U.S. EPA “State of VI Science” Workshop
Evaluating Alternative Vapor Intrusion Strategies Through Simulations Using Data-Rich Case Studies

Summary of Previous Workshop: Lessons Learned About Vapor Intrusion Site Assessment, Mitigation and Remediation

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PRAXIS ENVIRONMENTAL TECH. INC

Disclaimer

- This presentation represents the personal opinion of the authors and does not necessarily represent the policy of the organizations with which they are associated.
- New science-based ideas are presented here to stimulate discussion and to move the field forward.

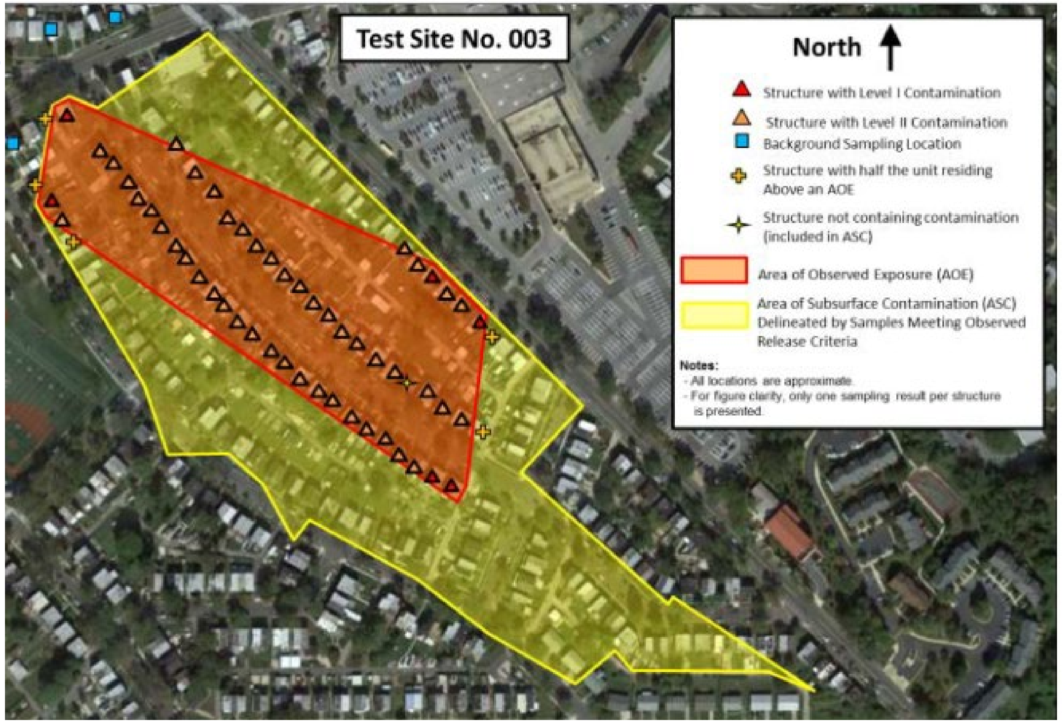
Indoor and Soil Gas Concentration Distributions: The Reality and What That Means for Site Assessment Strategies

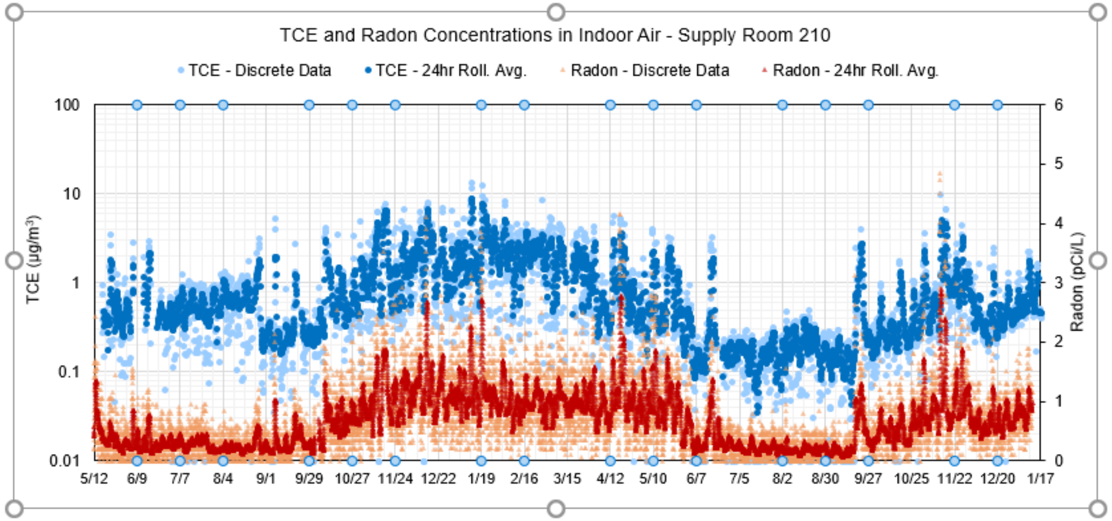
Key Concepts to Be Presented

- Definitions related to acceptable concentrations – reviewing EPA concepts and state implementation
- How effective your sampling will be is dependent on the shape and range of the real, underlying distribution.
- Because of temporal variability most typical current sampling strategies have a high risk of false negatives in indoor air.
- Subslab and deep soil gas are somewhat less variable
- Therefore, concurrence of multiple lines of evidence remains an important concept
- Indicator and tracer (I&T) based sampling; as well as longer duration samples can improve performance of sampling strategies.

VI Site Assessment Challenges

- Indoor concentrations vary strongly with building envelope specific characteristics
- Tens of thousands of sites to assess
- A large number of buildings and zones within individual buildings often need to be assessed (10’s to 1,000’s)
- Indoor concentrations change widely over time (1 to 2 orders of magnitude)
- Site decision making typically requires a multiple lines of evidence (sampling multiple media)





2019 2019 2020 2020 2021

Aerial image a DC dry cleaner site, reprinted from “Technical Support Document for U.S. EPA’s Final Rule: Addition of a Subsurface Intrusion Component to the Hazard Ranking System” ; Appendix D.

Data graph from a VA industrial building reprinted Lutes et. all AEHS presentation 2021 “Eighteen Months of High Resolution Indoor and Subslab Temporal Observations from an Industrial Building”

Goals/Definitions from EPA 2015 VI Guide

- Guide requires evaluation of chronic effects for both cancer and noncancer and short duration non-cancer effects where appropriate.
- "*EPA recommends basing the decision about whether to undertake response action for vapor intrusion on a consideration of a reasonable maximum exposure*"
- **reasonable maximum exposure (RME) =**

A semi-quantitative term, referring to the lower portion of the high end of the exposure distribution; conceptually, above the 90th percentile exposure but less than the 98th percentile exposure.

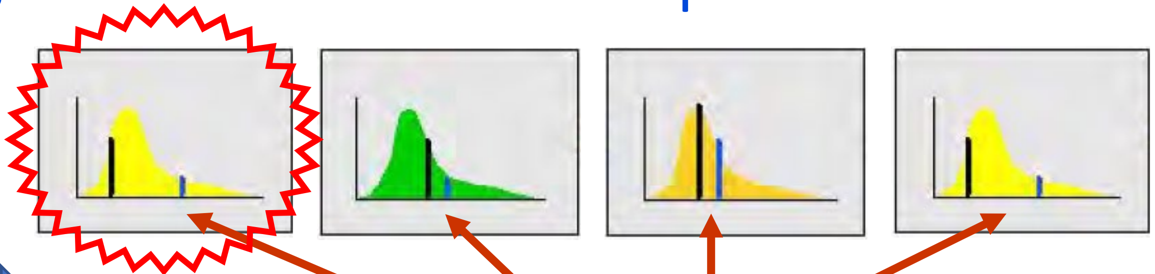
- The **RME** as defined by USEPA (1989) Risk Assessment Guidance for Superfund (RAGS) is a combination of central tendency and high-end values for concentration, exposure time, frequency and duration.

EPA (2015) Manages the Risk of False Negatives/Positives with These Key Concepts

1. Seeking "concordance" or "agreement" from Multiple Lines of Evidence (MLE)
2. Requiring decisions to be made based on "reasonable maximum exposure (RME)... "above the 90th percentile exposure but less than the 98th percentile exposure."
3. Calling for the use of differential pressure measurements to determine if conditions are likely to provide RME
4. Suggesting the use of long-term time integrated indoor air samples
5. "Background" vapor sources are managed by limiting analysis target list, building survey; subslab to indoor air comparisons = "multiple paired samples"

The first two concepts are much less prevalent/explicit in state guidance documents, which suggests that states may be managing the risk of false negatives with other strategies, such as decision making with a strong emphasis on subslab soil gas data. States that do use MLE, as EPA suggests, do so using decision matrices of SS/IA.

Estimating the Inhalation Exposure Concentration (EC)



USEPA (2009) RAGS Part F, Supplemental Guidance for Inhalation Risk Assessment

$$EC = (CA \times ET \times EF \times ED)/AT$$

EC ($\mu g/m^3$) = exposure concentration;
CA ($\mu g/m^3$) = contaminant concentration in air;
ET (hours/day) = exposure time;
EF (days/year) = exposure frequency;
ED (years) = exposure duration; and
AT (ED in years x 365 days/year x 24 hours/day) = averaging time

$$\text{Cancer Risk} = EC \times \text{Toxicity Value}$$

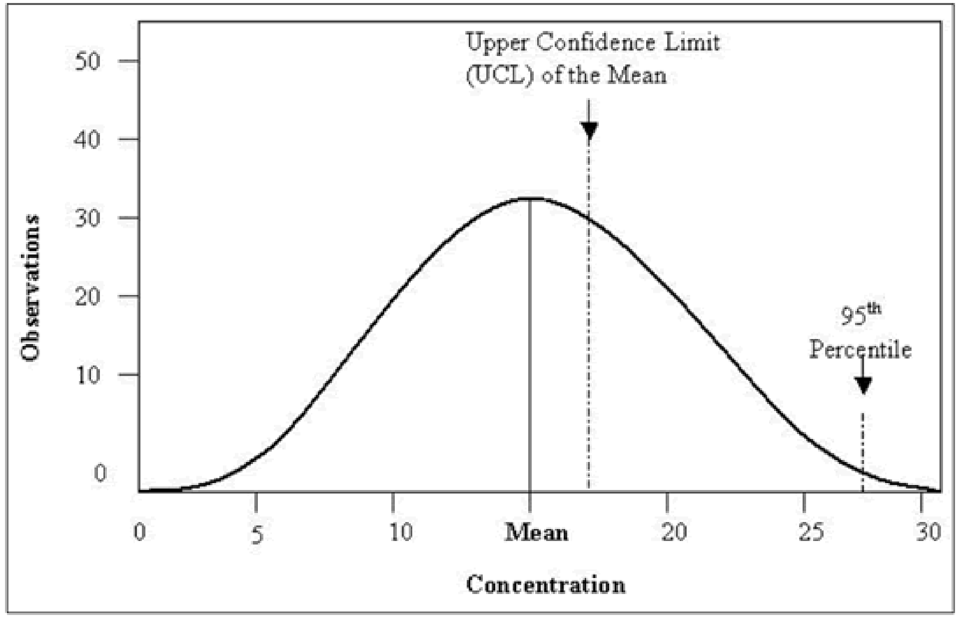
$$\text{Noncancer Hazard} = \frac{EC}{\text{Toxicity Value}}$$

Risk Management (USEPA, 1991)

- Cancer: 1E-06 to 1E-04
- Non-cancer hazard: 1

- RME needs to account for:
  - Uncertainty in chemical concentration (CA); and
  - Variability in exposure parameters (ET, EF, and ED)
- Chemical concentration:
  - Use estimate of arithmetic average (e.g., 95UCL)
  - Account for time and space (exposure area)
  - 95UCL can be > max with limited data or extreme variability

USEPA (1992) Supplemental Guidance to RAGS: Calculating the Concentration Term



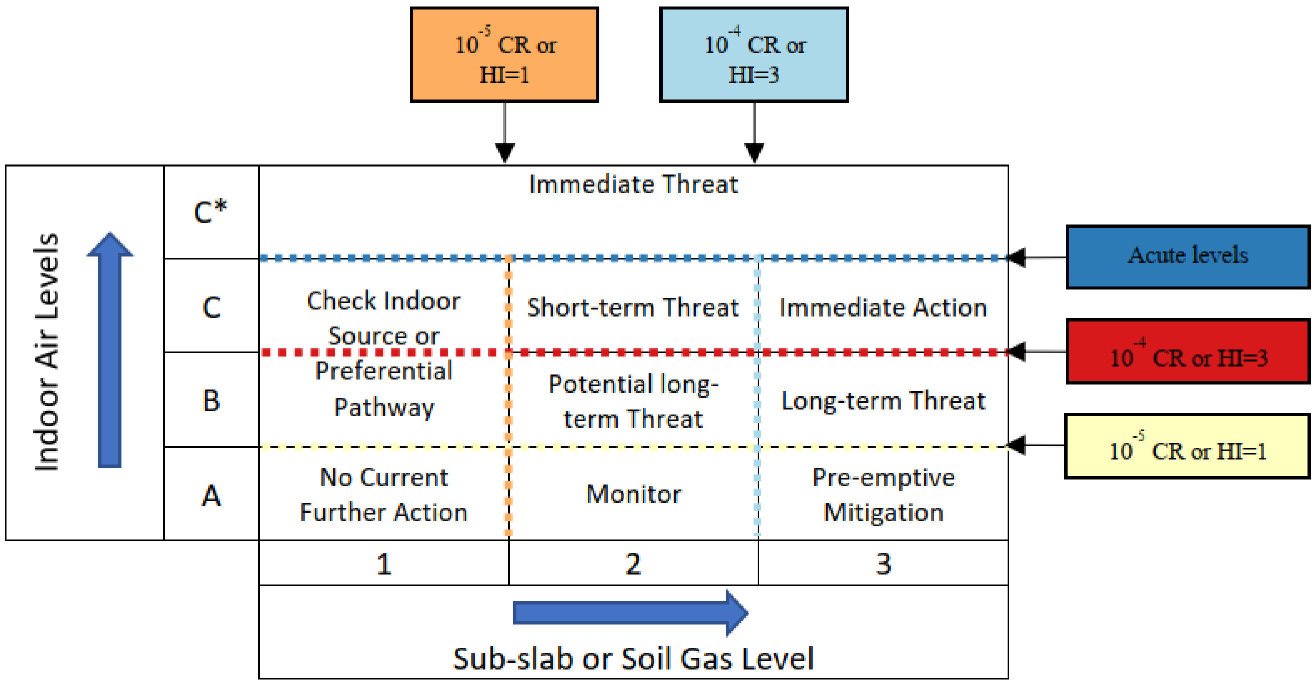
Some States Emphasize Soil Gas in Decisions Over Indoor Air

- **MI:** *"because of the variation and potential for indoor air samples to be influenced by ambient air sources, decisions regarding potential risk and completion of response actions must be weighted toward the sub-slab soil gas sampling results".*
- **WI:** *"Response actions for vapor intrusion are required primarily based on sub-slab vapor concentrations, but the timing for vapor mitigation can take into account other factors,." "If the results from sub-slab vapor samples are at or over vapor risk screening levels, then interruption or mitigation of the vapor exposure pathway is required per Wis. Admin § NR 726.05."*
- **TN**: *"collect soil gas data and use it as the primary line of evidence to assess the VI pathway ". "It is unrealistic to expect a building slab to remain static over time, and it is impractical to control or monitor the integrity of a slab for decades, as is sometimes proposed. Therefore, current favorable indoor air monitoring results cannot be extrapolated into the future with any certainty"*
- **IL:** *"Indoor air samples are highly susceptible to bias from occupant sources…. Sample collection is also invasive, requiring site evaluators to obtain access to indoor space. For these reasons, TACO does not contain a table of indoor air remediation objectives and the use of indoor air data to demonstrate compliance is limited to a Tier 3 evaluation"*

Many States and Regions Use a Soil Gas and Indoor Air Matrix

- Many state use soil gas vs indoor air matrix-type approaches to evaluate MLE
- A conservative subslab concentration requires mitigation regardless of any VOC indoor air data.
- EPA regions 2, 4, 5 and 7 also use matrix approaches.

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



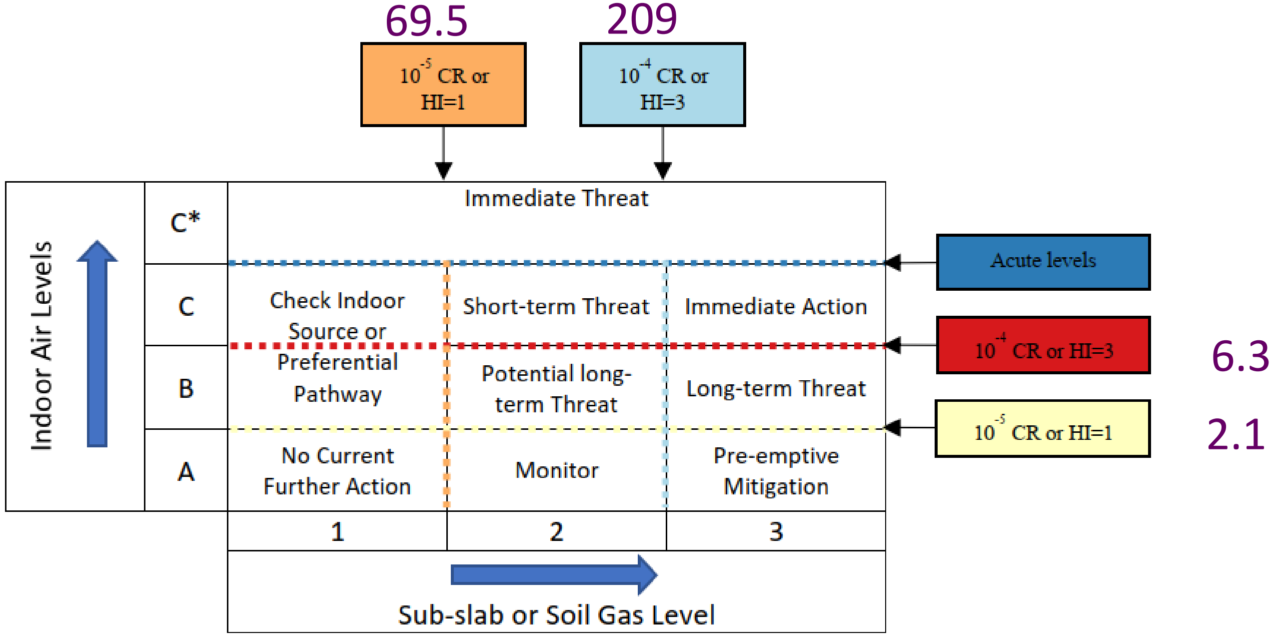
Notes:

CR Carcinogenic risk
HI Hazard Index

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

Region V Matrix – Applied to TCE

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



Notes:

CR Carcinogenic risk
HI Hazard Index

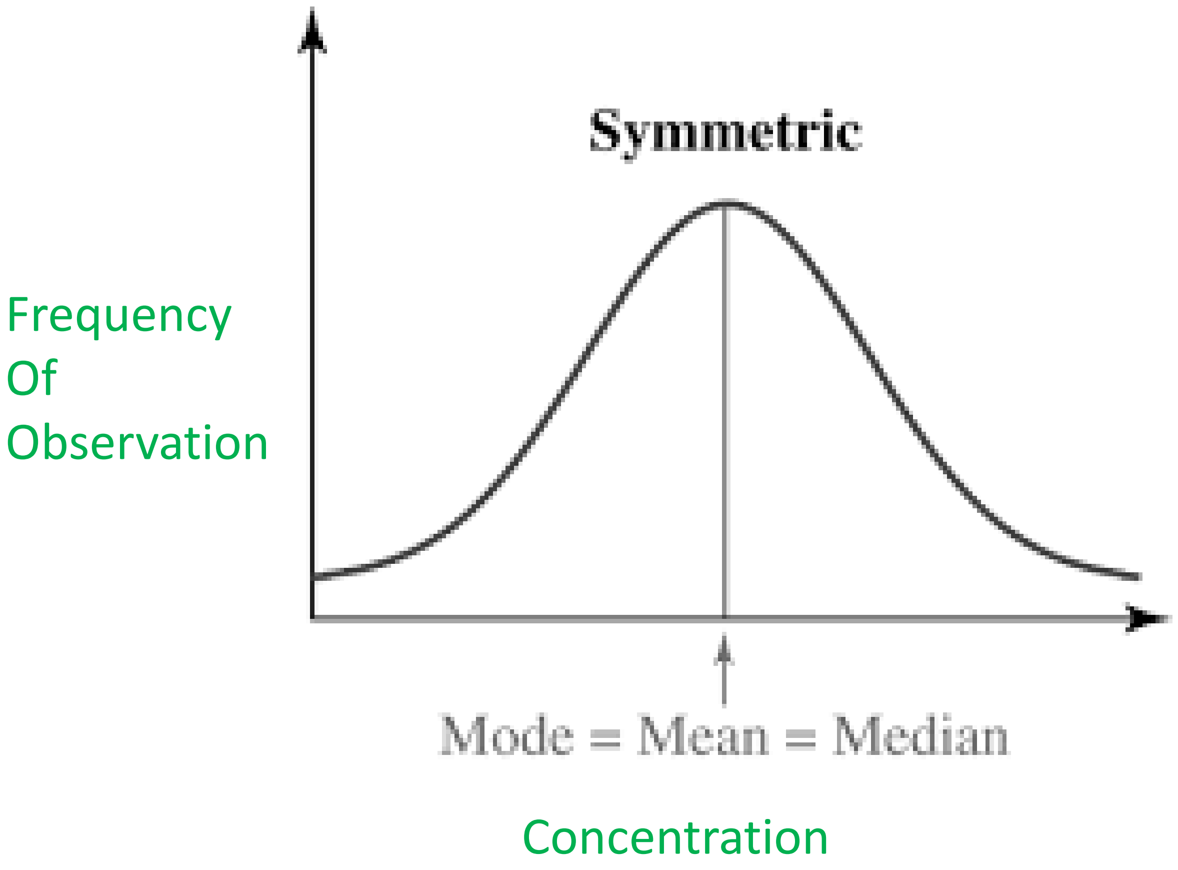
Figures from US EPA Region 5, Superfund and Emergency Management Division, Vapor Intrusion Handbook, March 2020

TCE Concentrations from VISL Calculator as of 10/3/24 for Residential in µg/m^3

Table 8-2. Decisions Associated with Vapor Intrusion Categories

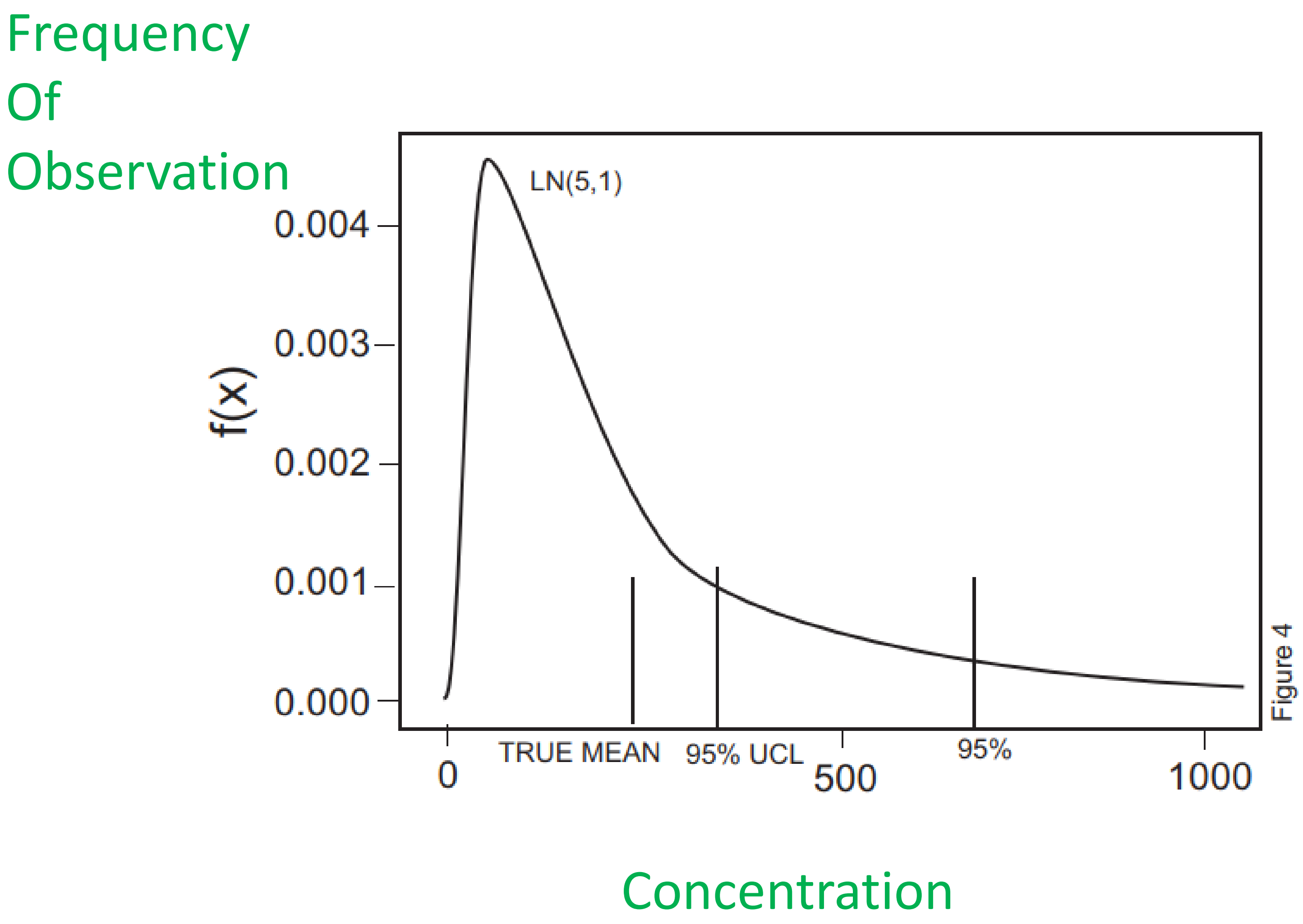
	Air Results		
Category	Indoor	Sub-slab	Decision
C1	>Acute or RML	<RSL	Likely indoor source; warn homeowner of hazard
C2	>Acute or RML	>RSL, <RML	Concern about acute exposure; plan for remediation within weeks
C3	>Acute or RML	>Acute or RML	Concern about acute exposure; plan for remediation ASAP; consider 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

If The Distribution is Symmetrical (or Normal) It is Easier to See the Mean With a Few Samples



With a symmetrical distribution you have a 50% chance to be above the mean with at least one sample and a 75% chance to be above the mean with at least one of two samples.   The median is the most common sample (highest frequency).

But: It is Harder to Observe the True Mean With a Small Number of Samples When the Distribution is Skewed - as it Often Is in Environmental Samples



Skewness is a measure of the asymmetry of the distribution.

Figure Reprinted from EPA/600/R-97/006

The Performance of Purely Random Sampling Can Be Determined Mathematically if the Metric is the 90th Percentile of the Distribution (a noncancer criteria assumption)

- You have a 10% chance with one random sample of observing the >90th percentile of any distribution.
- You have a 19% chance with two random samples of observing the >90th percentile of any distribution.
- You have a 34% chance with **four** random samples of observing the >90th percentile
- You have a **90%** chance with **22** random samples of observing the 90th percentile at least once

Image from https://wi101.wisc.edu/2020/09/09/object-history-a-twenty-sided-die/

Explaining the Concept of 50% Cumulative Exposure With an Invented, Simplified, Ten Sample Example

(Note: *cumulative inhalation exposure* is *only a simple sum* to show what daily samples represented the most inhalation exposure and does not account for processes in the human body)

Median Concentration 2.5 μg/m^3

Mean Concentration 8.7 μg/m^3 (95th UCL is 8.96)
Mean Exposure 139.2 μg/day.

duration (days)	**Concentration (μg/m^3)**	**Percentile of the underlying distribution**	**Inhalation rate (m^3/day)**	**Exposure (μg/day)**	**Cumulative Exposure (μg)**	**Percent of cumulative exposure from individual sample**	**Percent of cumulative exposure**
1	1	0	16	16	16	1.1%	1.1%
1	1	0	16	16	32	1.1%	2.3%
1	2	22.2	16	32	64	2.3%	4.6%
1	2	22.2	16	32	96	2.3%	6.9%
1	2	22.2	16	32	128	2.3%	9.2%
1	3	55.5	16	48	176	3.4%	12.6%
1	5	66.6	16	80	256	5.7%	18.4%
1	11	77.7	16	176	432	12.6%	31.0%
1	20	88.8	16	320	752	23.0%	54.0%
1	40	100	16	640	1392	46.0%	100.0%
			Sum Total Exposure	**1392**	μg		
			50th percentile of cumulative	696	μg		

50th Percent of the cumulative exposure = 696 μg; 8 of 10 days contribute less then 50%!

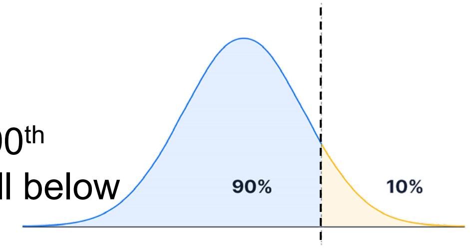
90th and 95th percentiles of underlying distribution

Key Point: The few samples at the top of a skewed distribution dominate the total long-term exposure.

Format of Box and Whisker Diagrams

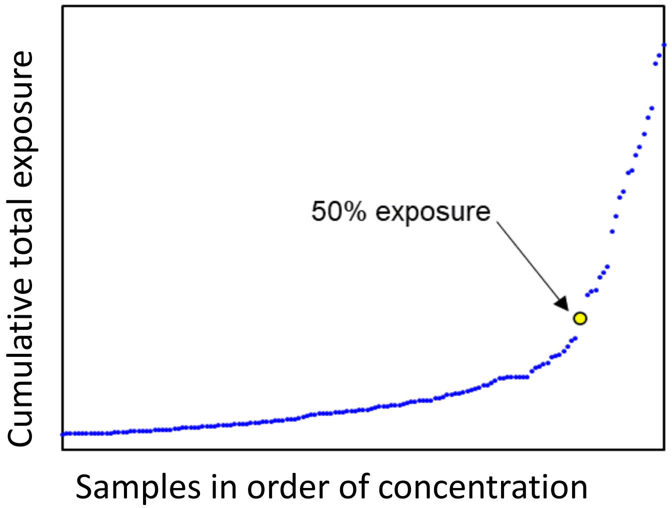
95th percentile
90th percentile

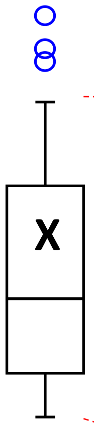
k-th percentile is a value below which a given percentage of *k* scores fall. For example, the 90th percentile is the value at which 90% of data fall below and 10% are above.



50% exposure

The value at which the sum of all data that fall above equals 50% of the total exposure. Total exposure is calculated at the sum of all data.





Outliers

Whisker extends from the top of Q3 to the largest data element that is less than or equal to 2.2 times the interquartile range (IQR). Values greater than 2.2 times the IQR are shown individually as outliers.

