The Intricacies of Really Understanding Vapor Intrusion- and What This Means for Modeling

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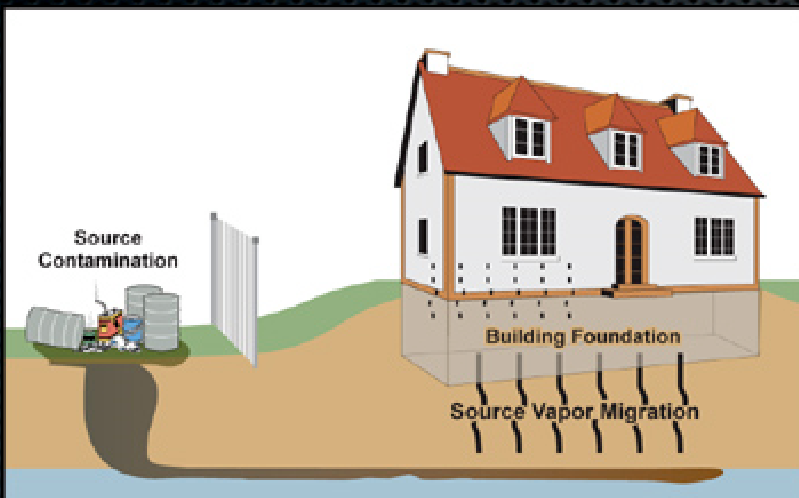


Vapor intrusion involves the migration of chemical vapors in the soil and groundwater to enter buildings through foundation cracks and joints. Sometimes vapor intrusion can result in long-term exposure of contaminants at harmful levels.

- Affects maybe 1/4 of the estimated inventory of 500,000 US brownfields sites.
- At present, no general EPA guidance, though draft guidance has been prepared.
- States regulate, but often very different standards in use.
- Also jurisdictional issues - who is in charge- OSHA? EPA? State?
- No agreement on site investigation practices.
- Limited use of quantitative modeling- very fieldwork based, empirical.

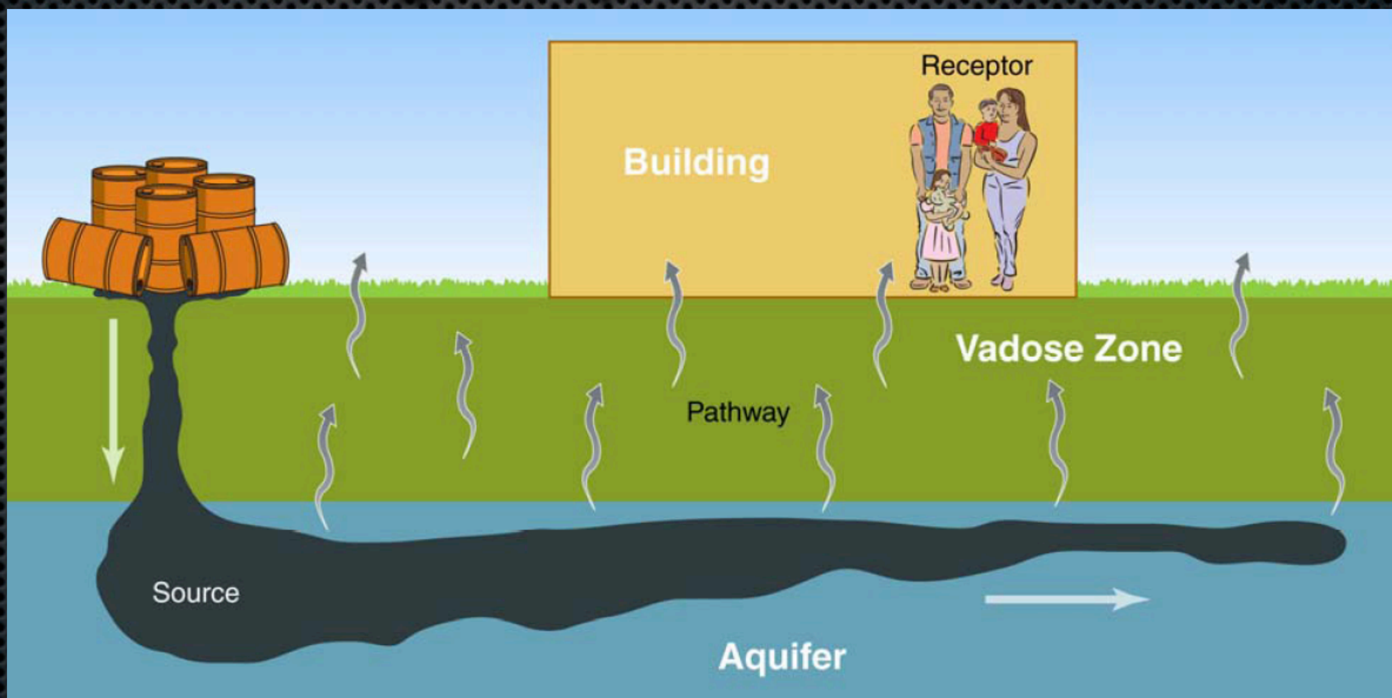
In environmental health risk assessment, for there to be a human health risk there must be a completed exposure pathway, involving identification of a

- **Source (But what if Source Strength is Variable?)**
- **Migration Route (What temporal variation is possible?)**
- **Receptor (Confounding receptor level situations?)**

-Does depth to GW matter?

-Does rain/ice make a difference? Other Seasonal/ weather effects?

-What about non-VI background?



Interstate Technology & Regulatory Council, 2007

- So the first step is to decide if a chemical is of concern (a COC)
- Set a maximum allowable exposure, assuming 30 years in a home, 350 days a year at home, whether children are involved...
- Set a regulatory indoor air concentration for the COC (C_{indoor})
- Widely varying, workplace to residence, state to state

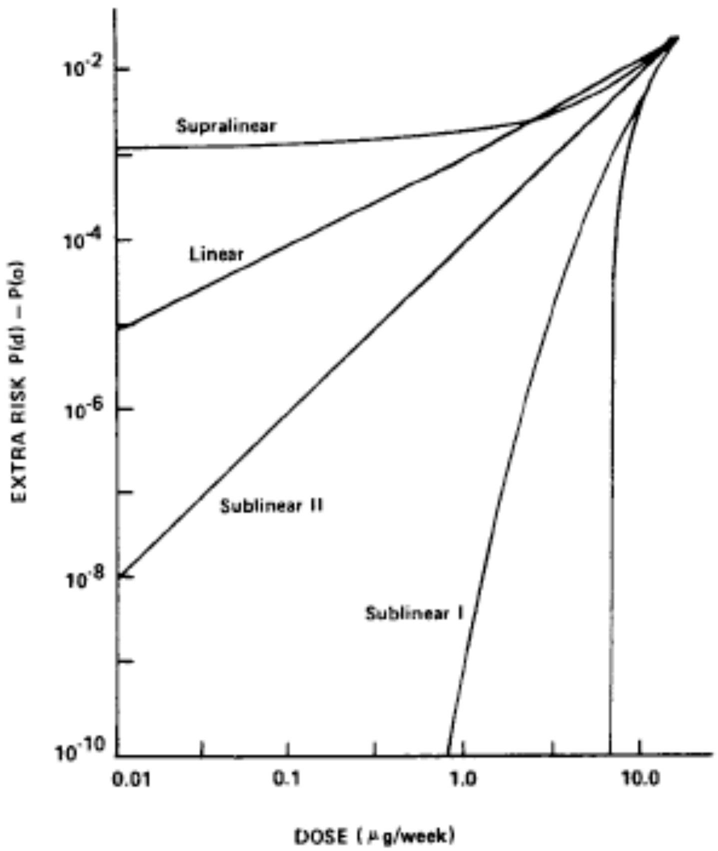
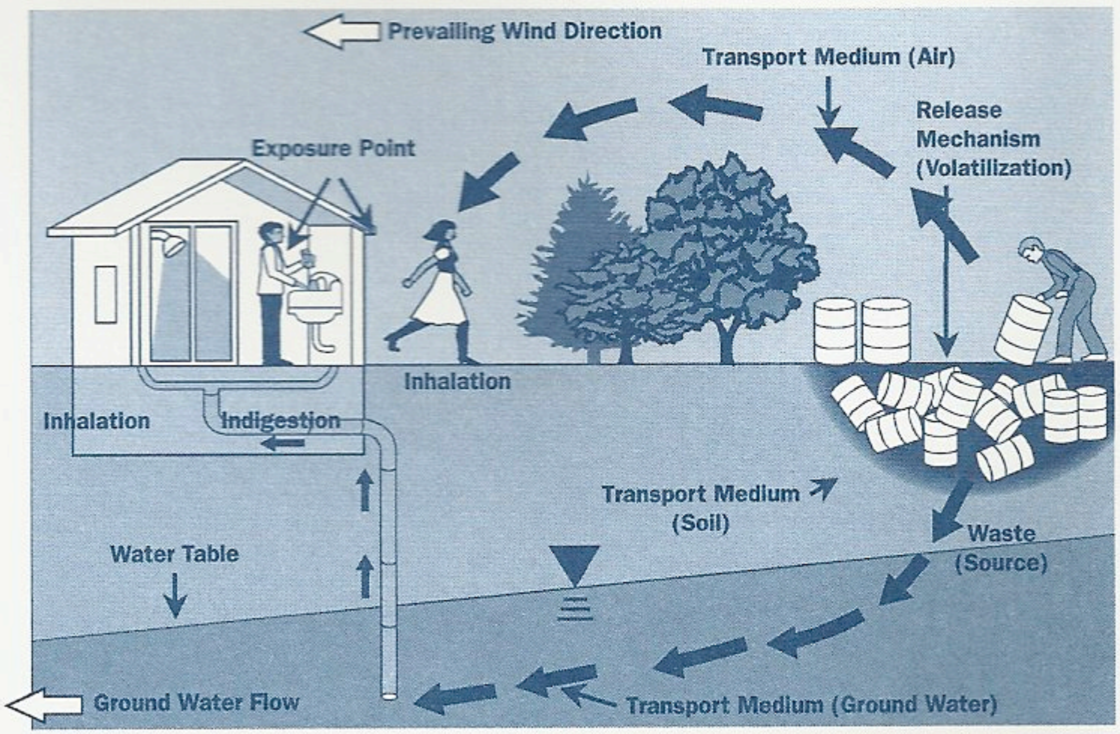


