Practical Considerations for Monitoring VOCs in Exterior Soil Gas

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Jacobs

Objective

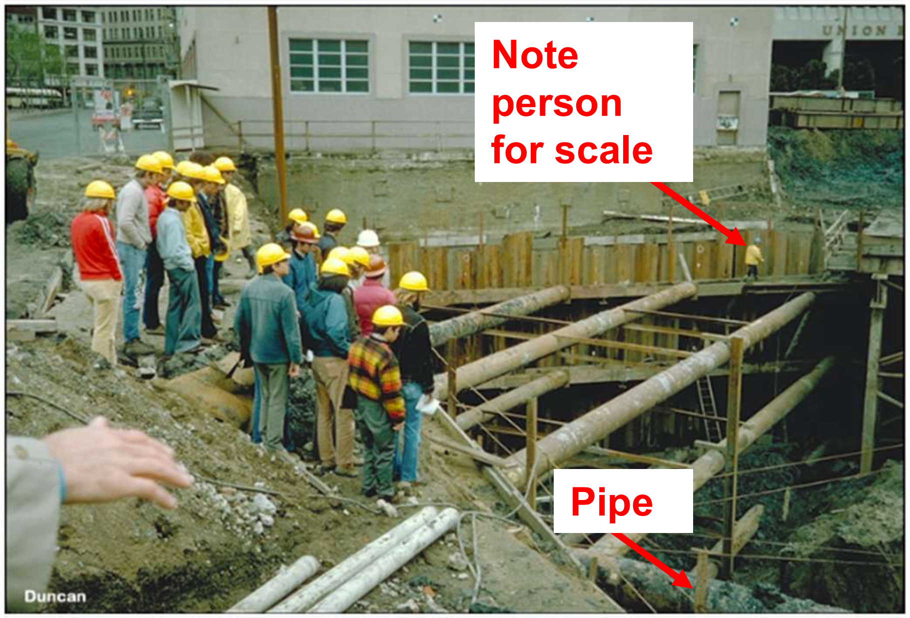
Explore the practical implications of a strategy to monitor VOC contaminated soil gas Exterior to buildings and “keep it away” from the human-built environment.

- How deep is the human-built environment (i.e. sewers)?
- How can we estimate the needed separation distance?
- How can we estimate the needed sampling density?
- How can we estimate the needed monitoring frequency?

The answers to these questions control the cost effectiveness of this site management approach.

Depth of the Human-Built Environment

Note Complex Utilities



This photo shows a sewer excavation in San Francisco supported by a driven sheet pile wall,

Reprinted from https://research.engineering.ucdavis.edu/gpa/excavations/excavation-support-systems/

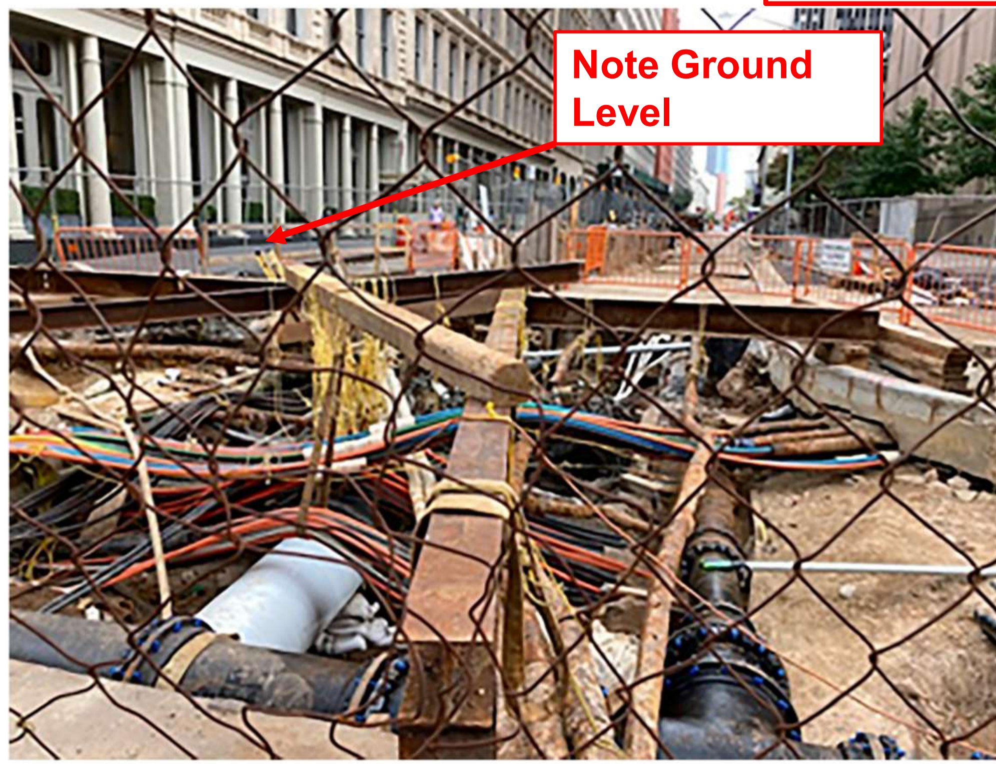
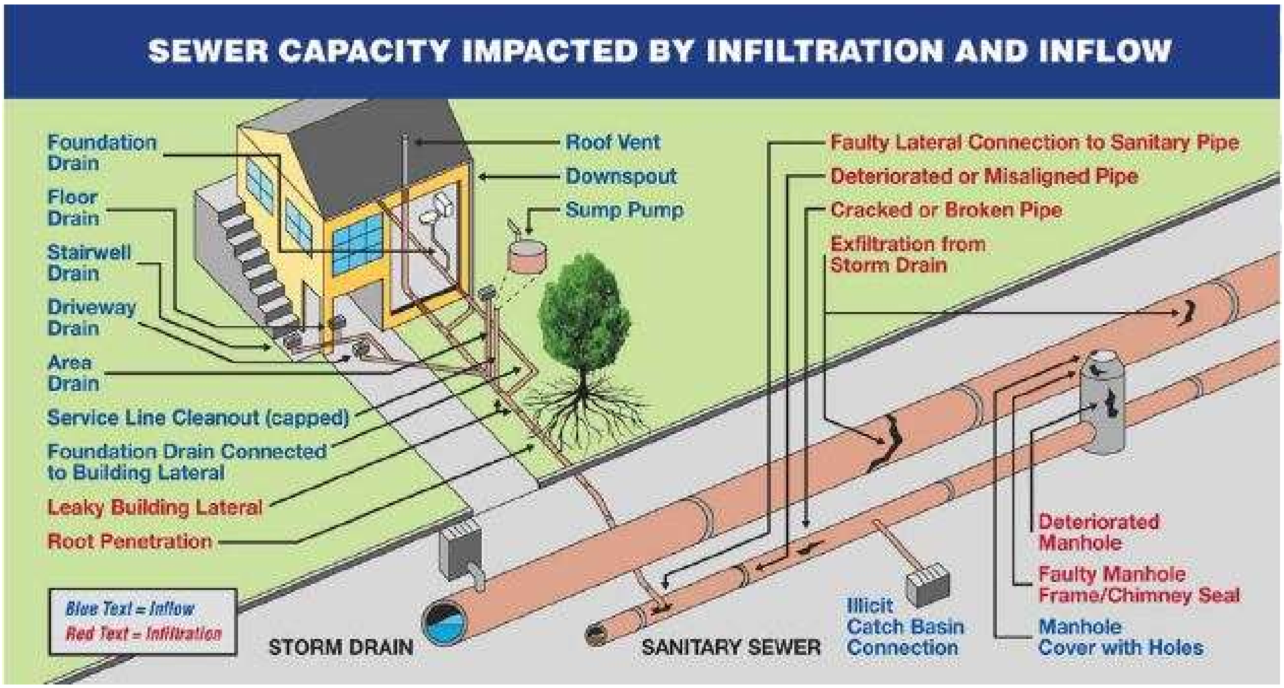


Figure 2. 40 Worth Street, NYC, roadway reconstruction project, November 2021.

Figure reprinted from https://par.nsf.gov/servlets/purl/10376332 Terri Matthews & Debra F. Laefer (2022): Local public right of way for surface and subsurface resource integration, Civil Engineering and Environmental Systems, DOI: 10.1080/10286608.2022.2095371

Characteristics of the Gravity Sanitary Sewer Cases In Preferential Pathway Cases Studied

- Most sewers transported VOCs on the neighborhood scale
- Most studied case were in residential buildings
- Range of building ages – from pre 1915 to late 1980's



Reprinted from:
Lutes, C.C., J. Kastanek, M. Radford, Q. Bingham, A. Madsen and C. Holton. "Profiling Important Atypical Vapor Intrusion Preferential Pathways – A Database Analysis"; Presented at AEHS, March 2017 San Diego CA.

http:/http://msdprojectwin.org/portals/0/Images/i_and_i_SSO.JPG
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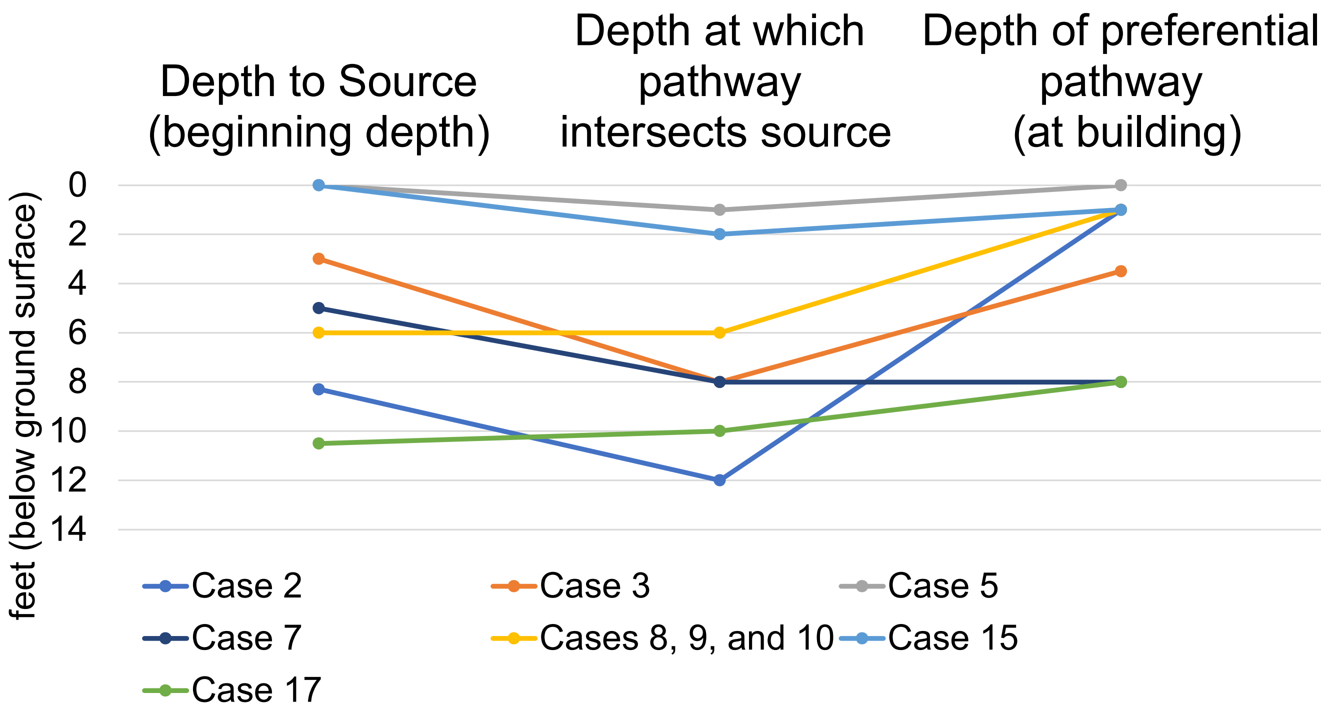
Separated Sewer System Illustrated

Utility Depth vs. Contaminant Depth in Known Preferential Pathway Cases



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Key Point: Range of depths where the utility and contaminant intersect in studied cases = 1 to 12 feet. But some areas have sewers at least 20 ft deep…..

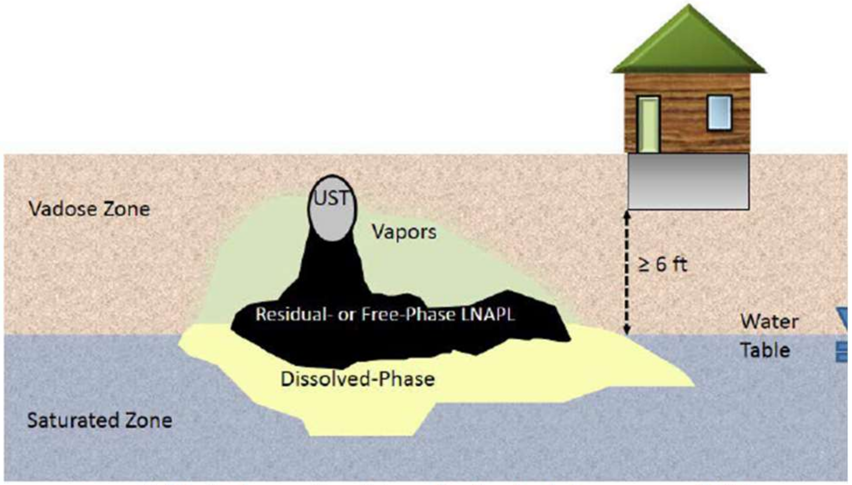
Key Things to Determine about Your Site's Sewers

How deep are the sewers at your site?

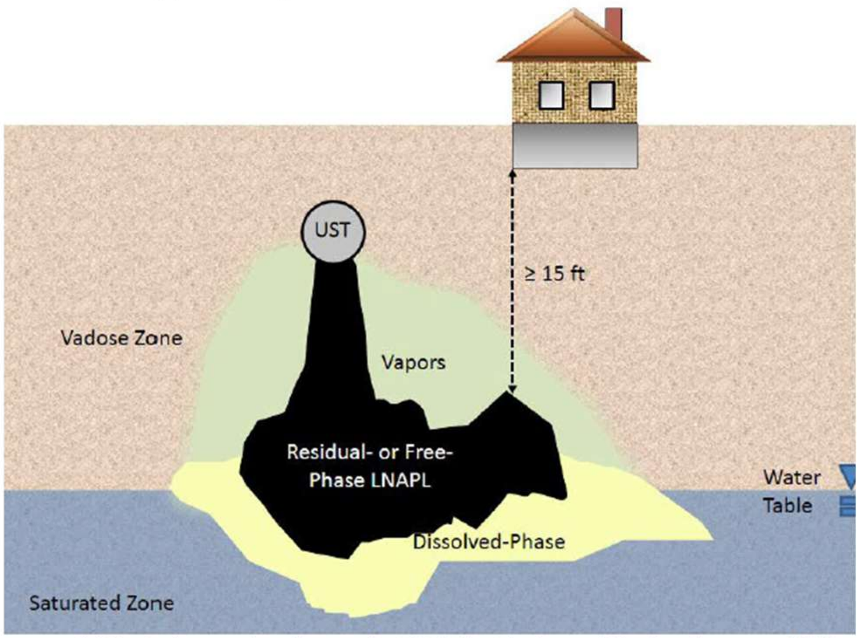
- Many jurisdictions require a minimum cover of 3-ft for flexible storm pipes to prevent cracking of the pipe under vehicle loading, with states in colder climates requiring greater depths (AK, CO, NY)
- Sewer interceptors receive flow from smaller pipe networks and convey flow to a treatment plant main. These larger receiving pipes can be over 20-ft below ground surface as they are to be located below all pipes discharging into their system to prevent reverse flow.

How leaky are the sewers at your site?

- The problem of leakage (or exfiltration) of sewage from conveyance infrastructure is also widespread, but less often studied than infiltration. An EPA report estimates exfiltration in sewer systems at 10% of total flow or greater.
- A transition point in conveyance infrastructure is a bend, drop, or connection that changes the flow conditions and may result in a pressure drop, increased turbulence, or an air gap. These changes in flow conditions may result in an increased likelihood for exfiltration and infiltration to occur of both liquids and gases
- In some areas sewers may have been recently rehabilitated to keep out stormwater.



(a) Vertical separation distance for dissolved-phase source of PHCs.



(b) Vertical separation distance for LNAPL (residual or mobile phase) source of PHCs.

Needed Lateral and Vertical Separation Distances

With a focus on both conventional vapor intrusion pathway and conduit pathways

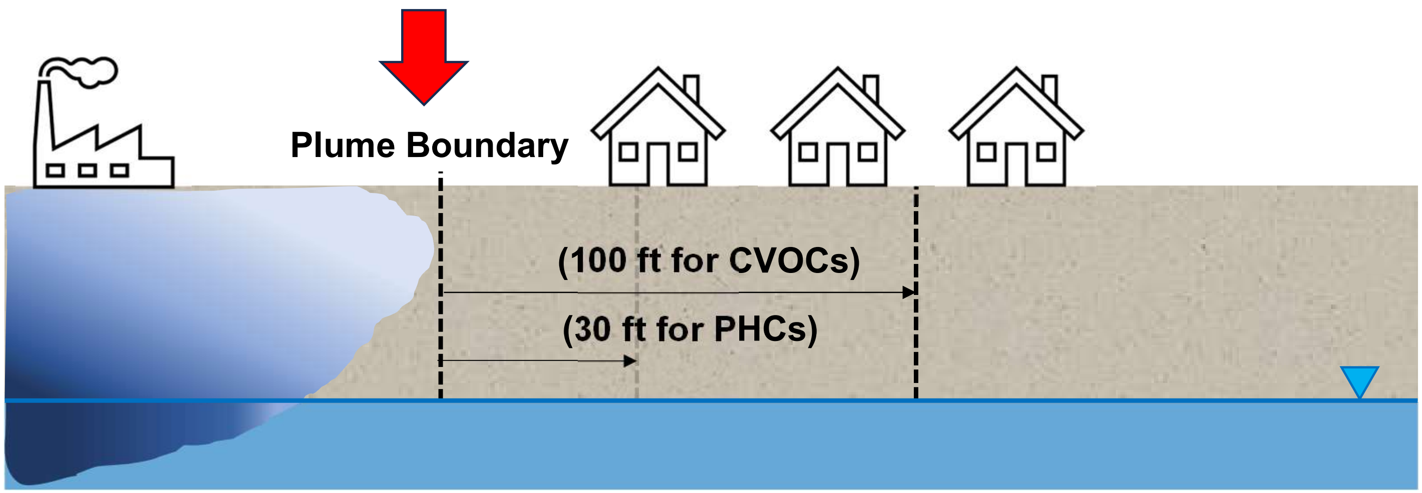
Lateral Separation Distances – Conventional VI Pathway

CVOCs

- Buildings within **100 feet** laterally or vertically from subsurface vapor concentrations of potential concerns (groundwater VISL) generally define an initial lateral inclusion zone for VI screening (EPA, 2015a), but distance is a site-specific decision.

