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Recent developments to improve the evaluation of vapour intrusion of petroleum hydrocarbons from groundwater

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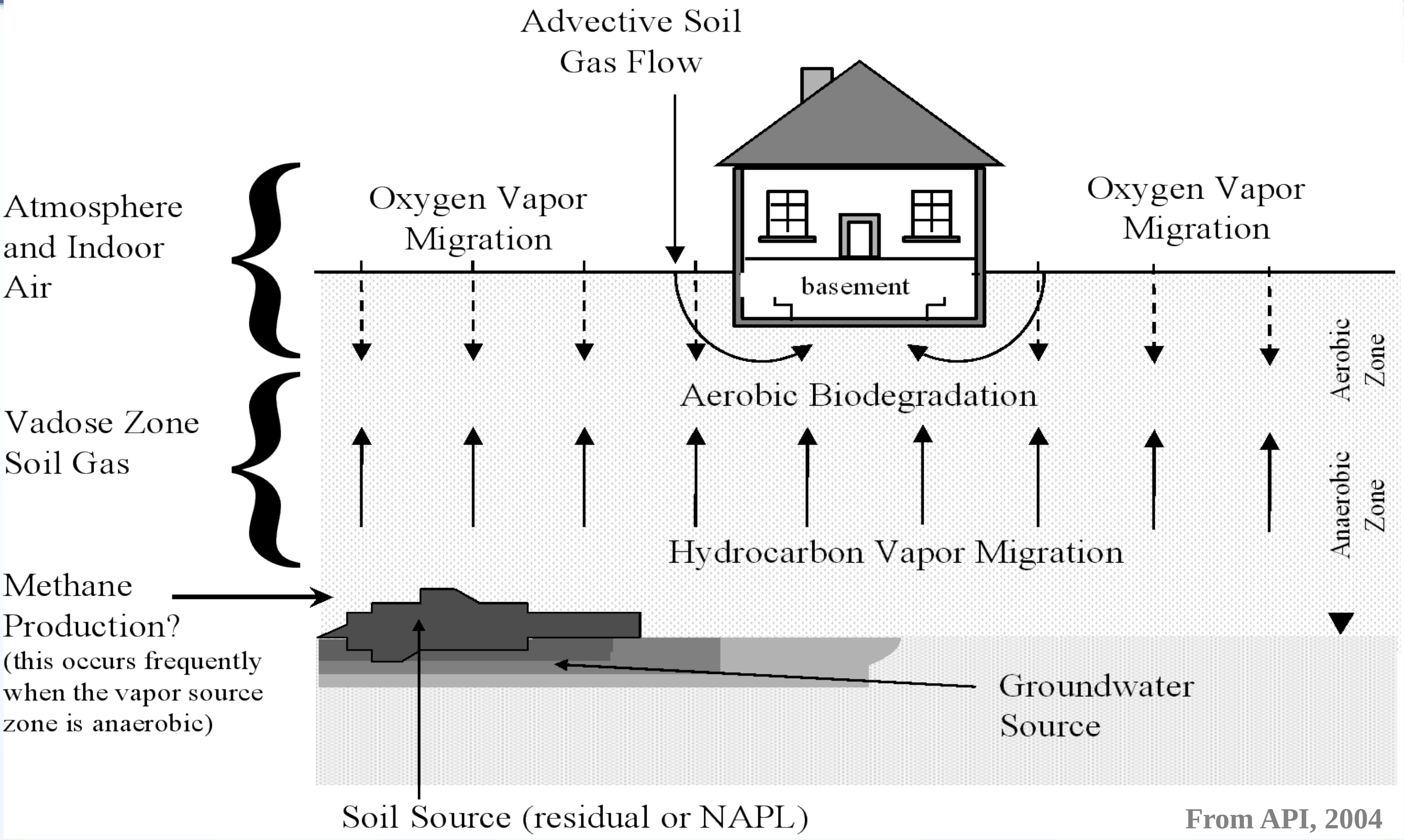
Introduction