Figure 4: Low dose properties of five dose-response functions. Results of alternative extrapolation models for the same experimental data. NOTE: Dose-response functions were developed for data from a benzo-[a]pyrene carcinogenesis experiment in mice conducted by Lee and O'Neill.[11]

Fundamental problem- extrapolation from animal data to low dose exposures

From Handbook of Carcinogen Testing by: Milman, H.A.; Weisburger, E.K. © 1994 William Andrew Publishing/ Noyes



From NEWMOA- "Improving Site Investigation"

May get indigestion (or worse), but what was meant was "ingestion"

Keep in mind- Other exposure routes can come into play (including resident-caused exposures)

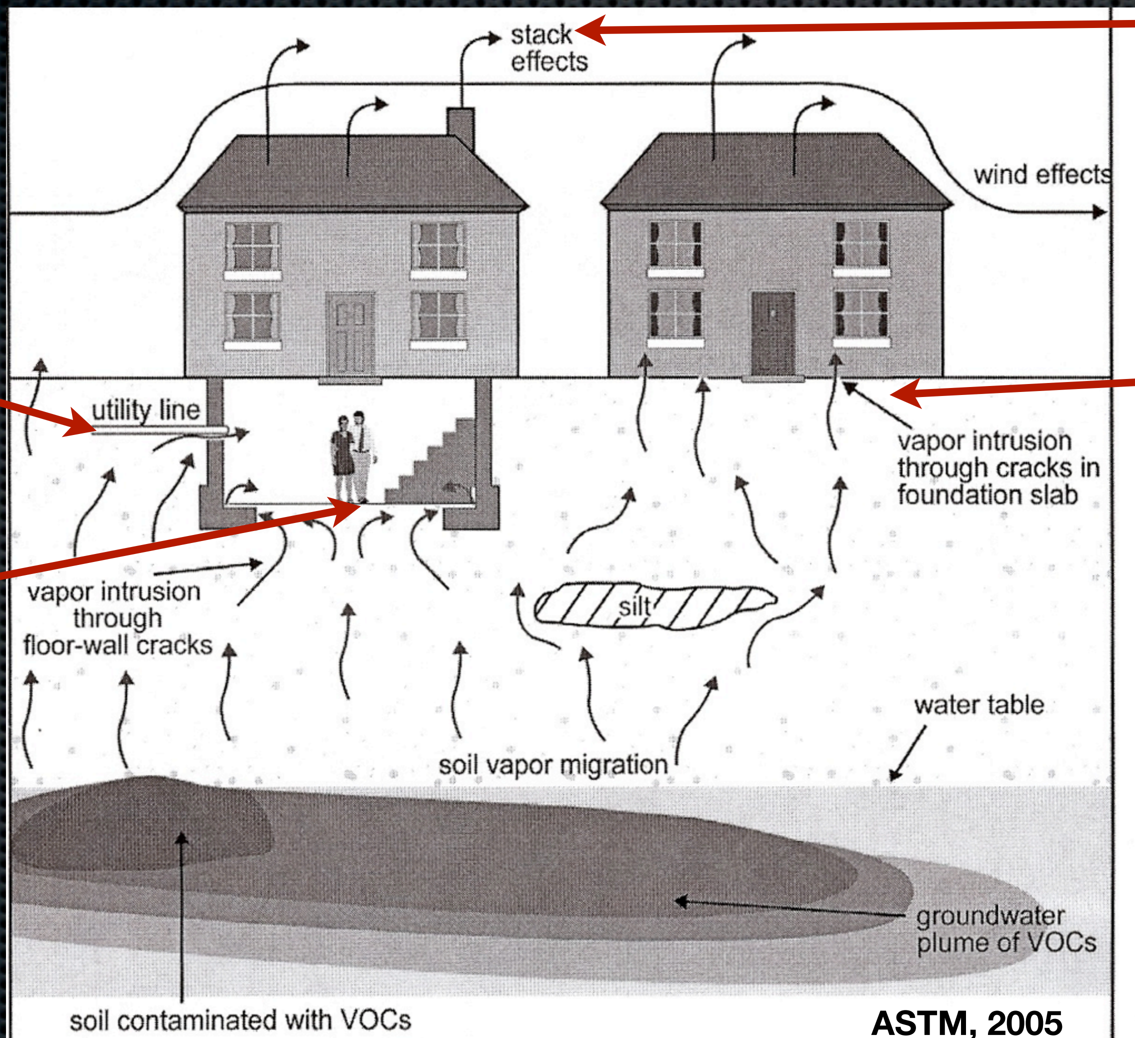
Also, can stop drinking polluted water, but replacing the 20 m^3/day of air we breathe is tough.

Results in building depressurization of 1 to 50 Pa (5 Pa typical)

“Preferential Pathway”

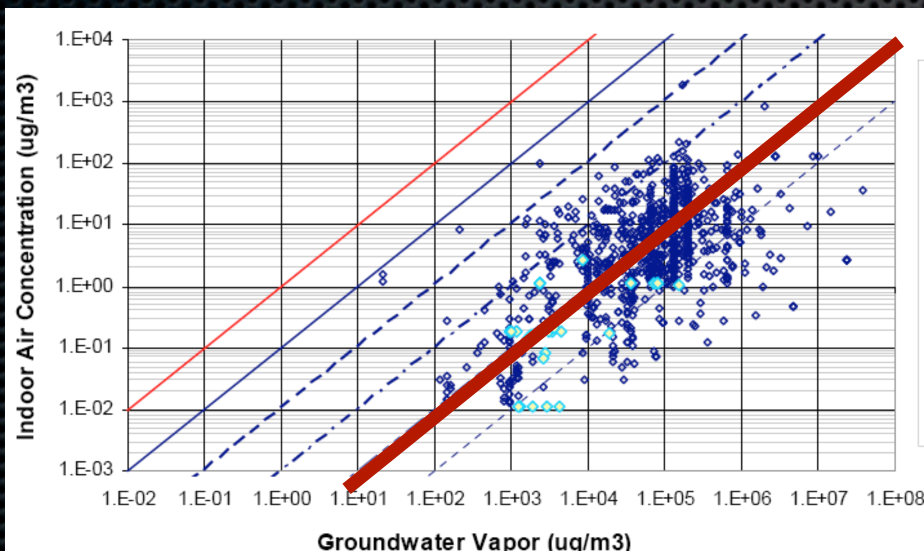
“Slab”

