State of Science and Practice for Assessment of Petroleum Vapour Intrusion

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Presentation Outline

- Conceptual site model for petroleum vapour intrusion (PVI)
- Technical basis for exclusion distance approach
  - Field data and rates
  - Empirical database studies
  - Modeling
- Framework for implementing exclusion distance approach
- Precluding conditions
- Sub-slab to indoor air attenuation factors (not directly related to PVI but added opportunity for database studies)
- Data gaps and concluding thoughts

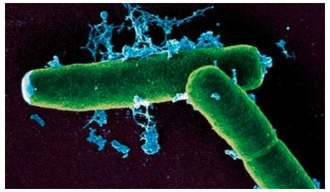
Aerobic Biodegradation Basics (ITRC IBT)

IN

Petroleum (food)

Oxygen (O_2)

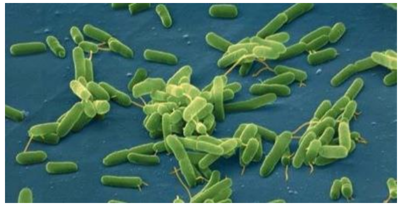
Microbes



OUT

Innocuous Waste products (CO_2 + H_2O)

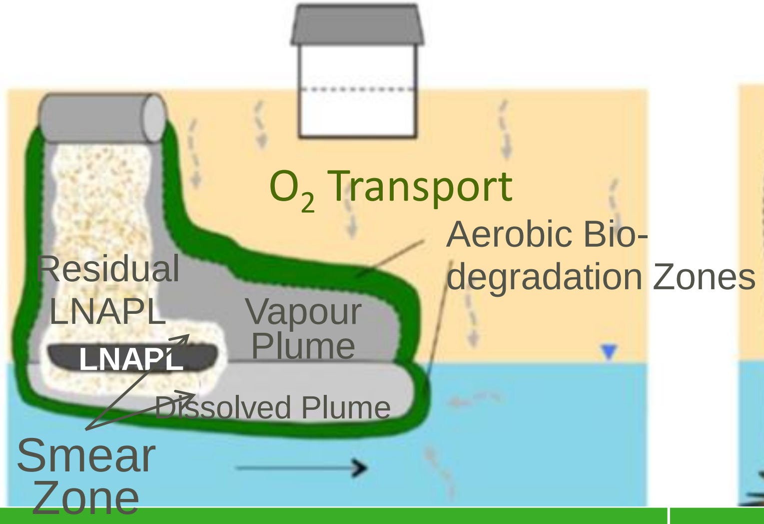
More Microbes

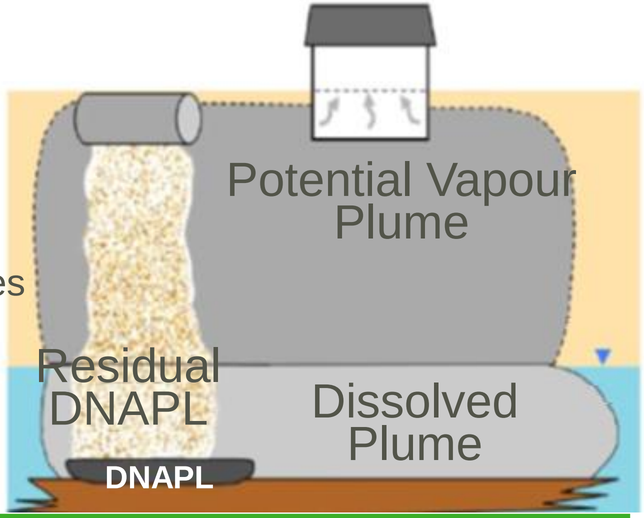


KEY POINT: **PHC degrading bacteria are found in all environments and can consume hydrocarbons rapidly in presence of O_2, limiting transport of petroleum vapors.**

USEPA "There are Important Differences Between Petroleum and Chlorinated Solvent VI" Guidance

Figure:
[Petroleum Hydrocarbons And Chlorinated Solvents Differ In Their Potential For Vapour Intrusion (PDF). EPA. *March 2012*.]

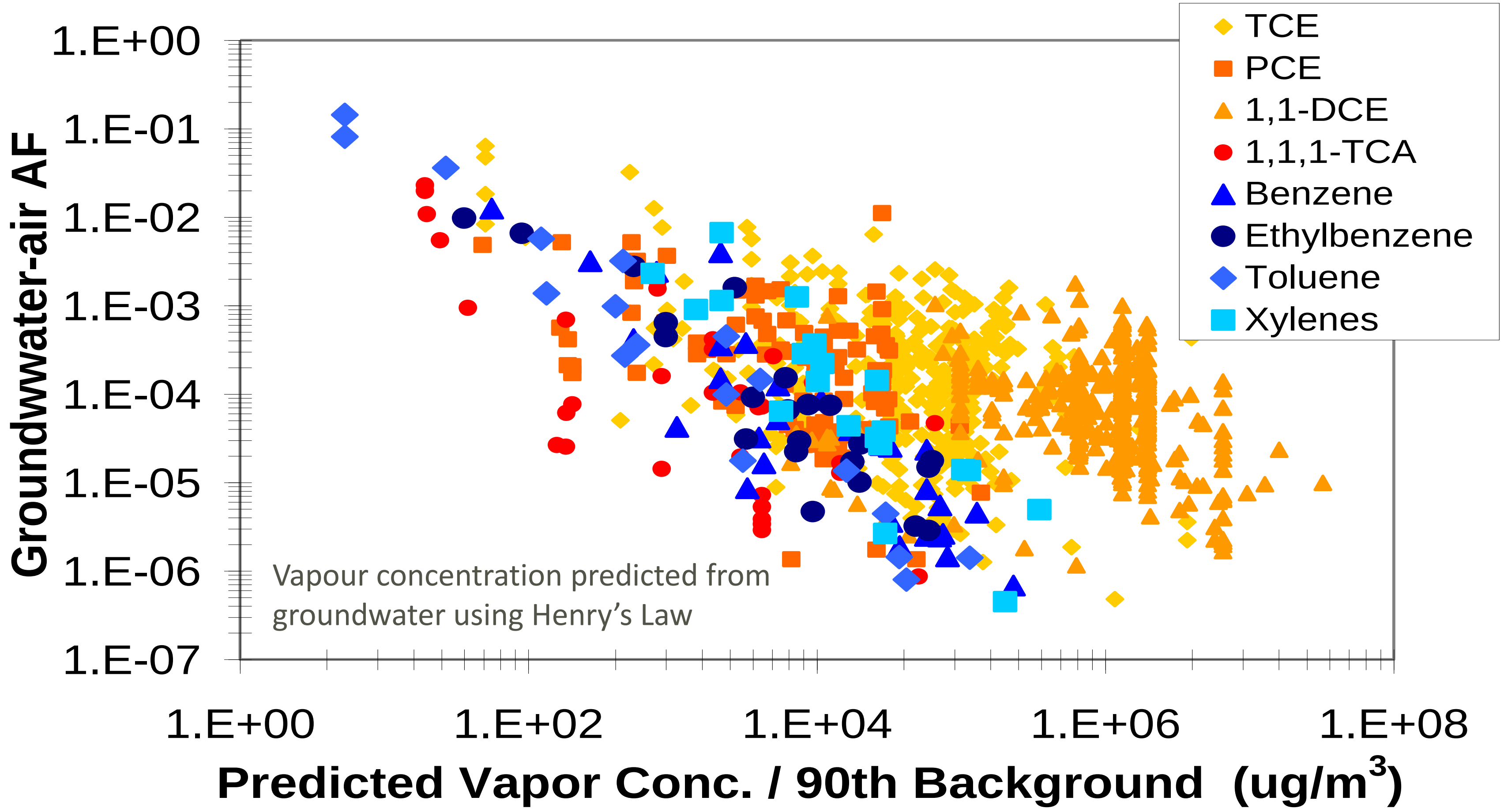




Variable	Petroleum	Chlorinated Solvents
Type of chemical	non-chlorinated hydrocarbon	chlorinated hydrocarbon
Example	Benzene	perchloroethylene (PCE)
Source Type	LNAPL	DNAPL
Aerobic biodegradation	Consistently very rapid	Consistently very limited
Vapour intrusion potential	Low	High
Degradation products	CO_2, H_2O	intermediates

KEY POINT: **Different approaches and models should be used for chlorinated & petroleum vapour intrusion (PVI)**

Attenuation Factor Analysis Illustrating Differences Between Petroleum & Chlorinated Solvents – 2008 Health Canada/CPPI Study