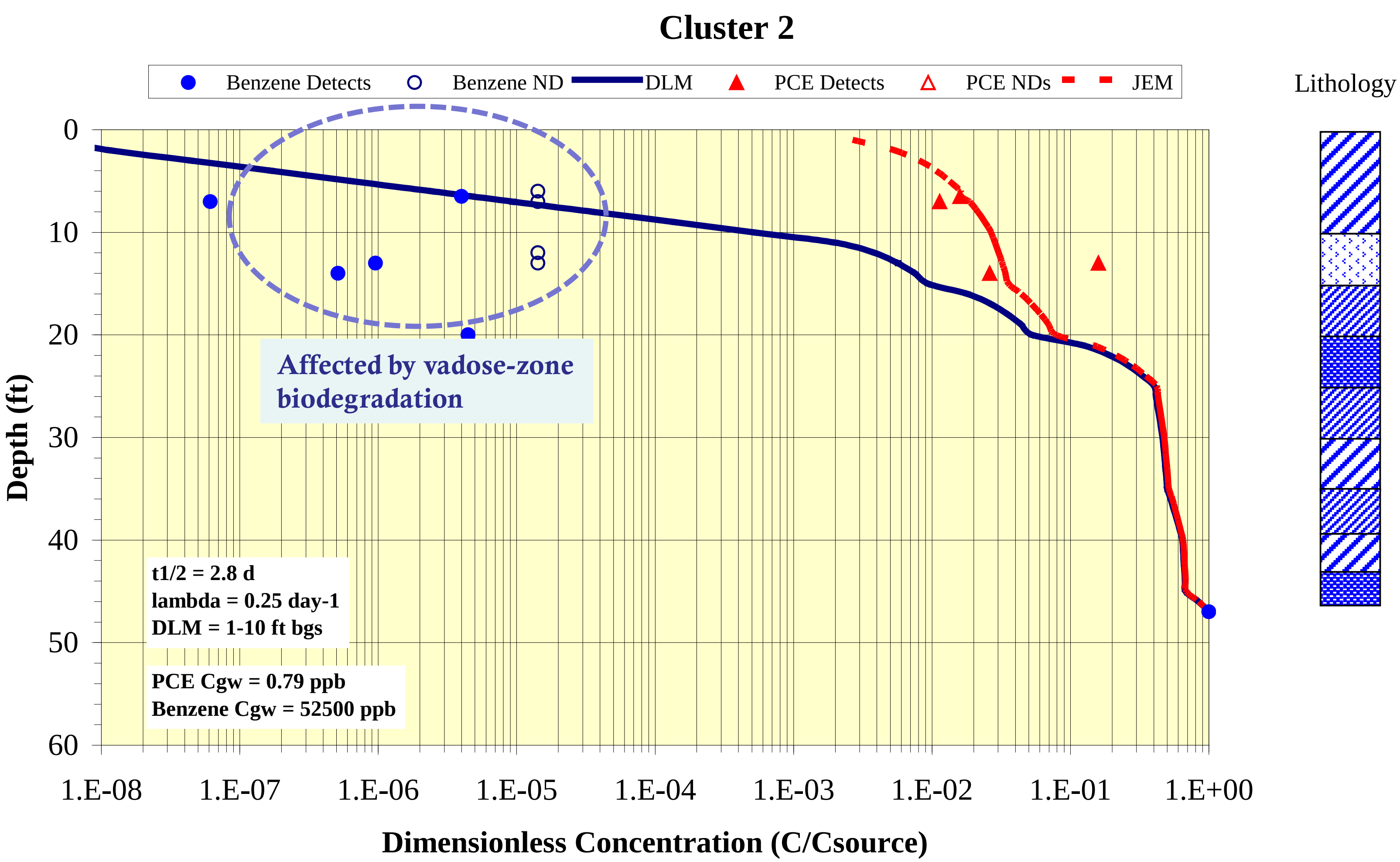
- Vapour intrusion of petroleum hydrocarbons is frequently assessed, but demonstration of complete pathway is uncommon
- Typical “multiple-lines-of-evidence” investigation strategies for chlorinated solvent plumes are not well-suited for many petroleum release sites
- Consider modeling and empirical evidence that captures natural vadose-zone biodegradation process to improve screening process
- Consistent with guidance from some US State agencies and being considered by US EPA and ITRC

Petroleum Vapour Intrusion Conceptual Model

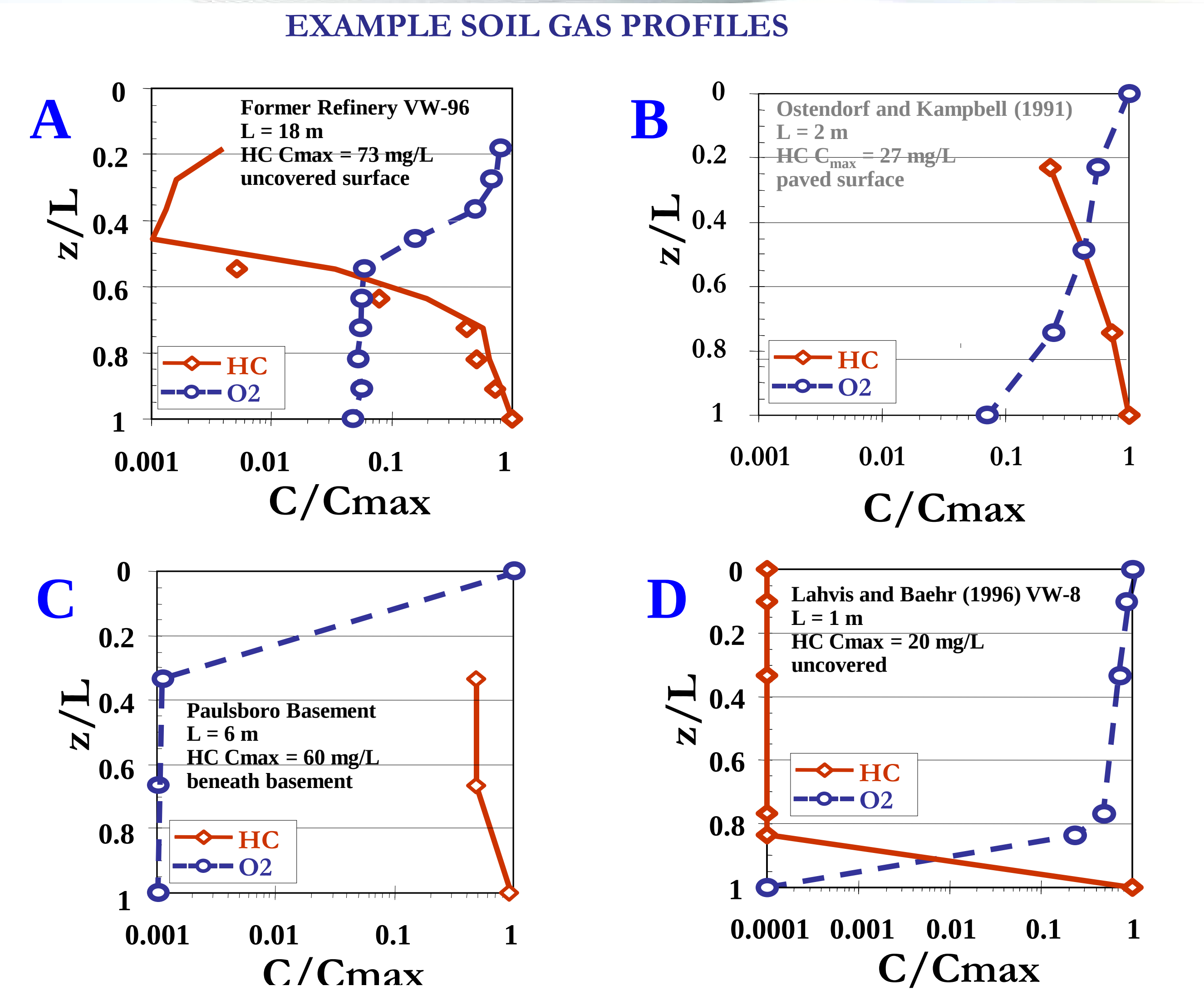


Vapour intrusion attenuation factor: $\alpha = C_{\text{indoor}} / C_{\text{soil gas}}$

