior ventilation patterns. Vapor migration tends to follow preferential cracks through the foundation slabs and only poorly penetrates through intact concrete. If the carpeting in these offices were removed, further investigation would probably show that the underlying concrete slab had no cracks or voids that facilitate vapor migration. Alternatively, the air exchange rate in the offices may be high enough to dilute out any vapor that does intrude through the floor.

- Significant levels were found in two other offices farther away from the hot spot, which were sampled more as “control samples” (instead of collecting ambient outdoor air). At first glance, it would seem that these results suggest that vapor intrusion is not predictably connected to “hot spots”; however, this is not the case. In each instance, there is a logical, adequate explanation why something was detected where nothing was expected. In one of the offices, the concentrations were detected because of residual consumer products desorbing from the building materials. In the second office, the contamination was due to vapor intrusion from a previously unrecognized subslab source (the leaking sewer line).
- Finding significant levels in the office that was formerly used for the printing supply office illustrates the problem one encounters because of volatiles sorbing and desorbing off of building materials, carpet, furniture surfaces, etc. Even though no consumer products were present during the time of sampling, their residues can continue to desorb from surfaces long after the cans and bottles containing the consumer products have been removed from the premises. Obtaining a thorough history of the use of an area can reduce additional, unnecessary assessment work.
- Finding the significant levels in the second office illustrates what may occur if all subslab source areas are not adequately determined. If further work had not found the broken sewer pipe underlying this area of the building, the results would have suggested that significant vapor intrusion was occurring from the hot spot under the building and that somehow these vapors were concentrating in this office area. This erroneous conclusion would undoubtedly lead to additional investigation of the HVAC system, more subslab sampling, modeling, scrutiny of the attenuation factors, etc.
- The SVE system can be modified to address the sewer line break by running a vacuum line over the roof of the building from the hot spot area. This is an easy way to remediate the subslab concentration at that spot if the distance between the locations and the aesthetics of running a branch line across the roof are not major factors in the design. If a branch line from the main SVE system cannot address the sewer line break, a small dedicated SVE system can be installed directly over that area; however, the cost may be significantly higher because of the need for two SVE pumps, filter collection systems, etc.
- Modification of the HVAC system is a practical and economical means to reduce the exposure dose for small areas that near borderline indoor concentrations.

5.E NEXT STEPS

- Monitor the SVE system; sample to ensure that the system is working sufficiently.
- Resample the warehouse rooms; determine whether risks are below commercial levels now that HVAC and SVE systems are operational. If so, it may not be necessary to resample as long as SVE and HVAC systems are monitored.
- Refer to the oversight agency regarding other remediation that may be necessary at the site (e.g., soil removal, groundwater remedy, etc.).

Scenario 6

Multifamily Dwelling Located Over a Former Gas Station

This scenario illustrates special issues in determining the significance of background concentrations of COCs and assessment for petroleum hydrocarbon vapors.

6.A DESCRIPTION

The Situation

As part of an urban land revitalization project, a former service station site and an adjacent vacant parcel were redeveloped into a high-end condominium complex. Five years after the complex was completed, a resident notified the complex's management company of petroleumlike fumes in his unit. After an inadequate response by the management company, the resident notified the public health department. A single air sample collected by the health department detected benzene at $4 \mu\text{g}/\text{m}^3$. Because the site was previously occupied by a service station that had experienced a UST release, the state UST regulatory agency was brought in to conduct an investigation to determine the source of the vapors.

Conceptual Site Model

A site visit and review of the state UST regulatory agency files allowed investigators to develop an initial CSM. The condo complex consists of two four-story buildings separated by a courtyard. The entire complex overlies a two-level parking garage with elevators to higher levels. Maps submitted to the agency by the former property owner indicate that the previously delineated and remediated LNAPL footprint lies beneath the building containing the unit of the resident who had complained about petroleum odors. During the site visit, investigators noticed that the sewer line to the building intersected the zone of contamination.

