Gaining a Better Understanding of Vapor Intrusion Using a 3-D Modeling Approach

Revised

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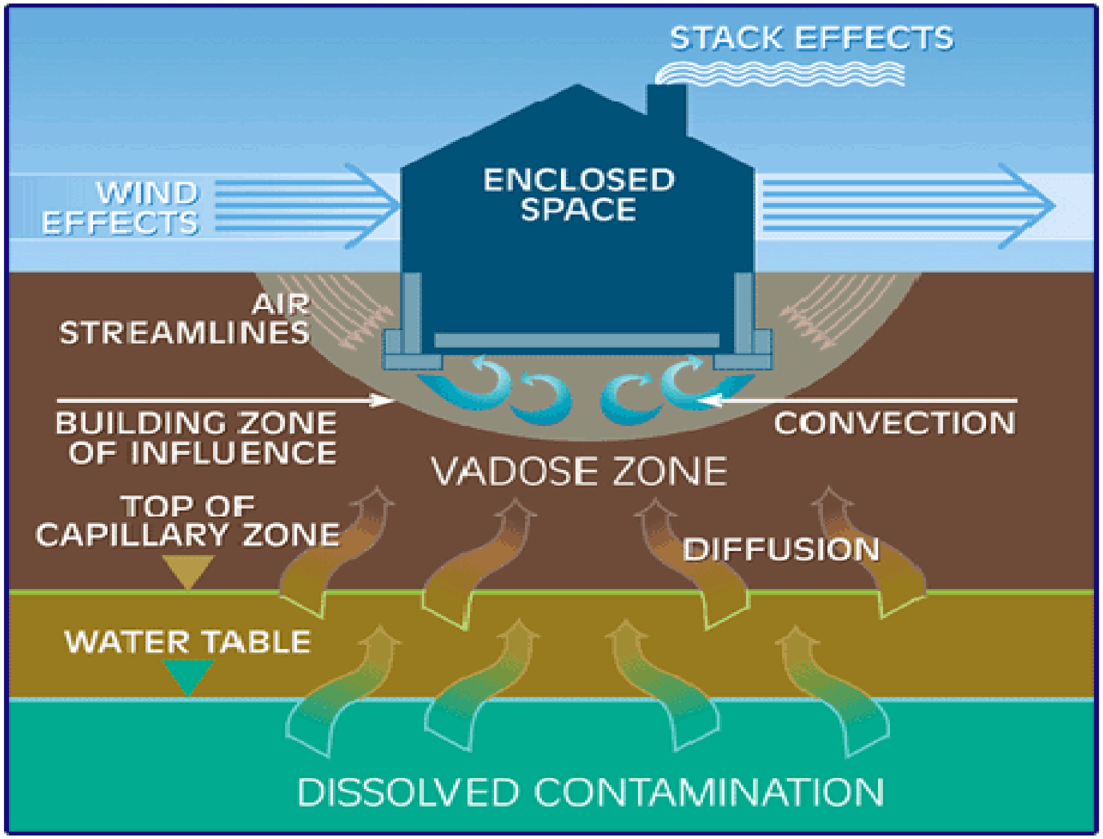
Introduction

As part of the Superfund Basic Research Program (SBRP) Brown developed a 3-D mathematical representation of vapor intrusion

VI is one of seven other projects being researched within the SBRP.

For more information, visit:

www.brown.edu/sbrp



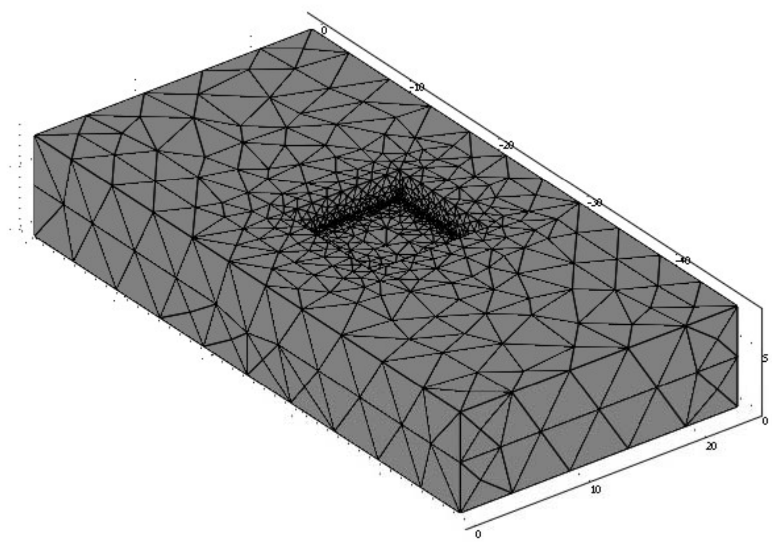
www.vaprotect.com/images/2006/10/17/graphic.gif

Modeling Approach

A finite element model (Comsol) is used to evaluate vapor intrusion using conventional fate and transport processes

The model solves the problem in 3 steps:

1. Gas flow through soil (Darcy's Flux)
2. Species transport
3. Indoor air concentration is calculated as a function of building exchange rate, soil gas flow into the building and concentration at the crack



Perimeter foundation crack present.
ΔP= -5 Pa

Gas Flow Through Soil

$$q = \frac{-\kappa \rho}{\mu} \frac{dP}{dx}$$

Darcy's Law for one dimensional incompressible flow

$$q = \frac{-\kappa \rho}{\mu} \nabla \phi$$

$$\phi = gz + \int_{Po}^{P} \frac{dP}{\rho}$$

Darcy's Law for 2D or 3D incompressible flow

q : *specific dischrg* (L/T)

κ : *permeability of the soil* (L^2)

μ : *visc. of the fluid* (M/LT)

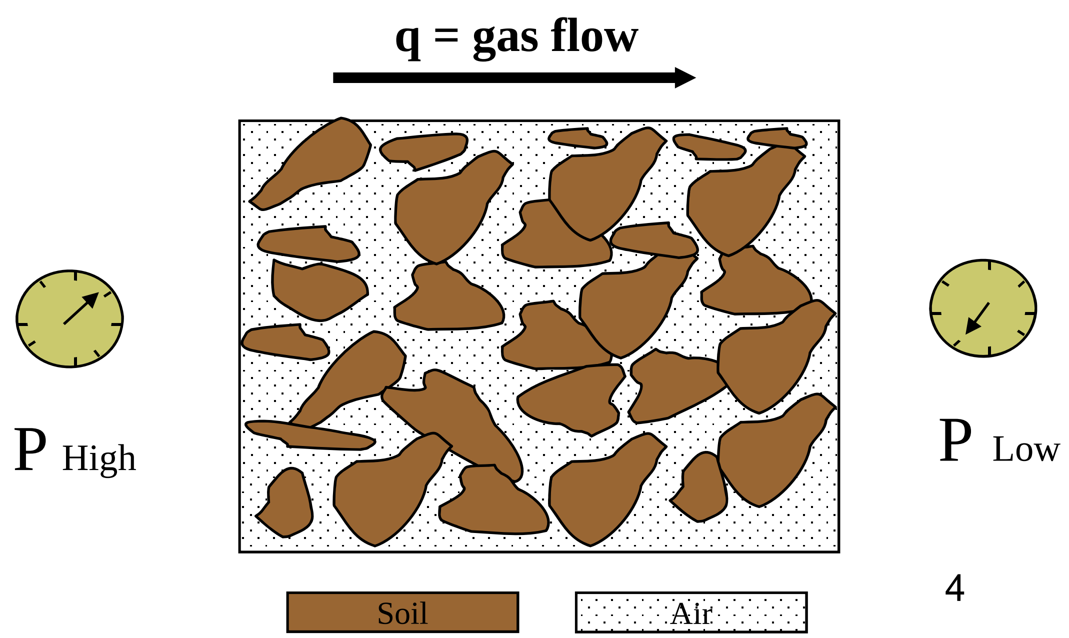
ρ : *density of the fluid* (M/L^3)