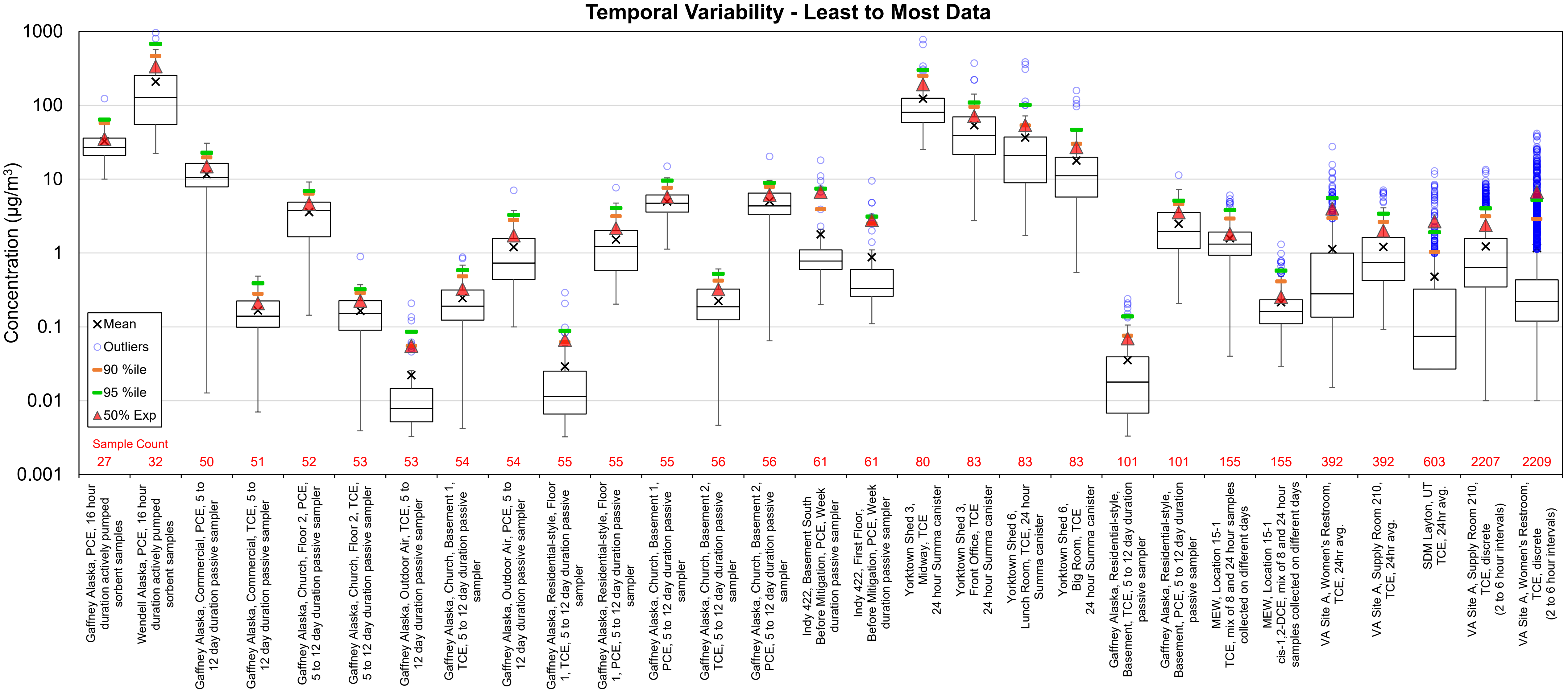
Quartile 3 (Q3)
Mean
Median
Quartile 1 (Q1)

Q3 and Q1 are the 75th and 25th percentiles.

Whisker extends from the bottom of Q1 to the smallest data element that is greater than or equal to 2.2 times the interquartile range (IQR). Values less than 2.2 times the IQR are outliers.

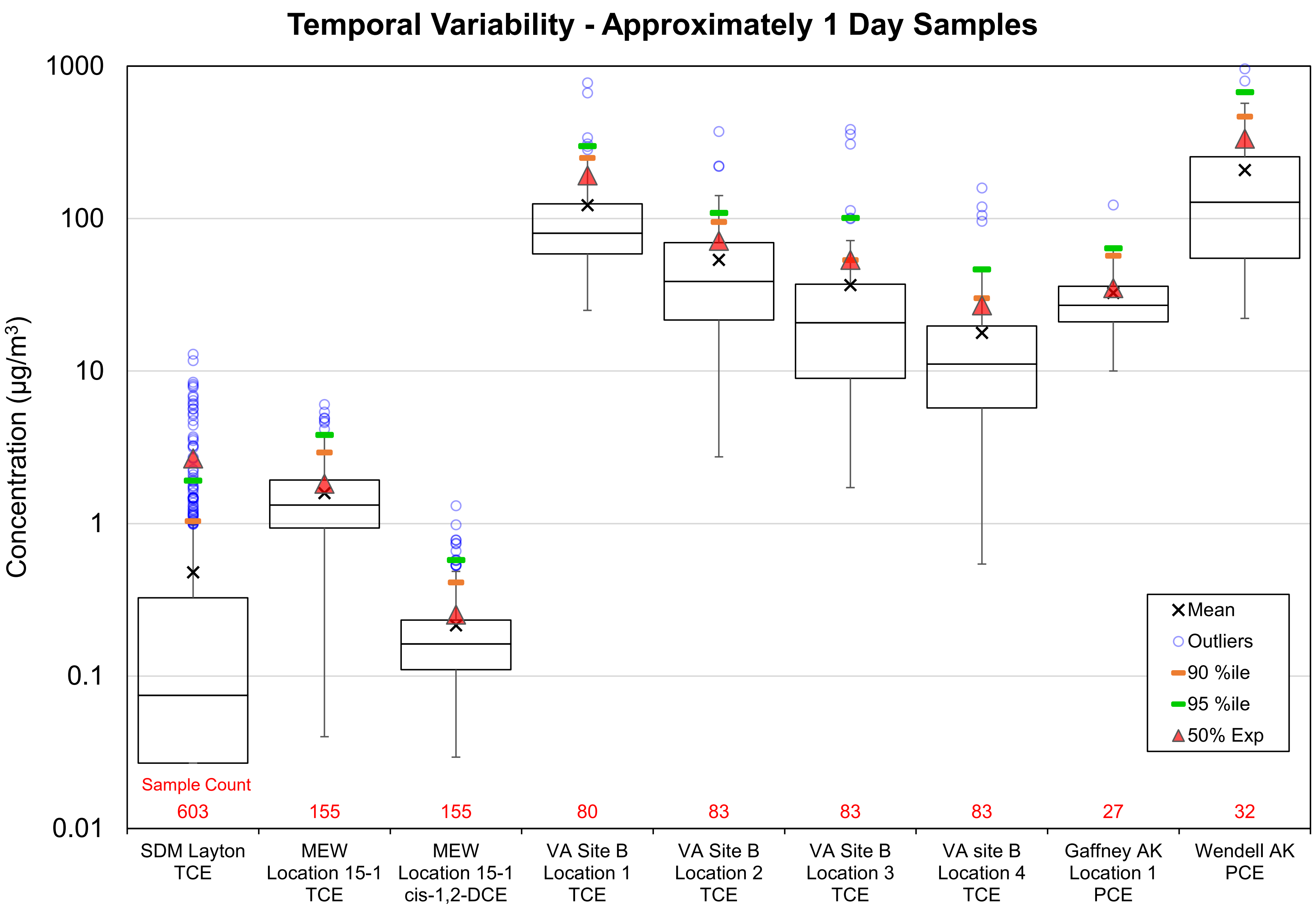
Median = value or quantity lying at the midpoint of a frequency distribution of observed values or quantities, such that there is an **equal probability** of one sample falling above or below it.

Temporal Variability of Indoor Air Concentrations Across 7 Sites



Key points:

1. The long-term mean is always above the median and sometimes above the 75th percentile.
2. Half the exposure often comes from only a small percentage of the days.
3. The more samples you take the more "outliers" you see. Note log axis – those outliers are really high!

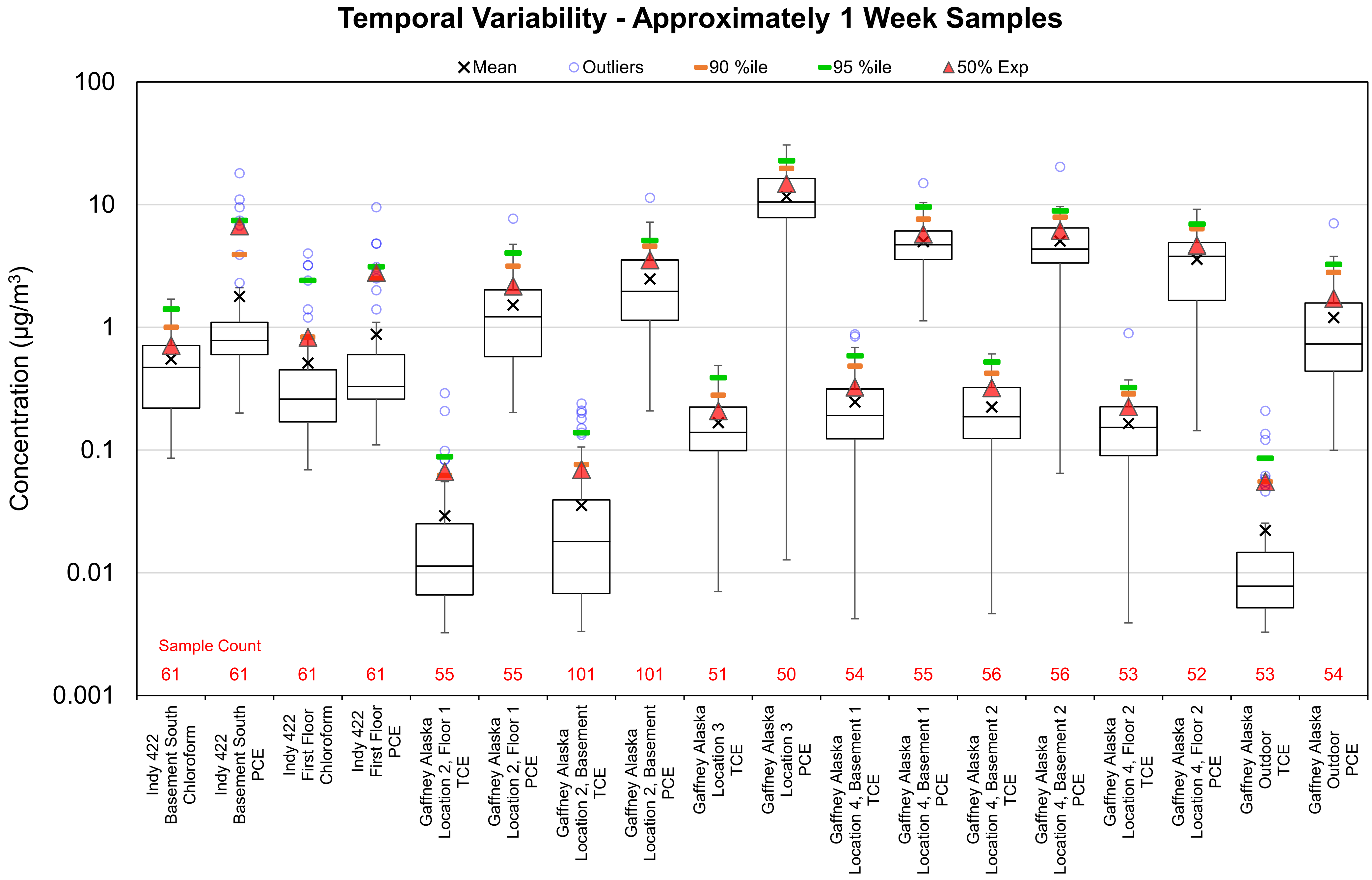


Key Points:

The **X** = true mean is almost always well above the median. So most of the samples will be below the mean.

The 50th percentile of total ▲ exposure is often above the 75th percentile.

Only at SDM is the 50th percentile total exposure above the 95th percentile.

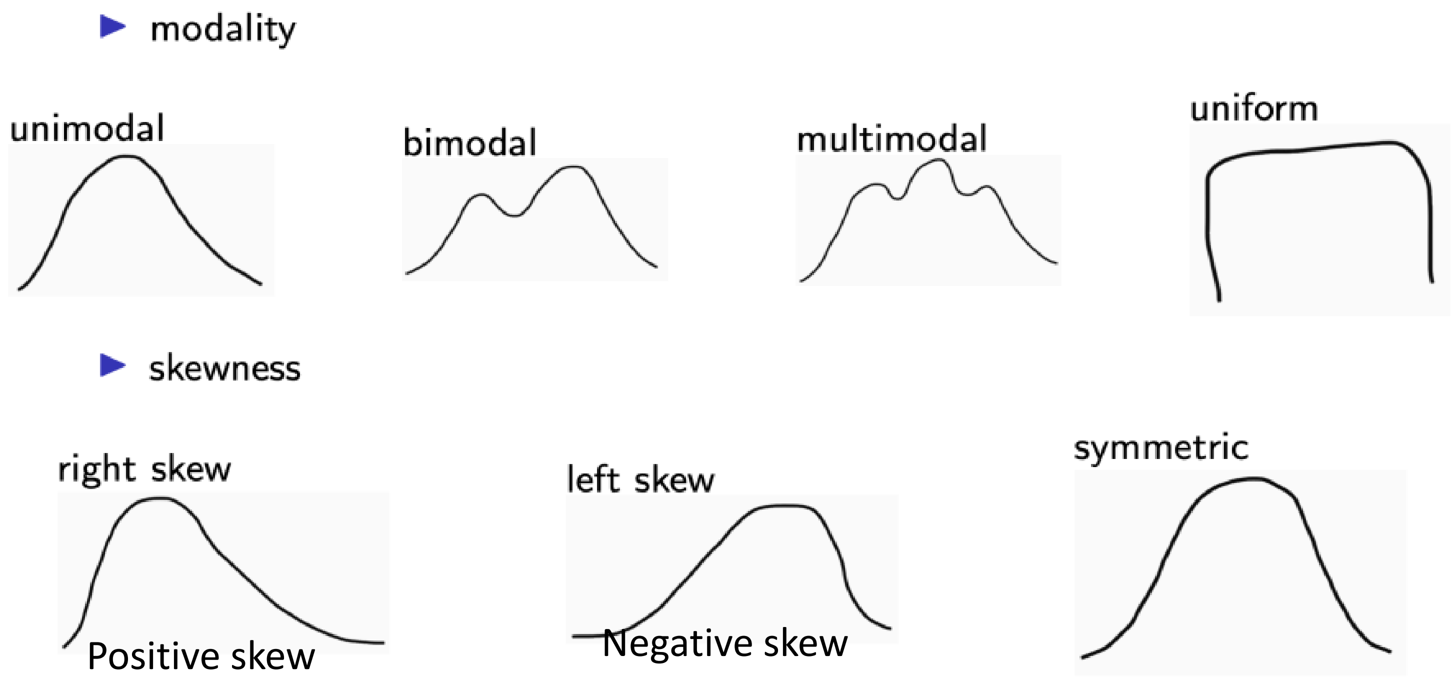


Key Points:

The **X** = true mean is almost always well above the median. So most of the samples will be below the mean.

The 50th percentile of total exposure is often above the 75th percentile.

Results of Statistical Tests of Distribution Types/Characteristics



Multimodal: More then one peak or mode, indicating that the data has multiple subgroups within the overall population

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

- 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. The Sun Devil Manor and Women's restroom 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.
- SDM = 5.4 skewness. VA site A bathroom = 5.5 skewness.

Goals for a Sampling Strategy

- Is a >90% confidence in making the assessment decision about an individual structure required? (<10% false negative?) or 95% confidence (<5% false negative?). Remember sites can have >100 structures.
- Sampling strategies should be applicable to a wide variety of buildings, using a minimum of easily available preexisting information; such as point of contaminant release and climate zone.
- Sampling strategies should be significantly better than random sampling, while still allowing a reasonable number of potential sampling days per year.
- Sampling strategies should be robust = perform well across a variety of situations (building types, climates, climate change)

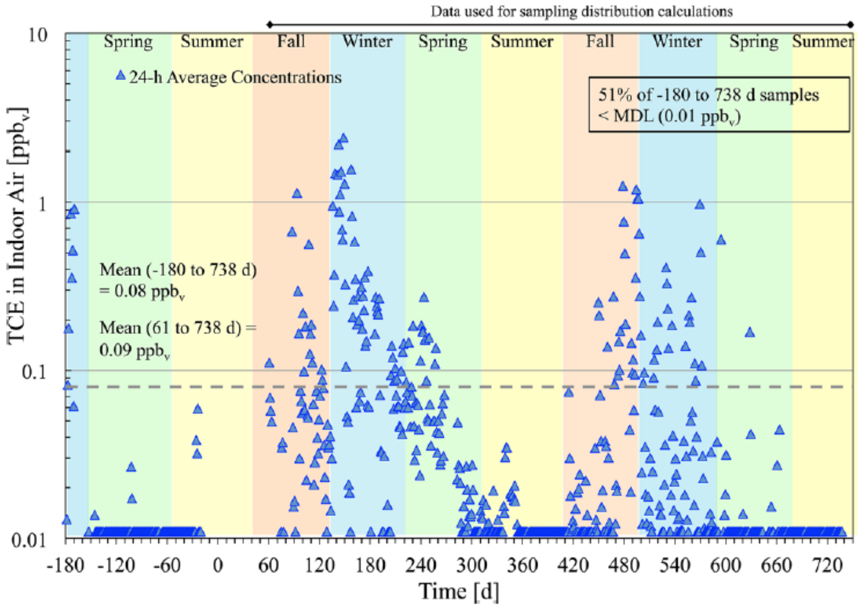
Sample Scheduling Approaches Tested in this Study

- One sample per calendar season (Winter = Dec 1 to Feb 28, Spring March 1 to May 31…..) – either winter/summer or four quarterly samples
- Half the samples in heating season (November 1 to March 31st), half not in heating season

- All samples in heating season.
- All samples in winter; all samples in summer etc.
- OR sampling event begun based on:
  - decrease in temperature day over day of 5 F
  - indoor/outdoor differential temperature of 15 F
  - negative differential pressure of 0.01 inches of water or 2.49 Pa or more
  - day over day increase in radon concentration of 0.5 pCi/l
  - threshold Level of > 2 pCi/l in radon
  - exceeding the 90th percentile of radon levels expected for the structure either based on heating season or the full data set.

- 24 hr duration samples or week duration samples compared
- Full details at https://iavi.rti.org/assets/docs/05_Lutes-Sampling_Strategies.pdf; journal paper in draft.

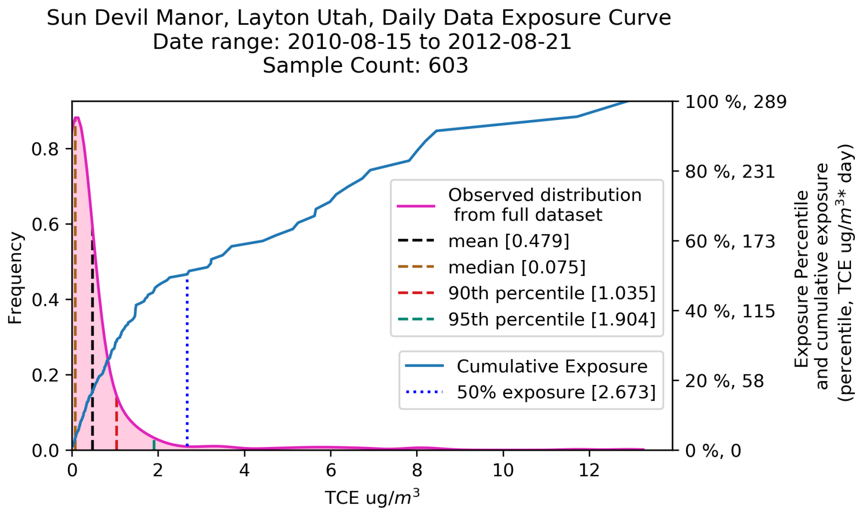
Sampling Performance With a Highly Skewed Distribution? (Sun Devil Manor 603 days)

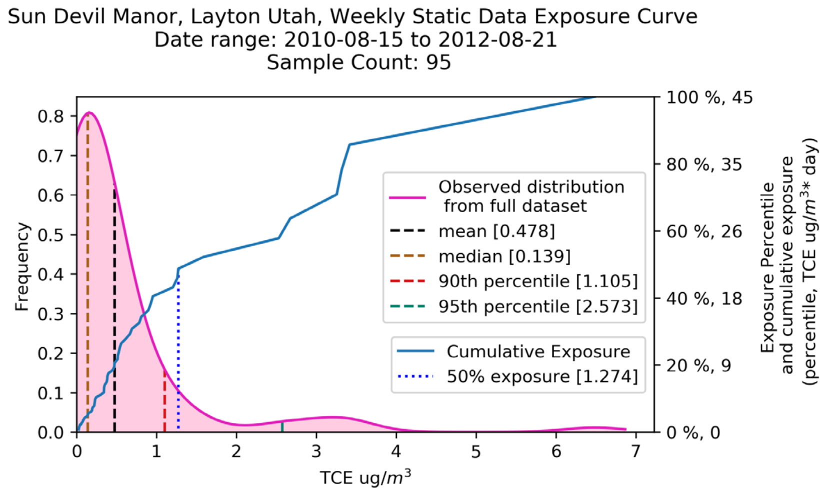


Above figure in ppb (1 ppbv= 5.5 µg/m^3)

Your chances of once

- Seeing TCE sample over the 90th percentile with four daily samples (vs four weekly):
  - Random = 35% (36%)
  - Only in heating season = 62% (68%), In winter only = 74% (80%)
  - When radon >90th of full radon dataset = 95% (100%)
- Seeing TCE over the 50th percentile of cumulative VOCs with four daily samples (vs four weekly):
  - Random = 16% (30%)
  - Only in heating season =31% (59%), in winter only = 40% (68%)
  - When radon >90th of full radon dataset = 60% (100%)





Key Points:

1) Weeklong sampling gives better odds than day long sampling

2) The 90th percentiles are almost identical for the daily and weekly distributions, but the 50th percentile of cumulative is quite different.

3) Preferential pathway case.

What Does Temporal Variability Look Like in Subslab at Sun Devil Manor?

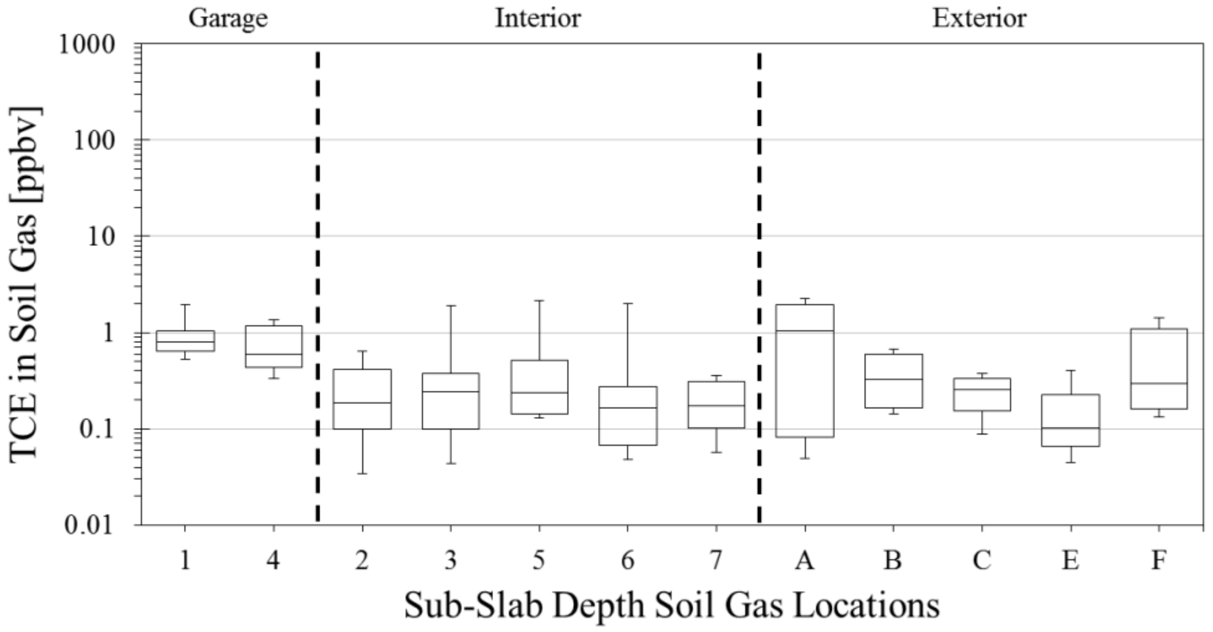


Figure 3.19. Box and whisker plot of TCE concentrations in soil gas at the sub-slab depth sampling points from August 2010 to August 2012.

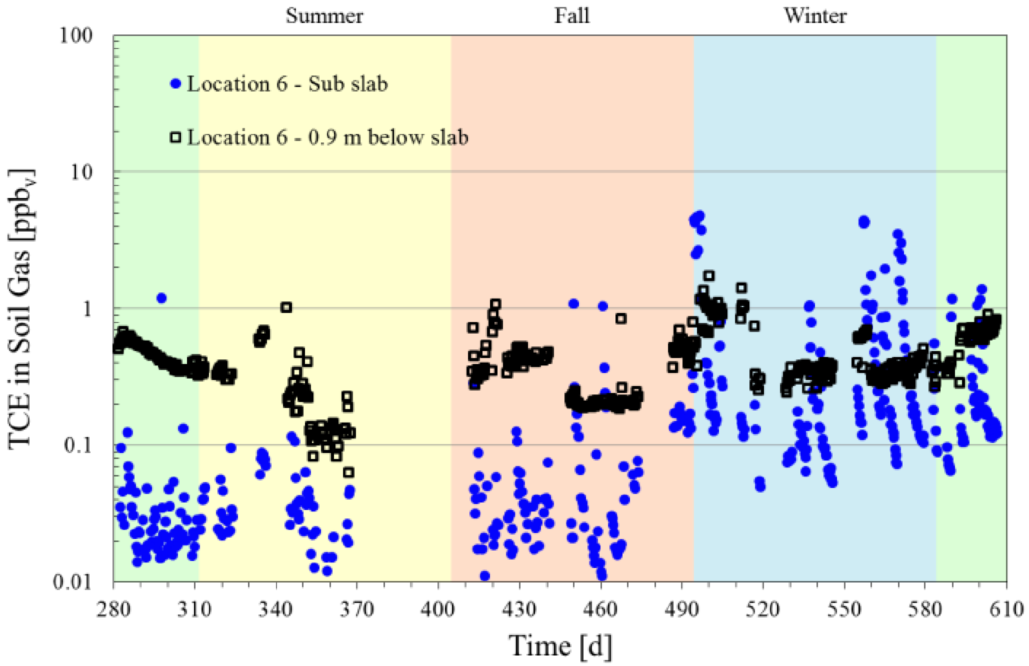


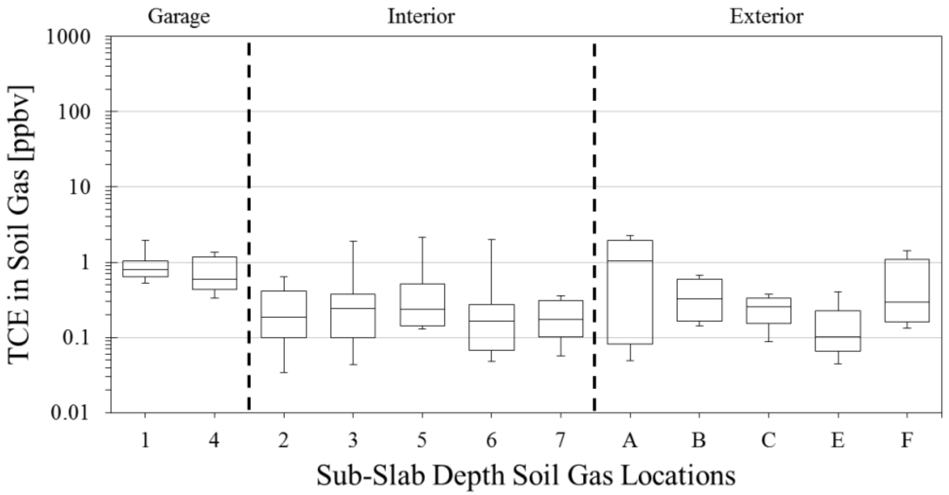
Figure III.21. TCE concentration in sub-slab and 0.9 m below-slab soil gas at location 6 from May 2011 to April 2012.

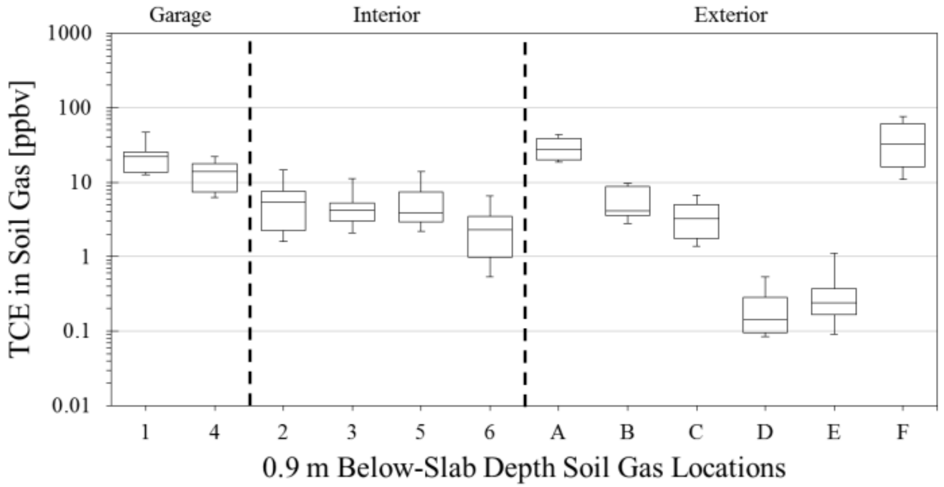
Key Points:

1) Subslab concentration spatially uniform
2) Subslab concentration less temporally variable then indoor air.
3) Subslab concentrations in the lowest risk tier in Region V matrix.
4) Subslab higher during periods when indoor air higher.