US EPA 2008 In-progress VI database and background indoor air quality study

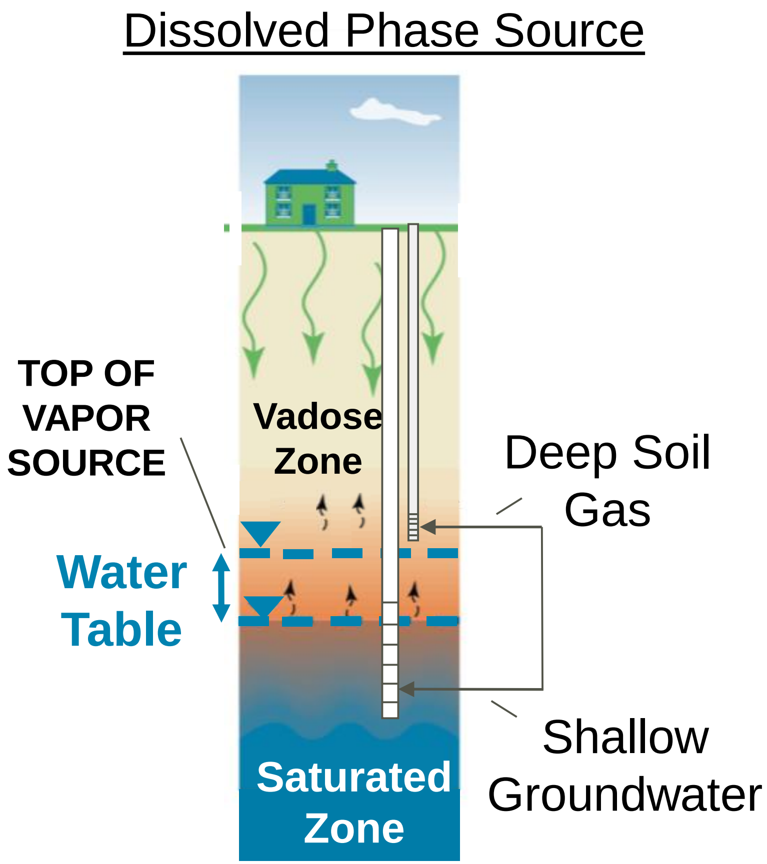
Chemical	Median of 90th Percentile (ug/m^3)
Benzene	14
Ethylbenzene	10
Toluene	60
m,p-Xylene	37
o-Xylene	11
PCE	6
TCE	**0.5**
111 TCA	5
11 DCA	INS
11 DCE	INS
cis-12-DCE	INS

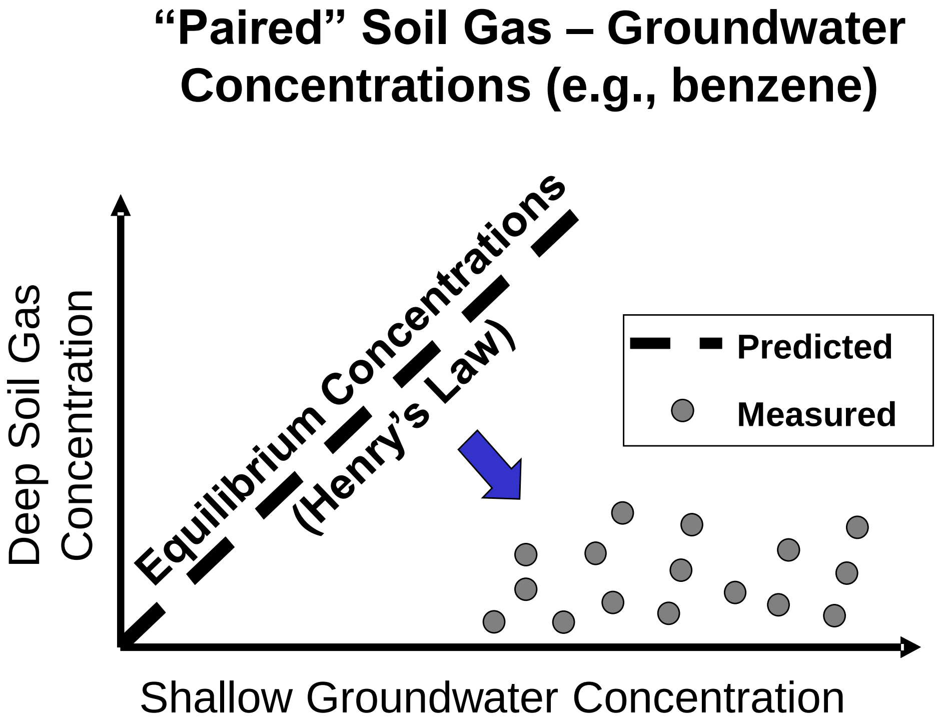
KEY POINT: **BTEX data show continued declining AF trend with increasing source concentration suggesting indoor air affected by background – suggests different approach needed**

Hers, I., L. Smith, N. Healey, P. Maisek. 2007. AWMA 3rd Specialty Conference on Vapor Intrusion Sept 27-28, 2007, Providence, Rhode Island

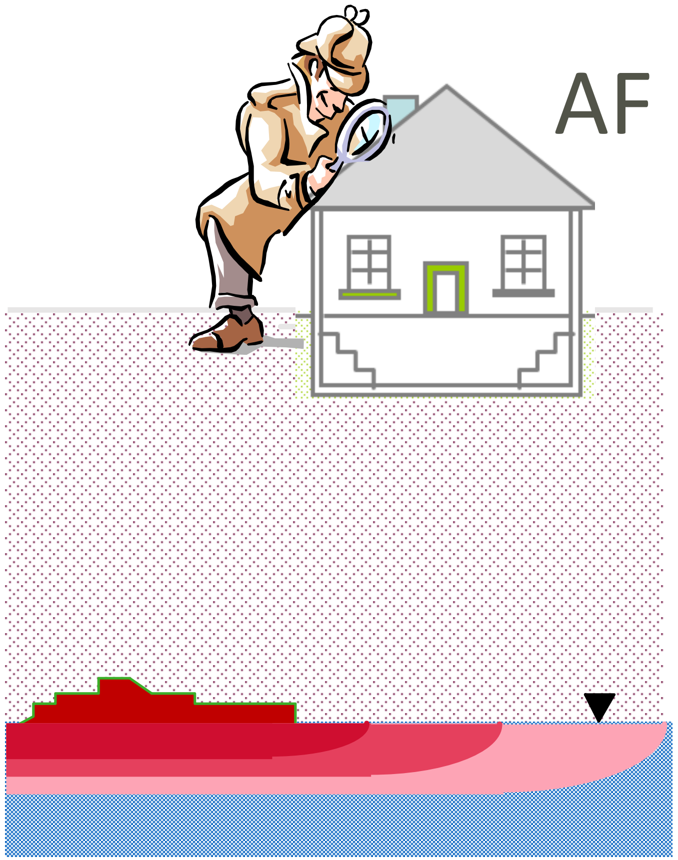
Case for Change
Value of Soil Gas and Groundwater RBSLs

- Measured soil gas concentrations << predicted based on equilibrium partitioning (Henry's Law) (e.g., dissolved-phase sources)
- Deep soil-gas and shallow-groundwater concentrations not well correlated

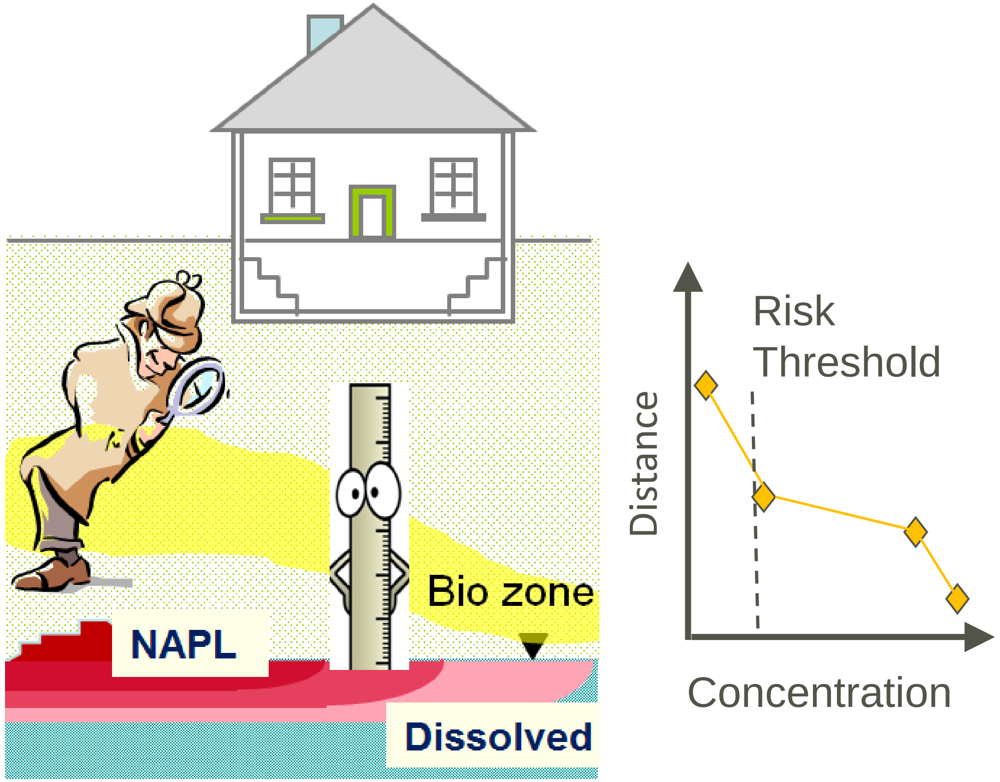




Biodegradation Screening Approaches



Attenuation Factor estimated from model (typically Johnson and Ettinger) with 10X or 100X **Bio-attenuation Factor** applied



Vertical screening distance estimated from empirical data

Consideration of Biodegradation in Site Screening

- Bio-attenuation factor (10-100x)
  - Health Canada
  - CCME
  - BC Environment
  - Ontario MOECC
  - New Jersey DEP
  - Massachusetts DEP[1]
  - New Hampshire DES

