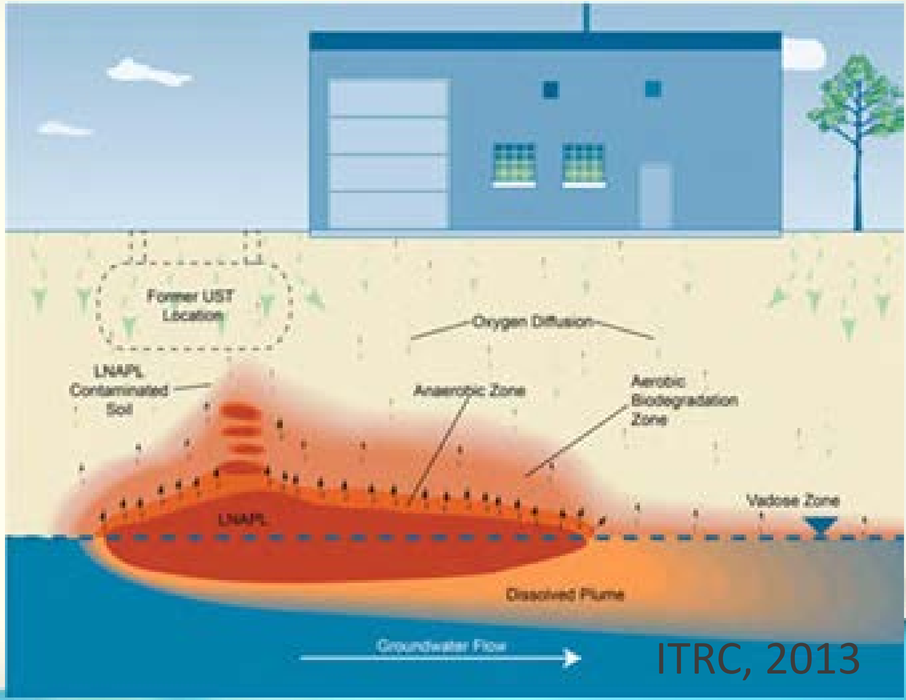
VAPOR INTRUSION



ITRC, 2013

State Bar of Michigan
Environmental Law Section

September 18, 2014

DEQ

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Vapor Intrusion!

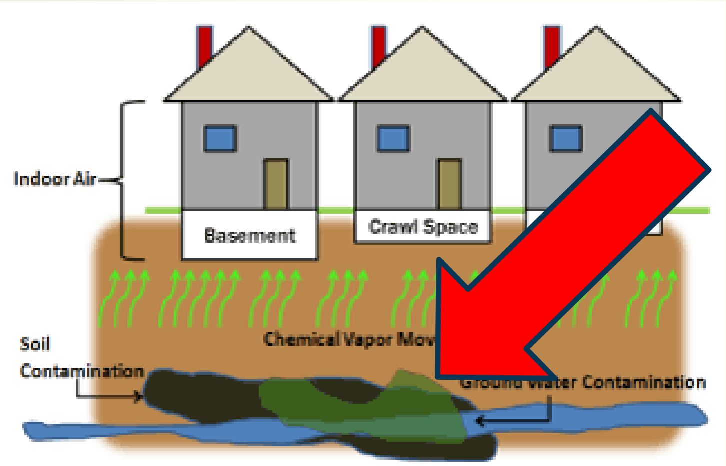
Objectives

- Introduce VI concepts and issues
- Sampling Media
- Issues that affect VI
- Helpful hints
- Installing a soil gas point

Terms

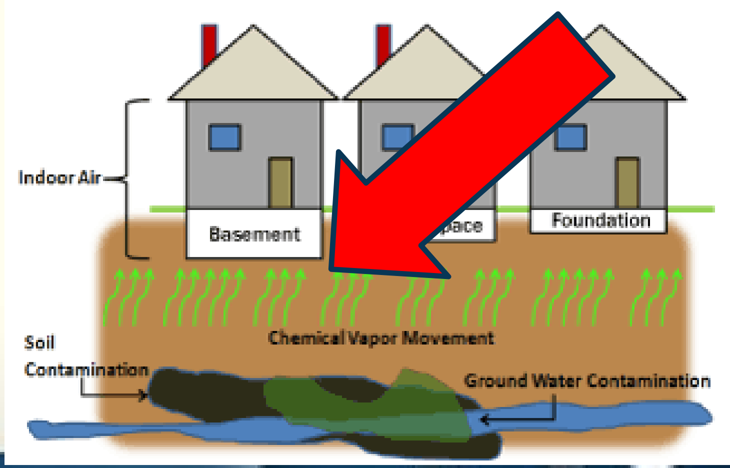
Concentrations in the soil, soil gas, and groundwater that generate vapors =

Vapor Source



Migration of vapors from contaminated groundwater or soil *into* an overlying building =

Vapor Intrusion



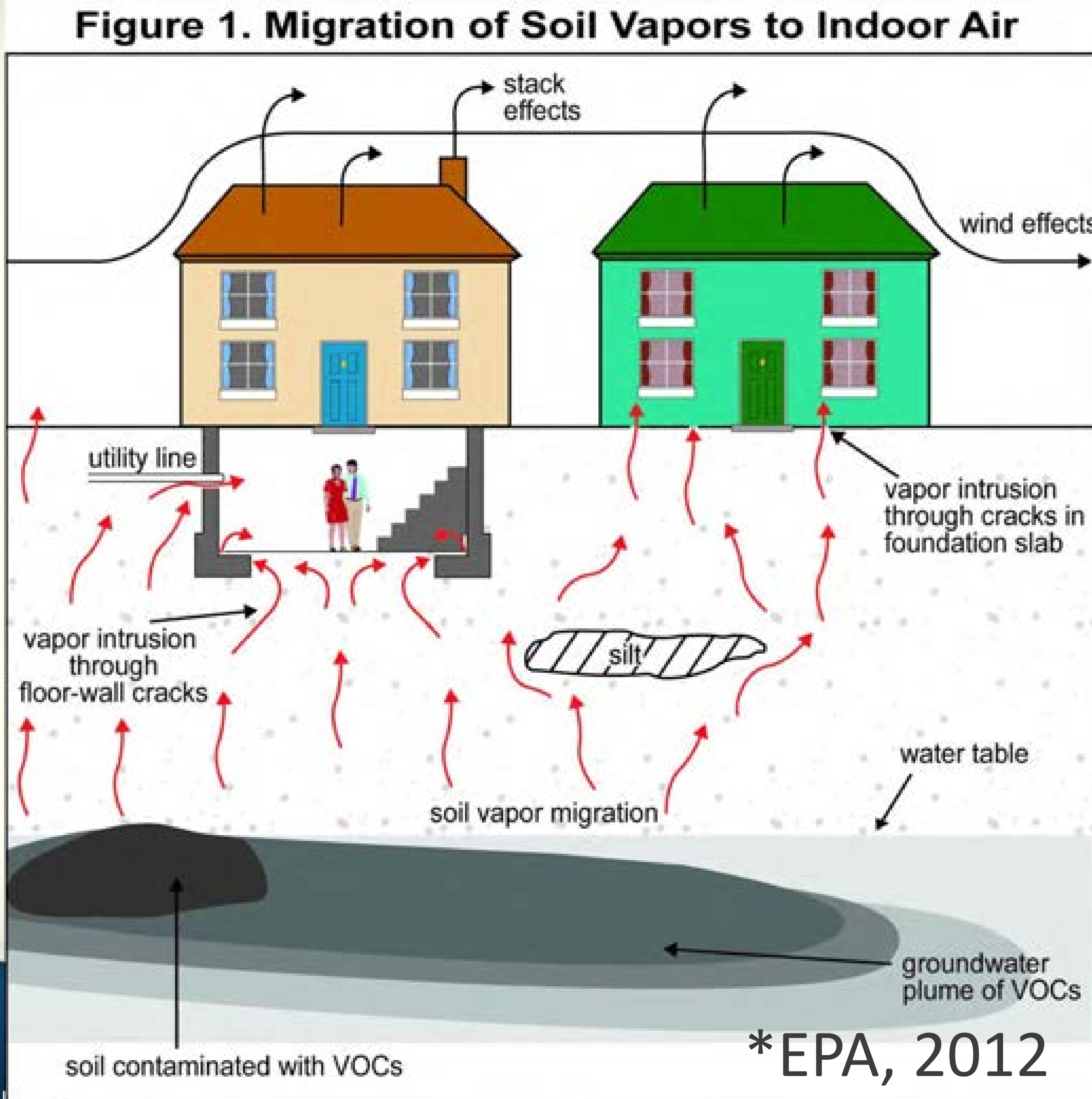
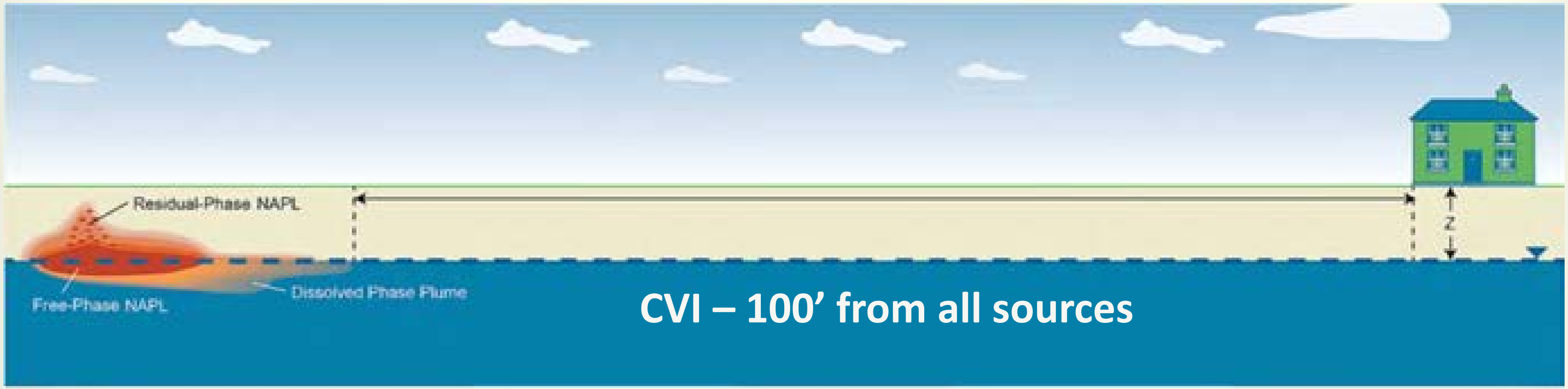
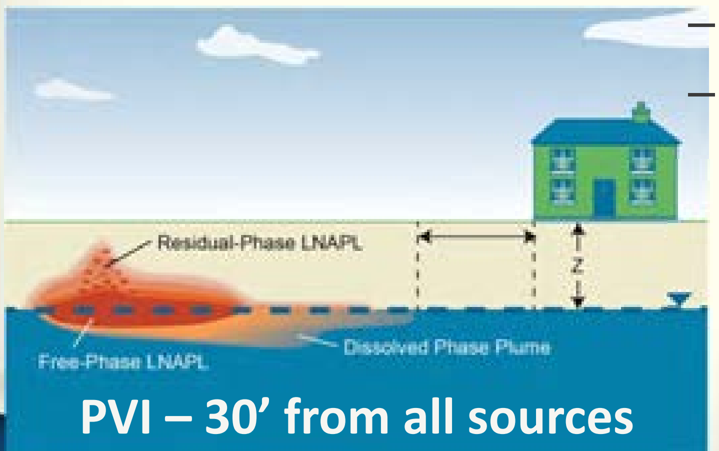


