How, When and Where Should We Be Sampling?

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U.S. EPA "State of VI Science" Workshop
Reliable Ongoing Human Exposure Protection to Vapor Intrusion Using Cleanup as the Simplest Approach

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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.

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.

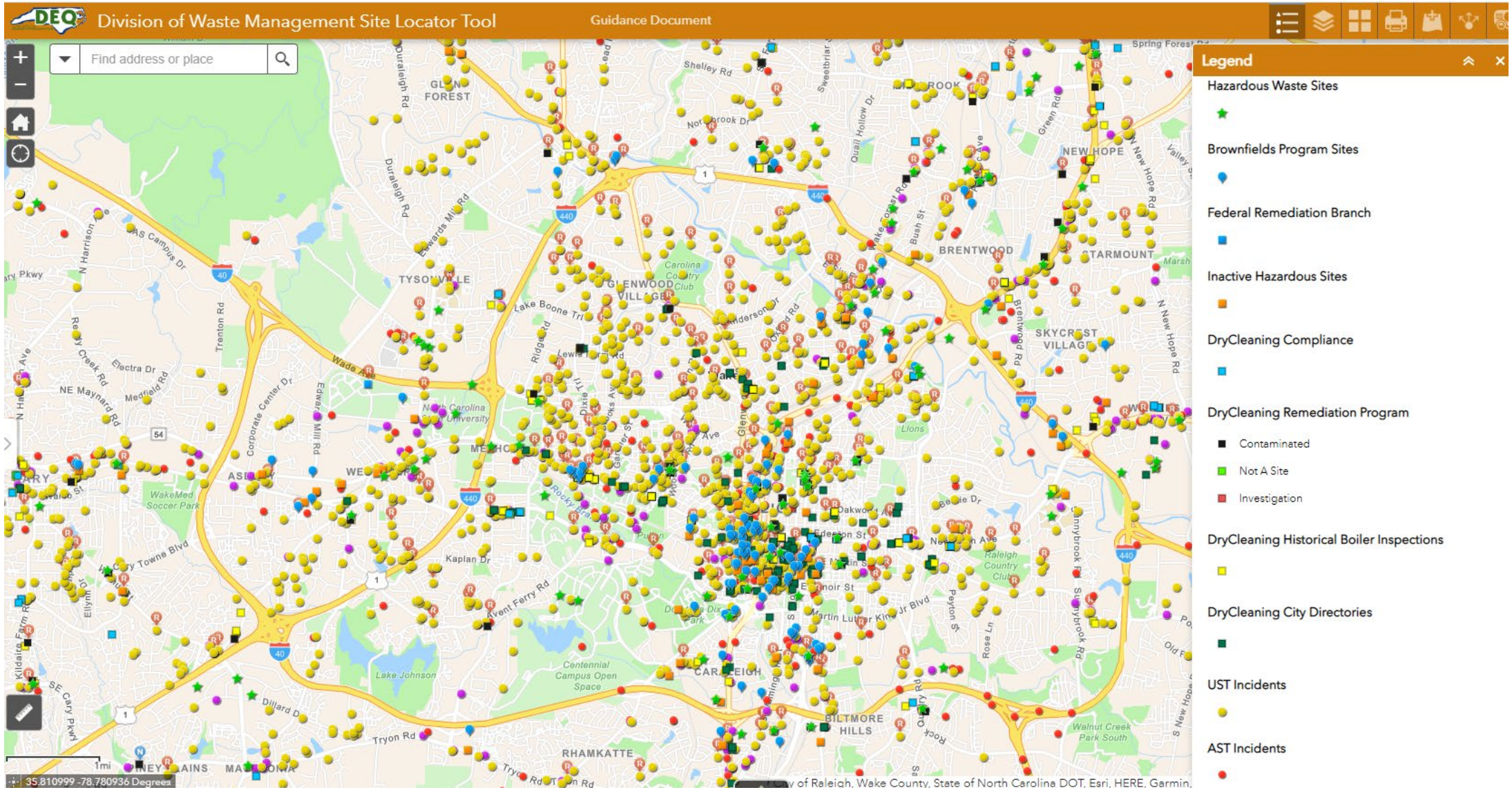
Are Our Sampling Strategies Working? Are We Assessing Enough Sites and Structures for VI Risk Management?

- 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)

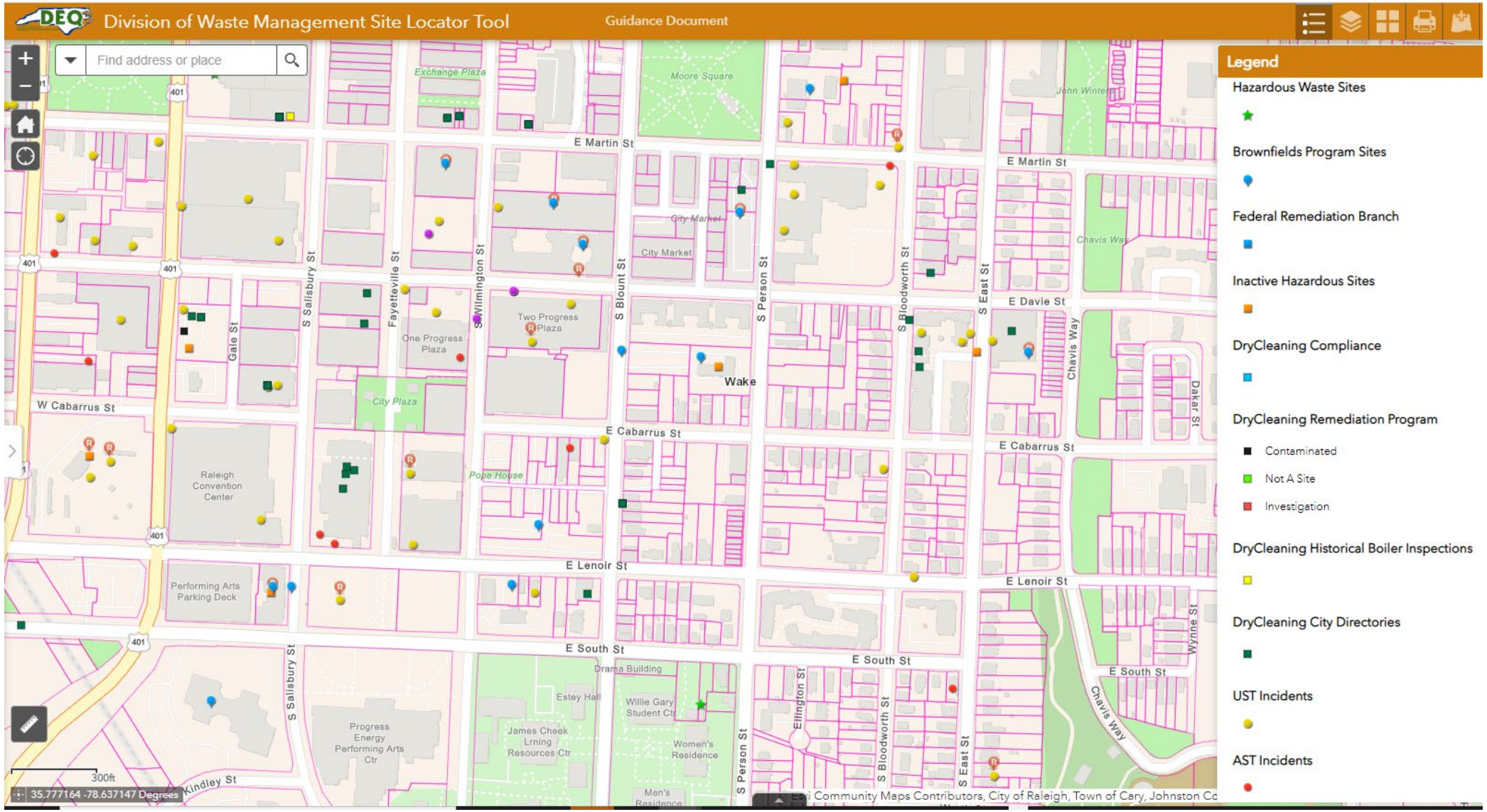
reprinted from https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=7dd59be2750b40bebebfa49fc383f688 as of 8/17/22