ϕ : *fluid potential*

P : *pressure of the fluid* (M/LT^2)

z : *elevation* (L)

g : *gravitational acceleration* (L/T^2)



Species Transport

$$\frac{\partial C_i}{\partial t} + \nabla F_i + R_i = 0$$

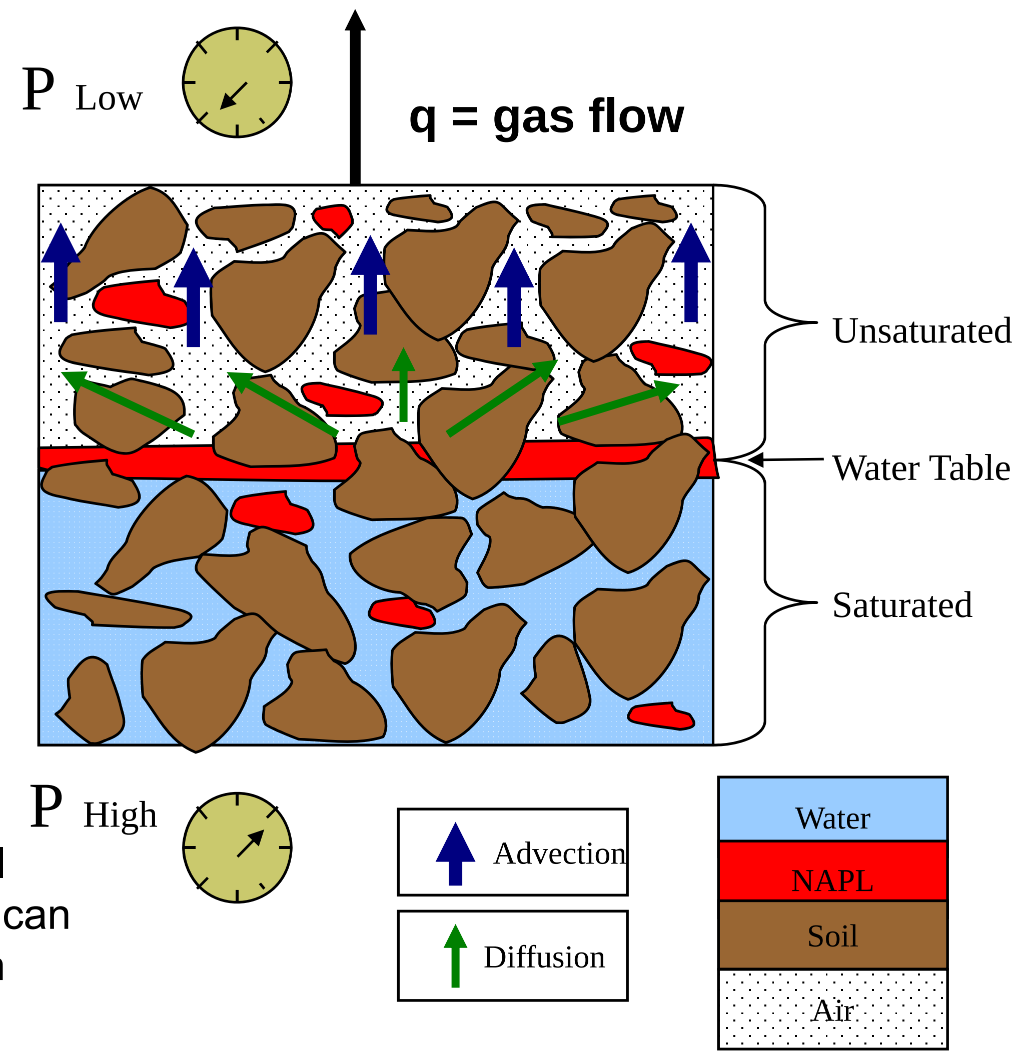
$$C_i = \eta_g C_{ig} + \eta_w C_{iw} + S_i \rho_b$$

$$F_i = q_g C_{ig} + q_w C_{iw} - D_{ig} \nabla C_{ig} - D_{iw} \nabla C_{iw}$$

Partitioning:

$$C_{ig} = H_i C_{iw}$$

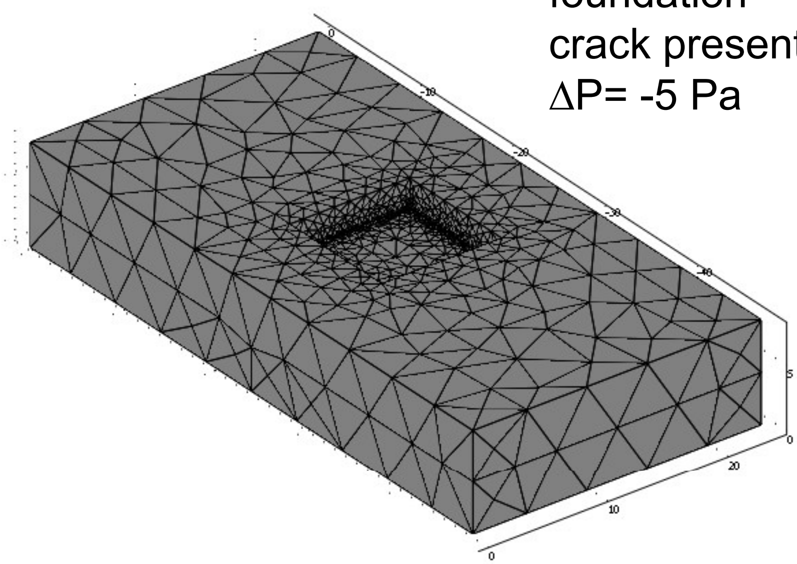
$$S_i = K_{oc,i}\, f_{oc}\, C_{iw}$$

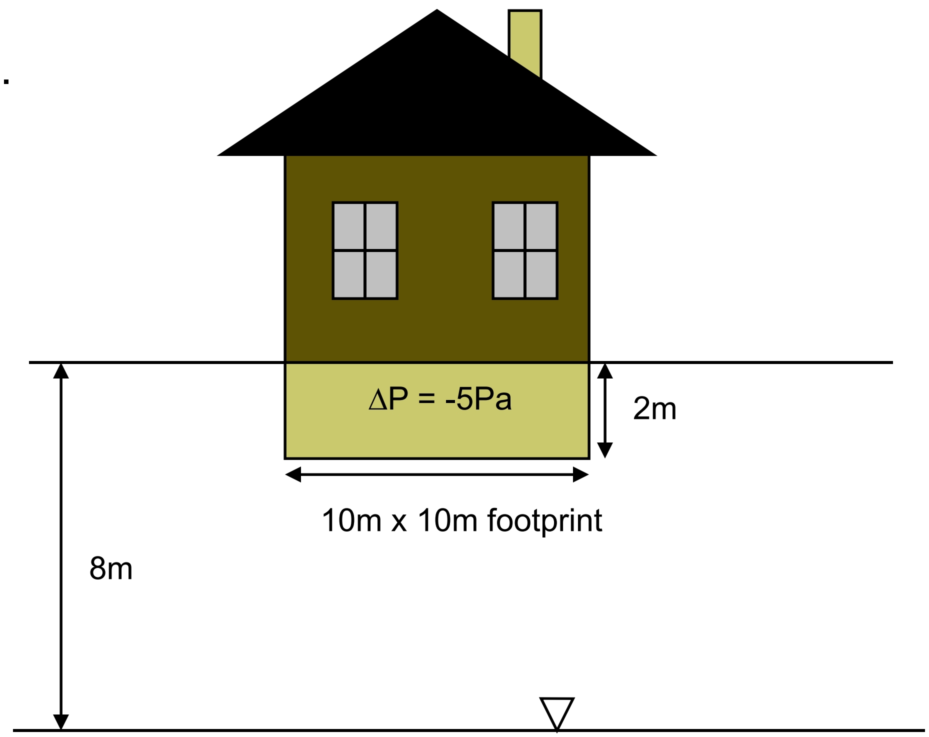


Non-aqueous liquids (NAPL) and residual contamination in groundwater and/or soil can act as the source for vapor contamination