Petroleum vs Chlorinated Behaviour



Evidence of Vadose Zone Biodegradation

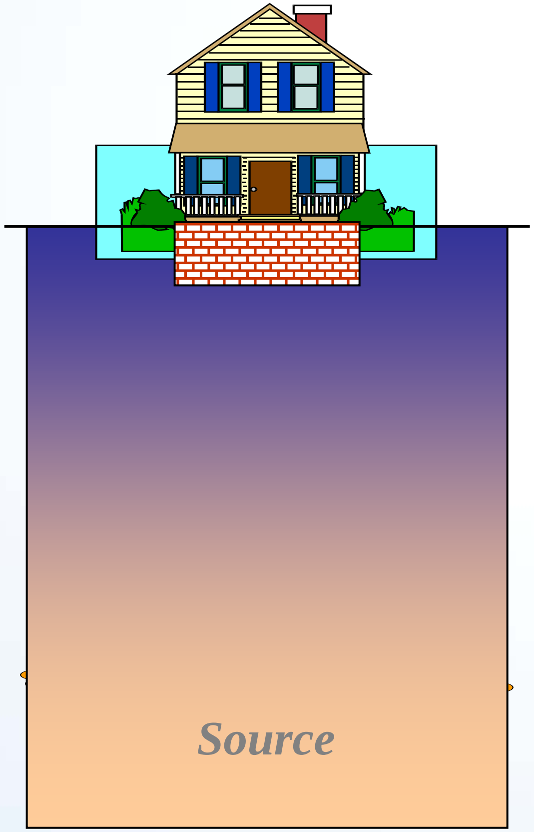


(Roggemans et al., 2001)

SOIL GAS PROFILES BEHAVIORS

- A: Oxygen Transport Limited
- B: Degradation Rate Limited
- C: Oxygen Deficient
- D: Source Diffusion Limited

Multiple Lines of Evidence Challenges



Indoor Air Evaluation

- Quantifying background contributions
- Mitigation decisions and implementation

Vapor Intrusion Modeling

- Default versus site-specific inputs
- Uncertainty in model predictions

Source Characterization

- Temporal and spatial variability
- Difficult DQOs

Challenges to MLE evaluations may be greater for petroleum hydrocarbon sites

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Indoor Air Sampling

- There are significant challenges to indoor air sampling for petroleum compounds
  - Occupant disruption
  - Temporal and spatial variability
  - Interpretation for future land use
  - Long-term sampling does not resolve uncertainty associated with background sources

- Typical indoor air measurement findings
  - Background concentrations are greater than risk-based levels
  - Indoor air concentrations are greater than outdoor air levels - even if vapor intrusion pathway is not complete
  - Difficult to distinguish indoor air results from background when soil gas concentrations are near screening levels.

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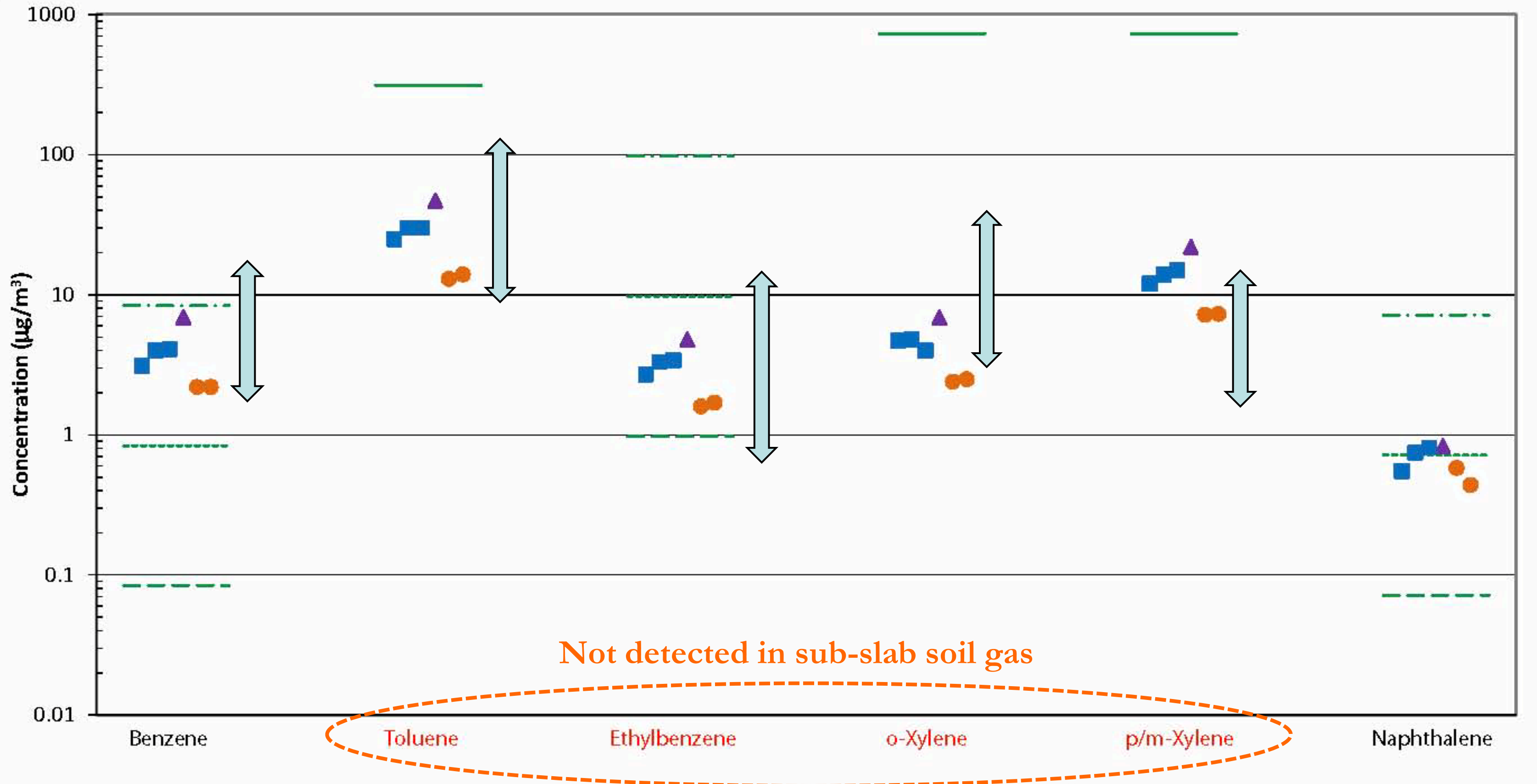
Indoor Petroleum Hydrocarbon Sources