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 Name, State	Number of Structures	Number of Groundwater Wells	Number of External Soil Gas Points
Redfield CO	562 in inclusion zone, 780 prioritized for sampling	104	
Endicott NY	233 initial, grew to 377 later	>34	
Hill AFB Utah	1,986 off base were sampled; 13 on base; another source says 3,100 homes	>1,400 monitoring and remediation wells	
Billings MT	1,500 in inclusion zone; 49 have actually been sampled	52	
Gaffney AK	151 in soil gas safe study inclusion zone; 32 (mostly commercial) have been sampled to date	47+	33 in routine investigation, 16 more in research study
Franklin IN	42 where sampling was requested, 37 actually sampled	17	20

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.

Estimating the Size of the U.S. VI Management Challenge

	Number of Chlorinated VOC Release Sites in the US	Number of structures potentially impacted per release	Proportion of Structures Not Already Adequately Assessed	Number of Structures Left to Assess		Cost per Building Assessment ($)	Future VI Stucture Assessment Cost ($)
Optimistic Case	150,000	10	0.7	1,050,000		20,000	2.1E+10
Pessimistic Case	300,000	100	0.9	27,000,000		60,000	1.6E+12
			Number Comparisions:			**Cost Comparisions:**	
			Number of US Commercial Buildings Per Energy Information Adminstration https://www.eia.gov/todayinenergy/detail.php?id=46118	5,900,000		**Annual EPA Budget (2022)** https://www.epa.gov/planandbudget/budget	9.6E+09
			Total housing Units in the US; census data summarized at https://www.infoplease.com/us/census/housing-statistics	115,905,000		**Annual DoD Budget (2021)** https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/FY21_Green_Book.pdf	7.1E+11

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

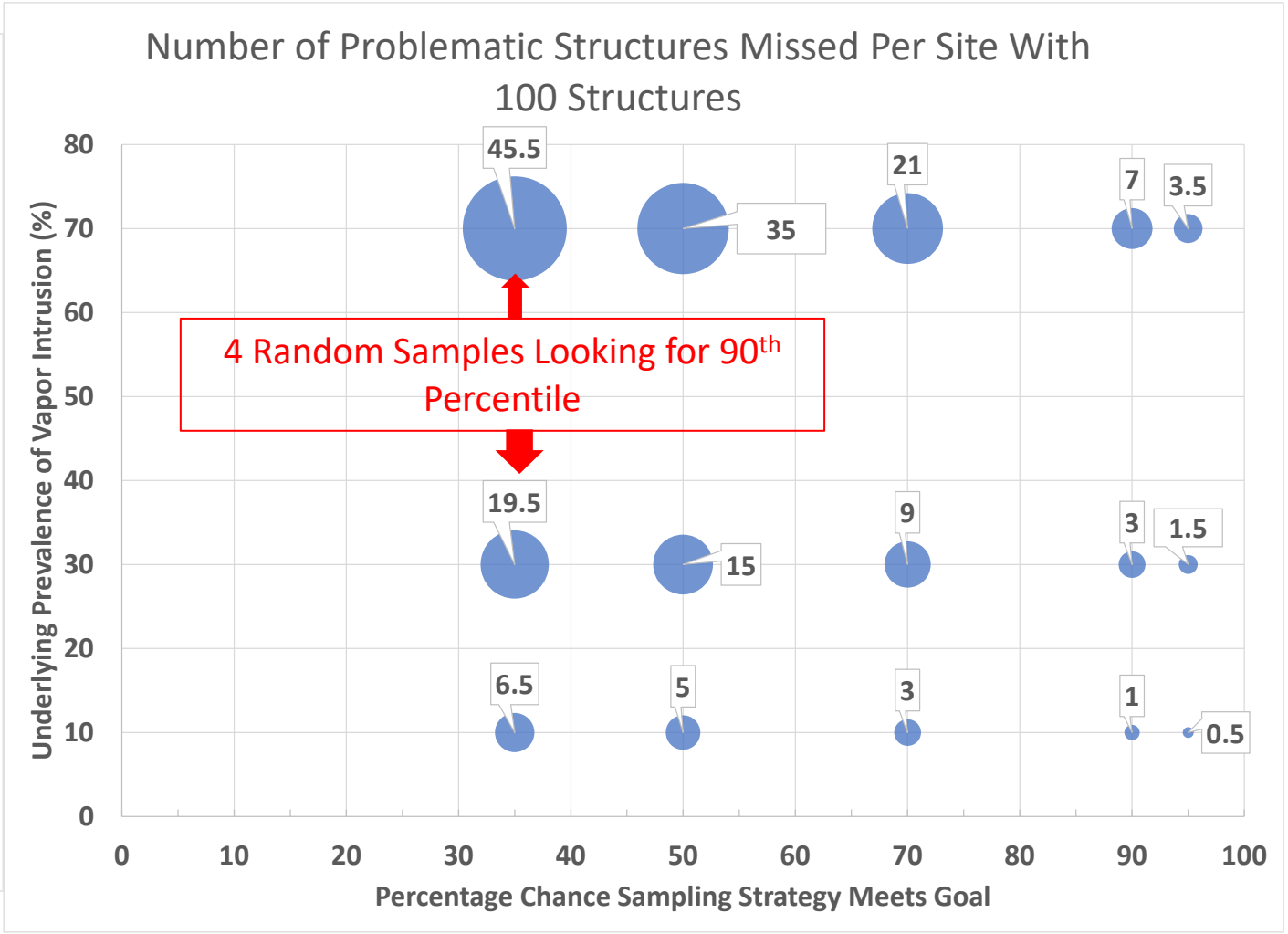
- **Indoor air: most states say one in the basement and one on the first floor and two or more rounds.**
- Most states allude to seasonal variability or worst-case conditions
- A few jurisdictions specifically suggest more rounds:
  - Maine mentions quarterly;
  - Mass. wants 2-4 rounds for sensitive 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