Subslab

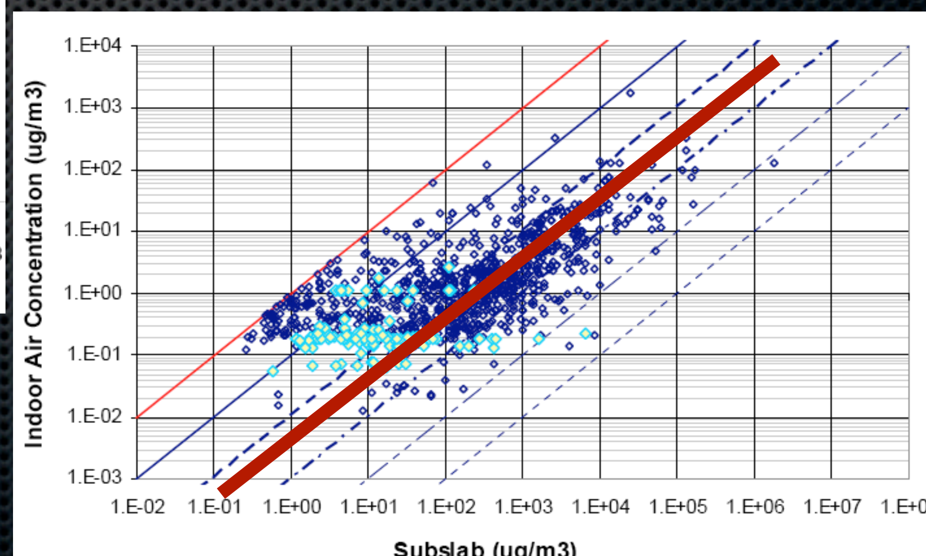


U.S. EPA empirical "attenuation factor" approach for predicting indoor air concentrations

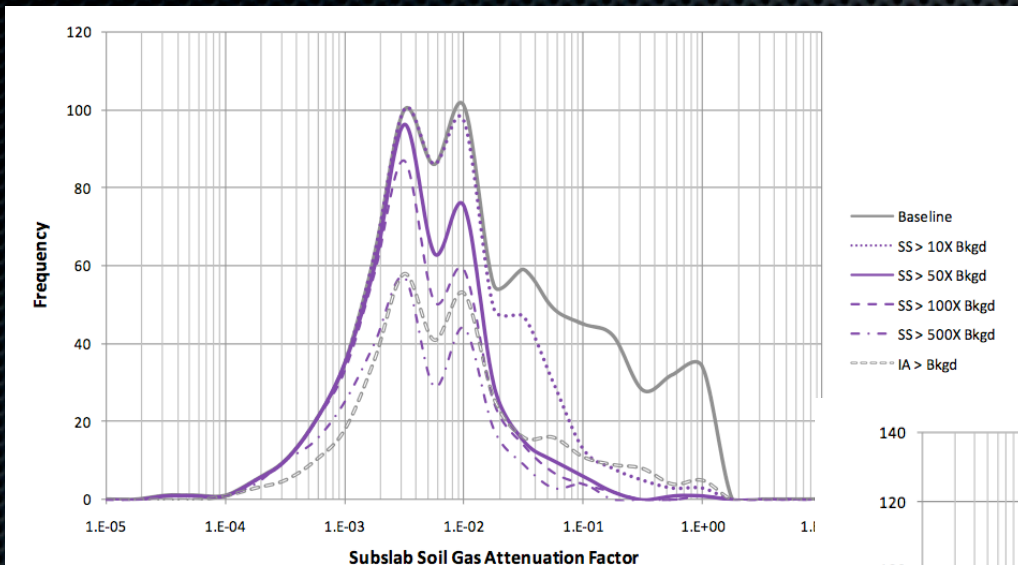
- $C_{indoor}/C_{groundwater\ source} = 10^{-4}$
- $C_{indoor}/C_{subslab} = 10^{-2}$ to 10^{-3}
- Based upon empirical observation.

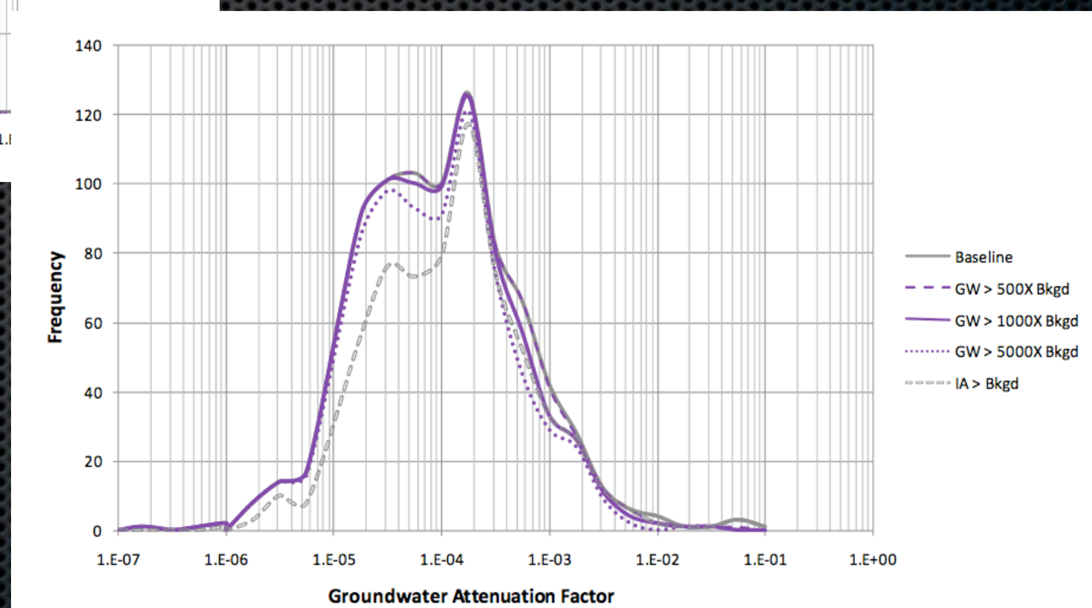


Groundwater Source-fairly conservative



EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings (March 16, 2012)





$$AF_{VI} = \frac{C_{IA-VI}}{C_{SS}} \times \frac{C_{SS}}{C_{SV}}$$

$$AF_{VI} = AF_{bldg} \times AF_{soil}$$

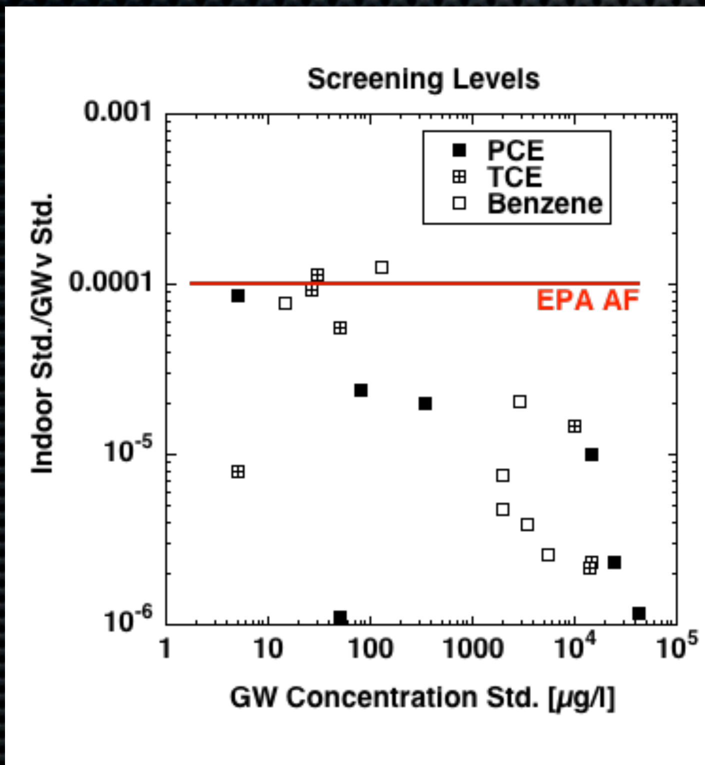
overall vapor intrusion attenuation factor (AF_{VI})

Table 2. Residential screening levels for selected VOCs.