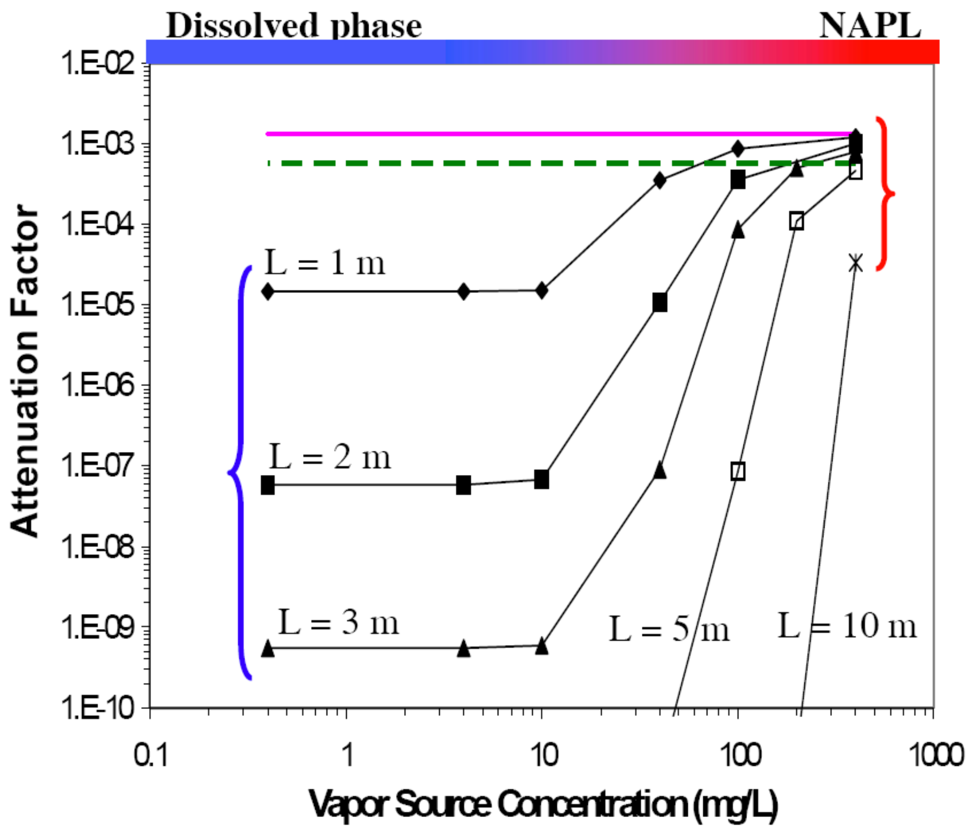
- Vertical exclusion distances
  - US EPA 2015
  - New Jersey DEP[2]
  - Interstate Technology and Regulatory Guidance (ITRC)
  - Wisconsin DNR
  - California Low Threat Guidance (Cal EPA)

KEY POINT:	**Adoption of vertical screening or exclusion distances increasing; many states have 30 ft lateral screening distance for PHCs**

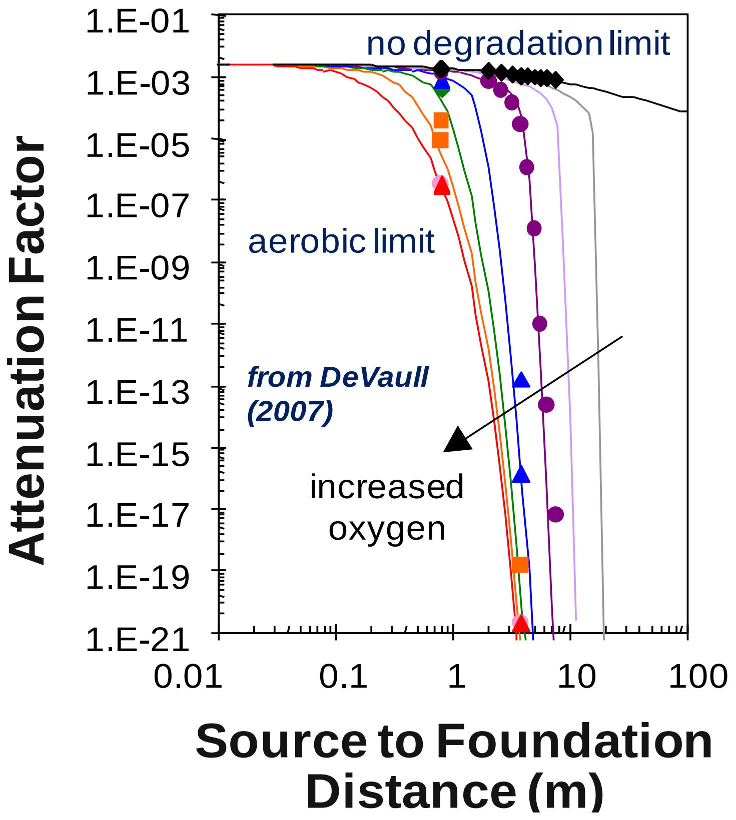
1. 10X bio-attenuation factor applied to BTEX for GW-2 standards; which do not apply beyond 15’ depth
2. Hybrid approach, 10X bio-attenuation factor applied to groundwater standards; guidance also includes vertical screening approach

Technical Justification for Exclusion Distances – Modeling Studies

Abreu et al. 2007

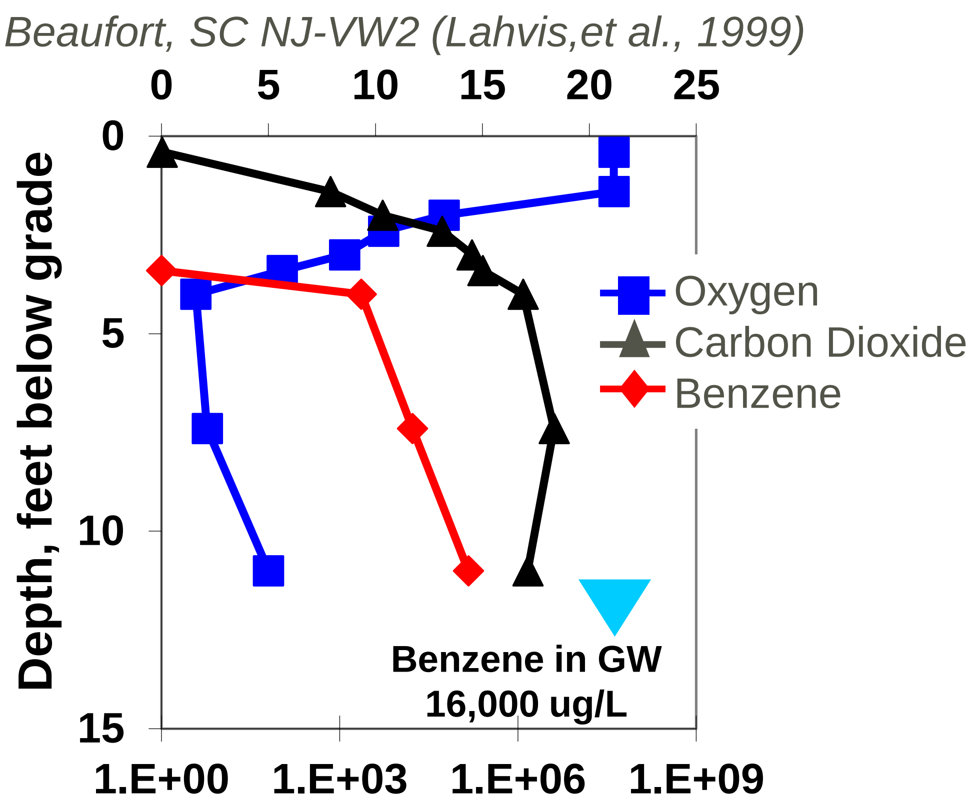


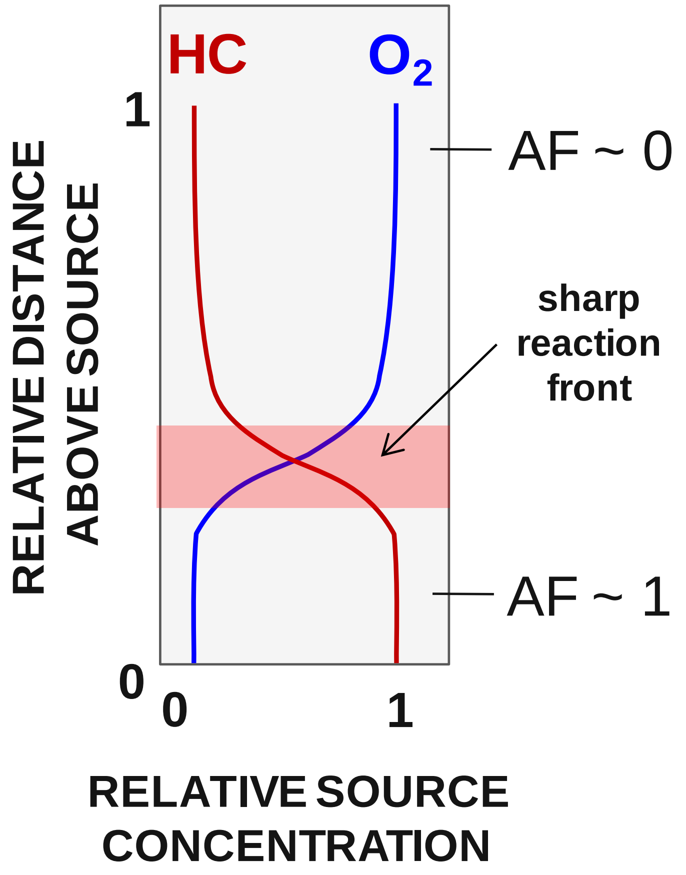
DeVaull 2007



KEY POINT: **Attenuation factor is depth dependent for reactive VOCs (hydrocarbons) with rapid rise in attenuation with increasing depth**