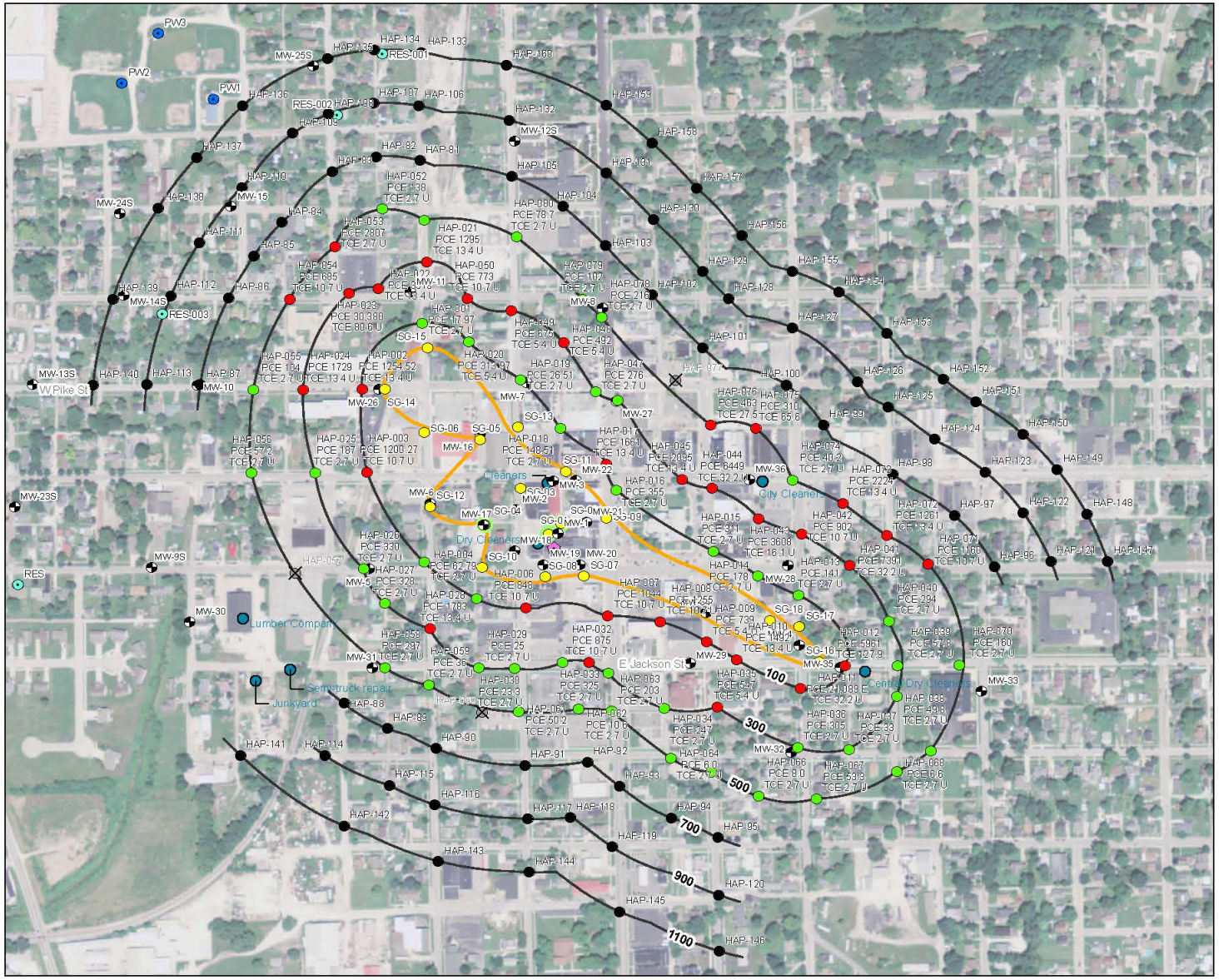


Key Point: If your sampling strategy is weak, and unacceptable VI is common, you miss a lot of problematic structures.

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



LEGEND

- Proposed Soil Vapor Point
- Possible Source
- Source - Industrial Dry Cleaner Site
- Monitoring Well
- Municipal Well
- Residential Well
- Permanent Soil Vapor Probe Location
- Permanent Soil Vapor Probe where TCE concentrations exceed residential VISL (16 µg/m³)
- Distance Measured from the Inner Orange Ring
- Current extent of PCE concentrations in Permanent Soil Vapor Probes that exceed residential VISL (360 µg/m³)

Phase 4 HAPSITE Results - December 7-11, 2015

- Phase 4 (Dec 2015) temporary soil vapor point with HAPSITE results of PCE, TCE, or PCE and TCE greater than the VISL
- Phase 4 (Dec 2015) temporary soil vapor point with HAPSITE results of PCE and TCE below the VISL
- Phase 4 (Dec 2015) temporary soil vapor point sampling location removed from Phase 4 HAPSITE soil delineation field event based on UFP-QAPP, Addendum 2 approach - If the two adjacent temporary SVPs from Rings 1 and 2 have HAPSITE results (PCE and TCE) that are below the residential shallow soil vapor VISLs, then the adjacent closest stepout SVP location on Ring 3 will not be sampled.

Notes:
1. All units are in µg/m³
2. PCE VISL is 360 µg/m³
3. TCE VISL is 16 µg/m³
4. VISLs are from VISL Calculator, Version 3.4, November 2015 residential exposure scenario, target ELCR = 1x10-6, target HI = 1, and default groundwater temperature = 25 degrees
5. U - HAPSITE result is non-detect
6. E - HAPSITE result exceeds calibration range and result is estimated
7. VISL - Vapor Intrusion Screening Level
8. PCE - Tetrachloroethene
9. TCE - Trichloroethene

0 187.5 375
Feet

Proposed Phase 5 Temporary Soil Vapor Point Sampling Locations for HAPSITE Analysis
PCE Plume Site, Indiana

ch2m

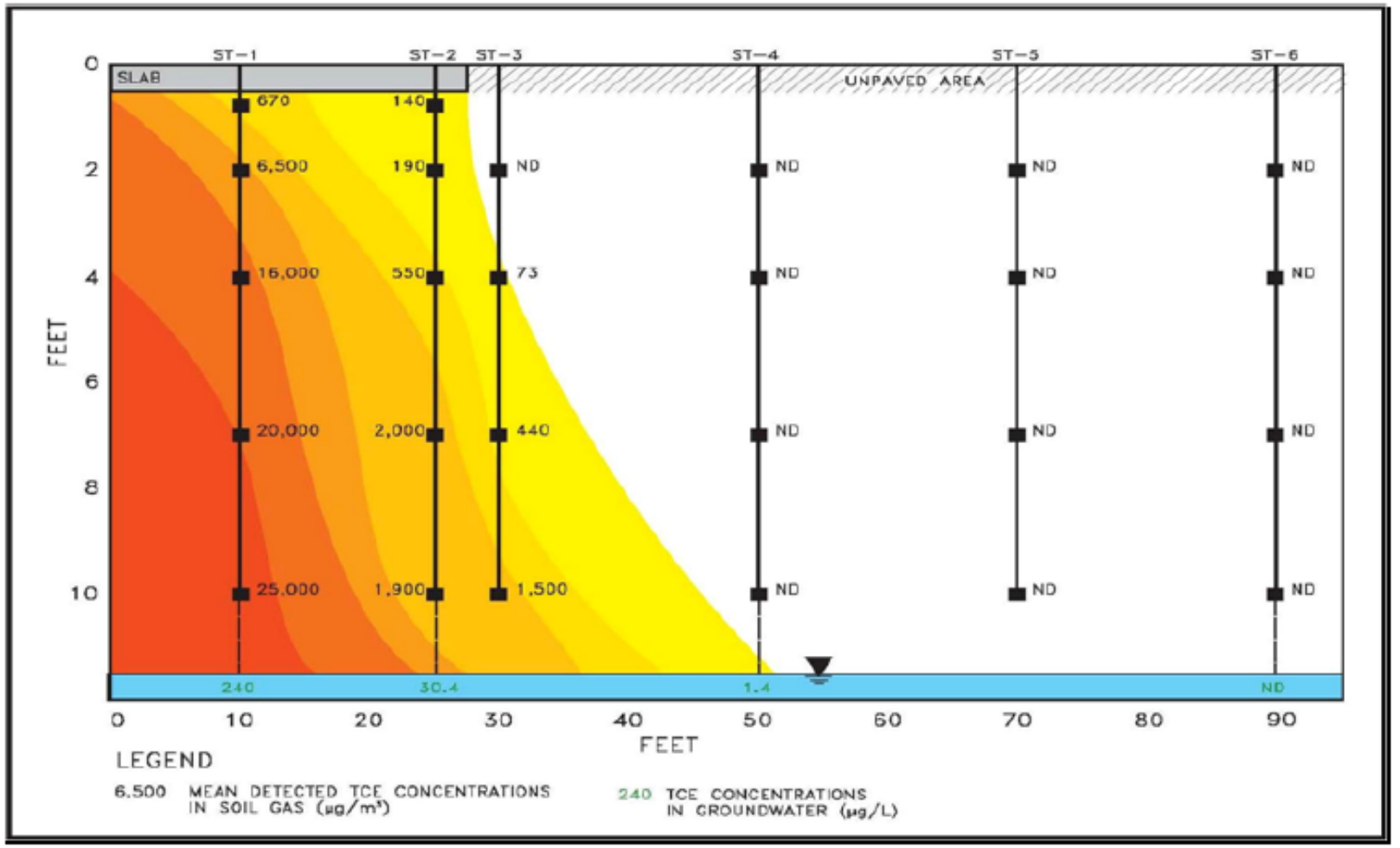
Key Point:
Field portable instrumentation testing of temporary soil gas probes in street right of ways can survey a large area reasonably efficiently.