State	Benzene			TCE			PCE		
	Groundwater	Soil Gas	Indoor Air	Groundwater	Soil Gas	Indoor Air	Groundwater	Soil Gas	Indoor Air
Alaska	5	3.1	0.31	5	0.22	0.022	5	8.1	0.81
California	NA	36.2	0.084	NA	528	1.22	NA	180	0.41
Colorado	15	NA	0.23	5	NA	0.016	5	NA	0.31
Connecticut	130	2490	3.3	27	752	1	340	3798	5
Indiana	95-850	250-1400; 25-140[a]	2.5	4.6-700	120-2000; 2-200[a]	1.2-4.1	7.4-1100	320-5200; 32–520[a]	3.2-10
Louisiana	2,900	NA	12	10,000	NA	59	15,000	NA	110
Maine	NA	NA	10[b]	NA	NA	NA	NA	NA	NA
Massachusetts	2000	NA	0.3	30	NA	1.37	50	NA	0.04
Michigan	5600	150	2.9	15,000	700	14	25,000	2100	42
Minnesota	NA	1.3-4.5	1.3-4.5	NA	NA	NA	NA	NA	20
New Hampshire	2000	95	1.9	50	54	1.1	80	68	1.4
New Jersey	15	16	2	1	27	3	1	34	3
New York	NA	NA	NA	NA	NA	5	NA	NA	100
Ohio	14	31	3.1	–	122	12.2	11	81	8.1
Oklahoma	5	3.1	0.27	5	0.17	0.017	5	0.33	0.33
Oregon	160	NA	0.27	6.6	NA	0.018	78	NA	0.34
Pennsylvania	3500	NA	2.7	14,000	NA	12	42,000	NA	36

Notes: Units are μg/L for groundwater and μg/m³ for soil gas and indoor air. See individual state guidance documents for additional information, including limitations and exceptions. Trigger or action levels for mitigation based on indoor air concentrations may be higher than the screening levels shown. [a]Second range of values shown is for subslab soil gas. [b]Chronic exposure value.

From Eklund, Folkes, Kabel, Farnum, in EM, 2007.



Data for CO, LA, CT, MA, NH, MI, PA. Henry's Law constants for benzene, TCE and PCE from EPA website, 25°C

Implication is that states with higher GW screening levels tend to look for Attenuation Factors that are greater than the EPA average when compared to indoor air screening levels (10^{-5} and 10^{-6}) are the very tail of the distribution.

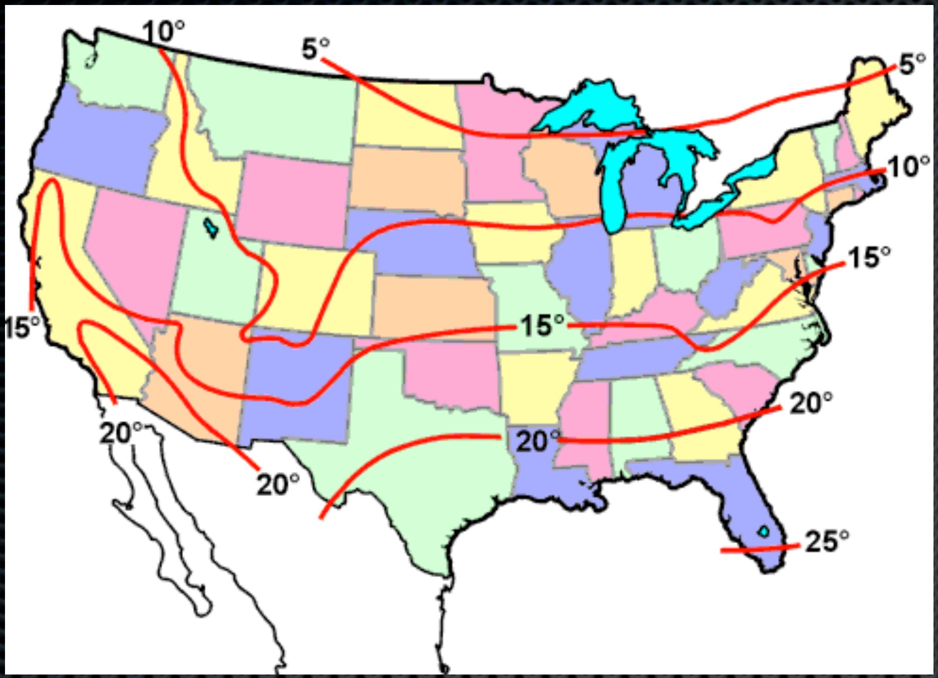
Table 4. Attenuation values used in state VI guidance.

State	Attenuation Coefficients Groundwater	Shallow Soil Gas	Deep Soil Gas	BTEX	Crawl Spaces
Alaska	0.001	0.1	0.01	NA	NA
California	NA	0.01 - 0.002	same as shallow	NA	0.002
Colorado	NA	0.1 (subslab)	NA	NA	1
Connecticut	0.001	0.001	NA	NA	NA
Indiana	NA	subslab = 0.1 soil gas = 0.01	0.01	NA	1
Louisiana	NA	NA	NA	NA	NA
Maine	NA	NA	NA	NA	NA
Massachusetts	Based on J&E model	NA	NA	Adjusted by 10x	NA
Michigan	Based on J&E model	0.02	0.002	NA	NA
Minnesota	NA	NA	NA	NA	NA
New Hampshire	Based on J&E model	0.02	0.02	Groundwater values adjusted by 10x	1
New Jersey	Based on J&E model	0.02	NA	0.002	1
New York	NA	NA	NA	NA	NA
Ohio	0.001	0.1	0.01	NA	NA
Oklahoma		0.1 (subslab)	0.1 (8-10 ft)	NA	1
Oregon	0.002	NA	NA	NA	NA
Pennsylvania	NA	0.01	NA	NA	NA

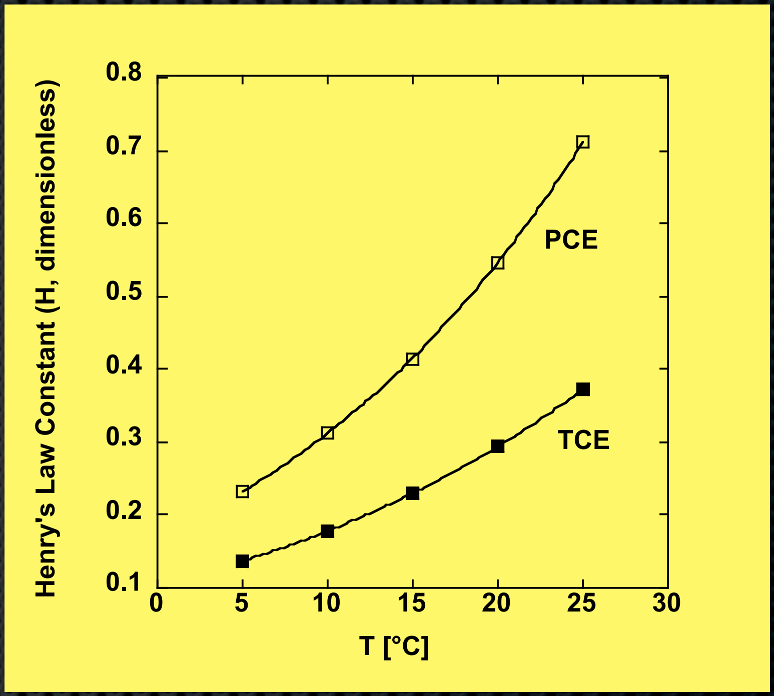
For example, a 2000 µg/L screening level for benzene in groundwater, would imply roughly a 40 $\mu g/m^3$ indoor air criterion, at an AF of 10^{-4}.