Scenario Modeled

Perimeter foundation crack present. ΔP= -5 Pa

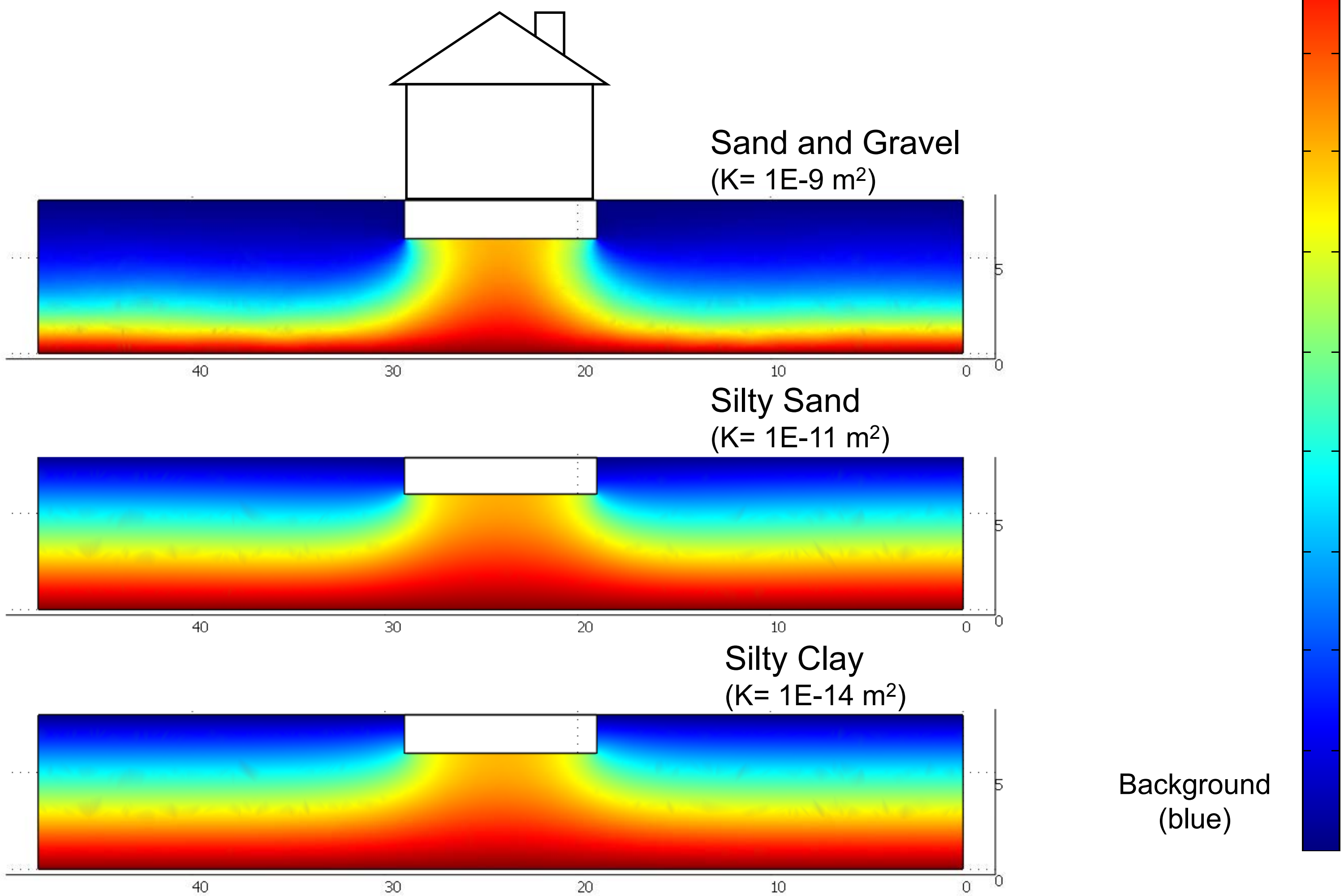




Source: 540 ug/L TCE in groundwater

Evaluated three K-values and one simple layered geology

Effect of Geology on Vapor Concentration Profiles



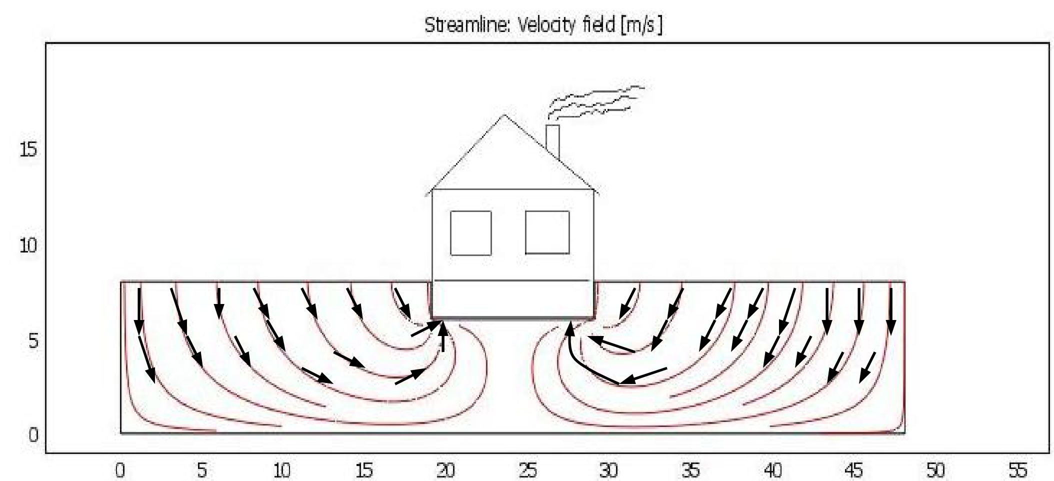
Effect of Geology on Vapor Intrusion on Indoor Air

Permeability	Q (m^3/s)	Conc. at crack (mg/m^3)	C indoor (mg/m^3)
High (K= 1E-9 m^2)	5.4E-3	51	7.1
Moderate (K= 1E-11 m^2)	5.4E-5	110	1.8E-1
Low (K= 1E-14 m^2)	5.4E-8	110	1.8E-4