20:50
Richard Wilson
Saatchi Gallery
Permanent Exhibit

Example Indoor Air Results



Notes:

Toluene, o-xylene, and p/m-xylene are non-carcinogens; the indoor air screening levels for these compounds are based on a Hazard Index = 1, not target risk levels. Compounds shown in red were not detected in sub-slab soil vapor.

↕ Typical background range (25%ile to 95%ile from Dawson and McAlary, 2009)

Legend:

Risk-Based Screening Level

- Target Risk = 1E-6
- Target Risk = 1E-5
- Target Risk = 1E-4
- Target HI = 1
- Indoor Sample
- Garage Sample
- Outdoor Sample

Residential Property with Attached Garage

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Figure 2

Santa Barbara | January 2011

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Biodegradation Modeling

- A variety of models are available:
  - Screening Bio-Model (Lahvis, 2006)
    Biodegradation throughout vadose zone
  - Dominant Layer Model (Johnson et al., 1999)
    Biodegradation in user-defined degradation zone
  - Oxygen Limited Model (DeVaull, 2007; API BioVapor, 2010)
    Biodegradation in zone of sufficient oxygen
  - Three Dimensional Model (Abreu & Johnson, 2005)
    Numerical code calculating VOC and oxygen fate and transport
- Biodegradation models require supplemental model parameters
- Typically used to assess significance of degradation on vapor intrusion rather than for site-specific risk estimates

Modeling Evaluation of VI Screening Criteria for Biodegradable Compounds

- Abreu and Johnson 3-D model used to calculate vapor intrusion attenuation factors for groundwater sources:
  - Source strength and depth
  - Soil type
  - Building type
  - Degradation rate
- Improve understanding of the key factors that affect vapor intrusion for aerobically biodegradable conditions
- Improve VI screening approach and sampling criteria for low source concentration (e.g. dissolved phase) petroleum hydrocarbon sites

Study summarized in
Abreu et al., 2009 and API, 2009

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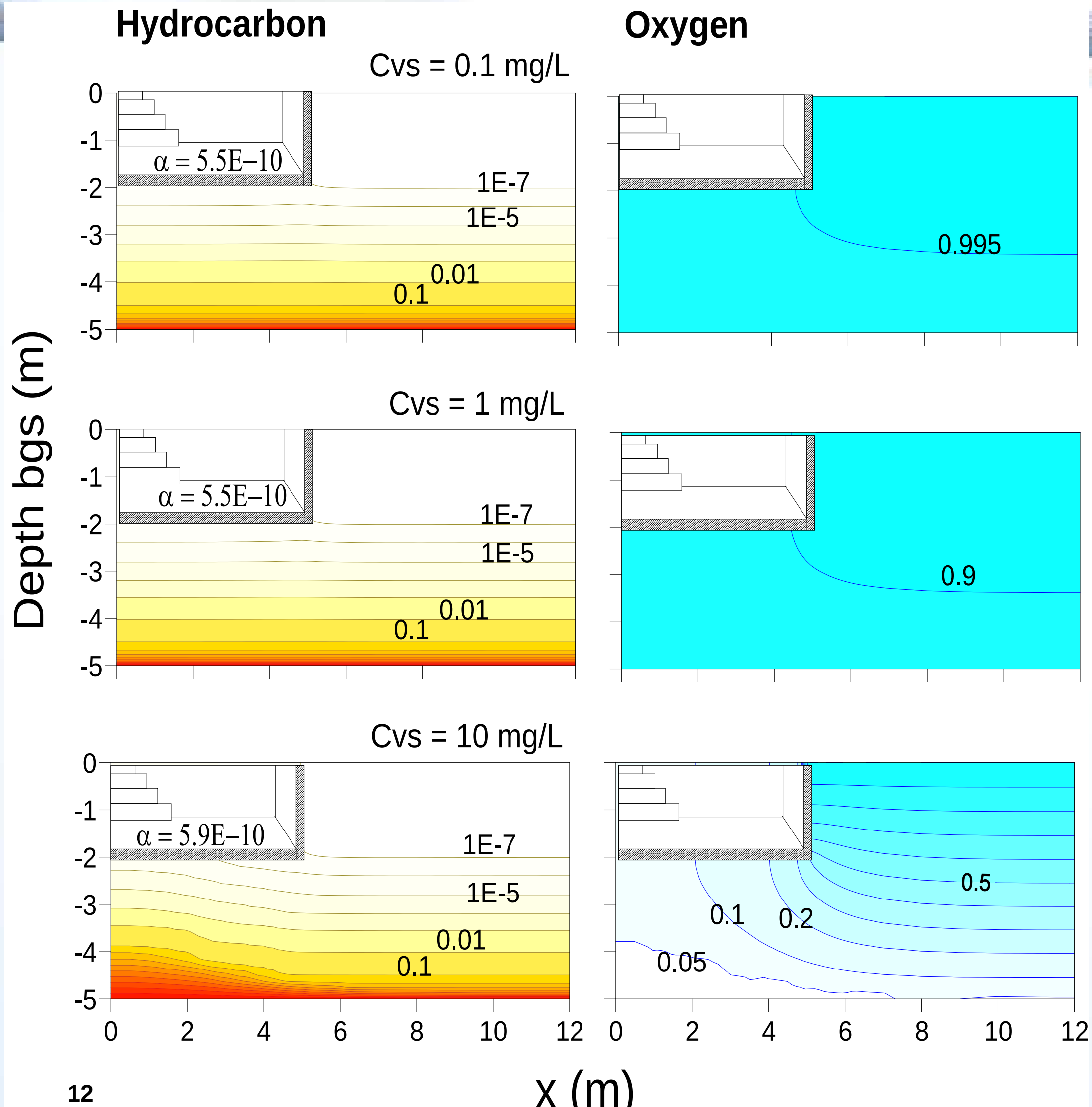
Effect of Vapor Source Concentration



