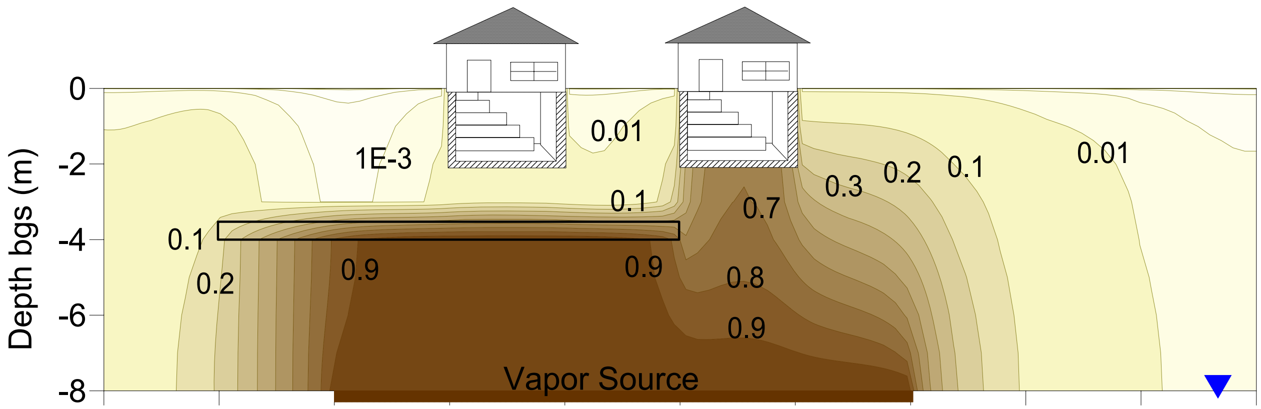
Conceptual Model Scenarios for The Vapor Intrusion Pathway



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USEPA Vapor Intrusion Workshop
AEHS Conference, March 2010
San Diego, CA

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Presentation Outline

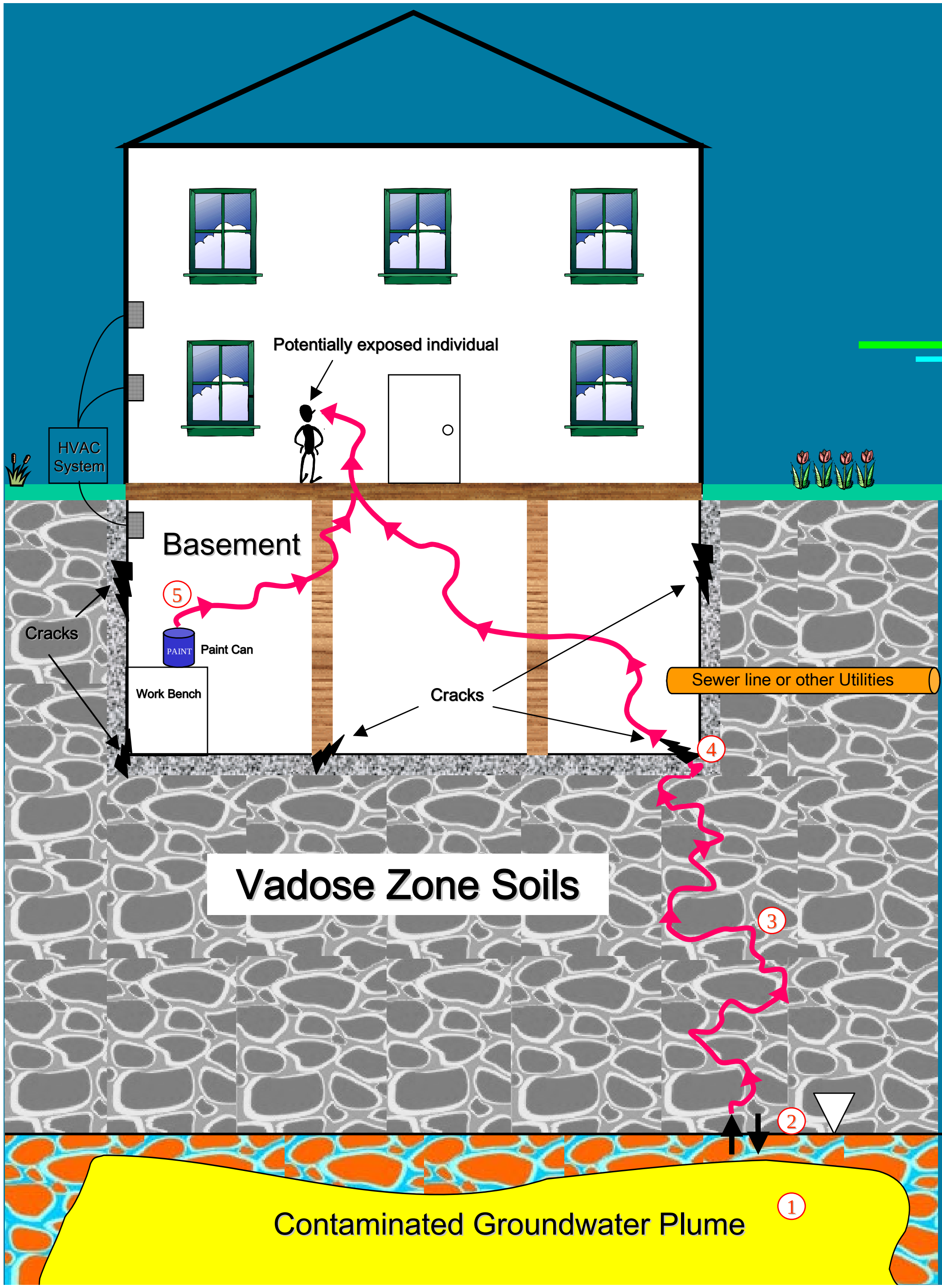
- Objective
- Vapor Intrusion (VI) Definition
- Brief Description of A&J 3D VI Model
- Vapor Fate & Transport Mechanisms
- Effect of Site Conditions on VI
- Remarks

Objective

- Provide an overview of key contaminant vapor fate and transport mechanisms for the vapor intrusion pathway
- Illustrate the effect of different site conditions on VOC concentration distribution in the subsurface and on the indoor air

Vapor Intrusion Pathway

What is it?



1. Source (GW & Soil)
2. Volatilization
3. Migration through porous
4. Infiltration through building envelope
5. Indoor sources can confound

Courtesy of Chris Lutes

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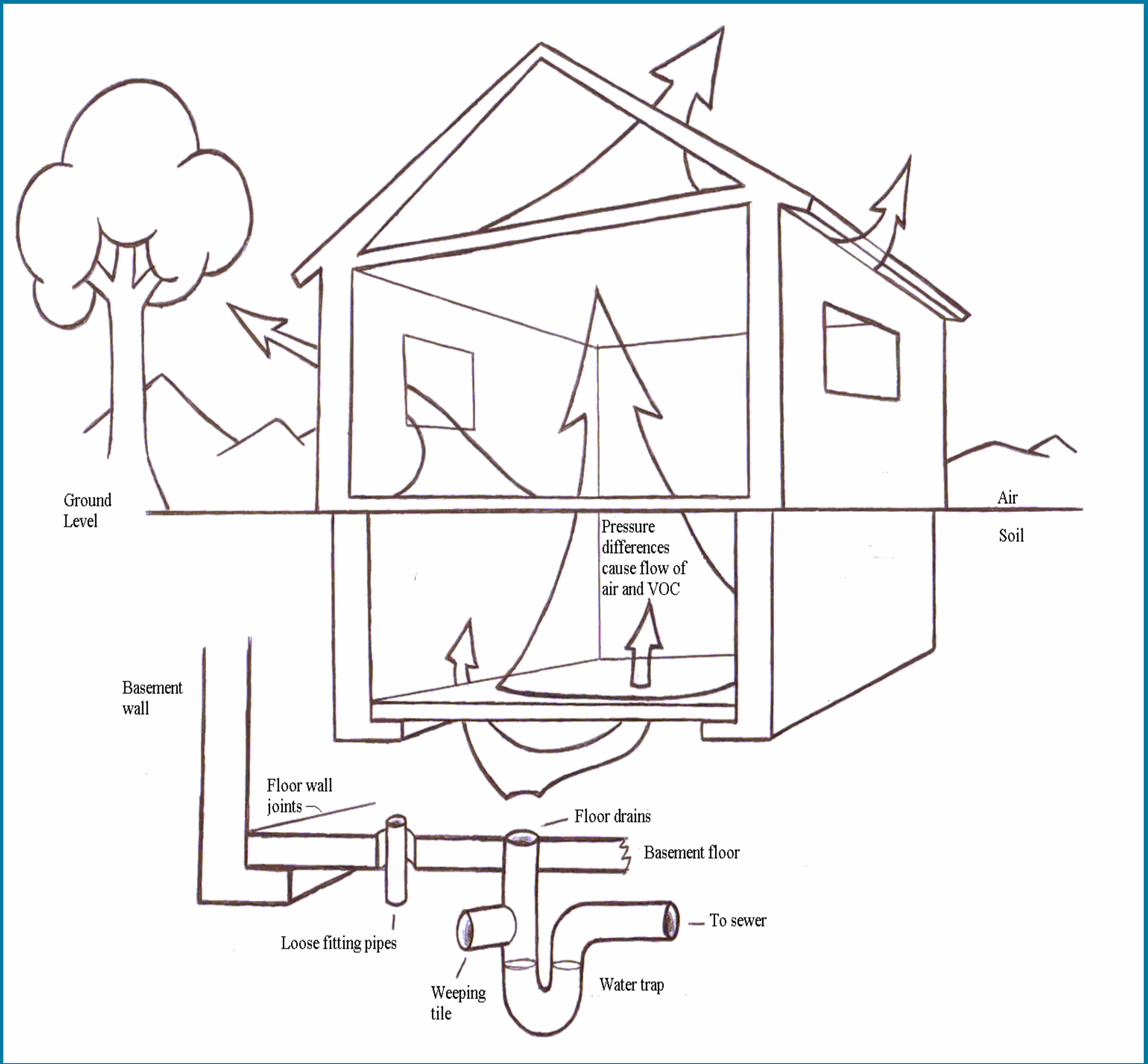
Foundation Entry Points

- Floor wall joints
- Loose fitting pipes
- Floor drains
- Cracks in foundation



Abreu, 2005 (adapted from Loureiro, 1987)

Type of Contaminants

Recalcitrant

- Very persistent (No degradation or slow degradation under natural conditions)
- Chlorinated hydrocarbons (e.g., PCE, TCE)
- Degradation products can be more toxic (e.g., Vinyl chloride)

Aerobically Biodegradable (see presentation in the afternoon)

- Readily degradable under natural conditions in the presence of oxygen
- Petroleum hydrocarbons (e.g., Benzene, Toluene)
- Degradation products less toxic (e.g., H2O, CO2)
- Methane byproduct under anaerobic conditions

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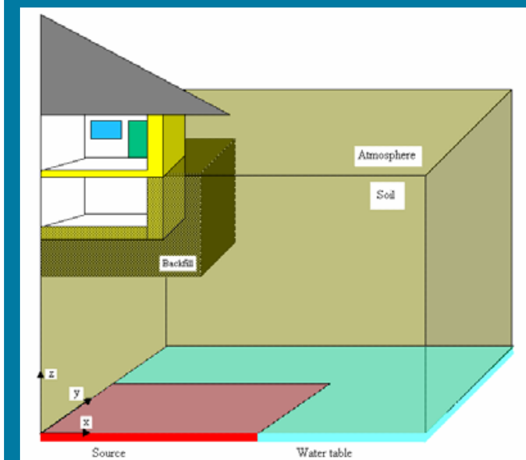
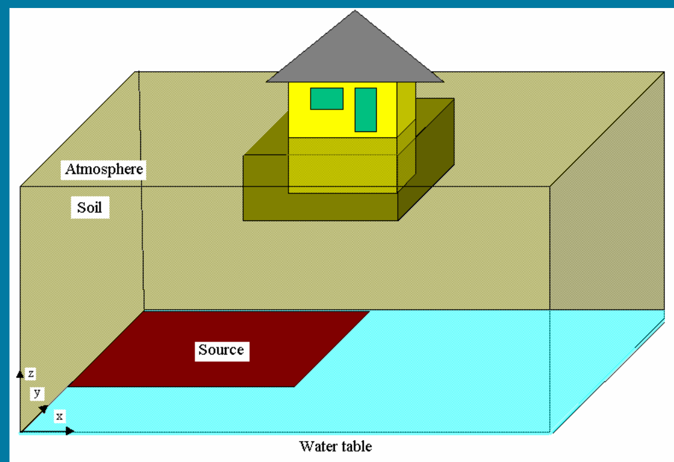
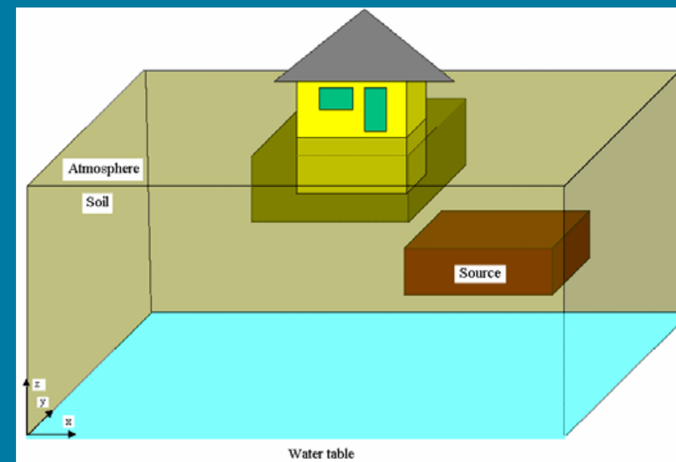
Abreu & Johnson 3D Model Overview

- The three-dimensional transient model solves equations for:
  - Soil gas flow
  - Multi-species simultaneous vapor transport (e.g., O_2, hydrocarbons)
  - Reactions (e.g. degradation) in the vadose zone with user-defined kinetics
- Model simulates transient contaminant transport and heterogeneous subsurface conditions
- The model description and results have been published in peer-reviewed journals and presented at several conferences & workshops sponsored by EPA and API.

