MODELING THE EFFECT OF AEROBIC BIODEGRADATION ON VAPOR INTRUSION

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Objectives

Apply Abreu and Johnson 3D model to:

- Visualize predicted concentration profiles around buildings for biodegradable chemicals
- Evaluate how aerobic biodegradation affects the attenuation factor α as a function of:
  - Vapor source concentration
  - Vapor source depth
  - Lateral distance from buildings
  - Biodegradation rates
  - Cracks location
  - Building construction

$\alpha = C^{indoor}/C^{source}$

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The Abreu and Johnson 3D Model

- The numerical code couples equations for the soil gas pressure field and air flow field with the multi-species contaminant transport and reaction equation

$$\frac{\partial P}{\partial t} - \left(\frac{\overline{P}}{\phi_g \mu_g}\right) \cdot \vec{\nabla} \bullet (K_g \cdot \vec{\nabla} P) = 0 \qquad \vec{q}_g = \frac{K_g}{\mu_g}(\vec{\nabla} p)$$

$$a_i \cdot \frac{\partial C_{ig}}{\partial t} = -\vec{\nabla} \bullet (C_{ig} \cdot \vec{q}_g) - \vec{\nabla} \bullet \left(\frac{C_{ig}}{H_i} \cdot \vec{q}_w\right) + \vec{\nabla} \bullet (D_i \cdot \vec{\nabla} C_{ig}) - R_i$$

$$Qck = \left(-\frac{w_{ck}^{3}}{12\mu_g \cdot dck}\right)\left[p - p^{indoor}\right] = w_{ck}\left(\frac{K_g}{\mu_g}\right)\frac{\partial p}{\partial z}$$

- Solved by finite differences method
- Time-varying building and atmospheric pressurization
- Multi-component systems (e.g., O_2, hydrocarbons)
- User-defined kinetics
- Variable building construction (basements, slabs, varying crack sizes and crack locations)
- Variable source characteristics (location, strength)
- Heterogeneous subsurface settings

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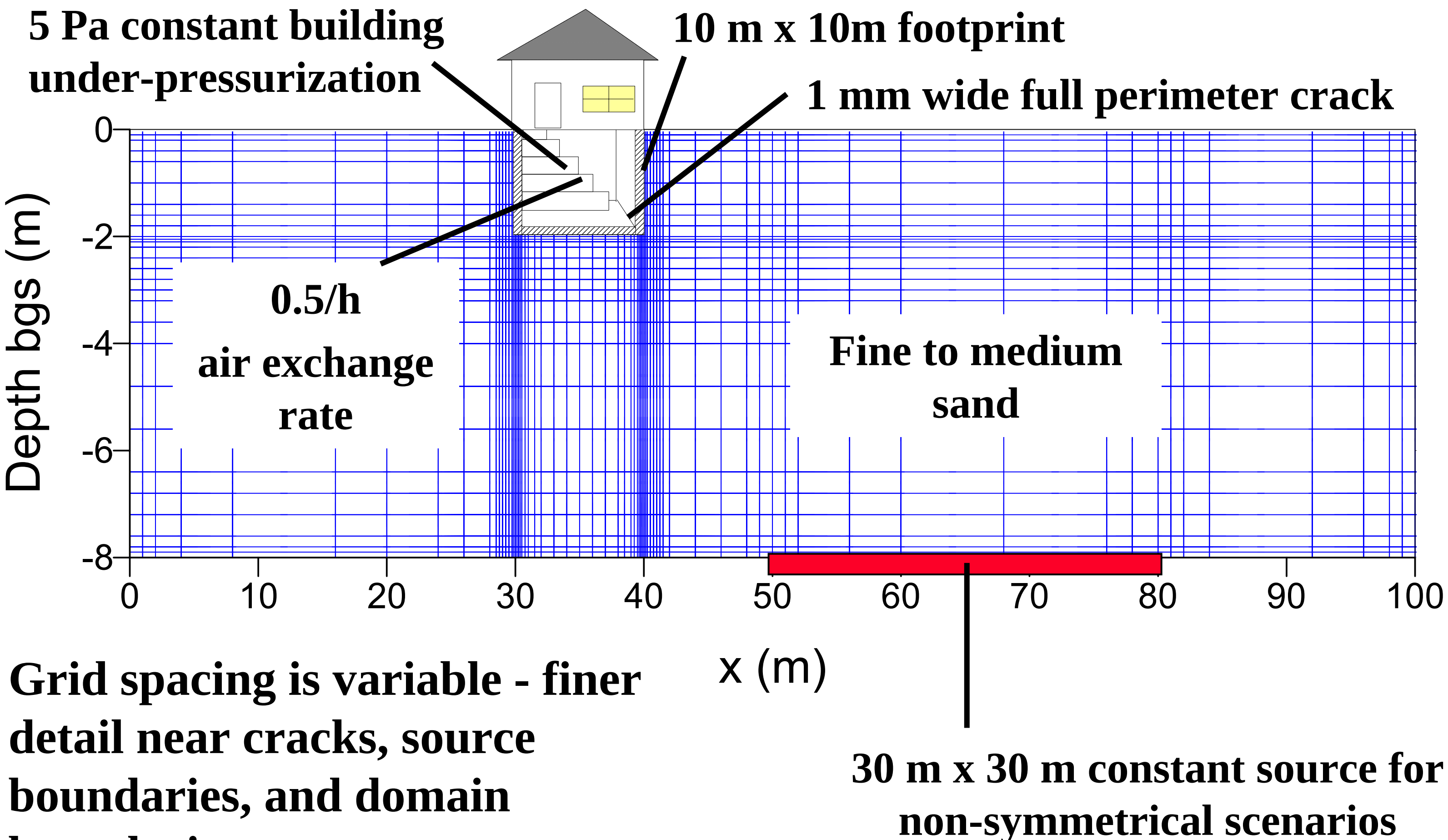
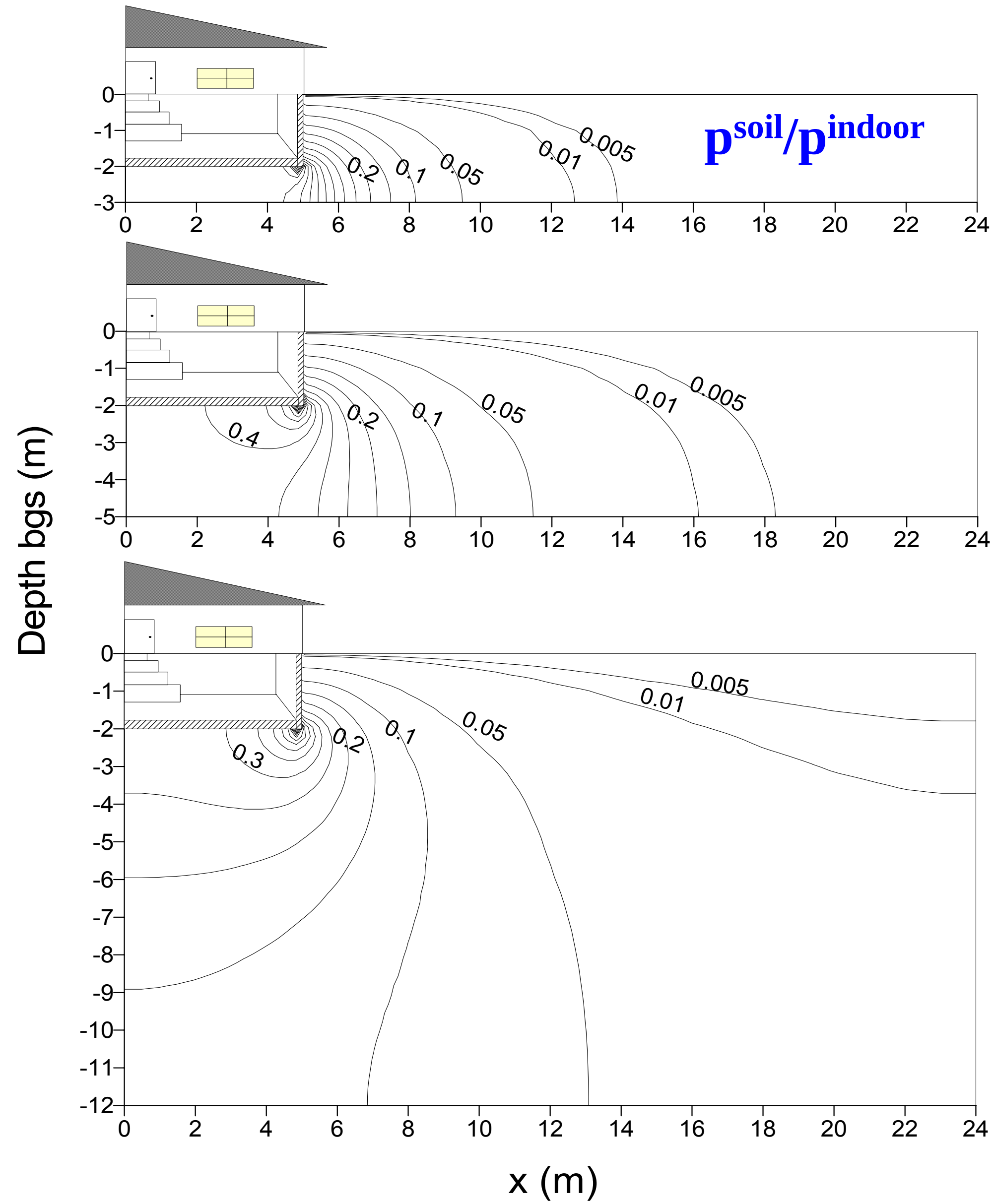
Model Inputs



Grid spacing is variable - finer detail near cracks, source boundaries, and domain boundaries