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

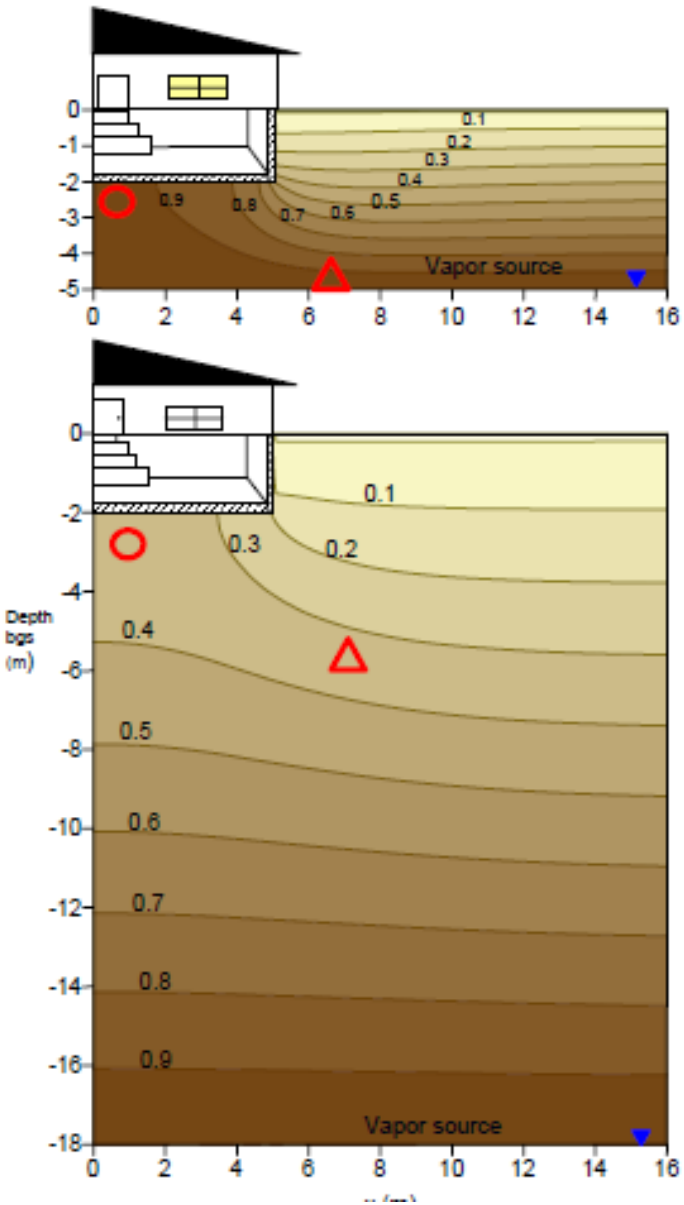


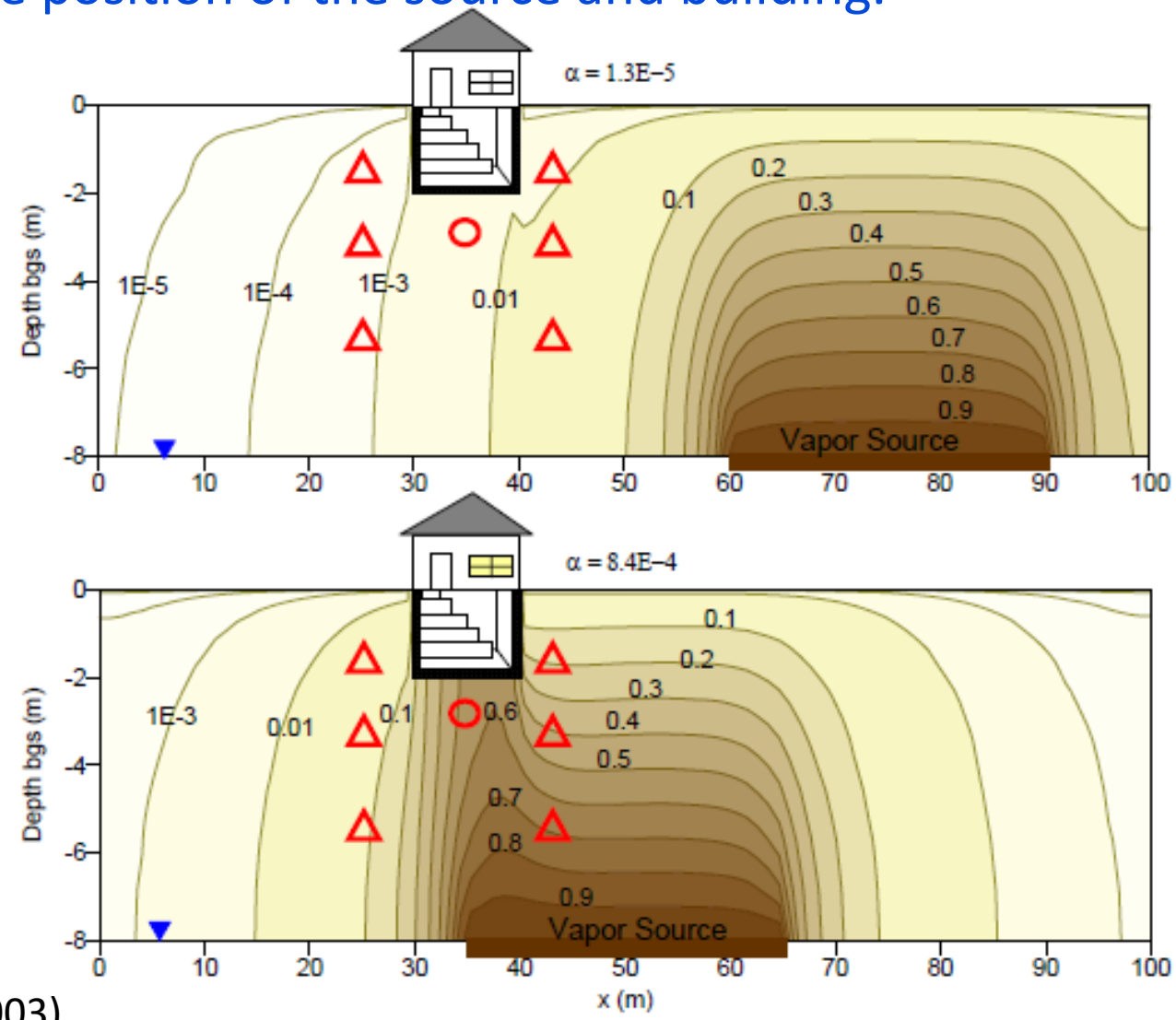
Key Point:
Shallow soil gas sampling strategies on open ground can underestimate concentrations under foundations/paved areas.