Technical Justification for Exclusion Distances – Field Data





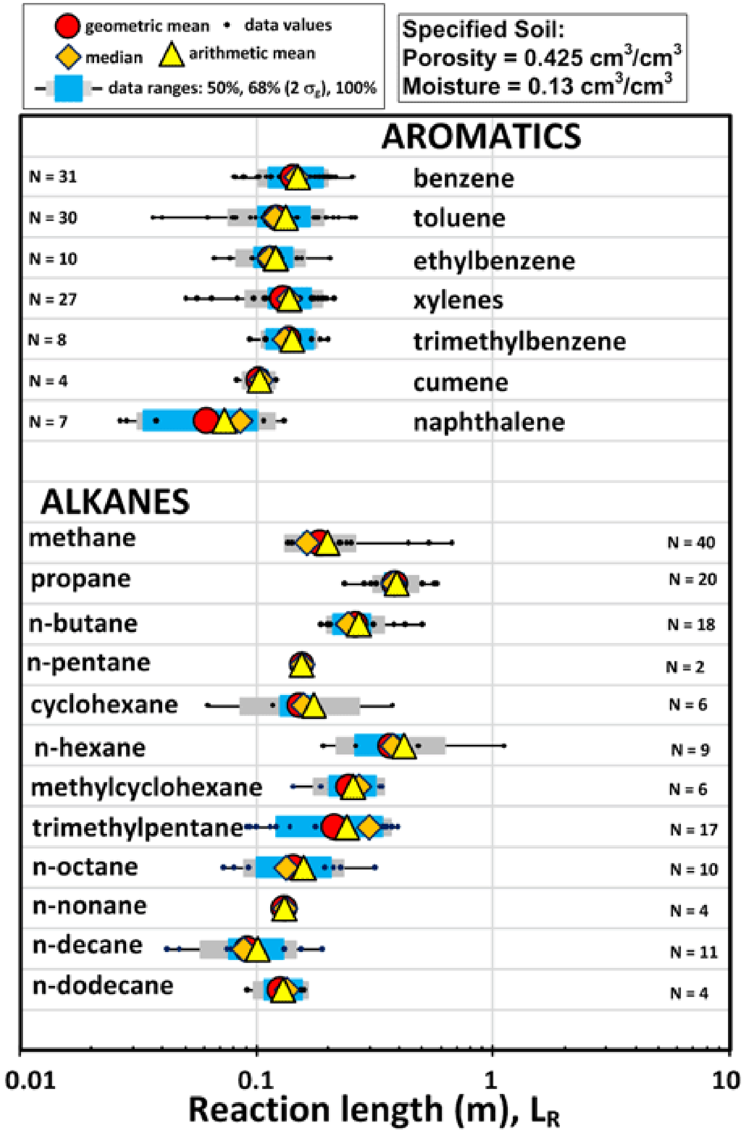
KEY POINT: **Sharp attenuation interface amenable to exclusion criteria, "all" or "nothing" bioattenuation type process**

Technical Justification for Exclusion Distances – Rates

- PVI risk is a function of biodegradation - diffusion ratio (reactive path length - L_R)

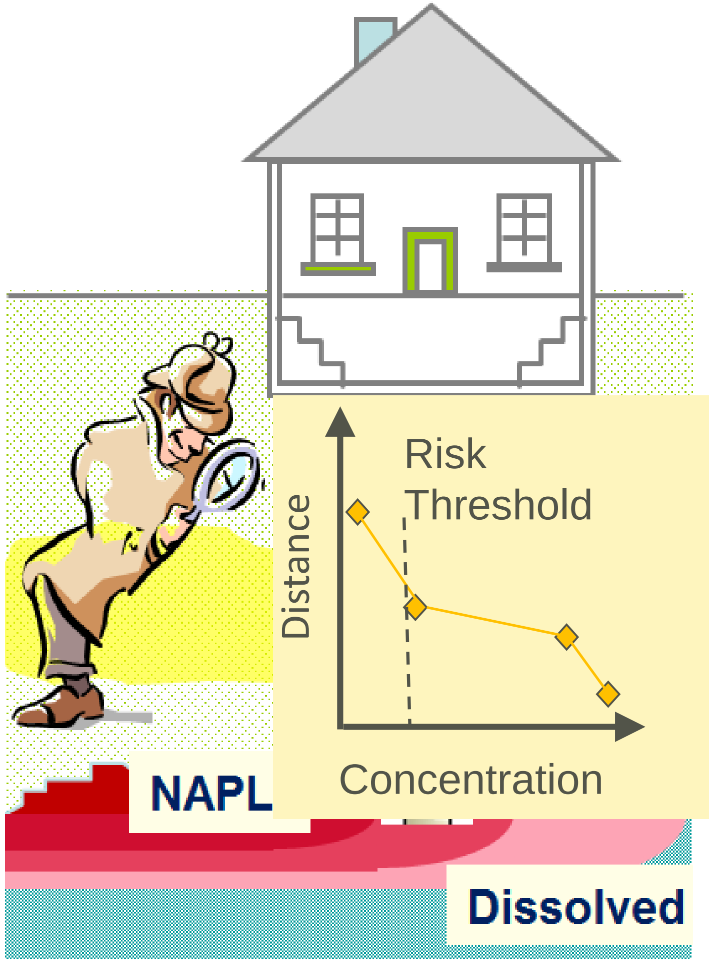
'reaction length' $$L_R = \sqrt{\frac{D_{eff} \cdot H_i}{\theta_w \cdot k_w}}$$

- Aerobic reaction rates are rapid (e.g., $t_{1/2}$ = hrs or days)
  - rates & reactive path lengths similar for many compounds
  - rates relatively instantaneous compared to diffusion/ advection (Davis et al., 2009)
- Also see rates in ITRC PVI 2014 Guidance appendix



DeVaull, G., 2011. Biodegradation rates for petroleum hydrocarbons in aerobic soils: A summary of measured data. Int. Symposium on Bioremediation and Sustainable Environ. Technol., June, Reno, NV, USA

Technical Justification for Exclusion Distances - US EPA PVI Database



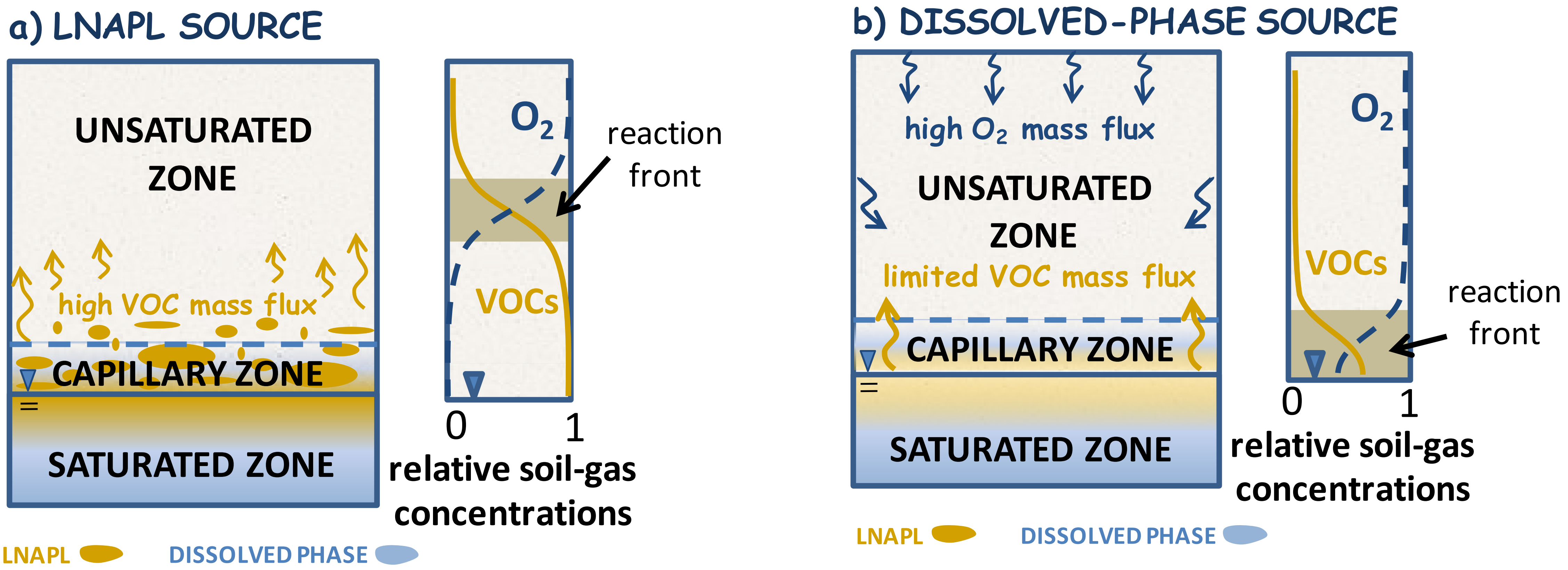
- 70 sites, 893 benzene soil vapour measurements
- Screening process to remove poor quality data
- Mostly gasoline, some diesel sites
- Wide range of geographical and environmental site conditions
- Thickness of clean, biologically active soil needed for attenuation of vapour to below risk-based thresholds, calculated using AF = 0.01 ($C_v = C_{air} / AF$)
- Analysis performed for 3 site types: 1) dissolved sites, 2) LNAPL – UST/AST and 3) LNAPL - industrial