Model Predicted Pressure Fields



Basement scenarios

Perimeter crack

Homogeneous soil

Cross-section through plane of symmetry

$p^{soil} = P^{atm} - P^{soil}$

$p^{indoor} = P^{atm} - P^{indoor}$

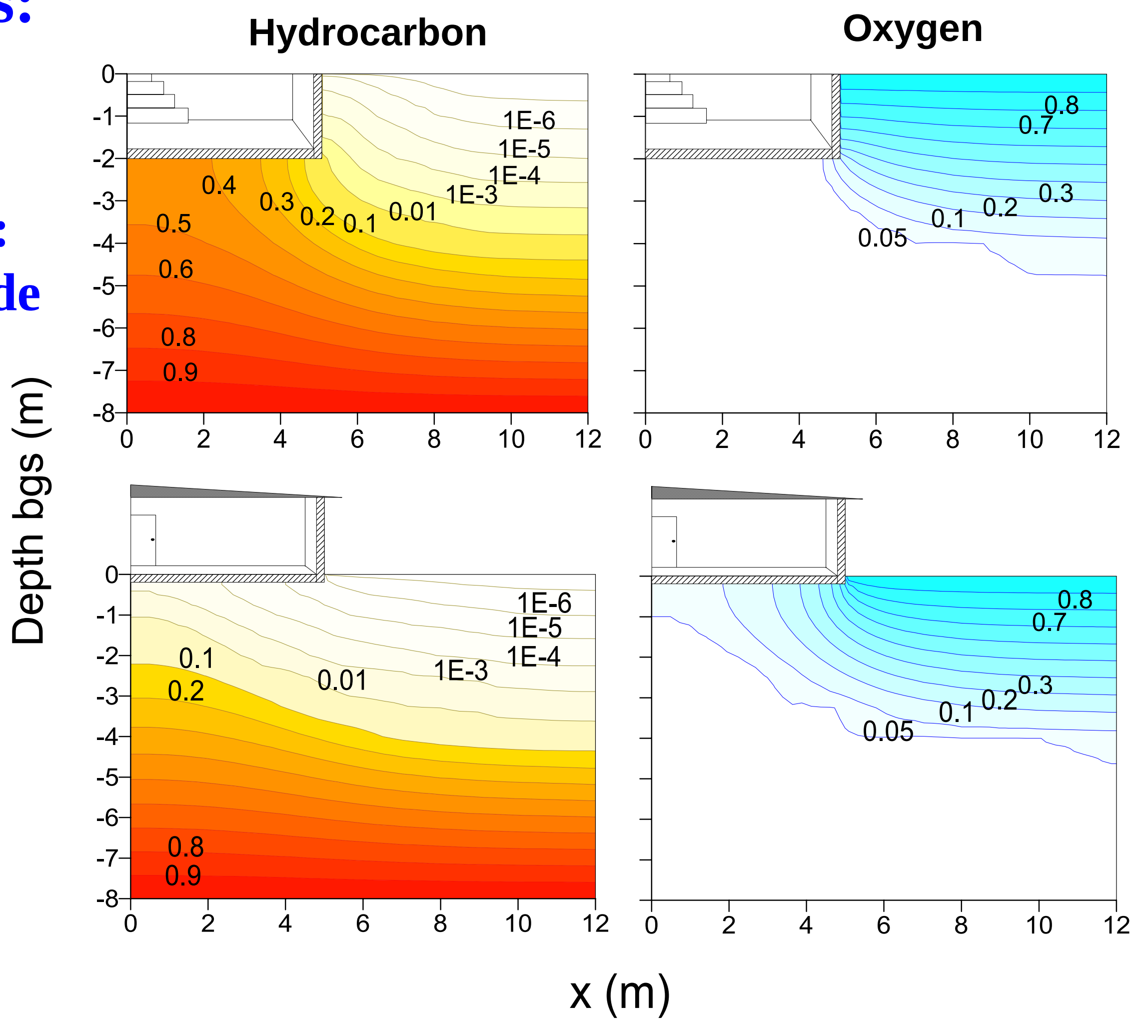
Effect of Aerobic Biodegradation

Presentation of results:

Concentration profiles on vertical cross-sections through center of building: Basement and slab-on-grade

Hydrocarbon conc. contour plots normalized to the source zone vapor concentration at the lower boundary

Oxygen conc. contour plots normalized to the atmospheric conc. at the ground surface



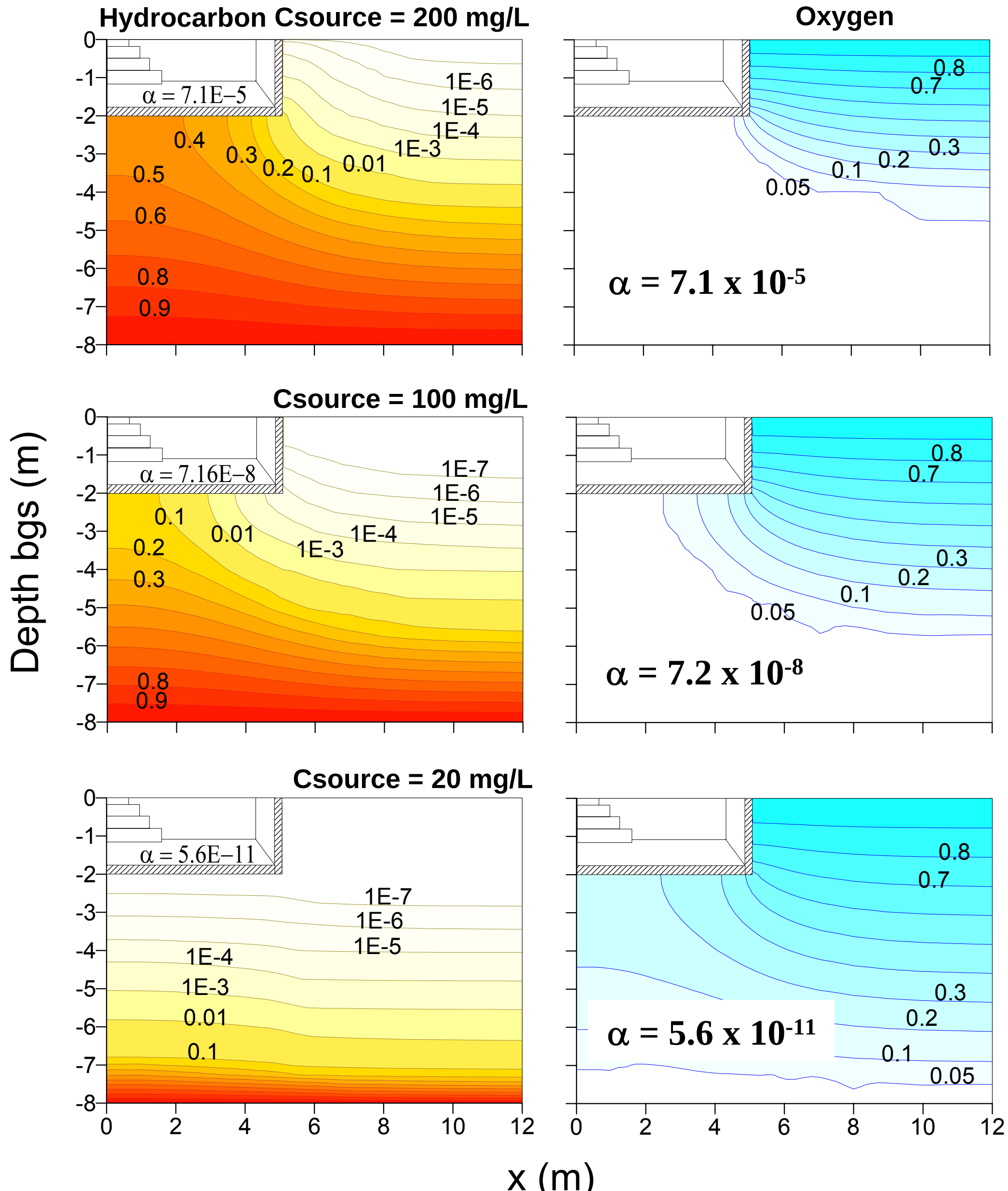
Effect of Source Concentration

[Basement Scenario]

[$\lambda = 0.18\ h^{-1}$]

Results suggest that there may be source vapor concentrations that are of little concern if soil gas beneath the foundation is well-oxygenated

(e.g., low concentration dissolved petroleum groundwater plume sources)



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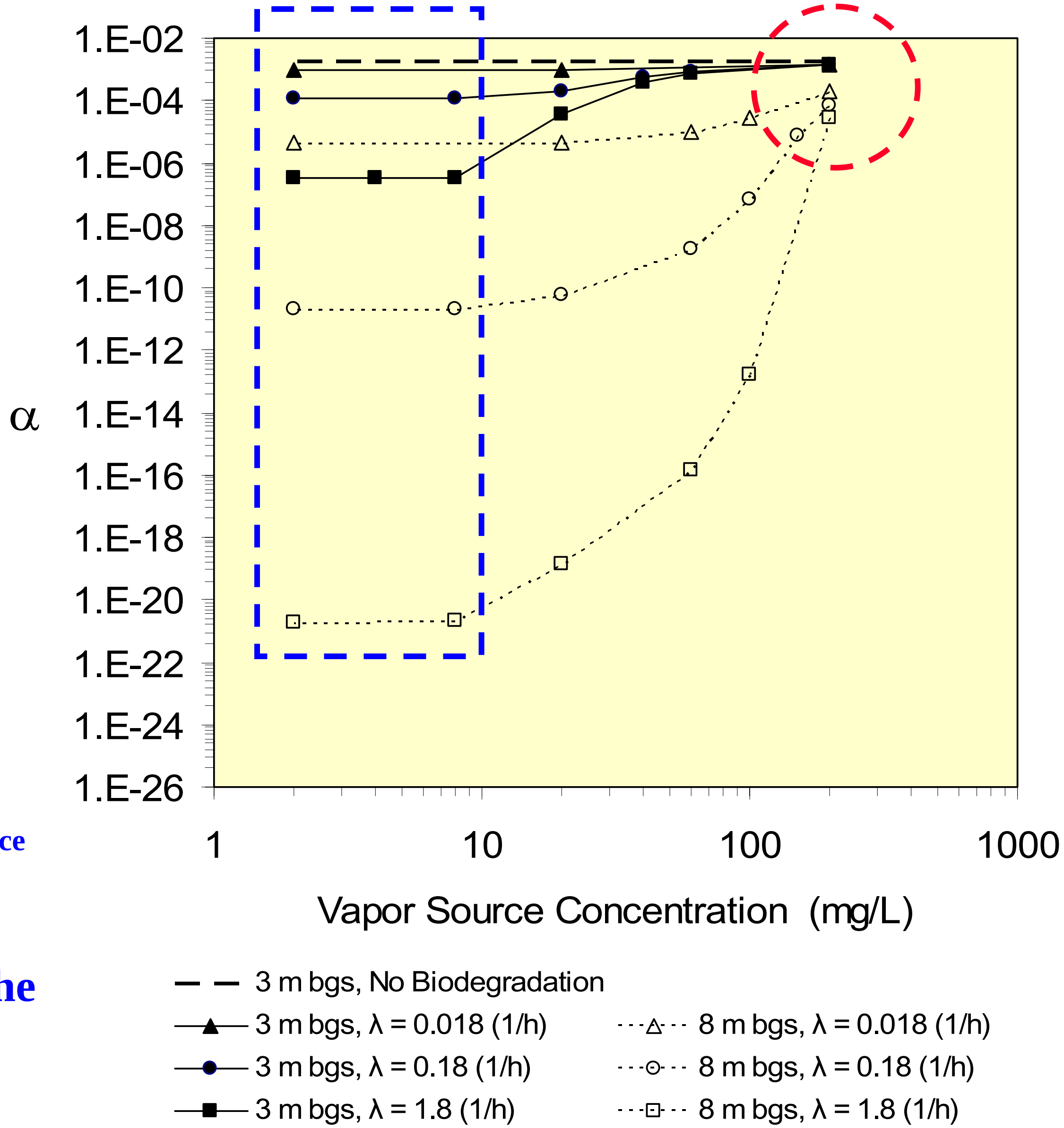
Effect of Source Conc. on α