Figures reprinted from Evaluation of Vapor Intrusion Pathway Assessment Through Long-Term Monitoring Studies by Chase Weston Holton, Dissertation, Arizona State University 2015

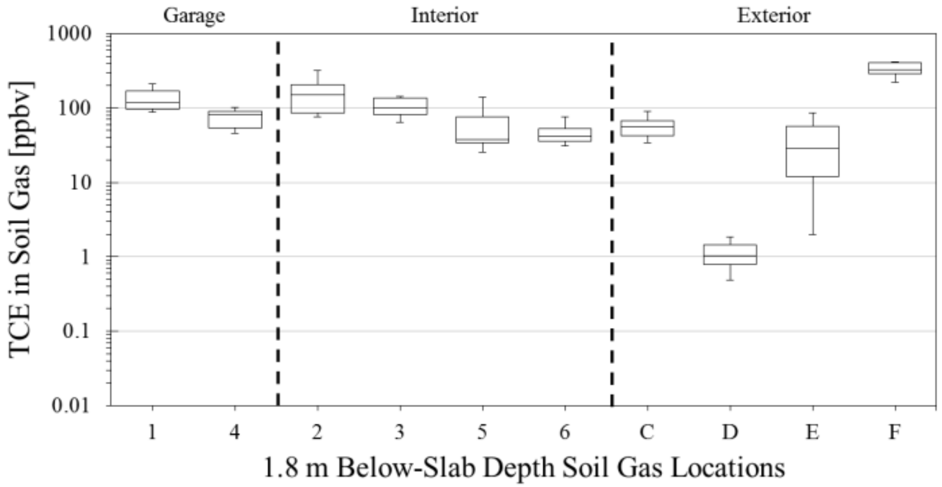
Comparing Subslab and Deep Soil Gas Variability at SDM





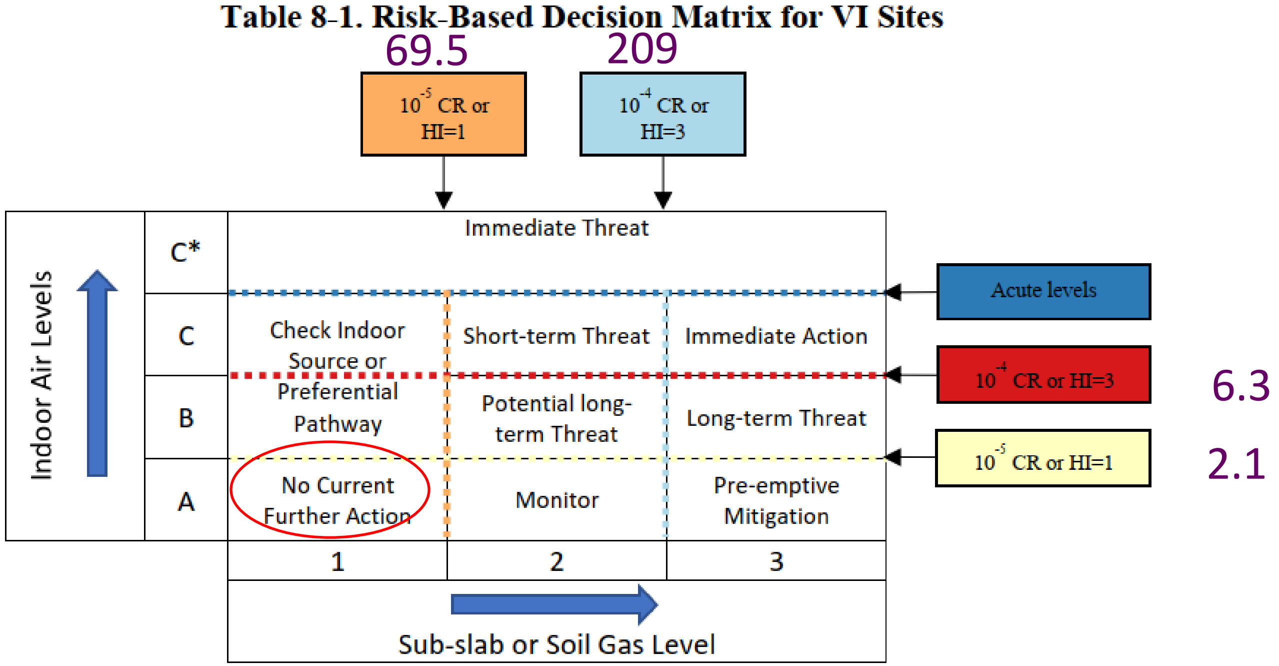
Key Points:

1. Temporal variability: indoor air >> subslab > deep soil gas
2. Spatial variability: deep soil gas > subslab
3. Groundwater concentration was 10 to 50 µg/l
4. The deep soil gas comparison to subslab soil gas suggested that VI was reduced substantially by vadose zone attenuation.
5. The indoor concentrations were ultimately discovered to be due to land drain to subslab preferential pathway – even though none of the subslab ports installed were high.



Figures reprinted from Evaluation of Vapor Intrusion Pathway Assessment Through Long-Term Monitoring Studies by Chase Weston Holton, Dissertation, Arizona State University 2015

How Would Sun Devil Manor be Interpreted Under Region V Matrix?



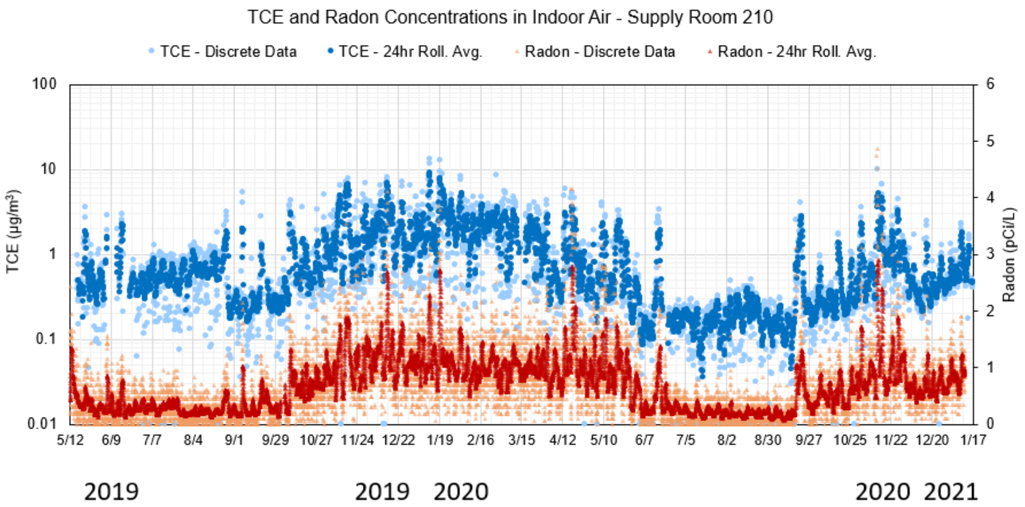
Figures from US EPA Region 5, Superfund and Emergency Management Division, Vapor Intrusion Handbook, March 2020

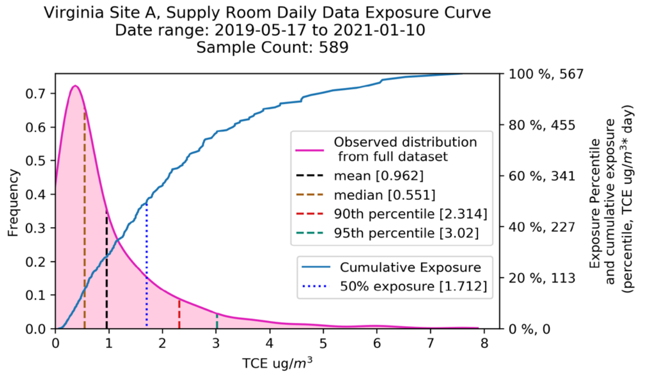
TCE Concentrations from VISL Calculator as of 10/3/24 for Residential in µg/m^3

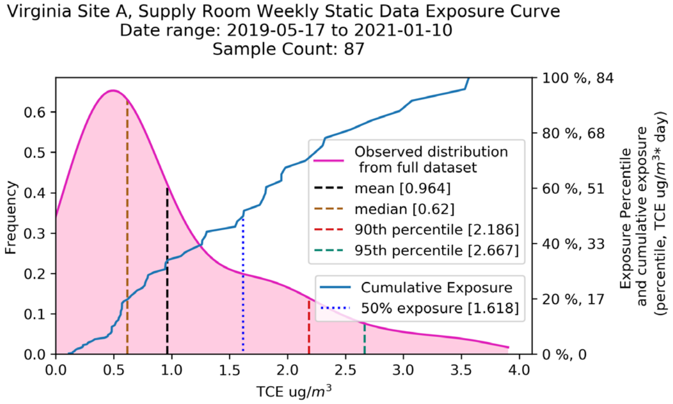
Key Points

1. Mean indoor concentration of 0.48 µg/m^3 is around 10^{-6} and
2. 95th percentile of daily 1.9 µg/m^3 is below HQ=1, so indoor air is in the lowest risk category A.
3. Subslab concentrations are also in the lowest category 1 (<10^{-5}). So A1 = No current further action.
4. Indoor air was not a big risk. But data illustrates how skewed VI distributions can be and how the vast majority of the samples contribute very little the cumulative total exposure and are far below the mean.
5. Sparse sampling might have led to the right answer by chance despite inaccurate exposure estimates.

Sampling Performance, Moderate Skew: VA Site A: Supply Room (589 days)







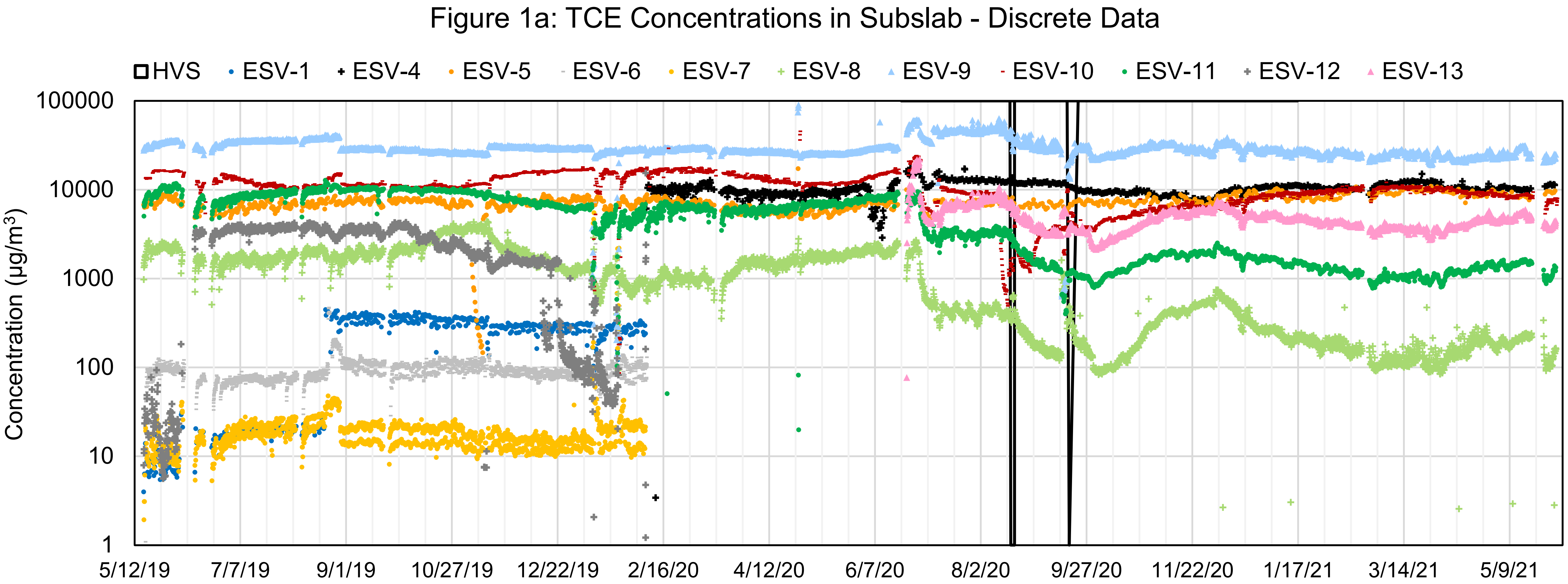
Your chances of

- Seeing a TCE sample over the 90th percentile once with four daily (four weekly) samples:
  - Random: 34% (36%)
  - Only in heating season: 67% (74%), only winter: 71% (87%)
  - Radon >90th full radon dataset: 77% (95%)
  - Radon >2 pCi/l: 100% (100%)

- Seeing TCE over the 50th percentile of cumulative VOCs once with one of four daily (four weekly) samples
  - Random: 49% (63%)
  - Only in heating season: 86% (97%); Only winter: 90% (99%)
  - Radon >90% of full radon dataset: 93% (100%)
  - Radon >2 pCi/l: 100% (100%)

Key Points:
1) Weeklong sampling performed better than day long sampling
2) In this case the characteristics of the weekly and daily distributions were quite similar for both the 90th percentile and 50th percentile cumulative exposure.
3) Zone has "classic" stack effect behavior from a source directly under building.

What Does Temporal Variability in Subslab Look Like at VA Site A?
Supply Room Zone is ESV-11 (Dark Green); Very Close ia ESV-10 (Dark Red)



Key Point: Subslab concentrations stable for months. Occasional changes wouldn't normally be observed with extended sampling time.

Paper in Review: "Influence of Sampling Collection Time and Volume on Observed Subslab Soil Gas Volatile Organic Compound Concentrations"
Published *The Representativeness of Subslab Soil Gas Collection as Effected by Probe Construction and Sampling Methods.* Groundwater Monitoring & Remediation, June 2024.
https://doi.org/10.1111/gwmr.12663

What Does Temporal Variability in Subslab Look Like at this VA Site A? Concentrations in µg/m^3

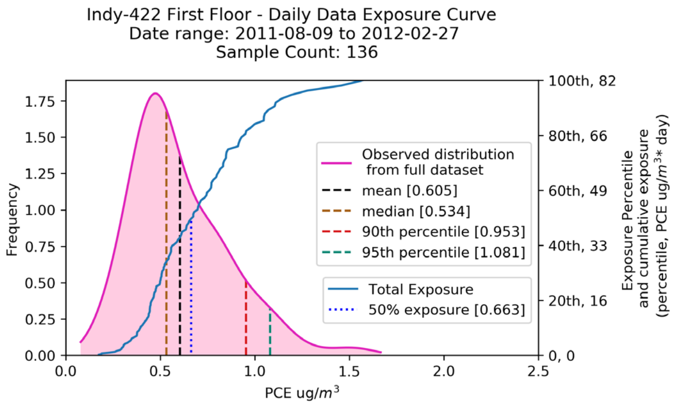
Sampling Zone	Nearby Office	Supply Room
Sample ID	ESV-10	ESV-11
Start Date	5/16/2019	5/16/2019
End Date	1/9/2021	1/9/2021
5 %ile	3,471	1,192
10 %ile	4,792	1,533
25 %ile	8,729	2,983
Median	11,425	6,437
75 %ile	14,708	8,630
90 %ile	16,328	10,039
95 %ile	16,789	10,347
Maximum	45,404	12,817
75/25th	1.7	2.9
90/10th	3.4	6.5
95/5th	4.8	8.7
Average	11,200	5,974
StDev	4,384	3,142
% Detected	100.0%	99.9%
Count	4,826	4835

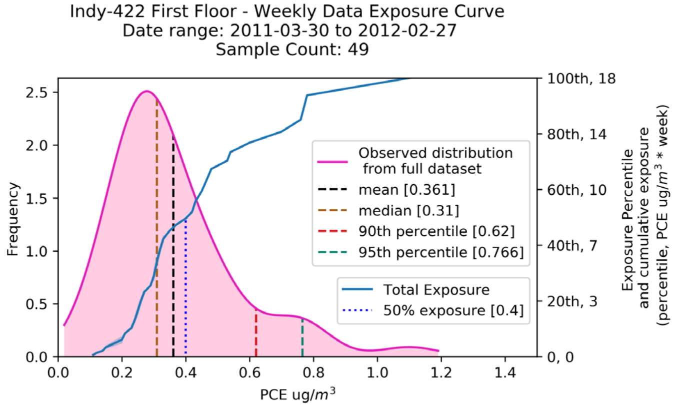
Key Point:
1) Spatial and Temporal Variability is limited despite thousands of measurements over 2 years.

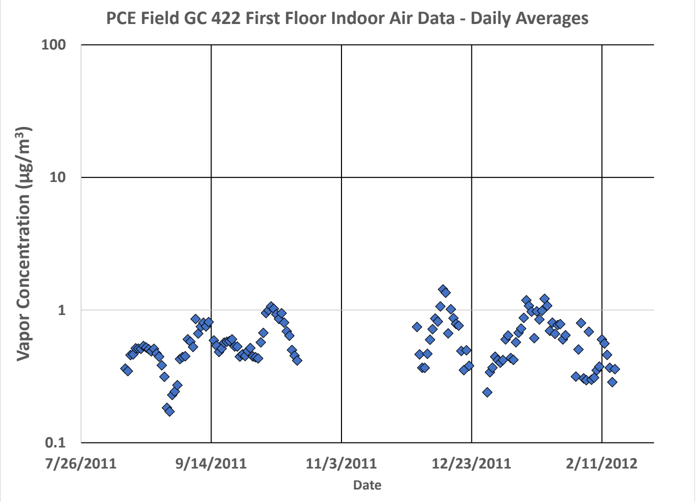
Sampling Performance With Slight Skew – Indianapolis First Floor:
Daily (8/9/11 – 2/27/12)
Weekly (3/30/11 -2/27/12)

Your chances of once

- Seeing PCE sample over the 90th percentile with four daily (four weekly) samples:
  - Random = 37% (36%)
  - Only in heating season= 51% (39%) or in winter only = 51% (31%)
  - When radon >90th of full radon dataset = 58 % (80%)
  - When radon >90th of heating season Rn, in heat season= 85% (80%)
- Seeing PCE over the 50th percentile of cumulative VOCs with four daily (four weekly) samples:
  - Random = 81% (81%)
  - In winter only = 91% (95%)
  - When radon >90th of full radon dataset = 99% (100%)
  - When radon >90th of heating season Rn, in heat season=100% (93%)







Key Points:

1) Weeklong sampling sometimes better than daylong sample compared to daily distribution.

2) Daily and Weekly distributions from different time periods here.

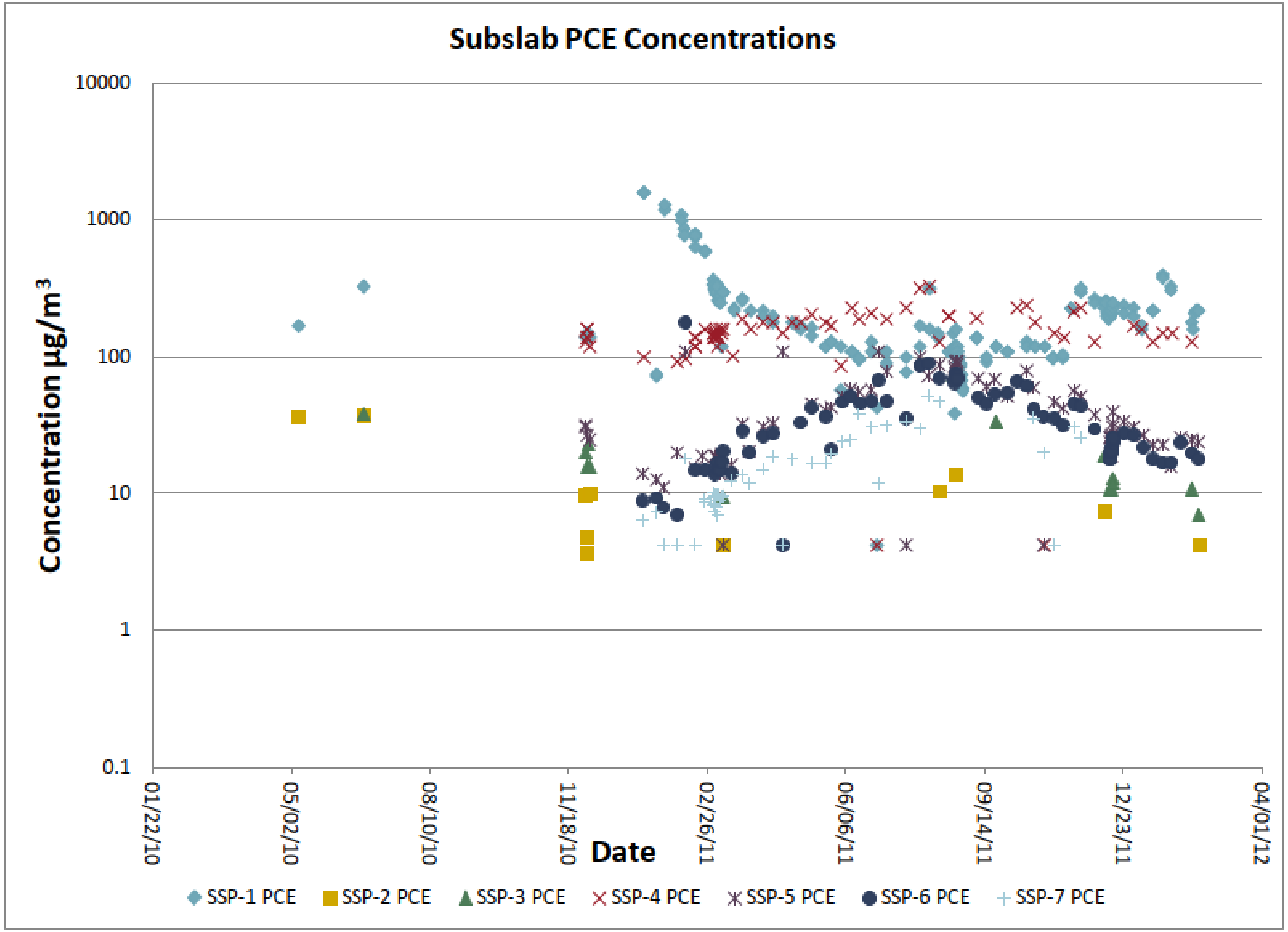
3) This case is at a distance from source, preferential pathway influenced on neighborhood scale.

What Does Temporal and Spatial Variability In Subslab Look Like Under Indianapolis Duplex Basement?

Approximately 13 months of weekly grab samples.

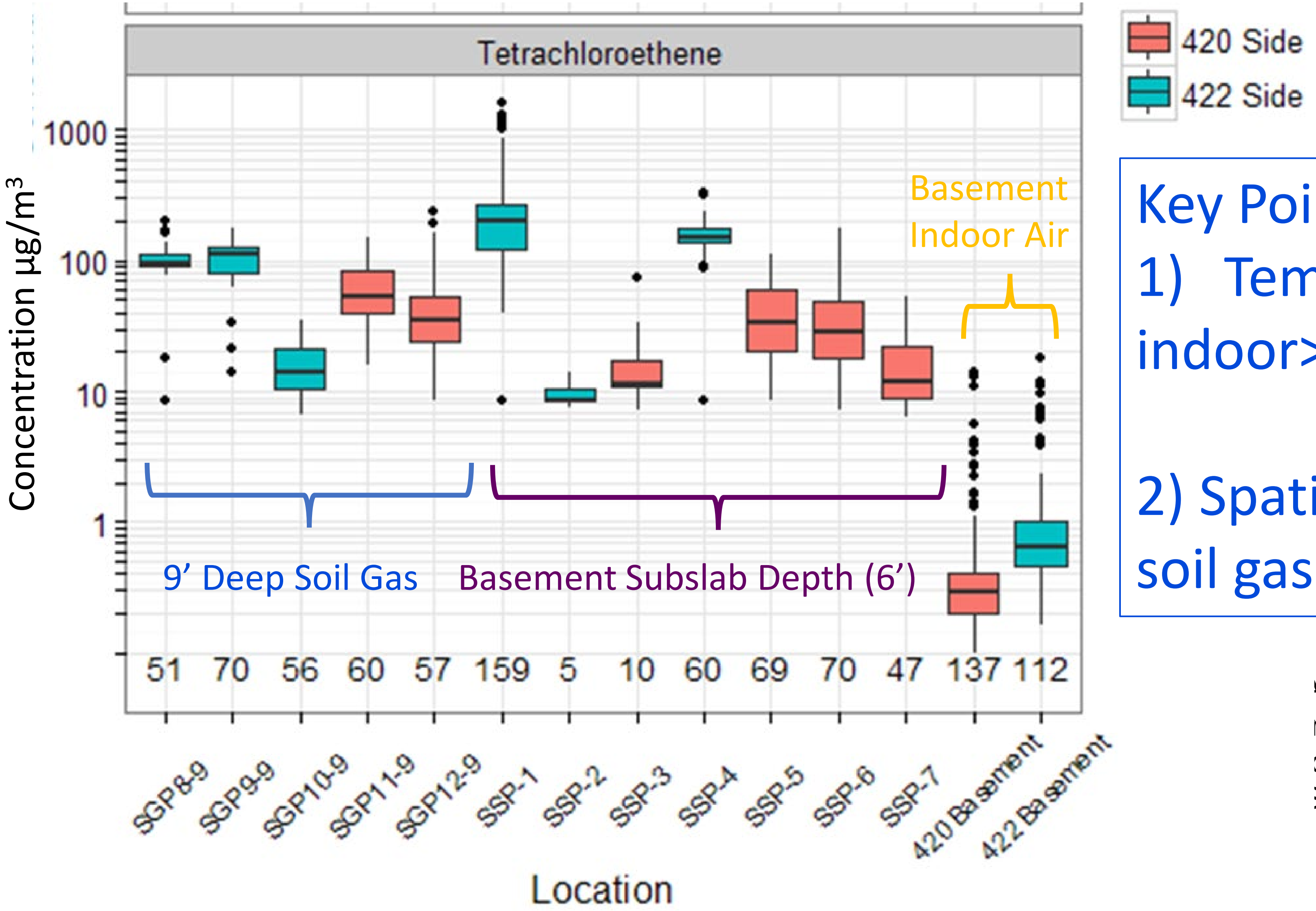
SSP-1, SSP-2, SSP-4 are under the Heated Portion of the Duplex.
SSP-3, SSP-5, SSP-6 and SSP-7 are under the Unheated Portion of the Duplex

Key Point:
Gradual temporal change, distinct spatial variability in winter.



“Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variations” EPA/600/R-12/673, September 2012.

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



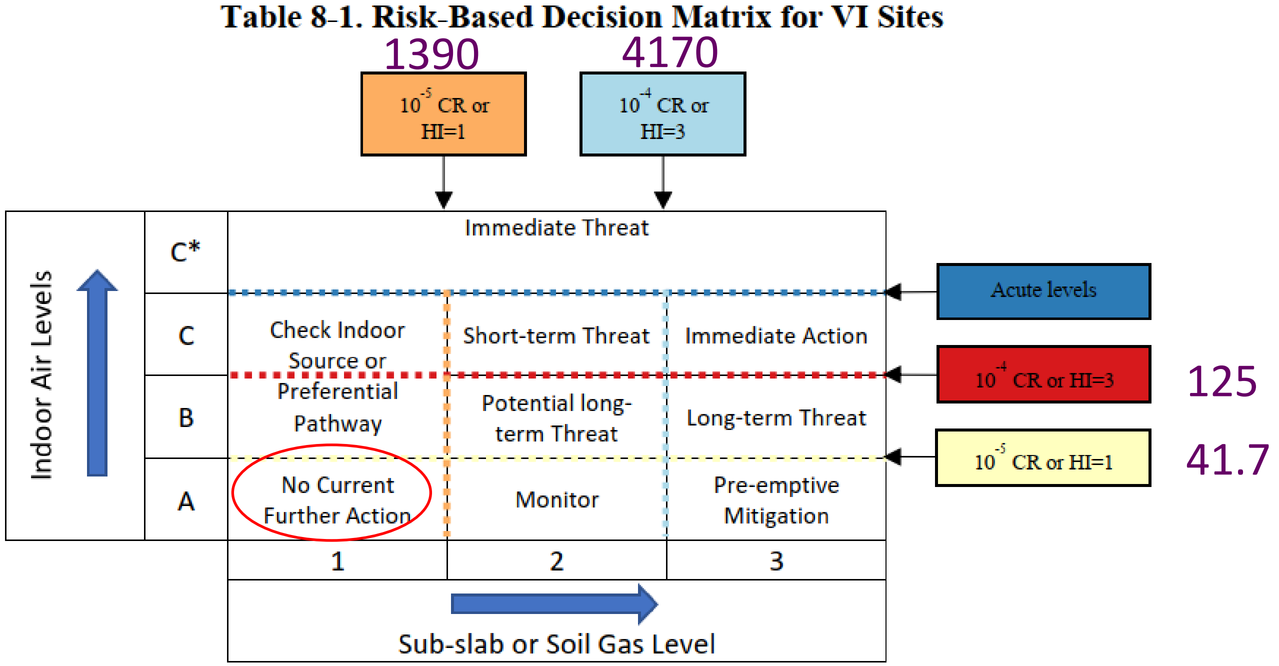
Key Points:

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.

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

Answer would have been very different using California toxicity values.

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.
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.

Comparing Daylong and Weeklong Sample Durations

- One week or longer duration samples can be collected with passive sampling (Schumacher 2012), capillary controller Summa canisters (Rossner, 2020, 2023); or other advanced canister flow controllers (Entech, 2023)
- The sampling and analysis costs for daylong and weeklong are similar, so longer, more representative observation periods may be preferred (EPA, 2015).
- One week duration samples are expected to exhibit less temporal variability than 24-hour (daily) samples and thus yield estimates closer to the mean of the long-term exposure distribution.
- Fewer weeklong samples will be needed to confidently observe goals around the mean.
- But will it then be more difficult to directly observe the concentrations towards the upper end of the distribution of daily average concentrations (i.e. 90th or 95th percentile) using weekly samples?

Alan Rossner , David P Wick, Christopher Lutes, Benjamin Stone, Michelle Crimi; "Evaluation of Long-Term Flow Controller for Monitoring Gases and Vapors in Buildings Impacted by Vapor Intrusion" International Journal of Environmental Research and Public Health, March 2023 Int. J. Environ. Res. Public Health 2023, 20, 4811. https://doi.org/10.3390/ijerph20064811.
Schumacher, B.; J. Zimmerman, J; R. Truesdale, C. Lutes, B. Cosky, B. Munoz and R. Norberg "Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variations" EPA/600/R-12/673, September 2012.
Entech Instruments "CS1200E Passive Canister Sampler"
United States Environmental Protection Agency (USEPA). 2015. "OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air."

Summary Across Multiple Sites – Sampling Analysis

- In each individual case analyzed, an I&T based sampling rule and/or a seasonal based sampling rule can be identified that substantially outperforms random indoor sampling.
- However, the top performing I&T based rule is not the same across all sampling zones, so additional mechanistic insight is needed to select *a priori* the optimum sampling rule for a given sampling zone.
- An *a priori* selection of sampling rule would need to be based on the information generally available before initiating sampling at a given building: climate zone, building type, and a conceptual site model describing the primary source of contamination (groundwater vs. soil).
- Making decisions based on four randomly or convenience based short term samples will not likely characterize the 90th or higher percentile of the concentration distribution.
- At some sites with highly skewed concentration distributions, making decisions based on four randomly or convenience based short term samples will underestimate the mean long-term concentration, because a small percentage of the dates contribute >50% of the total exposure.
- However, because many structures are either far above or far below screening levels you may make the right decision even with imperfect information.
- Soil gas samples are less temporally variable so using multiple lines of evidence is important.

How, When and Where Should We Be Sampling?

Current State of Practice

- RCRA 2020 corrective action baseline = 3,746 facilities
- CERCLA NPL = 1,336 facilities. Hundreds of thousands of additional sites are under state management. Substantial percentages of these sites include chlorinated solvent impacts.
- A small percentage of the total number of chlorinated solvent release sites have been assessed for vapor intrusion risk within the last 5 years or will be assessed within the next 5 years.
- Many assessments >5 years old relied on J&E modeling from groundwater only and didn't adequately consider soil sources or sewer transport.
- Most current assessments make decisions based on 1 to 4 rounds of 24hr canisters in 10 to 70% of the exposed structures. Evidence presented in this and previous workshop suggests that that approach does not accurately estimate exposure point concentration.
- Most practitioners/consultants performing VI assessments and most regulators overseeing them are not familiar with the limitations of canister based methods, and not familiar with more advanced methods.
- VI site investigations are widely perceived as costly, indeterminate and politically charged, and thus are often avoided by managers.

Current State of Practice – Part 2

- The concept of "reasonable maximum exposure" that is central in the EPA 2015 document is infrequently discussed/understood by practitioners. Because only small numbers of samples are taken, decisions are either made using maximum concentrations observed, or maximums are thrown out as apparent outliers.
- A significant number of states manage the risk of temporal variability in indoor air by making decisions primarily or exclusively based on sub-slab soil gas concentrations. This would be overly conservative in some buildings.
- Attenuation factors (AFs) are a very widely used tool for VI site assessment. Many concerns have been raised regarding the 2012 EPA database study used to set default residential AFs (i.e. small number of rounds in each studied building, lack of representation of certain geographies and building types).
- Yao (2013 ES&T) based on EPA database reanalysis: "*there is only a very weak trend of indoor air concentration with groundwater source concentration*". DoD industrial building confirms that indoor concentration is not a linear function of groundwater concentration. Yet our practice still predominantly starts with groundwater plume delineation and an attenuation factor as the first step in VI site management and deemphasizes mass storage in vadose zone soils.