Vertical Distances

Dissolved Sites	LNAPL – UST/AST	LNAPL - Industrial
5 ft ITRC 6 ft USEPA	15 ft ITRC 15 ft US EPA	18 ft ITRC 30 ft USEPA

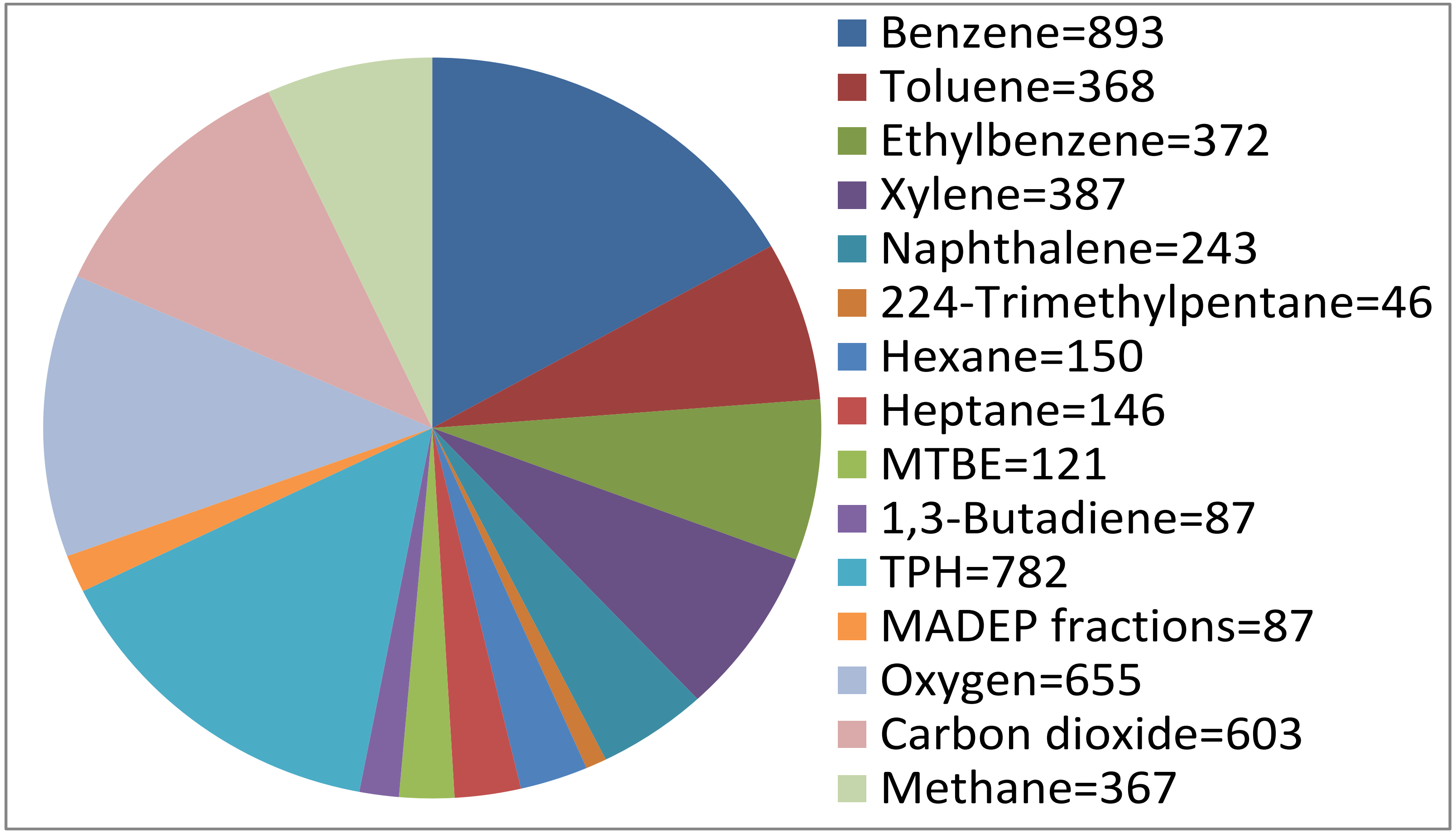
US EPA, 2014. Evaluation of Empirical Data to Support Soil Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Compounds. Rep 510-R-13-001. Prepared by Golder & RTI.

Conceptual Site Model – LNAPL vs. Dissolved Sources



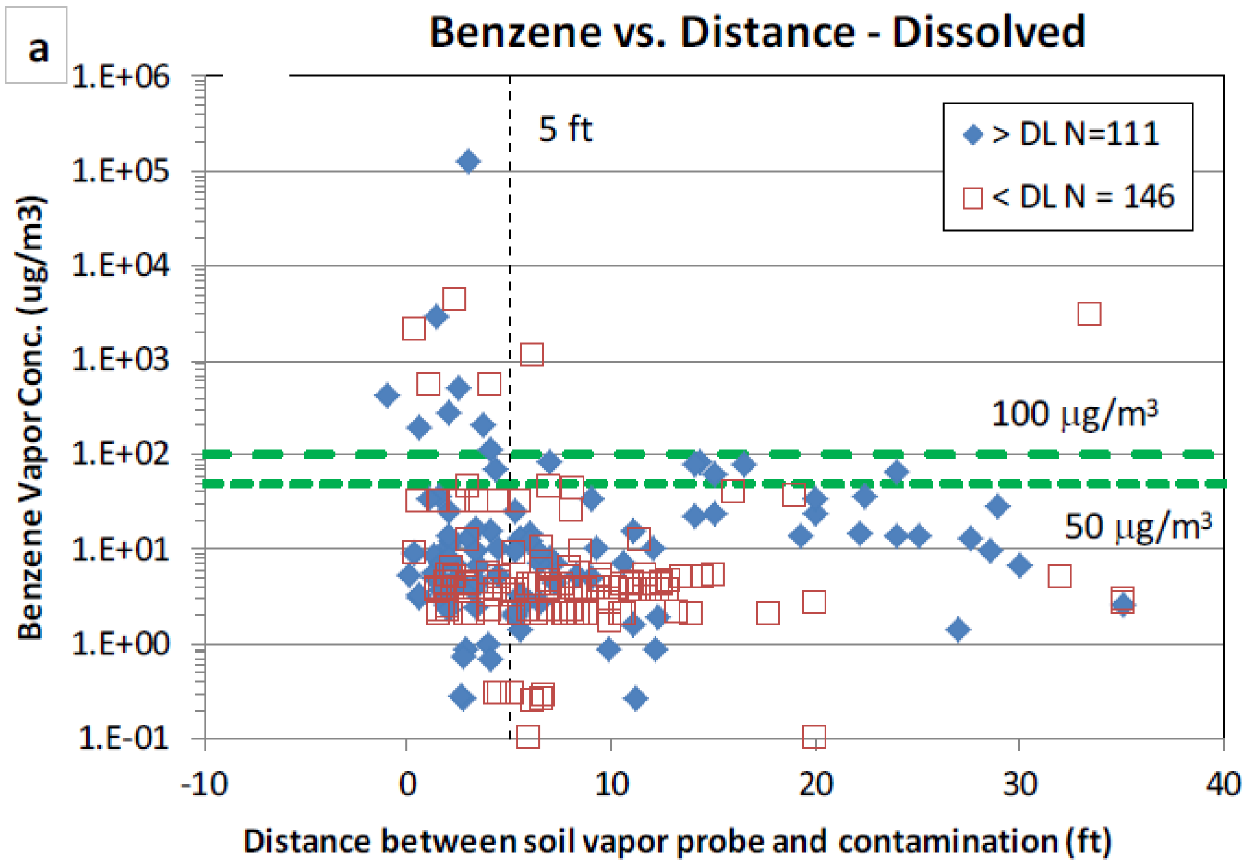
KEY POINT: **LNAPL and dissolved-phase sources are unique with respect to VI risk potential**

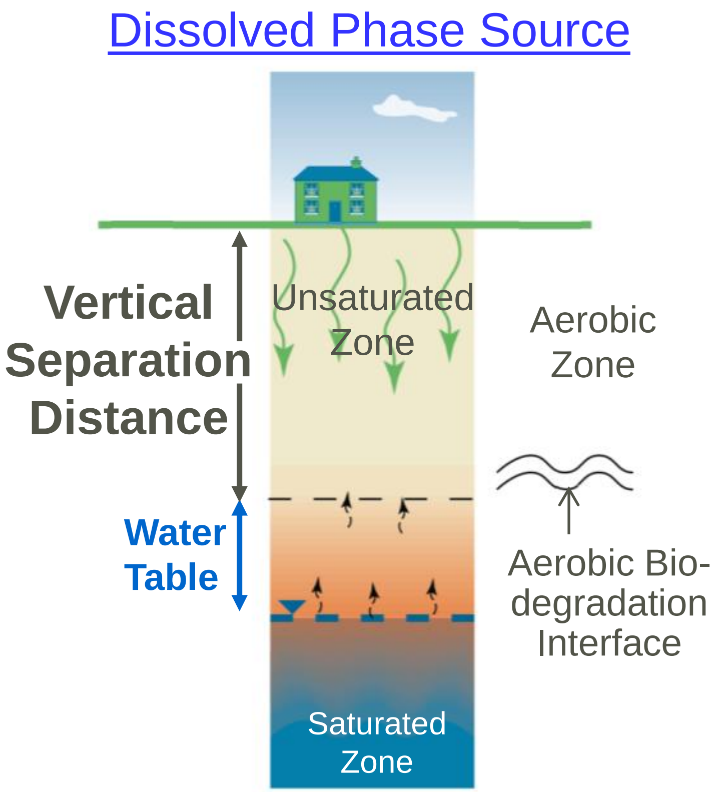
Technical Justification for Exclusion Distances - US EPA PVI Database