Figure 1. Migration of Soil Vapors to Indoor Air
stack
effects
wind effects
utility line
vapor intrusion
through cracks in
foundation slab
vapor intrusion
through
floor-wall cracks
silt
water table
soil vapor migration
groundwater
plume of VOCs
soil contaminated with VOCs

*EPA, 2012

Screening Distances

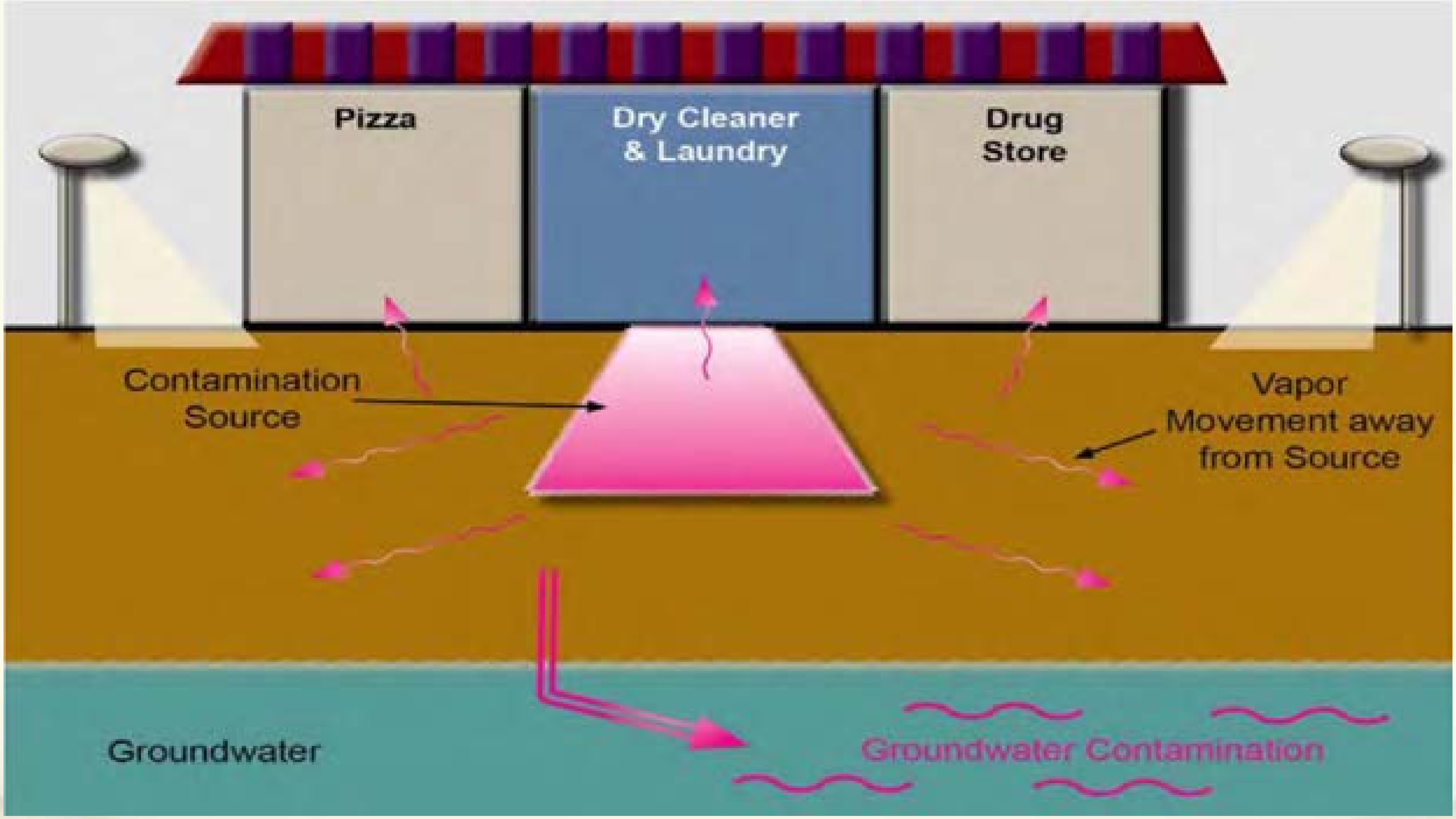




– PVI = Petroleum
– CVI = Chlorinated VOCs

CAN IMPACT ADJACENT PROPERTIES!

Typical VI Scenarios



How do we investigate VI?

Advantages and Disadvantages Associated with Sampling Media

Media	Pros	Cons
Groundwater sampling	Commonly collected during the course of an investigation Helps assess potential downgradient impacts of VI Can be performed at properties having no existing buildings	May not accuratly represent vapor concentrations when sources are present in the vadose zone
Soil sampling	Commonly collected during the course of an investigation Can be performed at properties having no existing buildings Detections may indicate VI issues	VOC loss on sampling may be significant, which can mean vapor concentrations may be significantly underestimated May not accuratly represent vapor concentrations when sources are present adjacent to collected sample
Soil gas sampling	Can provide an estimate of vapor concentrations near the source or near buildings Collected near buildings; can be performed without entering the structure Can be performed at properties having no existing buildings	Lateral and vertical spatial variability Results may not be representative of vapor concentrations under a building May not reflect how soil gas concentrations will change if a building is subsequently built on a currently vacant property
Sub-slab sampling of vapors beneath buildings	Can provide measure of vapor concentration directly below indoor air space Closest subsurface sample to receptors	Method is intrusive Cannot be performed at properties having no existing buildings
Indoor air sampling	Can provide direct measurement of indoor air concentrations	Indoor contaminants and lifestyle sources may bias the data Method is intrusive Cannot be performed at properties having no existing buildings Varies significantly over time

Soil Samples and VI

- "Generally" not a good predictor
- Where the sample is collected matters

Soil (cont)

- **PROs**
  - Commonly collected during the course of an investigation
  - Sampling methodology is well accepted

- **CONs**
  - May not accurately represent vapor concentrations when sources are present adjacent to collected sample
  - VOC loss on sampling may be significant