The RIDEM GW GB cleanup standard for benzene is 140 µg/L, which translates to a 1.4 $\mu g/m^3$ effective average indoor standard, based upon EPA average AF.

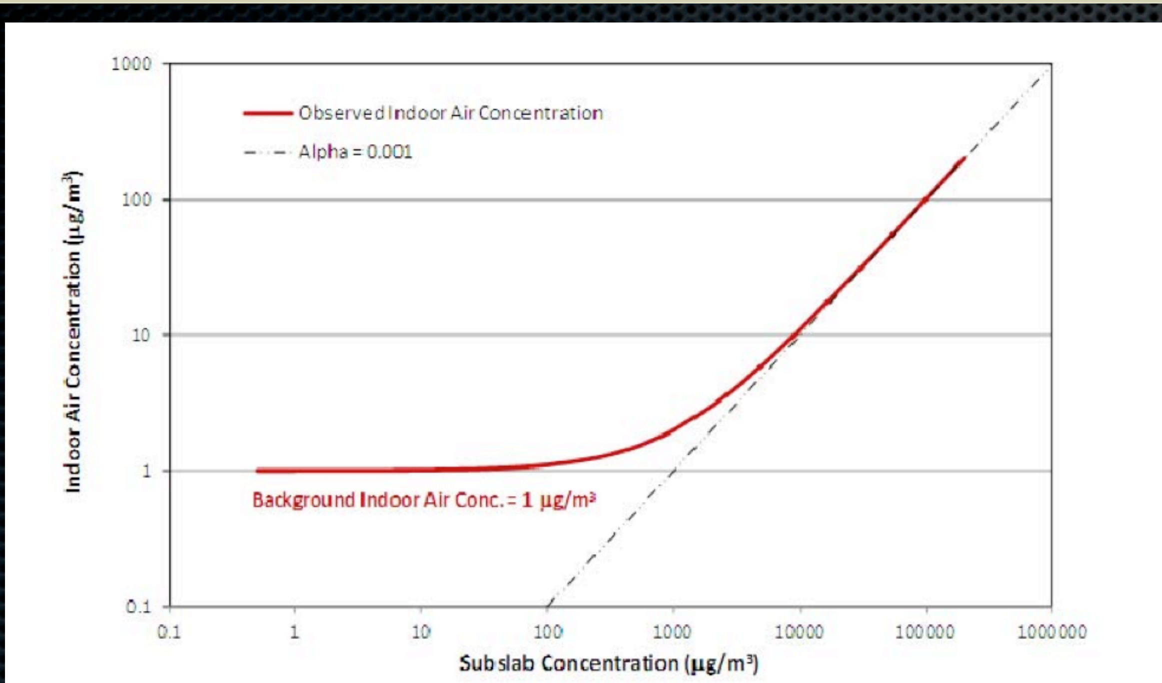
Even Henry's Law can be a challenge...So what is $C_{groundwater\ source}$?



Shallow groundwater temperatures (Collins, 1925)



Washington, 1996



EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings (March 16, 2012)

The empirical Attenuation Factor includes contributions from the "true" Attenuation Factor (*AF_{VI}*) and (indoor) background. In EPA analysis, C_{SV} represents COC concentration at any reference point in the soil path (including at the source).

$$AF_{EMP} = \frac{C_{IA}}{C_{SV}} = \frac{(C_{IA-VI} + C_{IA-BKGD})}{C_{SV}} = AF_{VI} + \frac{C_{IA-BKGD}}{C_{SV}}$$

$$AF_{EMP} = [\ AF_{bldg} + \frac{C_{IA-BKGD}}{C_{SS}}\ ] \times AF_{soil}$$

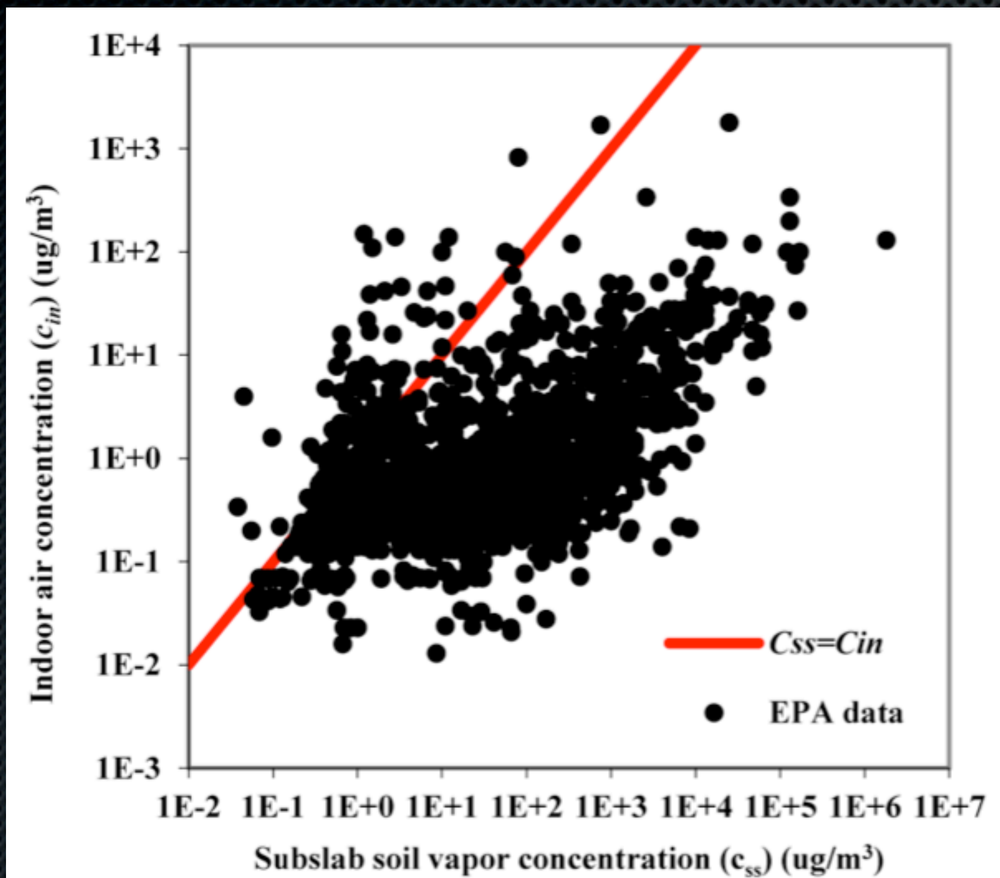
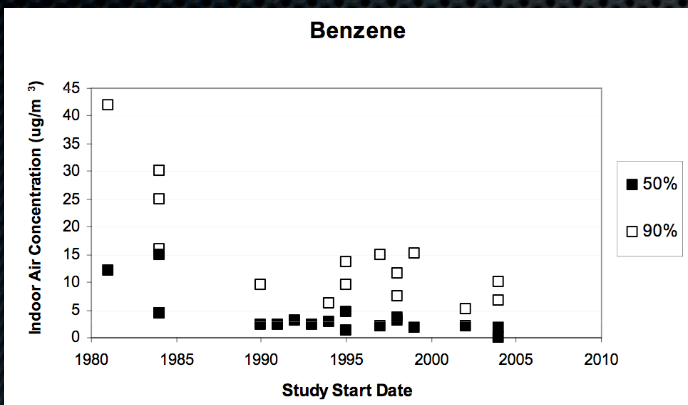
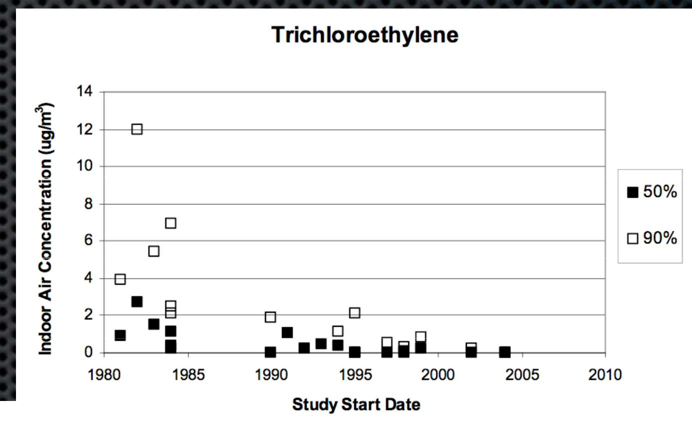