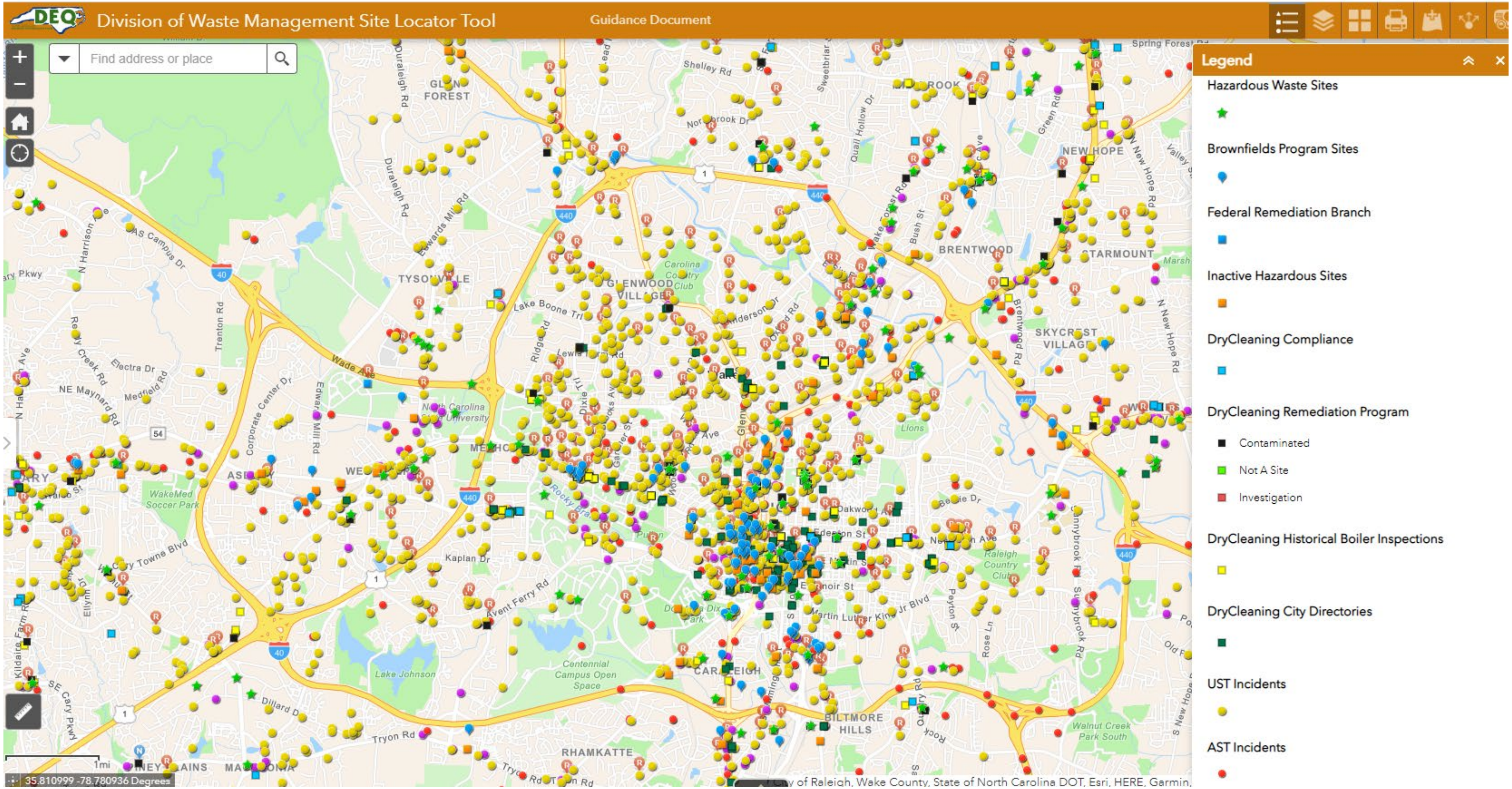
Are Our Sampling Strategies Working?
Are We Assessing Enough Sites and Structures for VI Risk Management?
Do we need more efficient approaches?

- There is no known comprehensive national dataset of the status of vapor intrusion site investigations and mitigations.
- EPA (2004) estimated 294,000 contaminated sites to be remediated including CERCLA, RCRA, UST, DoD, DOE and State led sites. A high percentage of those sites include volatile organic compounds and require VI evaluation.
- A 2017 count of sites including Superfund NPL, RCRA cleanups, UST, accidental spill sites, Brownfields, defense sites, and abandoned/inactive mines referred to approximately 640,000 to 1,319,100 facilities https://www.epa.gov/report-environment/contaminated-land.
- In many urban neighborhoods there are numerous potential VOC sources within a short distance of each other leading to complex overlapping patterns of potential vapor intrusion impact.
- A large site can require assessment of 300 to 2000 structures.
- Let’s look at what that looks like at various geographic scales….

Density of Hazardous Waste and Petroleum Sites in One US City (Raleigh NC)

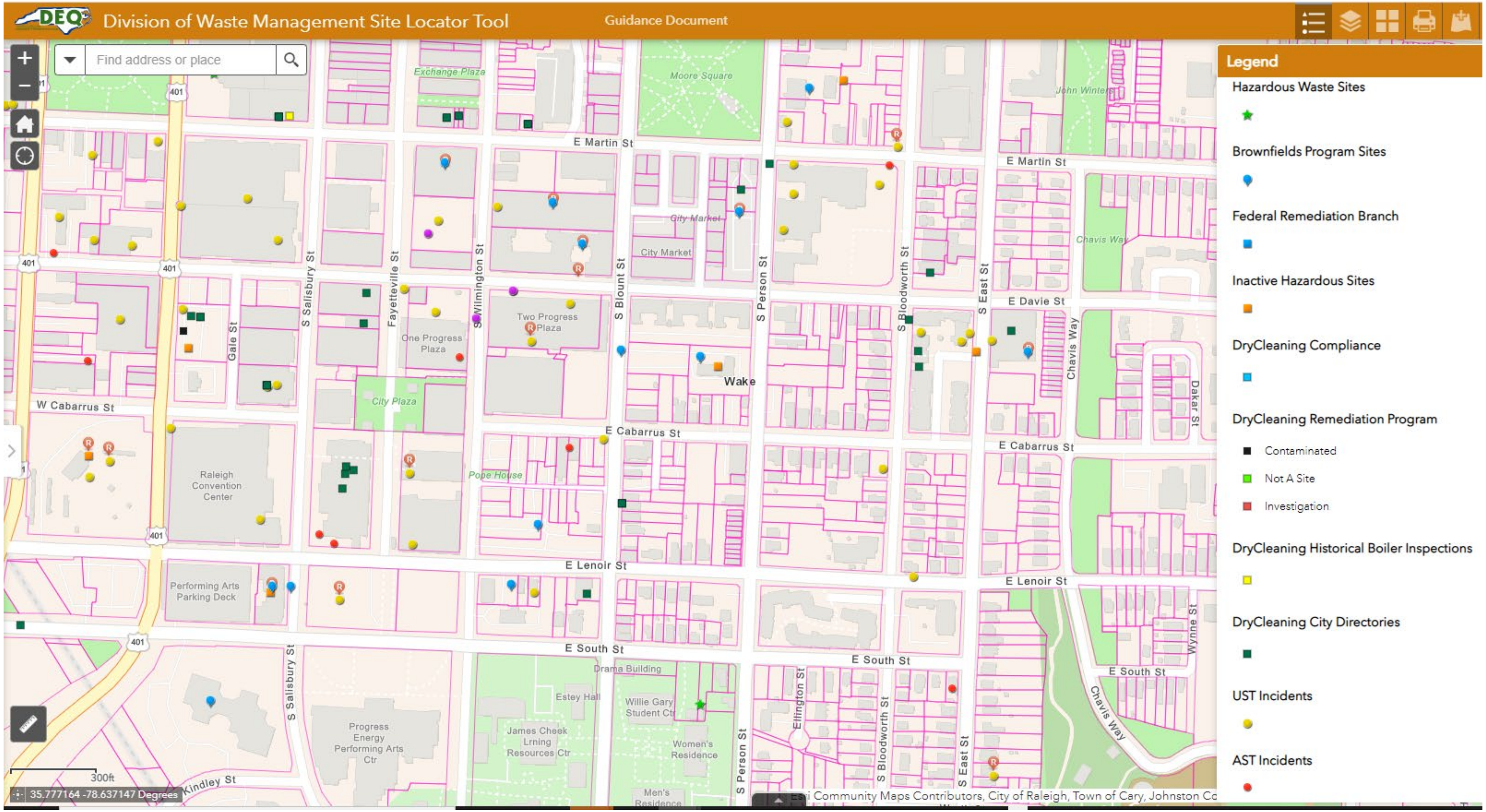
reprinted from https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=7dd59be2750b40bebebfa49fc383f688 as of 8/17/22

Key Point: As a society, we have a lot of sites to assess and manage so we need efficient methods!



Neighborhood Scale Example of the Density of Potential Hazardous Waste Sites, a Portion of Downtown Raleigh NC

reprinted from https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=7dd59be2750b40bebebfa49fc383f688 as of 8/17/22 **Key Point: Multiple sources are often close to each other in urban areas.**



Number of Structures in Inclusion Zone or # Evaluated at Some Famous Sites

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		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

Approximate Comparative Statistics on Sites

Site, State, Program	Structures sampled per groundwater well	Structures sampled per external soil gas point	% sampled structures mitigated	Proportion of Structures in Inclusion Zone Sampled
Redfield CO; RCRA	8	78	68	Very high
Endicott NY; RCRA	11		Nearly 100?	
Hill AFB Utah, CERCLA	2	98	5	moderate
Billings MT; CERCLA	4	2?	15	
Gaffney AK, State	1	1	3	High in commercial near source, low in residential tail of plume
Franklin IN, RCRA	0.5	2	48	Very high

Example of House to House Heterogeneity

Reprinted from Dawson and Wertz "Empirical VI Database, Background Indoor Air Review, Updated J&E Spreadsheet Model"

Practical Barriers to Structure Access

- What's in it for me (so that I 'open my doors' to allow access)?
- I don't want to know because it will hurt my property value
- I'm too busy to entertain you for multiple visits
- I don't trust the government (or PRP)
- I don't understand what you are talking about, or if this is really a serious problem?
- I want assurance that if you find a problem, you will fix it for me (investigation and remediation programs are generally disconnected).
- Lack of wholistic approach to indoor air quality and energy (oh well, it is 500x the screening level, but that is your gun cleaner, so it's been nice meeting you, I need to go).
- "You again? Aren't you done yet? Can't you tell me if there is a problem and leave me alone?"

Key Point: It may be preferable to manage the soil gas plume, because we can't get into every structure for a thorough sampling effort.

Current Number of Sample Locations and Rounds – Indoor Air (as of 2022)

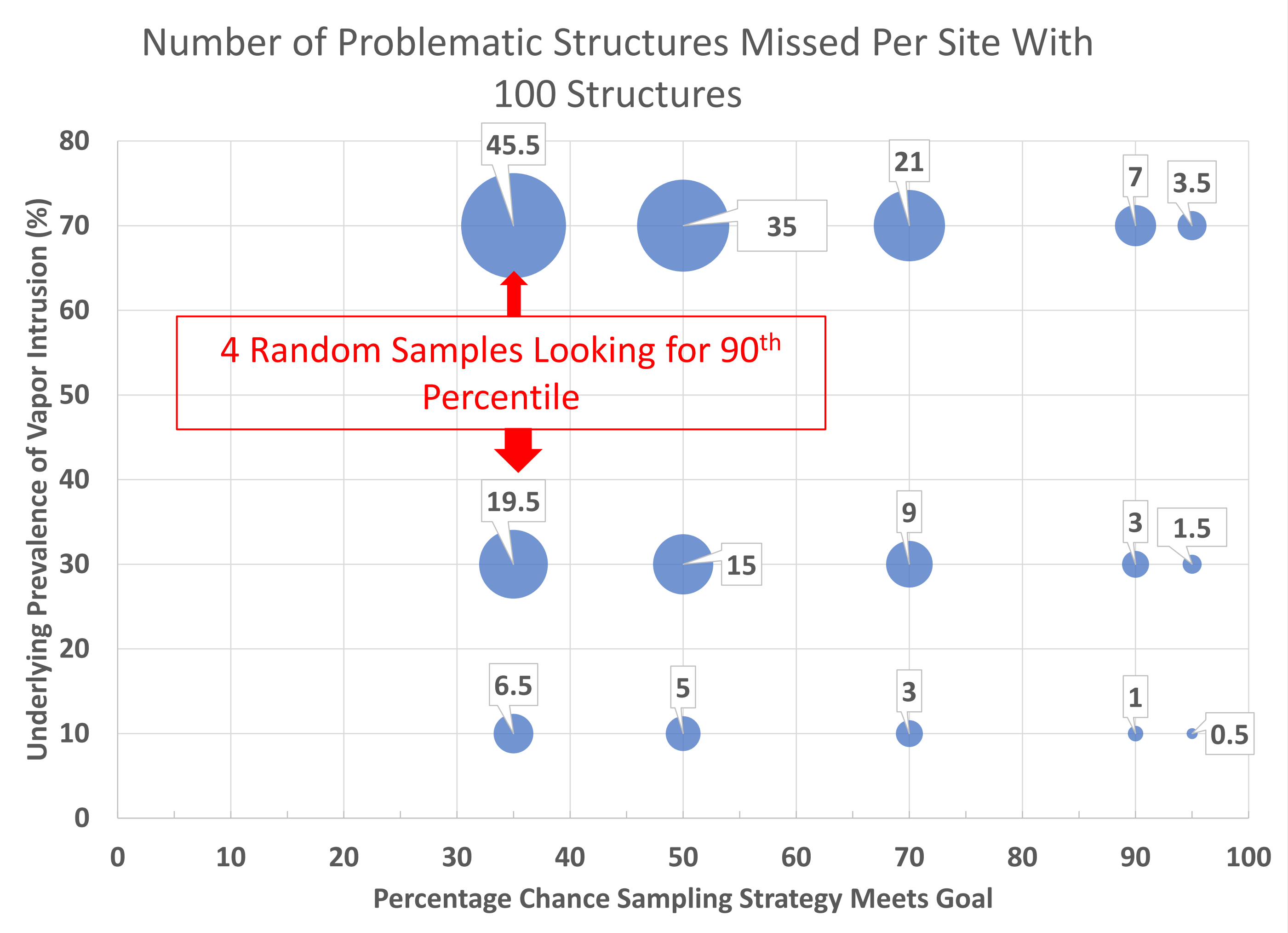
- **Indoor air: most states say one in the basement and one on the first floor and two or more rounds.**
- Most states allude to seasonal variability or worst-case conditions
- A few jurisdictions specifically suggest more rounds:
  - Maine mentions quarterly;
  - Mass. wants 2-4 rounds for sensitive receptors,
  - Michigan requires 3 to 4 rounds depending on subslab results
  - Washington calls for 3 active samples for short term exposure, or 2 multiweek passive
  - Wisconsin requires 3 times for residential, 2-3 times for schools, daycare and mixed use
  - Region VII calls for one year of quarterly samples
- A few jurisdictions allow one round with caveats
  - NJ allows one round if under worst case conditions
  - Ohio allows one round if under worst case conditions and subslab below screening level
  - NC allows one round if results are an order of magnitude below screening

Key points: The analysis previously presented shows that with typical distributions these sampling approaches have a high probability of underestimating the reasonable maximum exposure if you rely only on the indoor air. The right decision still might be made with poor estimate. Having soil gas data reduces the risk of false negatives.

How Many Buildings with Problematic VI Would Be Missed at Each Site if Sampling Strategy is Weak?

Scenarios analyzed:

- Percentage chance that sampling strategy meets the performance goal (i.e. sees the 90th percentile with at least one of four samples) = 35%, 50%, 70%, 90% or 95%
- Number of structures evaluated: 10, 30, or 100
- True underlying percentage of unacceptable VI in the population of structures (prevalence): 10%, 30% or 70%
- **Answers range from:** 0.5 buildings to 35 buildings missed

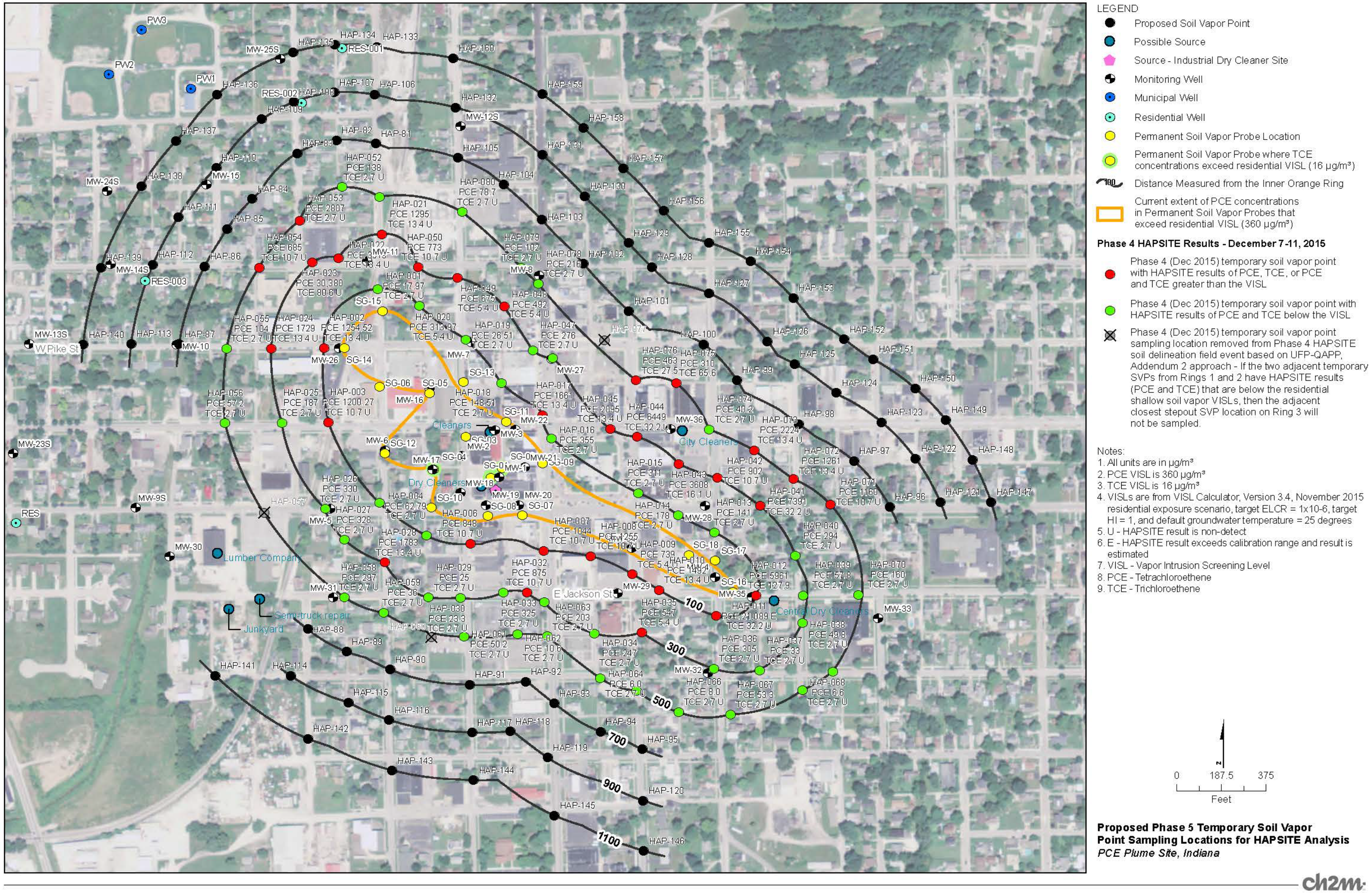


Key Point: If your sampling strategy is weak, and unacceptable VI is common, you miss a lot of problematic structures.

Number of Sample Locations and Rounds – Soil gas (as of 2022)

- Most states emphasize subslab over shallow external. However completeness is higher for external soil gas if right of ways can be used.
- Number of locations in a residence varies considerably, often based on square footage
  - One (or more) – DE, IN (if paired with IA), Region V
  - Two (or more) – CA, IN (w/o IA), LA (allows external), MI, OH, OR, PA
  - Three – AK, MT, NH, EPA (2015)
  - Two to four – MA
  - Three to six for footprint less than 2000 square feet – Region IX
  - Table or formula based on square footage – GA, MN, NJ, NC, TN, WI
- Most states call for multiple rounds, most make some reference to seasonality, several reference water levels

Example of Large Soil Gas Plume Delineation in a Small Midwestern Town



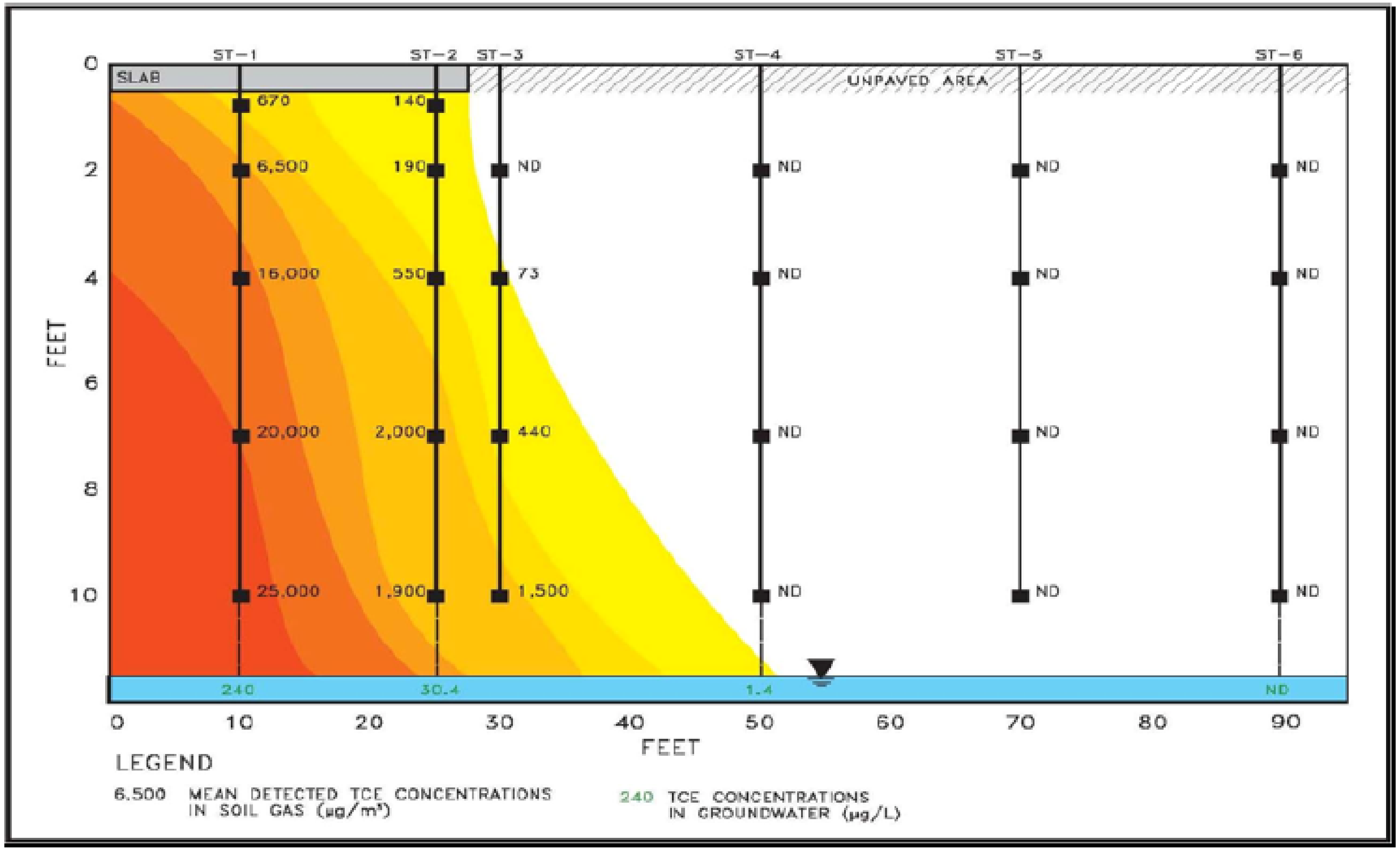
Key Point:
Field portable instrumentation testing of temporary soil gas probes in street right of ways can survey a large area reasonably efficiently.

Reprinted from Lutes and Knoepfle, 2016 AEHS Rapid, Efficient Delineation From VI Potential of A Large Soil Gas Plume Using HAPSITE and Other Lines of Evidence

A Caution re External Soil Gas Sampling

EPA United States Environmental Protection Agency

Measured Soil Gas Profile for TCE – Phase 1

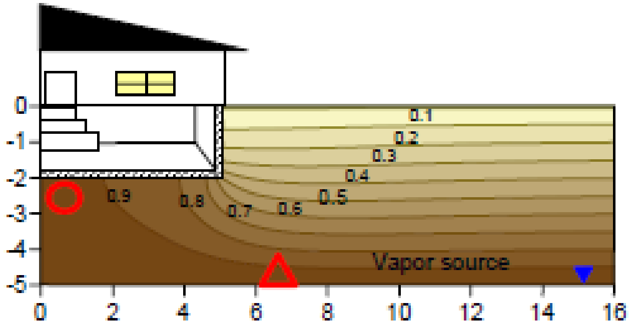


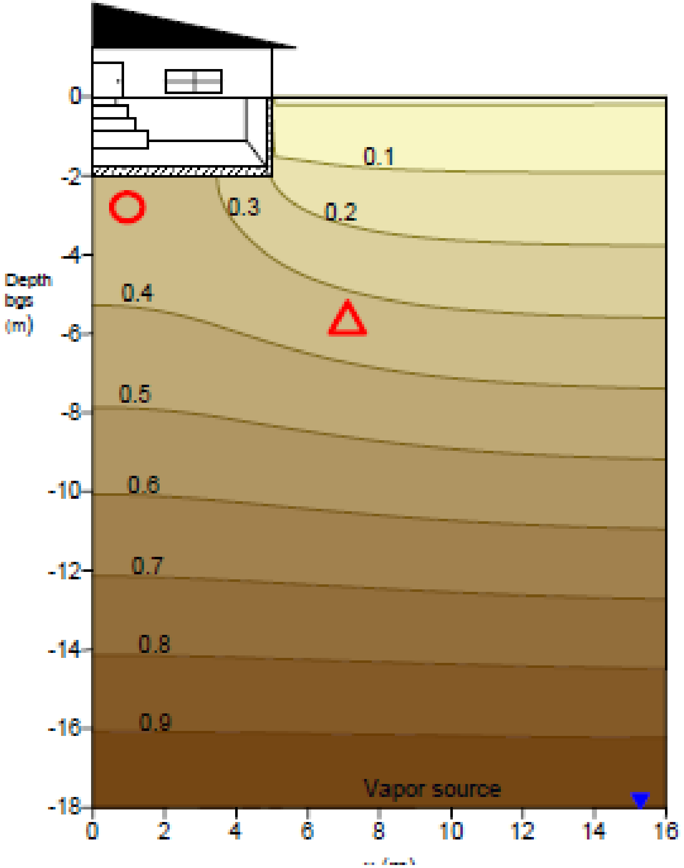
Key Point:
Shallow soil gas sampling strategies on open ground can underestimate concentrations under foundations/paved areas.

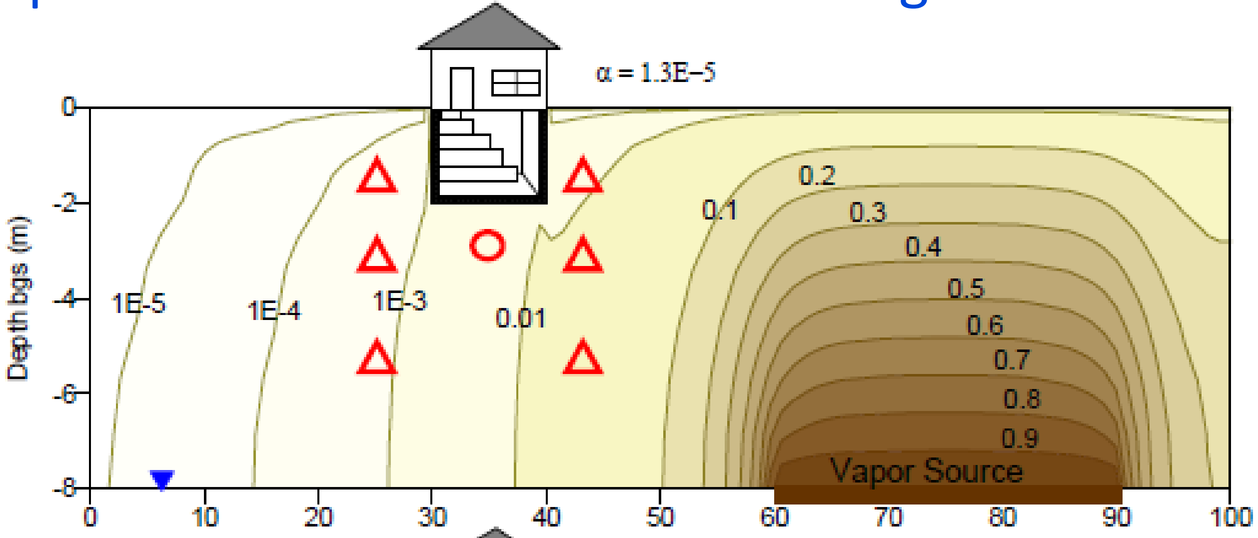
Reprinted from Schumacher et. all "Field Observations on Ground Covers/Buildings" AEHS 2010; data from NAS Lemoore

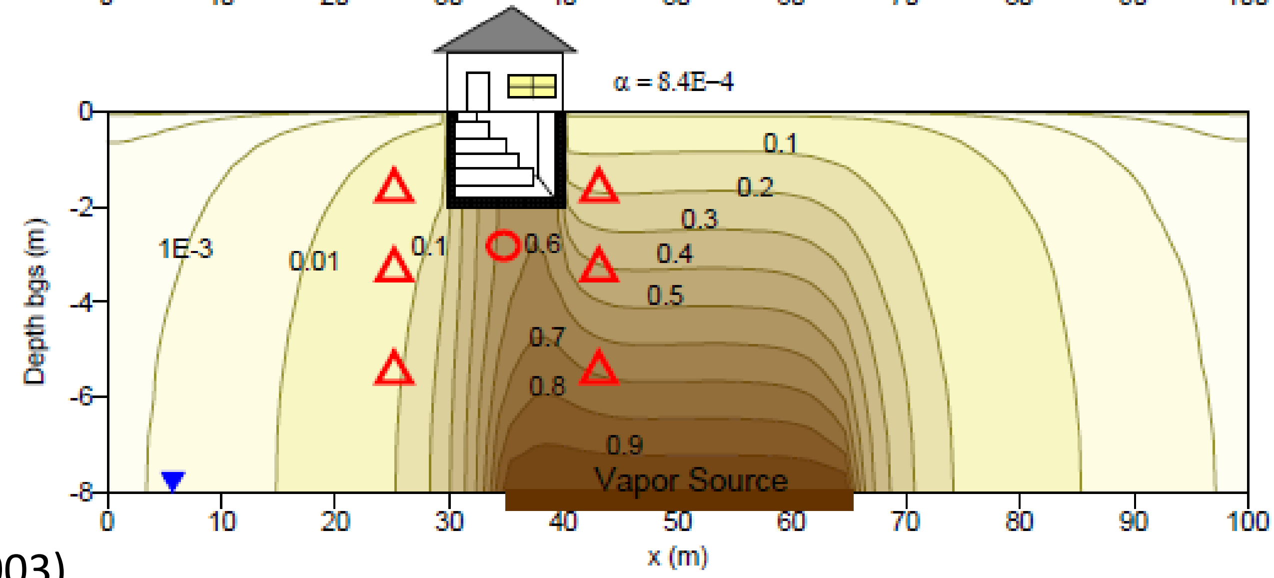
External Soil Gas vs. Subslab, Model Results; Various Deep Source Placements

Key Point: Whether external soil gas is conservative depends on depth and the position of the source and building.