- **Oxygen utilization increases with increasing source concentration**
- **α decreases with lower source concentrations**
- **α has small dependence on source concentration at lower values**
- **Bio-attenuation is significant**

Simulation Assumptions
Sand soil
Basement Scenario
Cvs = 0.1, 1, 10 mg/L
$\lambda = 0.79\ h^{-1}$

Also see *Conceptual Model Scenarios for the Vapor Intrusion Pathway.* USEPA, 2012

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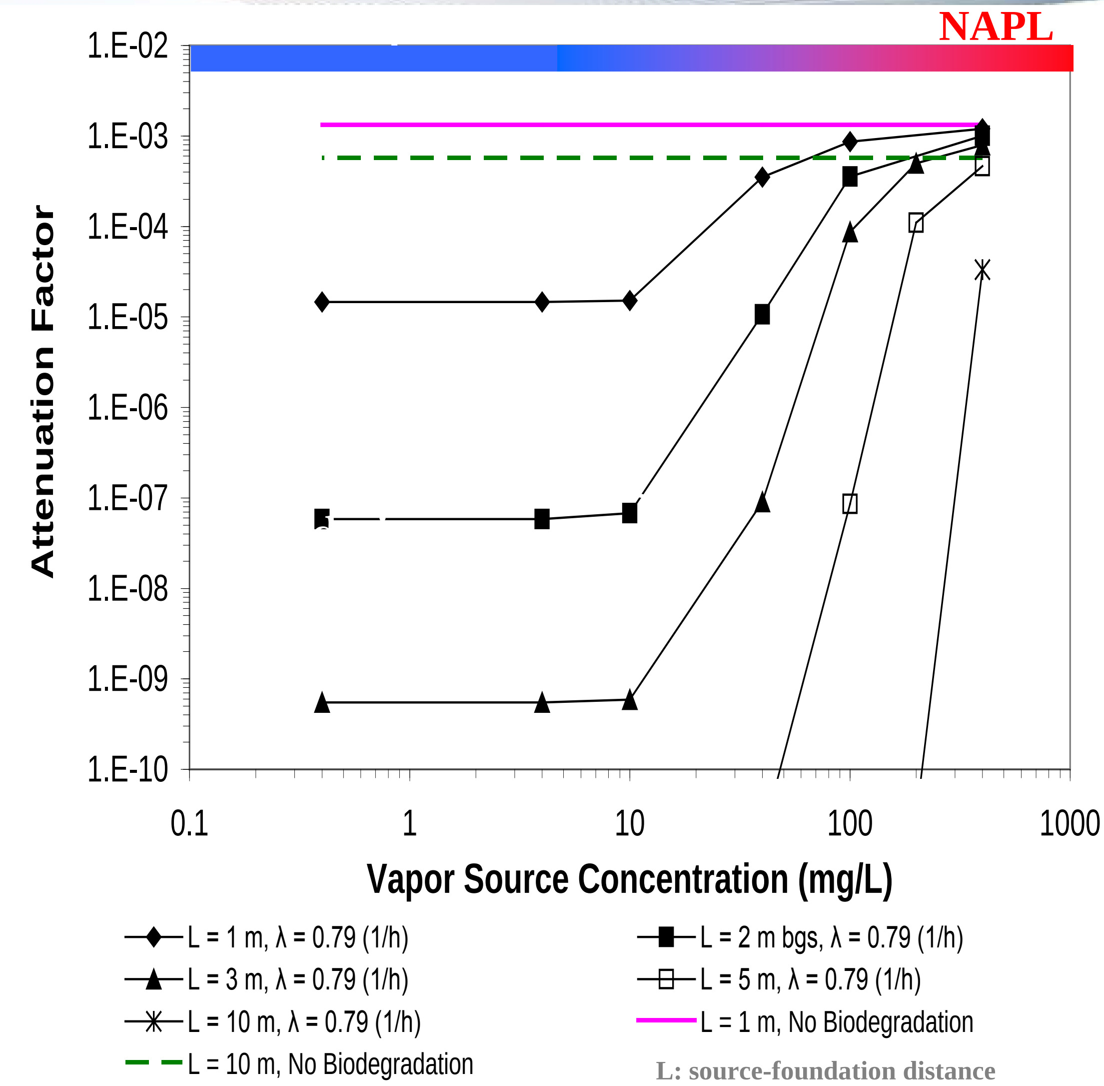
Impact of Biodegradation on Petroleum Hydrocarbon Vapor Intrusion