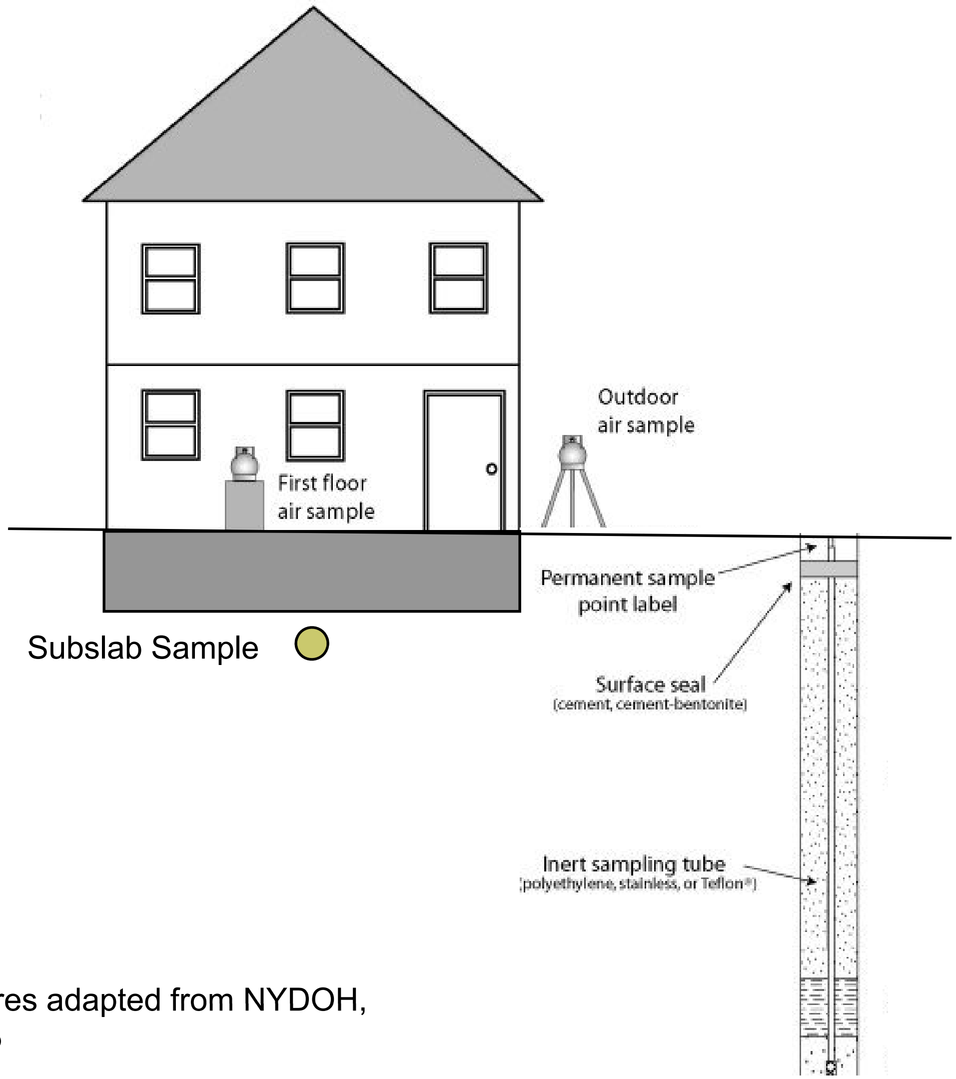
$$C_{indoor\ air} = \frac{Q^*C_{ck}}{V_b{}^*A_e+Q}$$

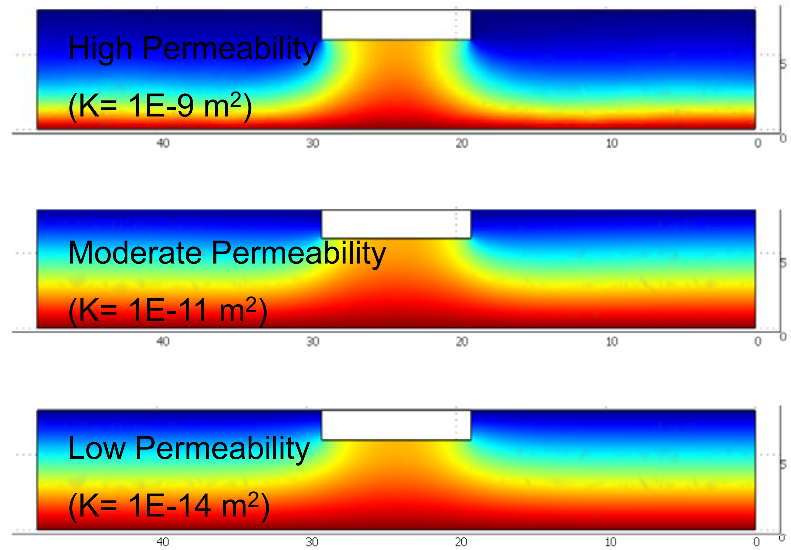
233 m^3 0.5 hr^{-1}

Atmospheric dilution is greatest for high permeabilities



Concentration Profiles and Sample Location



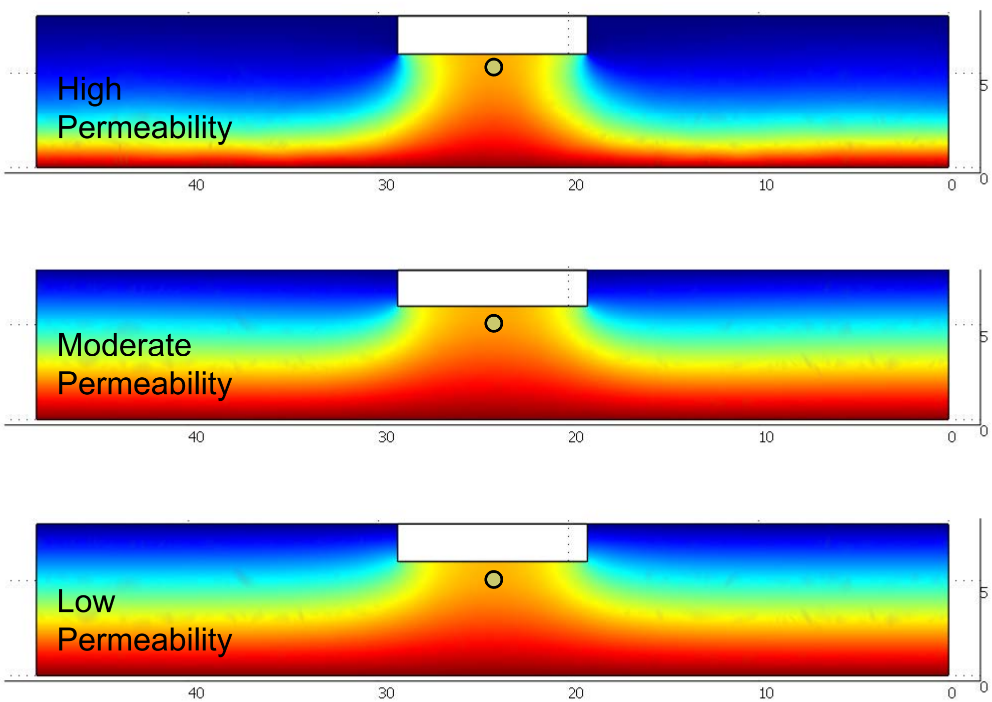


Figures adapted from NYDOH, 2005

We modeled concentrations at various sampling points using a sampling rate of 6L/8hr.