(EPA 530-R-10-003)

Summary: Available Methods for Improving Assessments

- Technologies and strategies that can substantially reduce the risk of false positive and false negative determinations of exposure point concentrations exist.
- There is no single technology/strategy that is the best choice for every site assessment; but 1-4 rounds of 24-hr canisters is rarely ideal.
- Well-established tools that can improve some assessments include:
  - Soil gas surveys
  - Building pressure cycling (BPC)/controlled pressure method (CPM)
  - Field portable GC/MS systems, and real-time on-site continuous GC systems
  - Long-term passive samples
  - Use of Indicators & tracers to help schedule VOC sampling or interpret results
- DoD VI matrix is one tool to help you select among these technologies

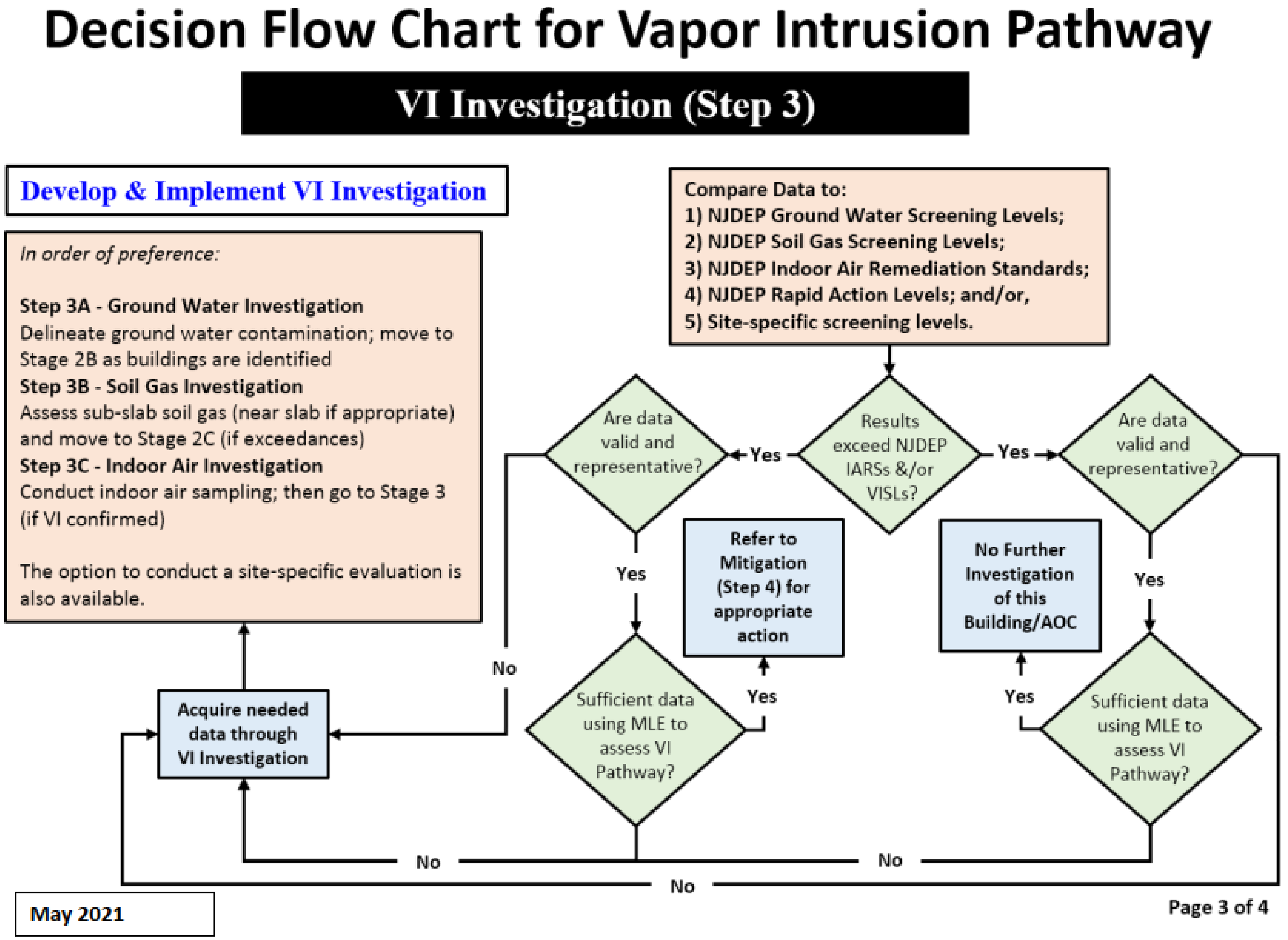
https://clu-in.org/download/issues/vi/7-Matrix-of-VI-Technologies-Fact-Sheet_Revised-Final-July-2019.pdf .

- These newer tools are used on <20% of VI investigations industry wide.

Comparing Economics of Continued Investigation, Mitigation and Remediation

Decision Points at Various Project Stages

- Which media to sample and how many?
- Whether to preemptively mitigate after some site delineation with external soil gas sampling but before indoor sampling in every building?
- Mitigate after some indoor VOC sampling?
- Individual house mitigation systems and/or vadose zone remediation/mitigation on neighborhood scale



Part of NJ 2021 Guidance Flow Chart

Current Limitations on Decision Making

- Decision makers most often lack quantitative models that could be used to select the near-optimum site investigation and mitigation strategy

- Experience-based intuition and group consensus-based decision-making methods are much more commonly employed than quantitative or systematic decision-making tools (Clayton, 2017). Near-optimum decisions are likely the result of a combination of quantitative and intuitive methods.

- We have good experience-based intuition on some things – for example should I buy a new car this year or keep fixing my old clunker? This presentation aims to strengthen our understanding of the tradeoffs in VI decisions.

Summary of Economics Analysis Results (2022 Workshop)

- Four strategies were compared: Random sampling, Seasonal sampling, ITS Driven Sampling and Mitigation based solely on Radon > ambient.
- There can be dramatic differences in cost between sampling strategies
- Frequently with the assumptions used cost advantages were provided by the radon only decision making, or the ITS guided sampling.
- Sampling costs tended to dominate over control (mitigation) costs in this analysis, and thus strategies that led to rapid decision making in favor of mitigation reduced total cost.
- Thus, counterintuitively in some cases more stringent action levels led to lower costs.
- Results are very sensitive to the action levels selected and the details of a given buildings concentration distribution. Therefore, more cases should be analyzed.

Conclusions from Previously Presented Economics Analyses (2023 Workshop)

- Simple spreadsheet models have been developed to compare:
  - Strategies that rely primarily on monitoring vs. Strategies that employ mitigation early
  - Strategies that focus on building specific mitigation vs. strategies that focus on area SVE
- The balance between mitigation early vs. monitoring to refine risk estimate before mitigating turns on how many rounds you need to be confident.
- In the source zone case, 8 buildings an acre, SSD without GAC exhaust treatment is slightly cheaper than SVE. But if SSD needs to have GAC then SVE is cheaper.
- When the same source zone has only 3 buildings then SSD cheaper. With 16 buildings SVE is much cheaper. Building density matters.

Real World Cost Cases for Residential VI Mitigation – Regulated Sites

Region	Reference	# Buildings	Total $	$/building	Notes
New England	DiLorenzo, 2014; AEHS	43	$1.4M	$30K	Stone foundations, multiple additions
Southwestern U.S.	Minchak, 2018	13 buildings, 21 Systems	$815K	$62.7K	Significant building envelope repairs, multiple systems in some structures
Pompton Lakes N.J.	Borough of Pompton Lakes, Undated	Numerous	NA	$8.8K	Install and first year testing, typical home allowance.
Midwest or Northeast US Case	Regan 2022; AEHS	19	$670K	$35.3K	Includes extra costs for extra construction home improvements in older homes

A common error is to directly apply low mitigation costs associated with the radon mitigation systems installed as part of a property transfer to more highly regulated VI situations.
"Radon mitigation typically costs between $771 and $1,179" realestate.usnews.com

This Presentation Builds on Previously Presented Analyses

CH2MHILL.

Nonresidential Building: Vapor Intrusion Lifecycle Cost Analysis

Chris Lutes, CH2M HILL, Raleigh N.C.

Presented at EPA Workshop at AEHS 2015: ***Long-Term Evidence-Based Protection & Sustainability in Residential, Commercial, and Industrial Buildings***

https://iavi.rti.org/assets/docs/WorkshopsAndConferences/07_Lutes_Commercial%20Building%20Mitigation%20Economic%20AnalysisCL_JDM7.pdf

Groundwater Monitoring&Remediation

Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation

by Christopher Lutes, Lloyd Stewart, Robert Truesdale, Jose De Loera, John H. Zimmerman and Brian Schumacher

Lutes, Christopher, et al. "Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation." *Groundwater Monitoring & Remediation* 42.4 (2022): 43-53.

Non-residential Building Vapor Intrusion (VI) Lifecycle Cost – When Is Preemptive Mitigation a Good Value?

Christopher Lutes (Christopher.Lutes@ch2m.com) (CH2M, Raleigh, NC, USA)
Jeffrey Minchak (Jeffrey.Minchak@CH2M.com) (CH2M, Albuquerque, NM, USA)

https://www.researchgate.net/profile/Chris-Lutes/publications

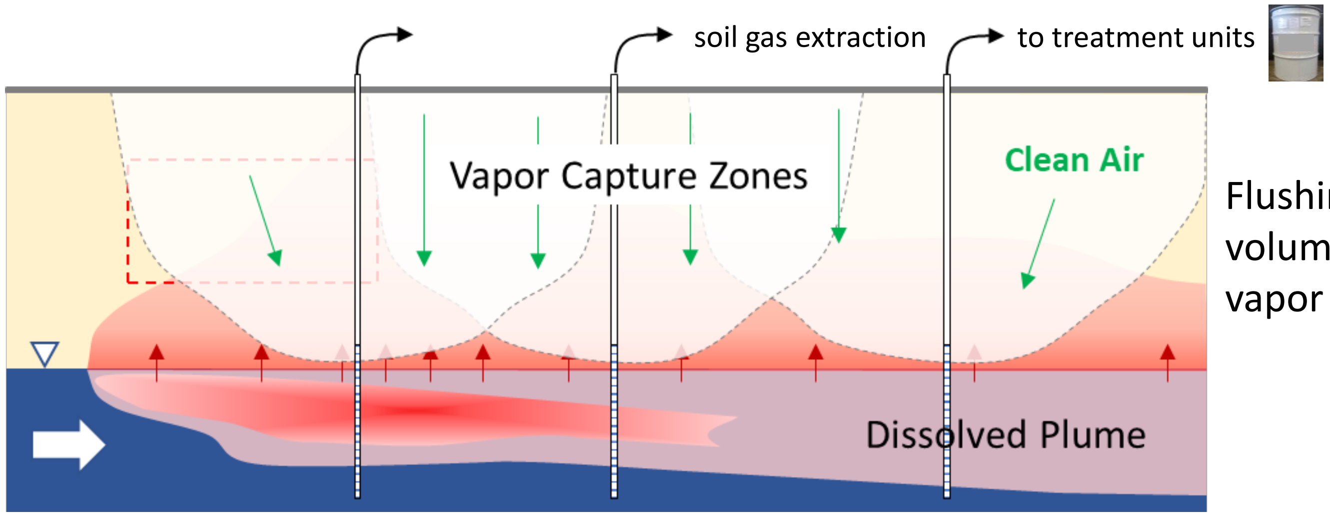
Economic Analyses of Vapor Intrusion Investigation, Mitigation and Remediation Decisions – What's Been Done and How Can it Help You?

Christopher C. Lutes, Jeffrey D. Minchak, Keri E. Hallberg, and Laurent C. Levy **Paper #1164201**

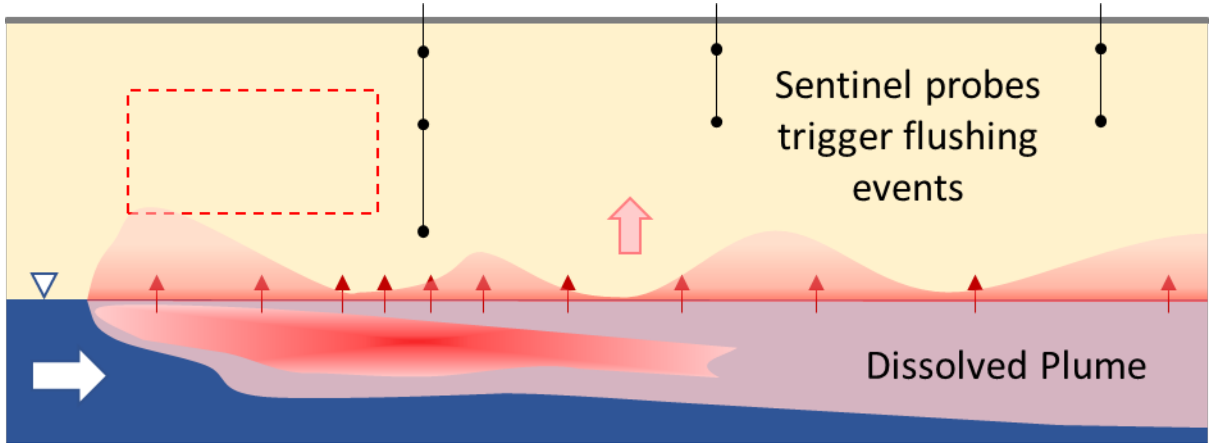
Jacobs; 111 Corning Rd Suite 200, Cary, NC 27518

Presented at: A&WMA's 115th Annual Conference & Exhibition San Francisco, CA June 27 – June 30, 2022

Design and Operational Concepts for VI Mitigation with SVE



Flushing several soil gas pore volumes suppresses the vapor plume, TEMPORARILY



Periodic monitoring of sentinel probes until a threshold concentration is detected; triggers flushing event

What’s Behind the Curtain?

- A spreadsheet calculation of costs for a hypothetical case (composite of experience)
- Broken out by tasks as an engineering professional would do when estimating costs:
  - Project management
  - Diagnostic Test
  - Design
  - Construction and oversight
  - Startup
  - Operations and Maintenance; Monitoring
- Further broken down into labor hours, individual materials items, analytical costs etc.
- Uses professional judgment, informed by regulatory guidance and vendor prices where available
- Not intended to be exact/binding estimate, but to illustrate the general trend of the tradeoffs and identify the sensitive parameters.

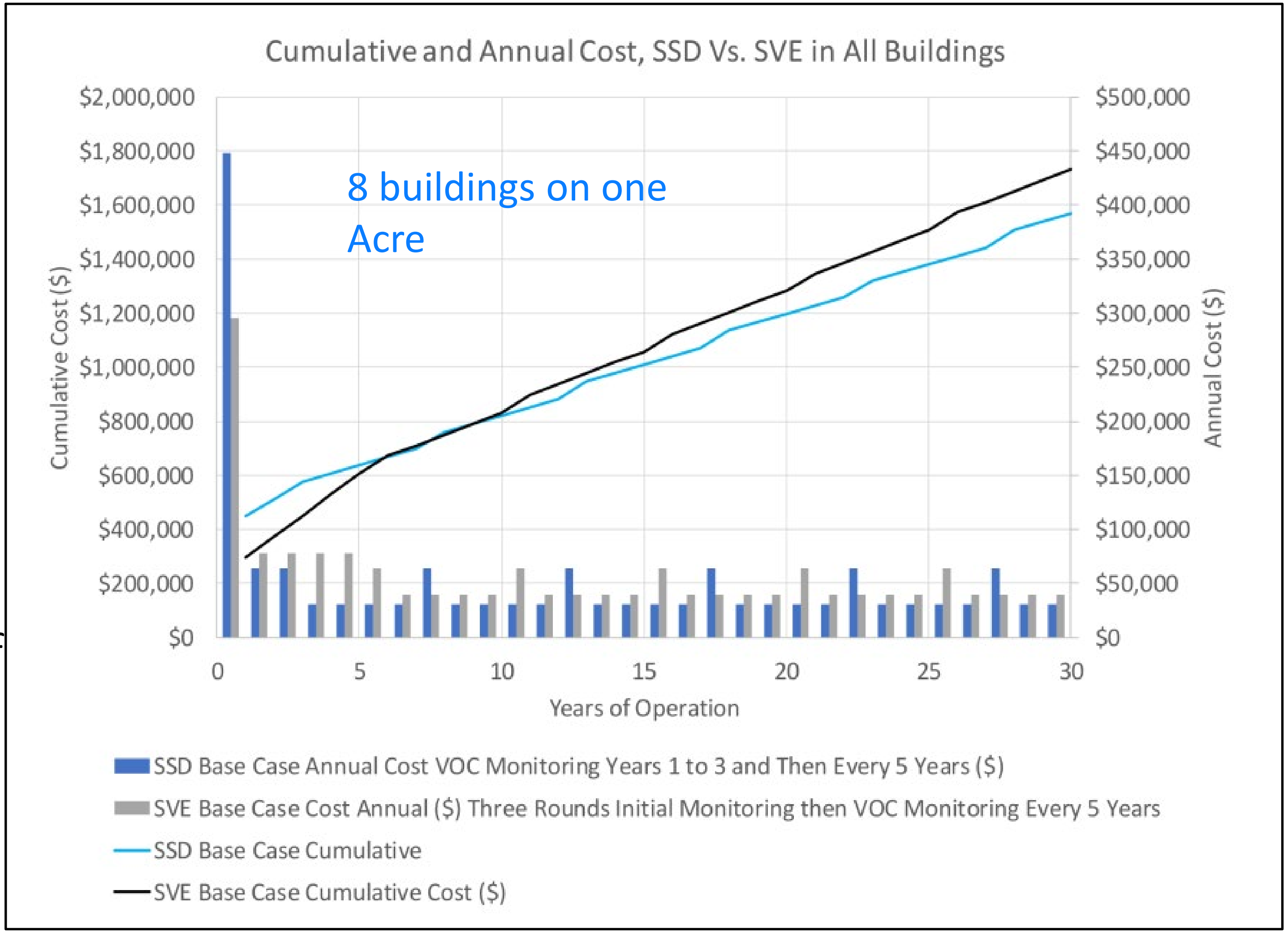
Situation: Multiple Commercial Buildings Close Together Over Source
Choice: Mitigate Buildings Individually (SSD) vs. SVE

Lutes, Christopher, et al. "Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation." *Groundwater Monitoring & Remediation* 42.4 (2022): 43-53.

- SVE performance and economics based on EPA funded field study
  - Stewart, Lloyd, Chris Lutes, Robert Truesdale, Brian Schumacher, John H. Zimmerman, and Rebecca Connell. "Field Study of Soil Vapor Extraction for Reducing Off-Site Vapor Intrusion." *Groundwater Monitoring & Remediation*. 40, no. 1 (2020): 74-85.
  - Fairly large SVE system: 20 HP blower, two 2000 lb vapor phase carbon modules, 4,000 lbs GAC used per year; 370 to 460 CFM
  - Eight buildings protected totaling 32,000 ft^2 on a total land area of 110,000 ft^2 (almost all paved)
  - assumes the SVE operation transitions from remediation to VI mitigation as the primary goal after 4 years using a subset of screens
  - Assumes the SVE effectiveness for VI monitored with three rounds indoor air (20 locations) plus a round every 5 years, and annual differential pressure
- Uses the Lutes & Minchak 2015 and 2016 mitigation costs scaled and applied to the eight buildings individually, and then summed.
  - Pressure field extension testing, plus three rounds of VOC monitoring in indoor air after installation, VOC monitoring in off-gas
  - Long term stewardship includes annual flow rate monitoring and differential pressure rechecks, indoor air every 5 years
  - No air emissions control on SSD

Base Case Results: SSD vs. SVE Costs

- SVE Capital $295K < SSD capital $448K
- SVE operational costs in early years when being used for mass removal are higher than SSD
- Costs equal after 6 years
- Total over 30 years SSD ($1,567K) modestly better cumulative then SVE ($1,733K)
- SSD benefits from the assumption of no off gas treatment
- But SVE provides additional source removal benefits

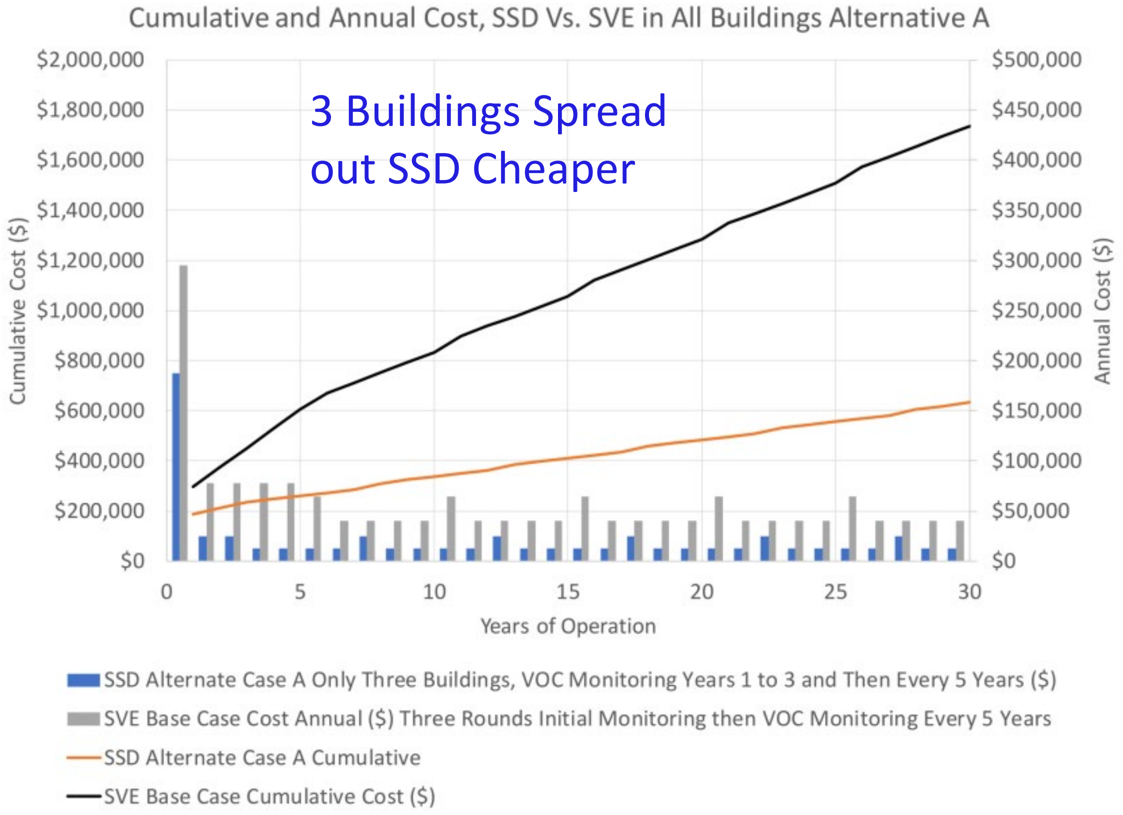


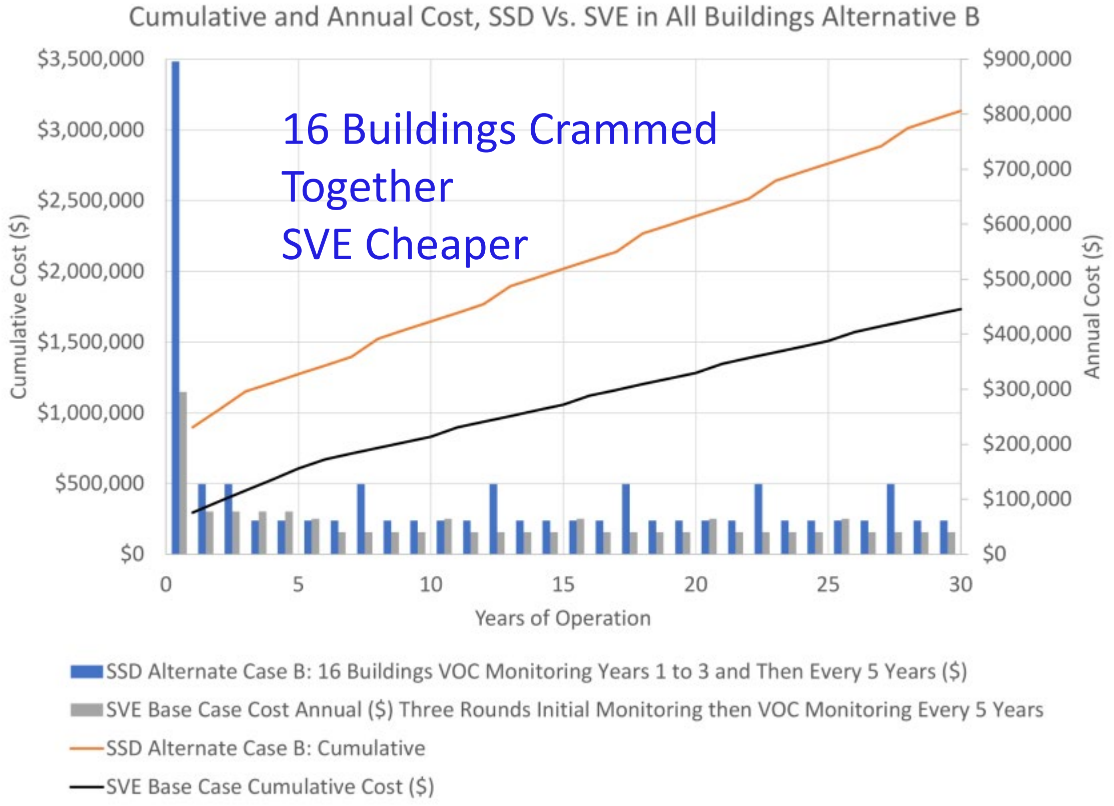
Sensitivity Analysis of Situation: Multiple Commercial Buildings Close Together Over Source; Choice: Mitigate Buildings Individually (SSD vs. SVE)

Analyses included in published paper

Red= Base Case Black = Alternatives

- Keep land the same, change percent of land area covered with buildings
  - 16% (only 3 of the 8 original buildings assumed to exist) = Alternate A
  - 30% (the 8 original buildings exist)
  - 58% (16 buildings now exist) = Alternative B





Limitations/Critiques of 2022 GWMR Analysis of SSD vs. SVE

- Although realistically representing a difference in how systems are often treated, analyzing SSD without offgas control is an “unfair” advantage for that technology.
    - Thus, we revised in this presentation to include an offgas control for SSD option.
- The EPA pilot site was a source zone with strong mass in soil and groundwater, thus the SVE blower and Granular Activated Carbon (GAC) was bigger than needed for long term continuous service, what would the results be like over a dilute plume?
    - Thus, we considered a thought experiment involving “relocating” the same buildings to place them over a dilute plume. A down-sized solar SVE system was costed.
- Would the results have been different if the buildings were residential instead of commercial?
    - Thus, residential buildings of the same footprint and foundation style but with more suites/apartments considered.