893 benzene vapor measurements
Analysis conducted for 10 compounds plus TPH fractions

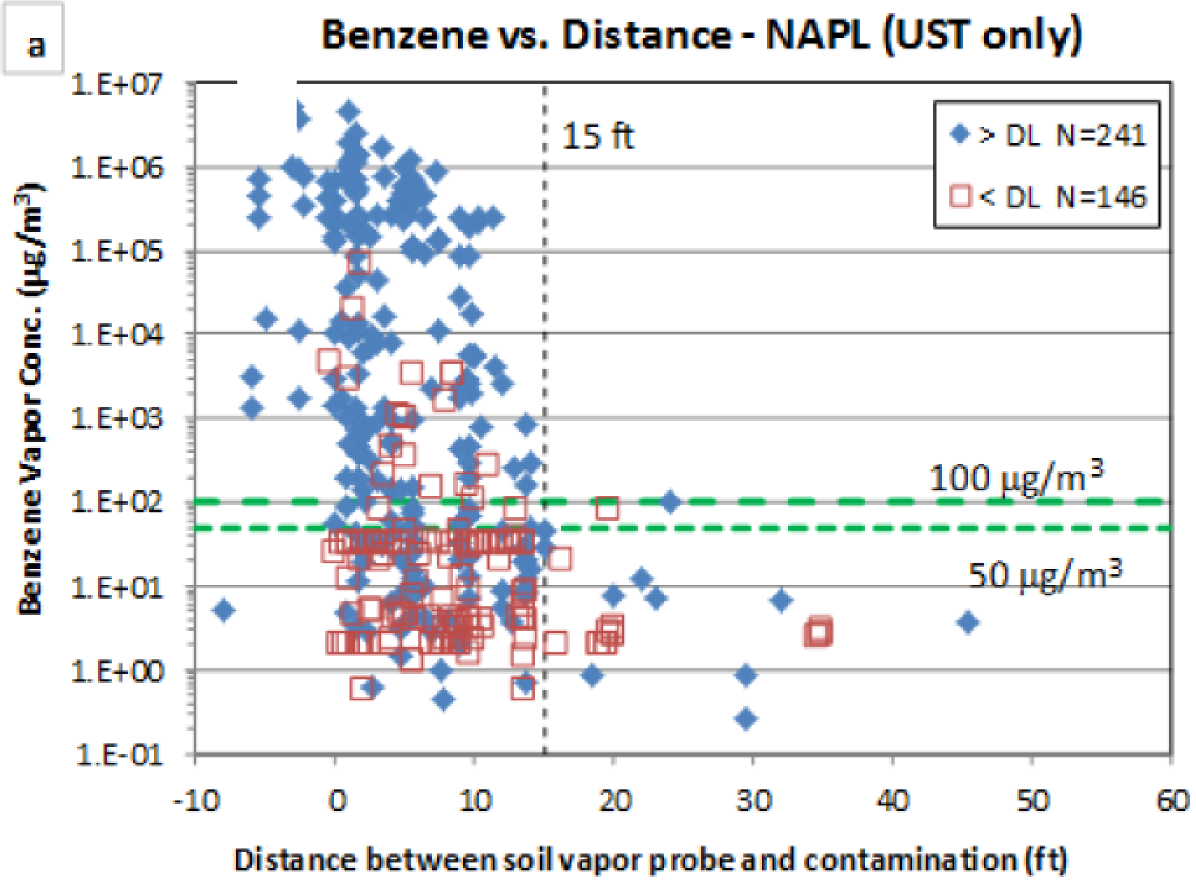
US EPA PVI Database – Dissolved Source Sites

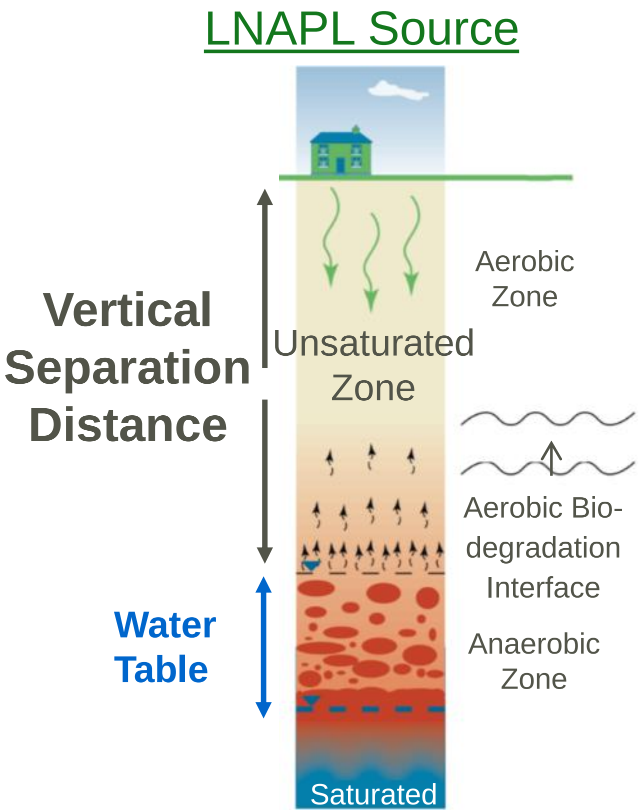




KEY POINT: **Vertical screening distance = 5 feet for dissolved sites. Benzene requires the greatest distance to attenuate compared to other chemicals analyzed**

US EPA PVI Database - LNAPL Source UST/AST Sites





KEY POINT: **Vertical screening distance = 15 feet for LNAPL UST/AST sites. Benzene requires the greatest distance to attenuate compared to other chemicals analyzed**

US EPA, 2014. Evaluation of Empirical Data to Support Soil Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Compounds. Rep 510-R-13-001. Prepared by Golder & RTI.

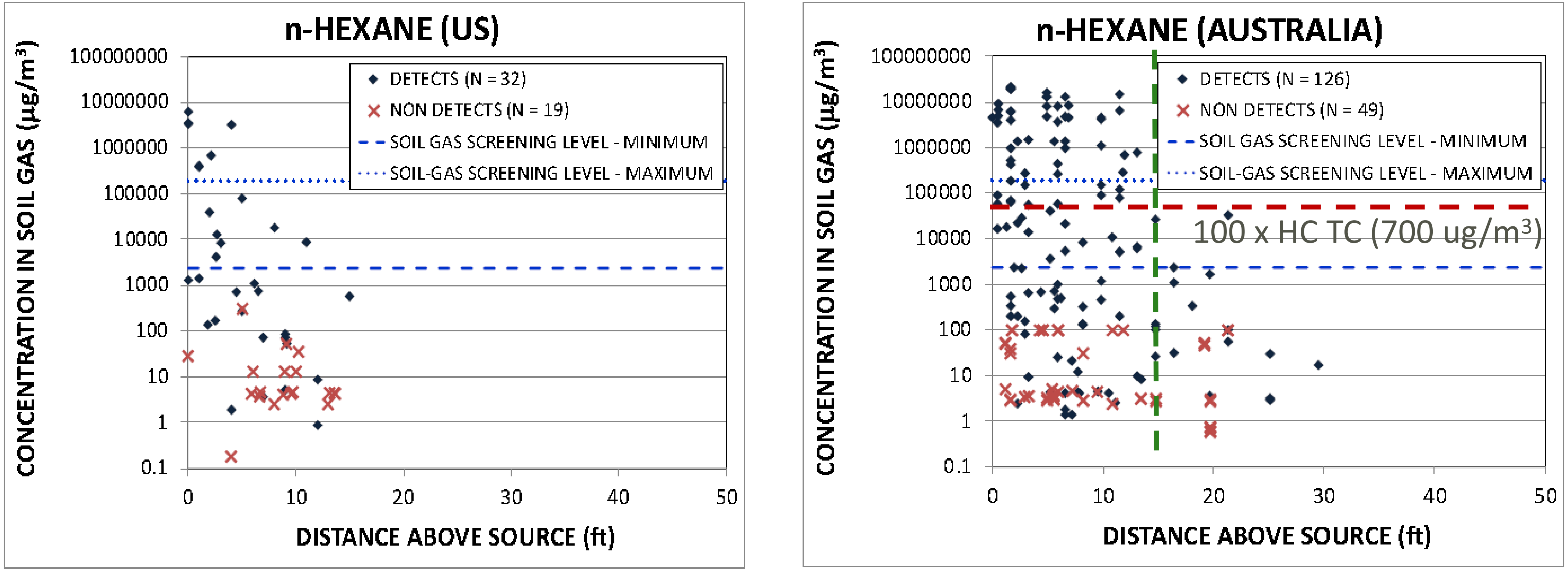
Comparison of CCME inhalation Tolerable Concentrations (TCs) and MassDEP PHC Fraction Reference Concentrations (mg/m^3)

	CCME	MassDEP
Aliphatics		
C>6-C8	18,310	
C5-C8		200
C>8-C10	961	
C9-C12		200
C>10-C12	1,000	
C>12-16	1,000	
Aromatics		
C>7-C8	400	
C>8-C10	200	50
C>10-C12	200	
C>12-C16	200	

KEY POINT: **Comparison of MassDEP PHC fractions (used in US EPA evaluation) likely more conservative than CCME fractions (TCs similar for individual compounds)**

US EPA and Australian PVI Database Analysis – LNAPL Sites

Lahvis (2017) conducted analysis of TPH, naphthalene and hexane data. TPH was not a reliable indicator; hexane screening distance was ~ 15 ft; naphthalene screening distance < 15 ft.