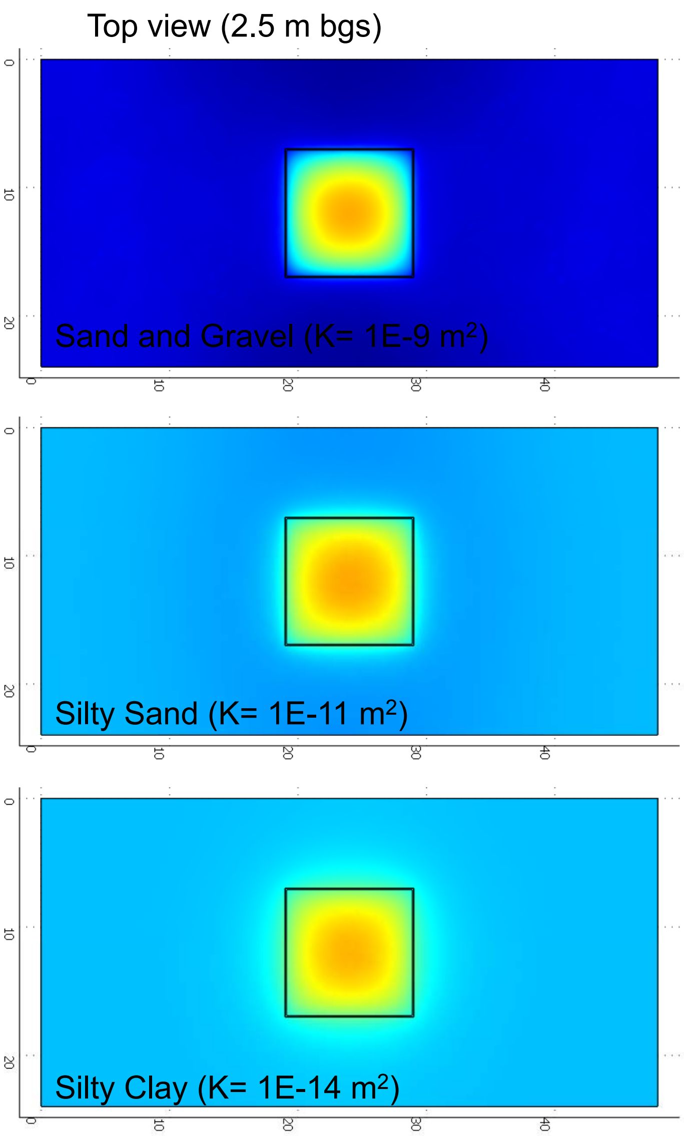
Where Should Samples be Collected?

Center of House 6 inches beneath foundation	Permeability	Sampling Location (mg/m^3)	Indoor Air (mg/m^3)	$C_{indoor}/C_{sampling.}$
	High ($K= 1E\text{-}9\ m^2$)	**190**	7.1	**3.6E-2**
	Moderate ($K= 1E\text{-}11\ m^2$)	**190**	**1.8E-1**	**9.3E-4**
	Low ($K= 1E\text{-}14\ m^2$)	**190**	1.8E-4	**9.4E-7**

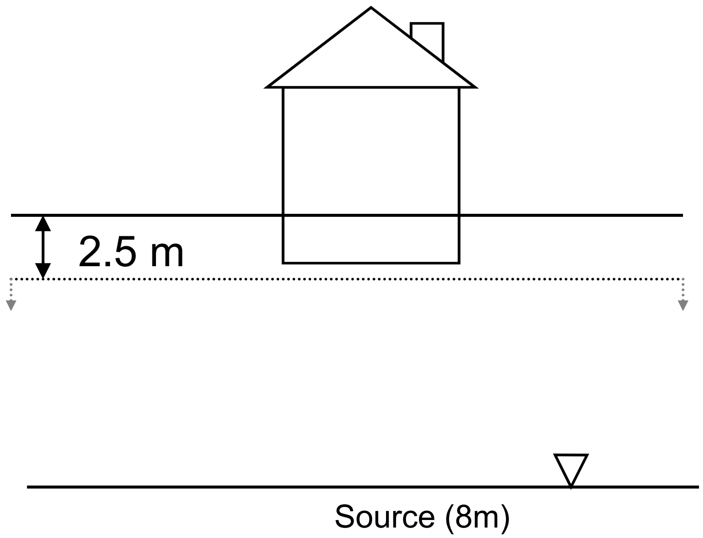


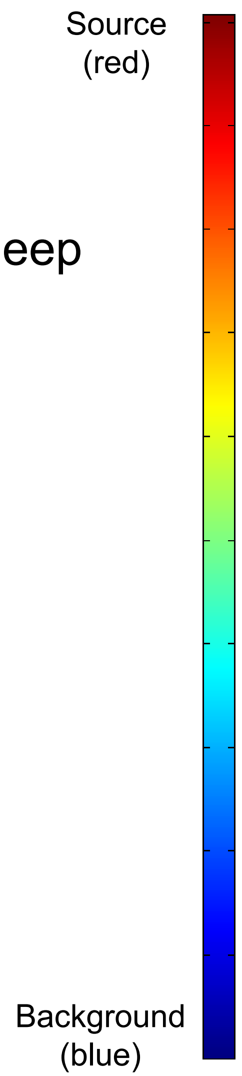
$$C_{indoor\ air} = \frac{Q*C_{ck}}{\underbrace{V_b}_{233\ m^3}*\underbrace{A_e}_{0.5\ hr^{-1}}+Q}$$

Effect of Geology on Sampling Depth for Characterization



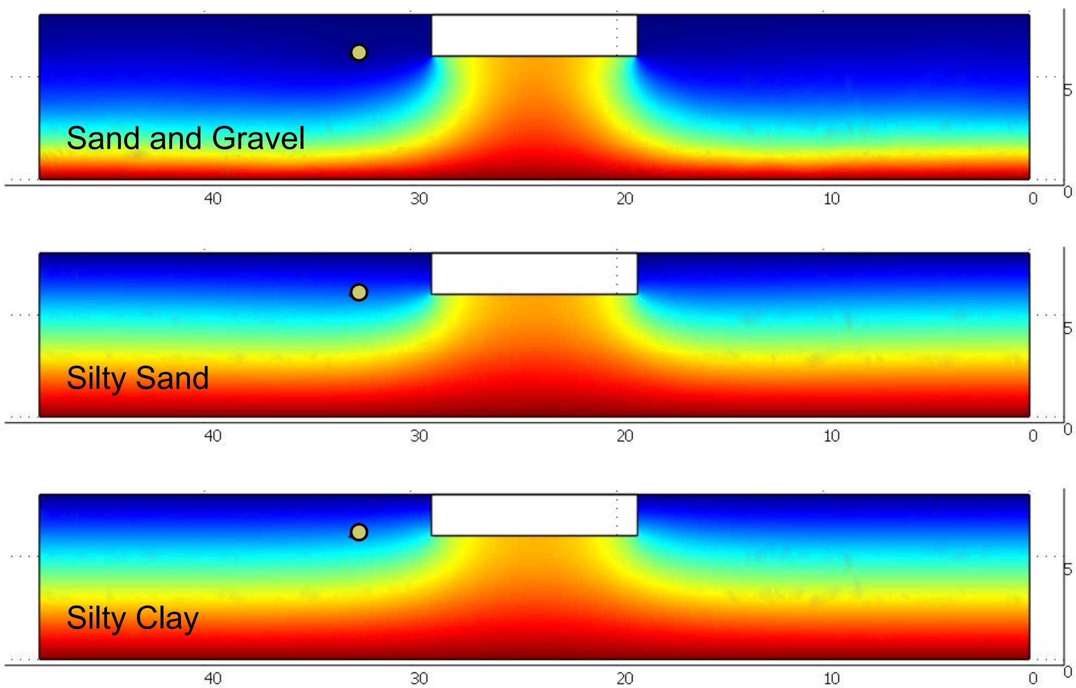
Soil Gas Concentration at 2.5 meters deep





Where Should Samples be Collected?