Photos To Show Building Style – Not from Actual Test Site

Photos reprinted from https://www.tri-c.edu/workforce/public-safety/simulated-scenario-village.html
https://www.nps.gov/places/wohlner-s-neighborhood-grocery.htm?utm_source=place&utm_medium=website&utm_campaign=experience_more&utm_content=small

Estimated SSD Cost Impact of Changes from Commercial and Residential No GAC to Residential with GAC

Commercial vs. Residential No GAC	
Commercial 1st Year Cost	$448,000
Residential 1st Year Cost	$497,000
Change	+11%
Commercial Subsequent years cost (3 years)	$94,000
Residential Subsequent years cost (3 years)	$108,000
Change*	+14%

Residential No GAC vs. Residential with GAC	
Residential no GAC 1st Year Cost	$497,000
Residential+ GAC 1st Year Cost	$521,000
Change	+5%
Residential no GAC Subsequent years cost (3 years)	$108,000
Residential + GAC Subsequent years cost (3 years)	$143,000
Change**	+32%

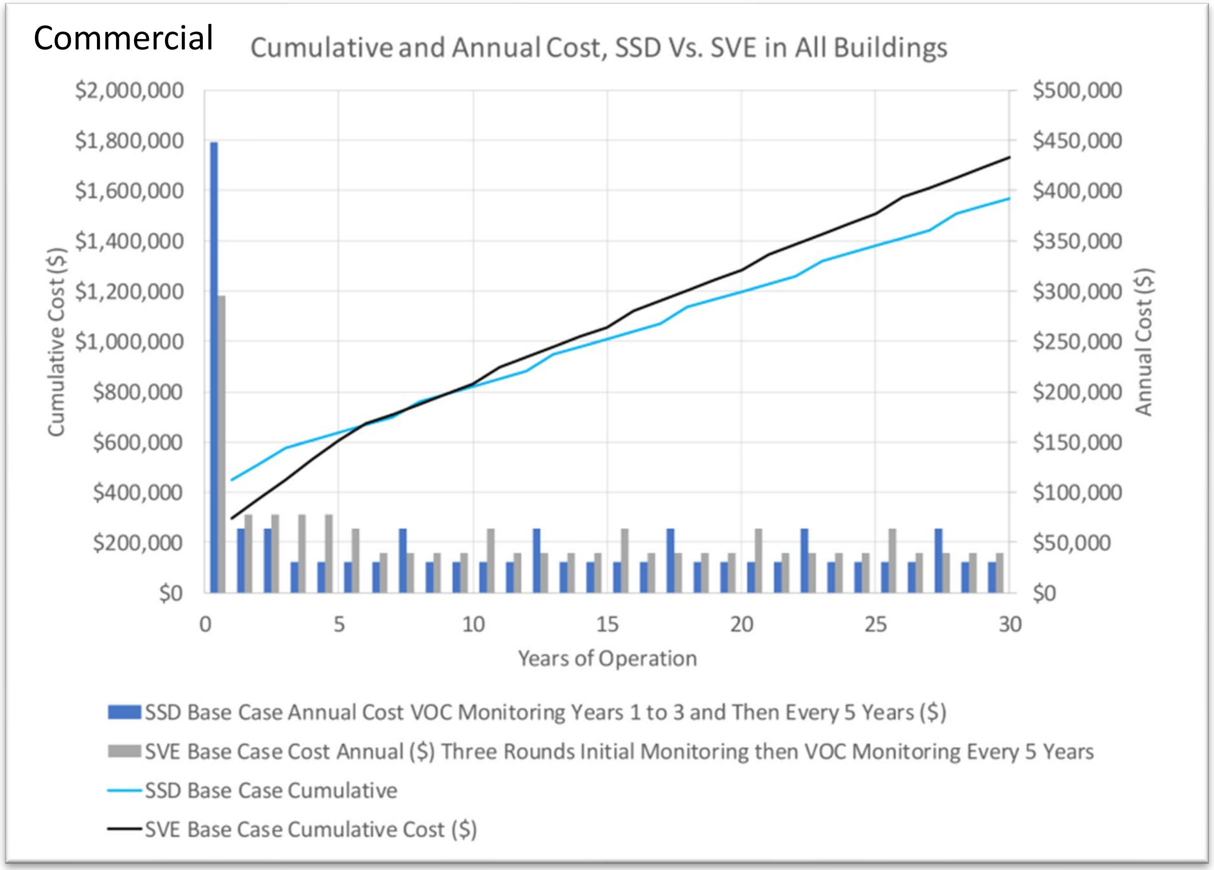
Commercial No GAC vs. Residential with GAC	
Commercial 1st Year Cost	$448,000
Residential+ GAC 1st Year Cost	$521,000
Change	+16%
Commercial Subsequent years cost (3 years)	$94,000
Residential + GAC Subsequent years cost (3 years)	$143,000
Change**	+52%

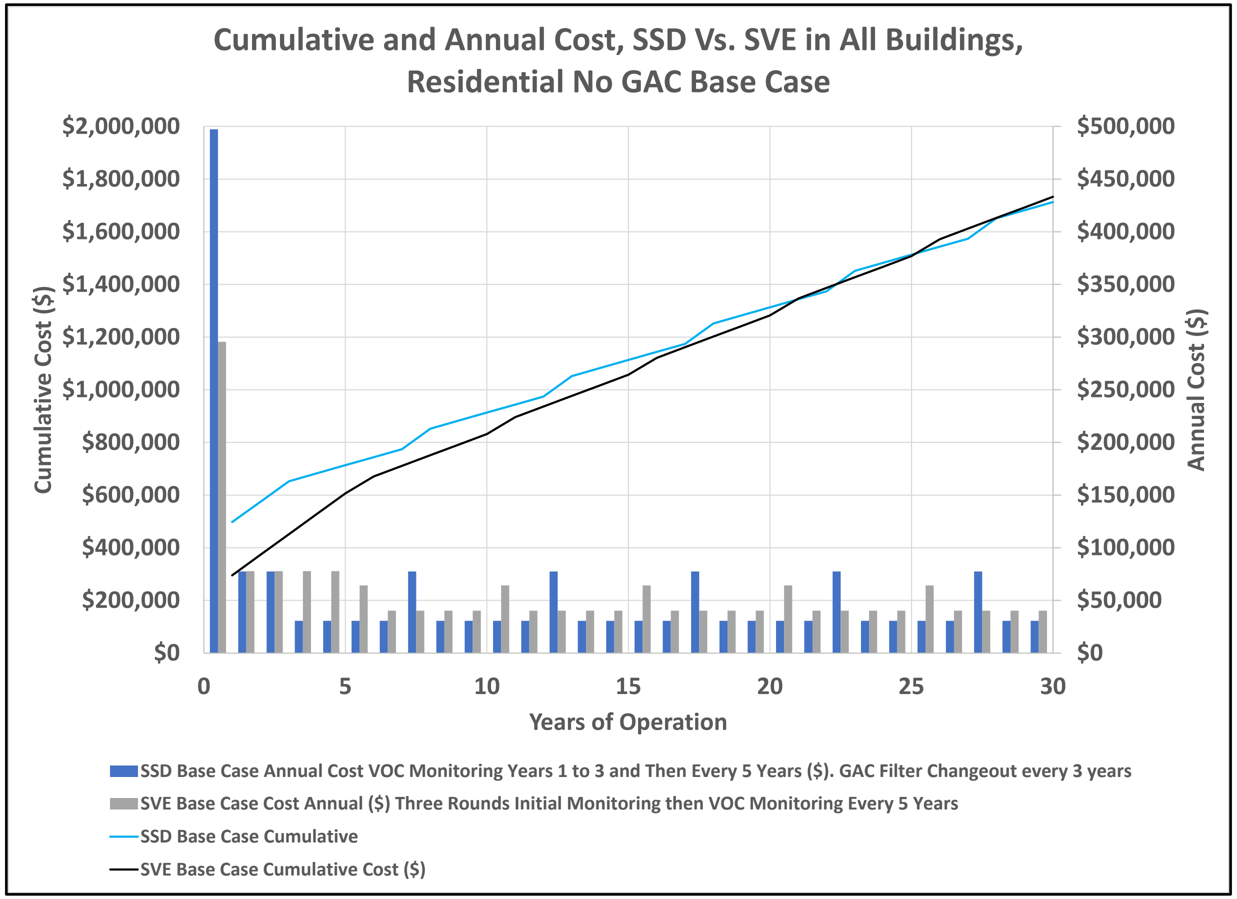
Notes:

* Cost of sampling at residential locations is higher than at commercial locations. More samples are collected at residential buildings based on number of residential units of each building (2 per unit).

** Cost increase is due mainly to GAC replacement (assumed to happen every 3 years)

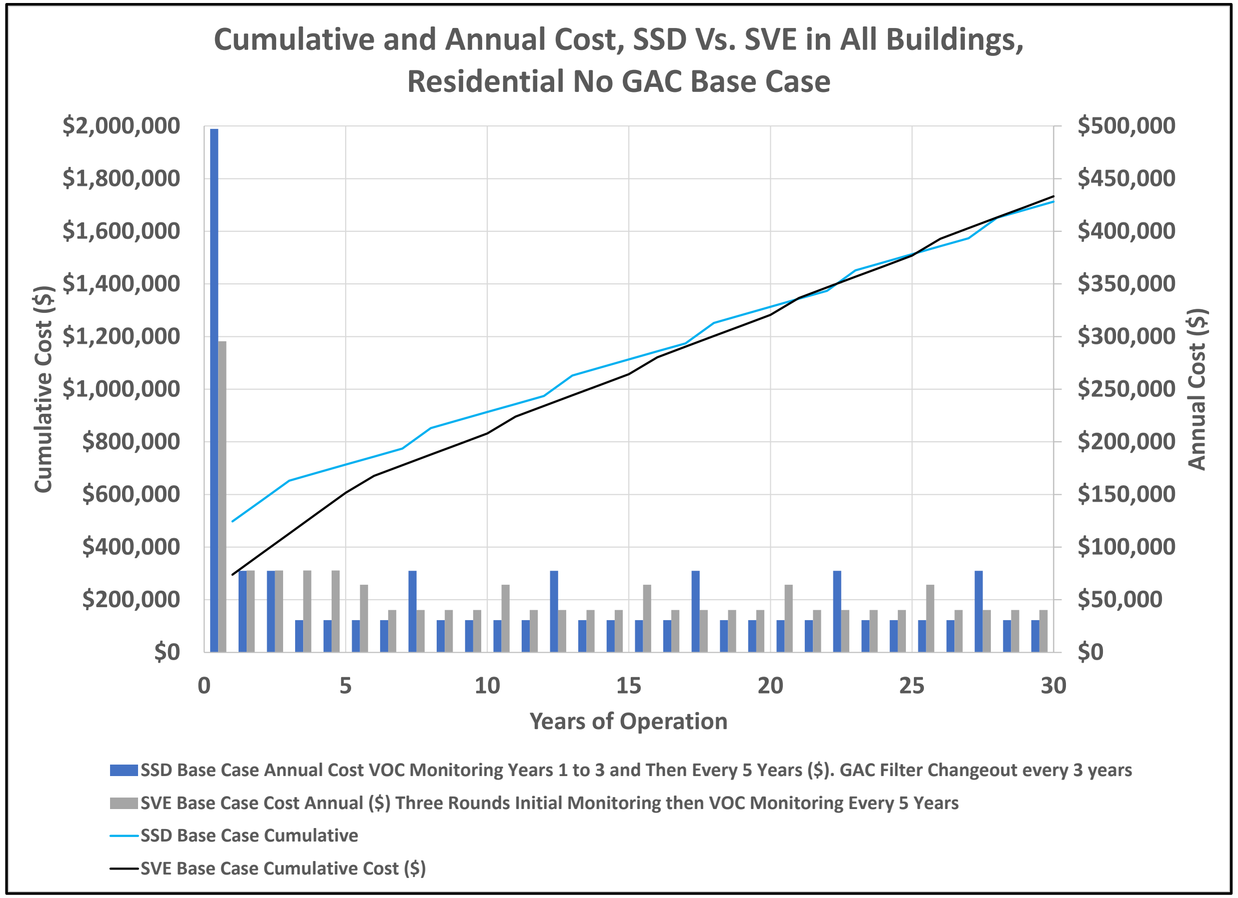
Impact of Going from Commercial Without GAC to Residential without GAC: Source Zone SVE as In Previous Paper

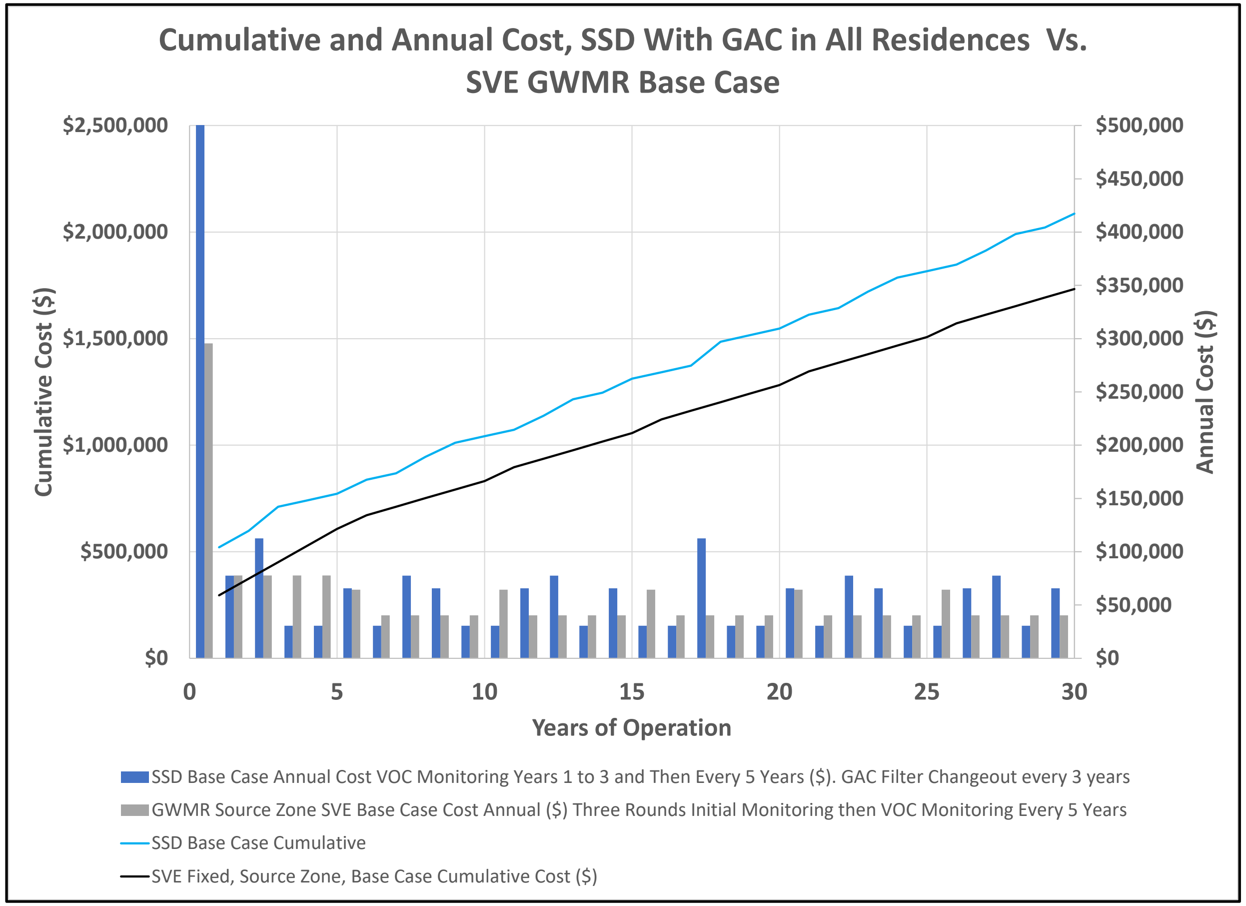




Commercial to Residential Change Raises SSD Cost slightly (more suites, Leads to Essentially a Tie)

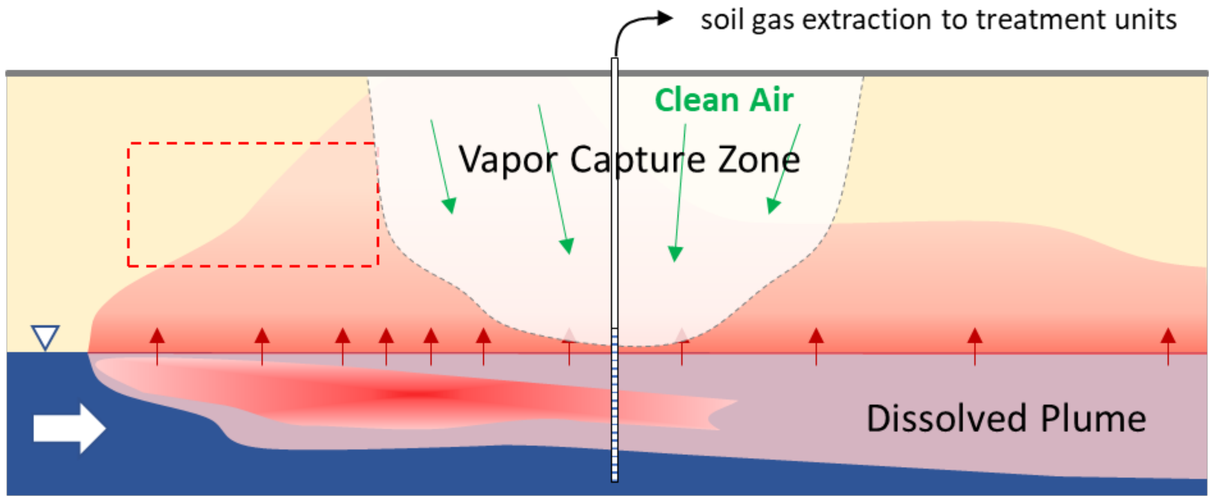
Impact of Going from Residential Without GAC to Residential with GAC; Source Zone SVE as In Previous Paper





Adding offgas treatment to SSD makes SVE the cheaper alternative

Design and Operational Concepts for VI Mitigation with SVE



How far does one well reach?

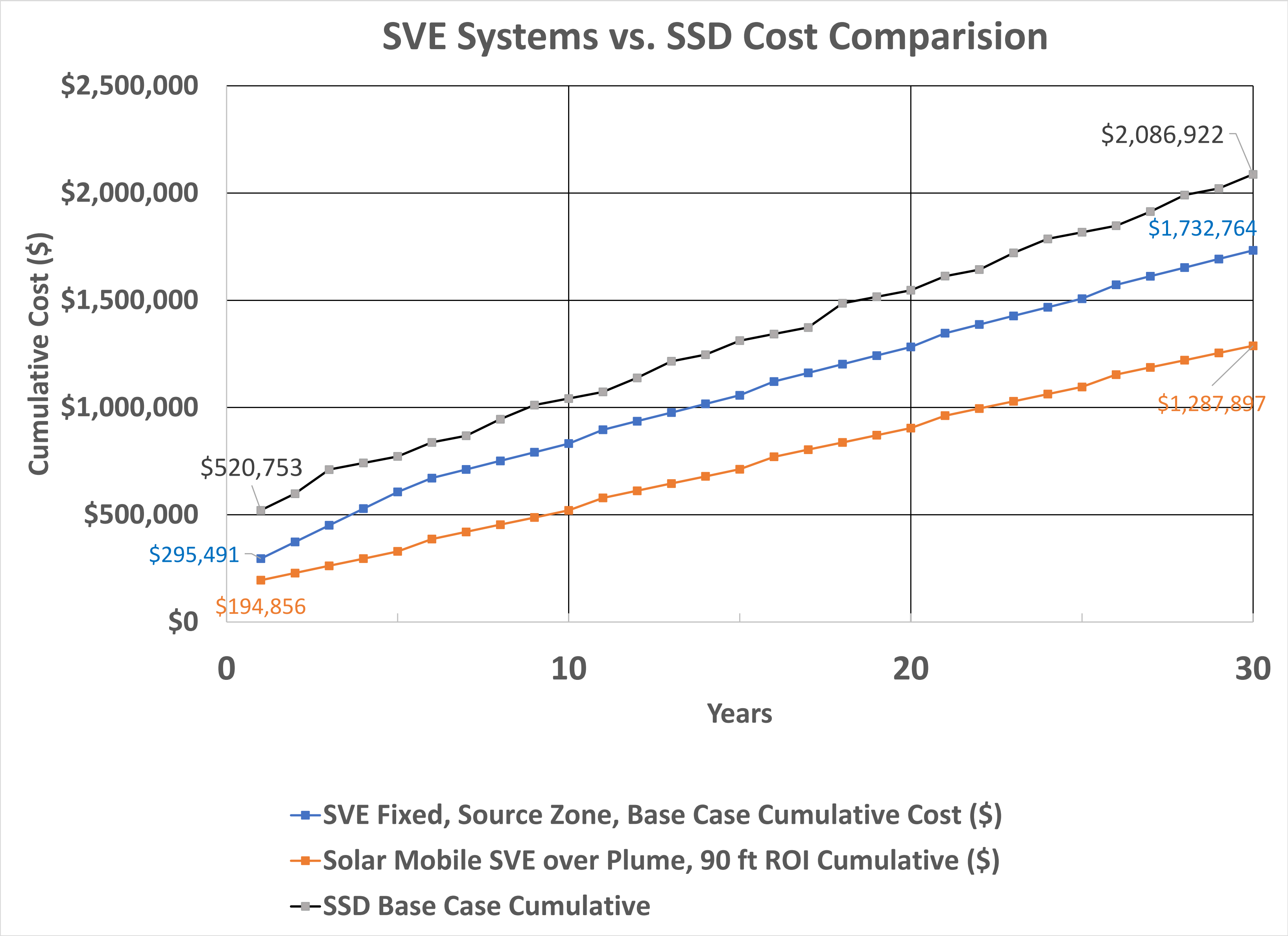
How many wells are required for a given surface area?

Can we perform the extraction with a self-contained, solar-powered system in a parking space?

New Option Analysis –Mobile Solar Powered Shallow SVE – System Will Be Described in Depth in Bo's Next Talk

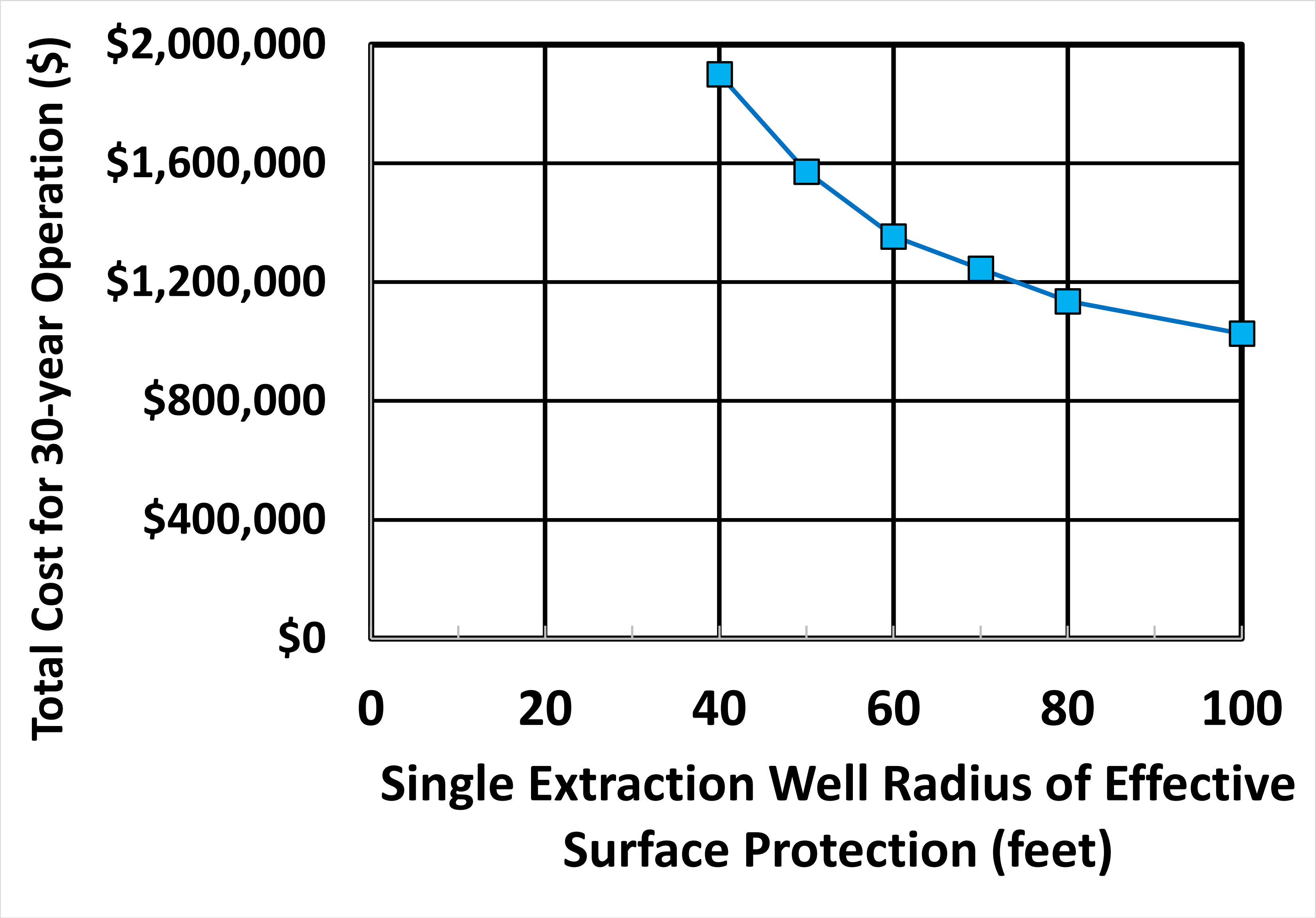
- Elements of estimate include:
  - Development of design basis through a one day pilot test with 1 HP rented system, 24 vapor samples
  - Design and purchase of trailer mounted SVE system with 5 HP Blower, controls, telemetry and solar power. Includes 2 * 200 lb carbon beds. Includes drilling three extraction wells and installing 2 multidepth sample ports.
  - Initial flushing and operational period; one week on each of several extraction wells with sample analysis; prepare site specific O&M plan
  - Operates one month on each well, only during periods when solar is sufficient
  - Annual Operating Cost, Quarterly sampling of sentinel wells
- Assumptions in Long Term Cost Analysis
  - First year includes short design pilot test, deploy SVE system, initial flushing & operation, Soil Gas and Offgas Monitoring
  - Subsequent years are routine mobile operations, with soil gas and offgas monitoring
  - Subslab monitoring only in buildings in years 1, 6, 11, 16, 21, 26…..

Impact of Changing from Fixed Source Zone SVE to Mobile Solar SVE



Key Point: Mobile, solar SVE over plume less expensive, even in capital cost, as compared to fixed source zone SVE.

Mobile Solar Soil Gas Sampling – Life Cycle Cost as Function of Radius of Influence – 1 Acre Site as in GWMR



Mobile Solar SVE – Life Cycle Cost as Function of Acreage

- Assumes a constant 90 ft ROI
- w/o subslab but with external soil gas and offgas monitoring

Size	Number of Extraction Wells	Design + Capital Cost ($K)	10 Year Cumulative Cost ($K)	30 Year Cumulative Cost($K)
1 Acre (as in 8 bldg. case)	2	$114	$465K	$1,136
7 Acres	12	$253	$1,301	$3,240

What Happens if I Don't Separately Attack the Original Source?

- It depends on the time for the "news of cleanup" to arrive at the downgradient location, but your grandchildren will save money in mitigation or downgradient SVE if you cut operating duration by attacking the source.
- Costs here are constant dollar, without inflation, without net present value
- Does not account completely for equipment wearing out, buildings going beyond economic life or environmental standards changing

	SSD in 8 Buildings (as in GWMR)	Solar, Mobile SVE over Plume
10 Year Cumulative Cost ($K)	$1,042K	$521K
30 Year Cumulative Cost ($K)	$2,087K	$1,288K
100 Year Cumulative Cost ($K)	$5,645K	$4,030K

"There is general agreement among practicing remediation professionals, however, that there is a substantial population of sites, where, due to inherent geologic complexities, restoration within the next 50-100 years is likely not achievable."
National Academy of Sciences "Alternatives for Managing the Nations Complex Contaminated Groundwater Sites", 2012

Potential Improved Site Management Strategies for Discussion

- Select representative volunteer structures in a neighborhood for intensive sampling, perhaps with I&T or GC but don't try to do every house at first. Promise those houses priority $ for mitigation.
- I&T can also be used to reduce mitigation cost and provide additional confidence.
- Emphasize delineation of and management of the soil gas plume. Use soil vapor extraction where possible to cutoff the pathway to multiple houses without intrusive work.
- Soil gas safe approach – emphasizes use of I&T, passive sampling and citizen science engagement. Seeks to minimize stigma by handling the problem at a neighborhood scale and turning soil gas safety into a positive feature.
- Complete delineation of the soil gas plume and expedite remediation to "pull it back" away from structures rather than spending so much money on structure by structure sampling.

Summary: Economics

- Simple spreadsheet models have been developed here to compare:
  - Strategies that rely primarily on monitoring vs. Strategies that employ mitigation early
  - Strategies that focus on building specific mitigation vs. strategies that focus on area SVE
- The balance between mitigation early vs. monitoring to refine risk estimate before mitigating turns on how many rounds you need to be confident.
- In the source zone case, 8 buildings an acre, SSD without GAC exhaust treatment is slightly cheaper than SVE. But if SSD needs to have GAC then SVE is cheaper.
- When the same source zone has only 3 buildings then SSD cheaper. With 16 buildings SVE is much cheaper. Building density matters.
- Changing building from commercial to residential primarily matters for SSD if number of ground floor suites changes.
- A mobile solar powered SVE system over a plume provides a significant cost advantage in the 1 acre, 8 building case vs. fixed, source zone SVE.
- The single mobile solar powered unit with the assumptions used here could serve up to 7 acres downgradient.

References for More Information: Economics

- *Economic Analyses of Long-Term Stewardship: Balancing Investigation, Mitigation and Remediation Decisions,* U.S. EPA "State of VI Science" Workshop, March 21, 2023 https://iavi.rti.org/assets/docs/14_Lutes-Economics_of_LTS.pdf
- *Economic Analyses of Vapor Intrusion Investigation, Mitigation and Remediation Decisions – What's Been Done and How Can it Help You*, in EM A&WMA's monthly magazine for environmental managers, August 2022.
- *Methods and Approach for Equivalent Protection Cost Effectiveness analysis of I&T vs. traditional sampling, screening & mitigation approaches*t U.S. EPA "State of VI Science" Workshop, March 15, 2022. https://iavi.rti.org/assets/docs/06_Kondash_Methods_EP_CL.pdf
- *Results and Interpretation of Sampling Strategy and Equivalent Protection Cost Effectiveness Analyses*" at U.S. EPA "State of VI Science" WorkshopMarch 15, 2022. https://iavi.rti.org/assets/docs/07_Lutes_Results_SSA_EPCEA.pdf
- *Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation*; Groundwater Monitoring and Remediation 2022, http://doi.org/10.1111/gwmr.12510.

References for More Information: Sampling Strategies and Performance

- *Sampling Strategy Performance: Daily and Weekly Durations: Comparing Random, Seasonal and Indicator- & Tracer-Guided* U.S. EPA "State of VI Science" Workshop March 21, 2023. https://iavi.rti.org/assets/docs/05_Lutes-Sampling_Strategies.pdf
- *"State and Regional Vapor Intrusion Site Assessment Guidance (As of Fall 2022)"* U.S. EPA "State of VI Science" Workshop, March 21, 2023. https://iavi.rti.org/assets/docs/03_Lutes-State_Regional_VI_Assessment.pdf
- *Prioritizing Buildings/Zones Using a Quantitative Decision Framework and Incorporating Indicators/Tracers into Vapor Intrusion Building Assessments* U.S. EPA "State of VI Science" Workshop, March 21, 2023 https://iavi.rti.org/assets/docs/09_Hallberg-Quantitative_Decision_Framework.pdf
- *Understanding the Relationship Between Indicators & Tracers and Vapor Intrusion: Dynamic time series regression modelling of indoor air VOC concentrations* U.S. EPA "State of VI Science" Workshop, March 21, 2023. https://iavi.rti.org/assets/docs/12_Mulhern-Time_series_regression.pdf
- *Summary of Relevant Vapor Intrusion (VI) Indicator and Tracer (I&T) Research: Recently Completed, On-going & Planned* EPA "State of VI Science" Workshop March 15, 2022. https://iavi.rti.org/assets/docs/05_Lutes_Summary_of_VI_Research.pdf
- *Observation of Conditions Preceding Peak Indoor Air Volatile Organic Compound Concentrations in Vapor Intrusion Studies;* Groundwater Monitoring and Remediation 2021 https://ngwa.onlinelibrary.wiley.com/doi/10.1111/gwmr.12452, Spring 2021, p 99-111.
- *Chlorinated vapor intrusion indicators, tracers, and surrogates (ITS): Supplemental measurements for minimizing the number of chemical indoor air samples—Part 1: Vapor intrusion driving forces and related environmental factors,* Remediation Journal, Published on line June 6, 2018, Volume 28, Issue 3; p 7-31.

References for More Information: Vadose Zone Remediation

- *Soil Vapor Extraction as a Tool for Soil Gas Management in Neighborhoods*, U.S. EPA "State of VI Science" Workshop March 21, 2023 and on-line webinar. https://iavi.rti.org/assets/docs/13_Stewart_SVE.pdf.
- *Soil Vapor Extraction for VI Protectiveness Across Multiple Buildings*" U.S. EPA "State of VI Science" Workshop: March 15, 2022. https://iavi.rti.org/assets/docs/08_Stewart_Truesdale_SVE-VI.pdf
- *Field Study of Soil Vapor Extraction for Reducing Off-Site Vapor Intrusion., Groundwater Monitoring & Remediation*. 40, no. 1 (2020): 74-85.
- *Engineering Issue: Soil Vapor Extraction (SVE) Technology* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-18/053, 2018.

References for Individual Sites

Gaffney Alaska

- *Seasonal Vapor Intrusion Variability Across Six Commercial Buildings in Fairbanks, Alaska – A Continental sub-Arctic Climate Zone with Inversions*, Presented October 3, 2023 at AWMA Specialty Conference Advancements in Vapor Intrusion and Emerging Contaminant Air Quality Issues, Chicago.
- *Gaffney Road Site, Fairbanks, AK Past, Present and Possible Future: Lessons Learned for Vapor Intrusion Site Management;* presented July 14, 2022 to Quarterly Meeting of State Coalition for the Remediation of Drycleaners.
- *Quantitative correlations observed and tested – Gaffney* EPA Workshop 2020 https://iavi.rti.org/assets/docs/05D_Gaffney_Mar2020.pdf
- *The predictable influence of soil temperature and barometric pressure changes on vapor intrusion."* Atmospheric Environment 150 (2017): 15-23

VA Site A

- *Impact of Hurricanes, Tropical Storms, and Coastal Extratropical Storms on Indoor Air VOC*; Groundwater Monitoring and Remediation, published on line March 28, 2024 **https://doi.org/10.1111/gwmr.12642**
- *The Representativeness of Subslab Soil Gas Collection as Effected by Probe Construction and Sampling Methods.* Groundwater Monitoring & Remediation, June 2024. **https://doi.org/10.1111/gwmr.12663**
- *Eighteen Months of High Resolution Indoor and Subslab Temporal Observations from an Industrial Building* Presented as part of U.S. EPA "State of VI Science", March 2021, Virtual. https://iavi.rti.org/assets/docs/04_High%20Res_Indoor_Subslab_2021_AEHS.pdf
- *Temporal Variability in an Industrial Building –Time Series and Machine Learning Analysis*; Groundwater Monitoring and Remediation https://ngwa.onlinelibrary.wiley.com/doi/10.1111/gwmr.12453 Spring 2021 p 87-98

Indianapolis

- *Quantitative correlations observed and tested - EPA Indianapolis duplex EPA's 2020 Vapor Intrusion Workshop* https://iavi.rti.org/assets/docs/05E_Indy_Duplex_Mar2020.pdf
- *Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variations* EPA/600/R-12/673, September 2012.