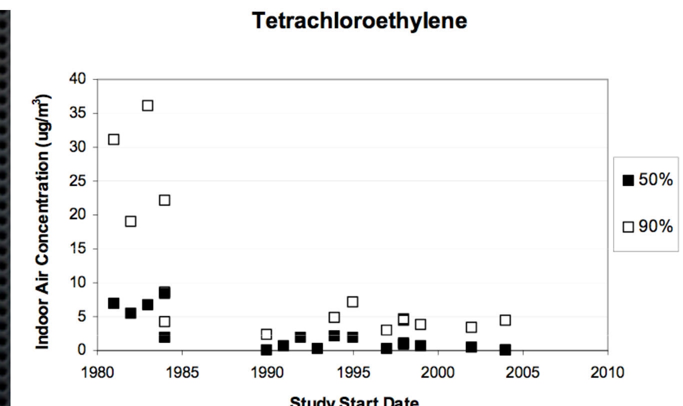
Fig. 5 Indoor Air Concentration as a function of subslab concentration [23]

It is a real effect, of concern in almost all data sets for the chlorinated solvents (i.e, TCE, PCE)

Need to watch what values you assume for background levels- they have gone down over time



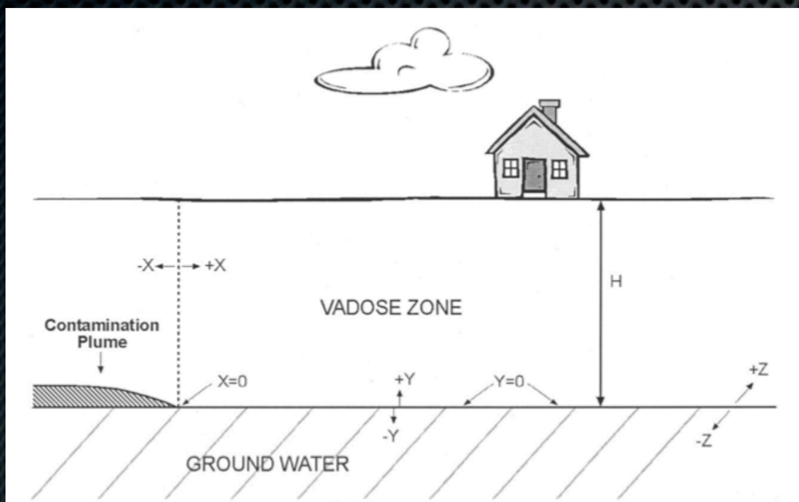




Source: Background Indoor Air Concentrations of VOCs in North American Residences: A Compilation of Statistics and Implications for Vapor Intrusion by Helen Dawson (EPA)

- A number of VOCs have typical (median) background concentrations above the 10^{-6} risk level (benzene, carbon tetrachloride, chloroform, methylene chloride, PCE)
- Several others exceed 10^{-6} risk levels about 10% of time (1,2-DCA, TCE, vinyl chloride)

How far is far enough??



$$D_e\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial C^2}{\partial y^2}\right) = 0$$

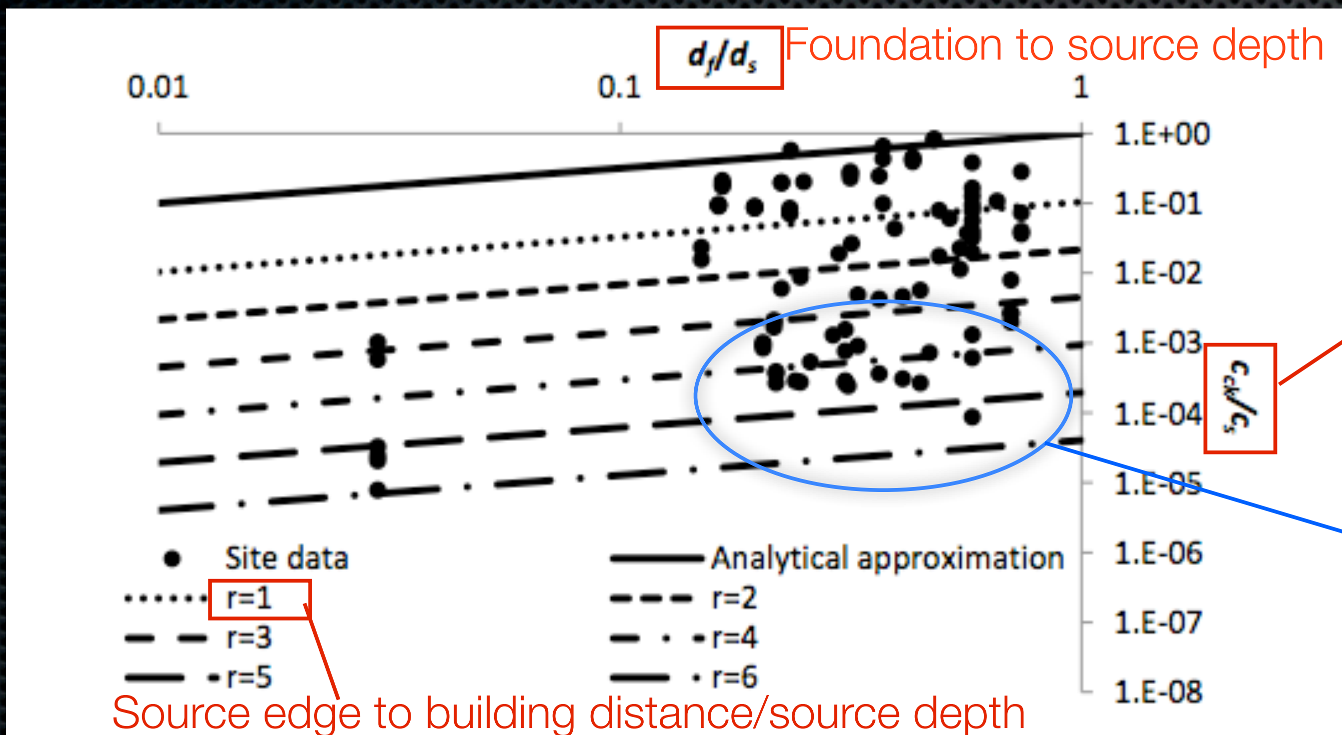
Lowell and Eklund, 2004

Solved simple 2-D Laplace Equation

insignificant at lateral distances of only $\eta = 5$. The value of 100 ft given in the U.S. EPA guidance is a conservative upper limit for sites with groundwater shallower than 10 ft and diffusion-limited vapor transport. Our work suggests that the risk from breathing contaminated indoor air from subsurface contamination need only be investigated for buildings within a relatively short distance (e.g., within one or two residential sized lots) from the edge of the contamination plume.

Echoed in various guidance documents, but challenged by Abreu and Johnson, 2005 for homogeneous soils.

How close should GW Source measurements be?