[Basement Scenario]

At high concentrations, the effect of biodegradation on α is minimal due to oxygen depletion beneath and near foundation

At low concentrations, α becomes independent of C_{source} because of the first-order kinetics and oxygen rich conditions everywhere, and the effect of biodegradation is more pronounced



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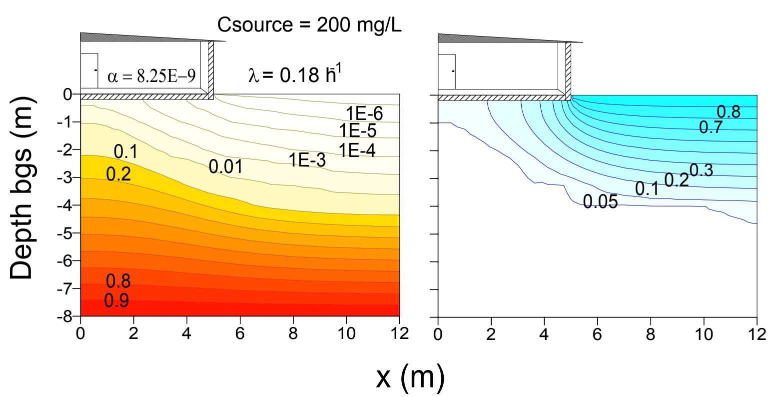
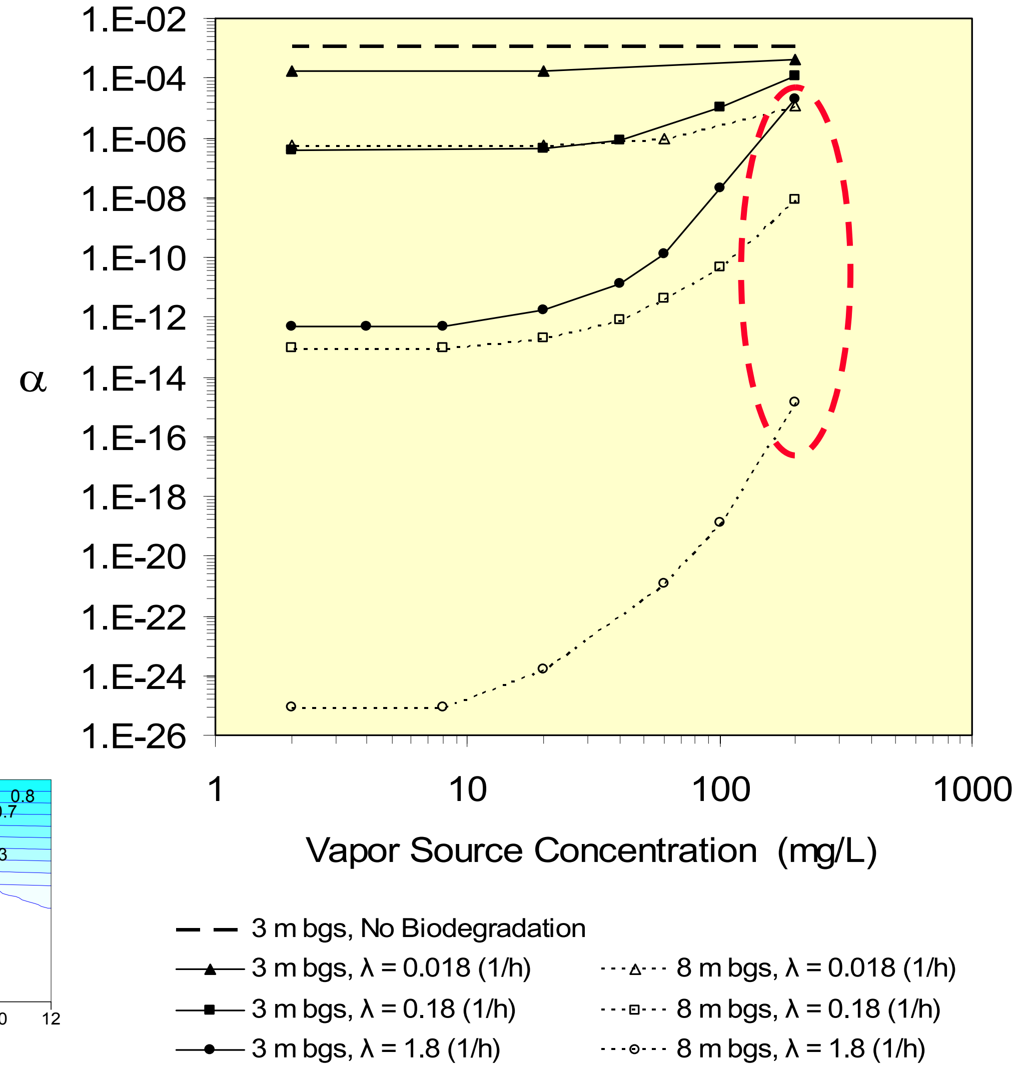
Effect of Source Conc. on α

[Slab-on-grade Scenario]

Similar trends as of basement scenario but α values are lower and it is more sensitive to λ

For high vapor source concentrations at 8 m bgs oxygen penetrates fully beneath the slab and the effect of biodegradation on α is significant





Effect of Depth

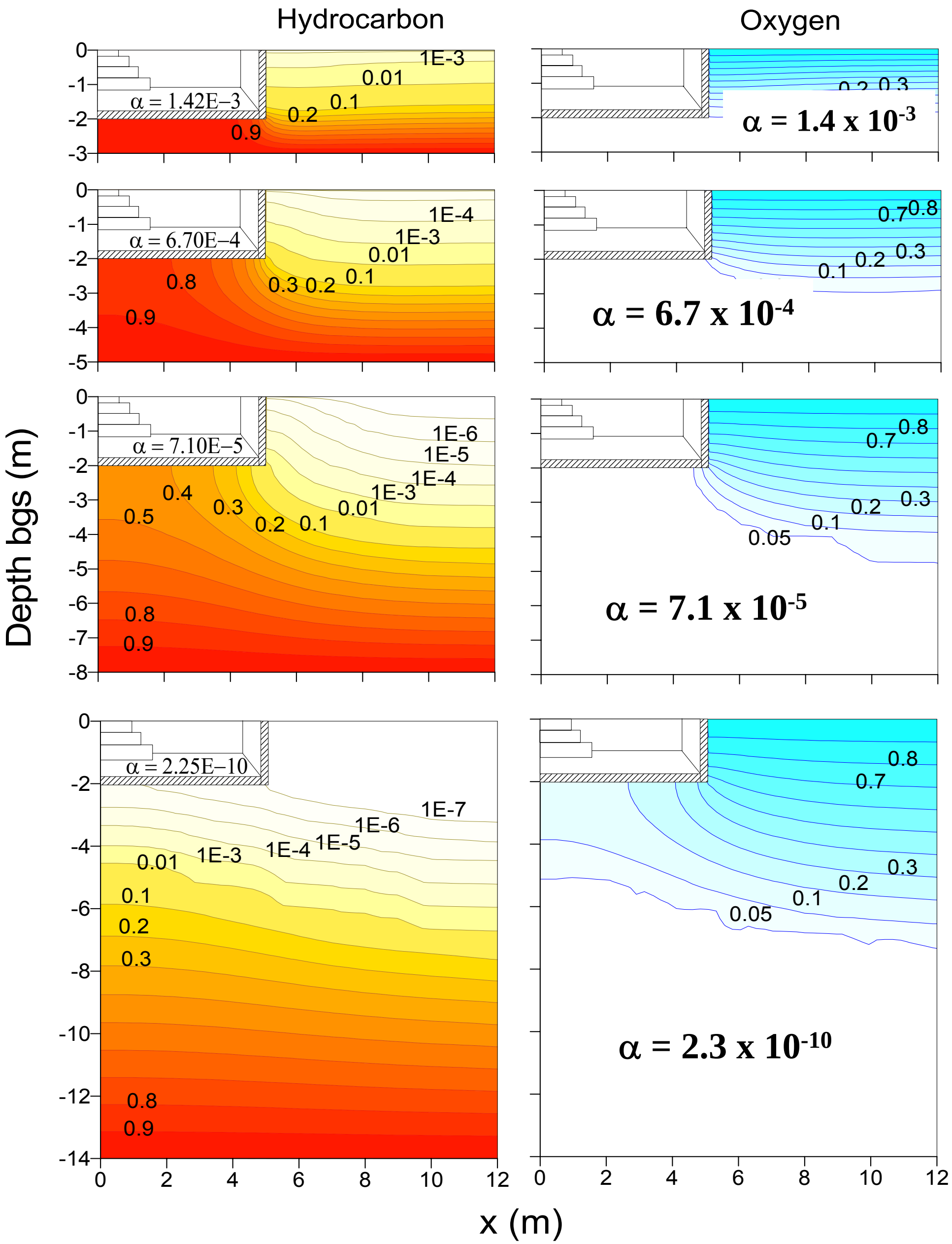
[Basement Scenario]

[Csource = 200 mg/L]

[λ = 0.18 h^{-1}]

Results suggest that, for a given source vapor concentration, there may be a critical depth beyond which vapor migration is of little concern

This depth will be a function of concentration and degradation rate at a minimum.