References for Individual Sites

VA Site B

- *Evaluation of Long-Term Flow Controller for Monitoring Gases and Vapors in Buildings Impacted by Vapor Intrusion,* International Journal of Environmental Research and Public Health, March 2023 Int. J. Environ. Res. Public Health 2023, 20, 4811. https://doi.org/10.3390/ijerph20064811.
- *Demonstration of a Long-Term Sampling Approach for Volatile Organic Compounds in Indoor Air*; Final Report ESTCP Project ER-201504, April 2020. https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201504

MEW

- *Temporal Variability, Part 1 (continued) Quantitative correlations observed and tested – Observations from available data sets: Moffett Field CA (Building 15), EPA Vapor Intrusion Workshop:* March 17, 2020. https://iavi.rti.org/assets/docs/05A_Moffett_Field_Mar2020.pdf
- *Results of a long-term study of vapor intrusion at four large buildings at the NASA Ames Research Center."* Journal of the Air & Waste Management Association 60, no. 6 (2010): 747- 758.
- *Time-variable simulation of soil vapor intrusion into a building with a combined crawl space and basement.* Environmental science & technology 41, no. 14 (2007): 4993-5001.

Sun Devil Manor (SDM)

- *Observations from Available Data Sets: Sun Devil Manor (SDM), Layton, UT EPA Vapor Intrusion Workshop:* March 17, 2020. **https://iavi.rti.org/assets/docs/05f_SDM_Mar2020.pdf**
- *Temporal Variability of Indoor Air Concentrations Under Natural Conditions in a House Overlying a Dilute Chlorinated Solvent Groundwater Plume.* Environ. Sci. Technol. 47(23):13347-13354. Accessed on June 1, 2020 at https://pubs.acs.org/doi/10.1021/es4024767.
- *Evaluation of vapor intrusion pathway assessment through long-term monitoring studies* (Doctoral dissertation, Arizona State University). Retrieved from https://repository.asu.edu/attachments/150778/content/Holton_asu_0010E_15040.pdf

SVE Results Summary

Provide preliminary design concepts for VI control in Soil Gas Safe Communities

"***Evaluation of VI Mass Flux from Transient Vertical Vapor Concentration Profiles***", Manuscript in Preparation

- AEHS East Presentation slides available

"***Analytical Solutions for Steady-State Gas Flow in Layered Soils with Field Applications***", Groundwater Monitoring & Remediation, January 2022, https://doi.org/10.1111/gwmr.12496

"***Development and Testing of New Design and Operational Concepts for VI Mitigation with SVE***", Manuscript in Preparation

For further Information

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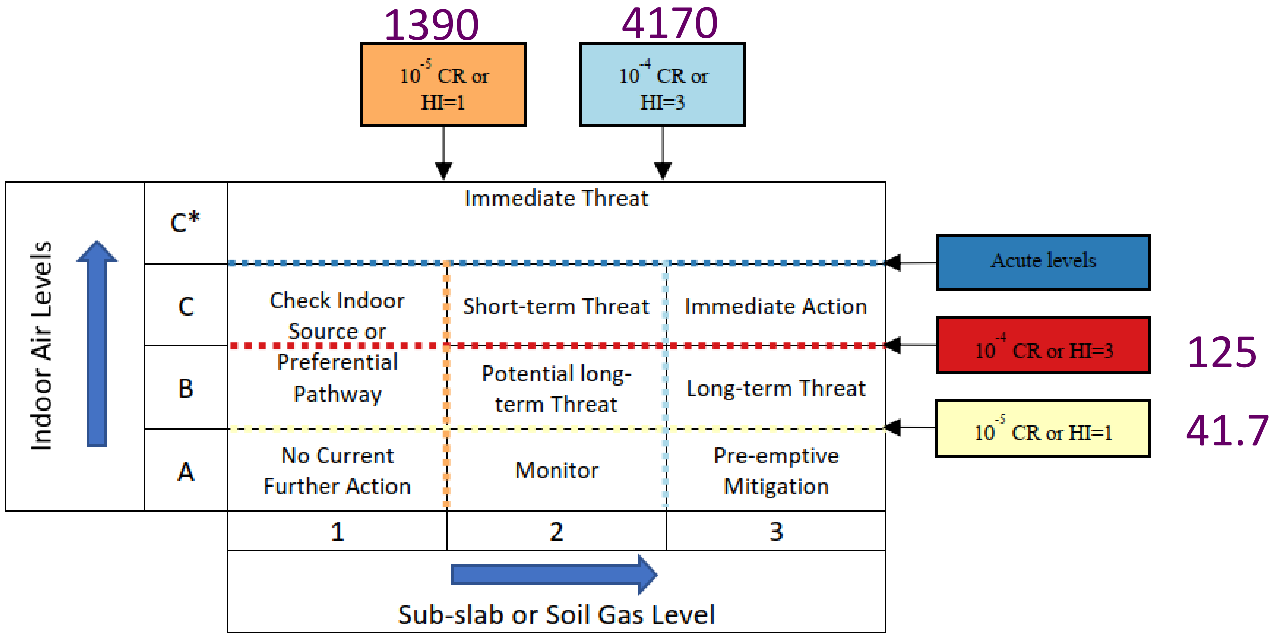
Backup Slides Only After This

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

Category	Air Results: Indoor	Air Results: 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

Summary of a Sampling Analysis

- A method for analyzing the performance of realistic sampling strategies using rich research datasets.
- In each individual case analyzed, an Indicator and Tracer (I&T) based sampling rule and/or a seasonal based sampling rule can be identified that substantially outperforms random sampling.
- However, the top performing I&T based rule is not the same across all sampling zones, so additional mechanistic insight is needed to select *a priori* the optimum sampling rule for a given sampling zone.
- An *a priori* selection of sampling rule would need to be based on the information generally available before initiating sampling at a given building: climate zone, building type, and a conceptual site model describing the primary source of contamination (groundwater vs. soil).
- Making decisions based on four randomly or convenience based short term samples will not likely characterize the 90^{th} or higher percentile of the concentration distribution.
- At some sites with highly skewed concentration distributions, making decisions based on four randomly or convenience based short term samples will underestimate the mean long-term concentration, because a small percentage of the samples contribute >50% of the total exposure.
- Extending sample durations to weekly provides in many cases a modest incremental benefit in increasing the probability of reaching a performance goal for a sampling approach.

Sampling Performance Analysis Approach: Did I&T Increase the odds of seeing upper end concentration?

Or

Or

Or

> ?

p90 of distribution, 95 % UCL of Mean or p50 of cumulative total exposure

Long Term Indoor Concentration Data Sets ≈real concentration distribution ≈ Approximation of Reality

Apply Sample Scheduling Rule

Test many 2 or 4 possible sample events – either day long or week long

Compare Subsample Mean or Max To

Performance Goal= VI Screening Level, True Distribution Mean or Percentile

Evaluate Whether Confident and Accurate Enough

Metric, Probability or Odds

Data Sets Tested in This Study (n is # sampling events for VOCs)

- Sun Devil Manor (Residential); unoccupied, with land drain open, without blower door, n=342 daily averages
- Indianapolis Duplex (Residential) – unoccupied, data from two floors; without mitigation; n=58 weeklong samples or 49 weeklong with high time resolution radon ; n=136 daily averages
- Moffett Field Building 15 (Commercial) – normal operating conditions; n =156 daily averages
- Gaffney Alaska (Commercial) – normal operating conditions, n= 27 days of sampling
- Virginia Site A (Industrial) – two locations – normal operating conditions n=589 daily averages

Sampling Performance Analysis Assumptions

Key Question: Will the proposed strategies help achieve better odds of observing upper end concentrations than random sampling?

- Most Scheduling Approaches Tested with 2 vs. 4 Sampling events
- Assumed computer or person would “evaluate” previous data at midnight to decide whether to sample that day or week (starting in theory at 12:01 AM).
- Evaluation could be automated/triggered sampling; human in the decision loop, weather forecast, or calendar based.
- All allowable combinations of sampling days based on scheduling approach considered equally likely.
- Days to be sampled will be defined as 24-hour block averages. Either one Summa sample or a daily block average GC result.
- Week samples defined as 7 day block averages, or the actual result of a 6 to 8 day passive sample.

Metrics, Probabilities, Tested (more tested and will be published, but only these two in this presentation)

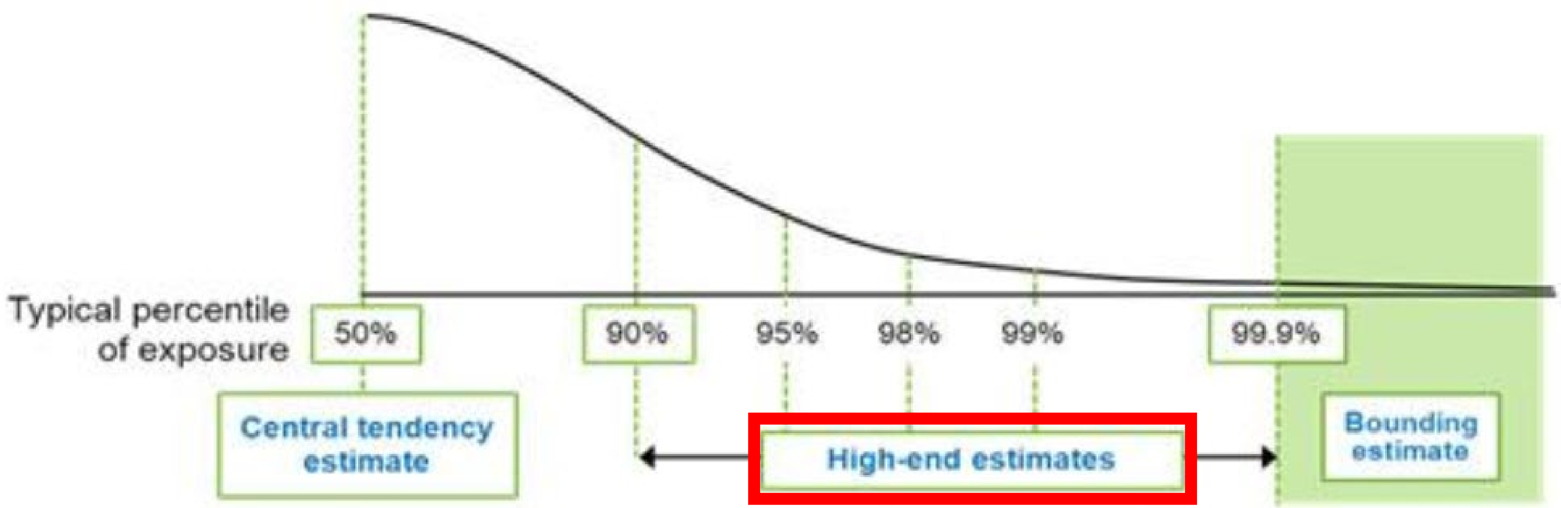
- At least one of the two or four samples will exceed the 90th percentile of the underlying distribution
- At least one of the two or four samples taken will come from above the 50% of total cumulative exposure point.

Reasonable Maximum Exposure (RME)

USEPA (1989) Risk Assessment Guidance for Superfund (RAGS)

RME = Highest exposure that is reasonably expected to occur

- Exposure depends on:
  - Chemical exposure concentration; and
  - Input parameters that describe the exposed population
- Values for inputs selected to give RME estimate
  - Combination of central tendency and high-end values

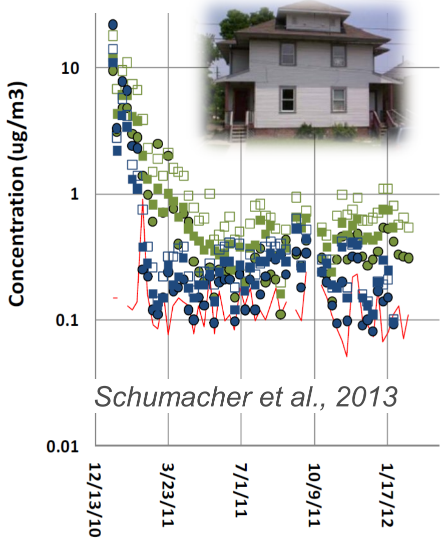


www.epa.gov/expobox/exposure-assessment-tools-tiers-and-types-deterministic-and-probabilistic-assessments

Considerations when Estimating Indoor Air Concentrations

$$EC = (\boxed{CA} \times ET \times EF \times ED)/AT$$

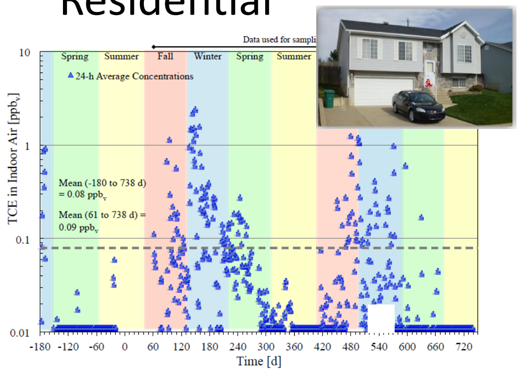
Residential



Schumacher et al., 2013

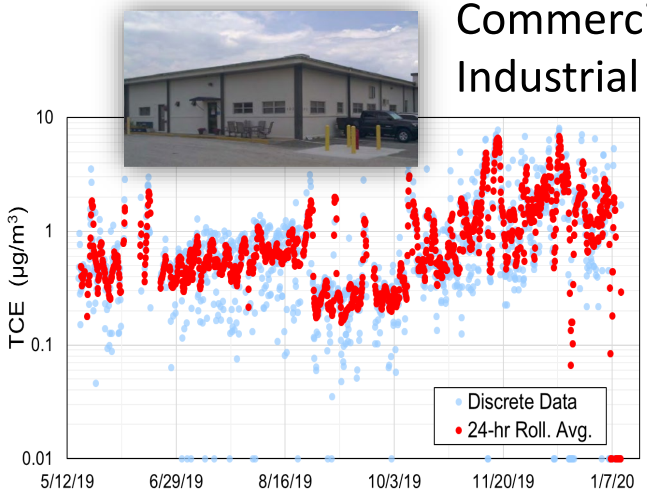
- Can 95UCL on mean be calculated with sufficient confidence?
- How to account for uncertainty/variability in time and space?
  - Timing, type, number, location/zone, frequency, and duration of samples?
- Should maximum or 95th/90th percentile indoor concentrations be used if unable to calculate 95UCLs?
- How can indicators/tracers/surrogates (ITS) increase confidence?

Residential



Johnson et al., 2015

Commercial/
Industrial

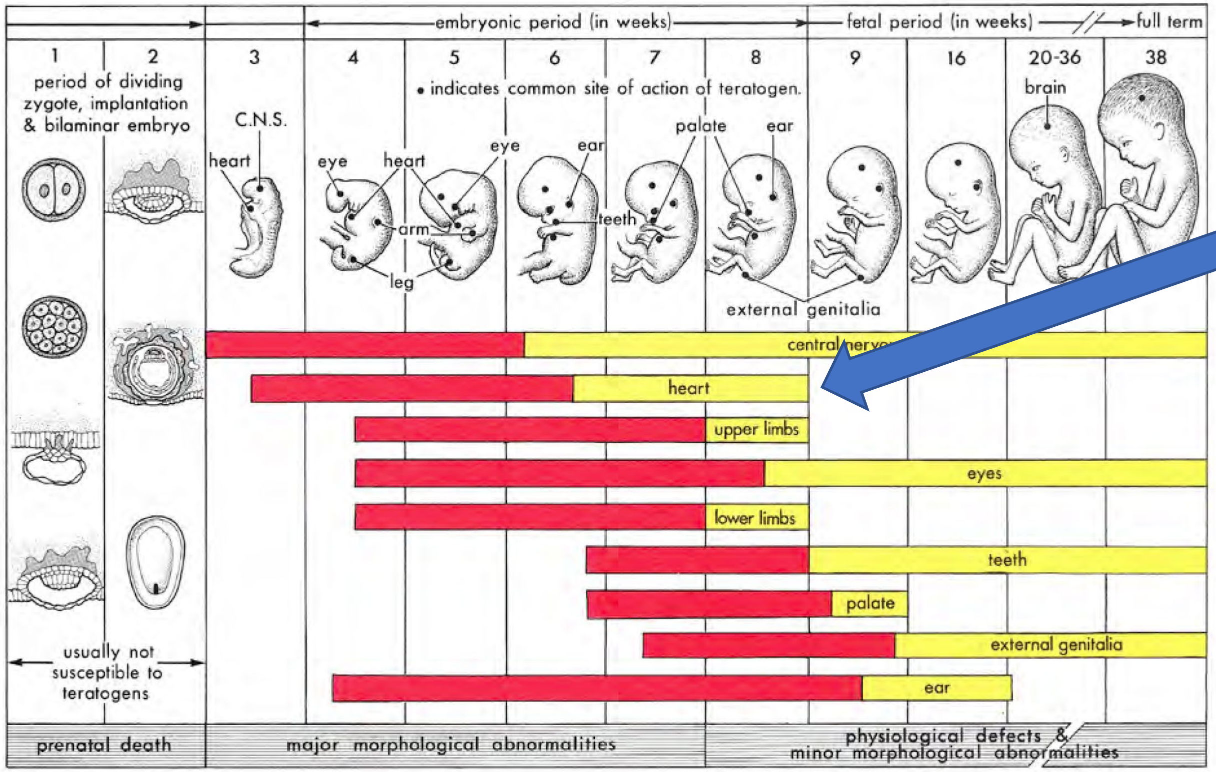


Short-Term Toxicity (cont'd)

> *"For developmental toxicants, the time period of concern is the exposure event. This is based on the assumption that a single exposure at the critical time in development is sufficient to produce an adverse effect."*

EPA (1989) RAGS

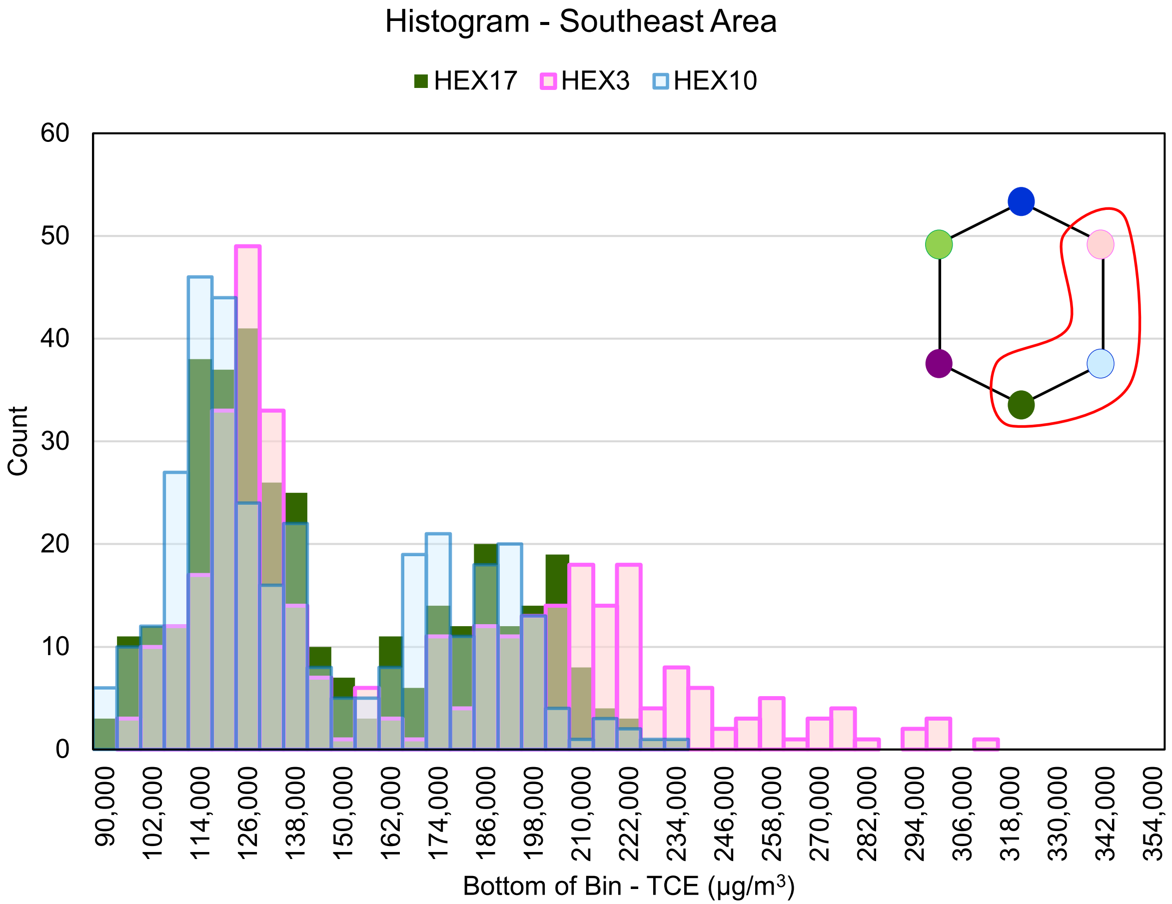
Critical Periods Of Development

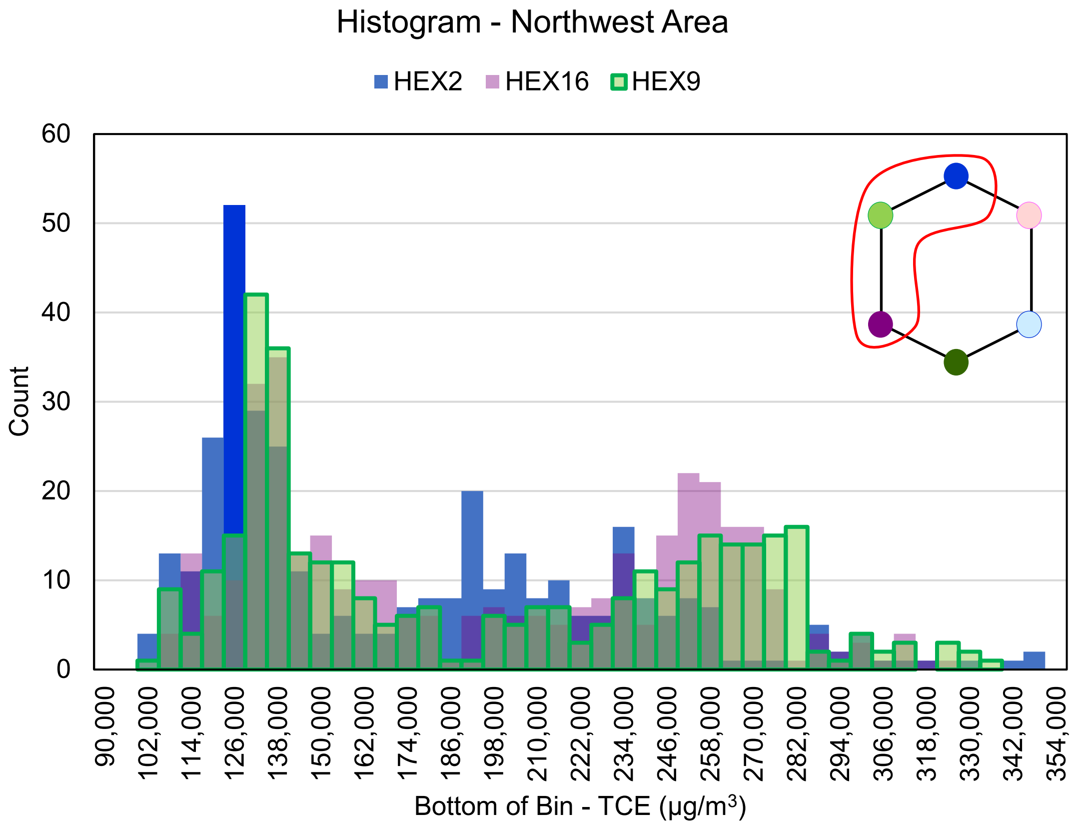


Critical period for fetal heart development

Moore, 1982; *The Developing Human*

What Does Temporal Variability in Subslab Look Like at this VA Site A (about 350 Daily Short Duration GC Measurements from 6 Tightly Clustered Locations)





Zimmerman, John H., Alan Williams, Brian Schumacher, Chris Lutes, Laurent Levy, Gwen Buckley, Victoria Boyd, Chase Holton, Todd McAlary, and Robert Truesdale. "The Representativeness of Subslab Soil Gas Collection as Effected by Probe Construction and Sampling Methods." *Groundwater Monitoring & Remediation*. First published: 08 June 2024 https://doi.org/10.1111/gwmr.12663

What Does Temporal Variability Look Like in Subslab at Sun Devil Manor?

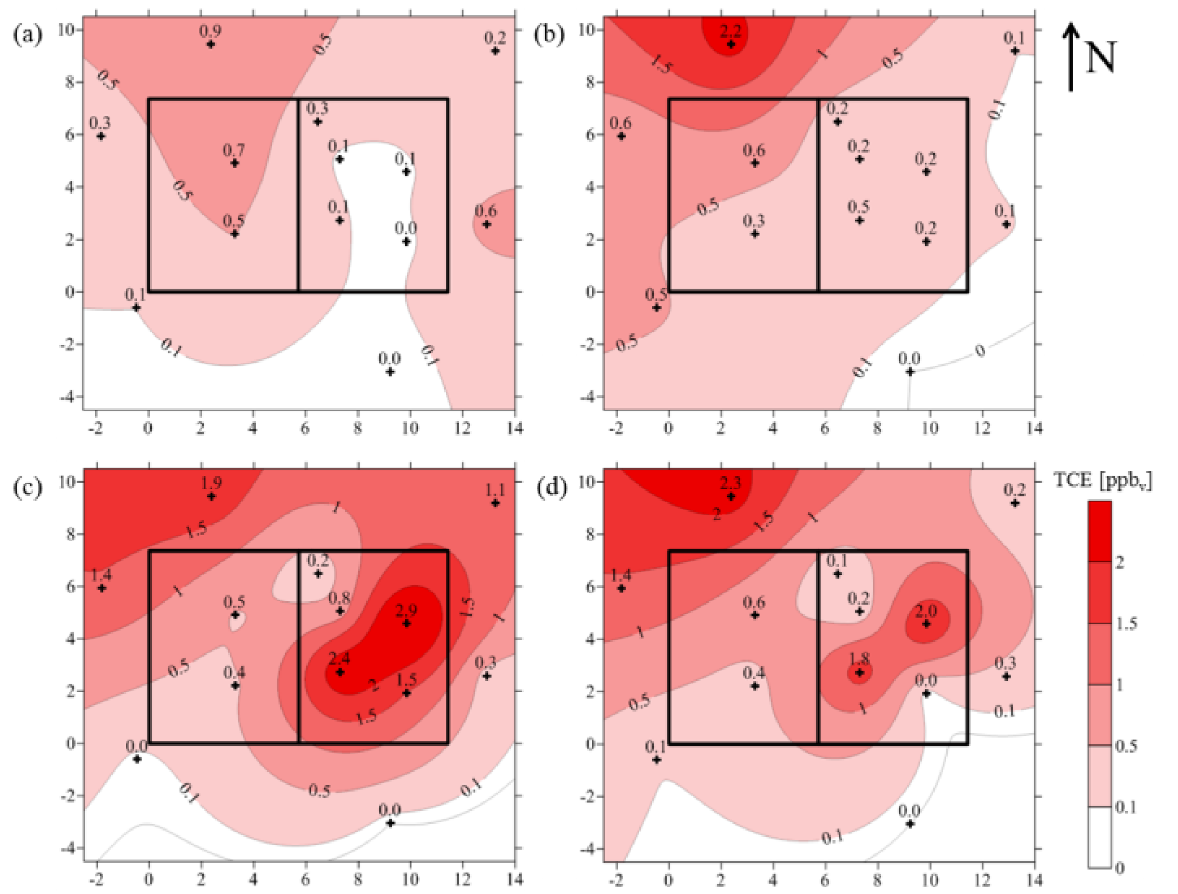


Figure 3.17. Soil gas concentration contour plots for the sub-slab depth sampling points from (a) September 2011, (b) November 2011, (c) December 2011, and (d) January 2012.

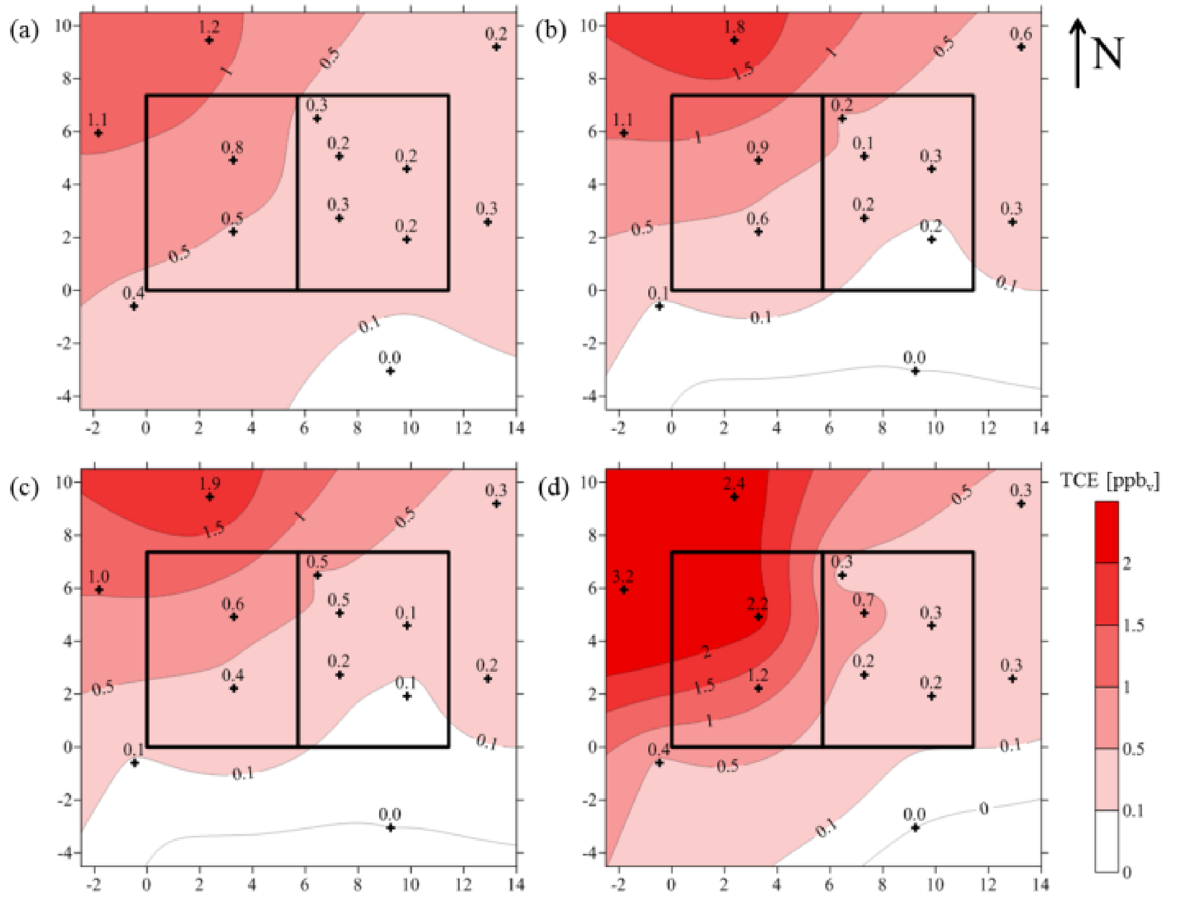


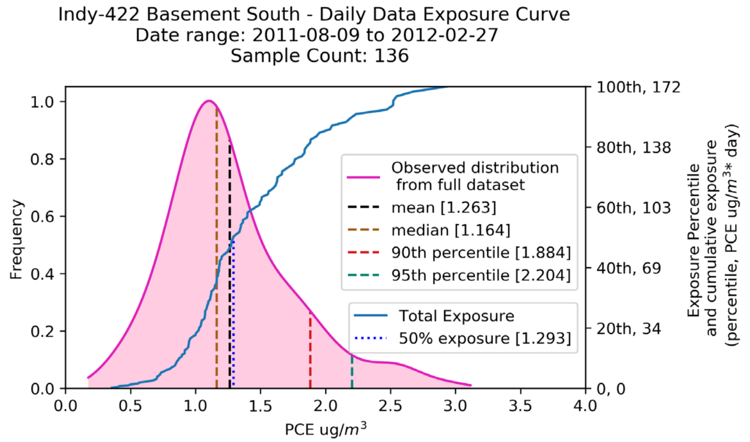
Figure 3.18. Soil gas concentration contour plots for the sub-slab depth sampling points from (a) February 2012, (b) April 2012, (c) May 2012, and (d) August 2012.