PHCs

- Buildings within **30 feet** of the PHC vapor source are within the lateral inclusion zone (EPA, 2015b)
- Shorter screening distances based on source strength and presence of oxygenated soils (see next slide)

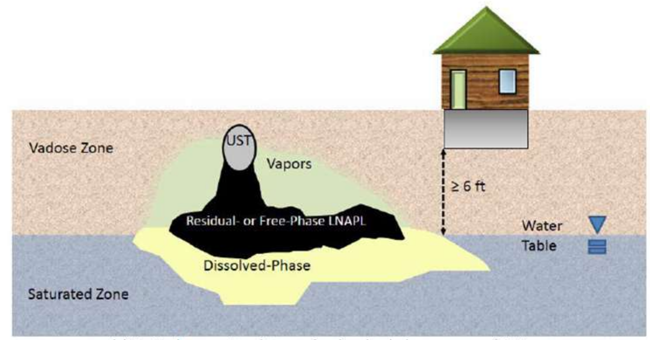


Reference: (1) USEPA 2015a, OSWER Technical Guide for Assessing and Mitigating the VI Pathway from Subsurface Vapor Sources to Indoor Air
(2) USEPA 2015b, Technical Guide For Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites

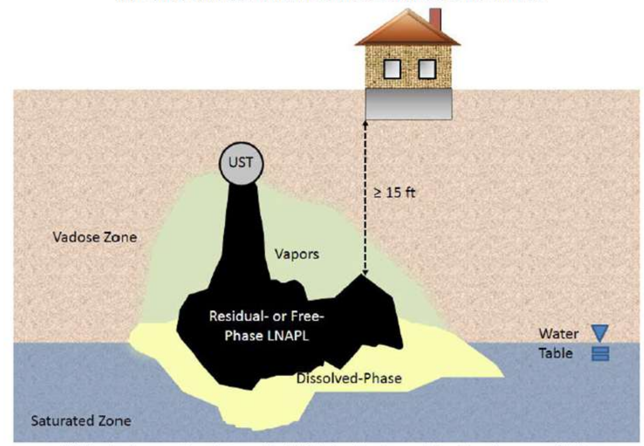
Vertical Separation Distance - PHC

Vertical Separation Distance –
PHCs and other VFCs capable of aerobic biodegradatation

- Vertical depth between subsurface source and building foundation that results in reduced VI potential.
- In many PVI scenarios, 6 to 15 feet vertical separation distance is sufficient to screen for VI potential.



(a) Vertical separation distance for dissolved-phase source of PHCs.



(b) Vertical separation distance for LNAPL (residual or mobile phase) source of PHCs.

References: USEPA (2015), Technical Guide For Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites; ITRC (2014); ITRC Petroleum Vapor Intrusion – Fundamentals of Screening, Investigation, and Management (PVI -1), https://projects.itrcweb.org/PetroleumVI-Guidance/

References Relevant to Separation Distance from Deep Sources

Conceptual Model Scenarios for the Vapor intrusion Pathway : EPA 530-R-10-003

- Based on the Abreu and Johnson 3D model (equilibrium)
- With source at 8 meters deep, lateral attenuation near the surface is at least 50x over 35 meters (115 ft). Attenuation C_{ss}/C_s is 0.01 or better (figure 22b).
- Near steady state vapor concentration reached in 10,000 days (27 years) 27 meters from the source with clayey silt. (Figure 41)
- Near steady state vapor concentration reached in 3,000 days (8 years) 30 meters from the source with fine sand (Figure 41)

Key Point: 100 ft separation distance well supported by 3D modeling

Abreu and Johnson, 2005, “Effect of Vapor Source−Building Separation and Building Construction on Soil Vapor Intrusion as Studied with a Three-Dimensional Numerical Model”

Reference: Abreu and Johnson, 2005, https://pubs.acs.org/doi/10.1021/es049781k

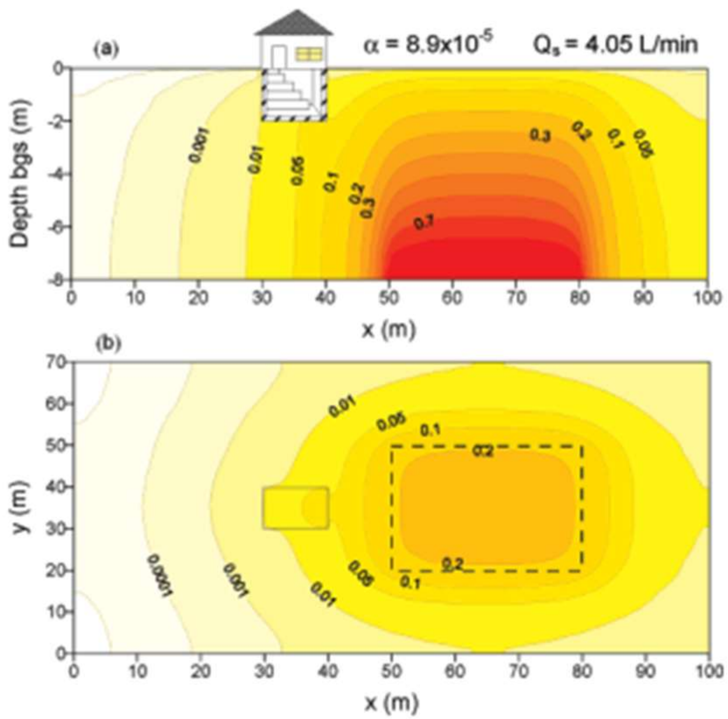


FIGURE 7. Normalized soil gas concentration distributions for vapor source edge and basement foundation center separation of 15 m: (a) vertical profile through the building and source footprint centerlines and (b) horizontal cross section at the foundation depth. The contours are normalized to the vapor source concentration.

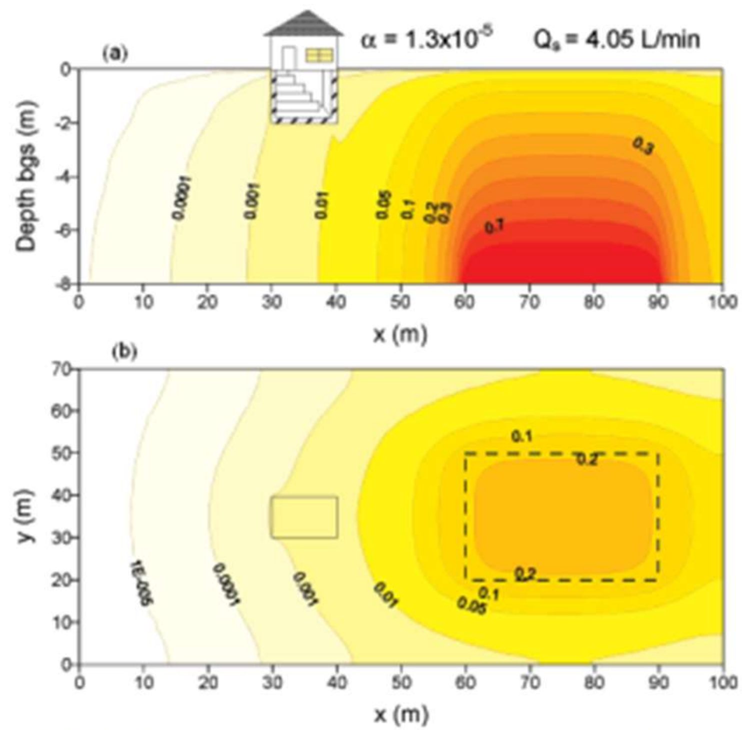


FIGURE 8. Normalized soil gas concentration distributions for vapor source edge and basement foundation center separation of 25 m: (a) vertical profile through the building and source footprint centerlines and (b) horizontal cross section at the foundation depth. The contours are normalized to the vapor source concentration.

“For example, α is 2 orders of magnitude less when a 30 m × 30 m source located 8 m below ground surface is displaced from the edge of the building by 20 m. The decrease in α with increasing lateral separation is greater for shallower source depths. For example, R is ~5 orders of magnitude less when a 30 m × 30 m source located 3 m below ground surface is displaced from the edge of the building by 20 m.”

References Relevant to Separation Distance: Yao et al. 2014 “Estimation of Contaminant Subslab Concentration in Vapor Intrusion Including Lateral Source–Building Separation”

- With the source at 8 meters deep and a 2-meter-deep basement foundation the building crack concentration is predicted to be 124x lower than the deep source concentration at 16 meters (52 ft) lateral separation.
- With the source at 8 meters deep and a 0.2-meter-deep slab on grade foundation the building crack concentration is predicted to be 556x lower at 16 meters (52 ft lateral separation). (Table 2)

Key Point: 100 ft separation distance or even less is supported by 3D modeling

References Relevant to Separation Distance: Yao et al. 2015

"*Evaluation of site-specific lateral inclusion zone for vapor intrusion based on an analytical approach*"

- Develops a new model "Analytical Approximation Method involving Lateral soil gas transport, Paved ground surface and Heterogeneous soil (AAMLPH)".
- "a buffer zone of 30 m laterally can serve well for cases with shallow sources with $C_s < 10^8$ µg/m^3 in the absence of significant surface cover, regardless of the source strength. But for the scenarios with deep vapor sources, the 30 m lateral separation distance can barely provide enough soil gas concentration attenuation in the presence of a strong vapor source, even if most area of the ground surface is open to the atmosphere."

Key Point: don't measure the 100 ft separation distance from extremely high concentrations i.e. 10^8 µg/m^3 soil gas or about 10^5 µg/l PCE in GW

Reference: Yao et al., 2015, Journal of Hazardous Materials, https://doi.org/10.1016/j.jhazmat.2015.05.024

Soil Gas Concentration vs. Distance to Primary Release – DoD Commercial Buildings

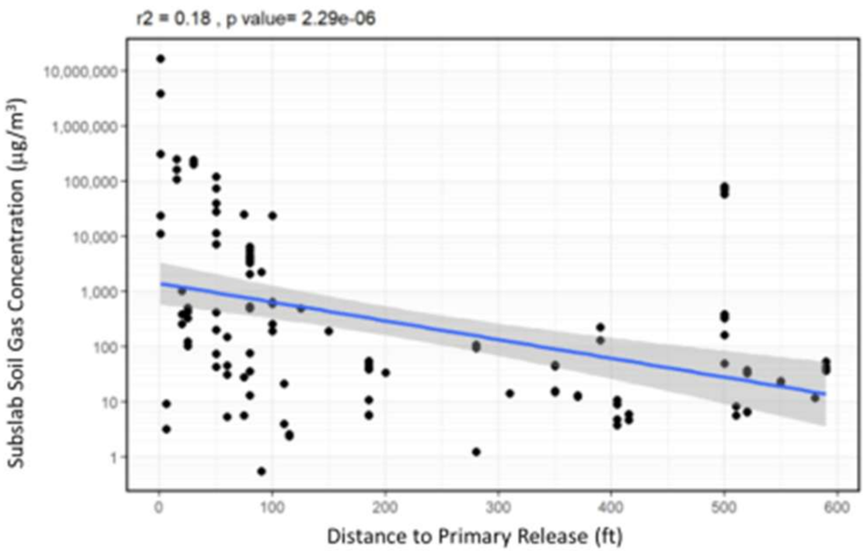


Figure 3-16. PCE Concentration in Subslab Soil Gas Versus Distance to Primary Release, Semi-log Plot
Reanalysis of Department of Defense Vapor Intrusion Database of Commercial and Industrial Buildings
Data where an atypical preferential pathway is suspected are not included.

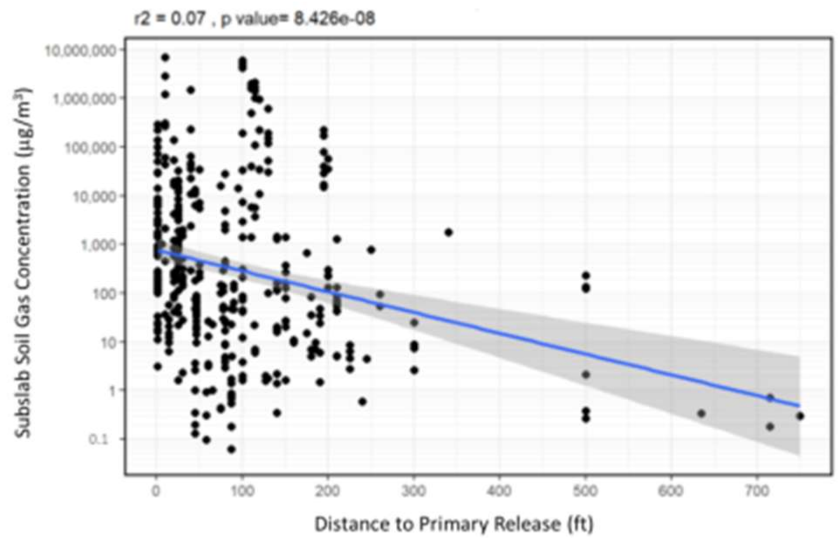


Figure 3-18. TCE Concentration in Subslab Soil Gas Versus Distance to Primary Release, Semi-log Plot
Reanalysis of Department of Defense Vapor Intrusion Database of Commercial and Industrial Buildings
Data where an atypical preferential pathway is suspected are not included.

Key Point: concentrations in subslab soil gas fall very sharply as distance from original release point increases.

Lutes, C.C., L.C. Levy, K.E. Hallberg, R. Gonzalez-Abraham, D. Caldwell, L.G. Lund, T.R. Walker and T.B. Lewis "Final Reanalysis of Department of Defense Vapor Intrusion Database of Commercial and Industrial Buildings" November 2021. Prepared for NAVFAC EXWC and NAVFAC Atlantic by CH2M HILL, Inc.
https://exwc.navfac.navy.mil/Portals/88/Documents/EXWC/Restoration/er_pdfs/v/Reanalysis_of_DOD_VI_Database_of_Comm_Ind_Buildings_Final_NOV21/Reanalysis%20of%20DOD%20VI%20Database%20of%20Comm%20Ind%20Buildings%20Final%20NOV21.pdf?ver=ujOoxNHDndzSmKvGzP-Q3w%3d%3d&timestamp=1652983111487

Separation Distance Summary

- Lateral separation distances for soil VI scenarios are available for both CVOCs and PHCs
- Vertical separation distances for soil VI scenarios are only emphasized for PHCs and aerobically biodegradable VFCs.
- In many cases the concentration of CVOCs beneath the slab is nearly equal to the concentration near the water table, but laterally extensive low permeability or high moisture geological barriers can be protective at some sites.
- Lateral and vertical separation distances for conventional "soil VI" scenarios often cite precluding factors that inhibit their application, including the presence preferential pathways…which we discuss in the next slide!