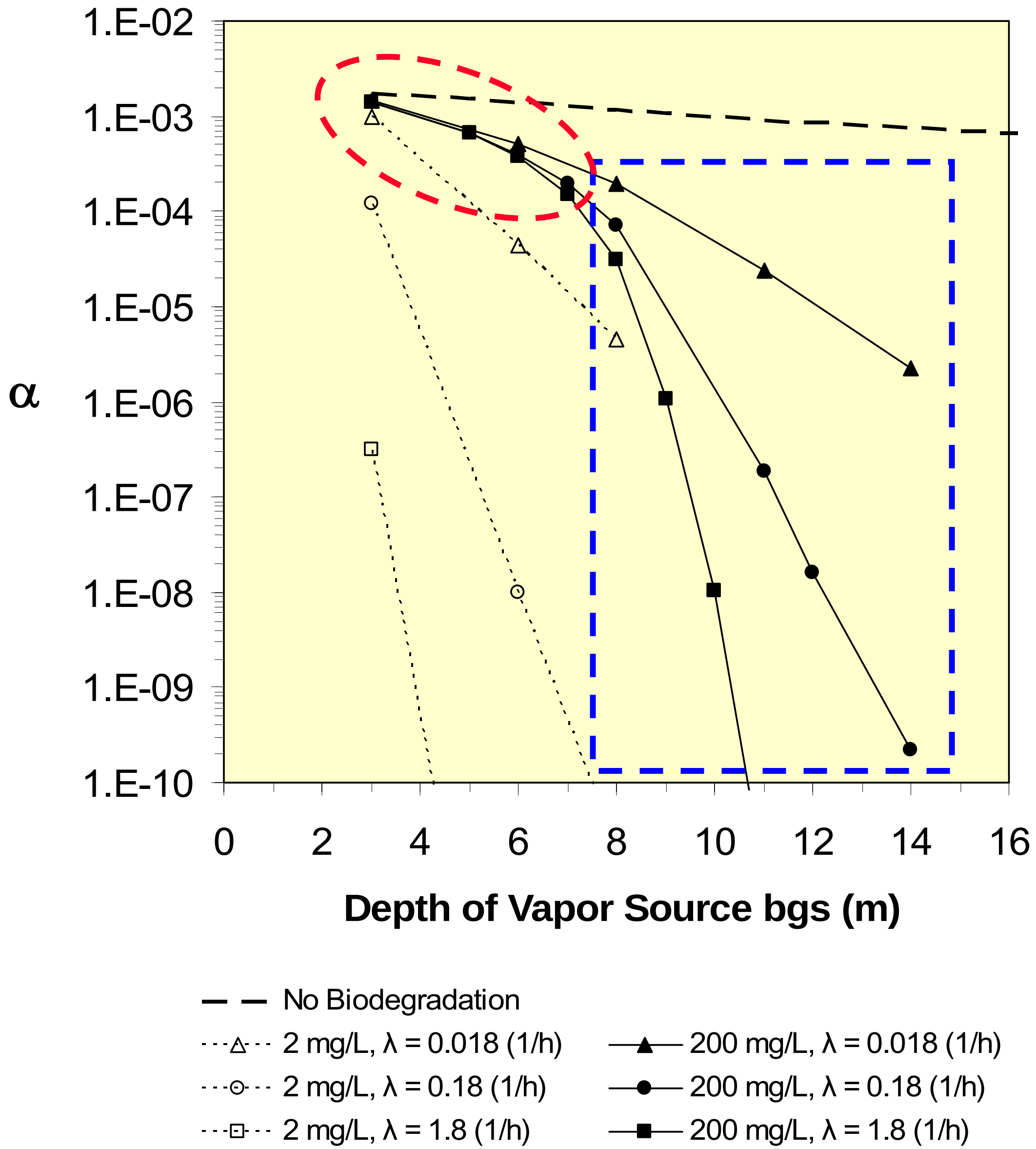
Effect of Depth on α

[Basement Scenario]

Combinations of source strength, source depth, and first-order biodegradation rate (λ)

High concentration cases show lower sensitivity to λ changes and depths for depths less than 8 m

Increasing sensitivity in α to depth and λ occurs as the depth increases and as the source vapor concentration decreases



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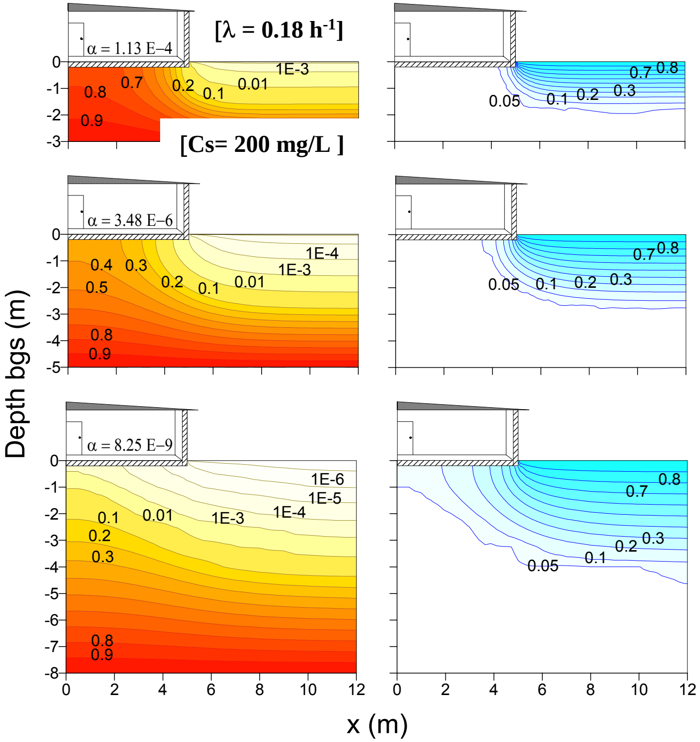
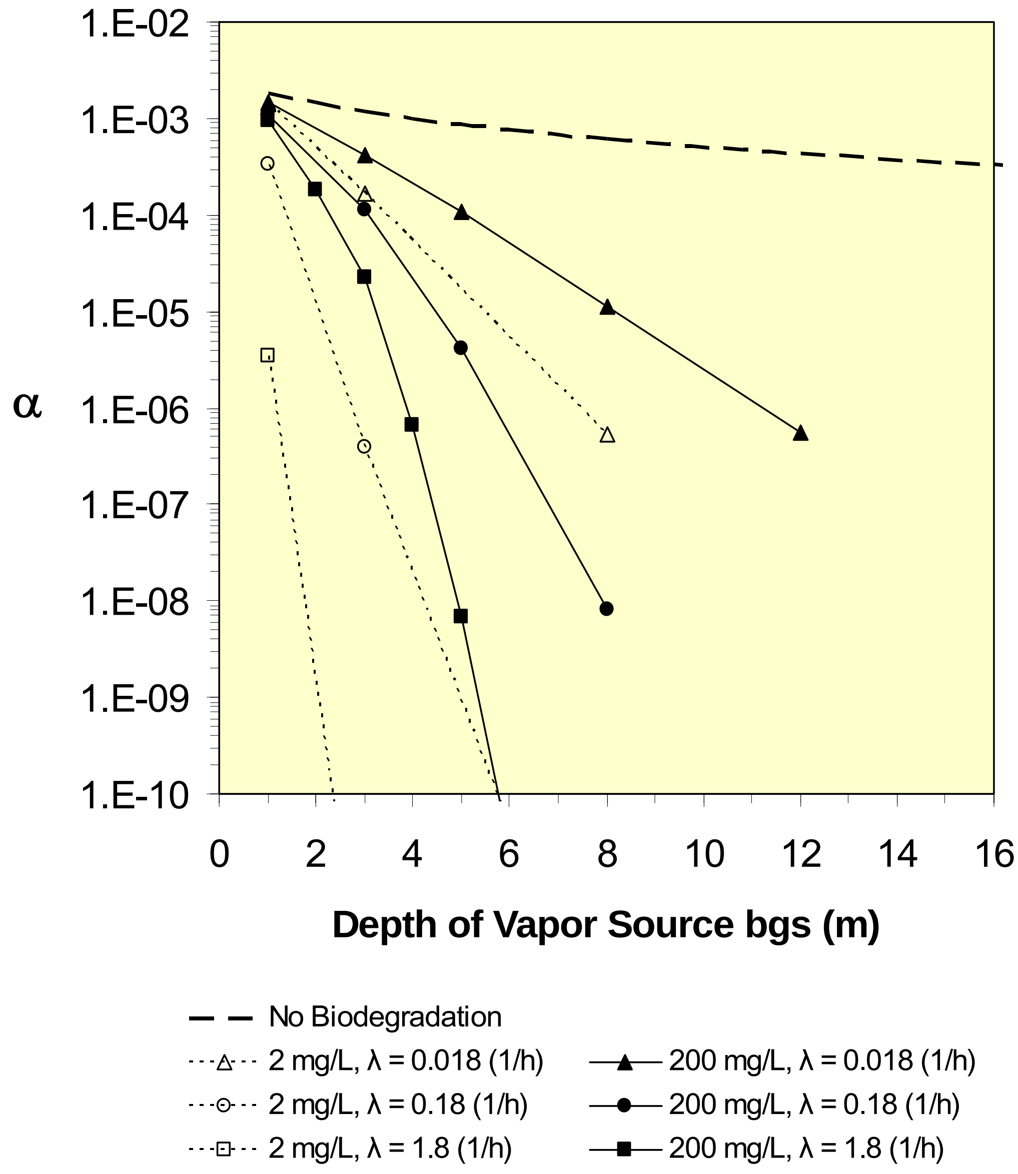
Effect of Depth on α