- Biodegradation is likely to have a significant effect on a for non-NAPL sources
- This effect is more pronounced for deeper sources
- For NAPL sources, effect of biodegradation on a may be minimal due to oxygen depletion

Modeling Assumptions:

Atmospheric O_2 source at ground level
Benzene source
No additional hydrocarbon sinks
Sand soil
Basement scenario
$\lambda = 0.79\ h^{-1}$

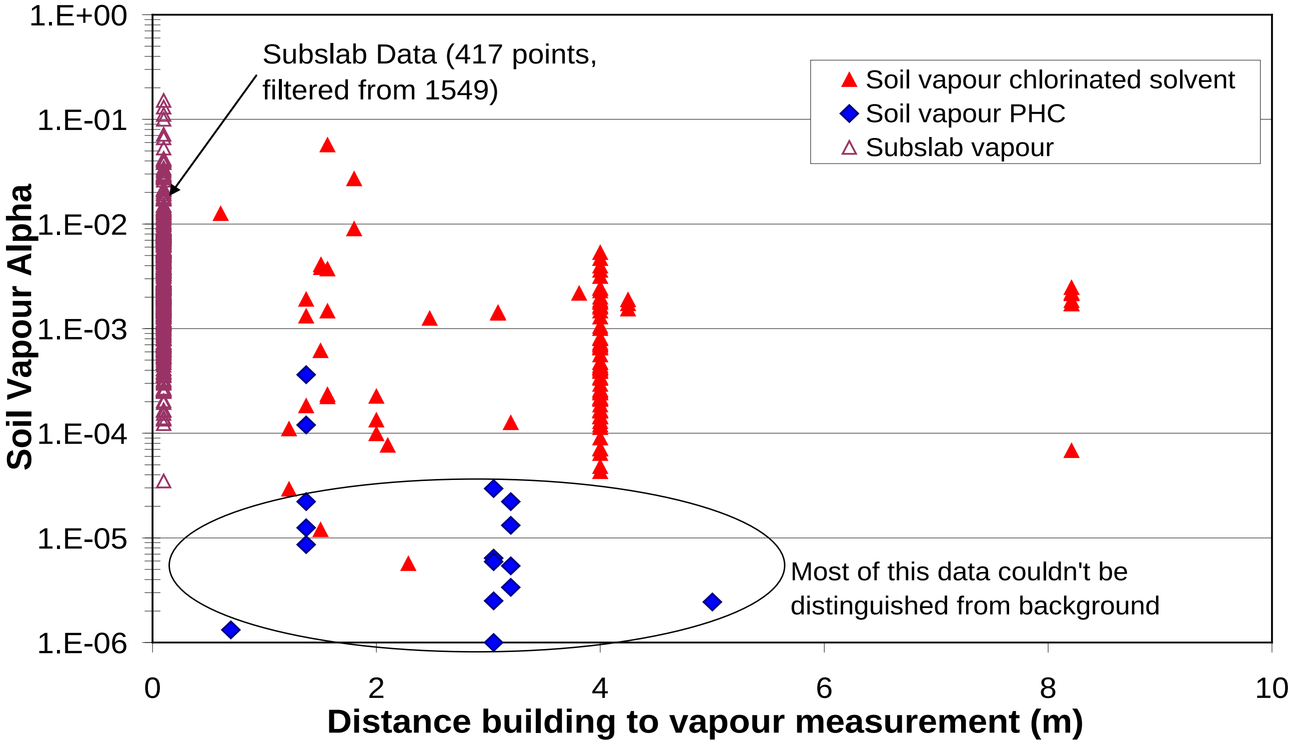
Modeling Study Implications

Findings of modeling study support:

- Improved VI screening process for petroleum hydrocarbons
  - Quickly screen out sites with low likelihood of VI concerns
  - Exclusion criteria which can be simply applied
- Development of sampling strategies for sites that do not screen out
  - Near-slab soil gas sampling is appropriate for moderate to low concentration sources
  - Sampling strategy may be used to confirm/support site conceptual model

Empirical Data Analysis

- USEPA has been focusing on evaluation of empirical data to estimate attenuation factors
- However, results reported by USEPA are predominantly based on chlorinated solvent sites and are not appropriate for petroleum hydrocarbons



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Petroleum Empirical Databases

- EPA Office of Underground Storage Tanks has developed a database focused on petroleum hydrocarbon sites
- Key contributors to petroleum vapour intrusion database and data interpretation:
  - R. Davis – Utah DEQ
  - Wright – Environmental Risk Sciences (Australia)
  - Peargin & Kolhatkar - Chevron
  - Matt Lahvis - Shell