4 m from house 2 m bgs	Permeability	Sampling Location (mg/m^3)	Indoor Air (mg/m^3)	$C_{indoor}/C_{sampling.}$
	High (K= 1E-9 m^2)	7.5	7.1	0.95
	Moderate (K= 1E-11 m^2)	64	**1.8E-1**	2.8E-3
	Low (K= 1E-14 m^2)	78	1.8E-4	**2.3E-6**

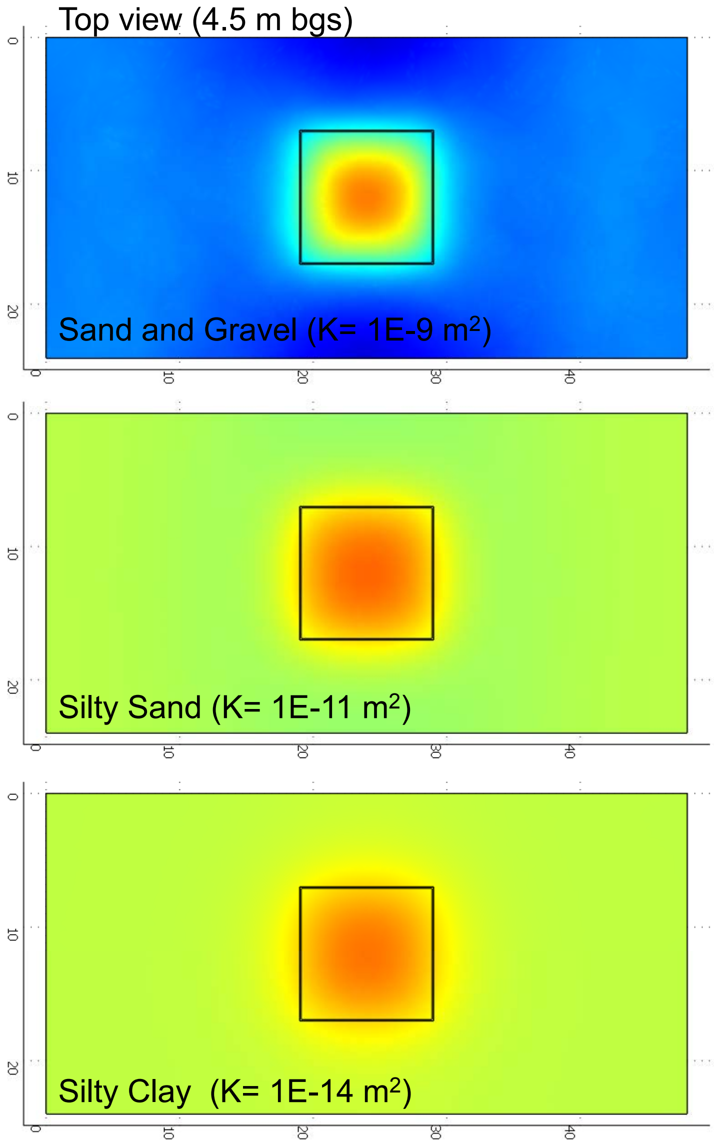


$$C_{indoor\ air} = \frac{Q*C_{ck}}{V_b*A_e+Q}$$

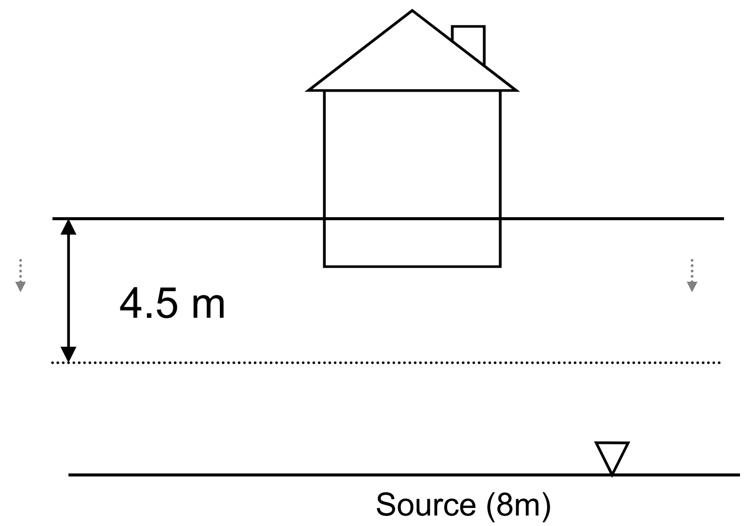
233 m^3

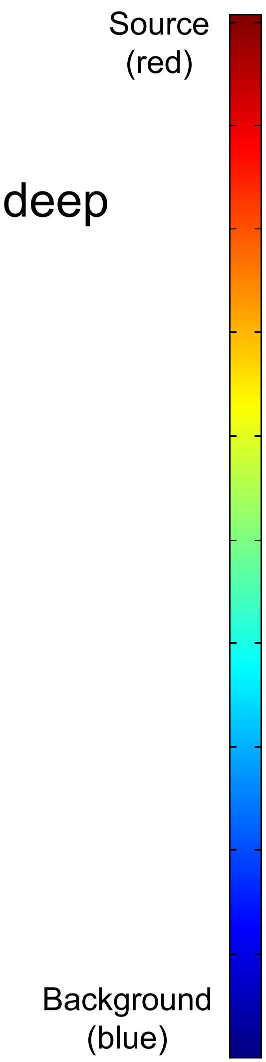
0.5 hr^{-1}

Effect of Geology on Sampling Depth for Characterization



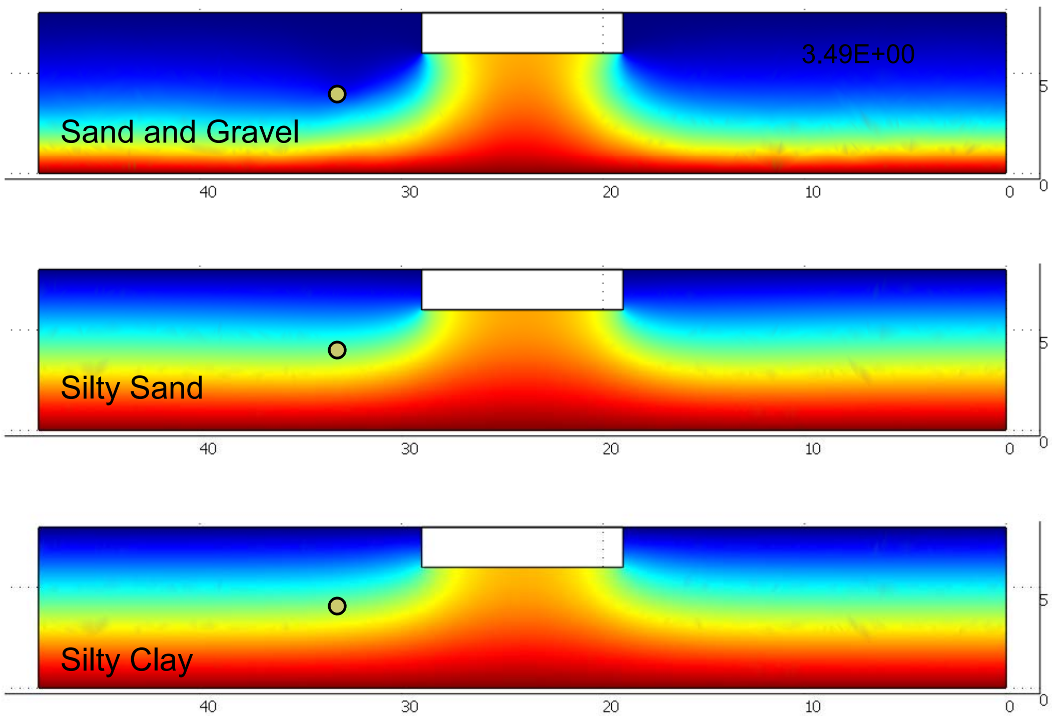
Soil Gas Concentration at 4.5 meters deep