[Slab-on-Grade Scenario]

Lower α values and more sensitivity to depth than the basement scenario





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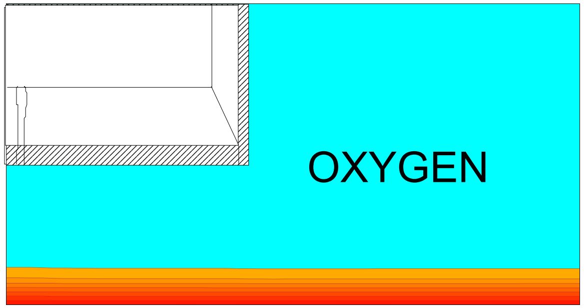
Effect of crack location on α

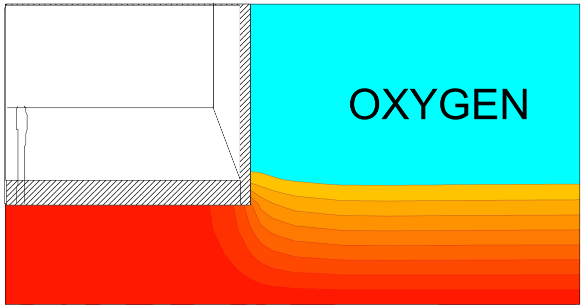
Not sensitive if

- Oxygen penetrates deep into the subsurface and fully beneath slab or
- Oxygen does not penetrate beneath the slab

Low conc. sources
Deep sources



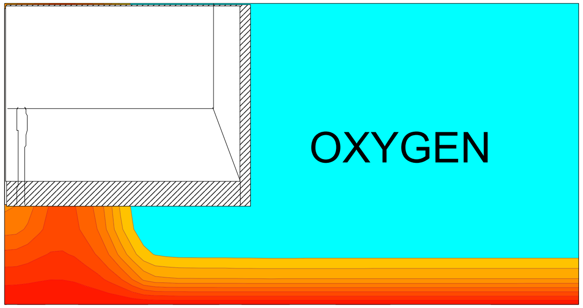
High conc. sources
Shallow sources



May be sensitive if

- Oxygen penetrates only partially beneath the slab

Transition between:
high-low source conc.
shallow-deep sources

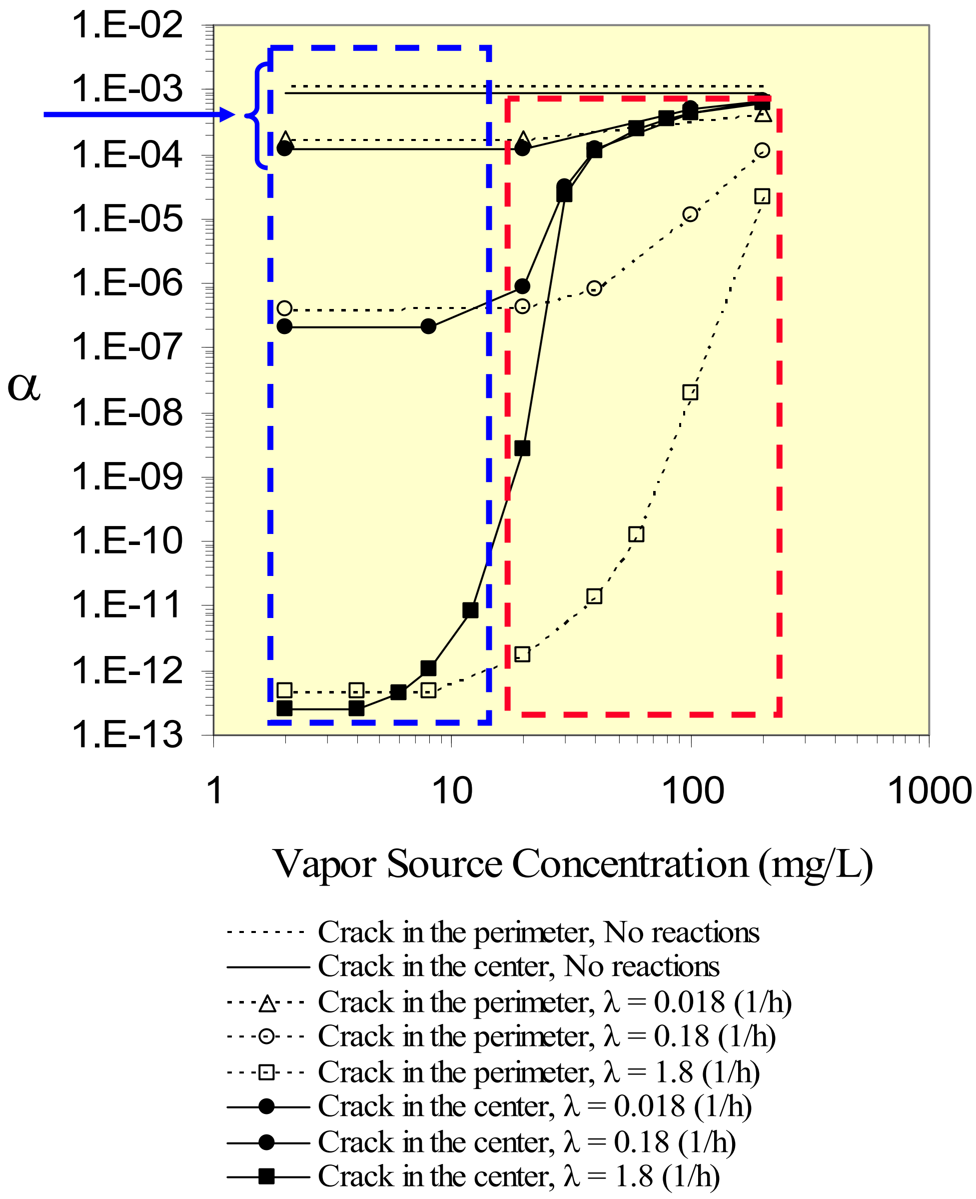


The sensitivity is a function of:

- Source depth
- Source concentration
- Foundation type
- Degradation rate

Effect of crack location on α as func. of conc.

Slab-on-Grade Scenario, Source at 3m bgs



Not significant for non-degradation or low λ cases (at any concentration)

Not significant for conc. <20 mg/L (for any λ case)

Significant for medium and high degradation rate scenarios in the concentration range of 20-200 mg/L

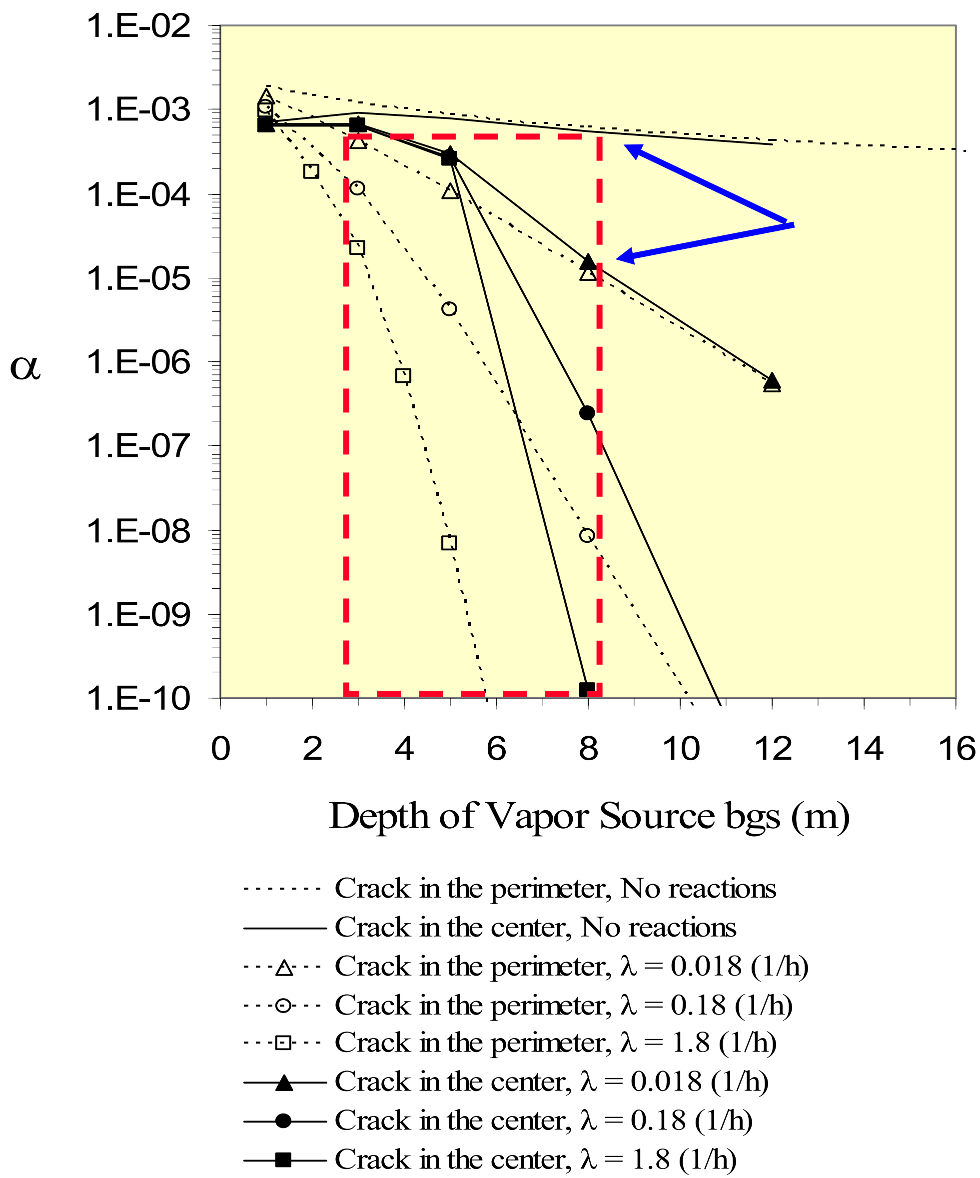
Effect of crack location on α as func. of depth