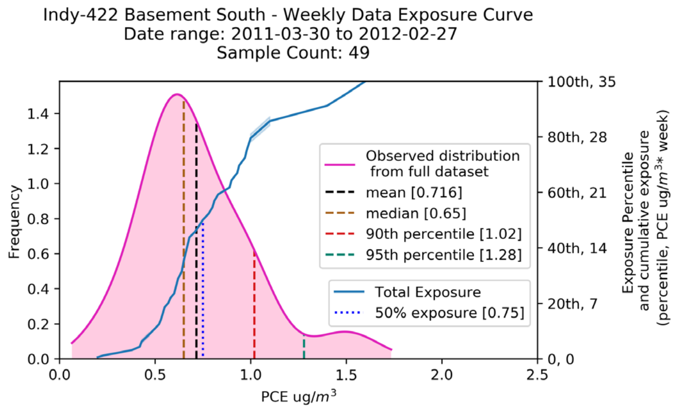
Figures reprinted from Evaluation of Vapor Intrusion Pathway Assessment Through Long-Term Monitoring Studies by Chase Weston Holton, Dissertation, Arizona State University March 2015

Sampling Performance in a Case With Slight Skew and Weaker Radon/VOC Correlation – Indianapolis South Basement:

Daily Data 8/9/11- 2/27/12

Weekly Data: 3/30/11 – 2/27/12





Your chances of once:

- Seeing PCE sample over the 90th percentile with four daily (weekly) samples:
  - Random 36% (36%)
  - Only in heating season 61% (53%), in winter only 61% (54%)
  - When radon >90th of full radon dataset 48% (0%)
  - When radon >90th of heating season radon and during heating season : 93% (0%)
  - Radon >2 pCI/l: 37% (33%)
- Seeing PCE over the 50th percentile of cumulative VOCs with four daily (weekly) samples:
  - Random: 84% (85%)
  - Only in heating season 98% (91%), in winter only 98% (90%)
  - When radon >90th of full radon dataset 64% (0%)
  - When radon >90th of heating season radon and heating season 99% (0%)
  - Radon >2 pCI/l: 86% (87%)

Key Point: Weeklong sampling compared to weeklong sample distribution was not better in this case than comparing daylong sampling estimated daily distribution. Available datasets were of different durations.
This case was influenced by a preferential pathway on neighborhood scale

External Soil Gas vs. Subslab, Model Results; Mixed Shallow and Deep Source Placement

(EPA 530-R-10-003)

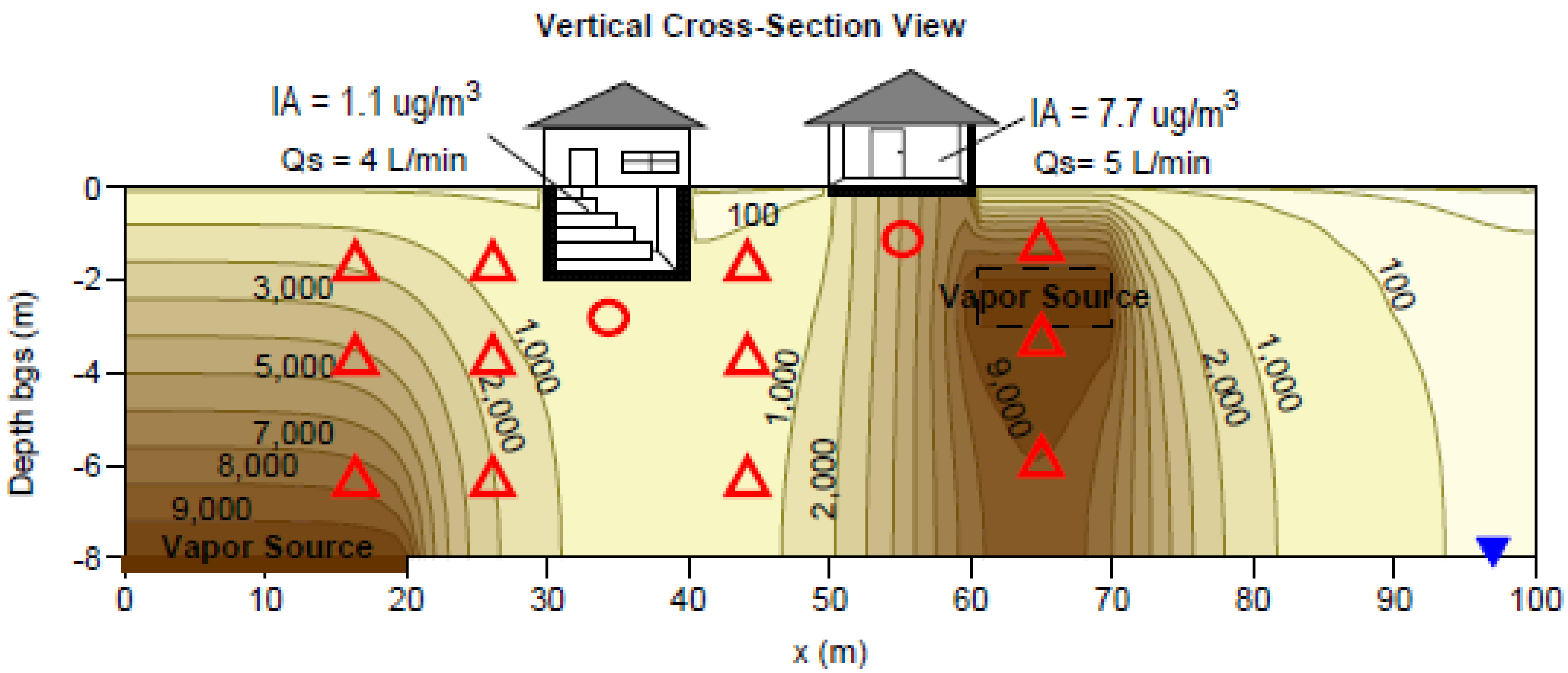


Figure 56. Scenario with multiple buildings and multiple sources. The symbols highlight areas for comparing soil vapor concentrations.

Notional Base Case Building Assumptions (Lutes & Minchak 2015)

- Commercial building: 7,200 square ft, 30 years old, Northern California, major metropolitan area
- Slab on grade, one floor, three tenants; single style of construction
- Not believed to be the primary release location
- Overall site is reasonably well understood – PCE in gw at 500 µg/l at 15 ft bls (aerobic case, TCE not expected to be driver). Source treatment just beginning 200 ft. upgradient, expected to require 30 years to reach VISLs
- Previous data on this specific building consists of one round of 24-hour indoor air sampling, at two locations, in summer. Results gave compound ratios potentially suggestive of vapor intrusion.
- Indoor air concentrations observed in one round of sampling were substantially greater than ambient concentrations.
- Indoor air concentrations in one round of sampling (normal HVAC conditions) were at roughly 50% of the value at which state would definitely require long term mitigation.

Situation: Single Commercial Building
Choice: Mitigate Early or Monitor and Hope to Avoid Mitigation???

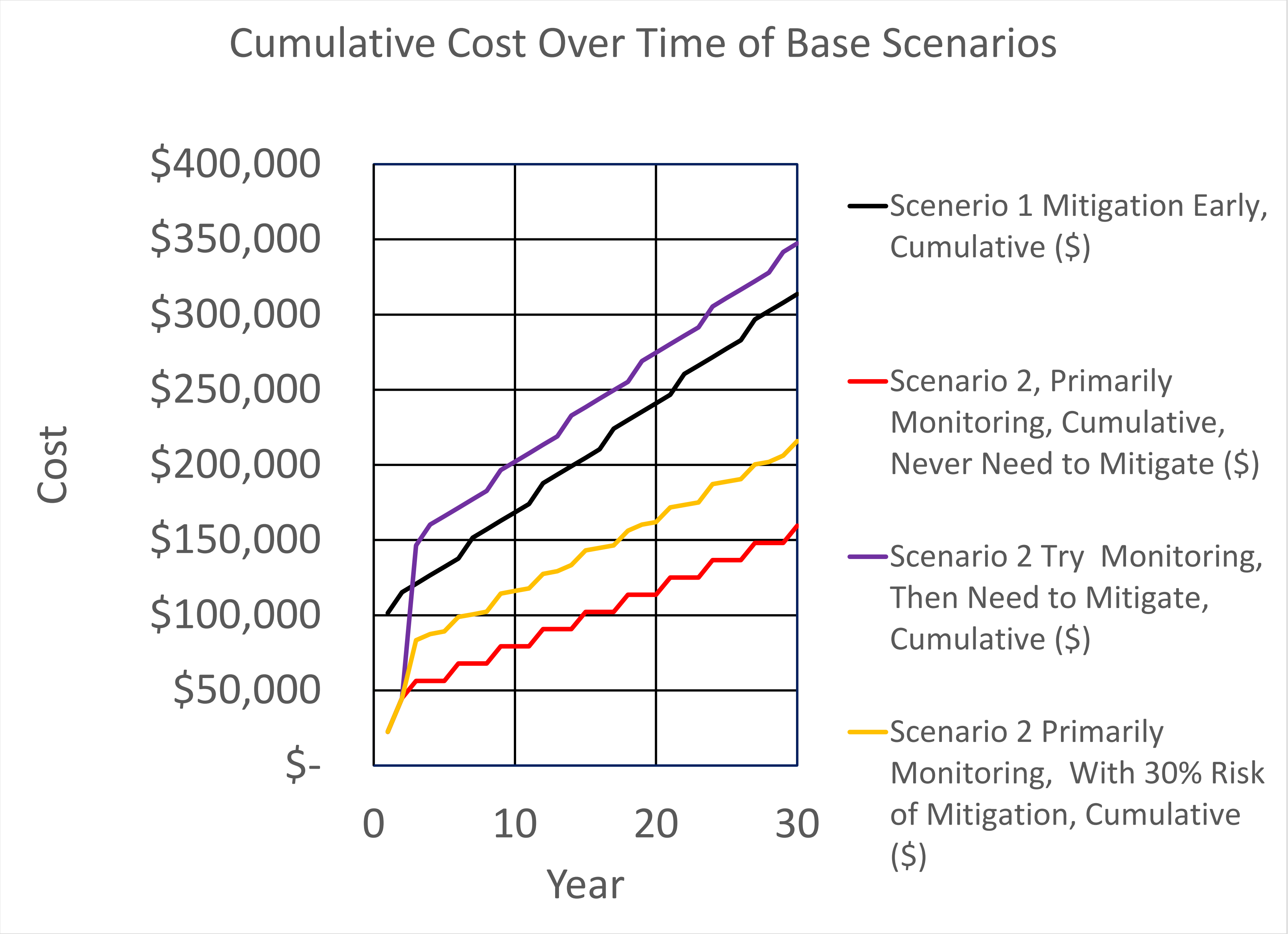
From: Lutes and Minchak 2016

Red= Base Case Black = Alternatives

- <u>Scenario 1: Mitigation Early</u>
  - Implement vapor intrusion mitigation with SSD immediately,
  - Monitor effectiveness sufficiently to verify adequate performance for chronic risk protection over all climatic conditions.
  - Long term monitoring for 30 years.
  - No change to building HVAC system.
- <u>Scenario 2: Primarily Monitoring</u>
  - Four rounds of monitoring to better define seasonal variability;
  - Intensive building survey to locate and eliminate potential indoor sources.
  - Mitigate if necessary.
  - If Ok after 2 years monitor once every 3 years

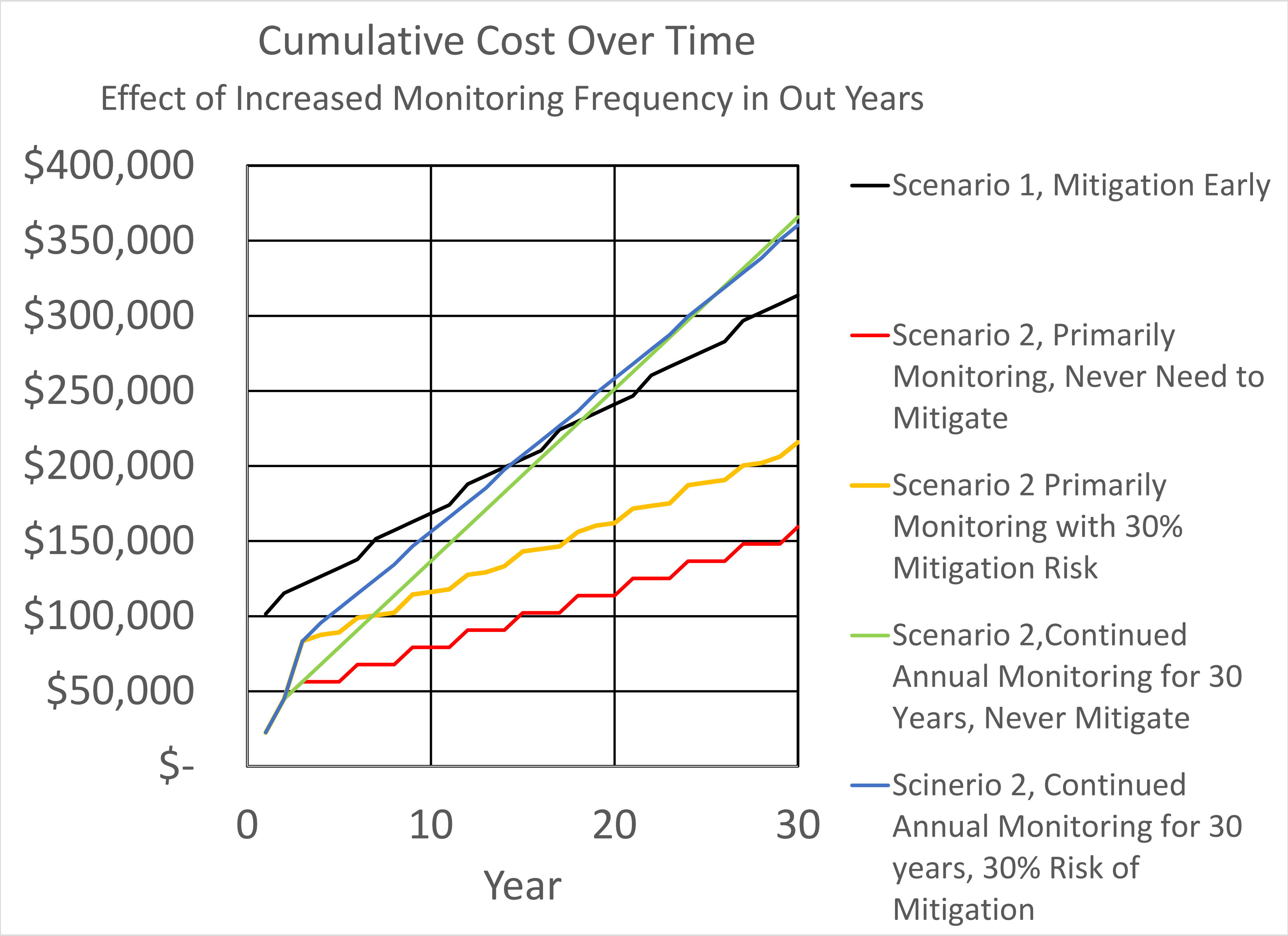
- Long term monitoring frequency without mitigation
  - Annual
  - Every 3 years
  - Every 5 years
- Long term sampling frequency after passing initial post mitigation monitoring
  - Every 3 years
  - Every 5 years
- Building size (scales number of samples, size of fan, extraction points, capital cost etc.)
  - 7,000 sq ft
  - 35,000 sq ft
  - 175,000 sq ft
- Building Complexity: 1, 3, 10 occupied suites/foundation additions
- System Intensity (based on soils permeability and heterogeneity)
  - 45 ft ROI; 0.14 HP of blower per 1,000 sq. ft.
  - 15 ft ROI; 0.5 HP of blower per 1,000 sq. ft.

Base Scenarios, Cumulative Costs; With and Without Mitigation



Key Point: Assume four rounds of monitoring in first year was considered sufficient, then every three years thereafter. In that case monitoring in a situation that has a 30% risk of needing mitigation is less expensive than going to mitigation early.

Sensitivity to Changing Monitoring Frequency in Scenario 2 (Going to Annual Monitoring in Out years



Key Point: Assume four rounds of monitoring in first year was considered sufficient, then annual thereafter if you didn't mitigate. But VOC monitoring on mitigated building was every 5 years.

In that case the mitigation early strategy eventually saves money.

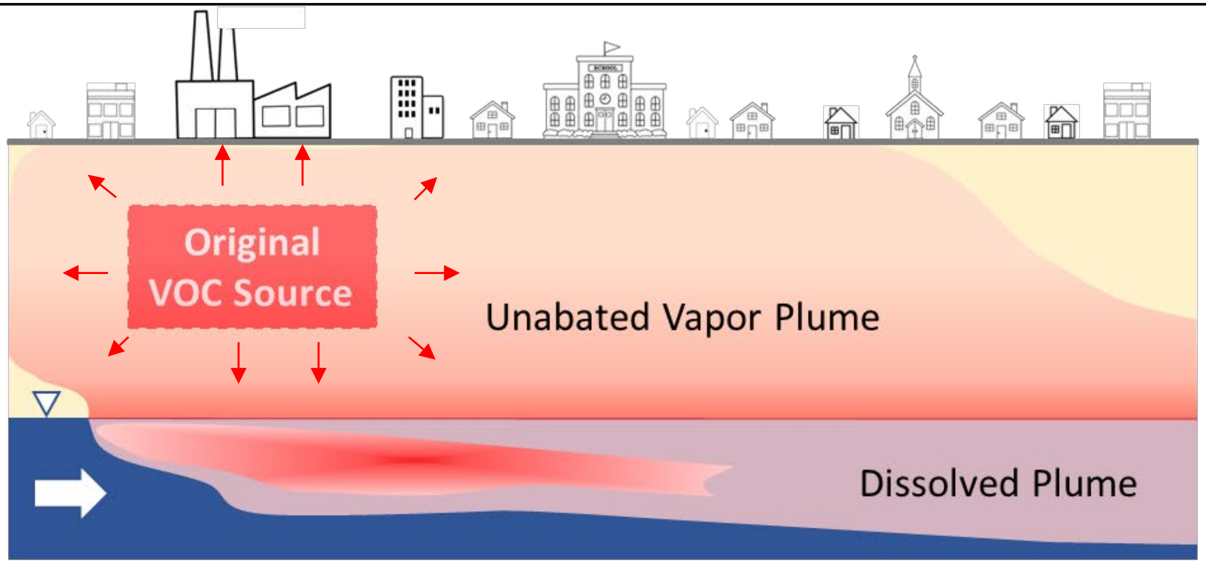
Mitigation Early vs. Monitoring Conclusions –

From Lutes and Minchak 2015/2016

- There are cases, where the economic tradeoff between a "mitigation early" and "monitoring until you have to mitigate" strategy is a close one.
- Going to mitigation early can raise the ultimate life cycle cost if there is a reasonable chance that monitoring will lead to a decision not to mitigate. But if you are almost certain to have to mitigate anyway, then several rounds of monitoring plus mitigation is more expensive.
- If you have to monitor annually for the long term without mitigation (to handle temporal variability), then mitigation is less expensive in the long term.
- Monitoring and mitigation have very different annual cash flows.
- The cost advantage of trying monitoring first is greater for larger, simple buildings (few suites/foundations)
- Note: A different analysis using the concept of "equivalent protection" to evaluate needed number of samples using a different tool, suggests mitigation first often wins. (Lutes, C. A.J. Kondash and C. Holton "Results and Interpretation of Sampling Strategy and Equivalent Protection Cost Effectiveness Analyses" oral presentation at 2022 Workshop https://iavi.rti.org/assets/docs/07_Lutes_Results_SSA_EPCEA.pdf)

What is a “Source of VOCs”?

– Step forward a decade or so after release to subsurface

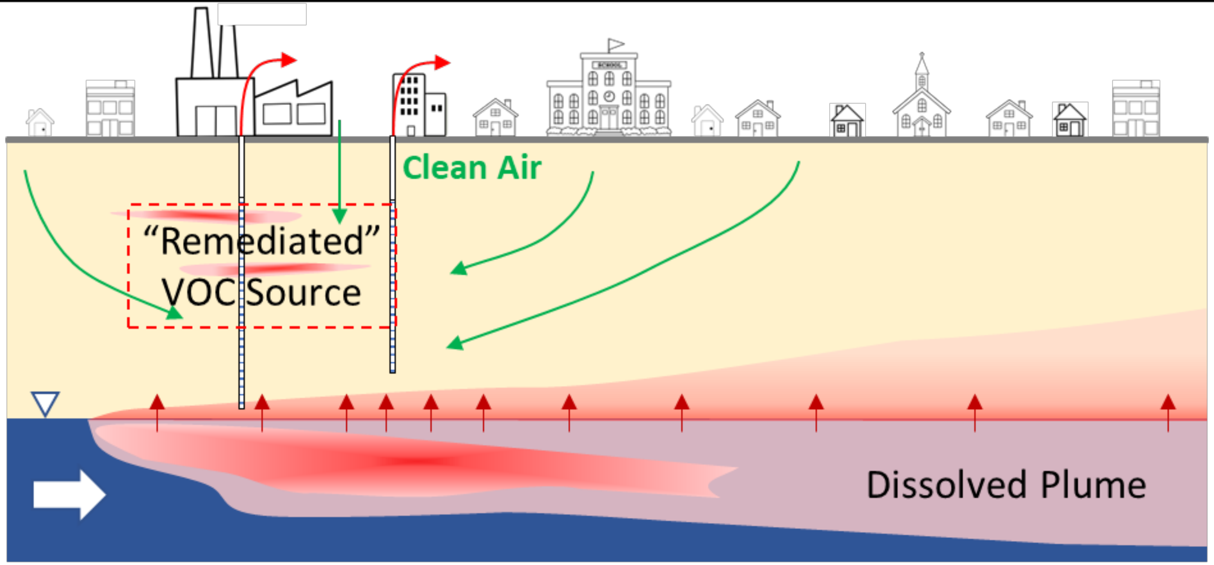


“Original Source” remains producing a persistent vapor plume

Contaminated groundwater migrates further and further downgradient

What is a “Source of VOCs”?

– First step in active remediation is usually soil vapor extraction (SVE) in vadose zone



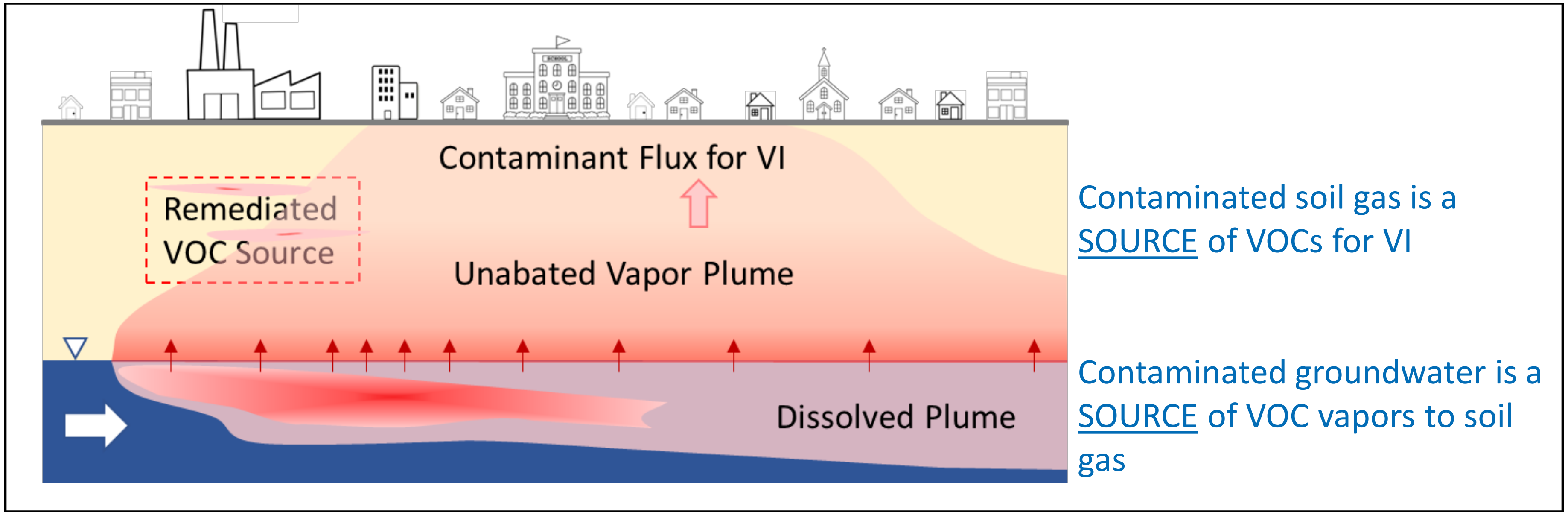
“Original Source” is gone! At least mostly, residuals remain. “Low levels” of VOC are in the soil gas

Contaminated groundwater now produces VOC vapors; it’s a **SOURCE**

– After some years of operation, SVE mass recovery is asymptotically low and “not worth continuing”

What is a “Source of VOCs”?

– Step forward a few years or a decade AFTER SVE ceases



– Sources for vapor intrusion persist in the groundwater and residuals in soils

SVE to Mitigate VI – Field Study

- SVE can mitigate through two processes:
    1. *Remove soil gas containing VOC vapors*
    2. *Create subslab depressurization (SSD)*
- Problem: Can SVE operation mitigate VI over significant distances?
- Consideration: Typical SVE for "cleanup" is large, permitted, and relatively expensive to operate.

Can a small SVE system handle downgradient "sources"?

Design and Operational Concepts for VI Mitigation with SVE

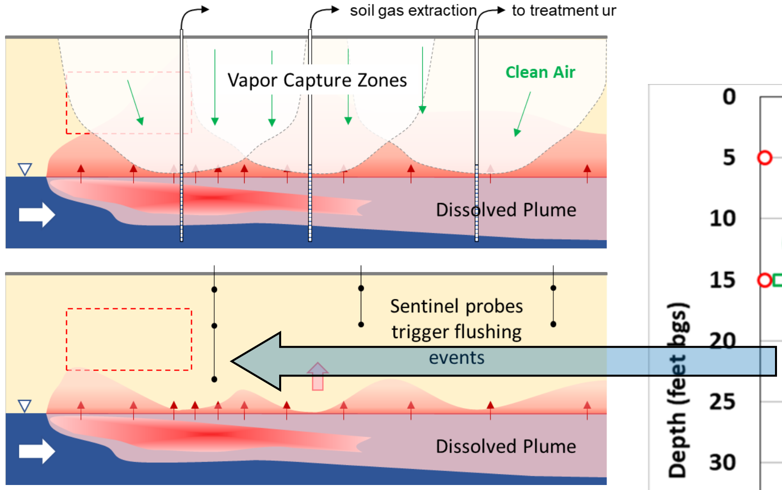
[SVE Sweep Rate] > [Vertical Mass Transport Rate] = [No opportunity for VI]

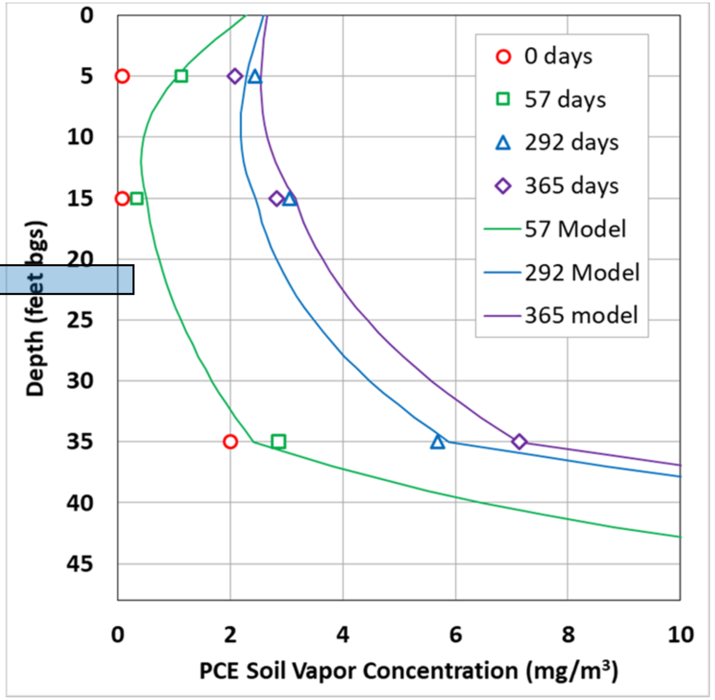
Design Issues:

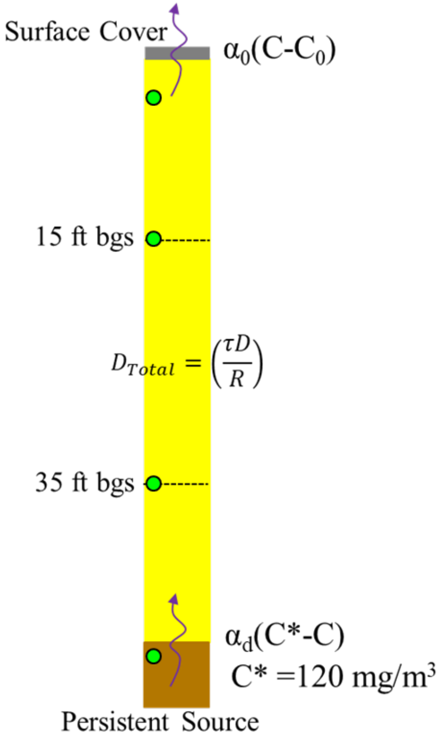
- How far does SVE reach laterally?
- What flow rate and duration provide adequate flush?
- How frequently does the zone require flushing?
- What are appropriate “sentinel” depths and concentrations?

Design and Operational Concepts for VI Mitigation with SVE

– frequency of flushing events







Design and Operational Concepts for VI Mitigation with SVE

Site Characteristics for Assessing Applicability & Design

- Water table depth
- Soil geology/stratigraphy
- Surface infrastructure / accessibility
- Groundwater/vapor concentrations