Reference: (1) USEPA 2015a, OSWER Technical Guide for Assessing and Mitigating the VI Pathway from Subsurface Vapor Sources to Indoor Air
(2) USEPA 2012 Conceptual Model Scenarios for the Vapor Intrusion Pathway

Separation Distances For Conduit VI Scenarios…

Example of Infiltration into a Sanitary Sewer
(Photo from Massachusetts Water Resources Authority http://www.mwra.state.ma.us/comsupport/ii/iiprogram.html)

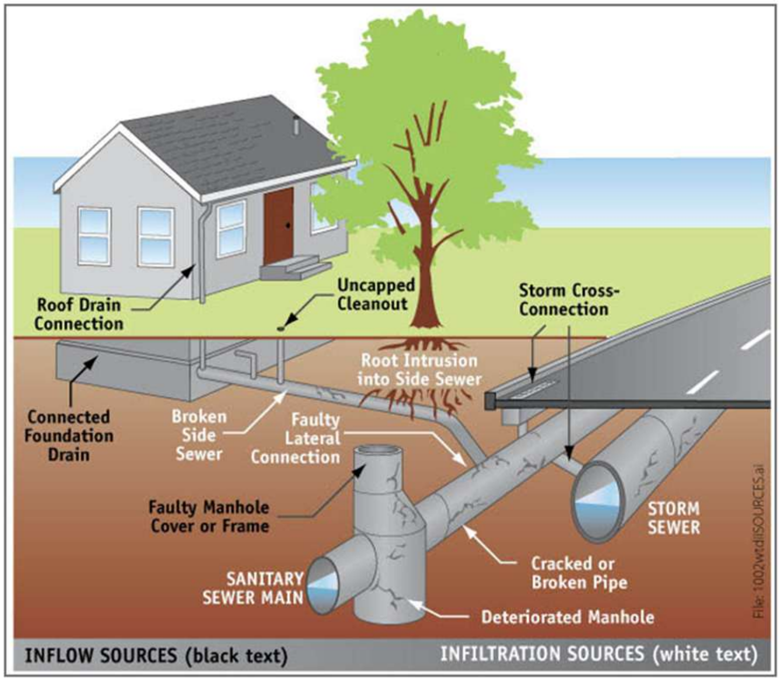
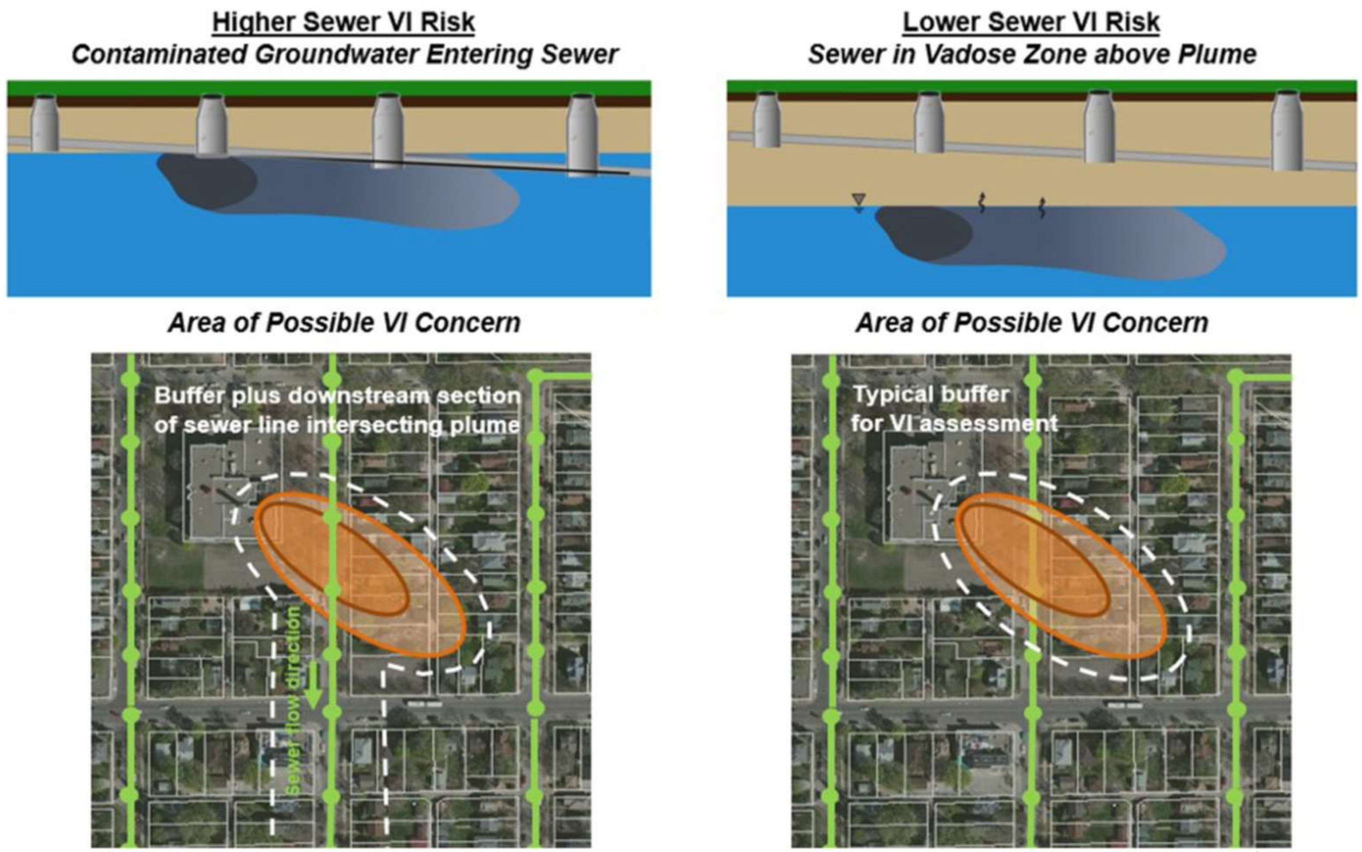


Figure 2: Inflow and Infiltration Sources *(Reprinted from King County, 2015 King County Wastewater Services, What is infiltration and inflow? http://www.kingcounty.gov/services/environment/wastewater/ii/what.aspx)*

Sewer VI Scenarios (Beckley and McHugh 2020)

Higher and Lower Vapor Intrusion Risk Scenarios:

Higher risk when the groundwater enters the sewer directly rather than soil gas.

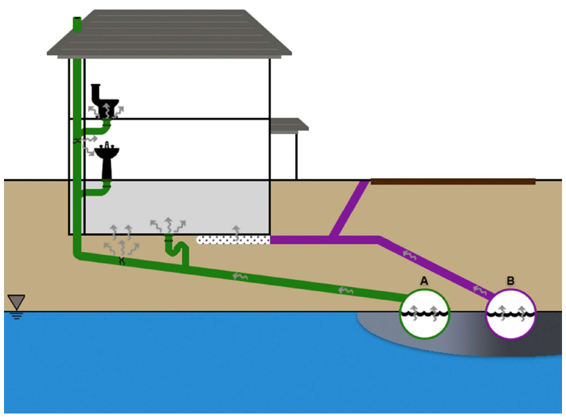


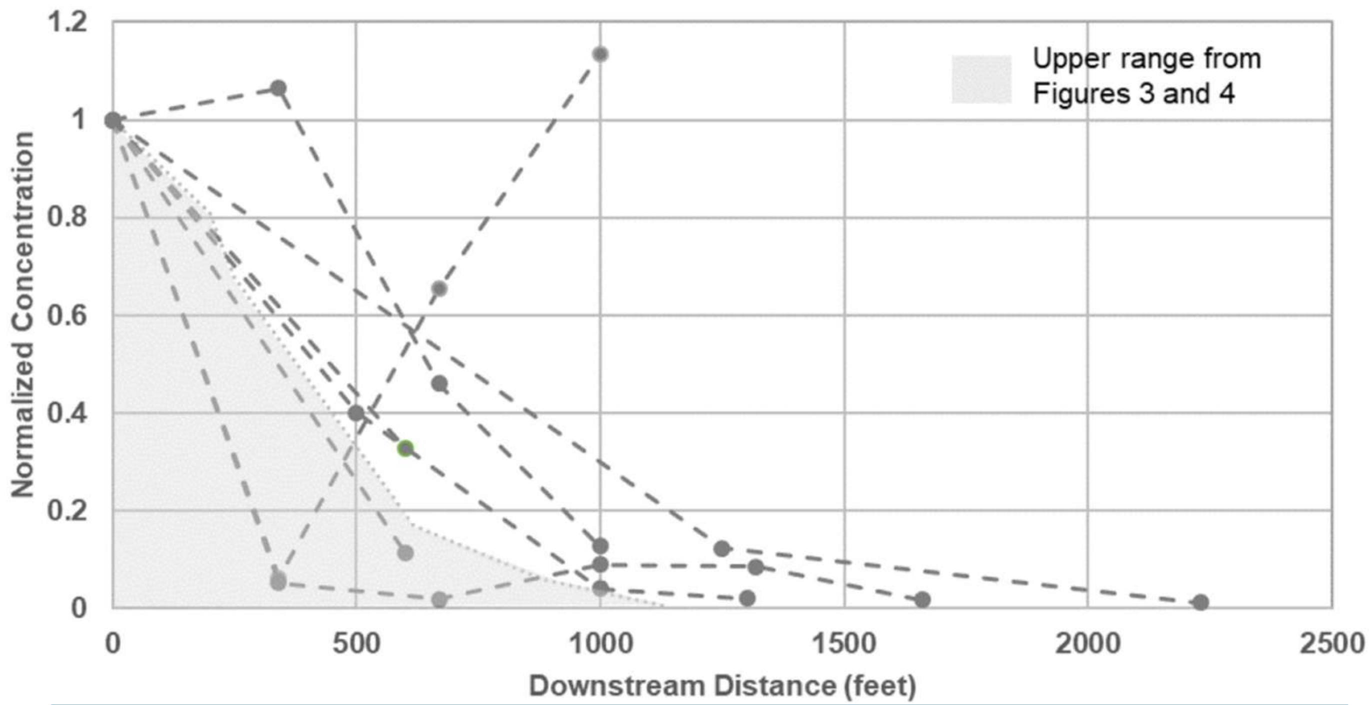
Reference: Figure 2, Beckley and McHugh, 2020, A conceptual model for vapor intrusion from groundwater through sewer lines, Science of the Total Environment, 698, 134283

Sewer Vapor Downstream Migration
(Beckley and McHugh, 2020)

Groundwater infiltration through sewer lines

(higher risk scenario)





Key point: Concentrations fall off after 1,000’ ft along sewer line

Reference: Beckley and McHugh, 2020, A conceptual model for vapor intrusion from groundwater through sewer lines, Science of the Total Environment, 698, 134283

Wisconsin DNR Guidance

- “Contaminated vapors typically decrease by 80% or more at **500 feet** from the source area within sewer conduits.”
  - Recommends sampling 500 feet up-flow and down-flow from where contaminants intersect conduit.
- Attenuation factor of 0.03 applied for calculation of sanitary sewer gas screening levels (SSGSL); applicable to all buildings

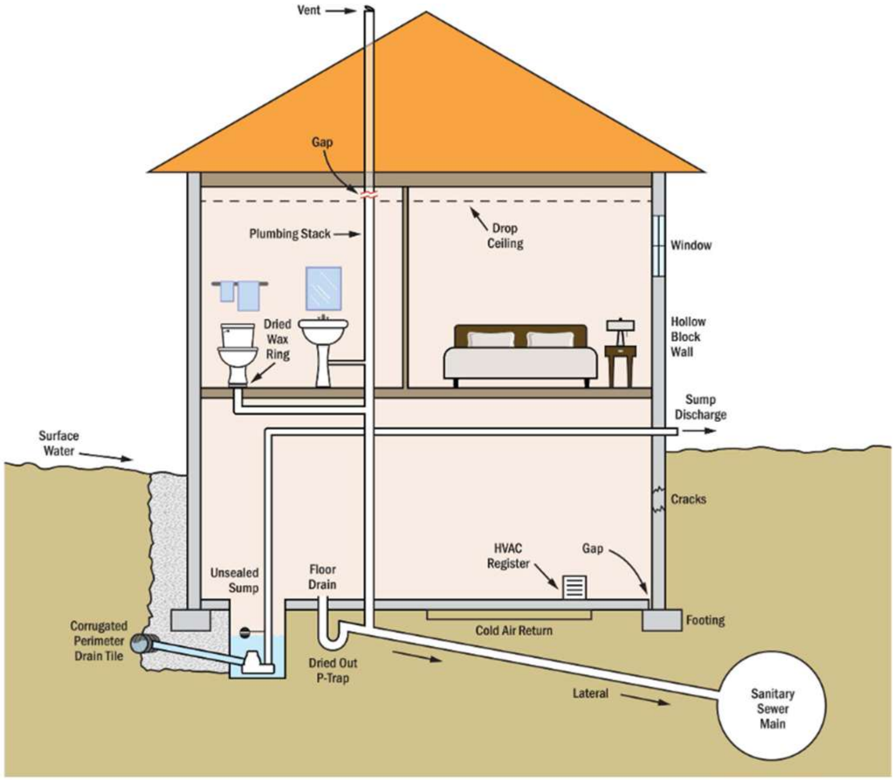


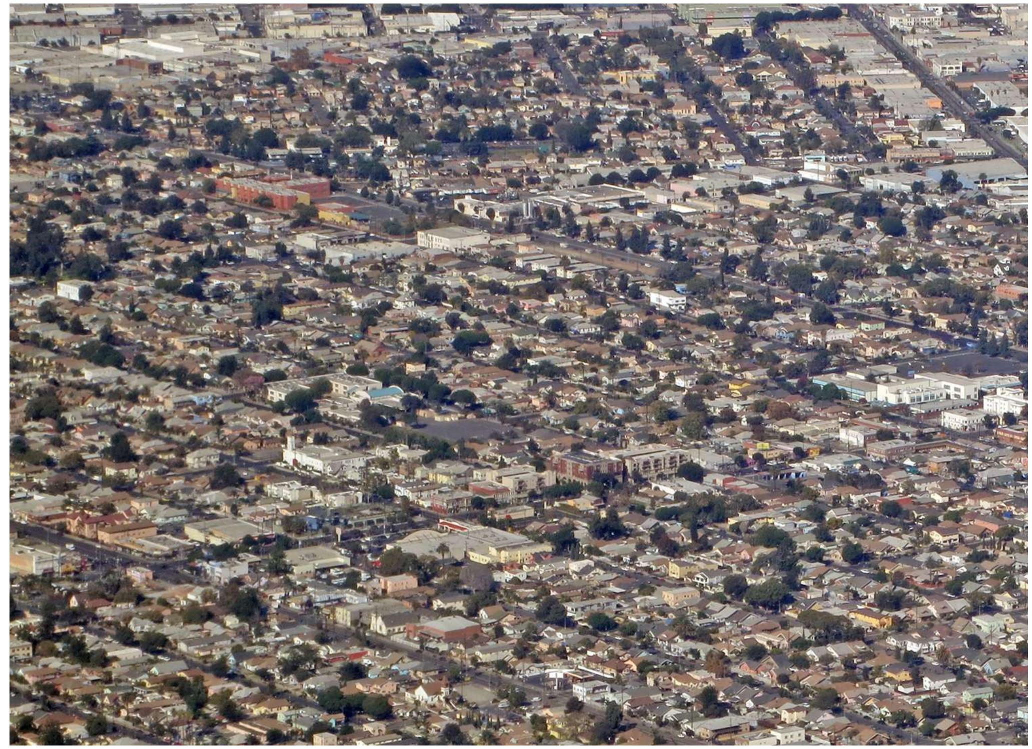
Image: Wisconsin DNR, 2021; https://widnr.widen.net/s/kxtjjk5hbg

Conduit VI Summary

- Vertical separation between impacted groundwater and sewers helps establish “sewer VI risk scenario” with direct contact between groundwater and conduits representing higher risk
- Lateral separation distances of >100-500 feet generally recommended for higher risk sewer VI scenarios due to groundwater intrusion into sewer lines
- Groundwater vapor to sewer vapor attenuation expected to be >33x based on field tracer studies

Needed Spatial Sampling Density?
(Acres per sampling point etc.)

Photo reprinted from Vogt 2025
https://news.unl.edu/article/most-rural-nebraskans-are-positive-about-their-communities-poll-shows



Part of Los Angeles Tracey Saxby, Integration and Application Network (ian.umces.edu/media-library)

Key Point: Needed sampling density is influenced by housing density.

Spatial Sampling Density Table

Reviewed seven well known, large sites based on publicly available information

Site, State, Program	Number of Structures	Number of Groundwater Wells	Number of External Soil Gas Points	Number Structures Mitigated	Approx. Size (Acres)
Redfield CO; RCRA	562 in inclusion zone, 780 prioritized for sampling	104	About 10	387	88
Endicott NY; RCRA	233 initial, grew to 377 later	>34	None?	490 systems at 434 Properties	350
Hill AFB Utah, CERCLA	2,456 off base structures were sampled; 13 on base; another source says 3,100 homes	>1,400 monitoring and remediation wells	Approximately 25	130	690
Billings MT; CERCLA	1,500 in inclusion zone; another source says 3,200 above plume; 190 have actually been sampled indoors	52	100 samples	28	976
Gaffney AK, State	151 in soil gas safe study inclusion zone; 37 have been sampled to date	47+	33 in routine investigation, 16 more in research study	1	40
Franklin IN, RCRA	42 where indoor sampling was requested, 37 actually sampled	About 85 including temp.	20	7 SSDS, 11 Plumbing; relined 2600 ft sewer	16
Pike and Mulberry, IN, CERCLA	80 sampled	37 shallow	141	14 or more	147 acres investigated, 28.5 acres exceed PRG in soil gas (FS table 2-5)

Spatial Sampling Density Table

Key points:
To delineate a site thoroughly in an urban/suburban area, you need roughly one sampling location per each 0.15 to 1.05 acres; no matter which media you choose to sample most thoroughly (groundwater, Exterior soil gas or indoor air). That suggests a spacing between sample points of 80 to 210 ft. This is consistent with one sample location per building in most neighborhoods. Delineation requirement may not be the same as making a correct house level mitigation decision.

Site, State, Program	Approx. Size (Acres)	Acres per structure	Acres per most numerous type of external delineation points	Acres per location of most numerous data type (including indoor air)	Qualitative Remarks on the Completeness of Delineation
Redfield CO; RCRA	88	0.16	0.85	0.16	high, extensive indoor air sampling with very high access rates
Endicott NY; RCRA	350	0.93	10.29	0.81	high, extensive premptive mitigation across a large area
Hill AFB Utah, CERCLA	690	0.28	0.49	0.28	moderate - extensive indoor air sampling program, but still many houses not sampled
Billings MT; CERCLA	976	0.31	18.77	5.14	low -early stages of investigation
Gaffney AK, State	40	0.26	0.85	0.85	moderate - commercial area well sampled, offsite area likely encounters multiple sources
Franklin IN, RCRA	16	0.38	0.19	0.19	
Pike and Mulberry, IN, CERCLA	147 acres investigated, 28.5 acres exceed PRG in soil gas (FS table 2-5)	0.36	1.04	1.04	high confidence in soil gas based delination

Land Use Patterns Change: Consider Both Current Conditions and Land Use During Release

1949 ←

City Market, Atlanta

← 2014

Figure reprinted from Hurley, 2014 https://blog.library.gsu.edu/2014/03/24/1949-atlanta-aerial-mosaic-project-reveals-built-environment-change/

McKellips Rd. & Stapley Rd. 1970

Phoenix Metro Area

1970 ←

McKellips Rd. & Stapley Rd. 2010

← 2010

Right slides reprinted from https://globalfutures.asu.edu/caplter/wp-content/uploads/sites/33/2024/06/Historical-Aerial-Photos-1.pdf

What Monitoring Frequencies Might Be Needed in Soil Gas?