Slab-on-Grade Scenario
High source conc. = 200 mg/L

Not significant for non-degradation or low λ cases (at any depth)

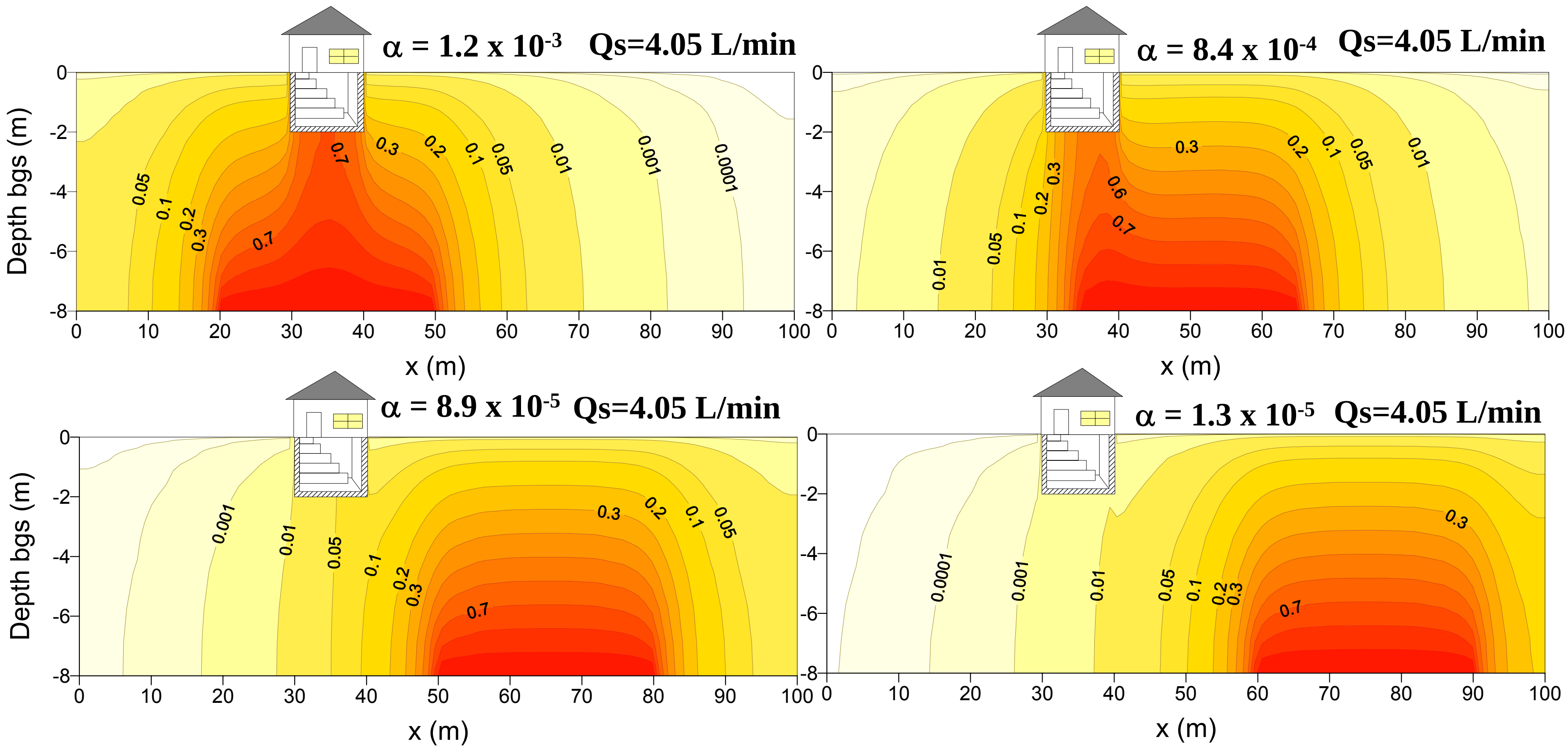
Not significant for depths >9 m bgs (for any λ case)

Significant for medium and high degradation rate scenarios in the depth range of 3-8 m bgs



Changes in α with Source Position

[No degradation scenario]



Changes in α with Source Position

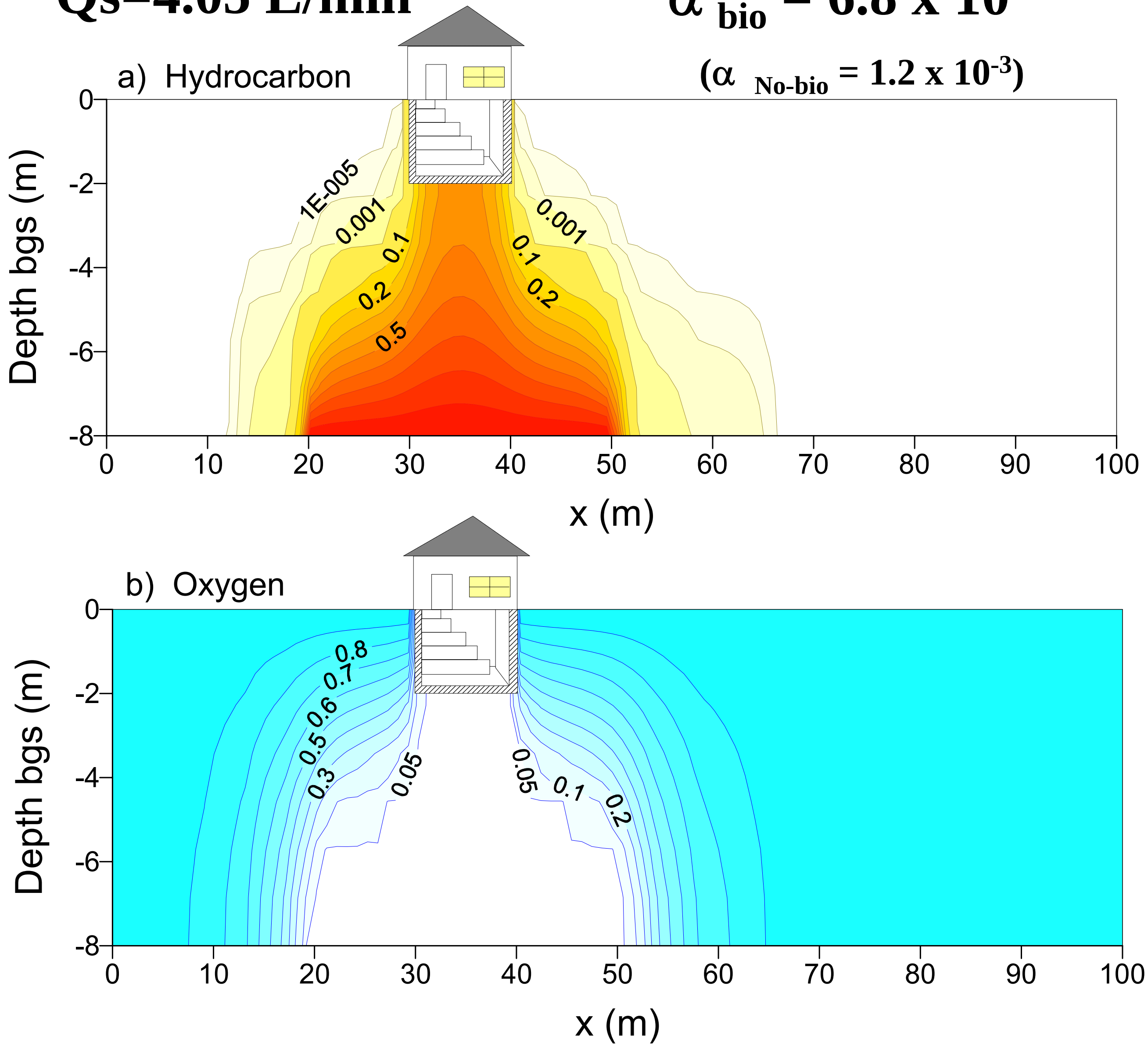
[Biodegradation, Basement Scenarios, Csource = 200 mg/L]

$\lambda = 0.18\ h^{-1}$

Qs=4.05 L/min

$\alpha_{bio} = 6.8 \times 10^{-5}$

$(\alpha_{No\text{-}bio} = 1.2 \times 10^{-3})$



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Changes in α with Source Position