Configurations Handled by the Model







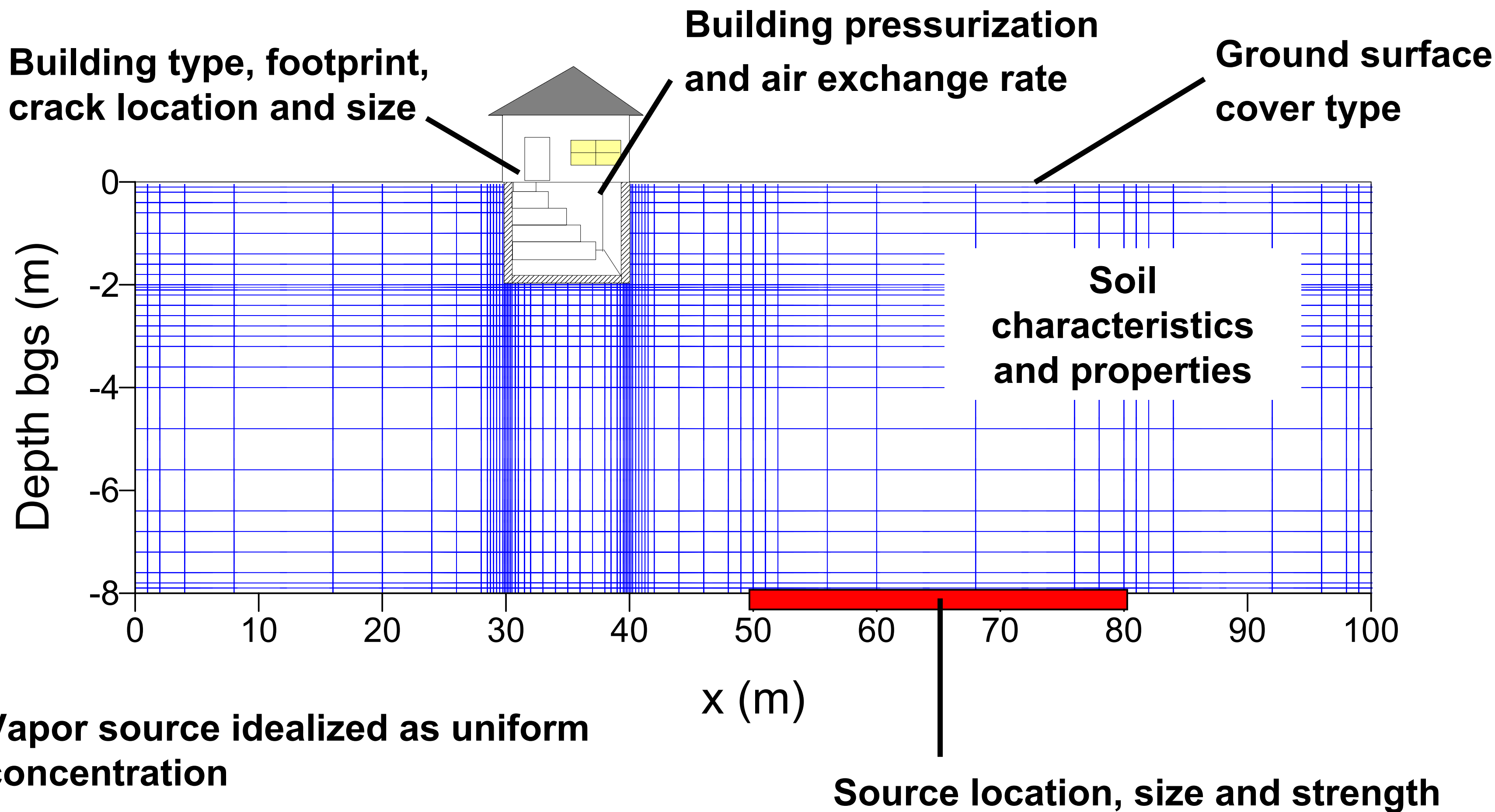
Symmetrical scenario with source at the water table or within unsaturated zone

Nonsymmetrical scenario with source at the water table

Nonsymmetrical scenario with source within the unsaturated zone

Can evaluate slab on grade or basement construction

Model Domain and Site Specific Inputs



Vapor source idealized as uniform concentration

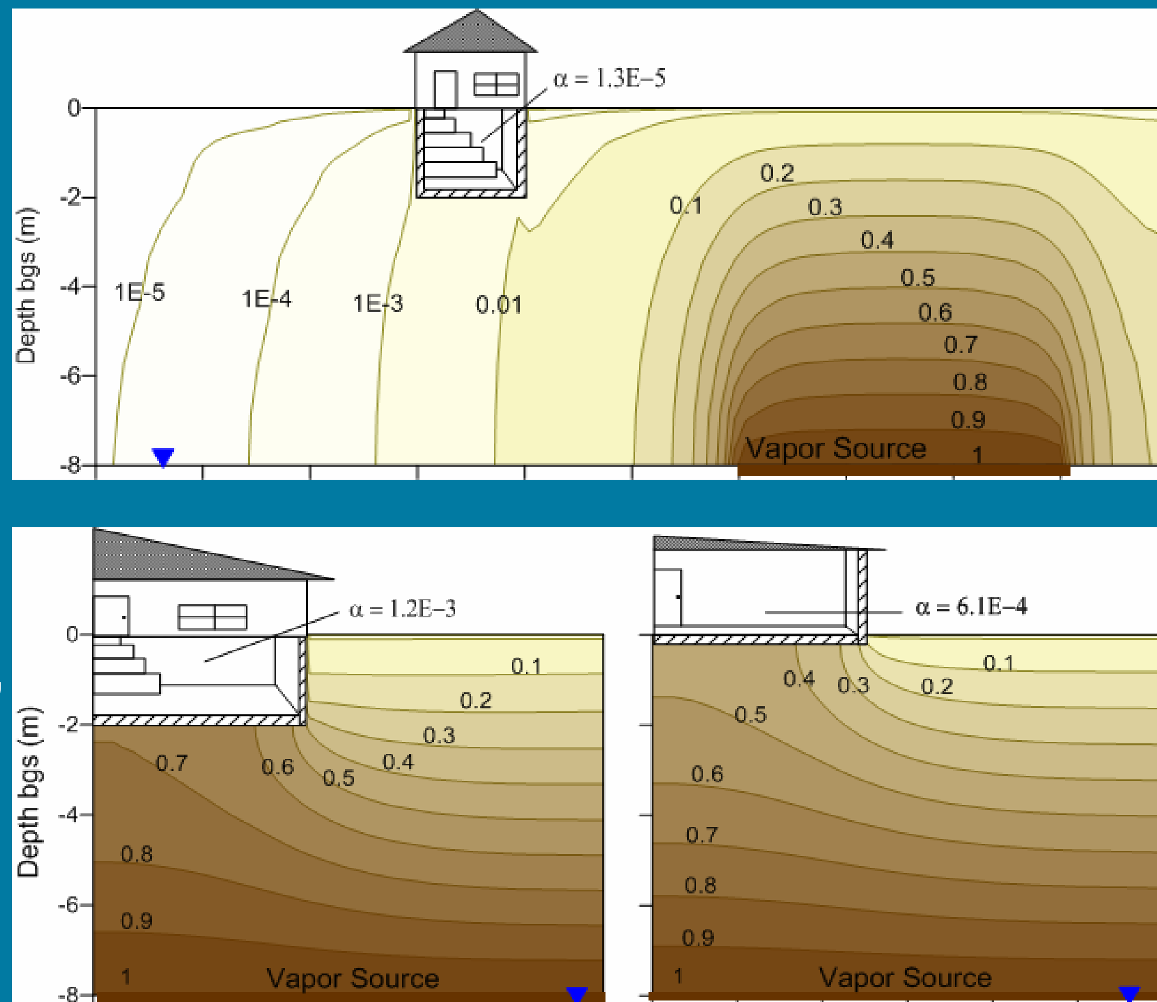
Only vapor transport, No GW transport

Presentation of Results

Vertical cross-sections through center of building showing:

- Concentration distribution normalized by source-zone vapor concentration
- VI attenuation factor,

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



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State-of-Science Advancements

Previously Existing Models

- 1D models (e.g.; Johnson and Ettinger Model)

  Simplistic geometry, one-dimensional transport, steady-state conditions, no biodegradation

A&J 3D Model Helped Advance Knowledge on

- source-building lateral separation
- site heterogeneous conditions,
- Sub-foundation vs. near-foundation soil gas
- oxygen limited aerobic biodegradation

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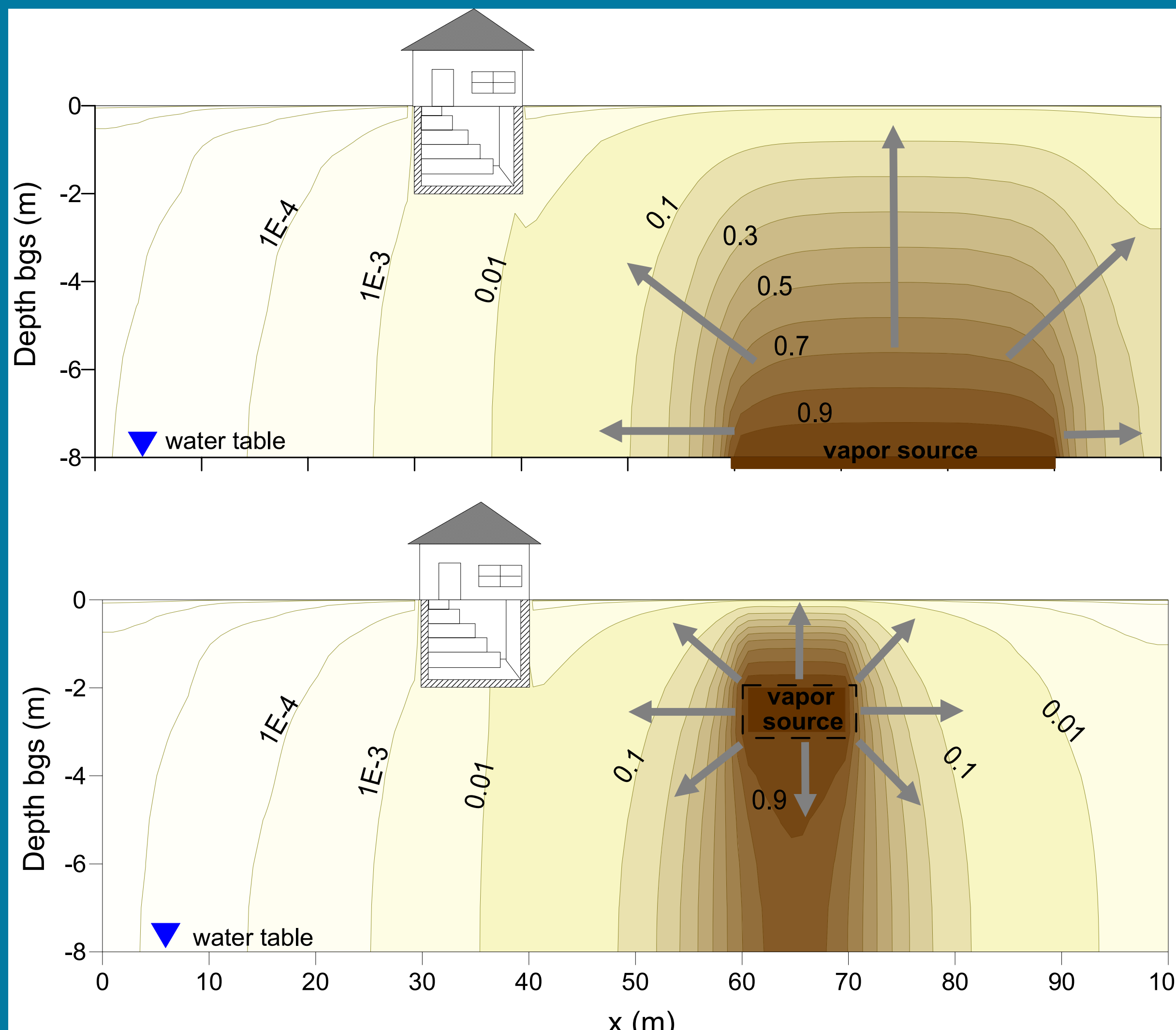
Key vapor fate and transport mechanisms