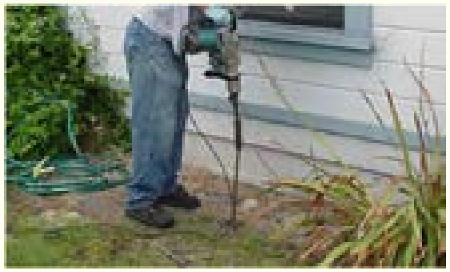
Groundwater

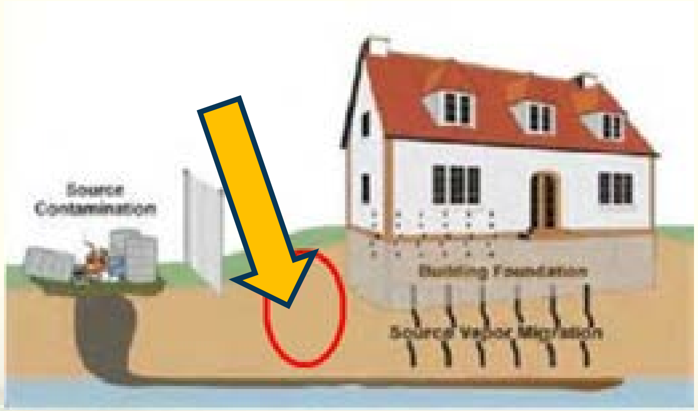
- **PROs**
  - Commonly collected during the course of an investigation
  - Can be performed at properties having no existing buildings

- **CONs**
  - May not accurately represent vapor concentrations when sources are present in the vadose zone
  - Modeled indoor air concentration

Soil Gas

- **PROs**
  - Can provide an estimate of vapor concentrations near the source or near buildings
  - Can be performed without entering the structure

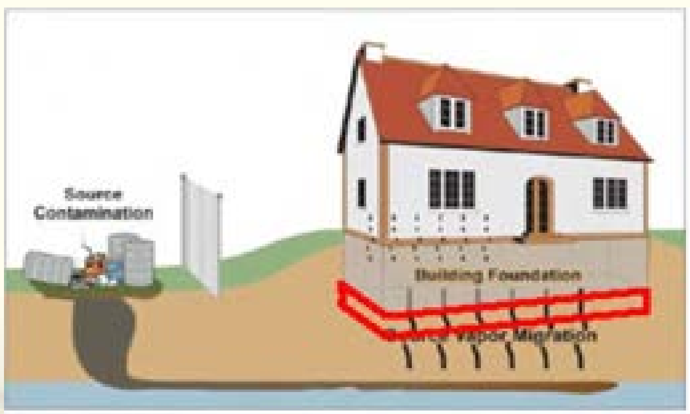




- **CONs**
  - Results may not be representative of vapor concentrations under a building
  - May not reflect how soil gas concentrations will change if a building is subsequently built on a currently vacant property

Subslab Soil Gas

- **PROs**
  - Can provide measure of vapor concentration directly below indoor air space
  - Closest subsurface sample to receptors

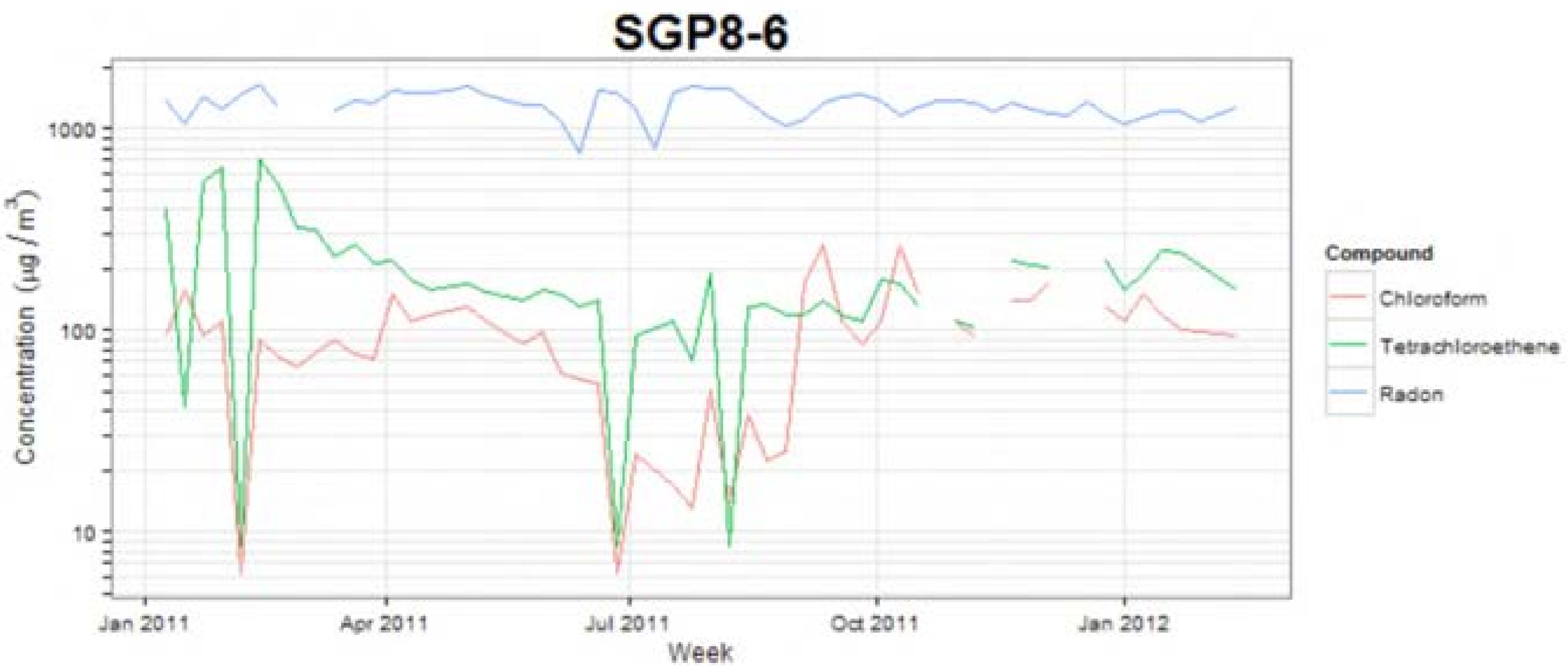


- **CONs**
  - Method is intrusive
  - Cannot be performed at properties having no existing buildings

Why not indoor air?

- Highly variable
  - Seasonal
- TWA vs. grab
- Expensive
  - Relocation
  - Prep/post
- Expect indoor air concentrations

Variability of Indoor Air



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EPA 2011 Indoor Air Study

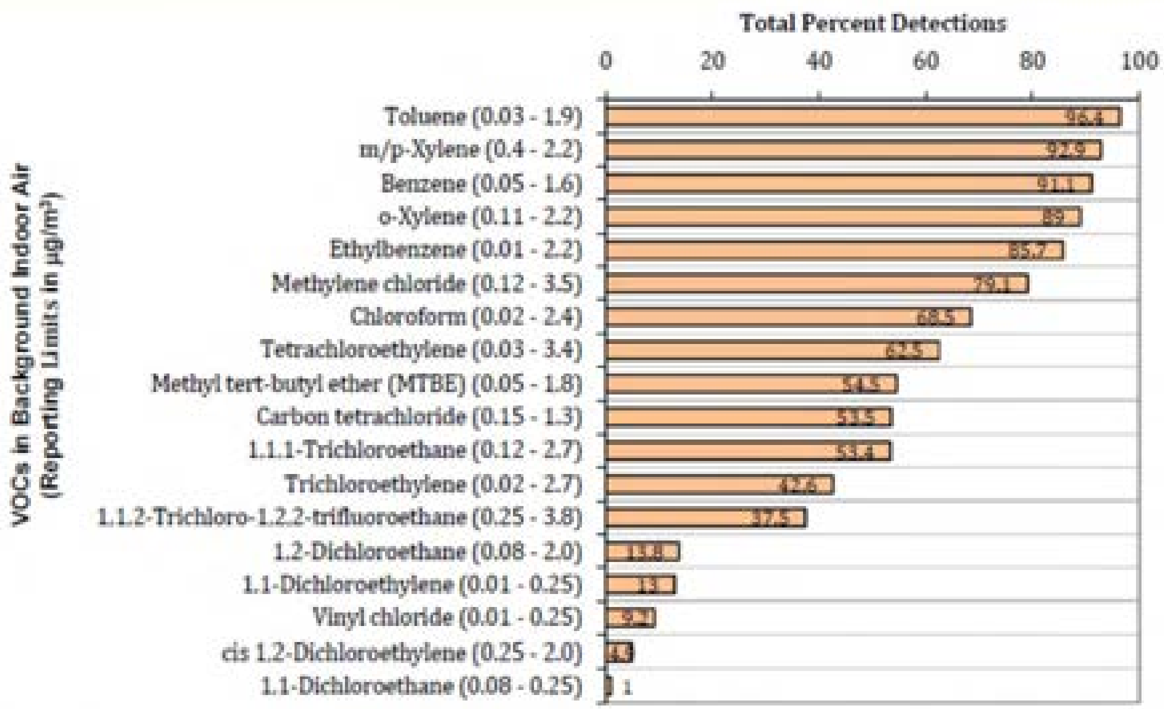


Figure 4. Total percent detections of common VOCs in background indoor air compiled from 15 studies conducted between 1990 and 2005. Range of reporting limits is shown in parentheses.

Some are easy to figure out. . .

PCE > 95% by weight
Can also include:

- TCE
- Toluene
- Acetone
- More. . .