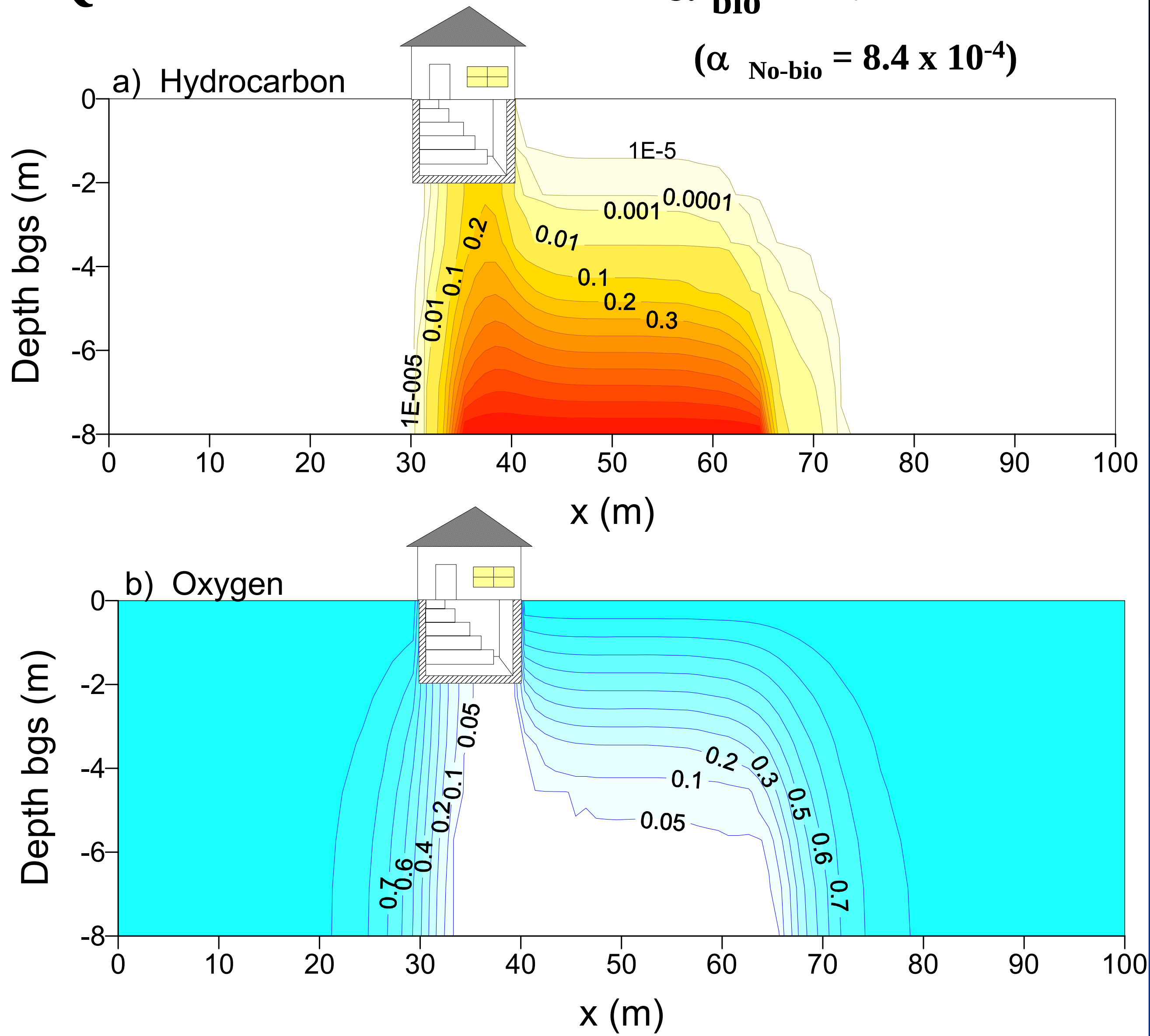
[Biodegradation, Basement Scenarios, Csource = 200 mg/L]

λ = 0.18 h^{-1}

Qs=4.05 L/min

$\alpha_{bio} = 5.0 \times 10^{-6}$

($\alpha_{No\text{-}bio} = 8.4 \times 10^{-4}$)



Changes in α with Source Position

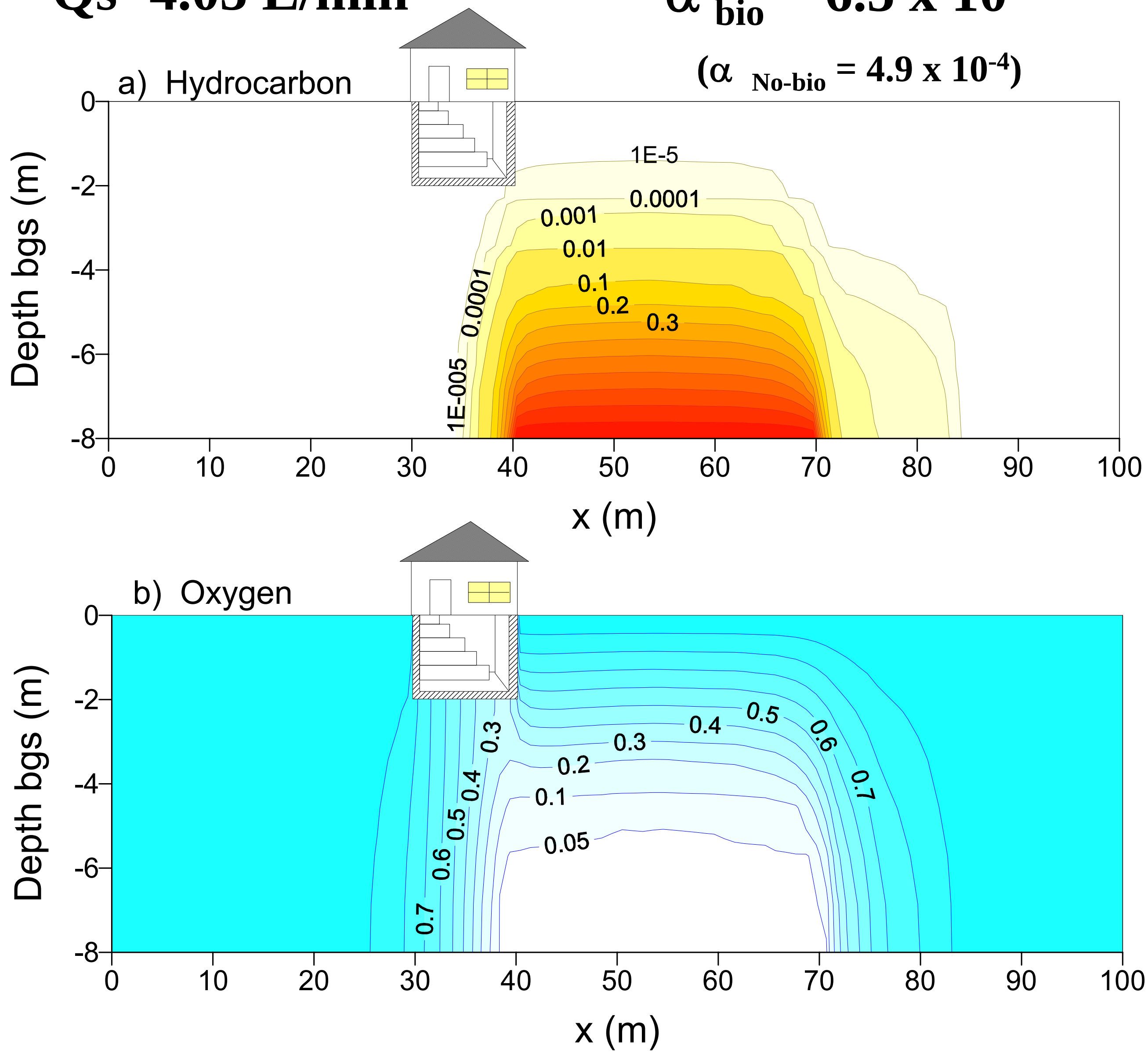
[Biodegradation, Basement Scenarios, Csource = 200 mg/L]

$\lambda = 0.18\ h^{-1}$

Qs=4.05 L/min

$\alpha_{bio} = 6.5 \times 10^{-9}$

($\alpha_{No\text{-}bio} = 4.9 \times 10^{-4}$)



Changes in α with Source Position

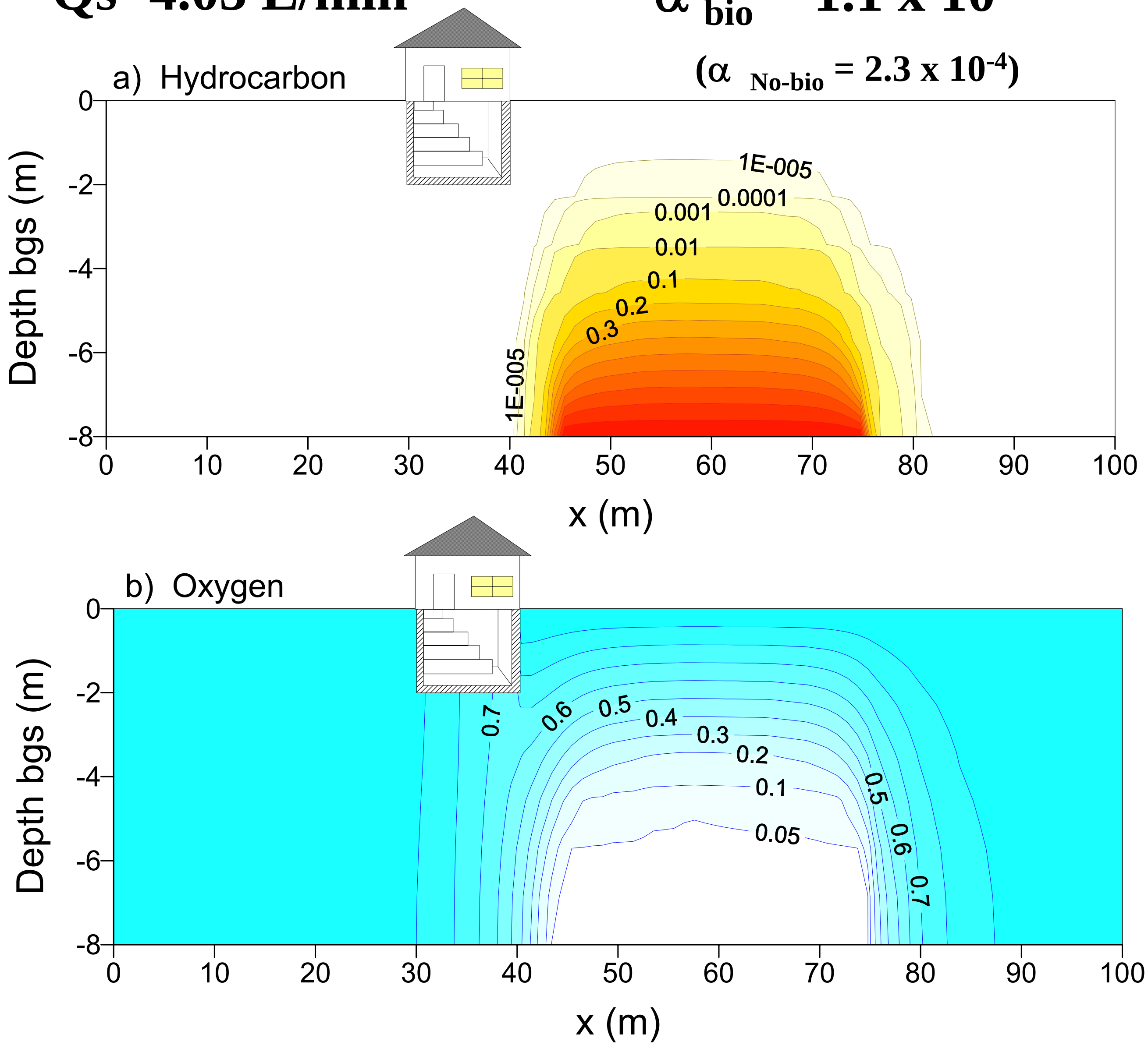
[Biodegradation, Basement Scenarios, Csource = 200 mg/L]