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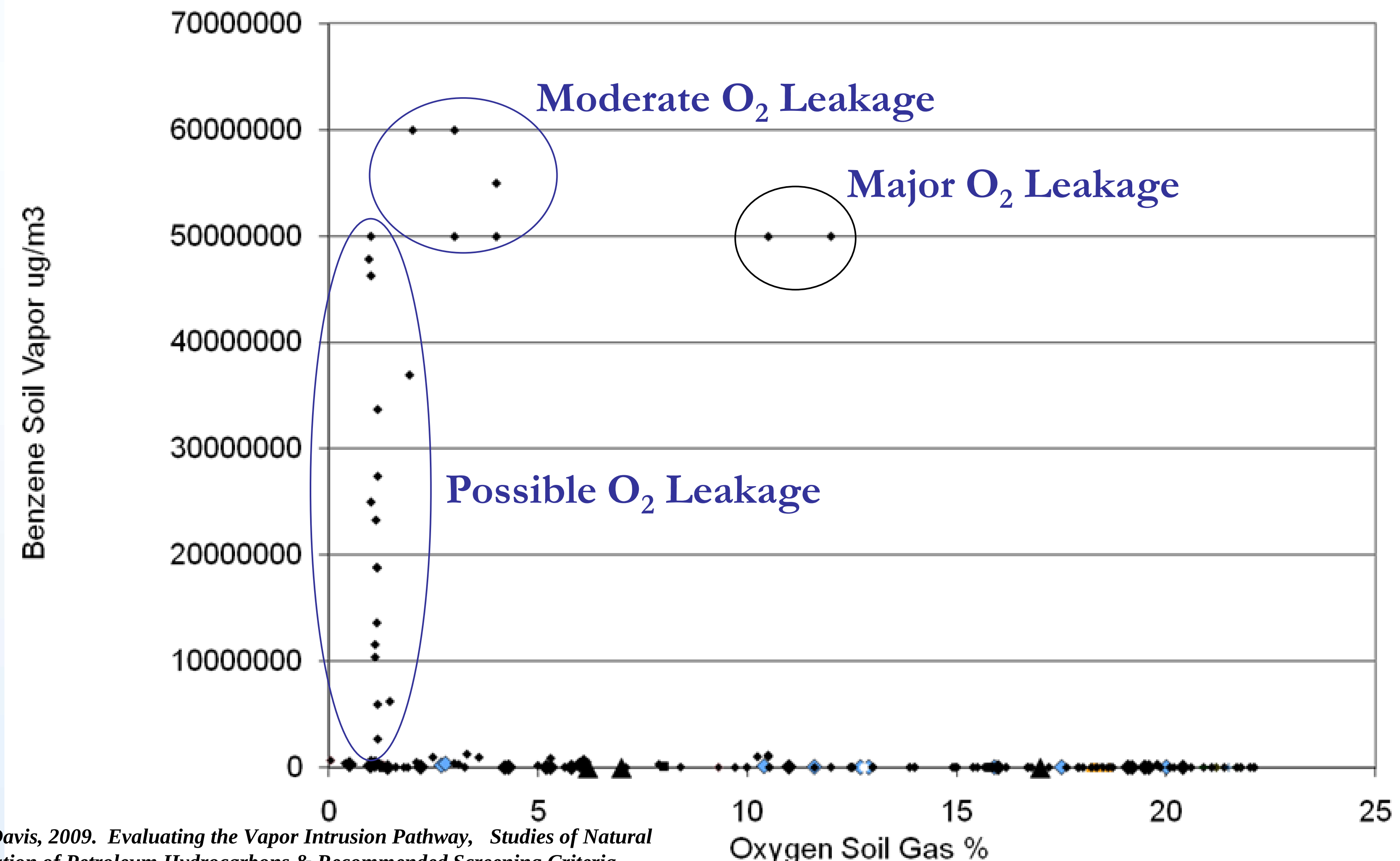
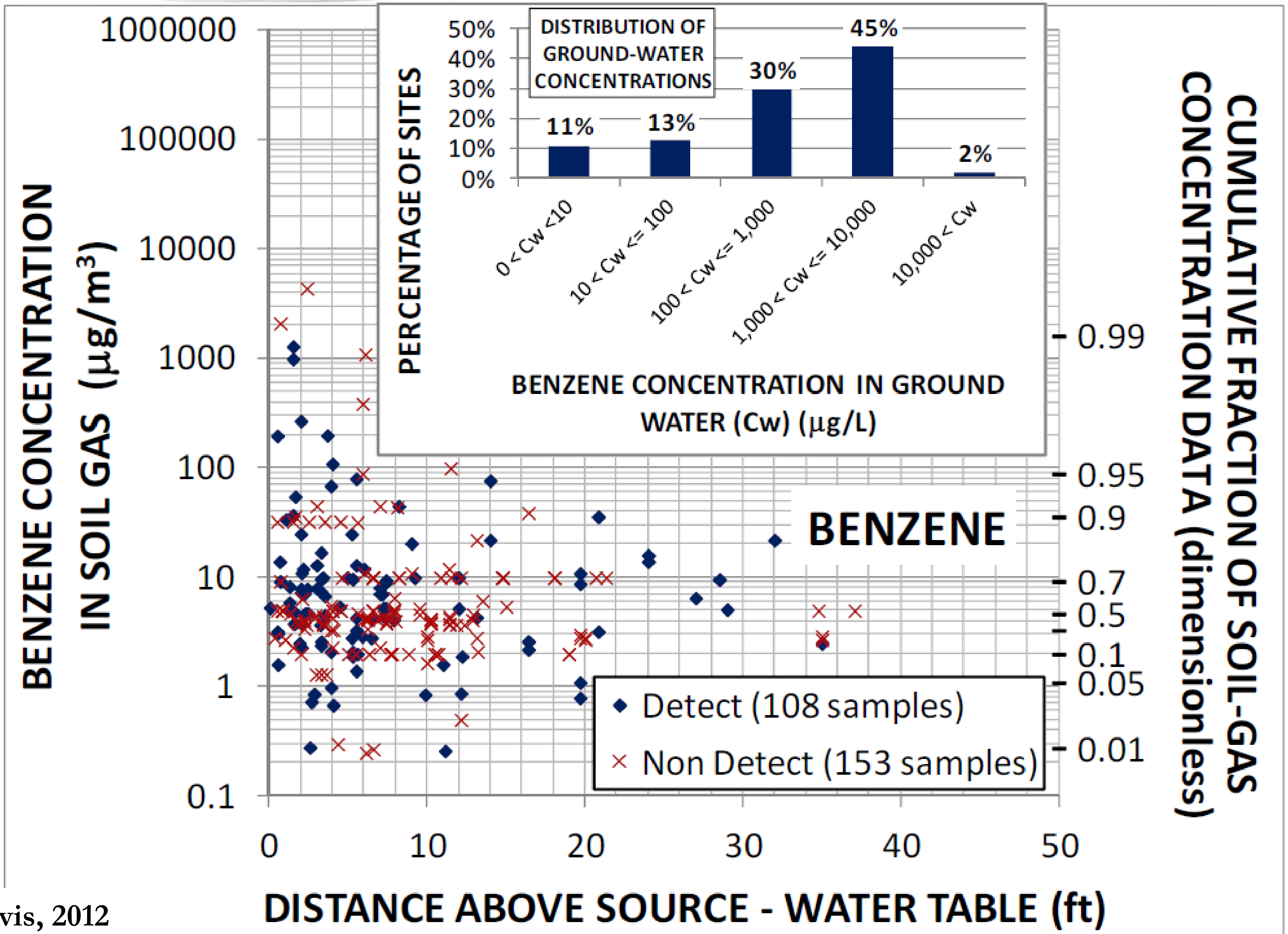
Correlation between Benzene and Oxygen Soil Gas Concentrations