Can include:

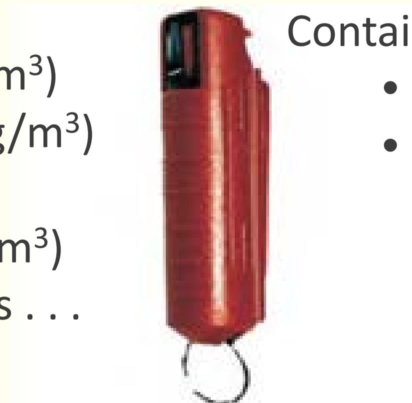
- TCE
- Toluene
- Acetone
- More. . .

- PCE

Some aren't

Contains:

- Naphthalene (31 $\mu g/m^3$)
- 1,4 Dioxane (2,100 $\mu g/m^3$)
- Toluene (120 $\mu g/m^3$)
- Ethanol (600,000 $\mu g/m^3$)
- And a bunch of others . . .



Contains:

- TCE
- PCE (up to 95% by weight)

Contains:

- Ethylbenzene (3,400 $\mu g/m^3$)
- Toluene (660 $\mu g/m^3$)
- TPH (390,000 $\mu g/m^3$)
- And more . . .

1,2 DCA

Grilling with flavor. . .

Why not OSHA values?

- Not designed for the "non-worker"
- Requires awareness training, PPE, and/or medical monitoring
  - *"Simply complying with OSHA's antiquated PELs will not guarantee that workers will be safe."* - David Michaels, Assistant Secretary of Labor for Occupational Safety and Health

- OSHA may be acceptable
- **<u>NOT RESIDENTIAL</u>**

Indoor Air

- **PROs**
  - Can provide direct measurement of indoor air concentrations

- **CONs**
  - Method is intrusive
  - Indoor contaminants and lifestyle sources may bias the data
  - Varies significantly over time
  - Cannot be performed at properties having no existing buildings

What does the data mean?

$$\text{attenuation factor} = \frac{\text{Indoor Air Concentration}}{\text{Source Concentration}}$$

$$\text{attenuation factor} = \alpha$$

$$\alpha \text{ X (Source Concentration)} > \text{Indoor Air Concentration}$$

=

<u>POTENTIAL VAPOR INTRUSION</u>

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Johnson and Ettinger (1991)

$$\alpha = (C_{indoor}/C_{source})$$

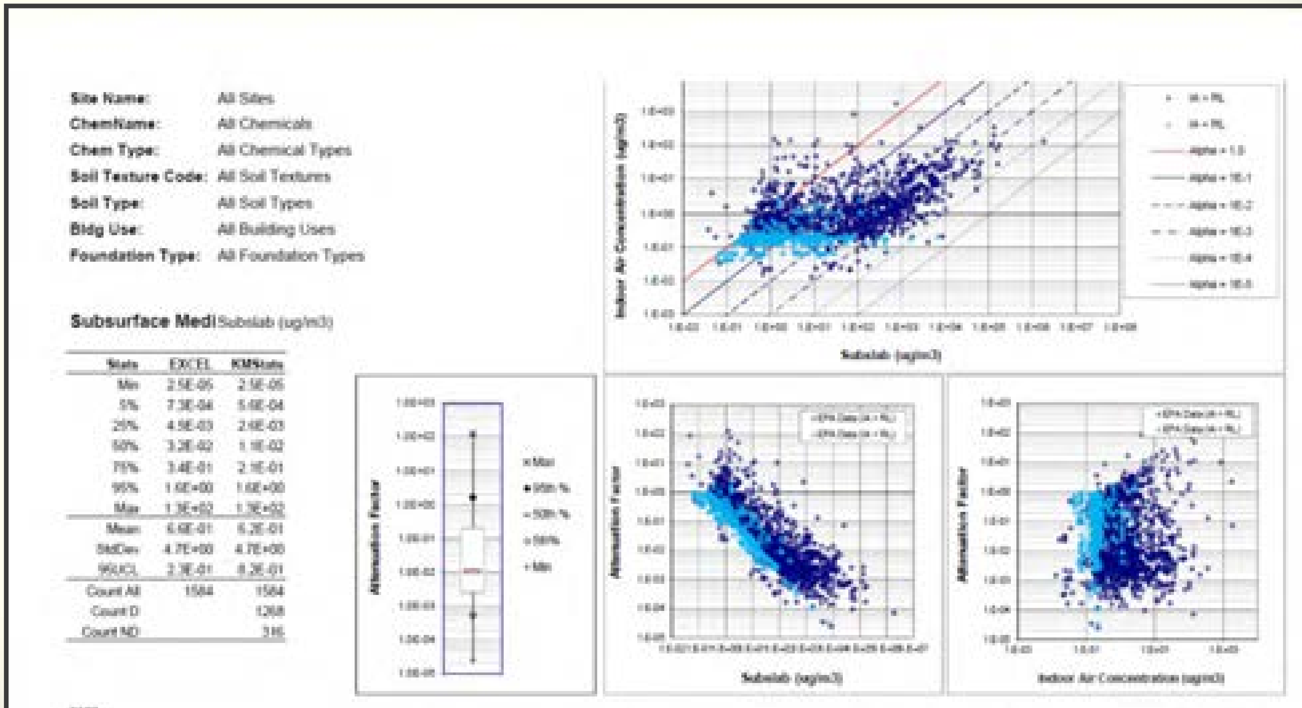
$$\alpha = \frac{\left[\left(\frac{D_T^{eff} A_B}{Q_{building} L_T}\right) x \exp\left(\frac{Q_{soil} L_{crack}}{D^{crack} A_{crack}}\right)\right]}{\left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_{building} L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[\exp\left(\frac{Q_{soil} L_{crack}}{D^{crack} A_{crack}}\right) - 1\right]\right]}$$

*Johnson, P. C, and R. A. Ettinger. 1991. Heuristic model for predicting the intrusion rate of contaminant vapors in buildings. Environ. Sci. Technol. 25: 1445-1452

Empirical Evidence

http://www.epa.gov/oswer/vaporintrusion/vi_data.html

- Over 1,600 “paired” data points



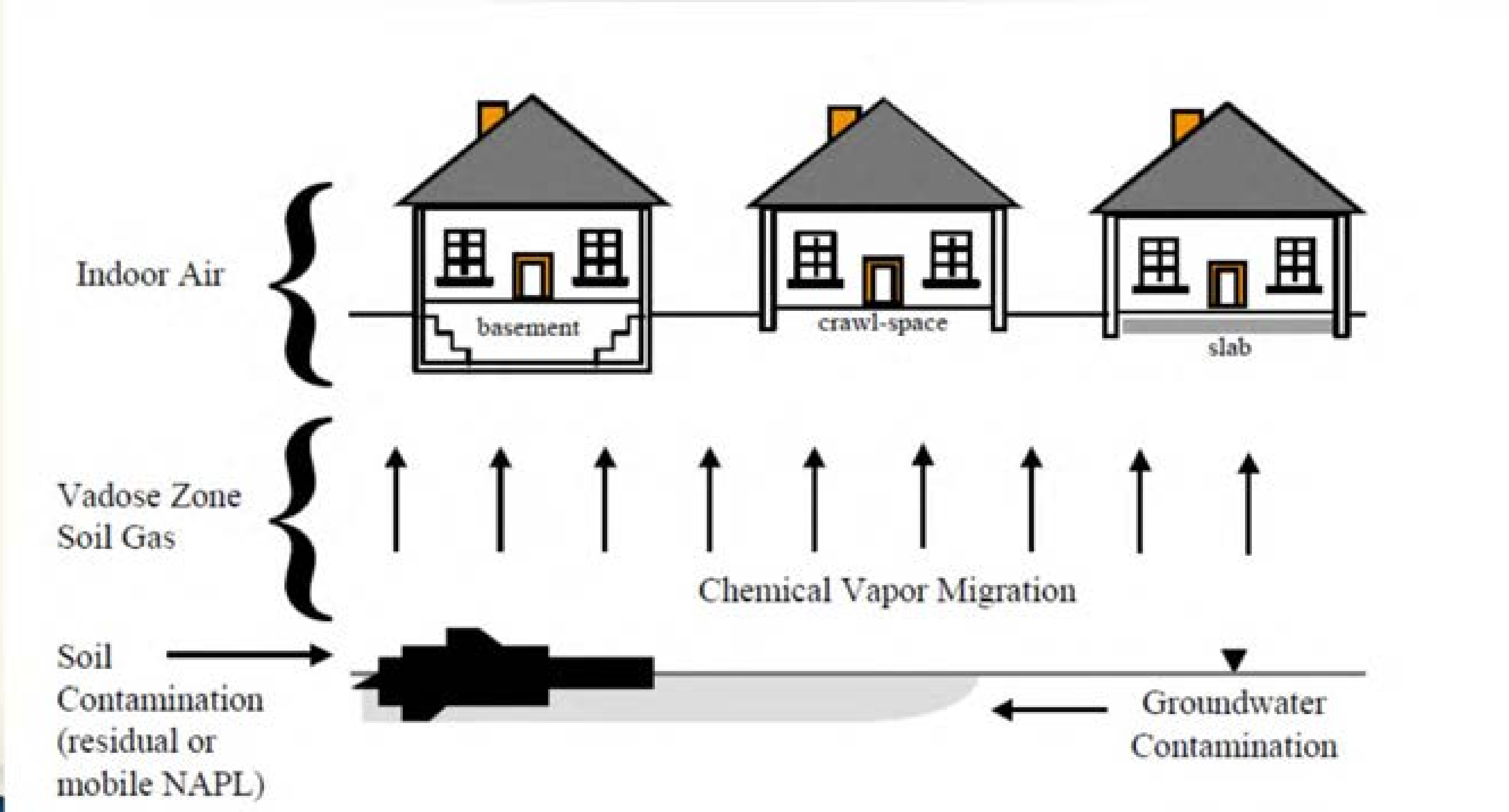
Interpreting the Results

- Variability (spatial and temporal)
  - Construction
    - Size of structure
    - Slab-on-grade vs crawlspace
    - Heating and cooling systems
  - Precipitation and weather
  - Measurement method