Data Distribution Comparisons From Well Studied Buildings At A Distance From Sources

- Including exterior soil gas and subslab soil gas
- Providing insight into the degree of expected spatial and temporal variability
- See earlier discussions of Sun Devil Manor and Fairbanks Church

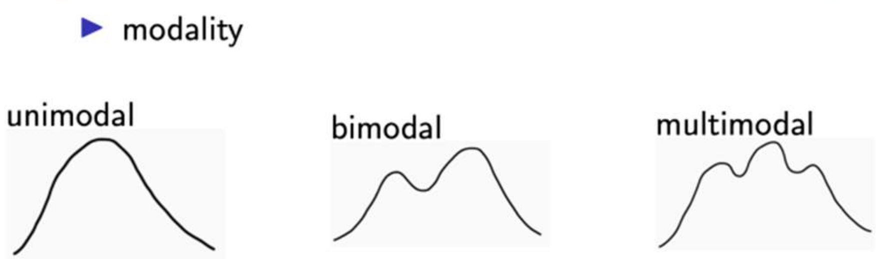
Previous Study Conclusion for Soil Gas

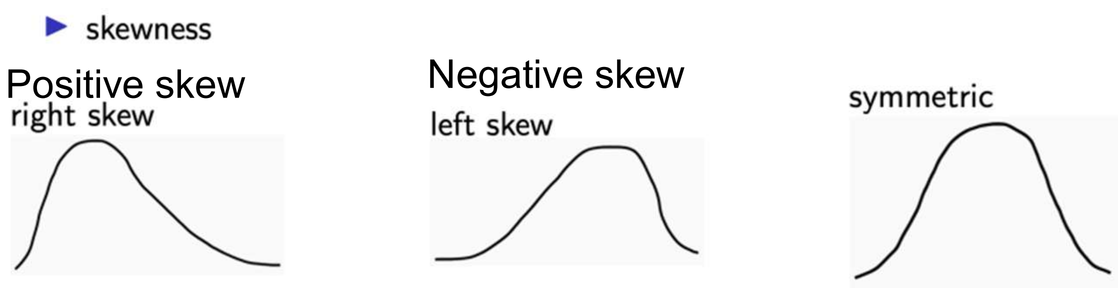
- Previous conclusions were that the degree of temporal variability decreased with depth. While that is still true, the overall degree of temporal variability in deep soil gas is still substantial which is important if decisions are being made with a sparse number of samples.
- The temporal variability of soil gas is primarily seasonal while the temporal variability of indoor air has a strong day to day variation on top of seasonal. Therefore, extending the duration of soil gas sampling within current limits is not helpful.
- The degree of spatial variability in soil gas is higher than temporal variability even within a single lot/building.
- From: Johnson et al. 2012; Lutes, Johnson and Truesdale, 2014; Schumacher et al 2012, Zimmerman 2024, 2025a, 2025b

Results of Statistical Tests of Distribution Types/Characteristics Indoor Air Temporal Data

- Of all the distributions tested, only a few are multimodal = Sun Devil Manor, VA Site A Women's restroom and TCE in Fairbanks Church Basement. Two of these cases are known to involve preferential pathways/fluctuating water levels.
- Skewness is a measure of the asymmetry of the distribution. Skewness for normal distribution is near zero. Skewness >1 interpreted as "significantly positively skewed". Of 31 skewness tests on VI indoor data sets all were positive. 28 of 31 were skewness >1.
- Extremes: SDM = 5.4 skewness. VA site A bathroom = 5.5 skewness.

Key Point: Indoor distributions are skewed, thus hard to characterize with small sample numbers



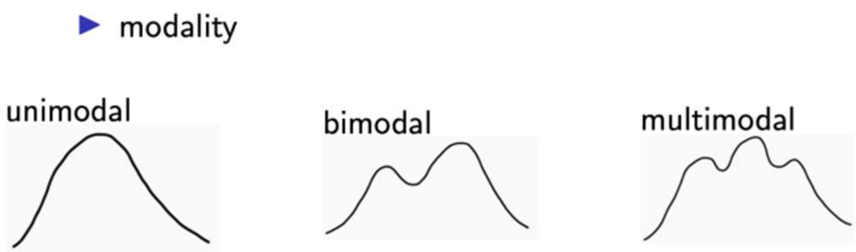


Graphic adapted from Y. Tian "Lecture 3 Probability Basics", Columbia University, 2022. https://www.columbia.edu/~yt2661/S1201/slides/lecture-3.pdf

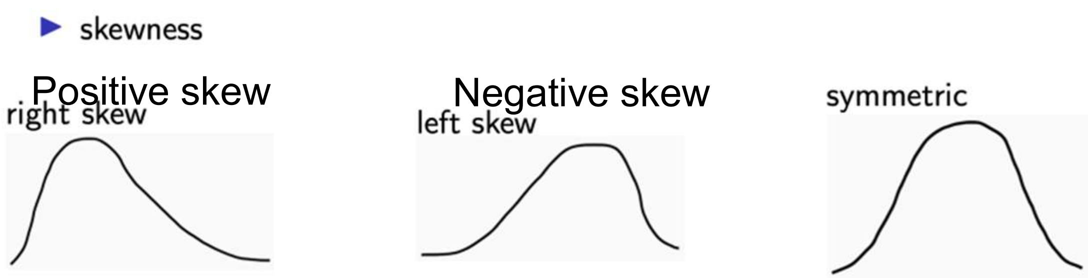
Results of Statistical Tests of Distribution Types/Characteristics Soil Gas Temporal Data

- SDM: Skewness of soil gas positive, but not as strongly as in the indoor air 4 of 7 subslab ports are significantly positively skewed (57%); 14 of 27 soil gas ports are significantly positively skewed (52%)
- Indianapolis 7 of 10 subslab and wall ports are positively skewed (70%) but only about 35% of the soil gas data sets examined are positively skewed (19/53). Degree of skew similar to indoor air.
- Fairbanks 3 of 3 subslab ports positively skewed (100%), 6 of 9 soil gas ports positively skewed (66%); degree of skew similar between soil gas and indoor air.

Key Point: Temporally skewed distributions might require more extensive sampling to define the upper end of the concentration distribution in shallow soil gas.



But remember: temporal variability in soil gas is mostly seasonal, so most methods of time integrated sampling don't help.



Graphic adapted from Y. Tian "Lecture 3 Probability Basics", Columbia University, 2022. https://www.columbia.edu/~yt2661/S1201/slides/lecture-3.pdf

Indianapolis Natural Conditions – Detailed Soil Gas Observations Interior and Exterior

- Approximately weekly samples for a year, with greater frequency during intensive rounds.

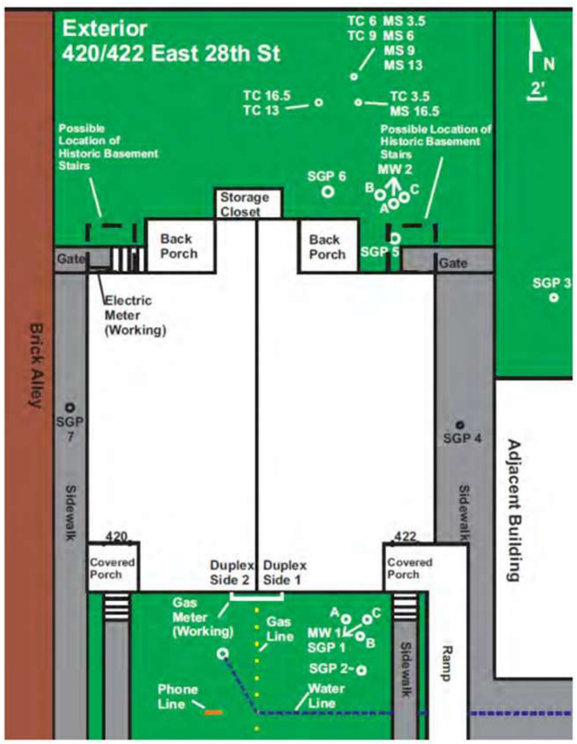


Figure 3-18. Exterior of test building showing utility corridors, ground surface cover, monitoring wells (MWs), soil gas points (SGPs), thermocouples (TCs), and moisture sensors (MSs).

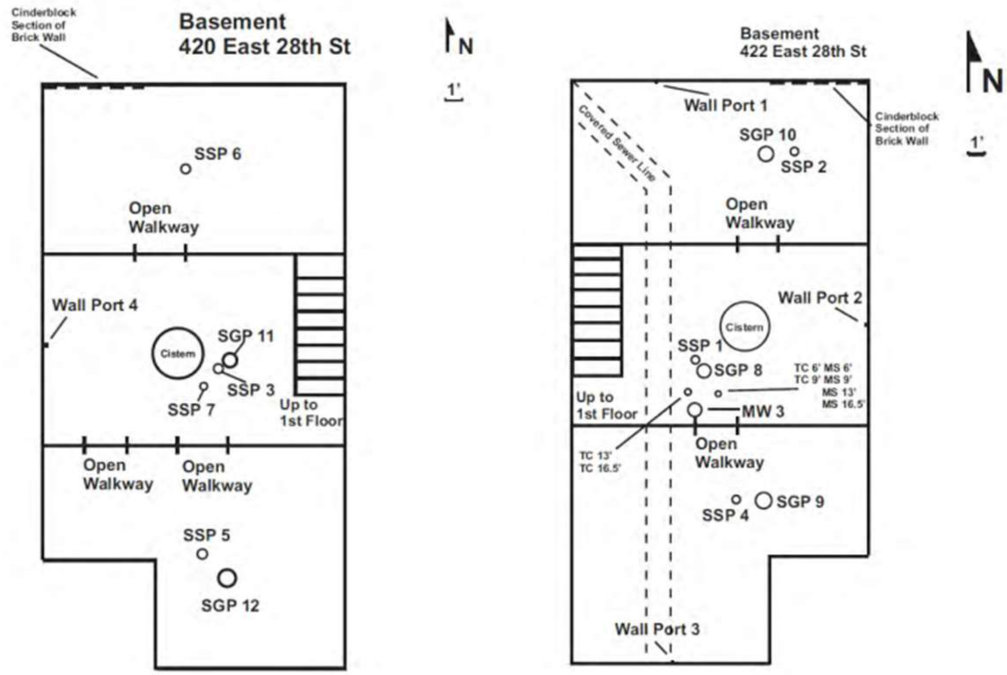
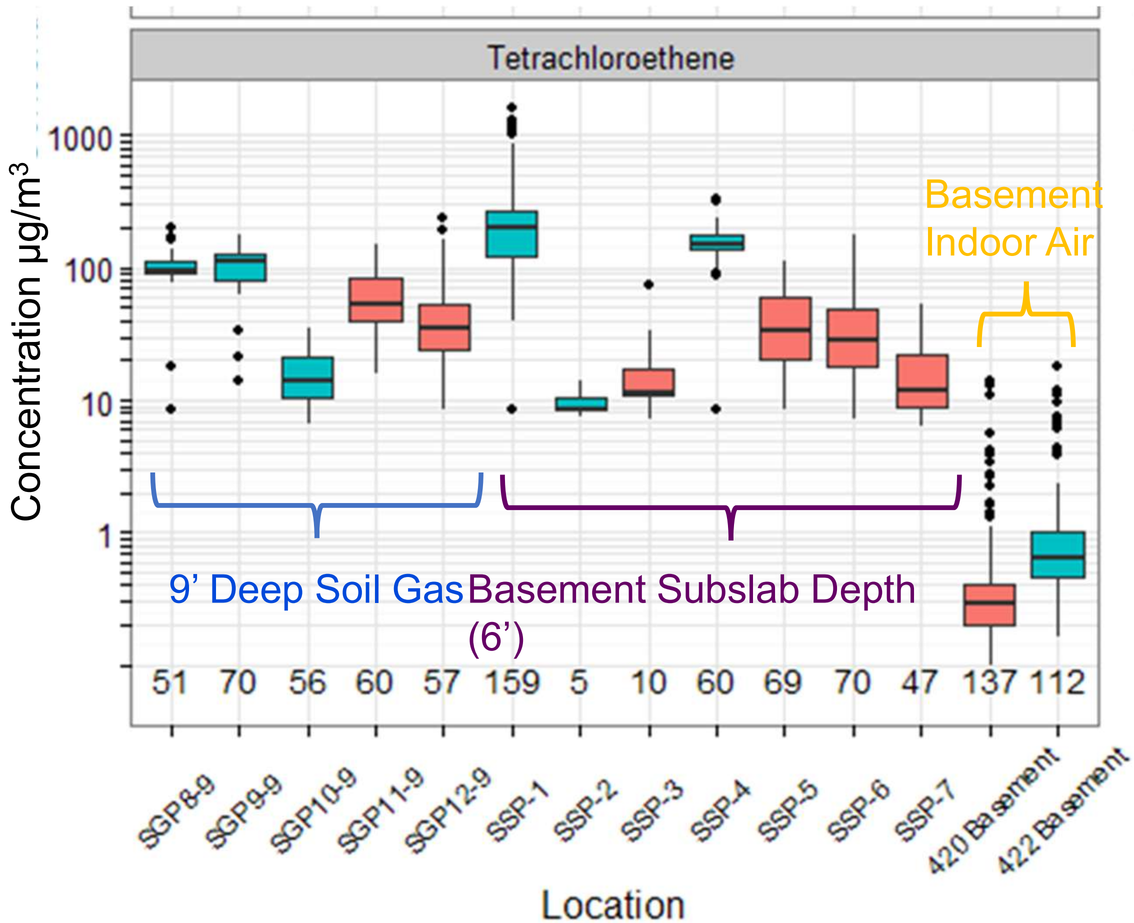


Figure 3-19. Interior floor plans of 420 and 422 East 28th Street showing sampling locations.

What Does Temporal and Spatial Variability In Soil Gas Look Like in Indianapolis Duplex?



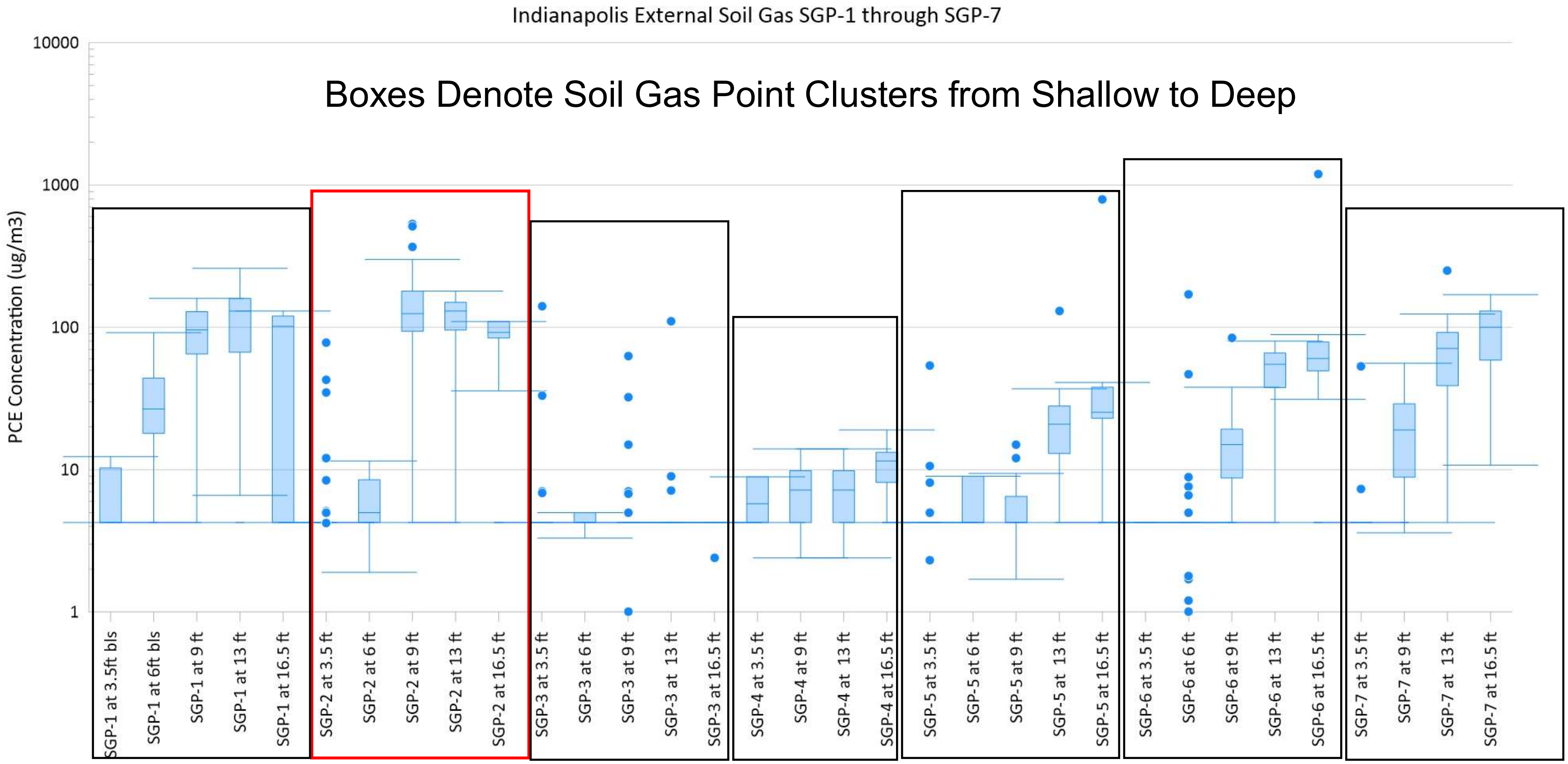
Key Points:

1) Temporal variability indoor> soil gas

2) Spatial variability soil gas > indoor

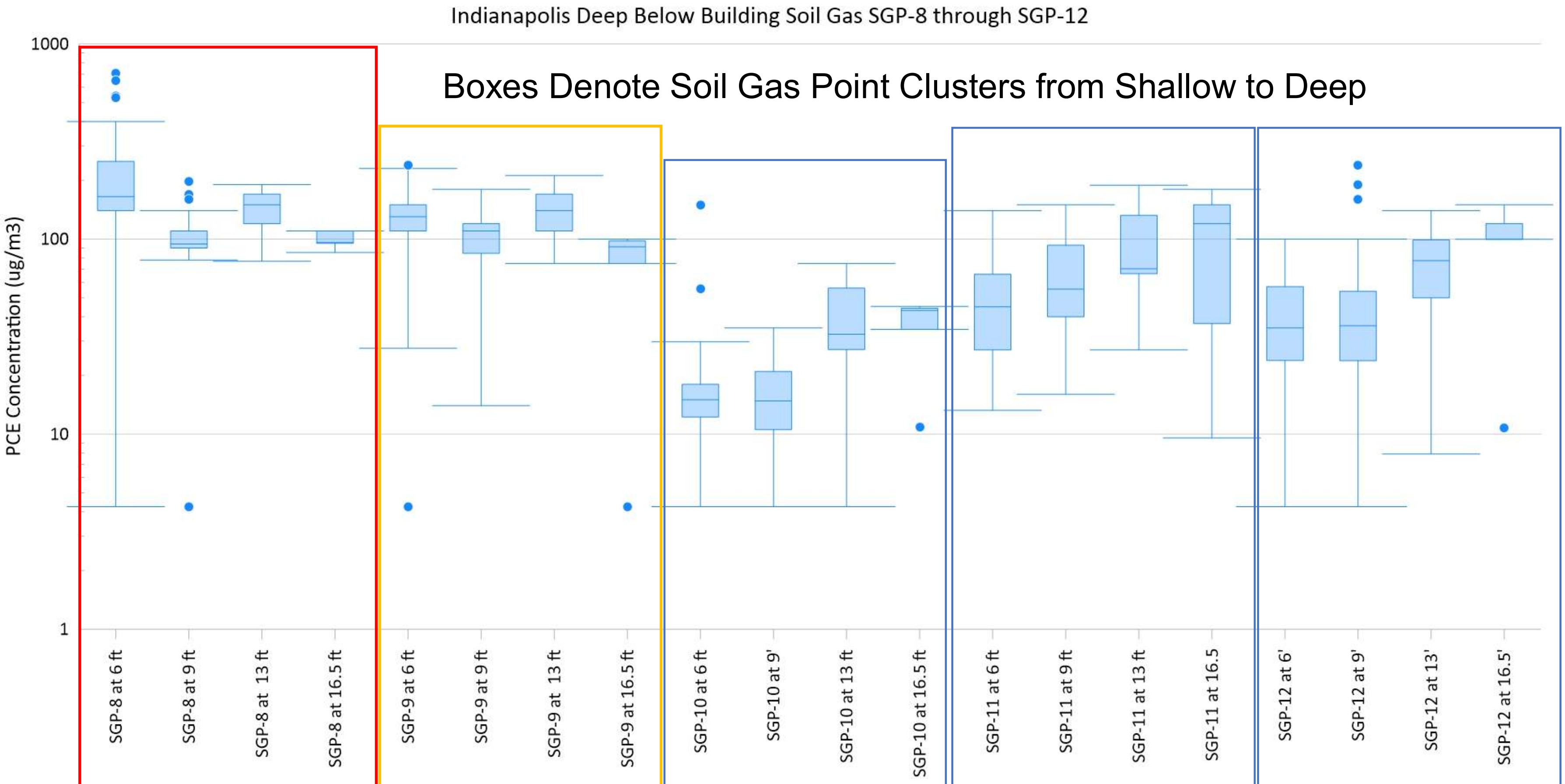
Adapted from figure 7-3 of "Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variations" EPA/600/R-12/673, September 2012.

TO-17 data n=4 to 104

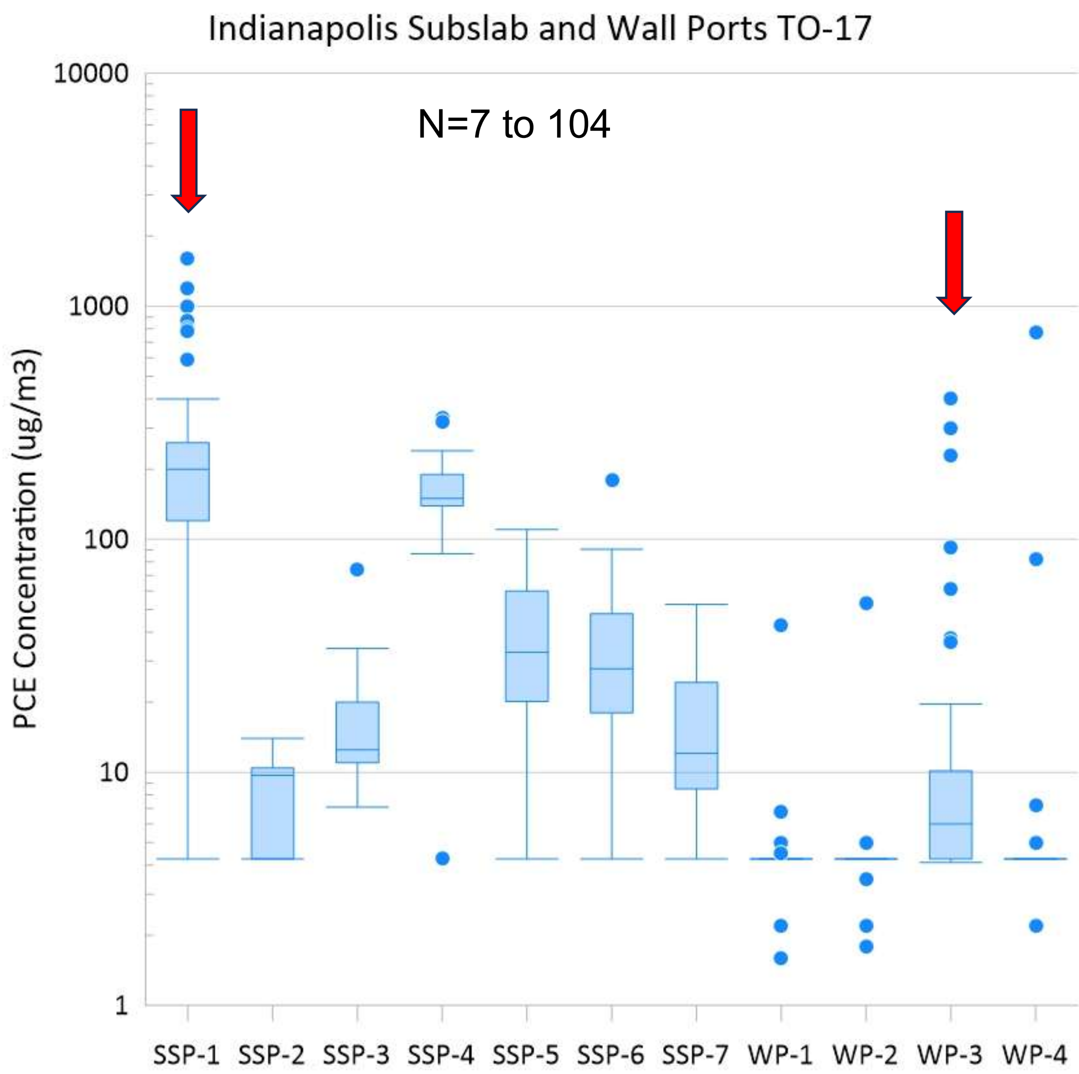


Key Points: Concentrations increase with depth at most locations but not SGP-2 in front of house – sewer line effect? Note log scale.

TO-17 data n=4 to 104

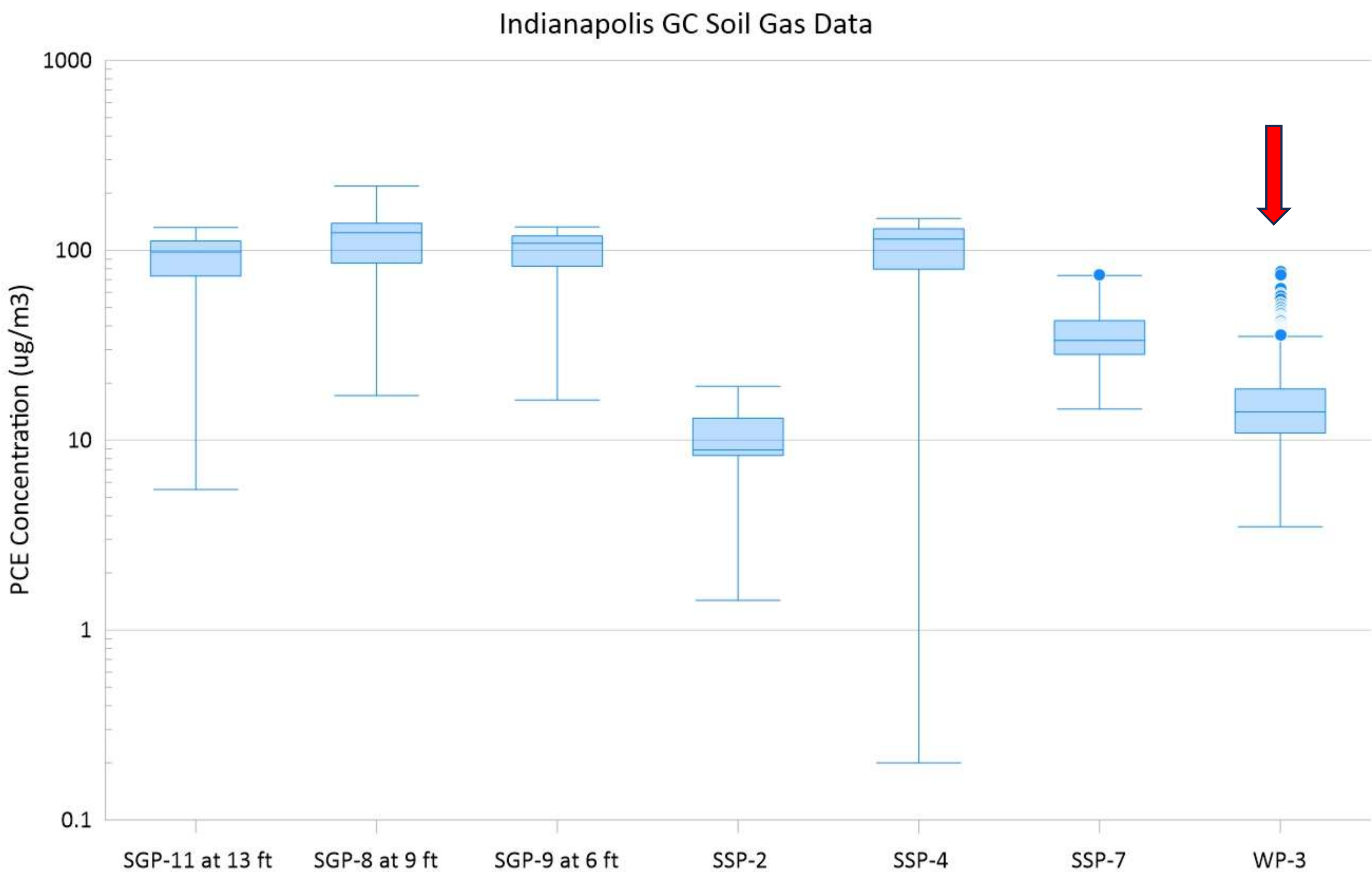


Key Point: Concentrations increase with depth but not at SGP-8 and SGP-9 near suspected sewer line leak to the southeastern side and east central area of the structure. Note log scale.



Key point:
Two locations (arrows) have the most skewed distributions. These are a basement wall port and a basement subslab port near the sewer lateral. Note log scale.

Indianapolis GC Soil Gas Data Natural Conditions n = 1378 to 1467



Key point:
The basement wall port also shows significant skew when observed frequently but other a shorter total duration with the GC.
Note log scale.

Indianapolis Natural Conditions Soil Gas Beneath Basement – GC Data

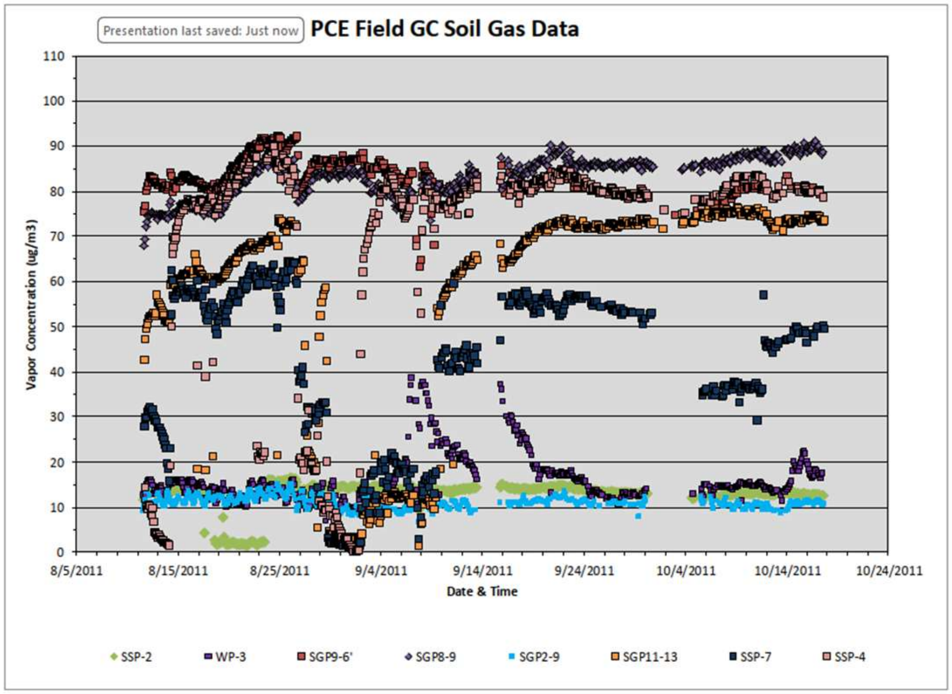


Figure 5-63. Online GC subsurface PCE soil gas data—Phase 1.

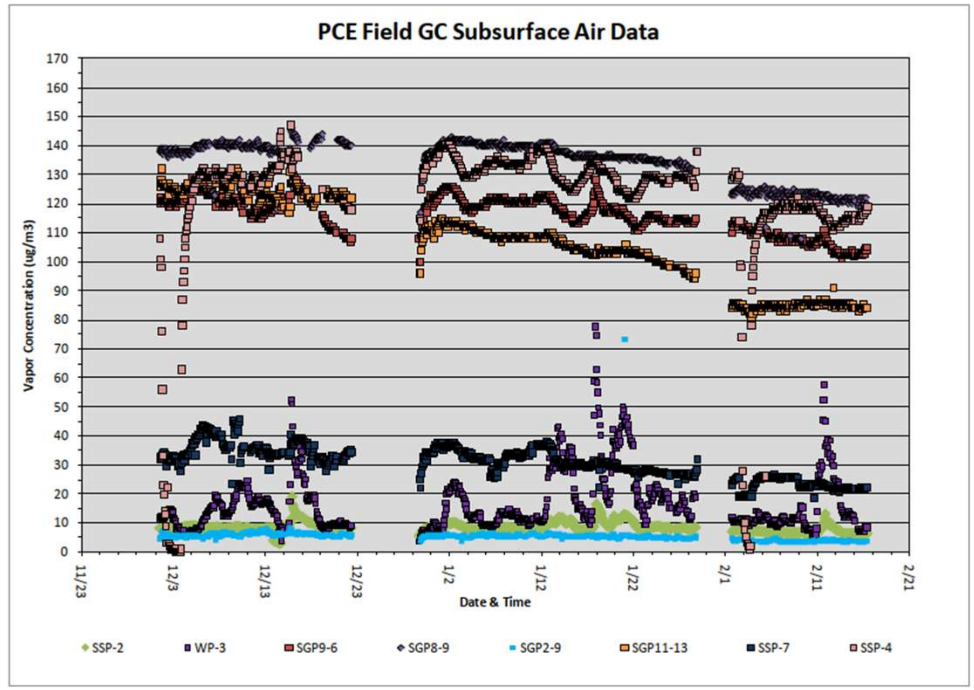


Figure 5-64. Online GC subsurface PCE soil gas data—Phase 2.

Key point: Over these approximately 3 month observation periods most soil gas points display limited, gradual variability. Note that these plots are on a numeric scale.