Diffusion

Transport due to concentration gradients

Dominant process close to the source

Normalized Vapor Concentration Profiles

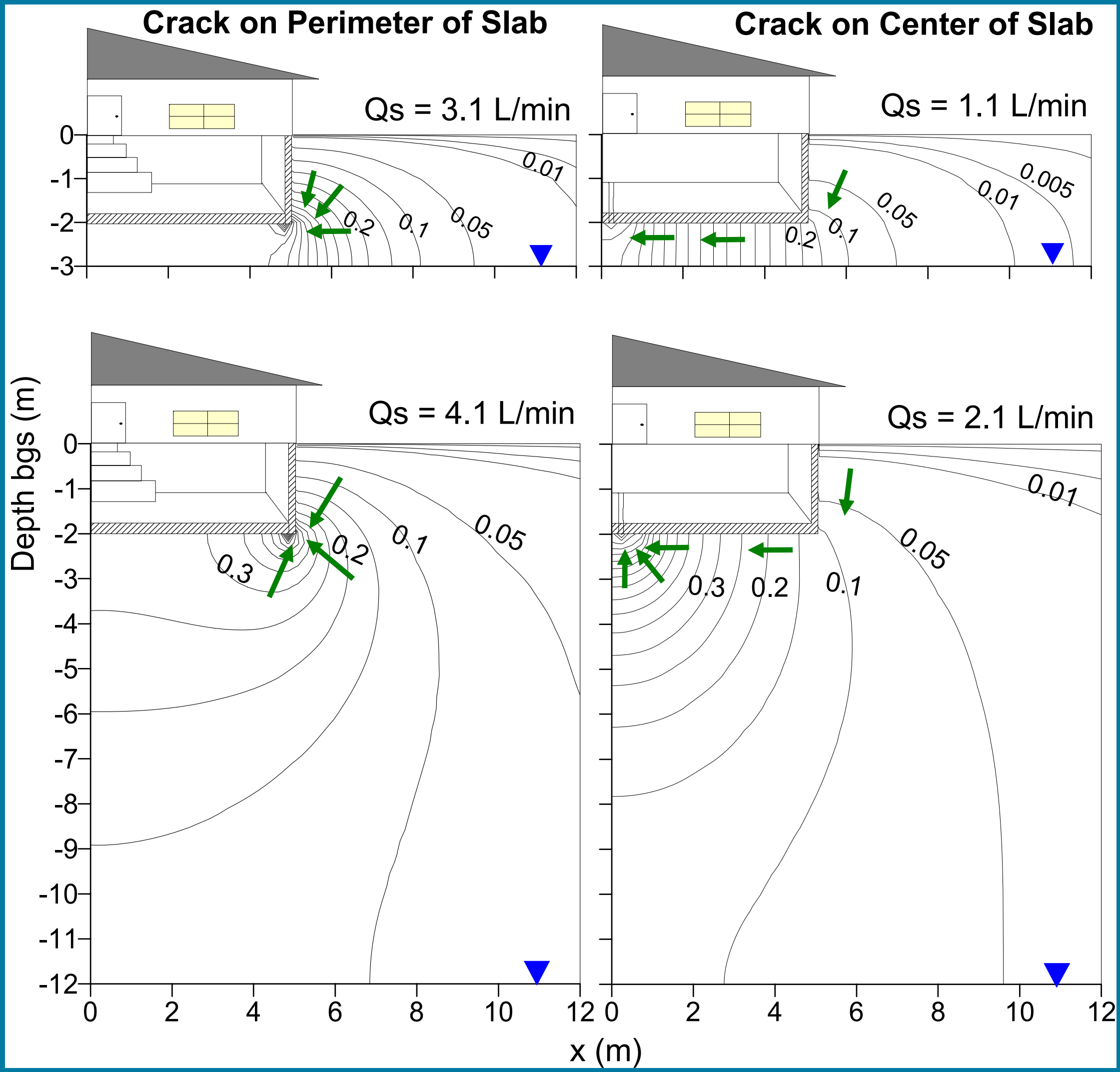


Advection

Transport due to air pressure gradients

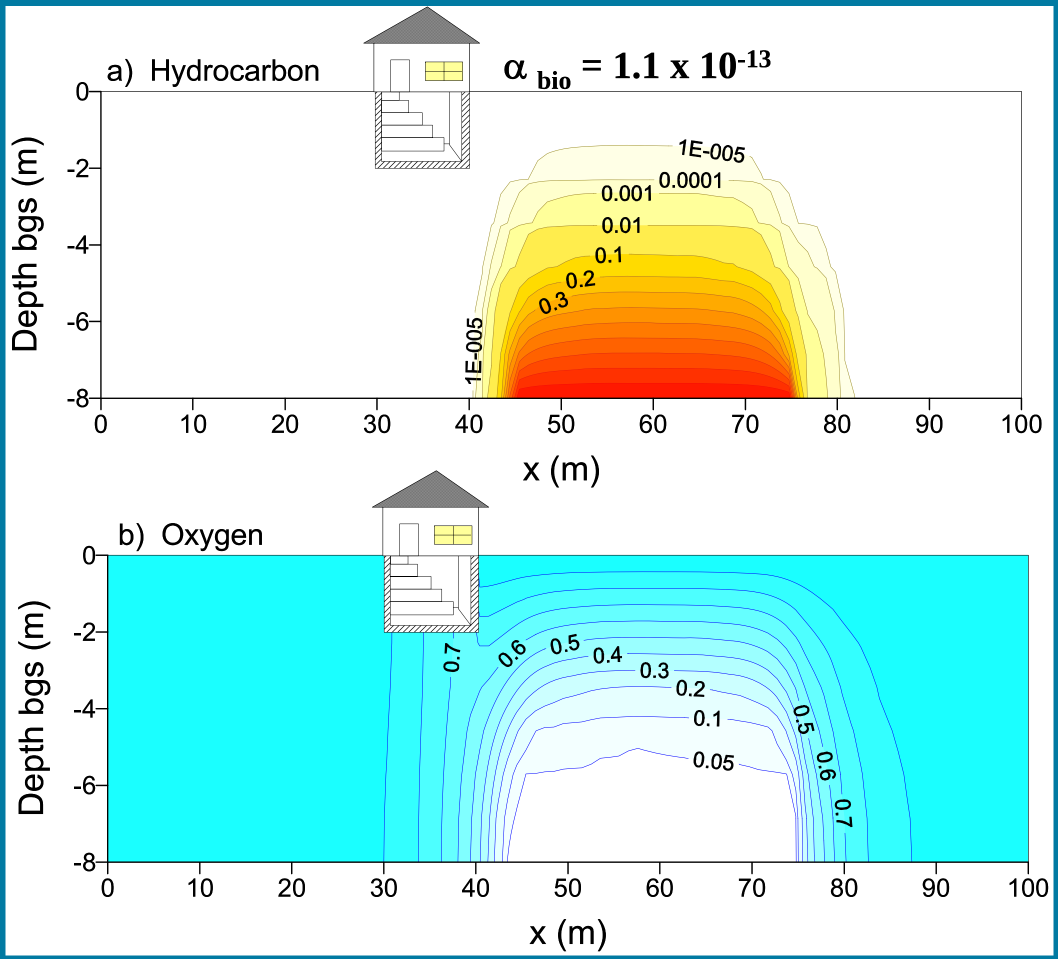
More significant close to the building

Normalized Gauge Pressure Field & Qs



Aerobic Biodegradation

- Decomposition of contaminants by microorganisms within vadose zone
- May significantly affect contaminant fate & transport
- Oxygen distribution within vadose zone is key



(Abreu and Johnson, 2005 & 2006)

(see afternoon section)

Effect of different site conditions on the VI pathway

This presentation focus on recalcitrant compounds, the afternoon presentation focus on aerobically biodegradable petroleum hydrocarbons

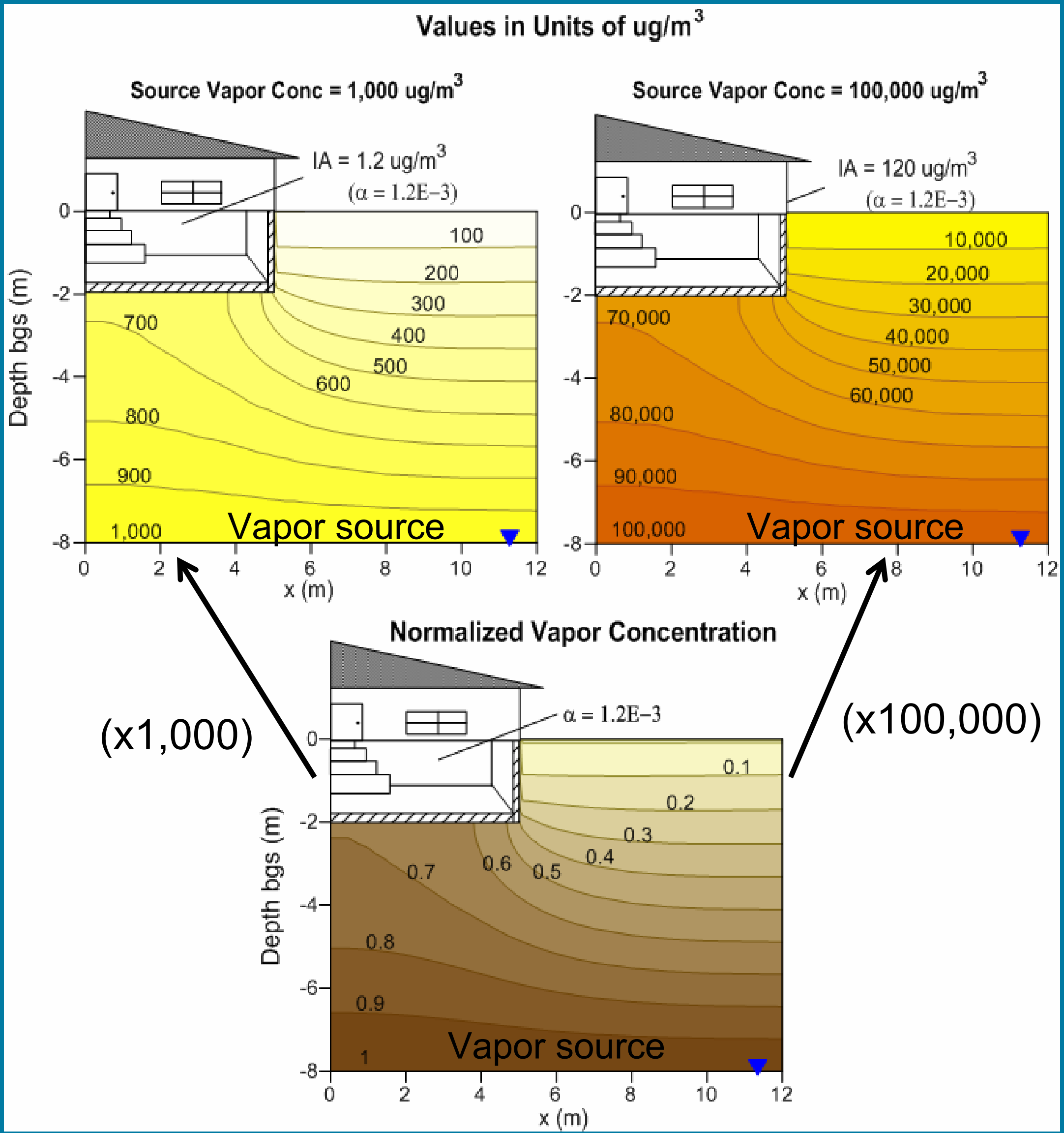
Steady-state conditions presented first

Transient conditions presented later

Source Vapor Concentration

Higher source concentration results in higher concentrations in subsurface gas and indoor air (if there is vapor intrusion and all other conditions are the same)

For recalcitrant compounds, normalized concentrations and α are independent of source concentration

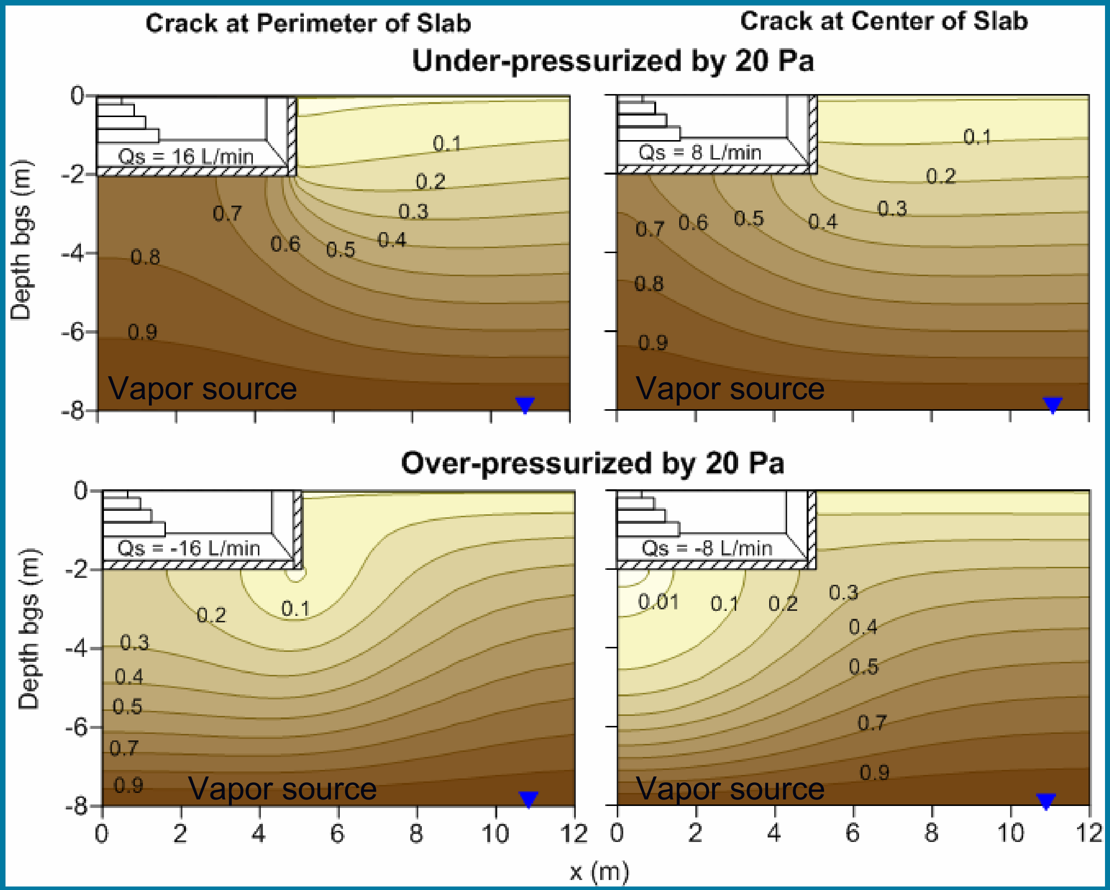


Building Pressurization

Steady pressurization

If building is under-pressurized the air flows from soil into building and may lead to higher sub-slab and indoor air concentrations