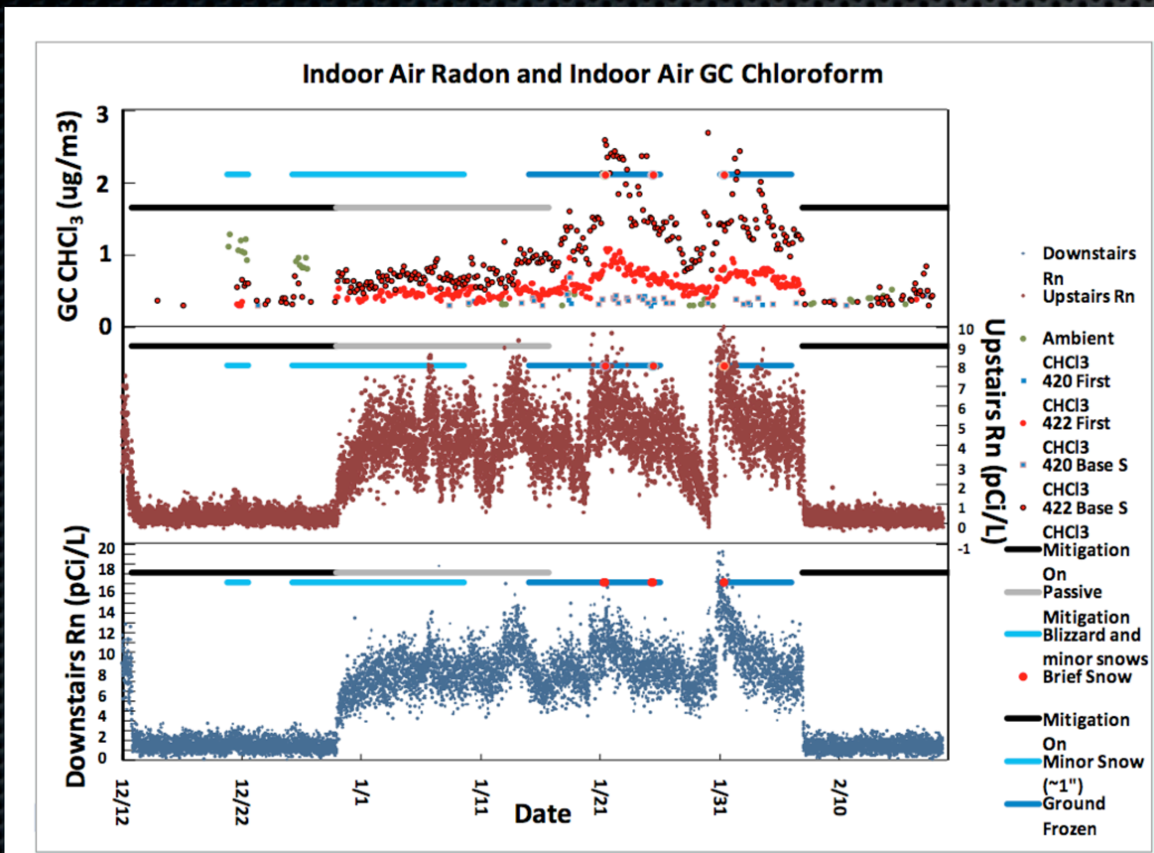
Yao et al. *Vadose Zone Journal*,2013

Subslab to Source Concentration

Unusually high source to slab attenuation can have an origin in GW sources that are not really that "close"

Consider 2 m deep basement, 4 m deep source, sampling GW at r= 5
i.e., 20 m away, can lead to significant extra attenuation

The Issue of Transients



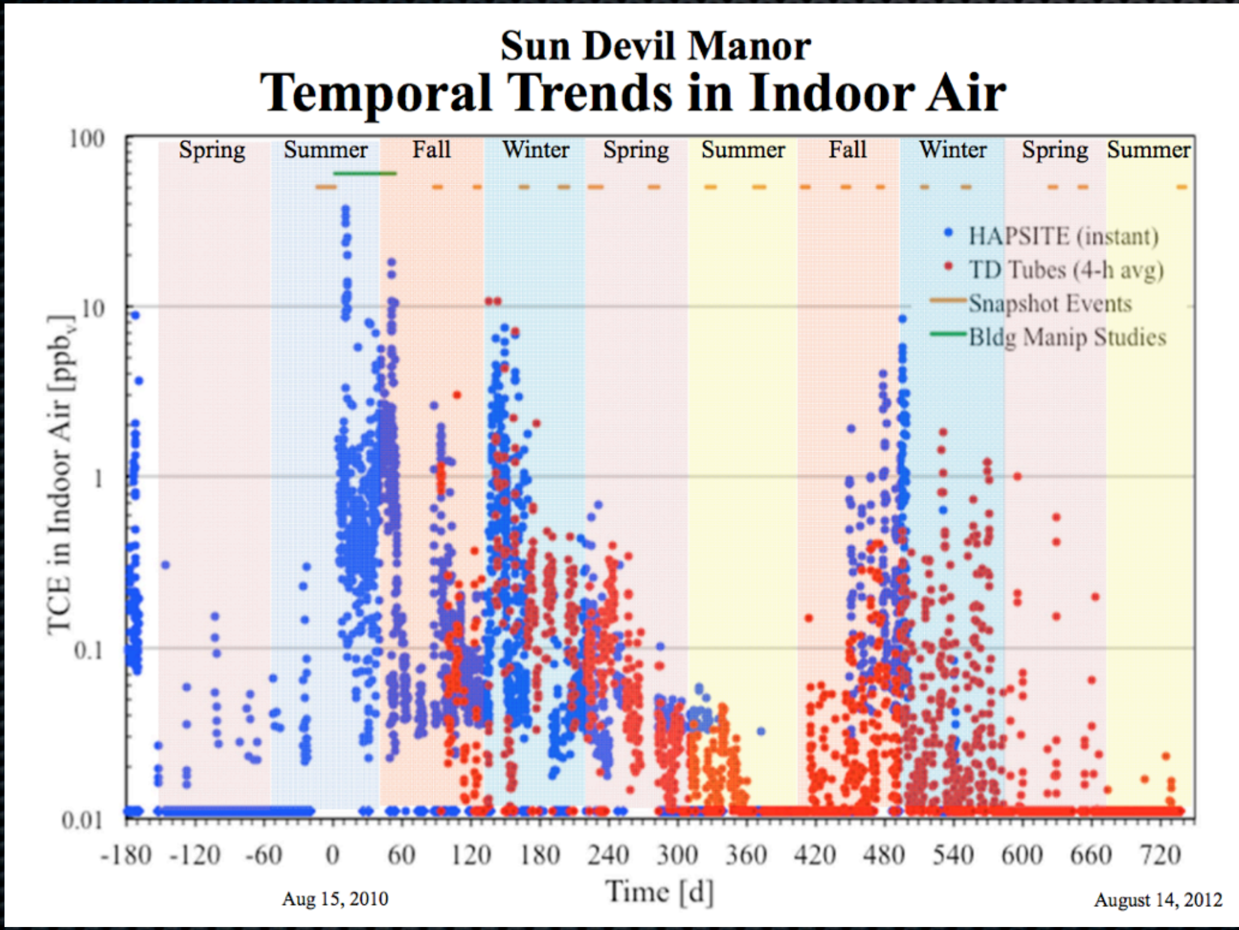
Sample data from a 2013 AEHS Conference Workshop by Schumacher et al.
Samples from a duplex in Indianapolis.

Note the wide variability over short sampling times.

Correlation with Radon not particularly good.

Seasonal variability in indoor air higher than in subslab.

Another example from Utah



From a paper by Lutes, Johnson and Truesdale, AEHS, 2013.