Previous remedial site investigations found the top of groundwater at 20 feet BGS. Soil borings consistently indicated the sandy soil from ground surface to 40 feet bgs. A previous consultant's report had delineated a petroleum hydrocarbon plume extending beneath the former UST pit to groundwater and spreading radially and slightly downgradient, creating a contaminated zone at the water table approximately 50 feet in diameter. A dissolved plume extended an additional 100 feet downgradient of the LNAPL plume.

Agency records of the remedial action showed that the gasoline-contaminated zone was remediated by soil vapor extraction. Concentration-based

Site Summary

- Former service station site
- Currently two condominium complexes separated by a courtyard
- Parking garage below condominiums
- Groundwater at 20 feet bgs
- Previous soil removal and closure by regulatory agency
- Sandy soils
- Sewer line intersects site
- Single odor complaint led to air sample by health department that revealed slightly elevated benzene levels

remediation goals for soil were met in the area of known contamination and a “No Further Action” letter was issued by the agency five years prior to construction of the condos.

Vapors emanating from the vehicles in the parking structure were thought to be a likely source of vapors. However, ongoing drought conditions and dewatering operations at a nearby construction site led investigators to consider the possibility that a previously unidentified and recently exposed LNAPL zone from the former service station was the possible vapor source.

6.B VI INVESTIGATION PROCESS

Use any existing data to assess whether the pathway is potentially complete. In this case, the only recent data that exists is one indoor air measurement. **No subsurface recent data exist to allow this determination, so additional data must be collected.**

Step 8. Choose Investigative Strategy

Based on the initial site CSM, five potential sources exist for the detected benzene:

- Upward migration of vapors from petroleum-contaminated soil and groundwater remaining from the former gas station
- Vapors transmitted along the utility corridor created by the sewer line that transects the former zone of petroleum contamination
- Gasoline vapors from the parking structure
- Ambient air
- Background sources

Table 6-1 summarizes the pros and cons of the various investigatory methods.

Table 6-1. Pros and cons of investigative methods for Scenario 6

Alternative	Pros	Cons
Indoor air sampling	⇒ Direct confirmation of previous measured result	⇒ Likely to have contributions from numerous sources ⇒ Cannot differentiate source ⇒ Legal complications
Groundwater or soil phase data	⇒ Can search for and delineate extent of contamination source	⇒ Logistically difficult at this site due to parking garage ⇒ No history of these matrices as likely sources ⇒ Vapor intrusion risk often overestimated from these matrices
Perform soil gas investigation	⇒ Can be used to locate source spatially and vertically ⇒ Less invasive, easily installed, greater number of sampling locations for lower cost	⇒ Attenuation factor unknown ⇒ Conservative screening levels

Decision: The condominium management company, its environmental consultant, and agency investigators agreed that a soil gas investigation was the best initial approach to determine whether previous contamination was a vapor source. The management company's newly hired consultant began preparation of a work plan, which included soil gas sampling and an investigation of the garage ventilation system.

Step 9. Design VI Investigative Work Plan

Since the location of the source is unknown, the first goal is to determine and delineate the source spatially by collecting soil gas at 5 feet below the parking garage on an even (50-foot center) spacing in all directions, starting below the location of the unit with the indoor air detection. If contamination is found, a depth profile of the soil gas in the location(s) of the highest concentration will be performed to assess whether the source is from the vadose zone or from the groundwater. In addition, at locations where contamination exceeding the risk-based screening levels is found at 5 feet bgs, soil gas samples will be collected immediately under the parking garage slab to see whether the contamination exists under the garage floor.

Since the source is unknown, having the ability to add sampling locations both spatially and vertically in real time will optimize the field effort, so on-site analysis is planned.

Determine Target/Screening Levels: The state oversight agency follows the EPA OSWER guidance. For benzene in soil gas at a 1-in-1-million risk level, the risk-based screening levels are $150 \mu\text{g}/\text{m}^3$ for soil gas samples collected 5 feet below a receptor and $3 \mu\text{g}/\text{m}^3$ for soil gas samples collected immediately below the slab.