If building is over-pressurized the air flows from building into soil and may lead to lower indoor air and sub-slab concentrations (if indoor air is clean)

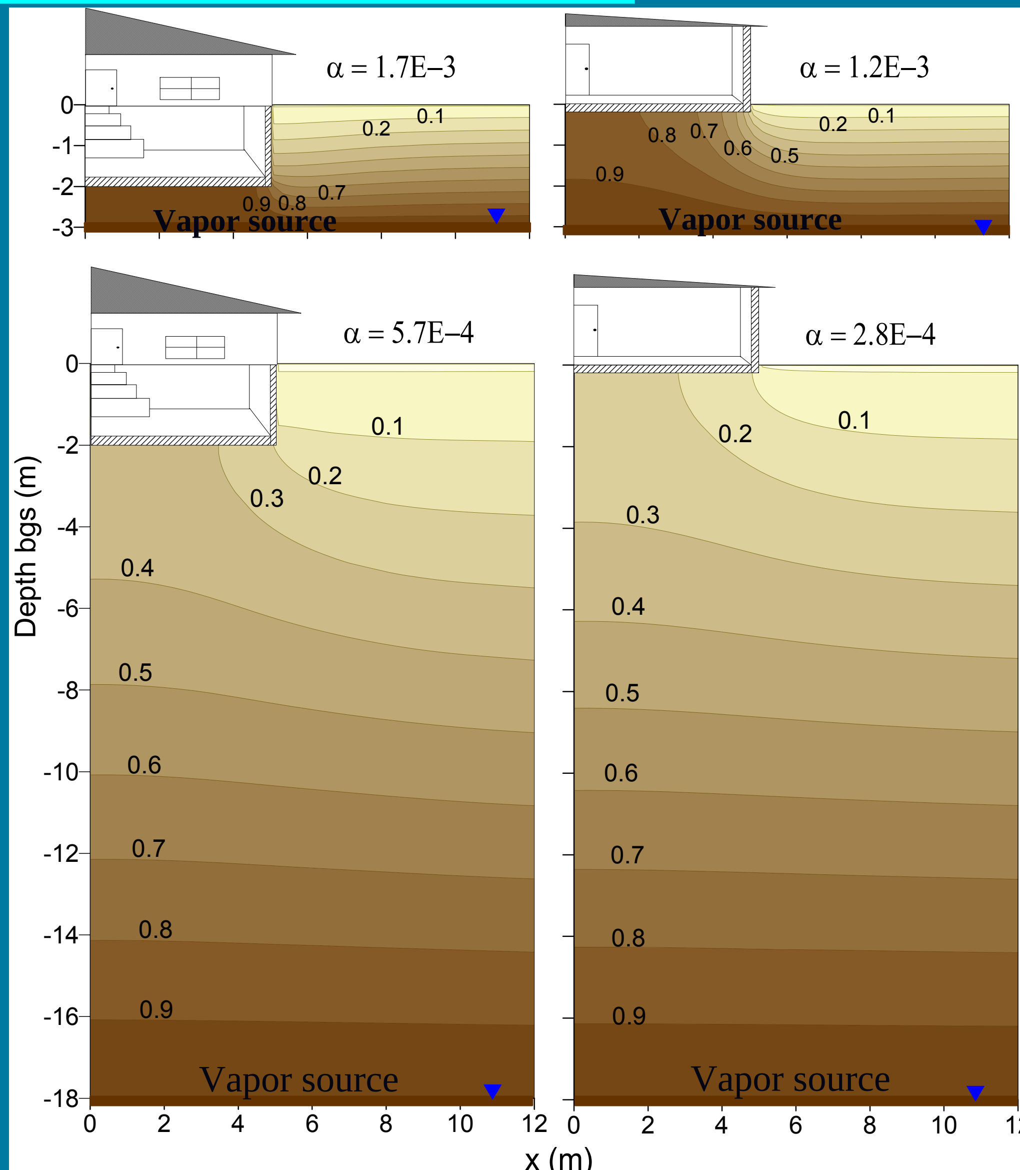


Source Depth & Building Type

Increased source depth results in decrease in α (i.e., greater attenuation)

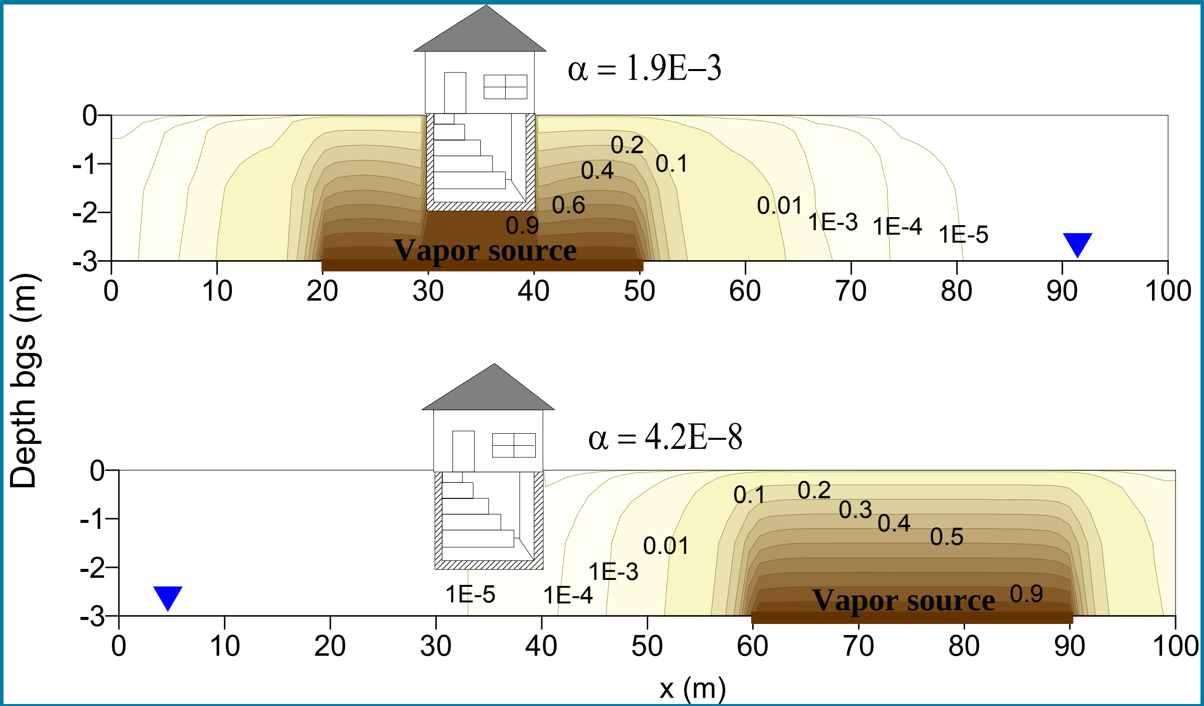
- Non-linear relationship

Sub-slab concentrations and α for buildings with basements are slightly higher than slab-on-grade construction



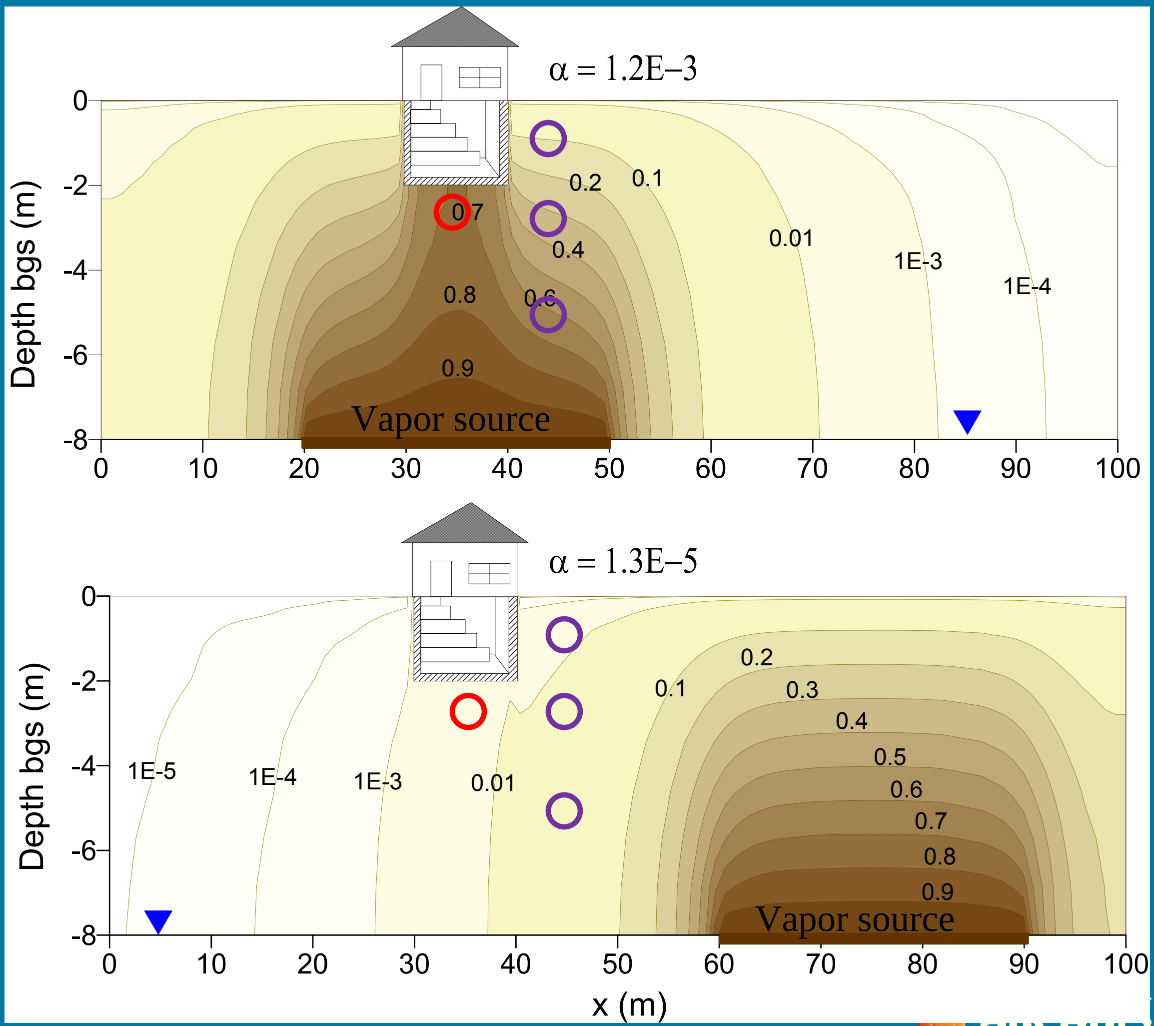
Source Lateral Distance Shallow Groundwater

A 20 m (66 ft) lateral distance separation results in decrease in α by five orders of magnitude