Interpreting the Results (cont)

– Distance to source
  - Assumes knowledge of the extent of source of vapors
– Depth to water (if a source)
– Soil characteristics
  - bulk density, total porosity, water filled porosity, soil water content, grain size
– System temperature (north vs south)
– Air exchange rate

Building Construction



Building Size and Source Location

EPA
United States Environmental Protection Agency

Measured Soil Gas Profile for TCE – Phase 2

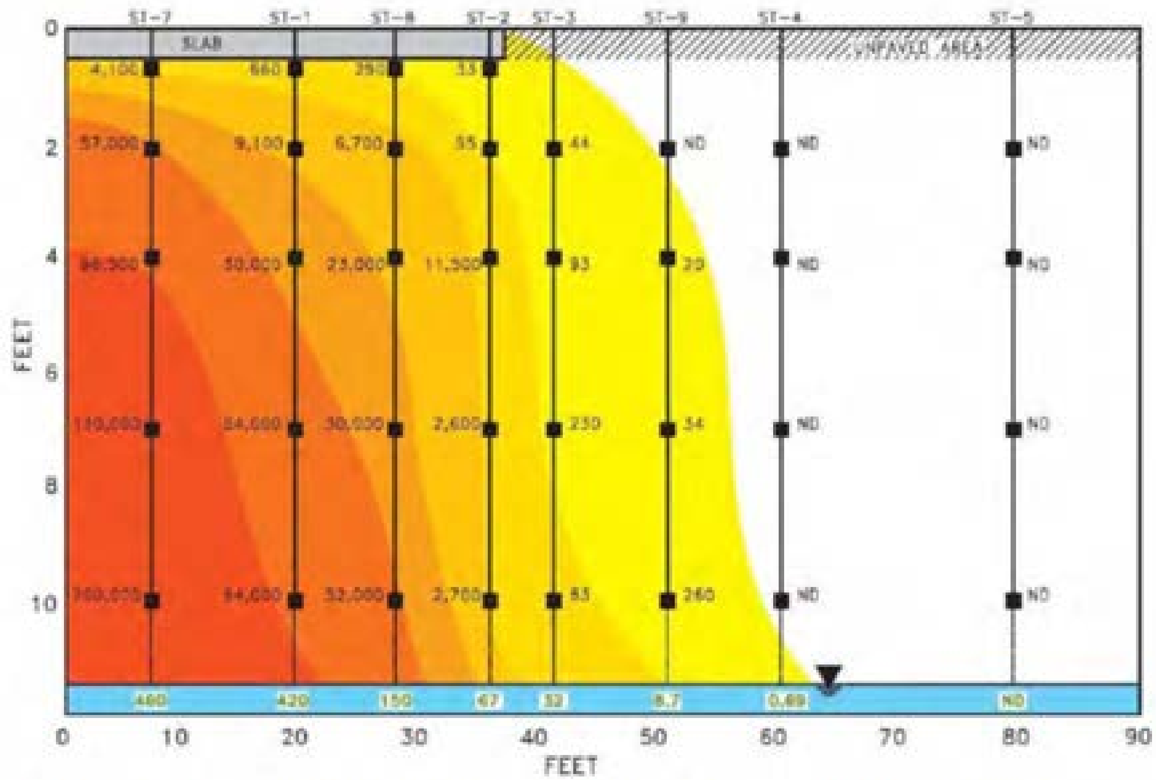
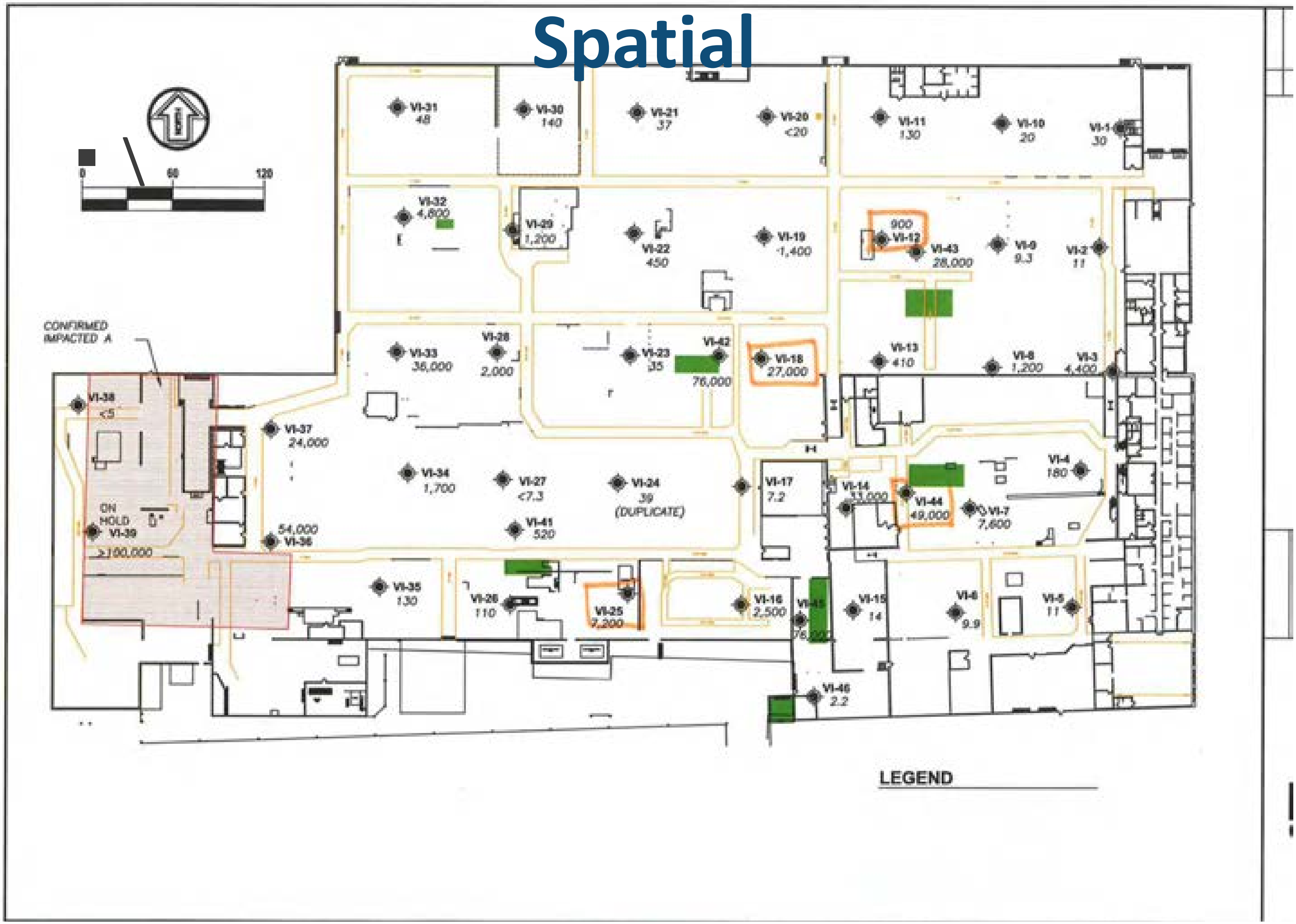


Figure 2-2. Soil gas and groundwater concentrations below a slab (Schumacher et al., 2010).