Tentative Conclusions Across Sites: Soil Gas Sampling Frequency

- Spatial variability more dramatic than temporal variability
- Temporal variability decreases with increasing depth.
- Temporal variability is frequently seasonal not short term, so seasonal sampling strategies make sense.
- PCE/TCE ratios are not necessarily consistent over time
- More work is required to quantitatively establish the effectiveness of various soil gas sampling strategies

Spare slides for Q&A and Background

Figure from Yao 2015

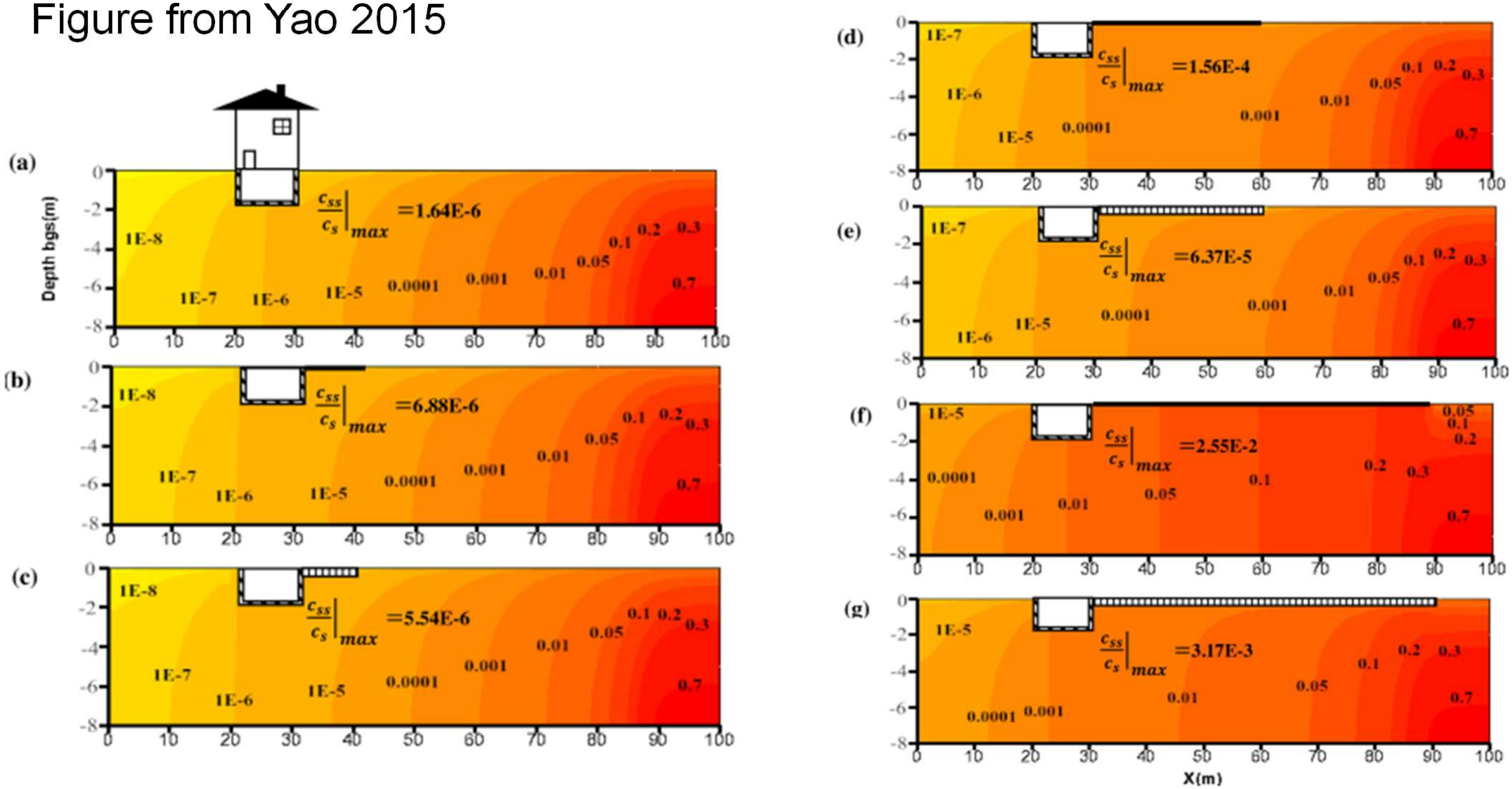


Fig. 2. Simulated soil gas concentration profiles for cases with (a) no surface pavements; (b) impermeable pavement of 10 meter width; (c) permeable pavement of 10 meter width and soil gas effective diffusivity as 1×10^{-10} m^2/s; (d) impermeable pavement of 30 m width; (e) permeable pavement of 30 m width and soil gas effective diffusivity as 1×10^{-10} m^2/s; (f) impermeable pavement of 60 meter width; (g) permeable pavement of 60 m width and soil gas effective diffusivity as 1×10^{-10} m^2/s The thicknes of permeable pavements are 0.2 m.

Figure from Yao 2015

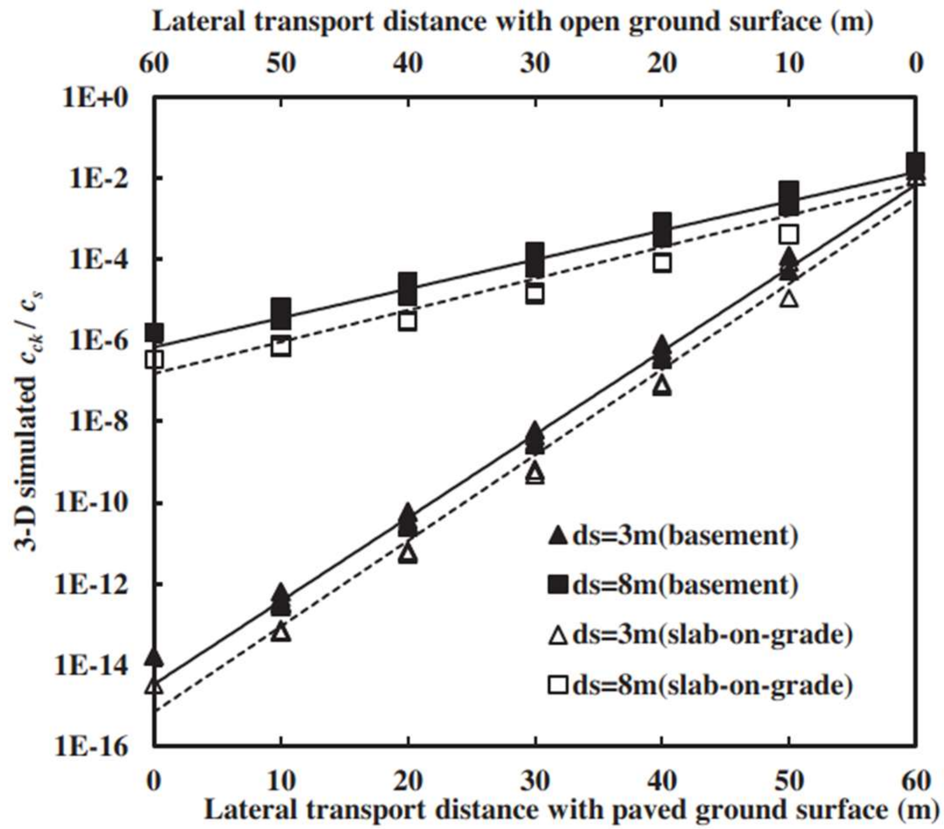


Fig. 5. The influence of surface cover on maximum contaminant subslab soil gas concentration for cases with $d_h = 60$ m (The solid and dashed lines are the fitting curves for cases with basements and slab-on-grade, respectively; points and circles mean different locations of pavements are employed).

This figure shows how attenuation factor is affected much more by surface cover for deep source vs. shallow source. The separation distance is held constant and the amount of paving increases left to right.

Figure from Yao 2015 – Effective Diffusion Distance

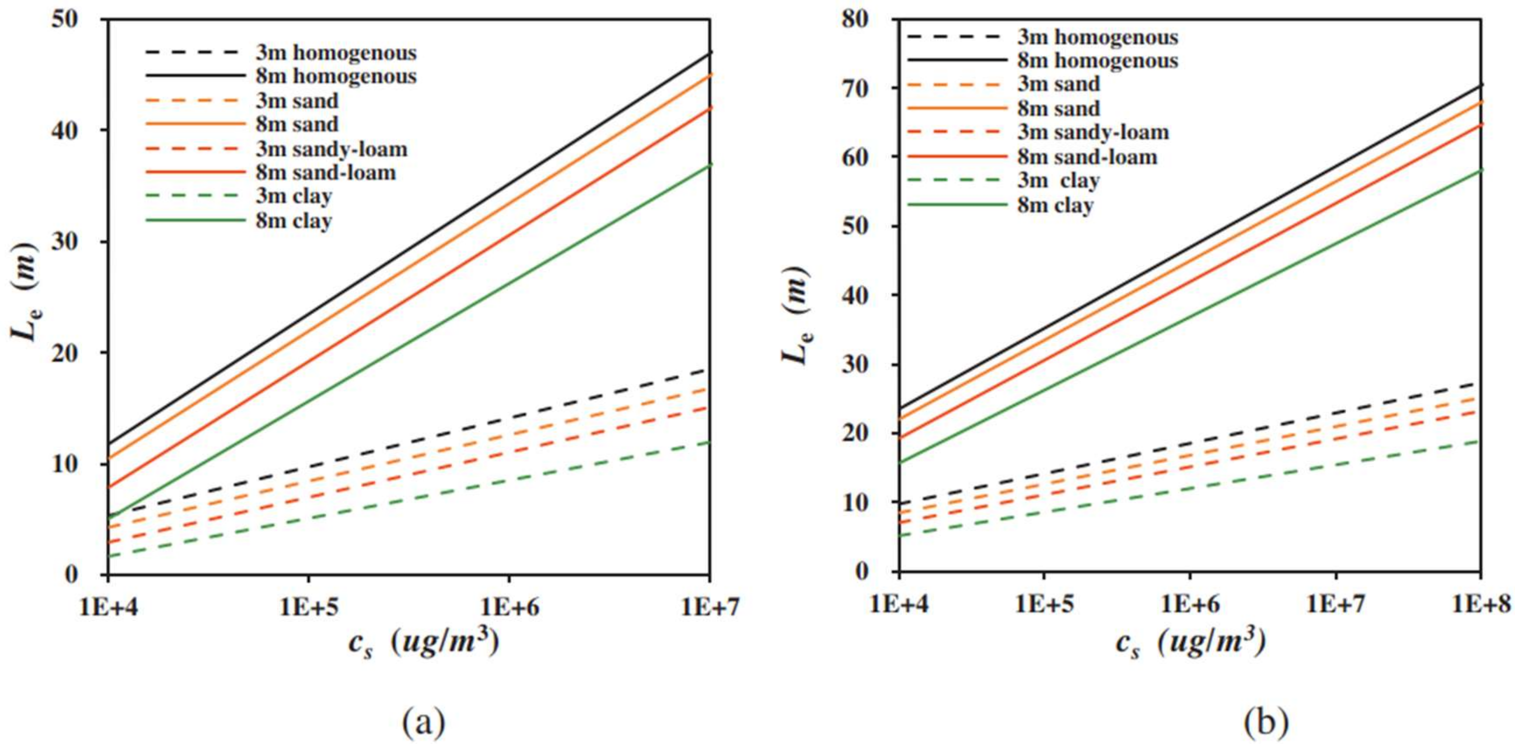


Fig. 8. The effective lateral diffusion distance (L_e) calculated for $\frac{C_{ss}}{C_s}|_{max}$ to reach (a) 500 ug/m^3 with AAMLPH as a function of source vapor concentration. ("3m sand" means the source depth is 3 m and the soil type is sand; the calculations are made for basement scenarios (d_f = 2 m)).

(a) C_{ss} = 500 μg/m^3 (b) C_{ss} = 50 μg/m^3

Indianapolis Near Structure Front Yard – South Side, Exterior Soil Gas

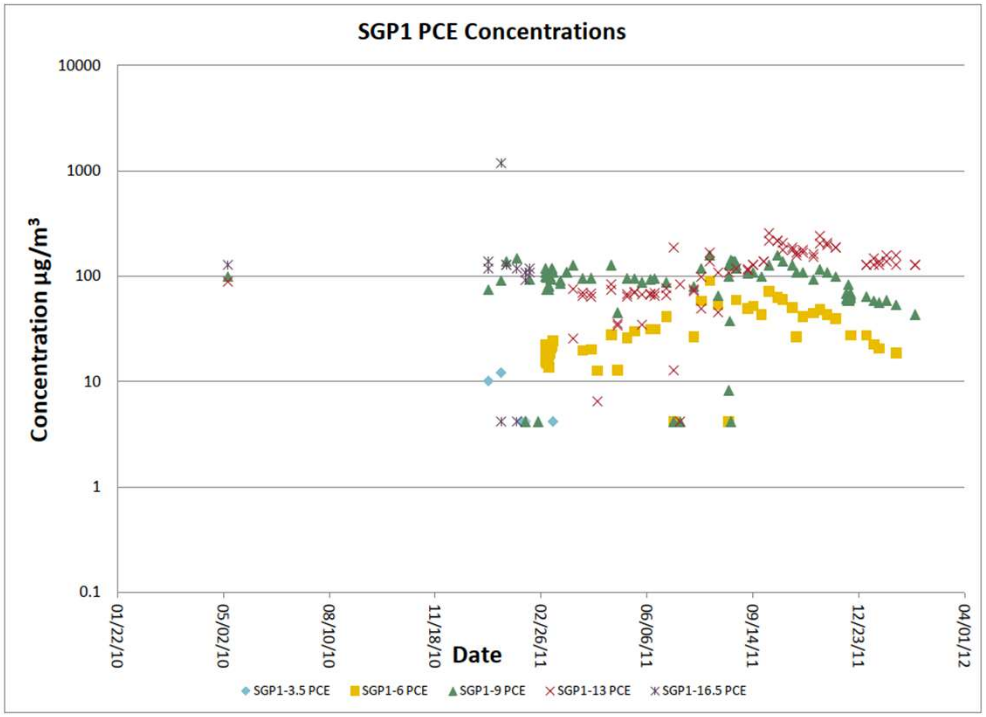


Figure 5-12. PCE concentrations at each of the SGP1 ports vs. time.

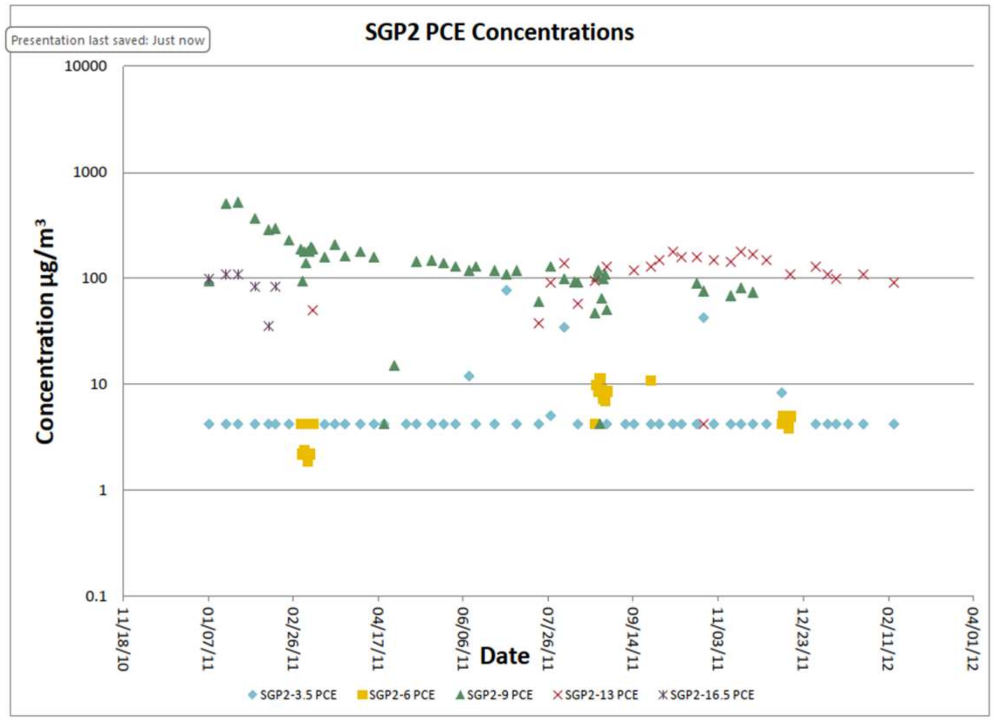


Figure 5-14. PCE concentrations at each of the SGP2 ports vs. time.

Points separated by about 6' horizontally.

Indianapolis Near Structure Side Yard – East Side, Exterior Soil Gas

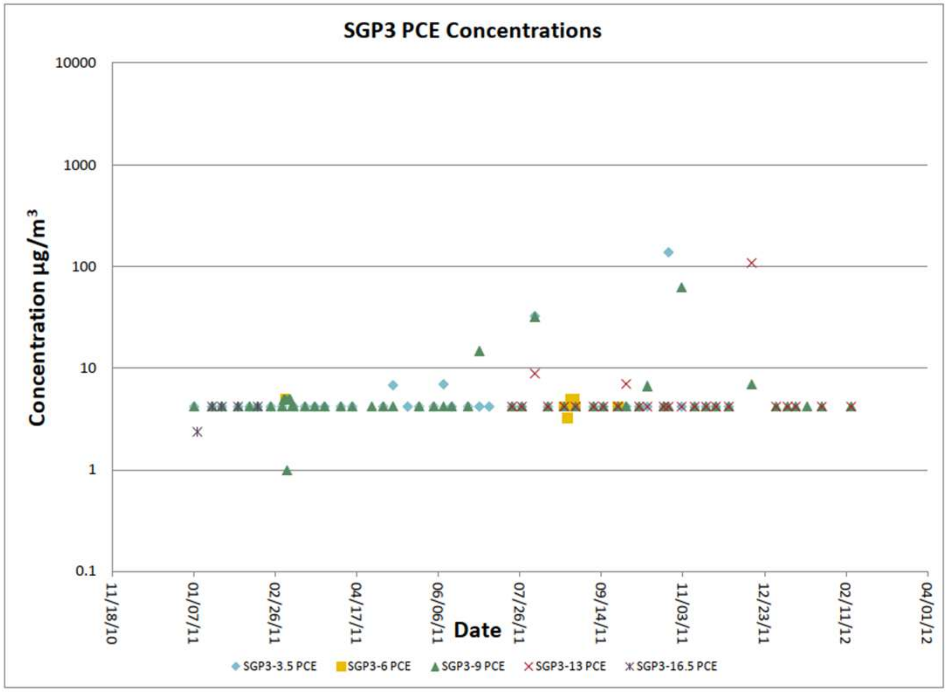


Figure 5-16. PCE concentrations at each of the SGP3 ports vs. time.