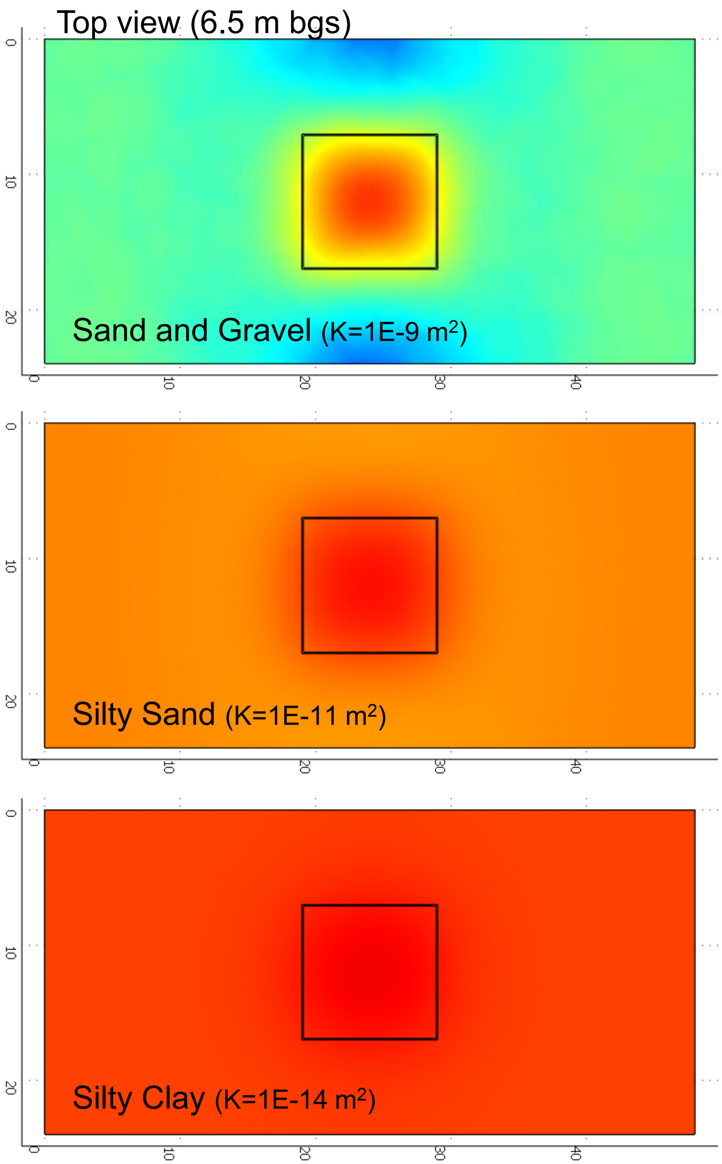
Where Should Samples be Collected?

4 m from building 4 m bgs	Permeability	Sampling Location (mg/m^3)	Indoor Air (mg/m^3)	$C_{indoor}/C_{sampling}$
	High (K=1E-9 m^2)	44	7.1	**0.16**
	Moderate (K=1E-11 m^2)	135	**1.8E-1**	**1.3E-3**
	Low (K=1E-14 m^2)	145	1.8E-4	**1.2E-6**

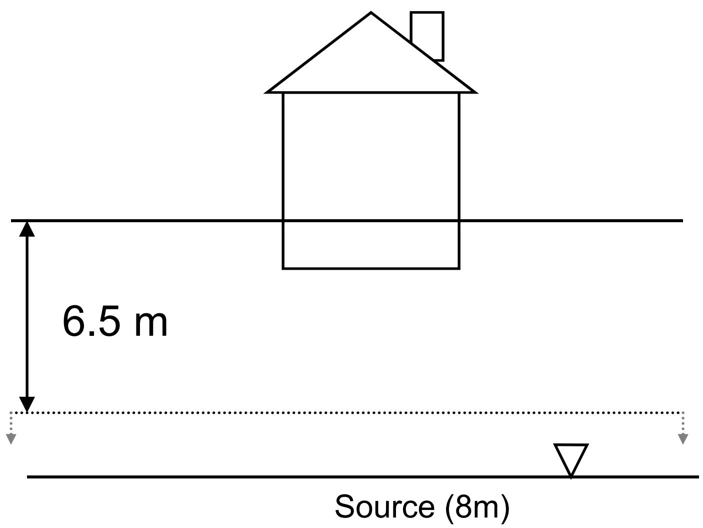


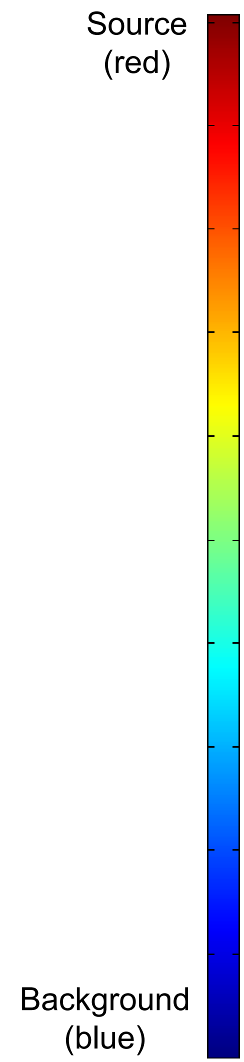
$$C_{indoor\ air} = \frac{Q*C_{ck}}{\underbrace{V_b}_{233\ m^3}*\underbrace{A_e}_{0.5\ hr^{-1}}+Q}$$

Effect of Geology on Sampling Depth for Characterization



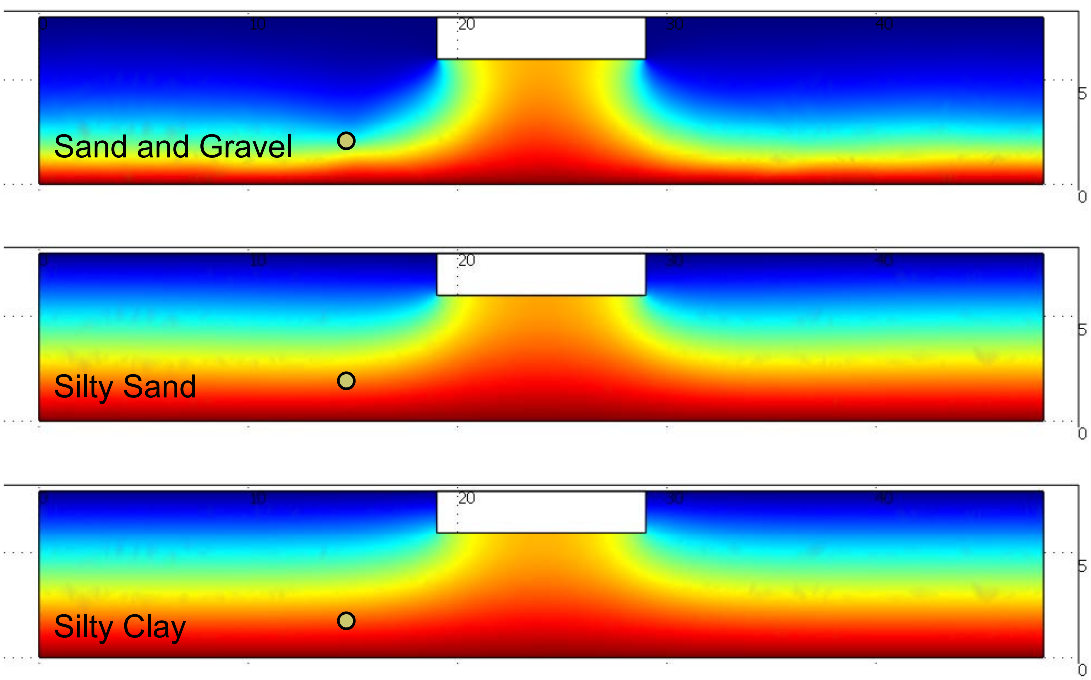
Soil Gas Concentration at 6.5 meters deep