From Davis, 2009. Evaluating the Vapor Intrusion Pathway, Studies of Natural Attenuation of Petroleum Hydrocarbons & Recommended Screening Criteria

Dissolve Plume Exclusion Distance Analysis



From Lahvis, 2012

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Proposed Petroleum Vapour Intrusion Exclusion Criteria

Investigators	Soil Gas Threshold	Dissolved Plume	NAPL Plume
Davis (2009)	ND	5 ft (1.5 m)	30 ft (10 m)
Peargin & Kolhatkar (2012)	300 µg/m³	0 ft (0 m)	15 ft (4.5 m)
Wright (2011)	50 µg/m³	5-10 ft (1.5 – 3 m)	30 ft (10 m)
Lahvis (2012)	30, 50, 100 µg/m³	0 ft (0 m)	13 ft (4 m)

Example Regulatory Application California EPA Water Board

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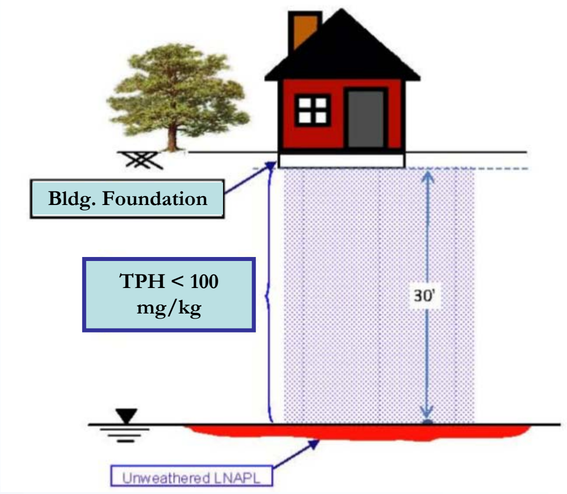
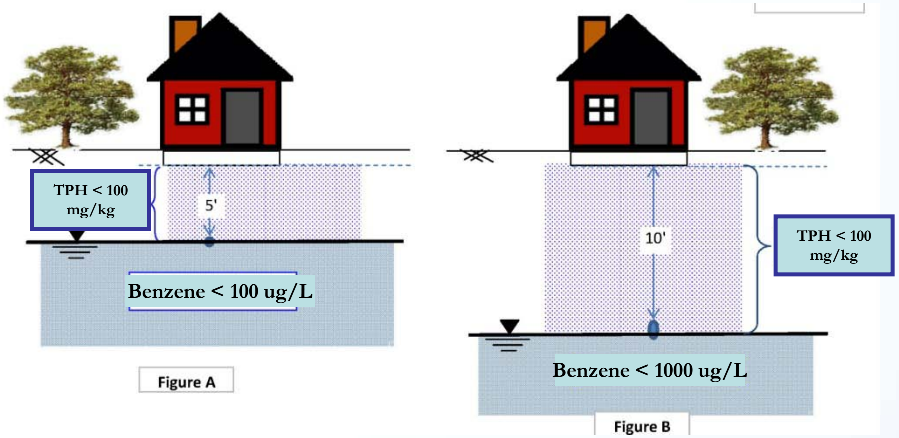
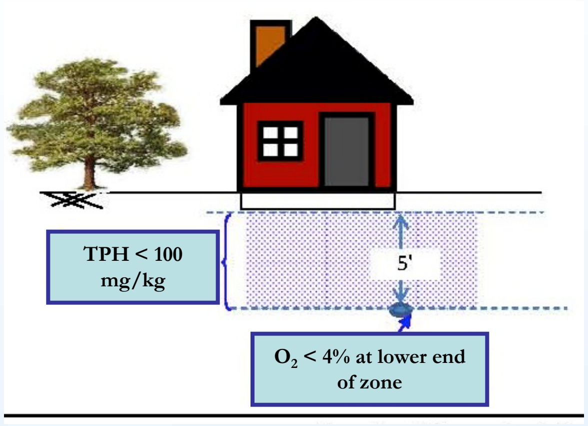
30 ft bioattenuation zone for sites with LNAPL



5 to 10 ft bioattenuation zone for dissolved plume sites



1000x bioattenuation factor when sufficient vadose zone oxygen demonstrated



From SWRCB 2012 policy for Low Threat Closure Sites applicable to petroleum UST sites

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Uncertainties

- Exclusionary criteria may not be applicable for:
  - Large petroleum release sites (e.g., refineries, depots)
  - Areas with large impermeable surface covers
  - Source areas where residual hydrocarbons in soil are present over plume
- Risk-management decisions
  - Acceptable risk-based soil vapor concentrations
  - False negative rate

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Summary

- Bioattenuation significantly affects the potential vapor intrusion of petroleum hydrocarbons and should be considered in decision-making process
- Traditional multiple lines of evidence approach will lead to many false-positive determinations
- Modeling and empirical data support the use of simple exclusionary criteria to screen out sites