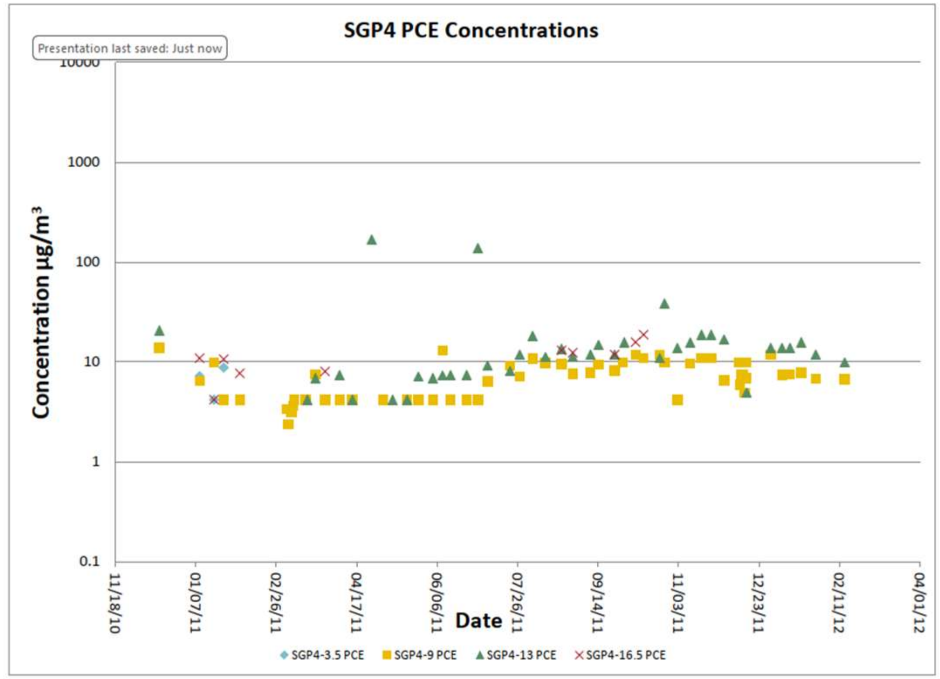
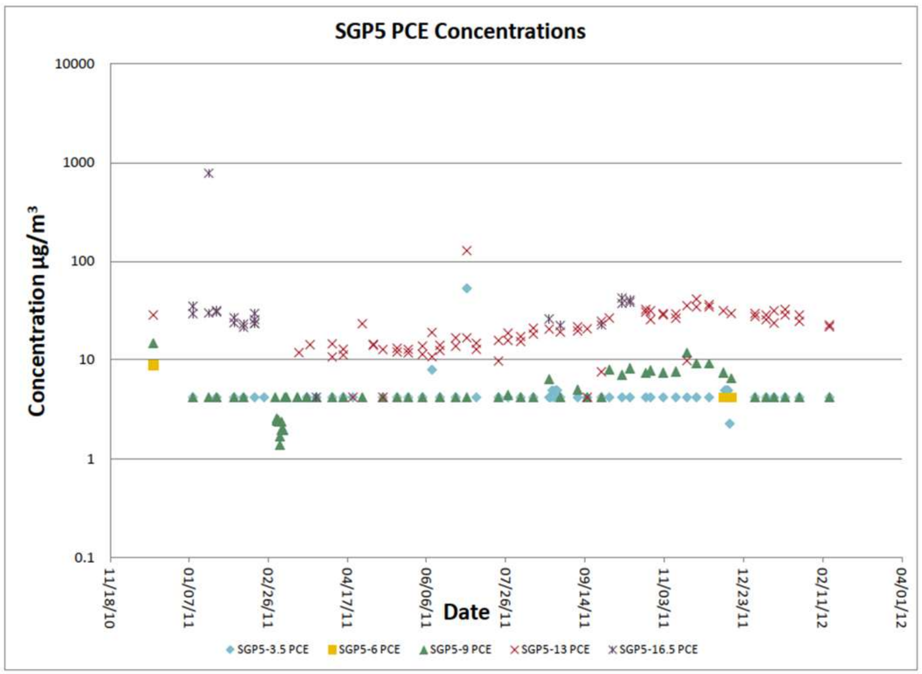


Figure 5-18. PCE concentrations at each of the SGP4 ports vs. time.

Points separated by about 15' horizontally

Indianapolis Near Structure, Back Yard (North)



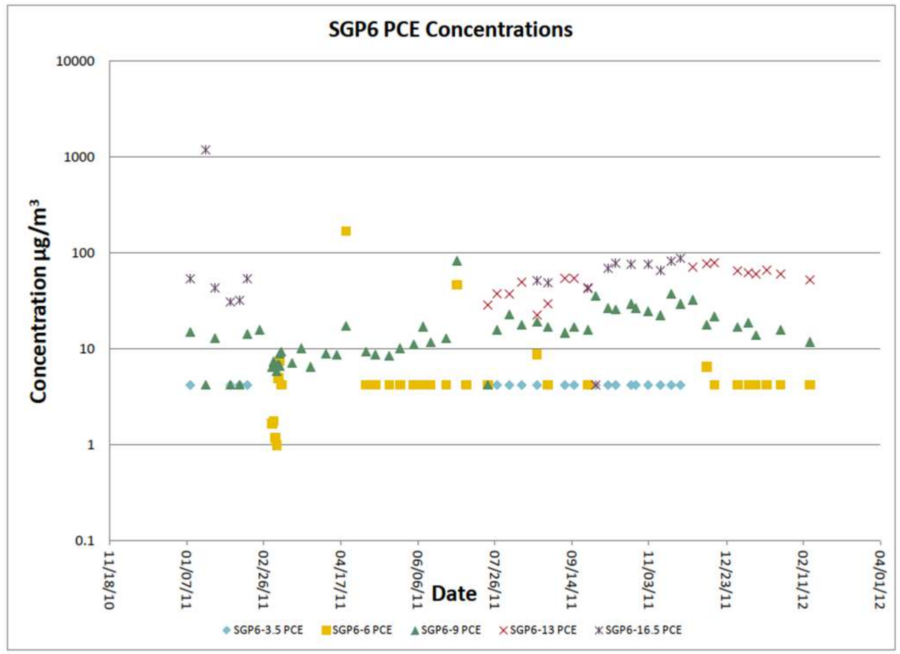


Figure 5-22. PCE concentrations at each of the SGP6 ports vs. time.

Points separated by about 10 ft horizontally

Indianapolis Near Structure Side Yard (West)

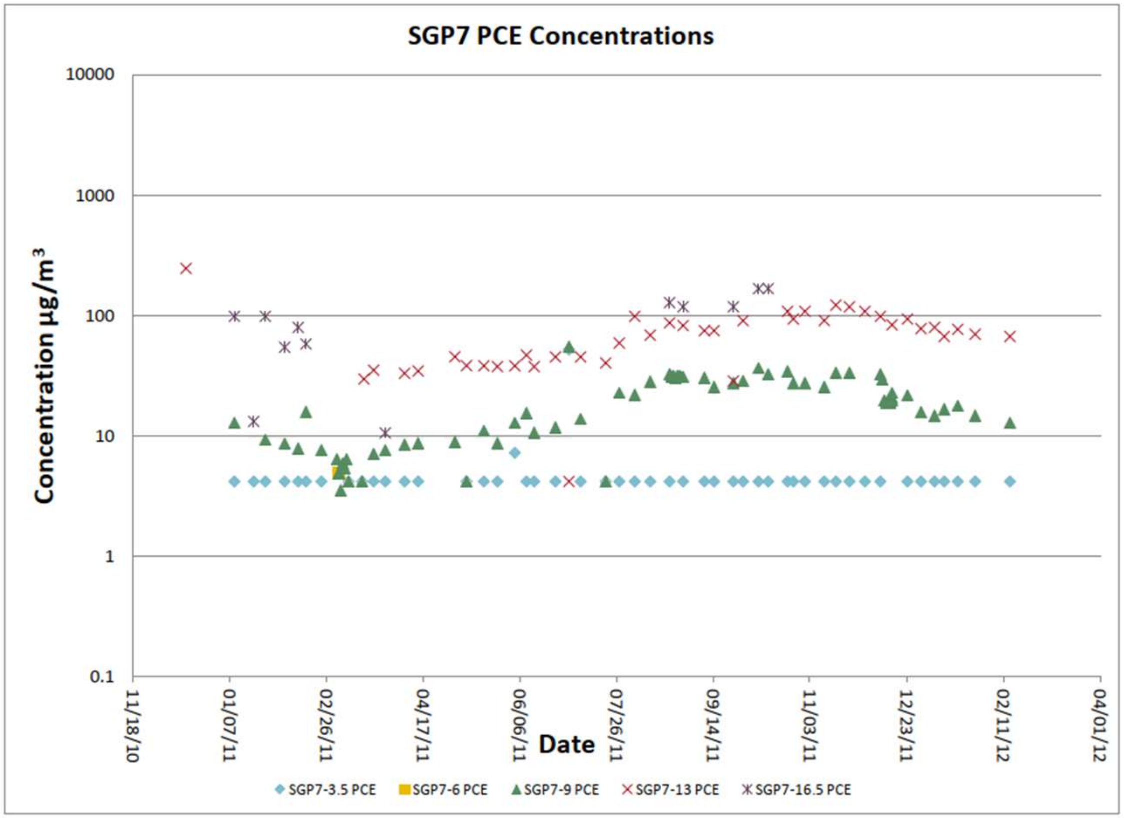
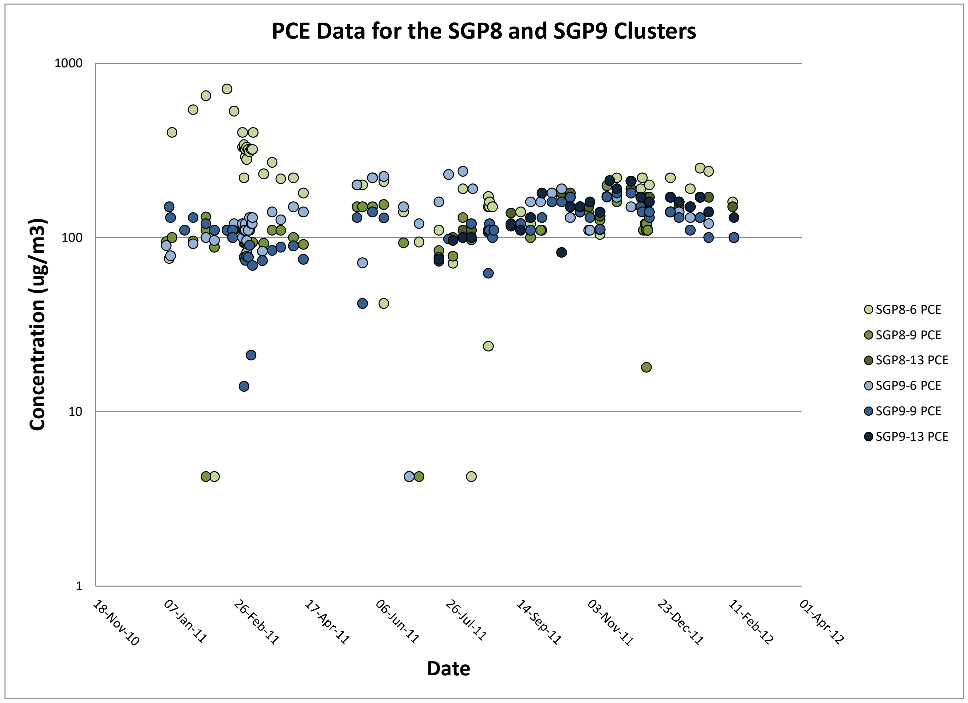


Figure 5-24. PCE concentrations at each of the SGP7 **ports vs. time.**

Indianapolis Beneath Structure – Heated East Side



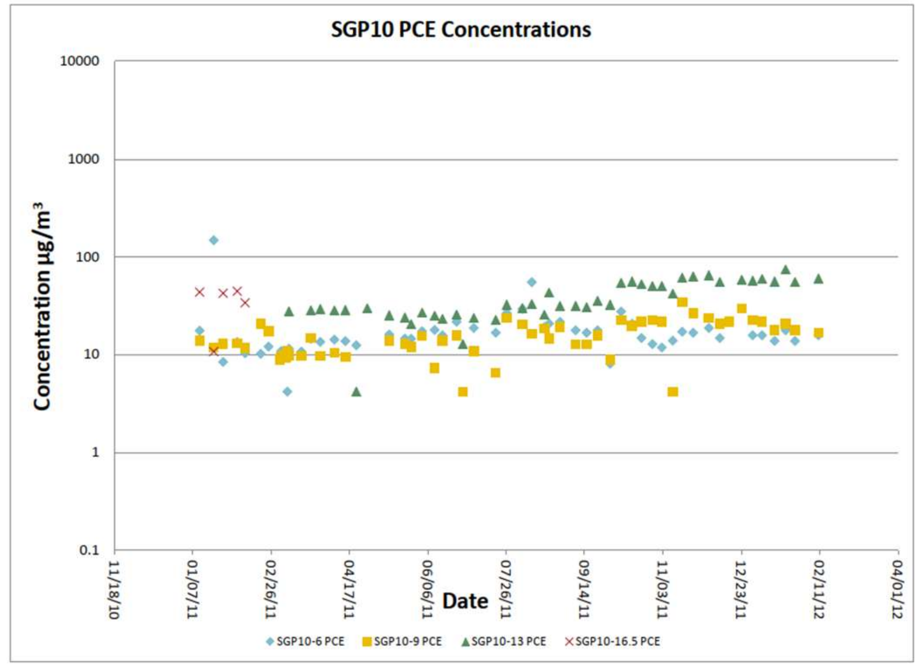


Figure 5-28. PCE concentrations at each of the SGP10 ports vs. time.

Indianapolis Beneath Structure Unheated West Side

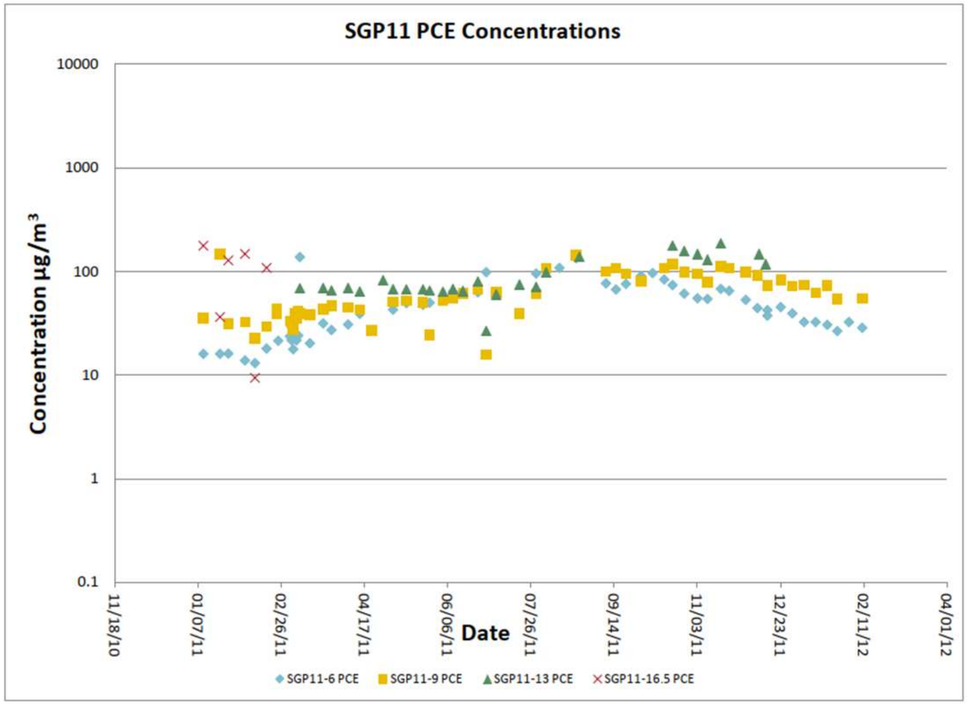


Figure 5-30. PCE concentrations at each of the SGP11 ports vs. time.