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)

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:
  - 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.

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.

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.

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Indianapolis

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MEW

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For further Information

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Backup Slides Only After This

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 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 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

REPEAT

> ?

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)

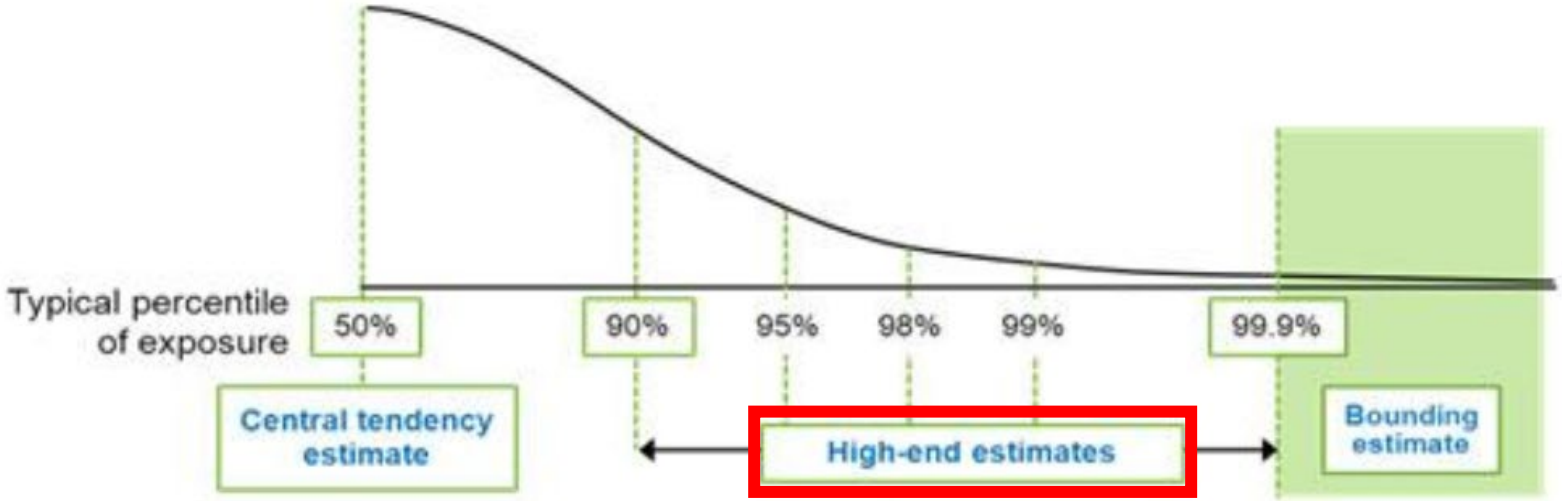
- At least one of the two or four samples will exceed the 90th percentile of the underlying distribution
- At least one of the two or four samples taken will come from above the 50% of total cumulative exposure point.

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

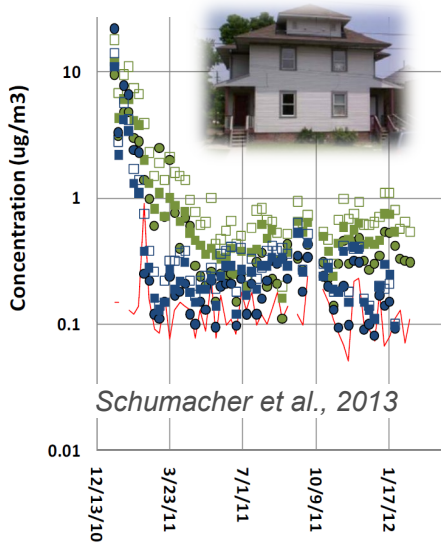


www.epa.gov/expobox/exposure-assessment-tools-tiers-and-types-deterministic-and-probabilistic-assessments

Considerations when Estimating Indoor Air Concentrations

EC = (CA x ET x EF x ED)/AT

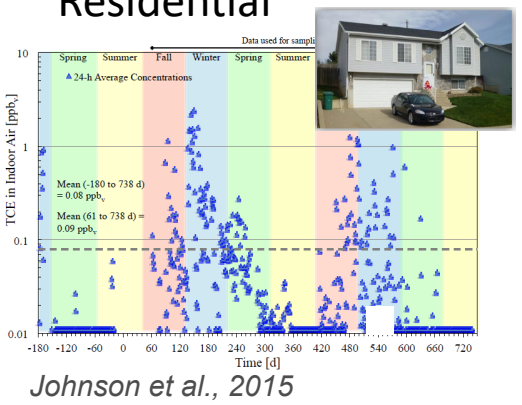
Residential



Schumacher et al., 2013

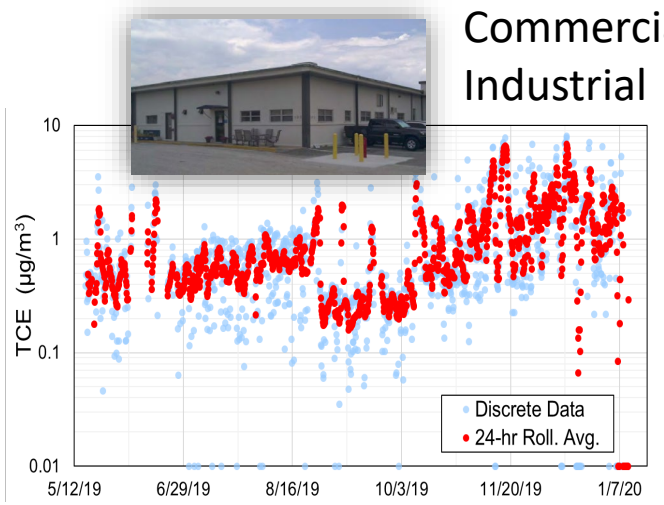
- Can 95UCL on mean be calculated with sufficient confidence?
- How to account for uncertainty/variability in time and space?
  - Timing, type, number, location/zone, frequency, and duration of samples?
- Should maximum or 95th/90th percentile indoor concentrations be used if unable to calculate 95UCLs?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