$\lambda = 0.18\ h^{-1}$

Qs=4.05 L/min

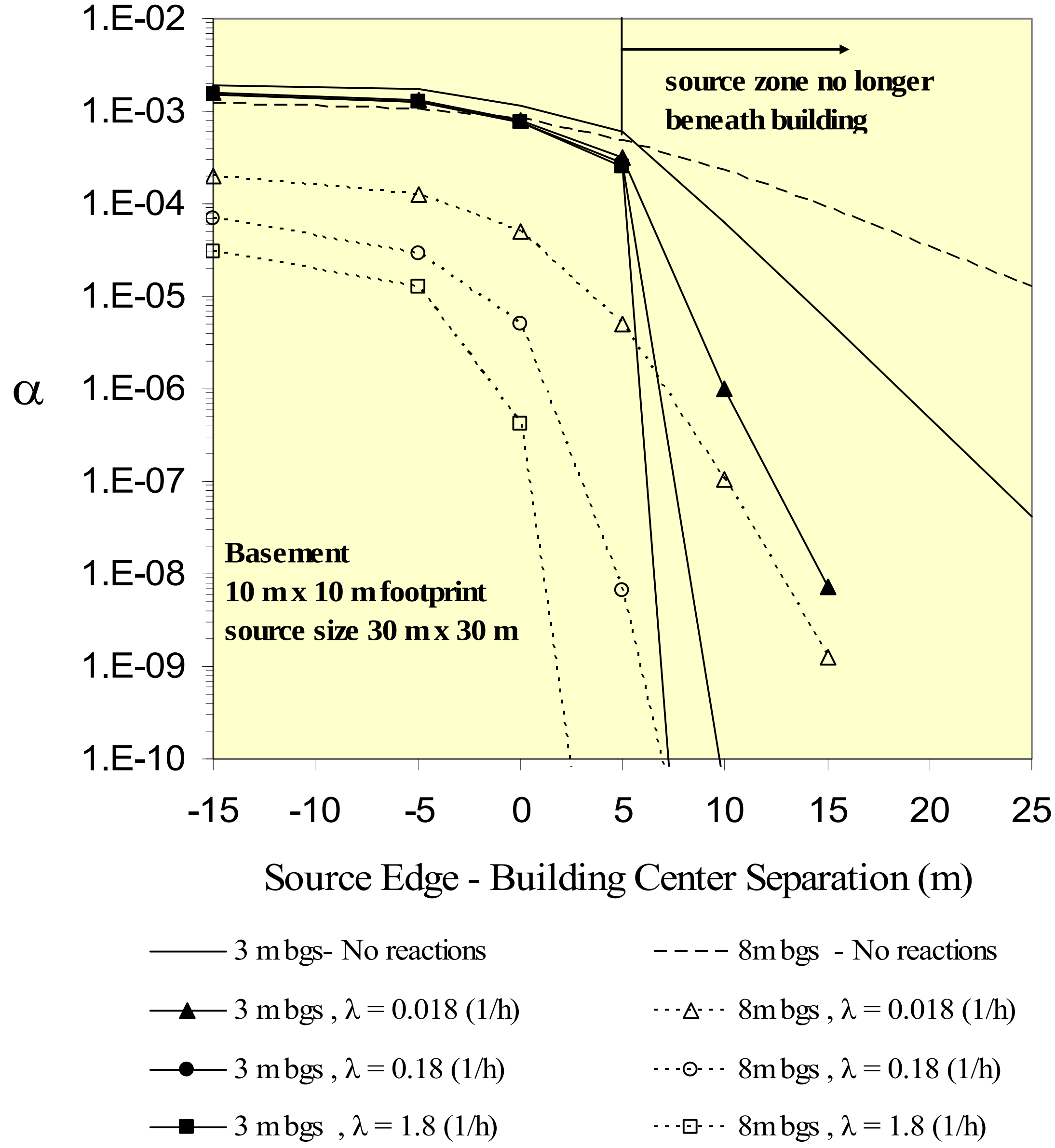
$\alpha_{bio} = 1.1 \times 10^{-13}$

($\alpha_{No\text{-}bio} = 2.3 \times 10^{-4}$)



Changes in α with Source Position

Basement Scenarios,
Csource = 200 mg/L,
Depth = 3 and 8 m bgs



Lessons-Learned for Scenarios with Aerobically-degradable Chemicals

- Vapor source concentration

  While biodegradation may be significant over a wide range of concentrations, the effect of biodegradation on α is more substantial for moderate to low source concentrations
- Vapor source depth

  Biodegradation effects are more pronounced for larger source-foundation distances
- Lateral distance from buildings

  Small source-building lateral separation (e.g., 5 - 10 m) can result in a very large reduction in α

Lessons-Learned for Scenarios with Aerobically-degradable Chemicals

- Biodegradation rates

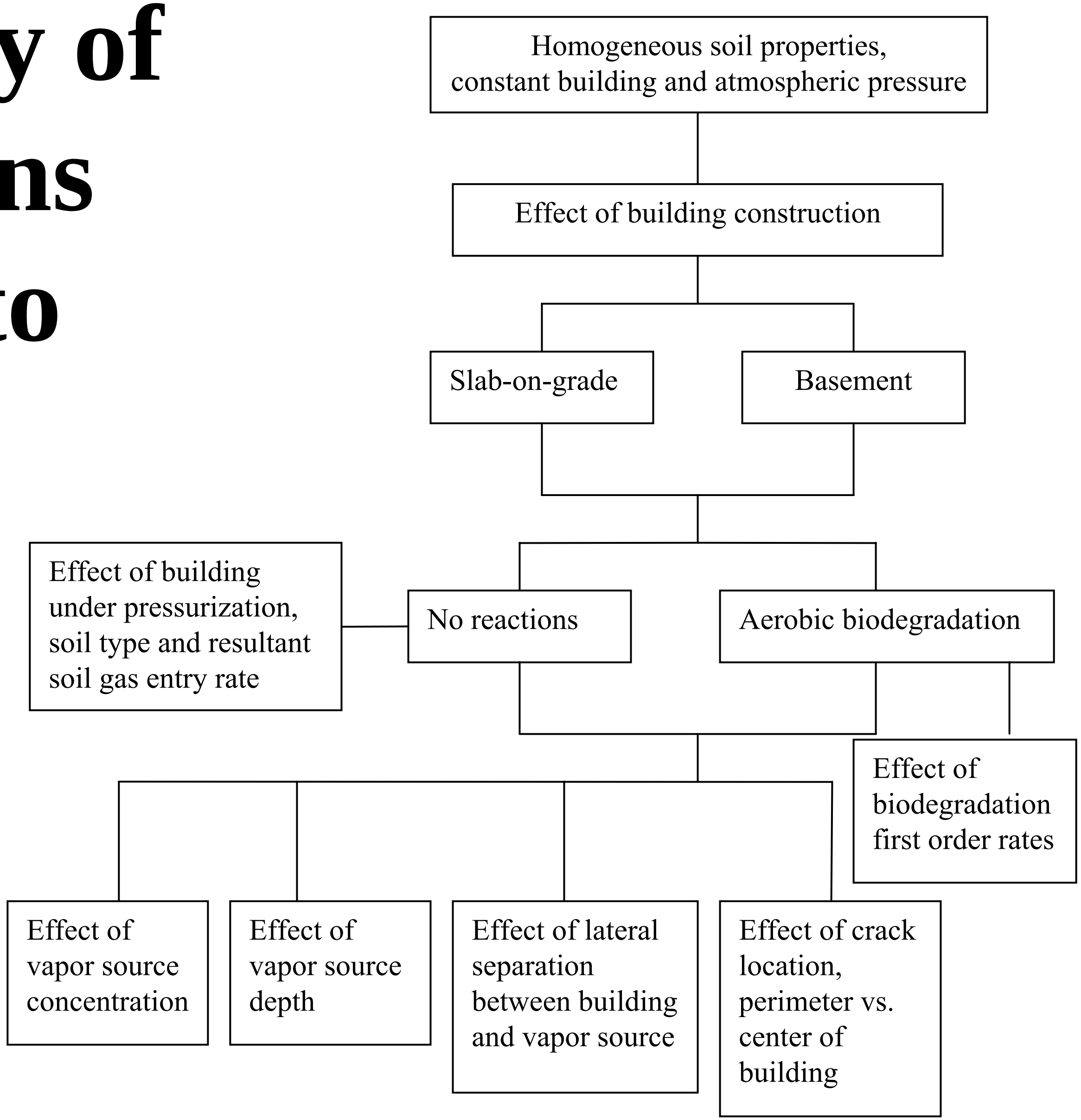
  Range of biodegradation rates considered - high degradation rates affects α more significantly than low degradation rates
- Crack location

  Model predicted α is not dependent on crack location for cases where biodegradation is significant and oxygen penetrates fully into the subsurface beneath the slab (i.e., low source concentration or deep sources)
- Building construction

  Slab-on-grade scenarios are more influenced by biodegradation than basement foundation scenarios

Summary of Conditions Studied to Date

(Abreu 2005)



Future Scenarios

- Layered lithology
- Wind blowing against the building
- Backfill and gravel layer around building foundation

References

1. Abreu, L.D.V. 2005. A Transient Three-Dimensional Numerical Model to Simulate Vapor Intrusion Into Buildings. Ph.D. Dissertation. Arizona State University.

2. Abreu, L.D.V. and P.C. Johnson, 2005. Effect of Vapor Source-Building Separation and Building Construction on Soil Vapor Intrusion as Studied with a Three-Dimensional Numerical Model. Environmental Science and Technology *39*(12), 4550-4561.

3. Abreu, L.D.V. and P.C. Johnson, 2005. Modeling the effect of aerobic biodegradation on soil vapor intrusion into buildings - Influence of degradation rate, source concentration, and depth. Submitted to Environmental Science and Technology (July 2005).

Questions/Comments?