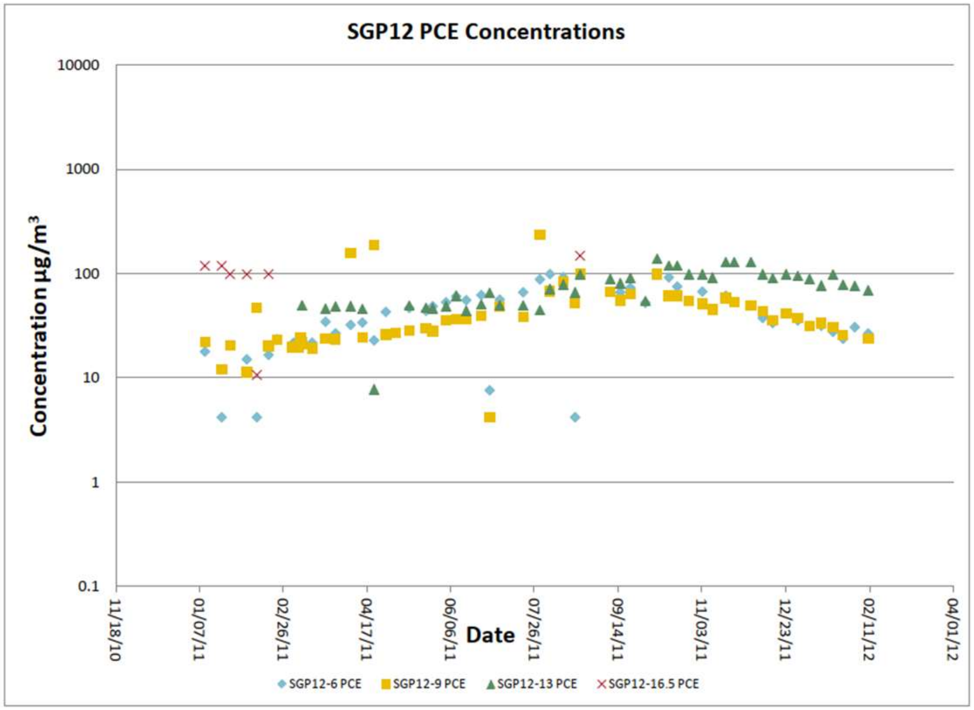


Figure 5-32. PCE concentrations at each of the SGP12 ports vs. time.

Indianapolis PCE Descriptive Statistics Subslab Soil Gas

Location1	Heating	Number Sample	Mean	SD	CV	Percentile.50	Percentile.90	Percentile.95
SSP-1	Off	35	115.3	47.5	0.4	110.0	160.0	191.0
SSP-1	On	67	292.5	237.1	0.8	220.0	388.0	793.7
SSP-2	Off	2	12.2	2.5	0.2	12.2	13.6	13.8
SSP-2	On	3	5.3	1.9	0.4	4.3	6.9	7.2
SSP-3	Off	9	21.1	21.4	1.0	11.0	42.0	57.9
SSP-4	Off	15	187.5	91.4	0.5	200.0	288.0	323.0
SSP-4	On	45	153.1	32.9	0.2	150.0	190.0	214.0
SSP-5	Off	67	43.9	29.7	0.7	32.8	90.1	98.2
SSP-6	Off	70	37.1	27.6	0.7	27.9	69.8	75.5
SSP-7	Off	46	16.8	11.9	0.7	12.1	33.0	38.1

Spatial variability More Significant than Temporal Variability

Indianapolis Exterior Soil Gas at 9' Descriptive Statistics

Spatial variability More Significant than Temporal Variability

Location1	Number Sample	Mean	SD	CV	Percentile. 50	Percentile .90	Percentile. 95
SGP1-9	86	90.6	38.6	0.4	95.5	137.5	140.0
SGP2-9	48	148.3	106.2	0.7	125.0	248.2	345.5
SGP3-9	54	6.2	8.9	1.4	4.3	5.0	9.8
SGP4-9	56	7.1	2.9	0.4	7.1	11.0	12.0
SGP5-9	54	5.0	2.0	0.4	4.3	7.9	8.7
SGP6-9	55	16.6	12.5	0.8	15.0	28.8	33.9
SGP7-9	68	19.3	11.2	0.6	18.5	33.0	34.0

Indianapolis Natural Conditions – Subslab and Wall Ports

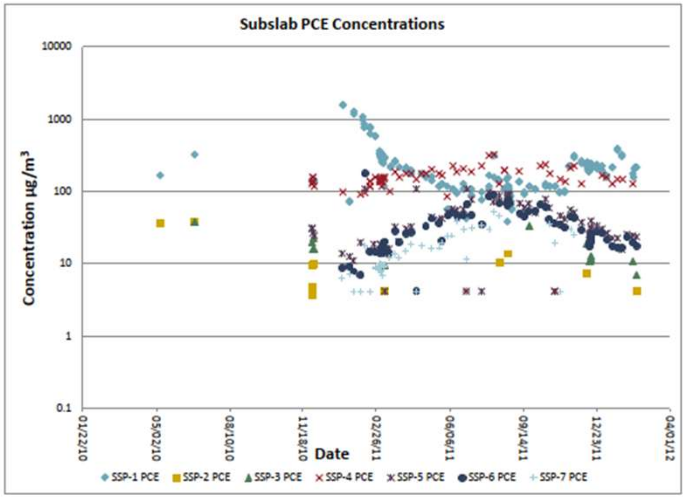


Figure 5-7. Plot of subslab PCE concentrations vs. time.

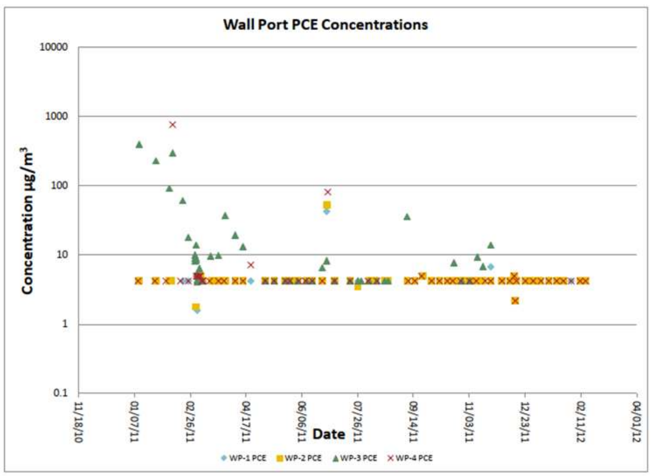


Figure 5-10. Plot of wall port PCE concentrations vs. time.

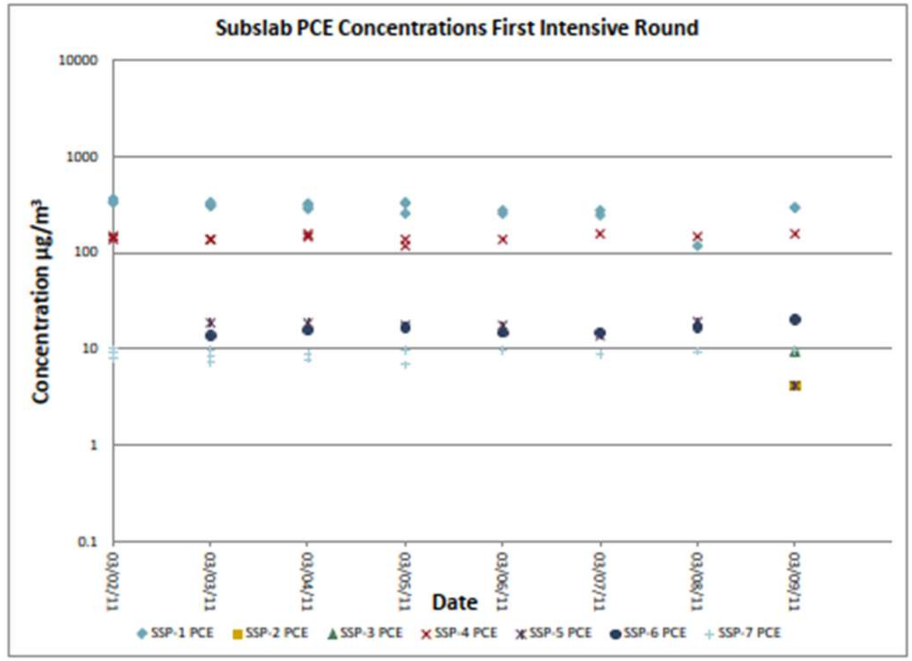
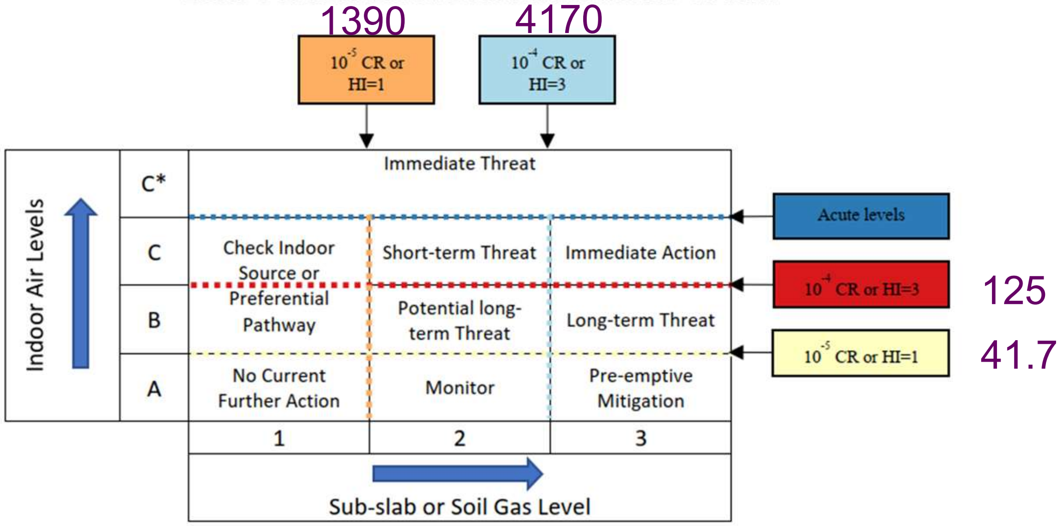


Figure 5-8. Plot of subslab PCE concentrations vs. time, first intensive sampling period.

Region V Matrix – Applied to PCE

Table 8-1. Risk-Based Decision Matrix for VI Sites



Figures from US EPA Region 5, Superfund and Emergency Management Division, Vapor Intrusion Handbook, March 2020

PCE Concentrations from VISL Calculator as of 10/3/24 in μg/m^3

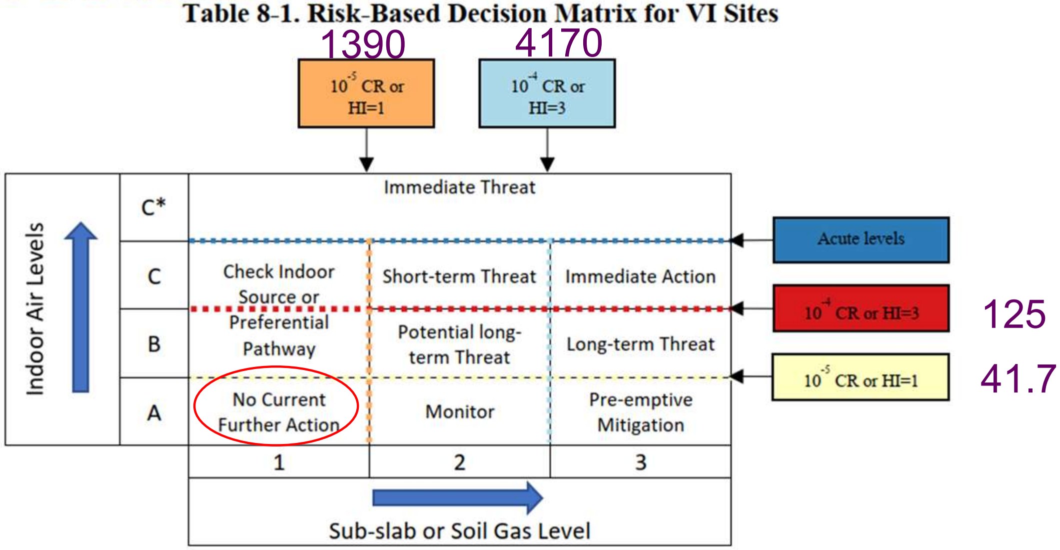
Notes:

CR Carcinogenic risk
HI Hazard Index

Table 8-2. Decisions Associated with Vapor Intrusion Categories

	Air Results		
Category	Indoor	Sub-slab	Decision
C1	>Acute or RML	<RSL	Likely indoor source; warn homeowner of hazard
C2	>Acute or RML	>RSL, <RML	Concern about acute exposure; plan for remediation within weeks
C3	>Acute or RML	>Acute or RML	Concern about acute exposure; plan for remediation ASAP; consider APUs
C3*	>1% LEL	>10% LEL	Immediate action; consider relocation depending on conditions
B1	>RSL, <RML	<RSL	Check potential for indoor source; notify homeowner of potential concern
B2	>RSL, <RML	>RSL, <RML	Concern about long term-exposure; develop strategy for inclusion in site
B3	>RSL, <RML	>Acute or RML	Concern about long-term exposure; more rapid remediation plan
A1	<RSL	<RSL	No further action at this time, pending new data
A2	<RSL	>RSL, <RML	Continue monitoring subsurface conditions
A3	<RSL	>Acute or RML	Consider pre-emptive mitigation to prevent future indoor air impact

How Would Indianapolis Basement Be Interpreted with the Region V Matrix – Applied to PCE – If Occupied



Figures from US EPA Region 5, Superfund and Emergency Management Division, Vapor Intrusion Handbook, March 2020

PCE Concentrations from VISL Calculator as of 10/3/24 in µg/m^3

Key Points:
1) Indoor Air Mean <10^{-5}, 95th Percentile <HQ = 1 so Row A
2) Subslab almost always <1390 µg/m^3 so column 1. Exterior soil gas almost always <1390 µg/m^3
3) Lines of evidence are in agreement.
4) A1 = “No further Action at this time, pending new data”
Note that this structure would be recommended for radon remediation under EPA guidelines.

How Would Indianapolis Basement Be Interpreted with the New York State Matrix – Applied to PCE – If Occupied

Soil Vapor/Indoor Air Matrix B

May 2017

Analytes Assigned:
Tetrachloroethene (PCE), 1,1,1-Trichloroethane (1,1,1-TCA), Methylene Chloride

	INDOOR AIR CONCENTRATION of COMPOUND (mcg/m³)		
SUB-SLAB VAPOR CONCENTRATION of COMPOUND (mcg/m³)	< 3	3 to < 10	10 and above
< 100	1. No further action	2. No Further Action	3. IDENTIFY SOURCE(S) and RESAMPLE or MITIGATE
100 to < 1,000	4. No further action	5. MONITOR	6. MITIGATE
1,000 and above	7. MITIGATE	8. MITIGATE	9. MITIGATE

mcg/m³ = micrograms per cubic meter

- No further action or monitor would be likely classification
- Sampling variability could have resulted in a mitigate decision if maximum used

Conduit Pathway Attenuation – SDM

Groundwater to sewer attenuation factors:

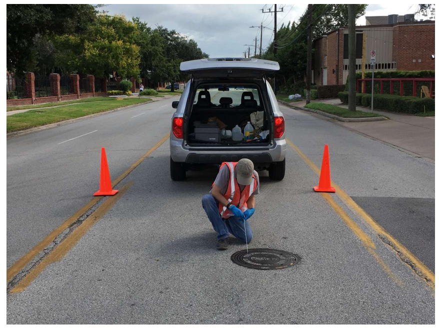
ASU VI Research House, residential house, Layton, UT

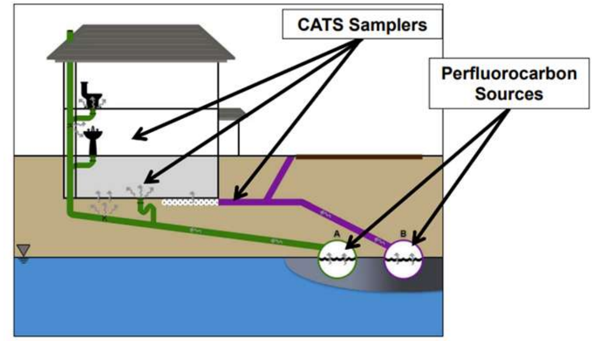
Sewer/Building Combination Tested:	*Land Drain Manhole to House*	*Sanitary Sewer Manhole to House*
Attenuation	20x – 40x	60x – 80x

Reference: Beckley and McHugh, 2020, A conceptual model for vapor intrusion from groundwater through sewer lines, Science of the Total Environment, 698, 134283

Conduit Pathway Attenuation

Groundwater to sewer attenuation factors





Site category	No. plumes	No. AFs	Attenuation factor	Attenuation
			Median (10th – 90th percentiles) [Note 1]	Median (10th – 90th percentiles) [Note 2]
A: direct interaction (sewer at or below water table)	6	59	1.3E−02 (6.7E−05–7.3E−02)	80× (15,000×–14×)
B: indirect interaction (sewer above water table)	28	137	1.3E−04 (1.9E−06–5.5E−03)	7900× (520,000×–180×)

Notes: 1) Attenuation factor calculated as sewer vapor concentration divided by equilibrium groundwater concentration. 2) Attenuation is the inverse of attenuation factor.

Reference: Beckley and McHugh, 2020, A conceptual model for vapor intrusion from groundwater through sewer lines, Science of the Total Environment, 698, 134283

Indianapolis Report Conclusions

13.1.4 The Use of External Soil Gas Samples as a Surrogate Sampling Location

- High concentrations of VOCs and radon were seen in tight loams directly under building (subslab ports and 6-ft soil gas ports) but not in external soil gas above the level of the basement floor (3.5 ft bls).
- External soil gas samples collected at 6 ft bls, the depth of the basement floor, had substantial VOC concentration variability and would have underpredicted subslab concentrations.
- In deep soil gas (13 and 16.5 ft), there was close agreement between the mean chloroform and radon concentrations at points underneath the building and outside of the building. In deep soil gas, PCE concentrations appeared lower on average and more variable for the points outside of the building than for the points beneath the building.

- PCE is apparently widely spatially distributed in site groundwater at concentrations well below the current 5 µg/L MCL.[2] The calculated volatilization from these shallow groundwater concentrations matches observed deep soil gas concentrations. Only a moderate degree of attenuation occurs in those deep soil concentrations as they are drawn toward the basement of the structure. Substantial attenuation occurs in the upper 6 ft of the site external soil gas, which is composed of finer grained materials than the soils. Substantial attenuation also occurs across the building envelope between subslab and indoor air.