Residential



Johnson et al., 2015

Commercial/ Industrial

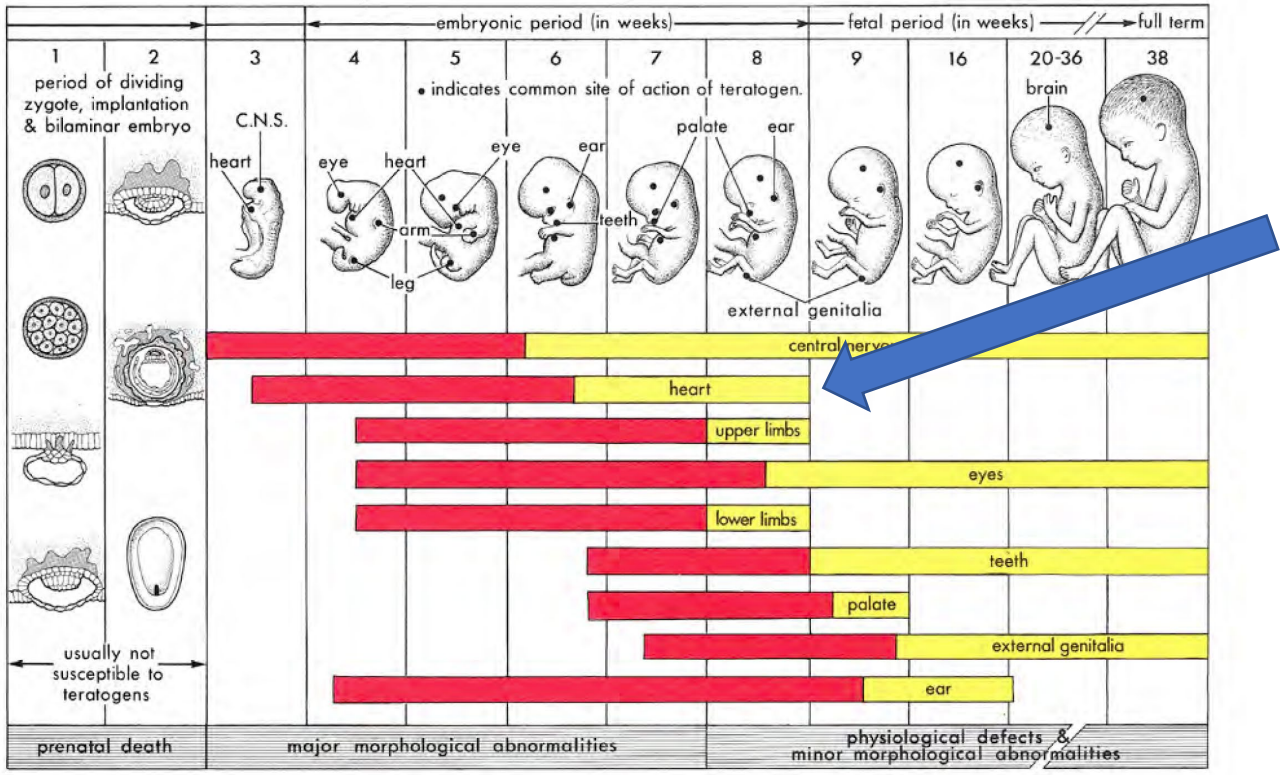


Short-Term Toxicity (cont'd)