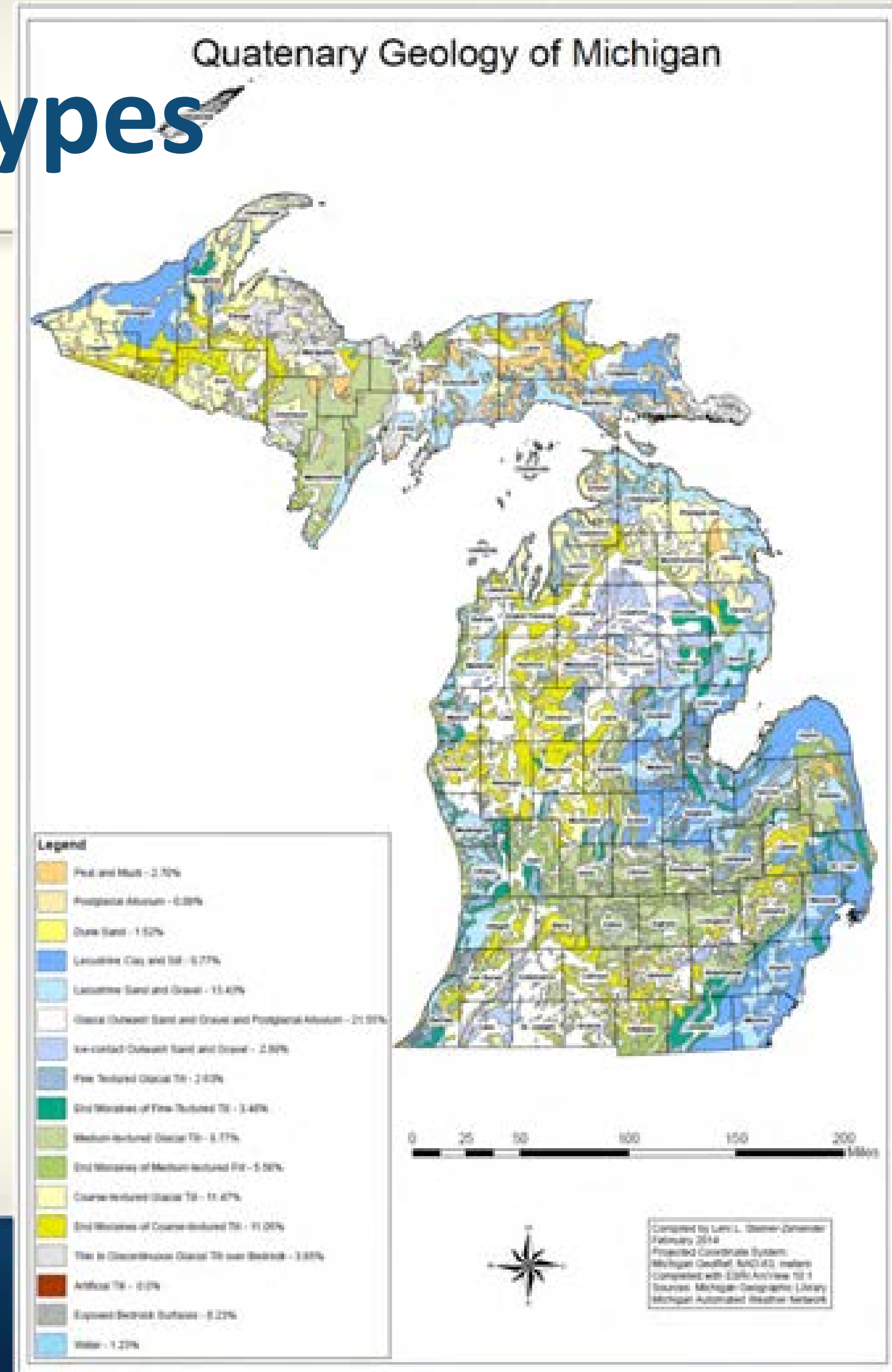
Spatial



CONFIRMED IMPACTED A
VI-31 48
VI-30 140
VI-21 37
VI-20 <20
VI-11 130
VI-10 20
VI-1 30
VI-32 4,800
VI-29 1,200
VI-22 450
VI-19 1,400
900 VI-12
VI-43 28,000
VI-9 9.3
VI-2 11
VI-33 36,000
VI-28 2,000
VI-23 35
VI-42 76,000
VI-18 27,000
VI-13 410
VI-8 1,200
VI-3 4,400
VI-38 <5
VI-37 24,000
VI-34 1,700
VI-27 <7.3
VI-24 39 (DUPLICATE)
VI-17 7.2
VI-14 33,000
VI-44 49,000
VI-7 7,600
VI-4 180
ON HOLD VI-39 >100,000
54,000 VI-36
VI-41 520
VI-35 130
VI-26 110
VI-25 7,200
VI-16 2,500
VI-45 76,000
VI-15 14
VI-6 9.9
VI-5 11
VI-46 2.2
0 60 120
LEGEND

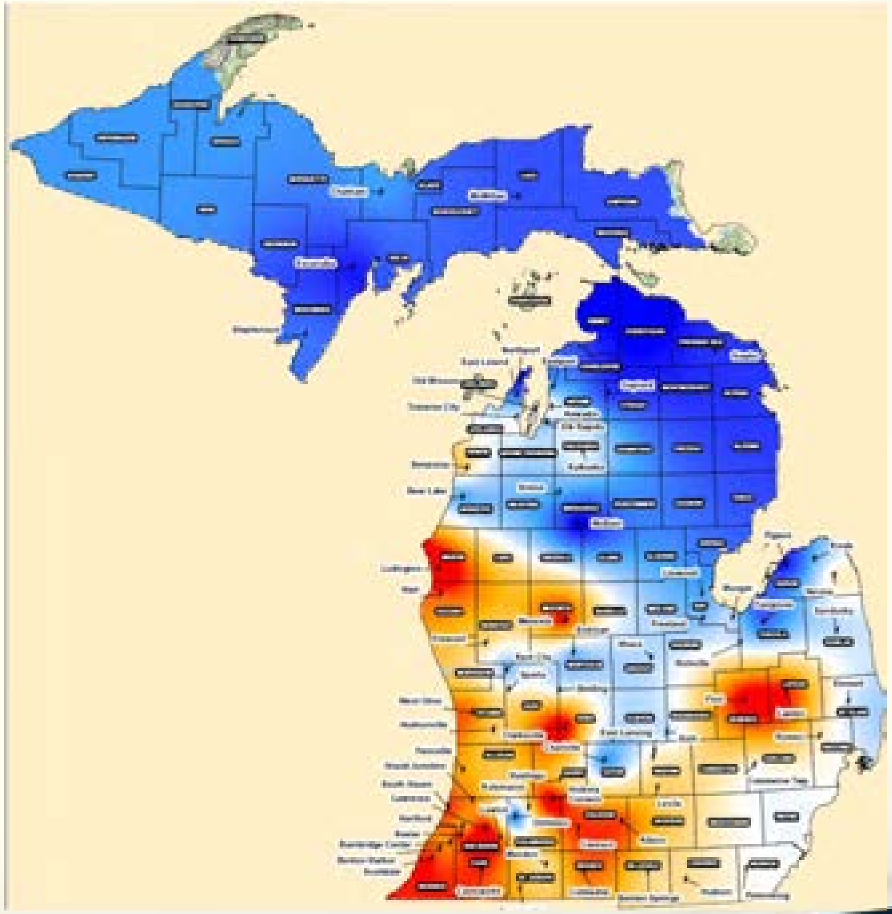
Soil Types

- Sand – 39.4%
- Loam – 36.7%
- Clay – 15.9%
- Other – 8.0%



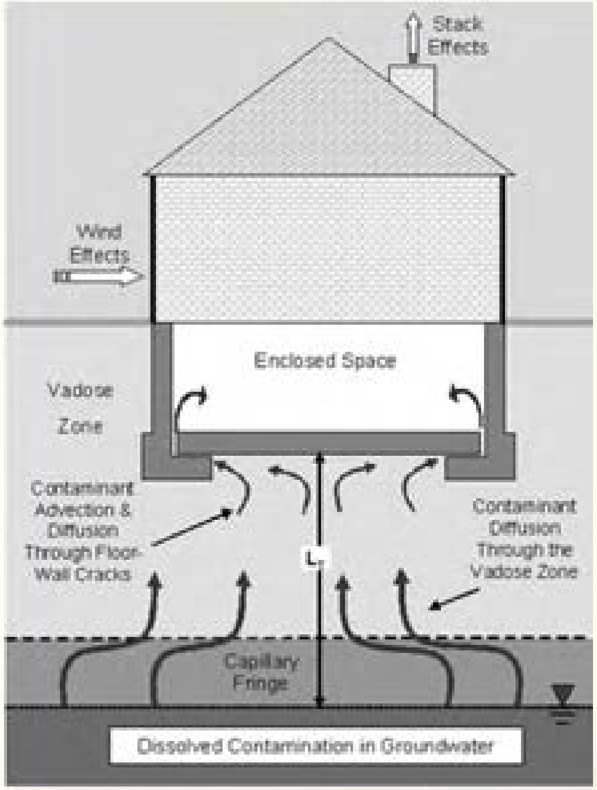
Temperature

- Assign temp based on identified county average
  - Data based on 72 Stations
  - Daily average
  - Up to 15 years of data



Multiple Lines of Evidence

- Soil gas spatial concentrations
- Groundwater spatial data
- Building construction
- Sub-slab soil gas data
- Indoor air data
- Soil stratigraphy
- Temporal patterns



Investigate vs. Presumptively Mitigate

Extra time and cost required for investigation

vs.

Cost to presumptively mitigate the site (allowed for under Part 201)

Response Actions

- Source Area Remediation
- Institutional Controls
- Building Controls

APPENDIX 1

Recommended Parameters for Common Petroleum Products

Parameters	Leaded Gasoline[1]	Unleaded Gasoline[2]	Petro. Solv[3]	Light Distillate Oils[4]	Residual Oils[5]	Used Motor Oils[6]	Waste Oils[7]	Unknown
BTEX	X	X	X	X		X	X	X
Trimethylbenzene Isomers (TMB)[8]	X	X	X	X	X	X	X	X
MTBE		X						X
1,2-Dibromoethane[1] (ethylene dibromide)	X					X	X	X
1,2-Dichloroethane[1]	X					X	X	X
PNAs[9]			X	X	X	X	X	X
Naphthalene/ 2-methylnaphthalene	X	X						X
Cadmium[10]						X	X	X
Chromium[10]						X	X	X
Lead[10]	X					X	X	X
Volatile Halocarbons[11]						X	X	X
PCBs							X	X

PNAs with HLC > 10^{-6}

- Naphthalene
- 2-methylnaphthalene
- Acenaphthene
- Acenaphthylene
- Fluorene
- Anthracene
- Phenanthrene
- Ethylene Dibromide (1,2-Dibromoethane)
- Fluoranthene
- Pyrene

*TO-15 can't analyze everything . . .