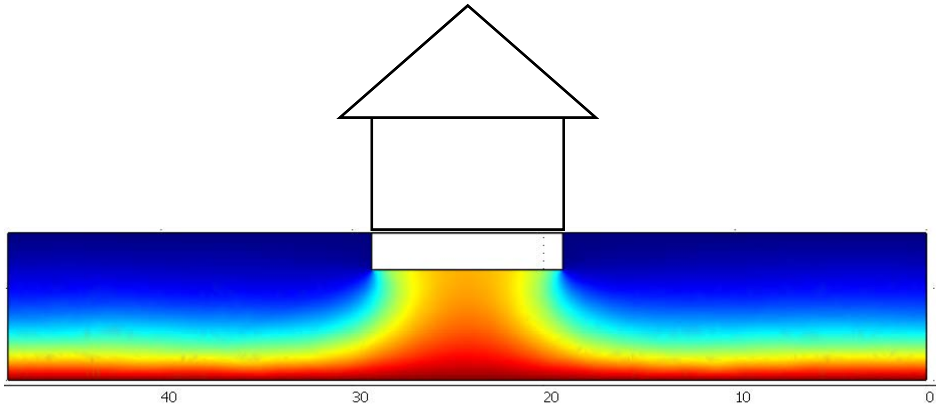
Where Should Samples be Collected?

4 m from house 6 m bgs	Permeability	Sampling Location (mg/m^3)	Indoor Air (mg/m^3)	$C_{indoor}/C_{sampling.}$
	High (K= 1E-9 m^2)	130	7.1	5.6E-2
	Moderate (K= 1E-11 m^2)	205	**1.8E-1**	8.8E-4
	Low (K= 1E-14 m^2)	210	1.8E-4	8.6E-7

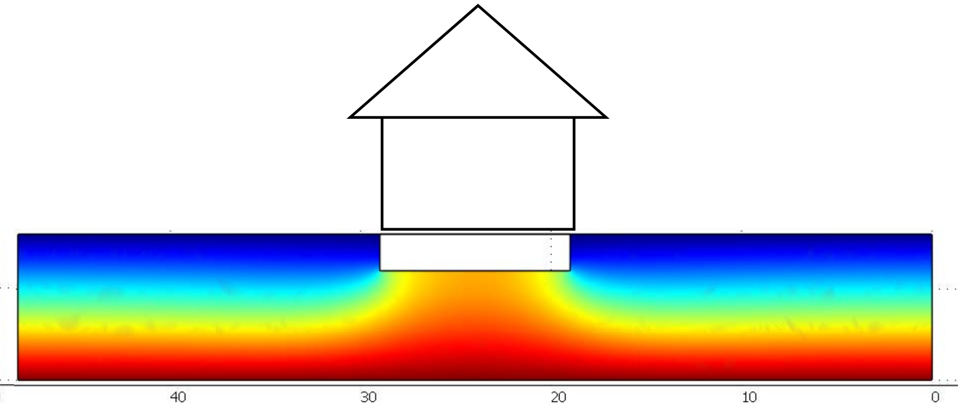


$$C_{indoor\ air} = \frac{Q*C_{ck}}{\underbrace{V_b}_{233\ m^3}*\underbrace{A_e}_{0.5\ hr^{-1}}+Q}$$

Overall Impact of Fate and Transport Processes



High Permeability (K= 1E-9 m^2)

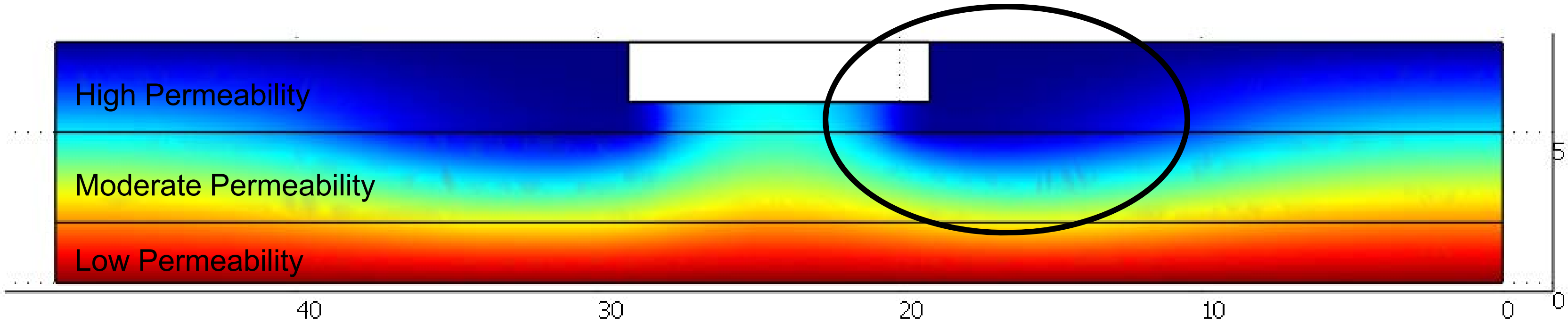


Low Permeability (K= 1E-14 m^2)

Concentration profiles are dependent on geology type.

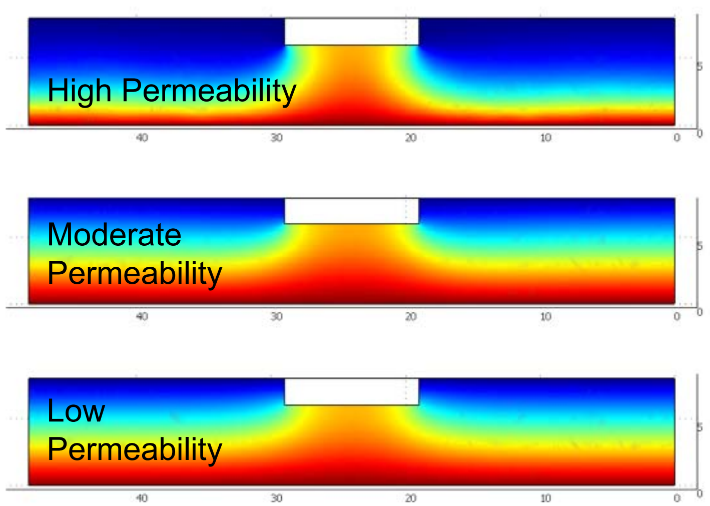
More permeable soils have greater potential for vapor intrusion risks, but tighter geologies may have higher subsurface vapor concentrations.

Simple Layered Geology



Permeability	Q (m^3/s)	Conc. at crack (mg/m^3)	C indoor (mg/m^3)
High	5.4 E-3	50.	7.1
Moderate	5.4E-5	110	1.8E-1
Low	5.4E-8	110	1.8E-4
Layered	4.4E-3	3.5	0.42

Recall:



Summary and Conclusions

- High soil gas concentrations do not necessarily indicate high vapor intrusion rates
- Low soil gas concentrations do not necessarily indicate low vapor intrusion rates
- The effects of geology should be carefully considered when designing a sampling plan
- Consequences of both gas transport and species transport should be considered before developing a sampling plan, or interpreting sampling results

Future Research Goals

- Evaluate the effect that sampling rate may have sample concentration (i.e. can sampling reverse gas flow into the building)
- Continue to evaluate geologic heterogeneities
- Consider more complex partitioning and biodegradation processes

Acknowledgements

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