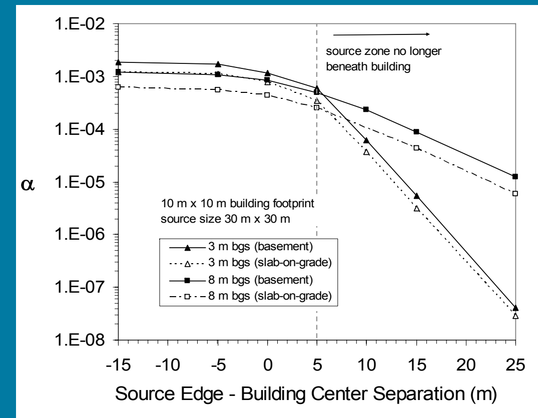


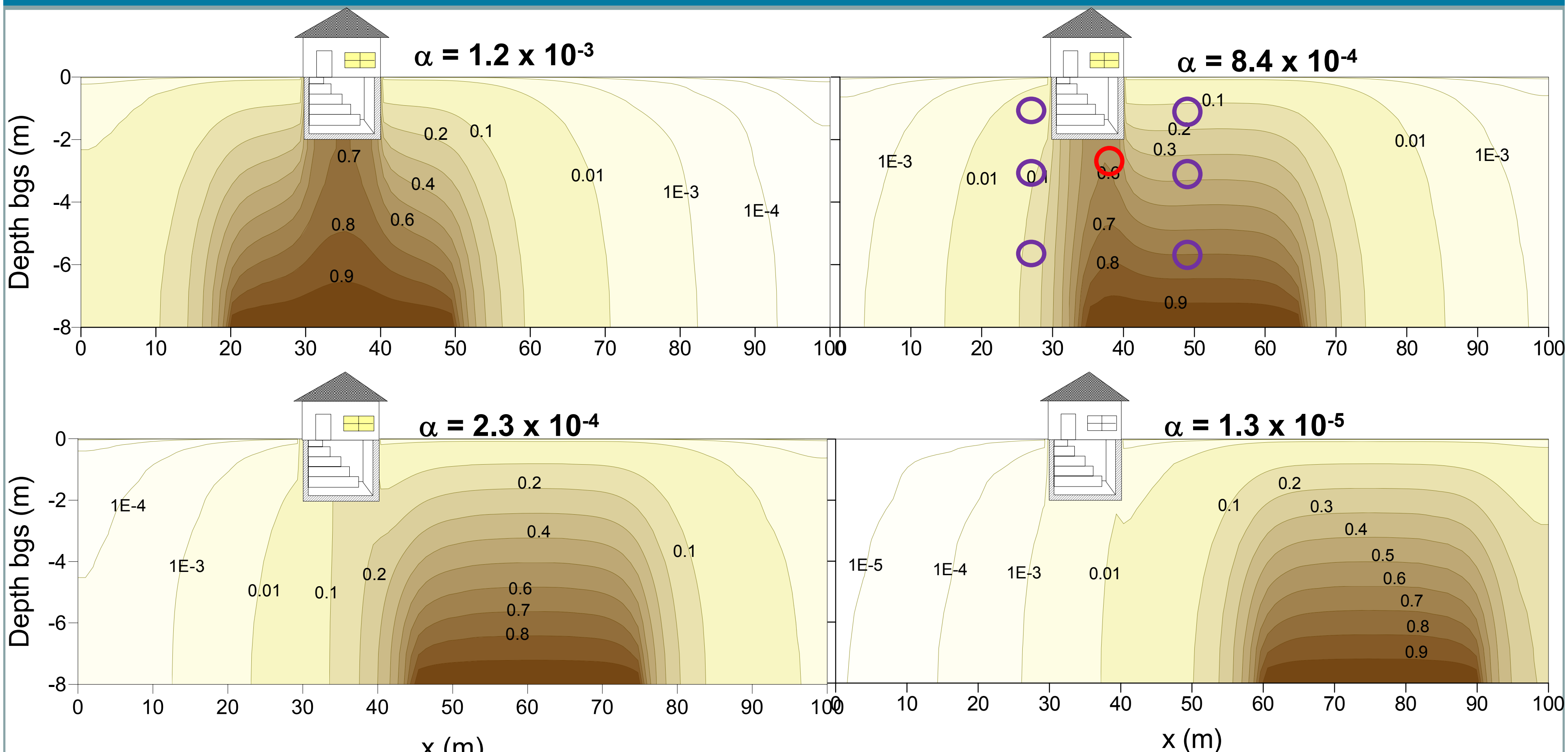
Source Lateral Distance Deep Groundwater

A 20 m (66 ft) lateral distance separation results in decrease in α by two orders of magnitude



Changes in α with Source Position

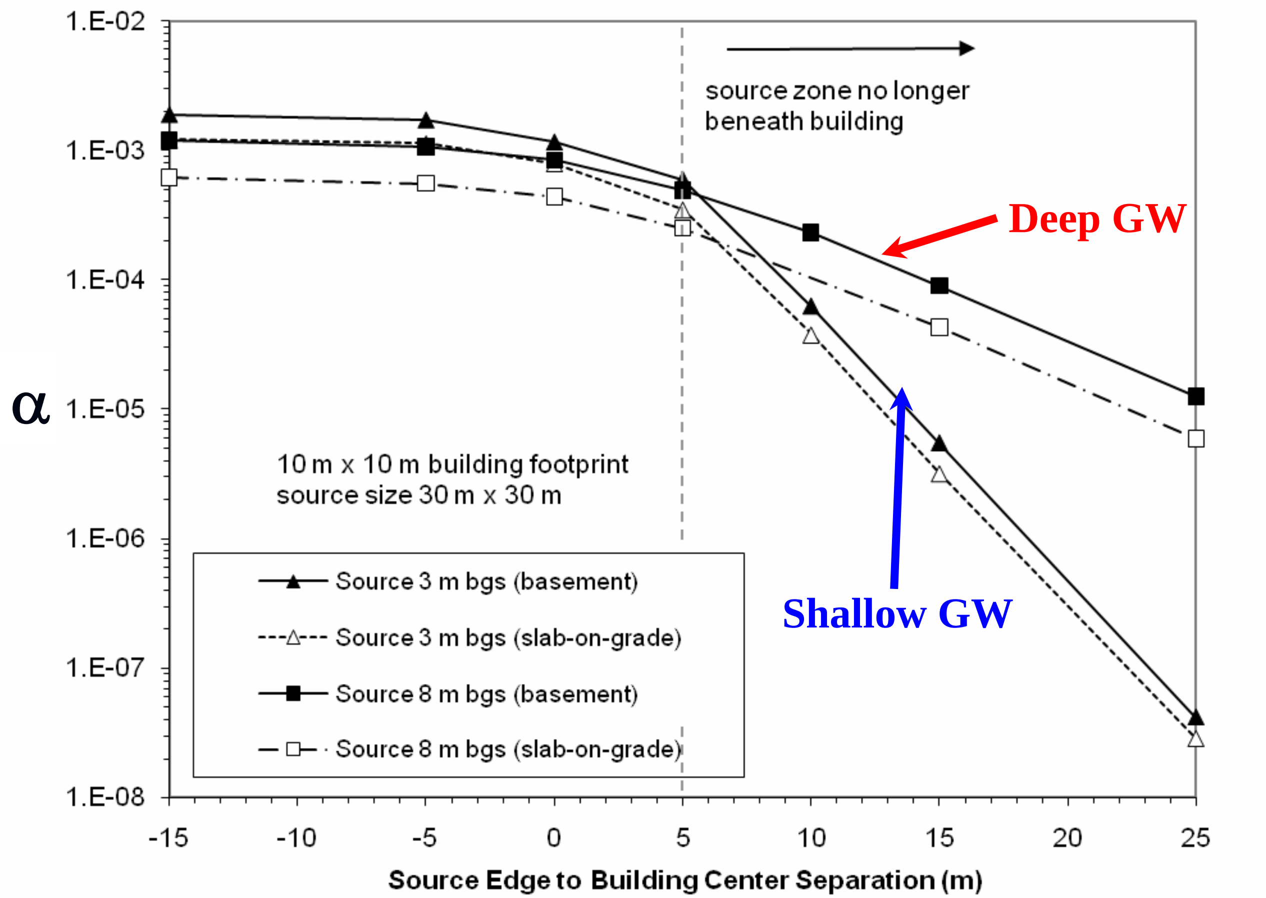




Source Depth & Lateral Distance

Under equal conditions

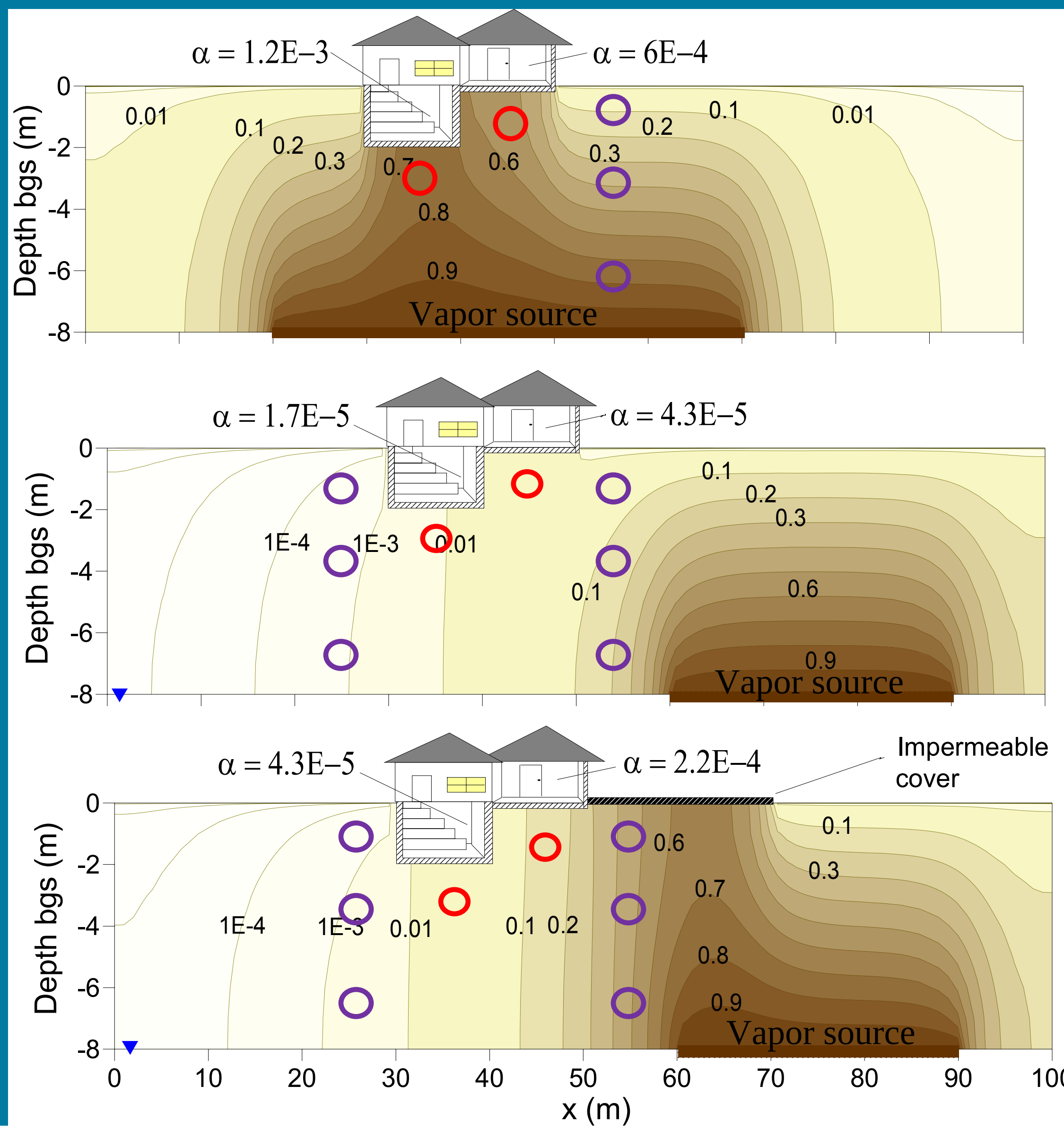
- Effect of lateral distance separation is more significant for shallow source scenarios
- Source depth has small effect when building is above source area
- Bldg. construction has small impact



Abreu and Johnson, EST 2005

Other Considerations…

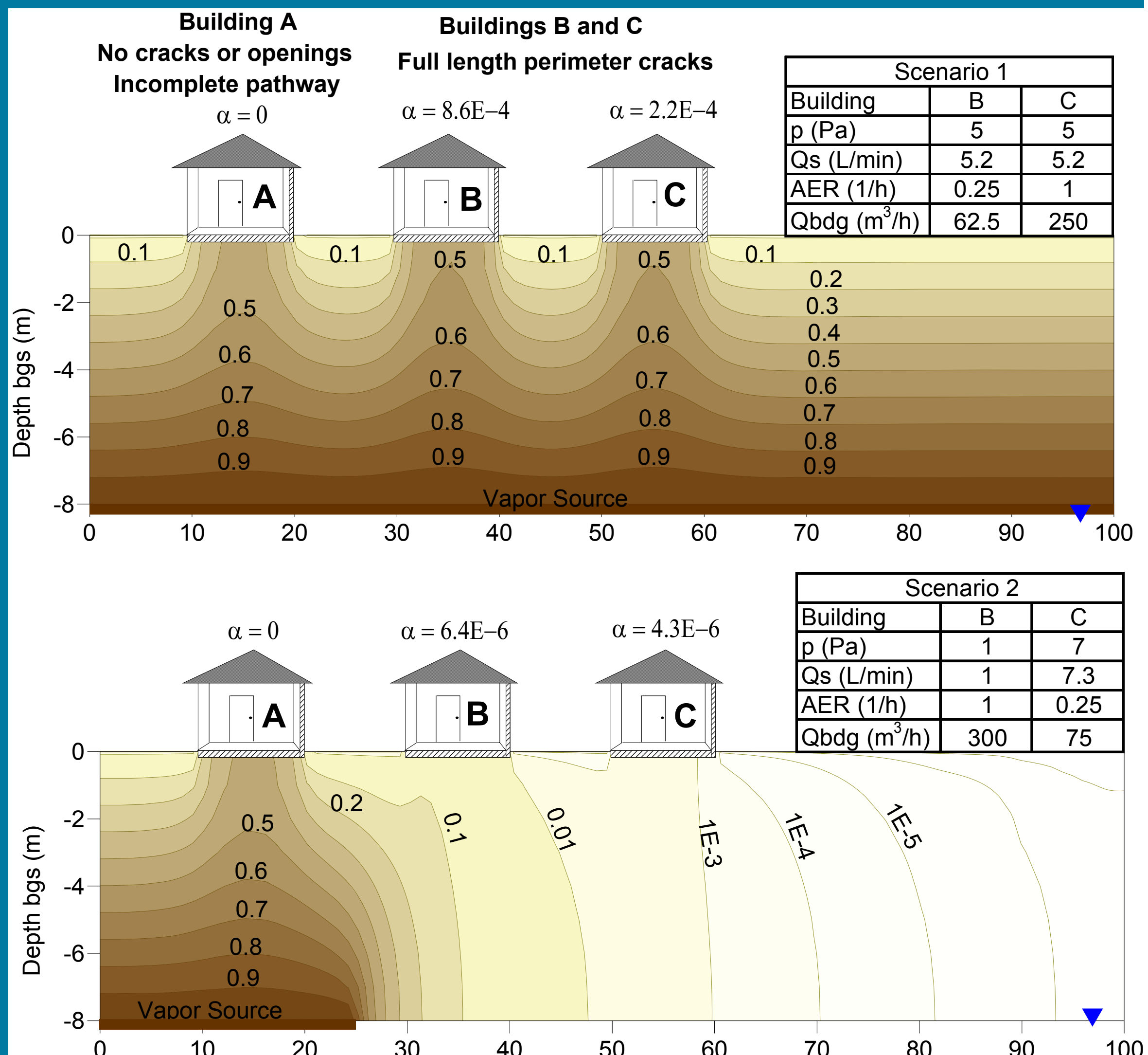
- Under equal conditions, α for slab-on-grade building is smaller than for basement
- Site conditions may lead to opposite finding:
  - Source location
  - Surface seal
  - Building ventilation
  - Multiple sources
  - Soil lithology