Common Soil Gas Methods

- TO-15
- TO-17
- TO-13A
  - (via Low-Flow)
- NIOSH
- EPA

NOT 8260!

NOTE: JUST LIKE SOIL AND GROUNDWATER, MORE THAN ONE METHOD MAY BE REQUIRED!

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Typical Soil Gas Concentrations

- SG concentrations can create headaches!
  - Typical Soil Gas Concentrations
    - Benzene near gasoline spill: >100,000 $\mu g/m^3$
      - TPH vapor: >1,000,000 $\mu g/m^3$
    - TCE near a degreaser: >75,000 $\mu g/m^3$
    - PCE under dry cleaner: >100,000 $\mu g/m^3$

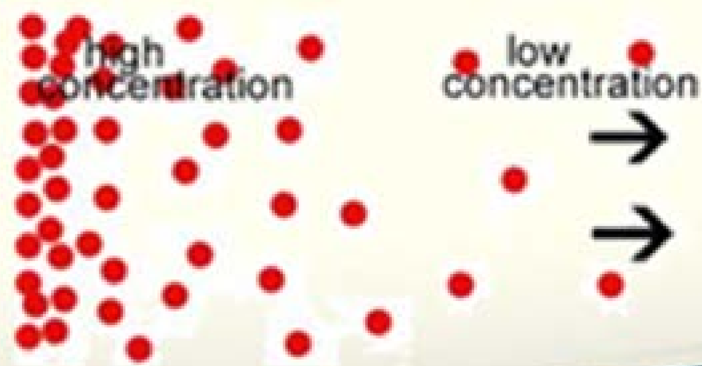
Something else to think about. . .

- How Fast Do Vapors Move?
  - Distance = $(2 * D_e * t)^{1/2}$

    where:

    D_e is the effective diffusivity.

    t is time



How Fast Do Vapors Move (cont)?

- For many vapors, the gaseous diffusion coefficient is approximately 0.1 cm^2/s
- Soil porosity varies depending on the type of *soil*
  - Several equations are available to calculate the effect of air-filled and total porosity on the diffusivity
  - Conservative approximation is that the porosity reduces the gaseous diffusivity by a factor of 10
  - ***D_e can be approximated as 0.01 cm^2/s***

How Fast Do Vapors Move (cont)?

Distance

$= (2 * 0.01\ cm^2/s * 31{,}536{,}000\ s)^{1/2}$

$\sim$ 800 cm = ~25 feet per year

~1 inch / day

Into and through the groundwater

in a year: 3 inches

~.008 inch / day

***Assumes liquid diffusion, not gaseous diffusion, coefficient for compounds is approximately 0.00001 cm^2/s**

Consider when sampling:

- Site geology
- Sample volume
- Sample collection vacuum
- Sample probe purging
- Soil gas equilibration
- Sampling interval
- Sampling method
- Weather?

Quality of the Data

GOAL is to collect reliable data!

- How much to collect?
  - – number of samples vs volume
    - Greater the volume, greater the uncertainty
    - More samples, better characterization
- Where will they be collected?
  - – Closer to surface, harder to collect
    - 5' bgs generally considered stable (building?)

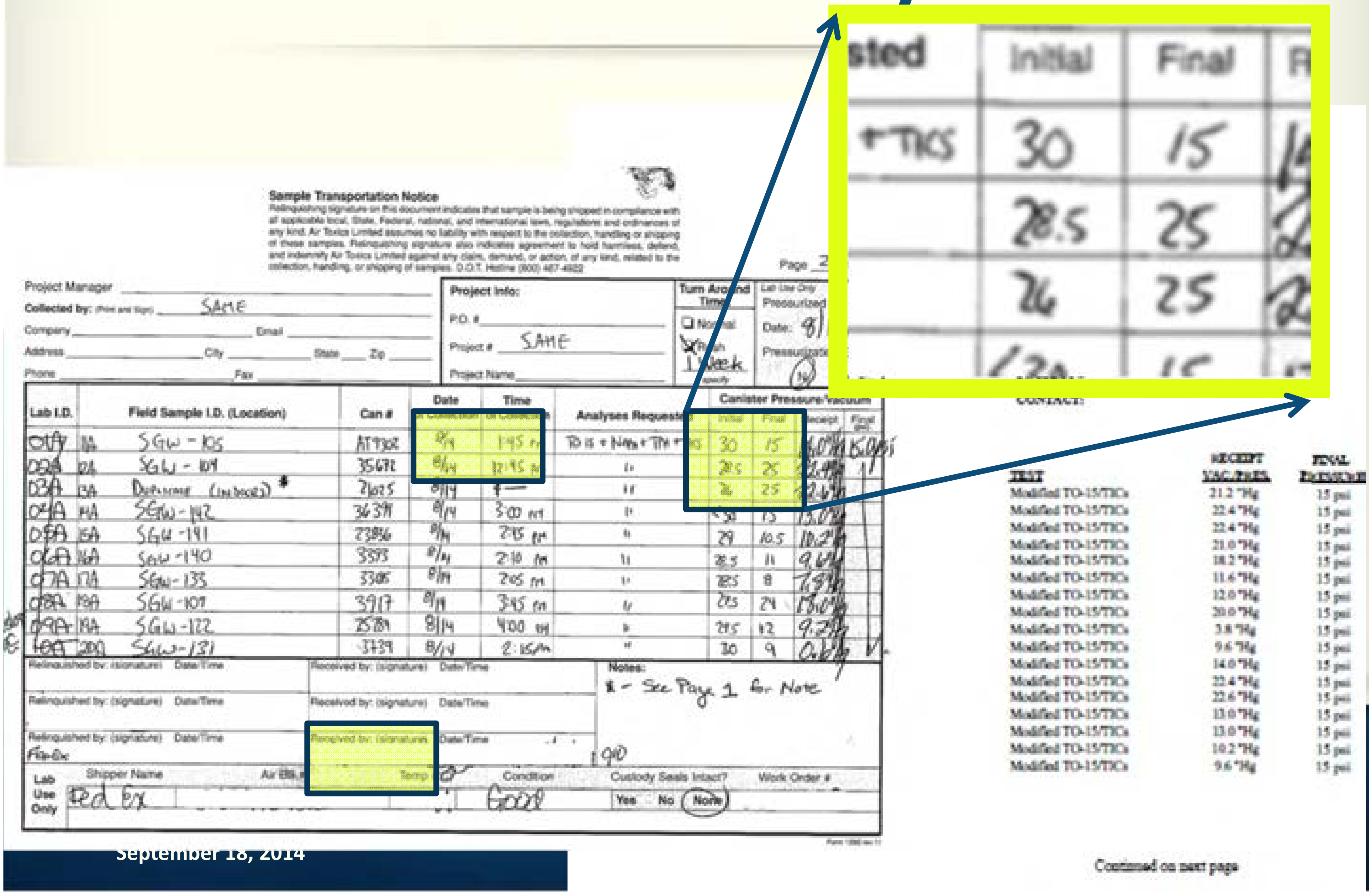
Quality of the Data (cont)

- When to collect
  - Weather
  - Seasonal effects
  - Extreme temperature variations
  - Heating/cooling of structure
  - Heavy periods of rain
- New vs old vs modified
- Will it change the concentrations?

Reliable Data Requires

- Just like soil and groundwater
  - Good sampling techniques
  - Good analytical methods
  - Good CSM (where is the source)
  - Understanding what the data means
- Experience with vapor sampling
  - Have they done this before?
  - Quality/experience of field staff? Sr or Jr?

Chain of Custody. . .