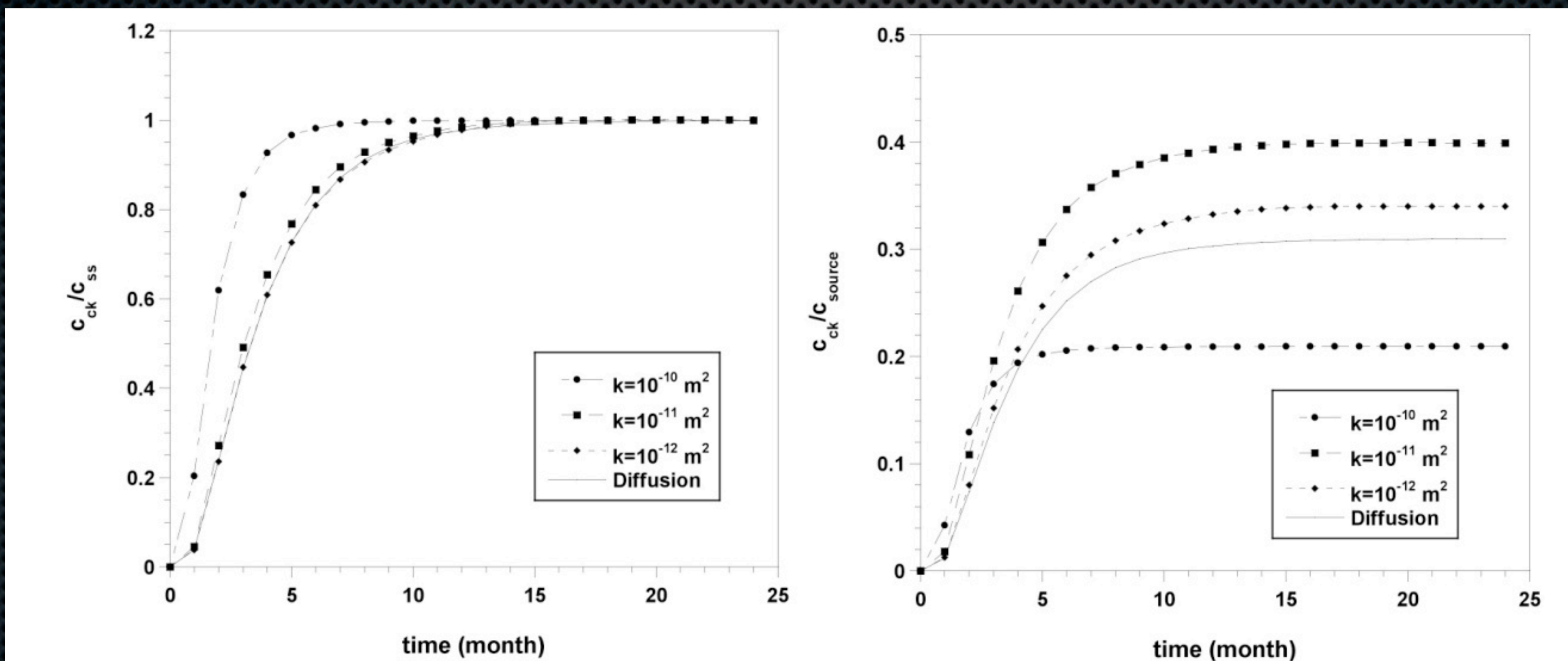
Different from Long Timescale Transient Situations

Darcy's Law

$$\left(x_p\left(1-\eta_g\right)+x_f\eta_g\right)\frac{\partial p}{\partial t}=\nabla\left(\frac{k}{\mu_g}\left(\rho_g g\nabla z+\nabla p\right)\right)$$

Advection and Diffusion

$$\frac{\partial C_{ig}}{\partial t}+\nabla(q_g C_{ig}-D_{ig}\nabla C_{ig})+R_{ig}=0$$

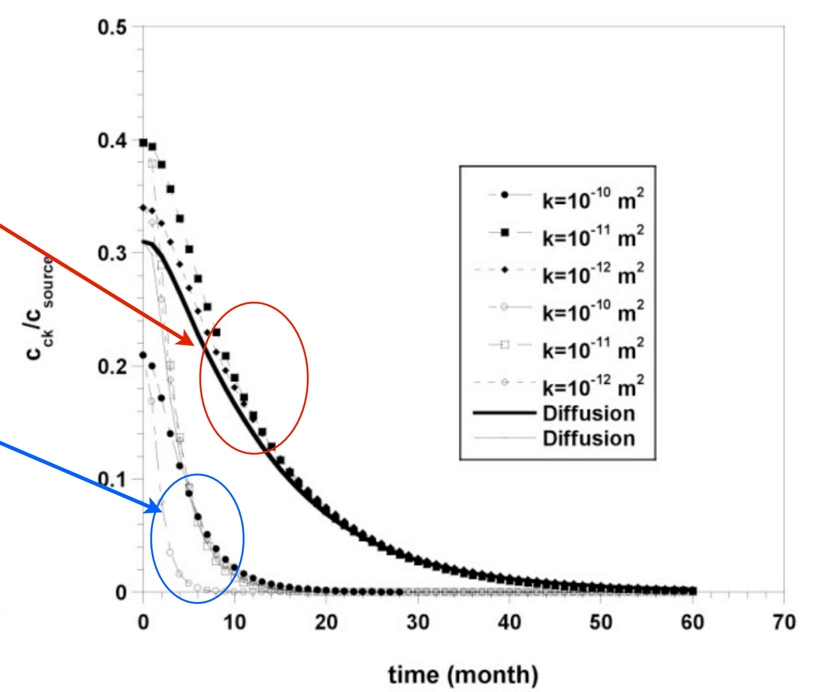


With sudden appearance of a source at 8 m-
shows typical response is diffusion rate determined

Time response of subslab concentration if the groundwater is “clean”at t=0 and

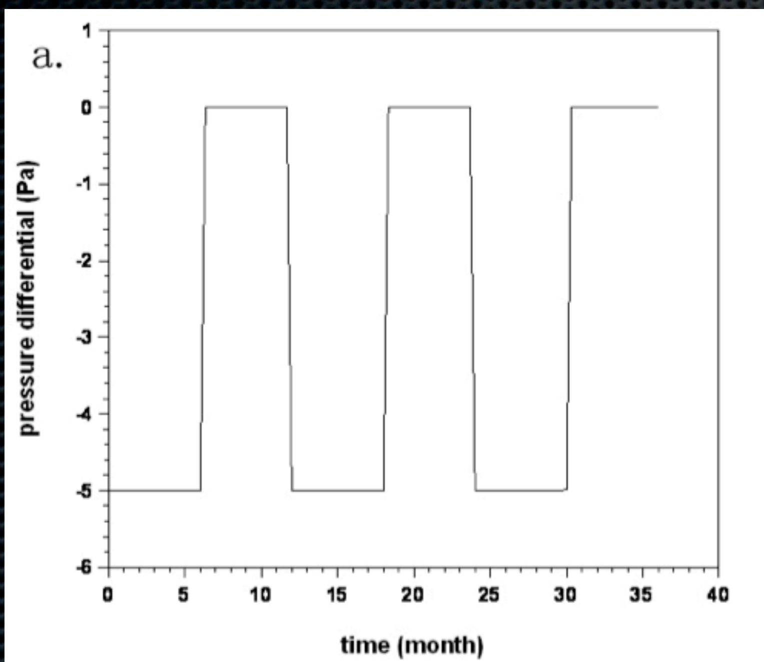
the groundwater does not act as a sink

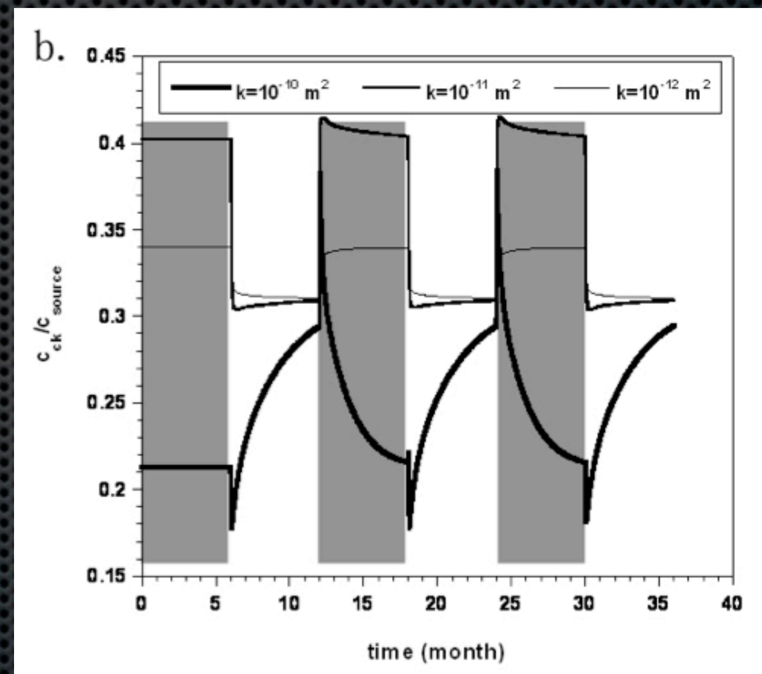
the groundwater acts as a sink



Note the very long timescales of response to “remediation”

Variation in Heating Season-Driven Stack Effect





Not a large seasonal variation

Summary

- There exists a large variation in Attenuation Factors, for reasons that are only partly understood.
- Essential to consider background concentrations (and to measure or at least use current estimates).
- How close should a GW monitoring well be, to be reliable?
- There needs to be the awareness of transients, some very short term, some seasonal, and some very long time scale.