Building Conditions & Ventilation

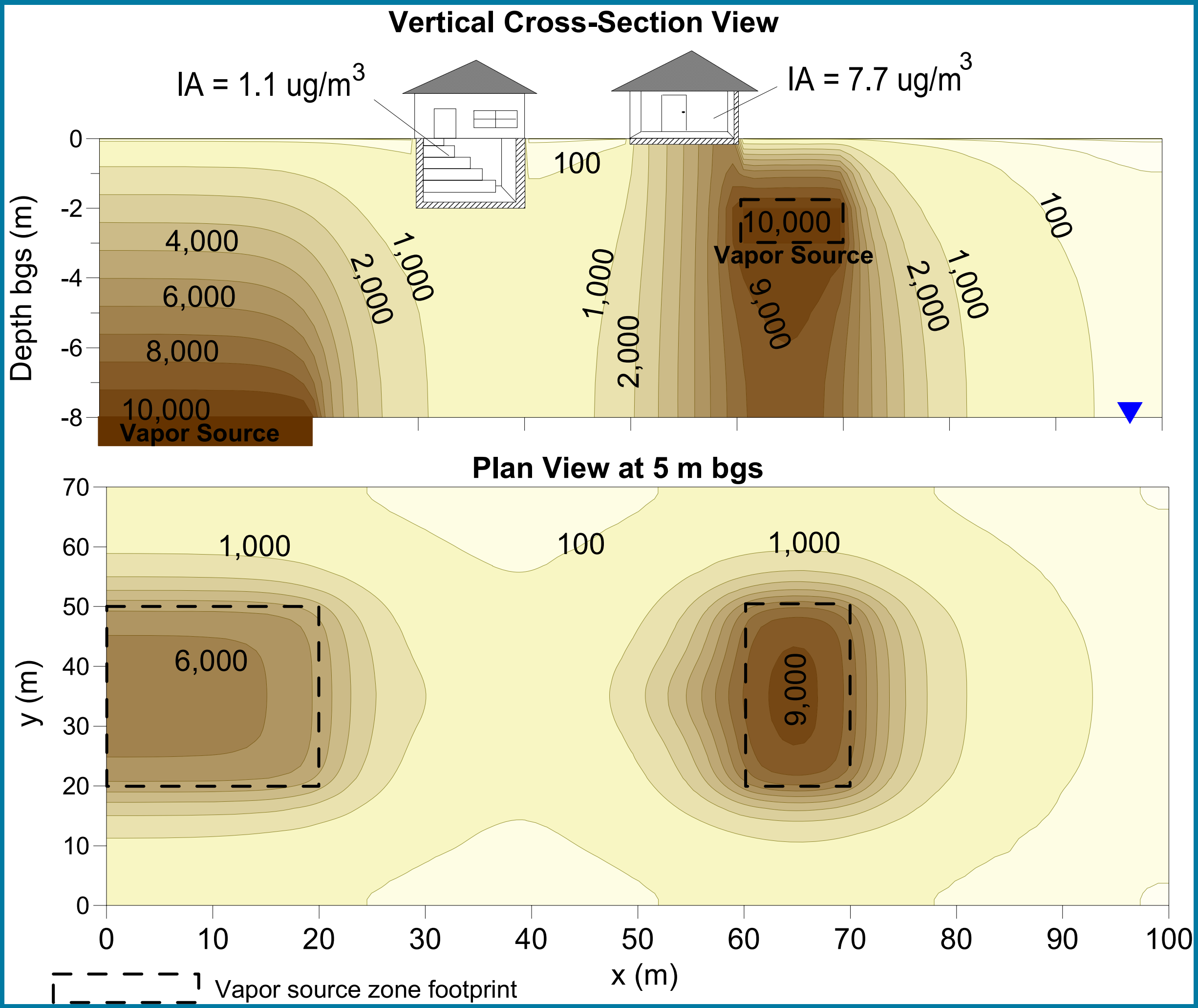
Other building related factors also affect the indoor air concentrations (or α values)

- Presence or absence of cracks
- Building ventilation (i.e., air exchange rate and building air flow rates)



Multiple Sources

Identifying multiple sources and their locations is key in understanding contaminant distribution and identifying buildings with potentially higher VI risks

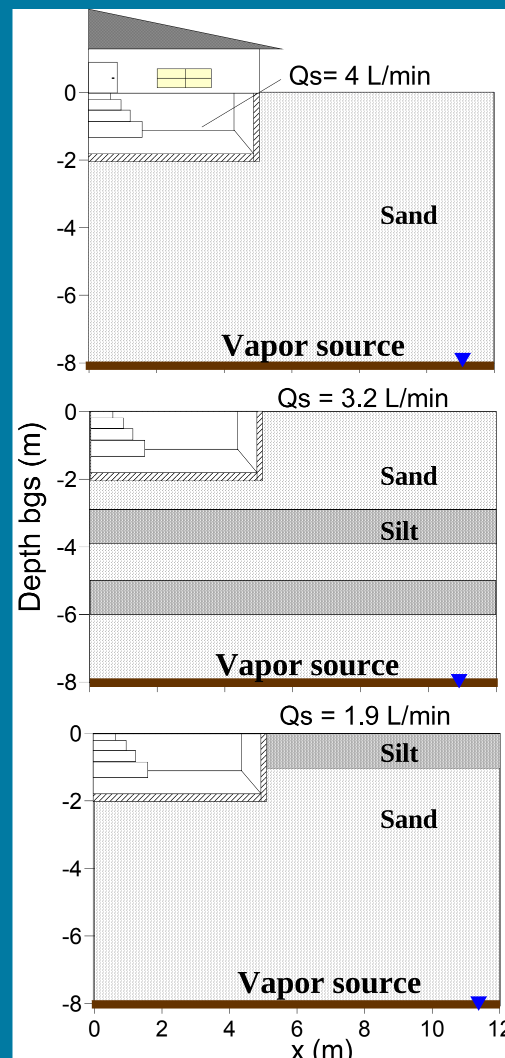


Layered Soils

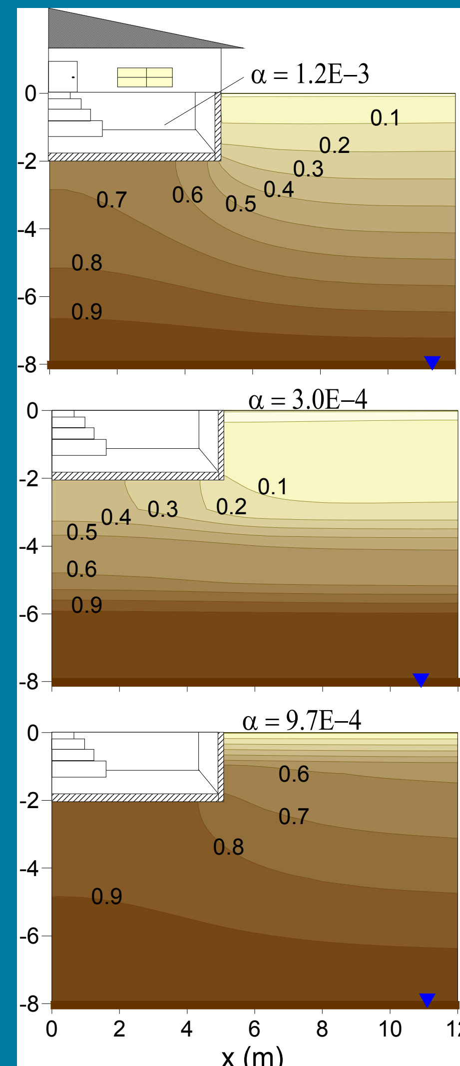
Moist, fine-grained soils may act as diffusive barrier

- Higher concentration below
- Lower concentration above

CMS



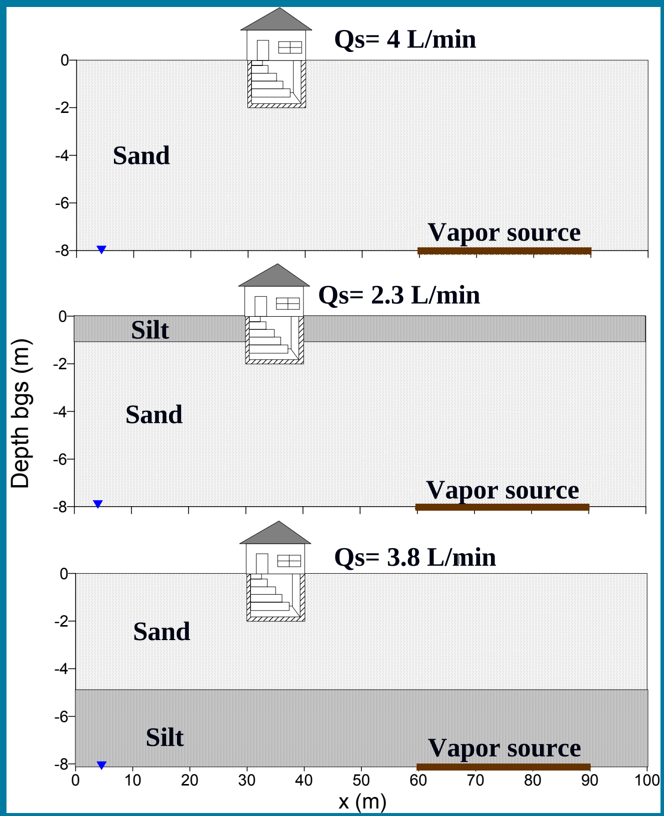
Results



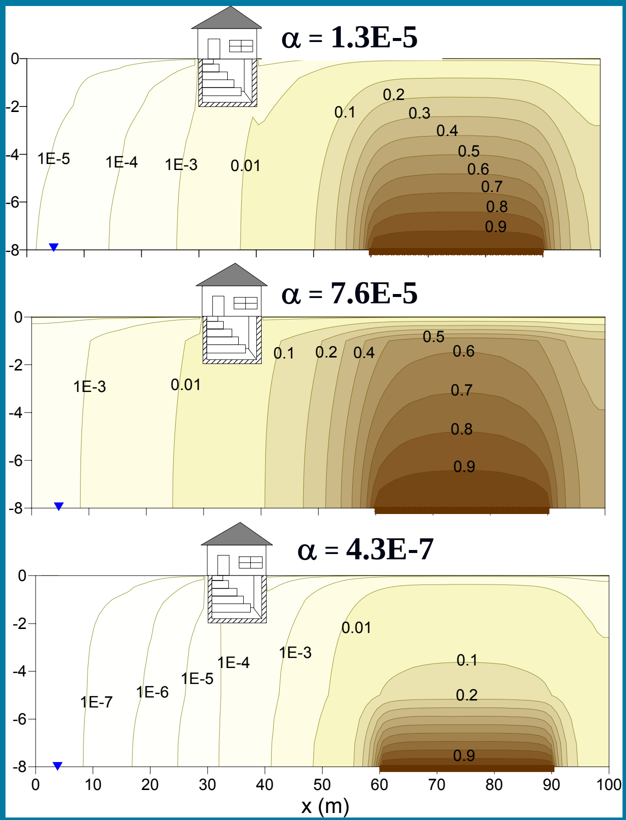
Layered Soils & Lateral Source

- High moisture content layer on ground surface may result in slight increase of lateral vapor migration
- High moisture content layer above the vapor source may significantly decrease vapor migration