Both EPA test methods 8021 and 8260 can be used for soil gas samples conducted on site and reach detection levels of $10\text{--}100 \mu\text{g}/\text{m}^3$. For the subslab samples, if the on-site analysis gives nondetect values, then samples will need to be collected for off-site analysis with a method (such as TO-15) offering a lower detection level.

Since the COC is a hydrocarbon, oxygen and carbon dioxide data will be useful to show bioattenuation and document the presence of highly aerobic soils. These data can be collected using GC or with a portable field meter such as a Landtec GEM-2000.

Steps 10 and 11. Collect and Interpret Data

The 5-foot soil gas data showed only one contamination zone located near the sewer line but not immediately beneath the condo unit. Maximum values were approximately $1500 \mu\text{g}/\text{m}^3$, which exceed screening levels by more than 10 times.

What is the source? Conduct vertical sampling for concentration profile. A vertical profile of the soil gas at the same location showed that concentrations did not increase with depth, so groundwater is not the source.

Is the sewer line the source? Collect additional 5-foot soil gas along sewer line. Additional soil gas data showed no correlation with sewer line. Only one localized subsurface contamination source of moderate strength appears to exist on the site at depths of 5 or more feet.

Is there a shallower source? Are high values underneath the parking garage slab? Collect subslab soil gas below garage at contamination zone. The maximum subslab value is about $50 \mu\text{g}/\text{m}^3$, which exceeds the EPA OSWER acceptable level of $3 \mu\text{g}/\text{m}^3$ for a slab-on-grade structure. However, this complex has a parking garage between the $50 \mu\text{g}/\text{m}^3$ value and the residences, so it is not likely that the benzene source is from the subsurface.

Could the garage be the source? Inspection of the ventilation system in the garage shows that the ventilation system is the type that operates intermittently when carbon monoxide levels build up to a value that turns the system on. Is the system operating enough to ventilate the garage effectively? And is there communication between the parking garage and the overlying condos?

What other tools or data can we collect to test this possibility? A tracer can be used to determine whether there is communication between the garage and condo. SF₆ was injected into the garage, and air samples were collected from the condo. The ratio of SF₆ in the condo to the garage showed about 5% leakage into the condo. Benzene measurements were taken again in the garage and condo unit to see how they compare. Benzene was $40 \mu\text{g}/\text{m}^3$ in the garage and $4 \mu\text{g}/\text{m}^3$ in the condo unit. The tracer study showing a 5% leakage rate into the condo unit implies a $\sim 2 \mu\text{g}/\text{m}^3$ benzene contribution to the condo from garage.

Step 12. Is Additional Investigation Warranted?

- The primary sources of benzene in the condo are from background sources and the garage.
- The source of benzene in the garage is likely from cars since subsurface soil gas values would be expected to be at least 10 to 100 times higher than the garage, but they are nearly equivalent.

6.C WHAT WAS UNIQUE ABOUT THIS SCENARIO?

- Detected indoor benzene was not from a subsurface source. This scenario gives a sequence of steps and questions that were taken to reach that conclusion.
- The expected contributions from background and ambient sources precluded simple indoor air sampling and necessitated the sequence of steps.

6.D LESSONS LEARNED

- Vertical profiles of soil gas are helpful to determine subsurface sources.
- Supplemental tools—in this case, tracers—can be useful in atypical situations.

6.E NEXT STEPS

- The contribution from the garage to the overlying residences can be reduced if the garage benzene value is reduced. This effect can readily be accomplished by changing the ventilation system in the garage to operate continuously.
- After the ventilation system is changed, it might be appropriate to remeasure garage and condo concentrations to see whether they decrease.
- Refer to oversight agency regarding other remediation that may be necessary at the site (e.g., soil removal, groundwater remedy, etc.).

APPENDIX A

Site Investigation Flowchart

**From Chapter 3, *Vapor Intrusion Pathway: A Practical Guideline*
(ITRC 2007)**