"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

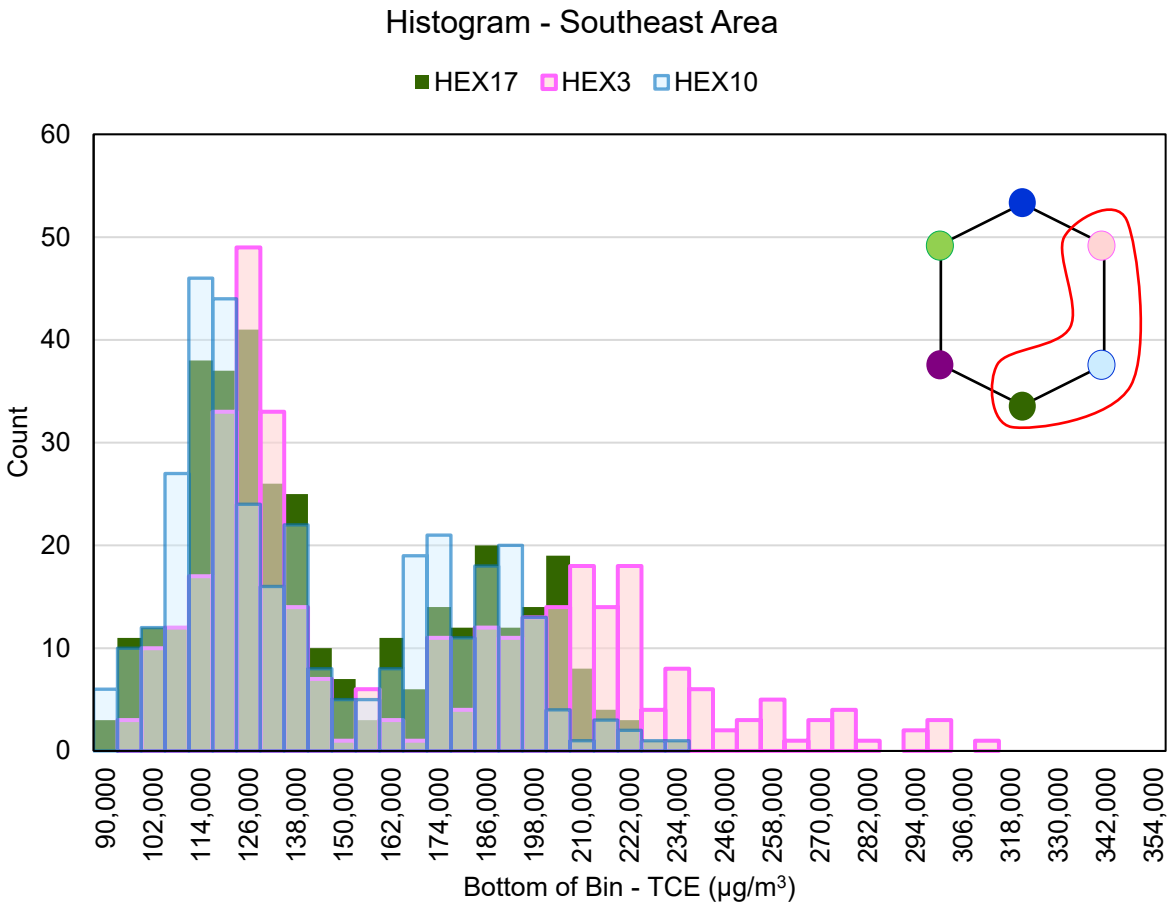
Critical Periods Of Development

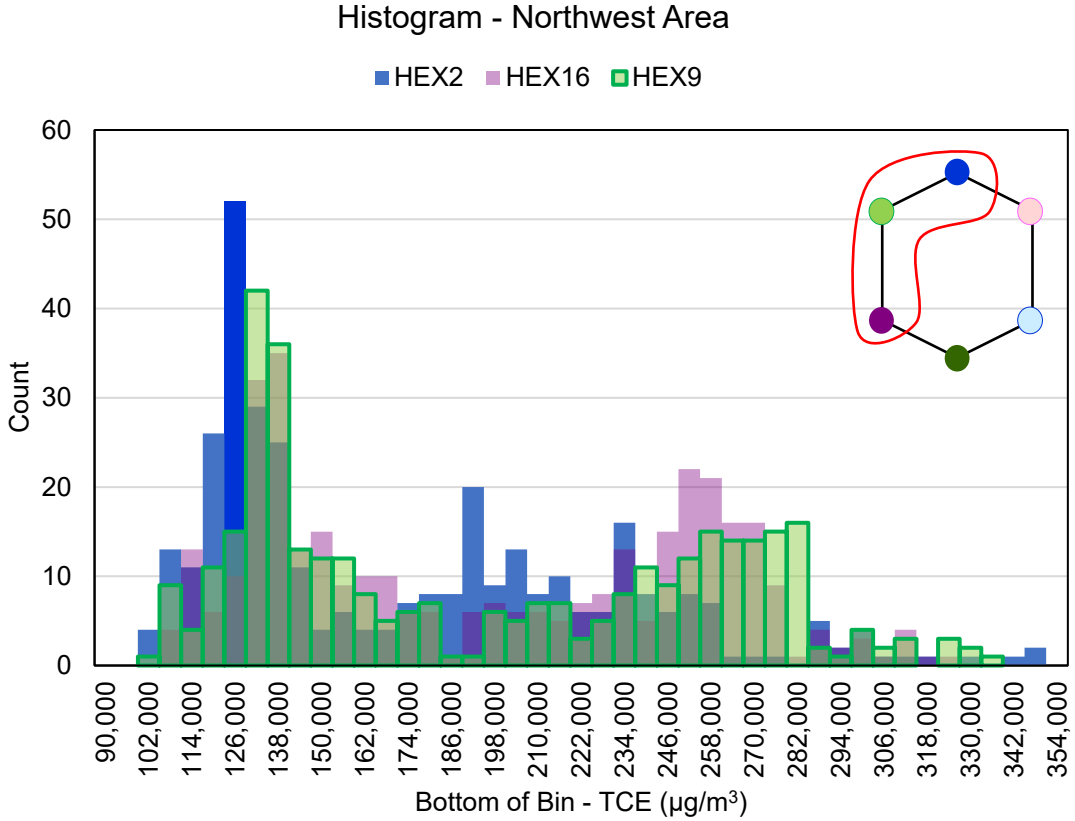


Critical period for fetal heart development

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?

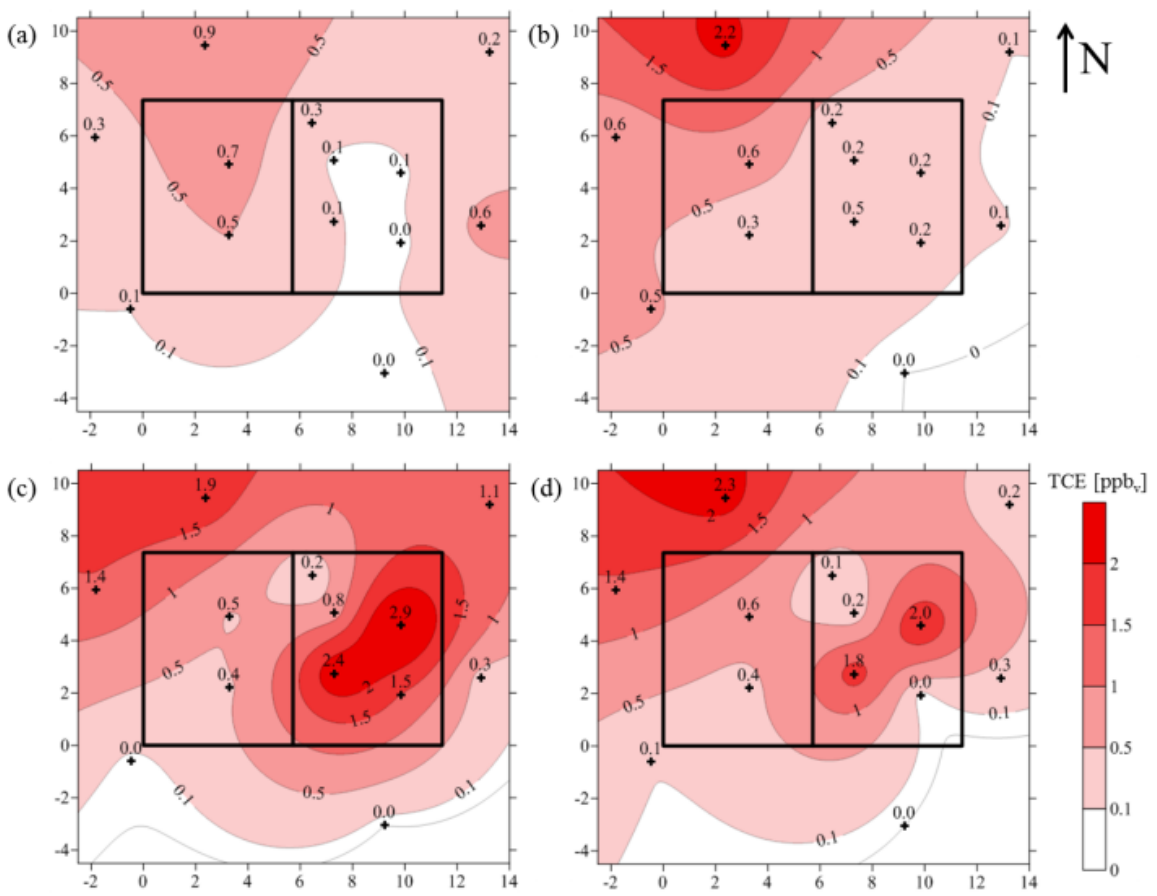


Figure 3.17. Soil gas concentration contour plots for the sub-slab depth sampling points from (a) September 2011, (b) November 2011, (c) December 2011, and (d) January 2012.