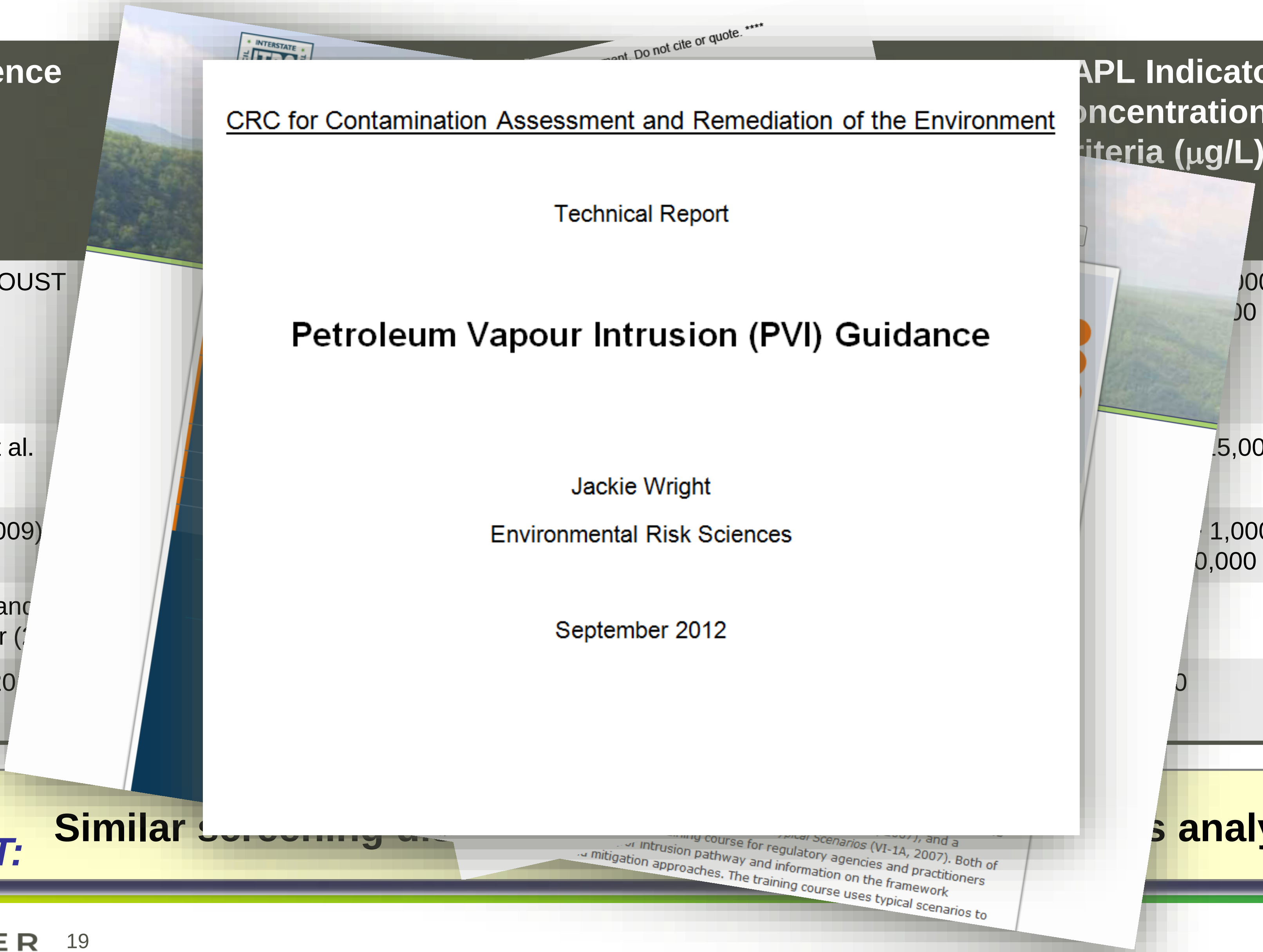


KEY POINT: **Hexane vertical screening = 15 ft for a soil gas screening concentration = 70,000 ug/m³**

Lahvis, M. 2017. Vertical Screening Distances for Assessing Total Petroleum Hydrocarbon Vapor. Intrusion Risk at Underground Storage Tank Sites. Presentation at AEHS Westcoast Conference.

Screening Distances Empirical Studies

Reference		APL Indicator Concentration Criteria (µg/L)
US EPA OUST (2013)		...00 ...0
Lahvis et al. (2013)		...5,000
Davis (2009)		... 1,000 ...0,000
Peargin and Kolhatkar (...		
Wright (20...		...0