CMS



Results



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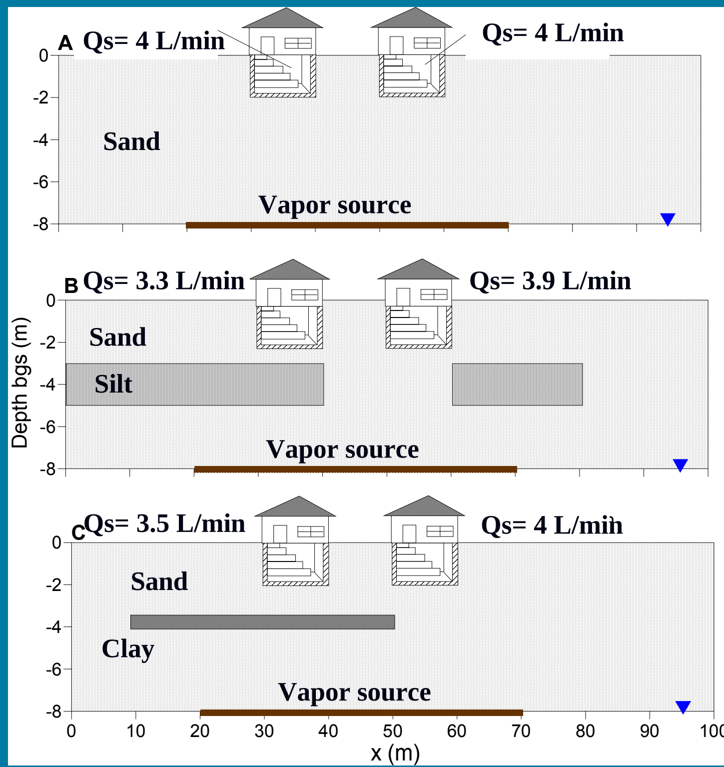
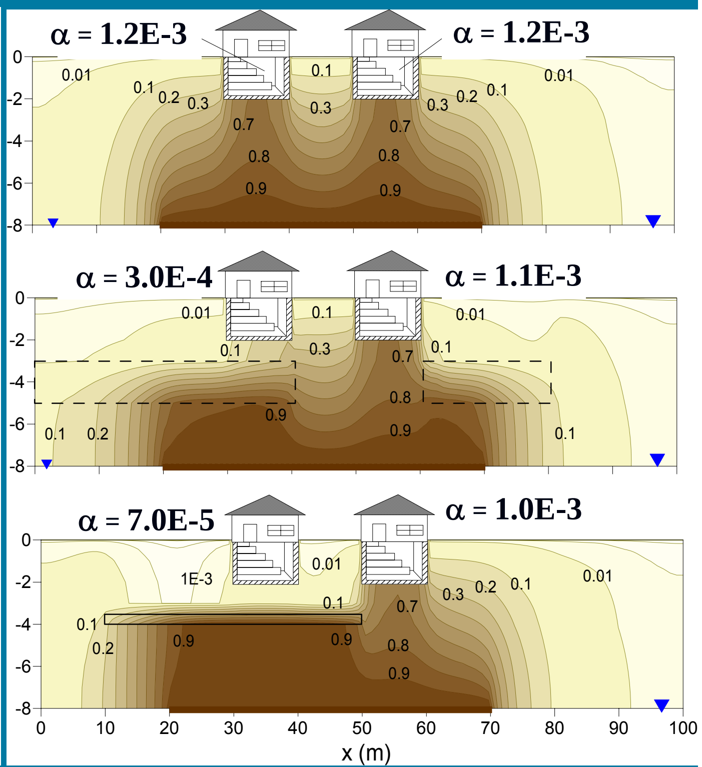
Heterogeneous Subsurface