Breakthrough. . . NOT a lab issue, a sampling issue

TO-15 (TO-15) Aliquot ID: 51570-001 Matrix: Air Analyst:

Parameter(s)	Result	Q	Units	Reporting Limit	Dilution	Prep Date	Prep Batch	Analysis Date	Analysis Batch
1. Acetone (NN)	310		ppbv	51	10	08/27/12	VA12H27B	08/28/12	VA12H27B
2. Benzene (NN)	6.0		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
3. Benzyl Chloride (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
4. Bromodichloromethane (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
5. Bromoform (NN)	U		ppbv	61	240	08/31/12	VA12H31A	08/31/12	VA12H31A
6. Bromomethane (NN)	U		ppbv	2.6	10	08/27/12	VA12H27B	08/28/12	VA12H27B
7. 1,3-Butadiene (NN)	U		ppbv	55	10	08/27/12	VA12H27B	08/28/12	VA12H27B
8. 2-Butanone (NN)	U		ppbv	12	10	08/27/12	VA12H27B	08/28/12	VA12H27B
9. Carbon Disulfide (NN)	18		ppbv	13	10	08/27/12	VA12H27B	08/28/12	VA12H27B
10. Carbon Tetrachloride (NN)	U		ppbv	2.7	10	08/27/12	VA12H27B	08/28/12	VA12H27B
11. Chlorobenzene (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
12. Chloroethane (NN)	U		ppbv	5.3	10	08/27/12	VA12H27B	08/28/12	VA12H27B
[illegible]	[illegible]		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
14. Chloromethane (NN)	73	J,L+	ppbv	27	10	08/27/12	VA12H27B	08/28/12	VA12H27B
[illegible]	[illegible]		ppbv	28	10	08/27/12	VA12H27B	08/28/12	VA12H27B
16. Dibromochloromethane (NN)	U		ppbv	2.9	10	08/27/12	VA12H27B	08/28/12	VA12H27B
17. 1,2-Dichlorobenzene (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
18. 1,3-Dichlorobenzene (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
19. 1,4-Dichlorobenzene (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
20. Dichlorodifluoromethane (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
21. 1,1-Dichloroethane (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
22. 1,2-Dichloroethane (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
23. 1,1-Dichloroethene (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
24. cis-1,2-Dichloroethene (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
25. trans-1,2-Dichloroethene (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
26. 1,2-Dichloropropane (NN)	U		ppbv	5.5	10	08/27/12	VA12H27B	08/28/12	VA12H27B
27. cis-1,3-Dichloropropene (NN)	U		ppbv	5.5	10	08/27/12	VA12H27B	08/28/12	VA12H27B
28. trans-1,3-Dichloropropene (NN)	U		ppbv	5.2	10	08/27/12	VA12H27B	08/28/12	VA12H27B
29. 1,4-Dioxane (NN)	U		ppbv	5.5	10	08/27/12	VA12H27B	08/28/12	VA12H27B
30. Ethyl Acetate (NN)	U		ppbv	28	10	08/27/12	VA12H27B	08/28/12	VA12H27B
31. Ethylbenzene (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
32. Ethylene Dibromide (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
33. 4-Ethyltoluene (NN)	U		ppbv	130	240	08/31/12	VA12H31A	08/31/12	VA12H31A
34. n-Heptane (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
35. Hexachlorobutadiene (NN)	U		ppbv	67	240	08/31/12	VA12H31A	08/31/12	VA12H31A
36. n-Hexane (NN)	U		ppbv	2.8	10	08/27/12	VA12H27B	08/28/12	VA12H27B
37. 2-Hexanone (NN)	U		ppbv	29	10	08/27/12	VA12H27B	08/28/12	VA12H27B
38. Isopropanol (NN)	150000	E	ppbv	3200	1100	08/31/12	VA12H31A	09/01/12	VA12H31A
[illegible]	[illegible]		ppbv	13	10	08/27/12	VA12H27B	08/28/12	VA12H27B

DEQ

TABLE 4
SOIL VAPOR ANALYTICAL RESULTS

Soil Vapor Monitoring Point	Screened Interval (feet bgs)	Sample Date	Lower Explosive Limit (LEL) %	Oxygen %	Hydrogen Sulfide ppm	Benzene ppbv	Toluene ppbv	Ethyl-benzene ppbv	m & p-Xylene ppbv	o-Xylene ppbv	Total Xylenes ppbv	Total Hydrocarbons as Gas ppbv	Carbon Dioxide %	Methane %	2-Propanol + ppbv
SVMP-1S	4.96-5.00	7/31/2012	NM	NM	NM	2.6	7.1	<1.0	3.2	<1.0	NA	1,580	<1.7	2.4	2,870
SVMP-1S	4.96-5.00	3/06/2013	0	19.1	0.0	<0.74	<0.74	<0.74	2.3	0.88	NA	365	NA	<4.0	22.5
SVMP-1S	4.96-5.00	6/05/2013	0	14.8	0.0	<16.1	77.1	68.0	NA	NA	2,950	219,000	NA	<4.7	NA
SVMP-1I	8.46-8.50	7/31/2012	NM	NM	NM	<20.5	<20.5	64.3	261	108	NA	4,050	4.2	<2.2	117
SVMP-1I	8.46-8.50	3/06/2013	1	20.9	0.0	<0.80	<0.80	<0.80	<1.6	<0.80	NA	1,040	NA	<4.4	2.9
SVMP-1I	8.46-8.50	6/05/2013	0	17.2	0.0	<64.4	<64.4	<64.4	NA	NA	260	10,300	NA	<7.0	NA
SVMP-1D	11.96-12.00	7/31/2012	0	18.2	0.0	<42.4	109	<42.4	531	60.5	NA	83,000	10.2	323	<42.4
SVMP-1D	11.96-12.00	3/06/2013	0	5.0	0.0	<1,330	<1,330	<1,330	9,560	<1,330	NA	680,000	NA	<5.8	<1,330
SVMP-1D	11.96-12.00	6/05/2013	0	19.1	0.0	<15.5	<15.5	<15.5	NA	NA	869	108,000	NA	<7.0	NA
SVMP-2S	4.96-5.00	7/31/2012	0	15.3	0.0	1.5	<1.0	3.7	4.8	<1.0	NA	1,050	4.3	<2.0	1.4
SVMP-2S	4.96-5.00	3/06/2013	0	17.4	0.0	<0.80	<.80	<.80	<1.6	<0.80	NA	358	NA	7.3	299.0
SVMP-2S	4.96-5.00	6/05/2013	0	15.0	0.0	1.0	11.0	3.8	NA	NA	29.2	5,230	NA	<6.5	NA
SVMP-2I	8.46-8.50	7/31/2012	0	17.2	0.0	<2.4	<2.4	<2.4	<4.8	<2.4	NA	1,510	7.9	<2.1	8.7
SVMP-2I	8.46-8.50	3/06/2013	0	9.7	0.0	<83.1	<83.1	<83.1	<166	<83.1	NA	9,290	NA	<5.7	<83.1
SVMP-2I	8.46-8.50	6/05/2013	0	19.3	0.0	4.3	38.9	7.7	NA	NA	42.2	2,900	NA	<7.0	NA
SVMP-2D	11.96-12.00	7/31/2012	0	18.0	0.0	<2,590	<2,590	2,720	40,900	<2,590	NA	1,630,000	11.0	202	<2,590
SVMP-2D	11.96-12.00	3/06/2013	0	10.2	0.0	11,200	7,070	24,800	787,000	18,000	NA	15,900,000	NA	<3.6	<665
SVMP-2D	11.96-12.00	6/05/2013	0	18.4	0.0	6,830	<1,030	6,990	NA	NA	276,000	20,200,000	NA	<6.8	NA
SMVP-3S	4.96-5.00	7/31/2012	0	19.5	0.0	<1.0	4.2	<1.0	<2.0	<1.0	NA	814	2.8	<2.0	132
SMVP-3S	4.96-5.00	3/06/2013	0	19.6	0.0	<0.78	<0.78	<0.78	<1.6	<0.78	NA	81.9	NA	<4.2	8.5
SMVP-3S	4.96-5.00	6/05/2013	0	20.9	0.0	1.9	1.3	6.2	NA	NA	34.8	4,500	NA	<8.2	NA

Questions that should be asked

- What level of uncertainty is acceptable?
  - Owner
  - Consultant
  - Financial institution/Other?
- Who is doing the sampling?
- Does my site conditions currently match the future?
  - If not what can be done?

Questions that should be asked

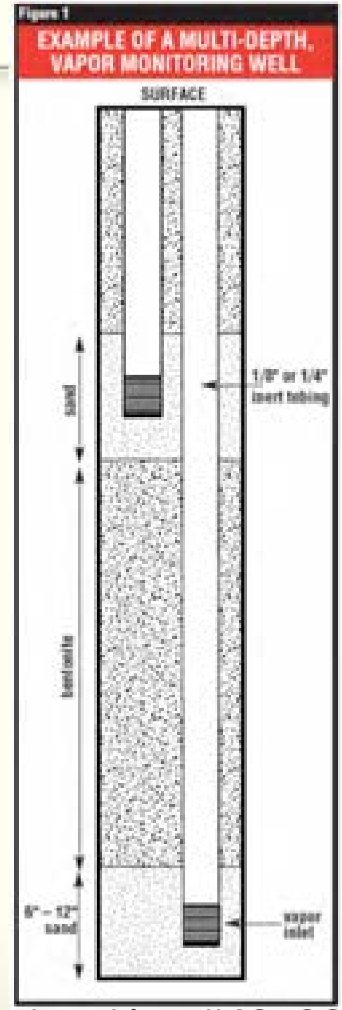
- What are the specific chemicals of concern need to be identified?
  - What methods are necessary and available?
  - Is there more than one method?
    - Is it an air method?
    - Is there a standard available?
    - Pros/Cons
  - What analytical method reporting limits are required?

Questions that should be asked

- Am I going to sample more than once?
  - How will that impact the data?
- What, where and when of sampling. . .

Closing

Soil Gas Wells



LustLine #42, 2002

Also called:

- Soil Gas Monitoring Point
- Vapor Monitoring Point
- Others

Sub-Slab Monitoring Point

THANKS!

Questions?

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