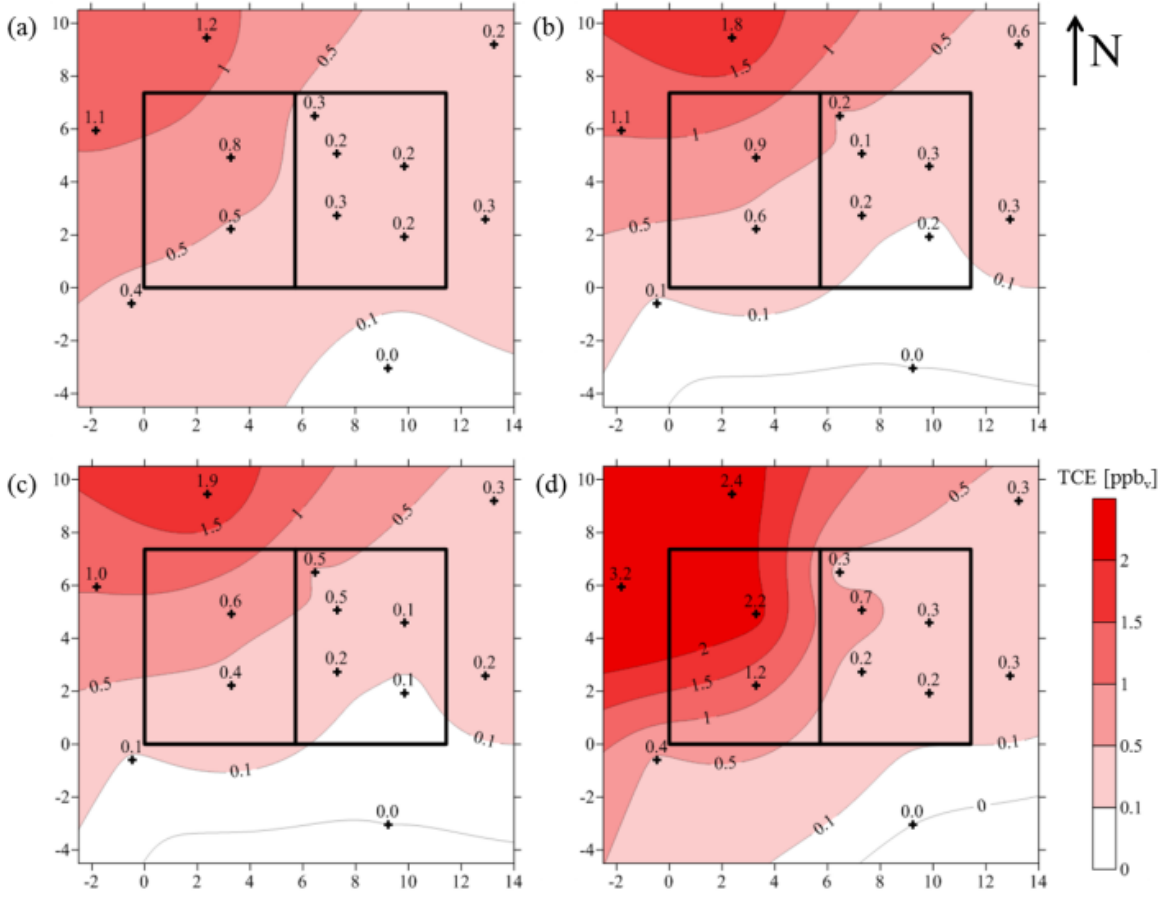
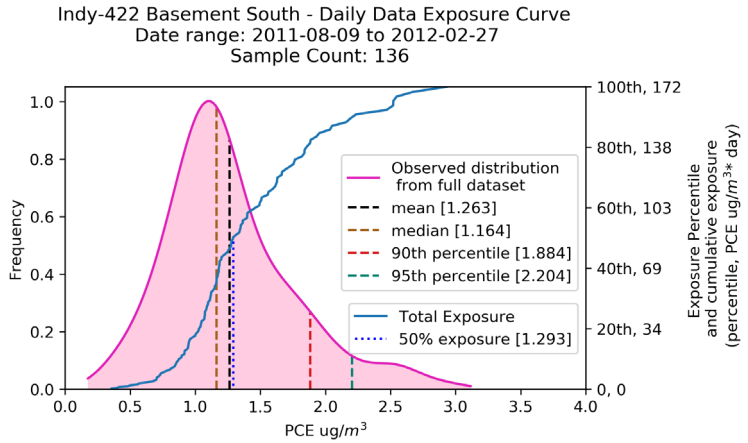
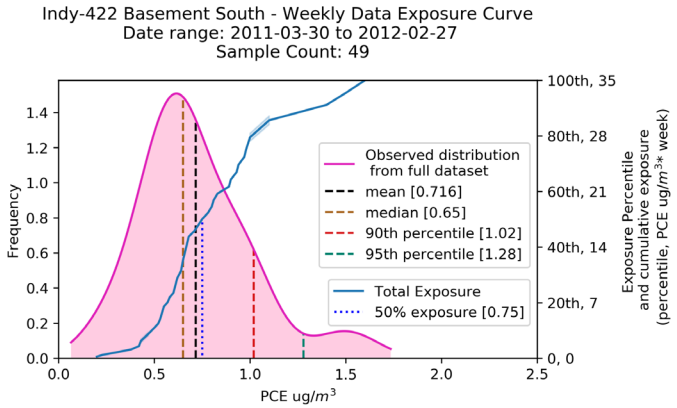


Figure 3.18. Soil gas concentration contour plots for the sub-slab depth sampling points from (a) February 2012, (b) April 2012, (c) May 2012, and (d) August 2012.

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)

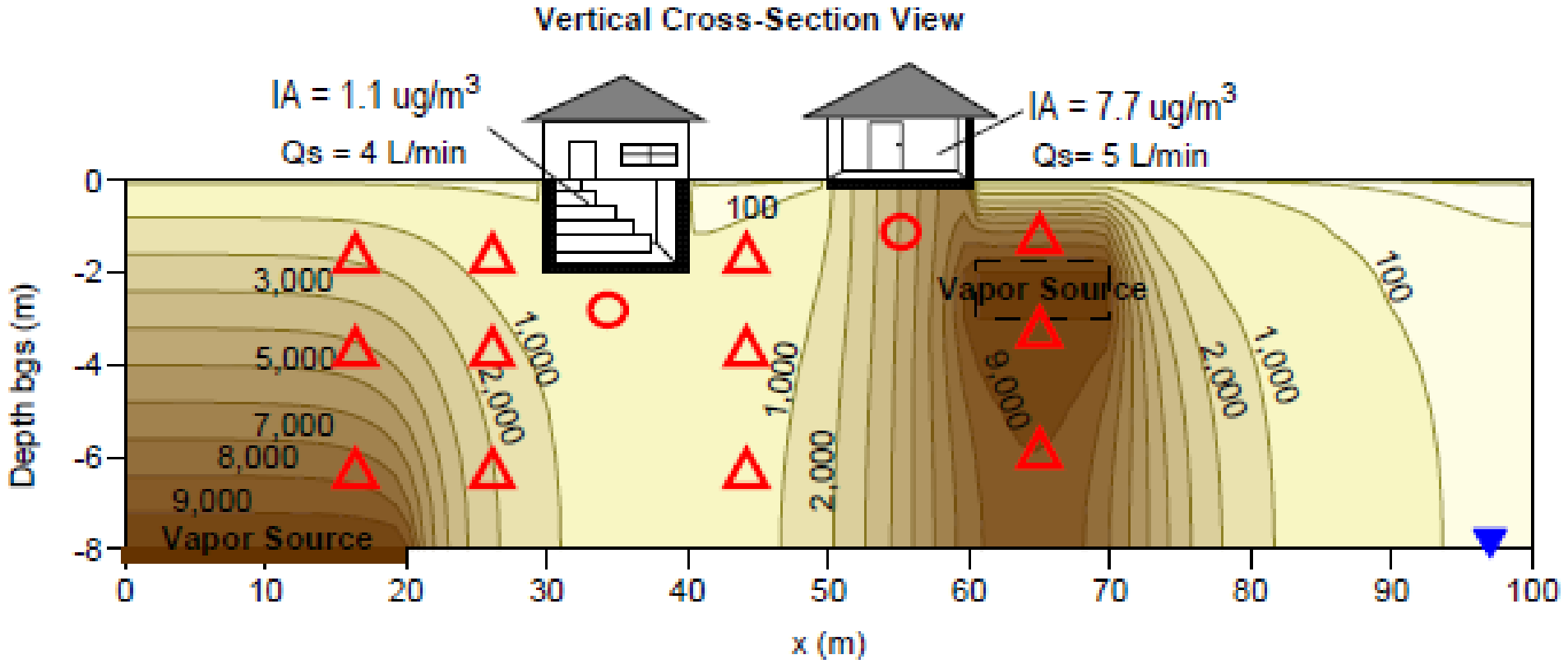


Figure 56. Scenario with multiple buildings and multiple sources. The symbols highlight areas for comparing soil vapor concentrations.