Results in spatial variability of soil gas concentration distribution

CMS

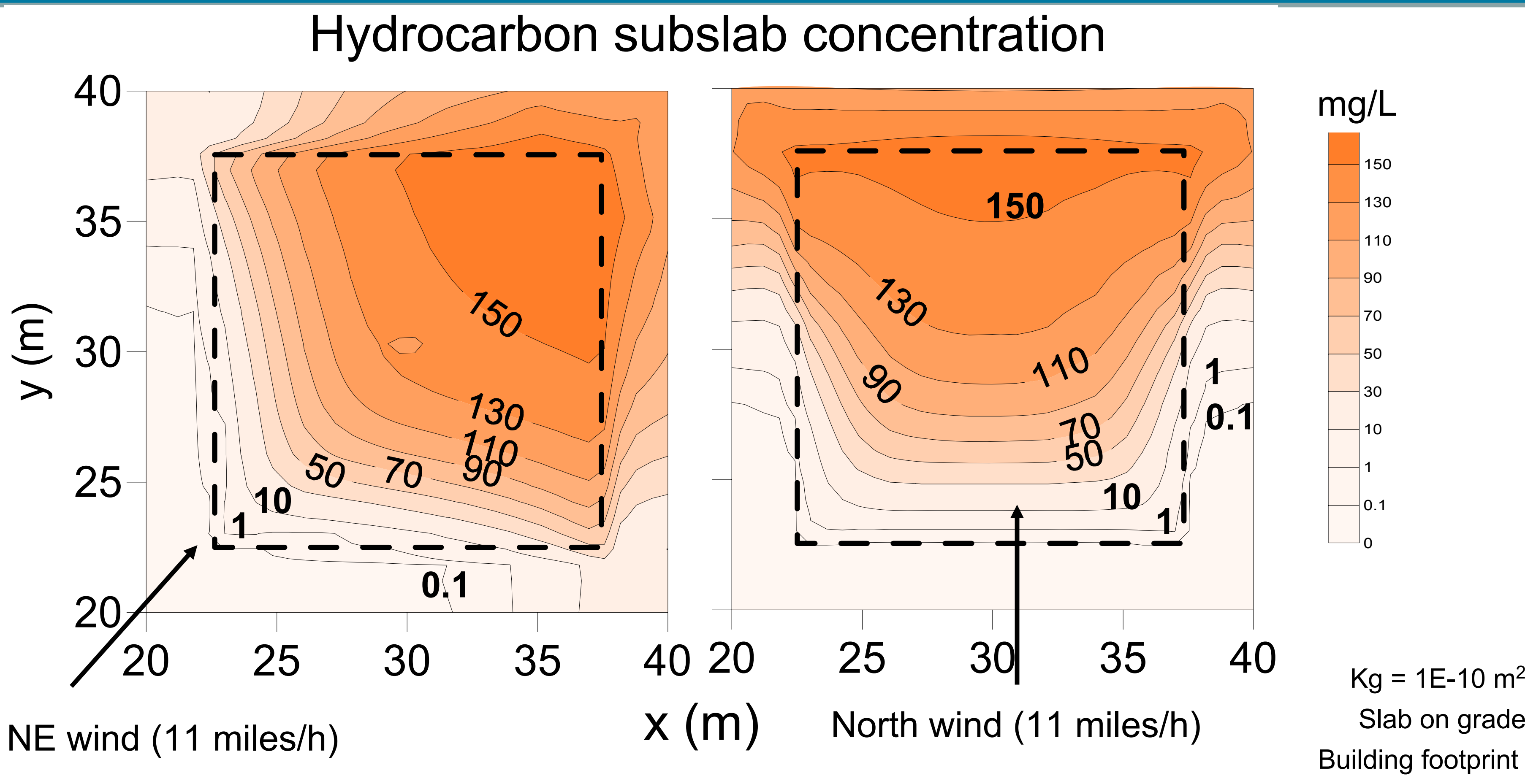


Results



Steady Wind Load

Can create non-uniform distribution of sub-slab concentrations

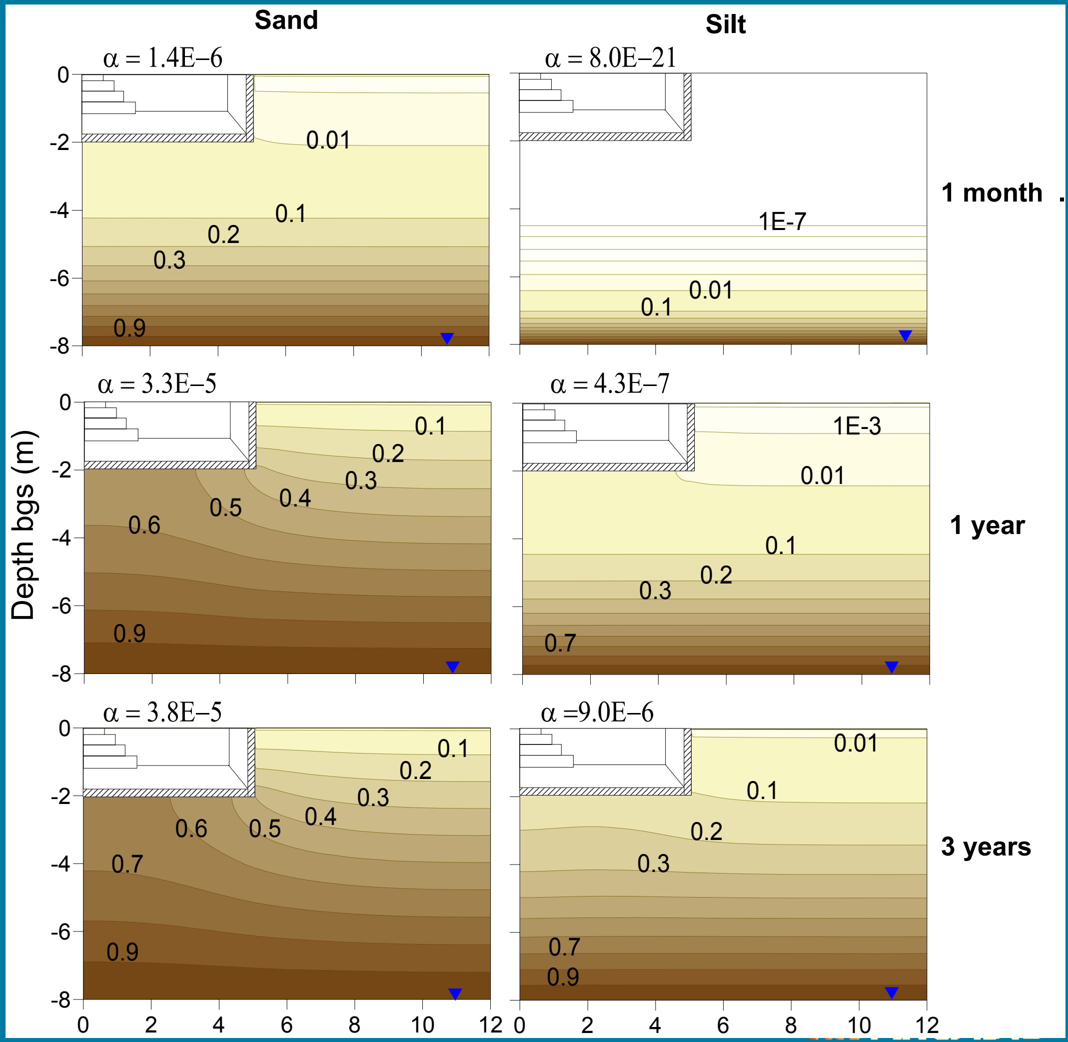


Transient Transport by Diffusion

Effect of Soil Moisture Content

Moisture content retards the migration of contaminants

Profiles & Time Since Source Release



Transient Transport by Diffusion

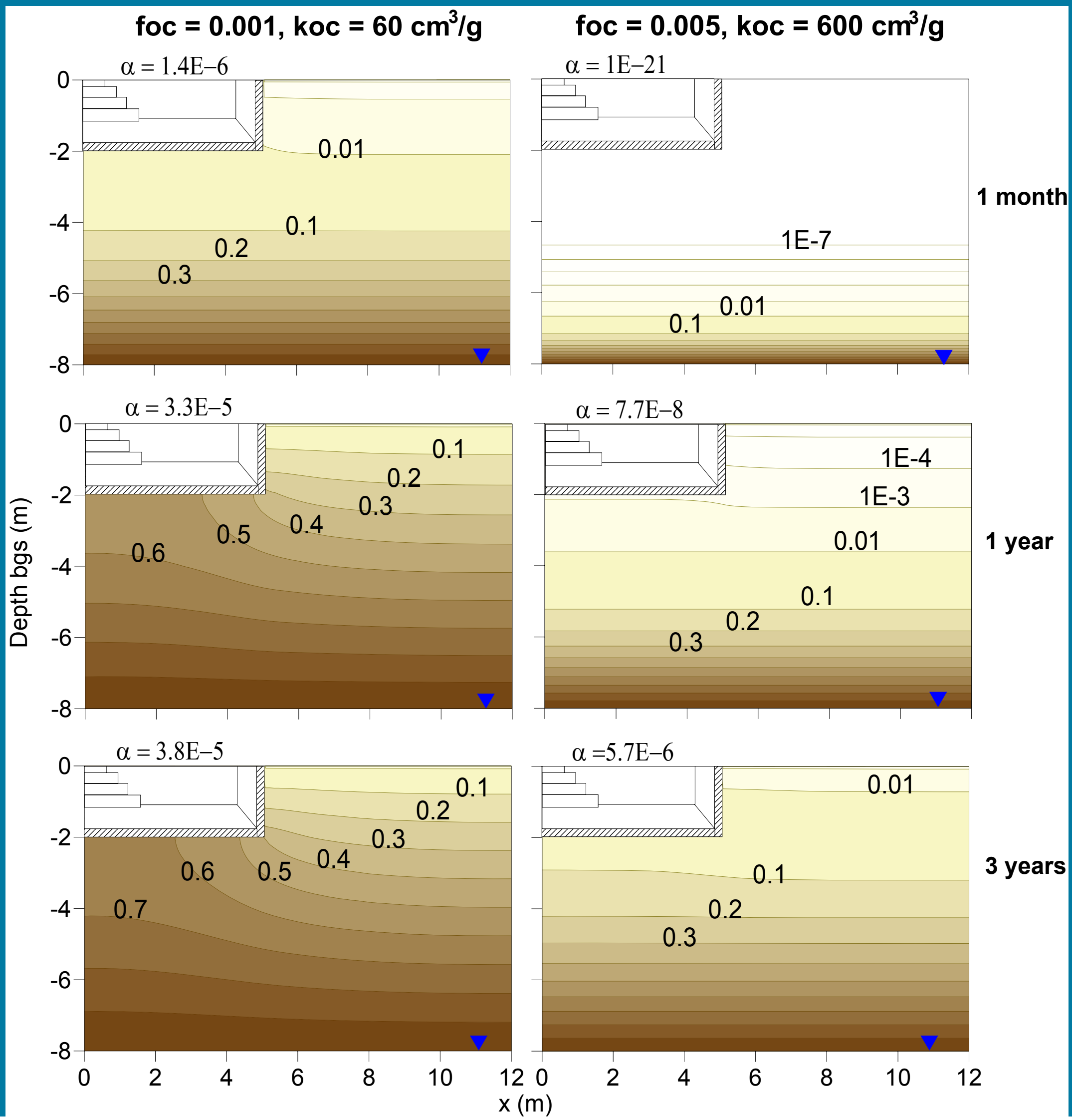
Profiles & Time Since Source Release

Effect of foc & koc

Chemical sorption to soil particles retards the migration of the contaminant

foc = fraction of organic carbon in soil

koc = sorption coefficient of chemical to organic carbon



Time to Reach Steady-State by Diffusion

Time is affected by

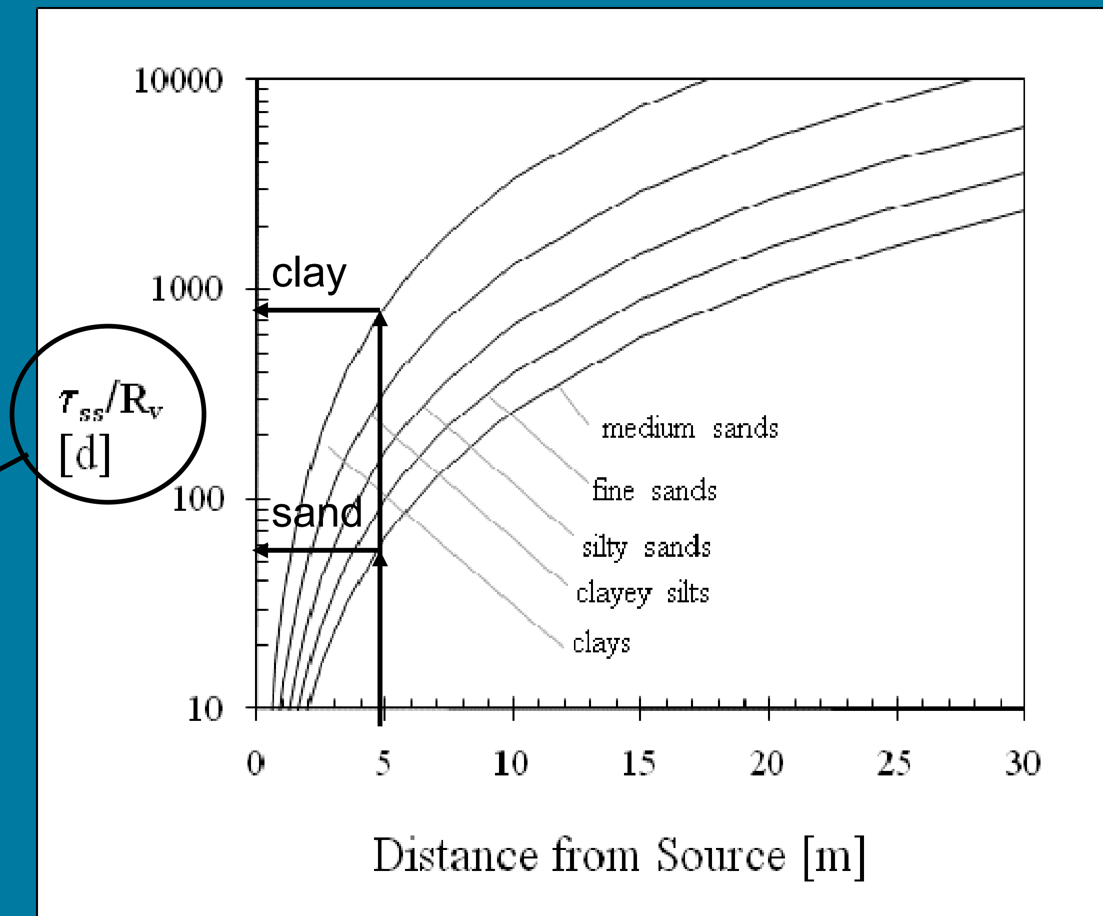
- Source depth & lateral distance
- Soil moisture & foc
- Contaminant properties (koc)

Multiply τ_{ss}/R_v by

Chemical retardation factor

$$R_v = \left(1 + \frac{\phi_w}{\phi_g H_n} + \frac{K_{oc,n} \cdot f_{oc} \cdot \rho_b}{\phi_g H_n}\right)$$

Non-retarded Time to Reach Near SS



Johnson et al. (1999)

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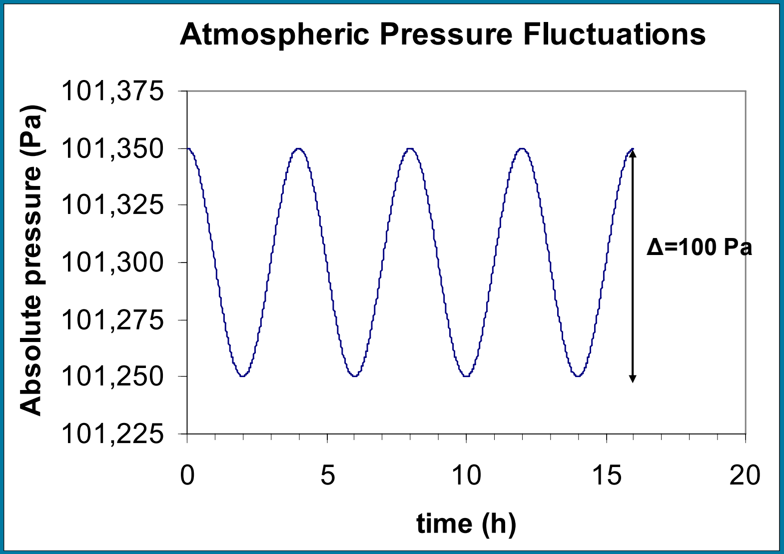
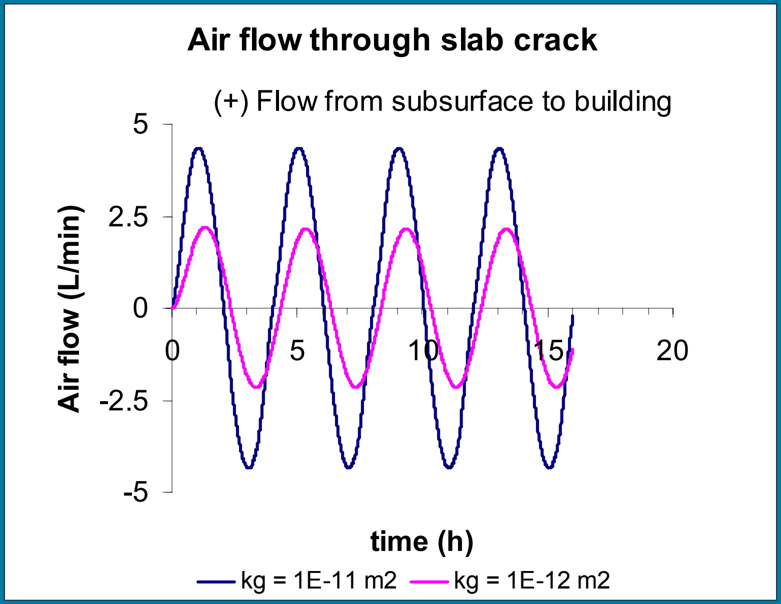
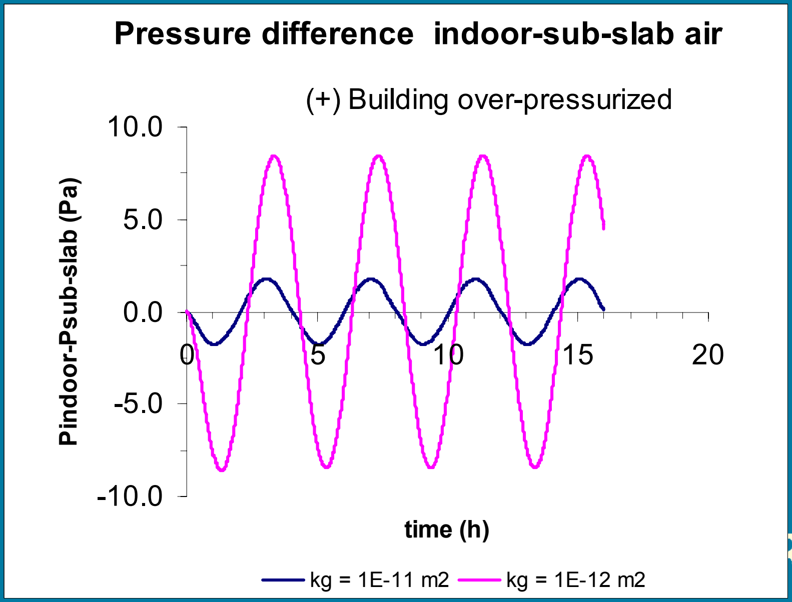
Transient Pressure Fluctuations

Fluctuations in building pressurization can affect the transport of soil gas into buildings as the air flow direction is reversed



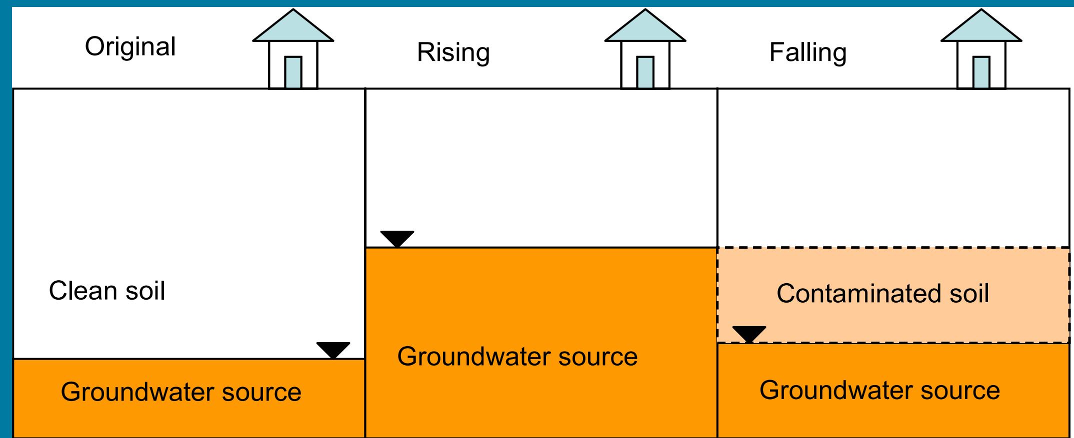




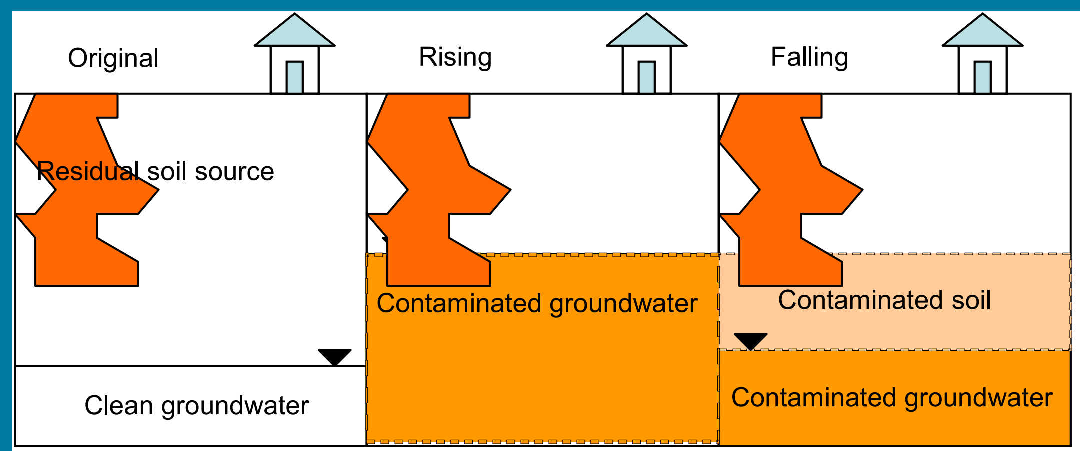
Fluctuations in Water Table Elevation

Fluctuations in the water table elevation may affect the distribution of contaminants in the subsurface and the source-foundation separation

Groundwater Source



Soil Source



Schematic illustration
(Not model simulated)

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Remarks

- VOC concentration distribution in the subsurface may not be uniform and can exhibit spatial and temporal variability (including the sub-slab concentration distribution).
- Factors that influence subsurface contaminant distribution and indoor air concentration:
  - ✓ Source concentration, depth and lateral distance
  - ✓ Soil physical properties
  - ✓ Site geology (i.e., subsurface heterogeneities)
  - ✓ Building conditions (construction, pressure, AER)
  - ✓ Surface seal (impermeable cover)
  - ✓ Time since contaminant release occurred
  - ✓ Aerobic biodegradation (see afternoon presentation)

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Remarks

- These vapor intrusion conceptual model scenarios can help practitioners develop a site-specific conceptual model, plan VI investigations, and interpret the results.
- The presented simulations are based on idealized and simplified assumptions about conceptual model scenarios to illustrate VI processes. These scenarios may not be representative of site-specific conditions, but may be used to guide site-specific VI evaluations.