...ment. Do not cite or quote. ****

CRC for Contamination Assessment and Remediation of the Environment

Technical Report

Petroleum Vapour Intrusion (PVI) Guidance

Jackie Wright

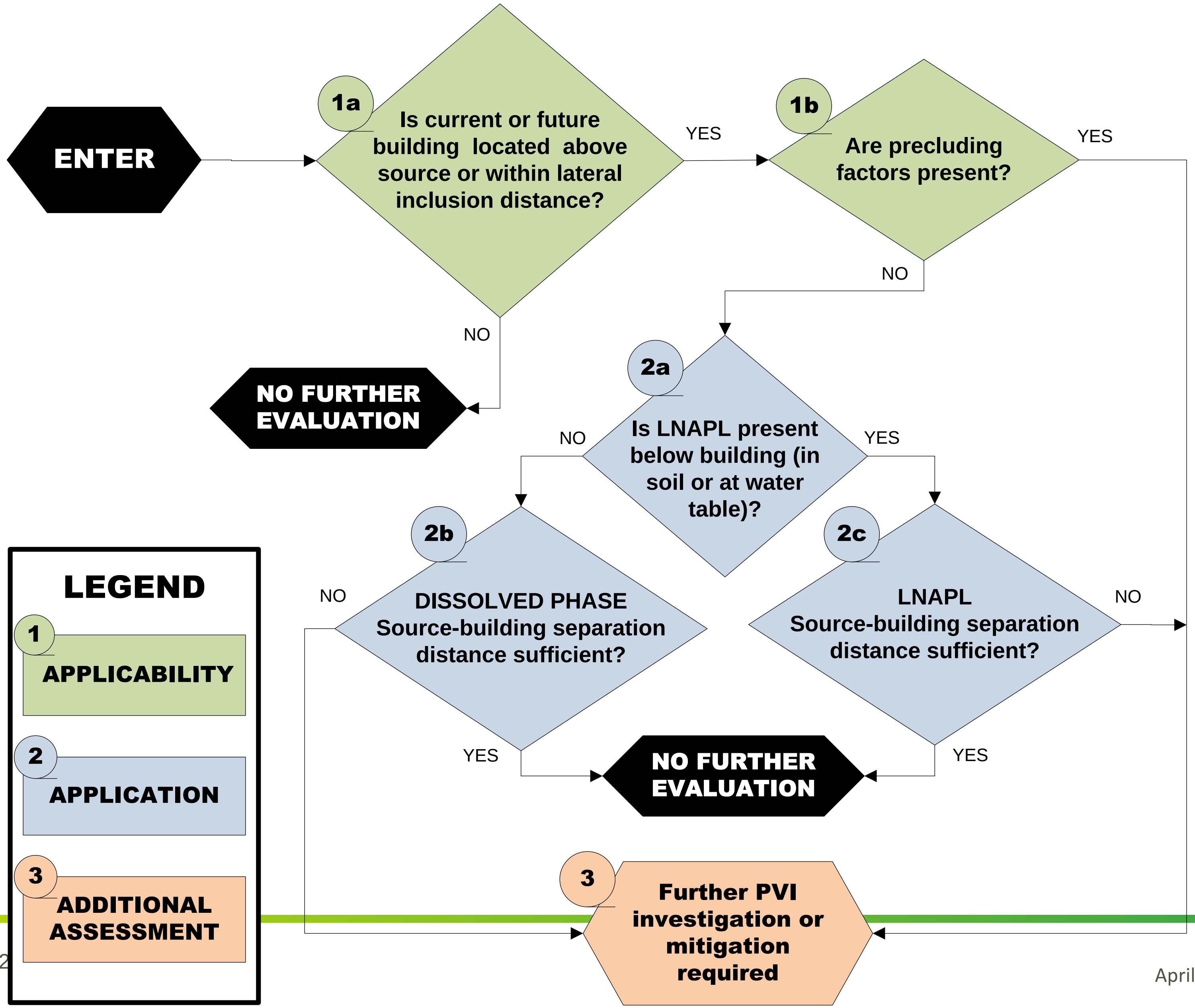
Environmental Risk Sciences

September 2012

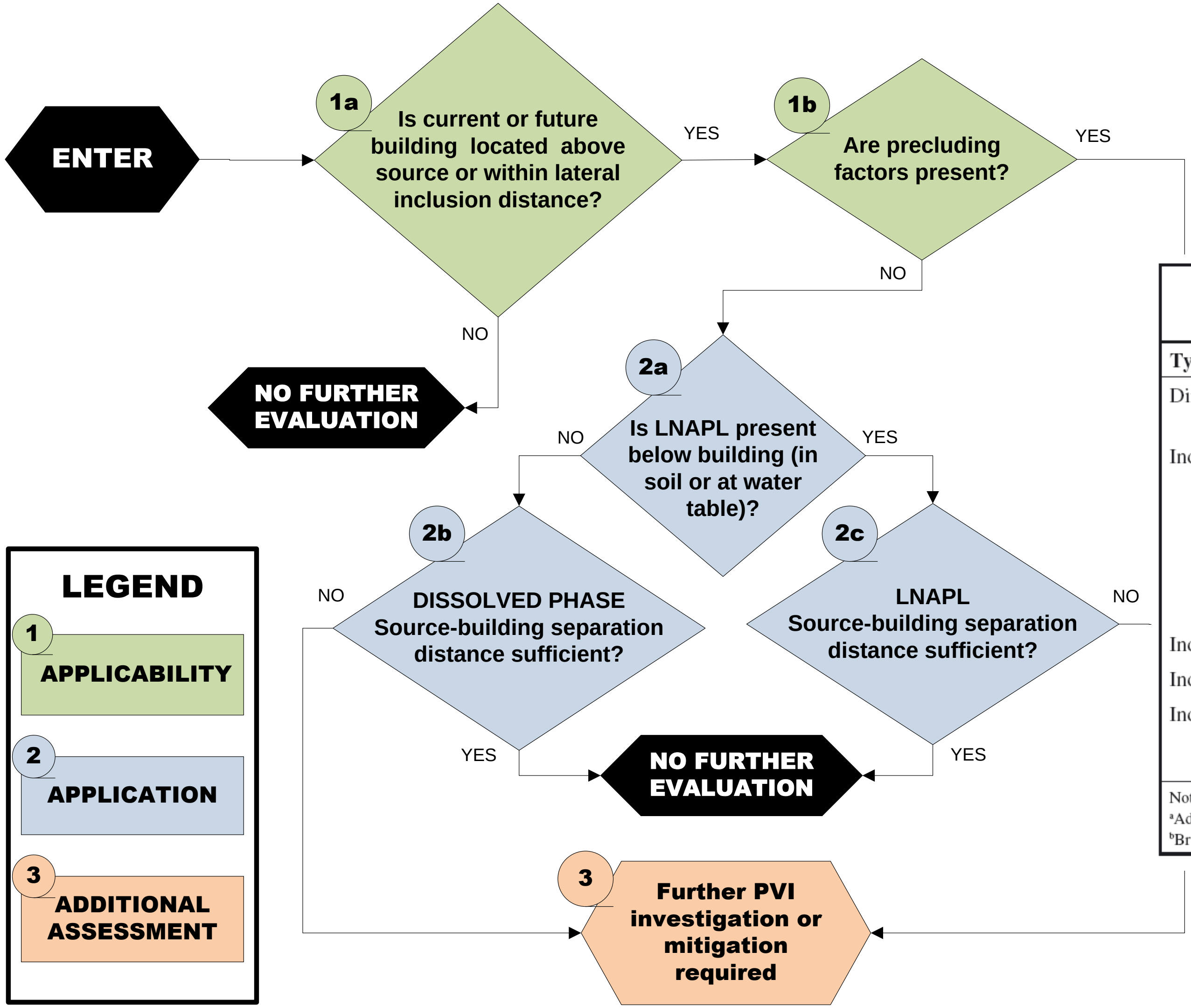
...Typical Scenarios (VI-1A, 2007), and a ...ning course for regulatory agencies and practitioners ...r intrusion pathway and information on the framework ...d mitigation approaches. The training course uses typical scenarios to

KEY POINT: **Similar s... ...s analyzed**

Screening Process (ITRC IBT)



Screening Process (ITRC IBT)



LNAPL INDICATORS

Table 2

Direct and Indirect Indicators of Residual-Phase LNAPL[a]

Type	Indicator	Measures and Screening Values
Direct	Current or historic presence of LNAPL in groundwater (including sheens) or soil	• Laboratory and field/visual observations, including paint filter, shaker, and dye tests
Indirect	COC and TPH concentrations approaching (more than 0.2) effective solubilities or effective soil saturation concentrations[b]	• Groundwater – Benzene morethan 3 mg/L – Gasoline (BTEX) more than 20 mg/L – Diesel more than 5 mg/L TPH-D • Soil – Gasoline more than 500 mg/kg TPH-G – Diesel more than 100 mg/kg TPH-D
Indirect	Organic vapor analyzer (OVA)	• More than 500 ppmV
Indirect	Fluorescence response in LNAPL range	• UV, LIF, or UVIF fluorescence above background levels (visual observation)
Indirect	Soil-gas profiles	• Hydrocarbon and CO_2 concentrations in soil gas that show no decrease (or O_2 concentrations that show no increase) or remain relatively constant with distance from source

Note: Concentrations lower than the reference values can also be indicative of LNAPL sources.
[a]Adapted from Garg and Beckett (2009, written communication).
[b]Bruce et al. (1991).

Precluding Conditions

- Precluding factors (ITRC PVI IBT)
  - Preferential pathways
    - Natural: karst or fractured geology
    - Anthropogenic: poorly-sealed utility line (e.g sewer, water)
  - Expanding/advancing plume
    - See also ITRC’s Evaluating LNAPL Remedial Technologies for Achieving Project Goals (LNAPL-2, 2009)
  - Certain fuel type (e.g., lead scavengers or > 10% vol/vol ethanol)
    - See also ITRC's Biofuels: Release Prevention, Environmental Behavior, and Remediation (Biofuels-1, 2011)
  - Certain soil types (e.g., peat [foc>4%] or very dry soils [<2% by vol.])
- Possible additional precluding factors
  - Large buildings?
  - Cold climate?

Modeling Studies of Oxygen (O_2) Shadow Below Buildings (defined as O_2 < 1%)

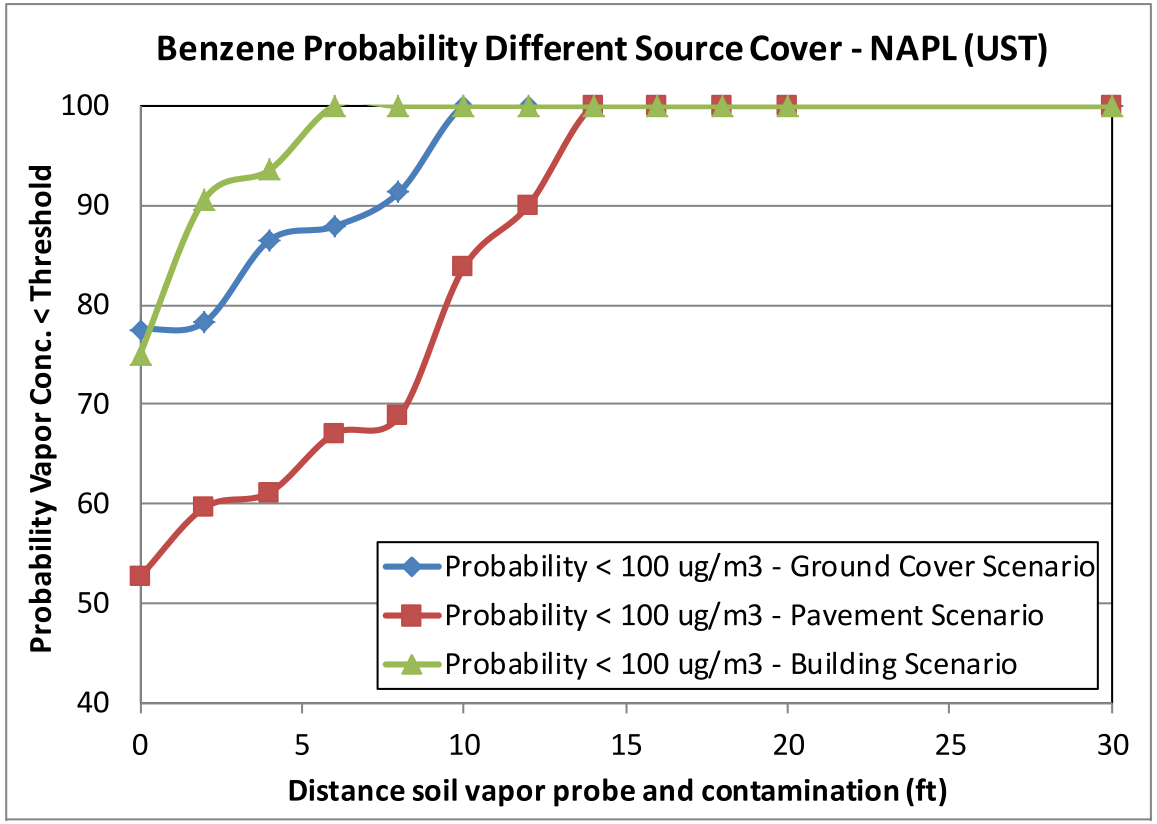
- USEPA (2013) - Abreu-3D numerical model
  - Impervious slab
  - Distance to contamination source = 15 ft. (4.6 m)
  - TPH C_V = 10 mg/L (highly weathered gasoline or fresh diesel): O_2 shadow for building = 30 m by 30 m, but not 20 m by 20 m
  - TPH Cv = 1 mg/L (dissolved): O_2 shadow did not form for largest building (632 m by 632 m)

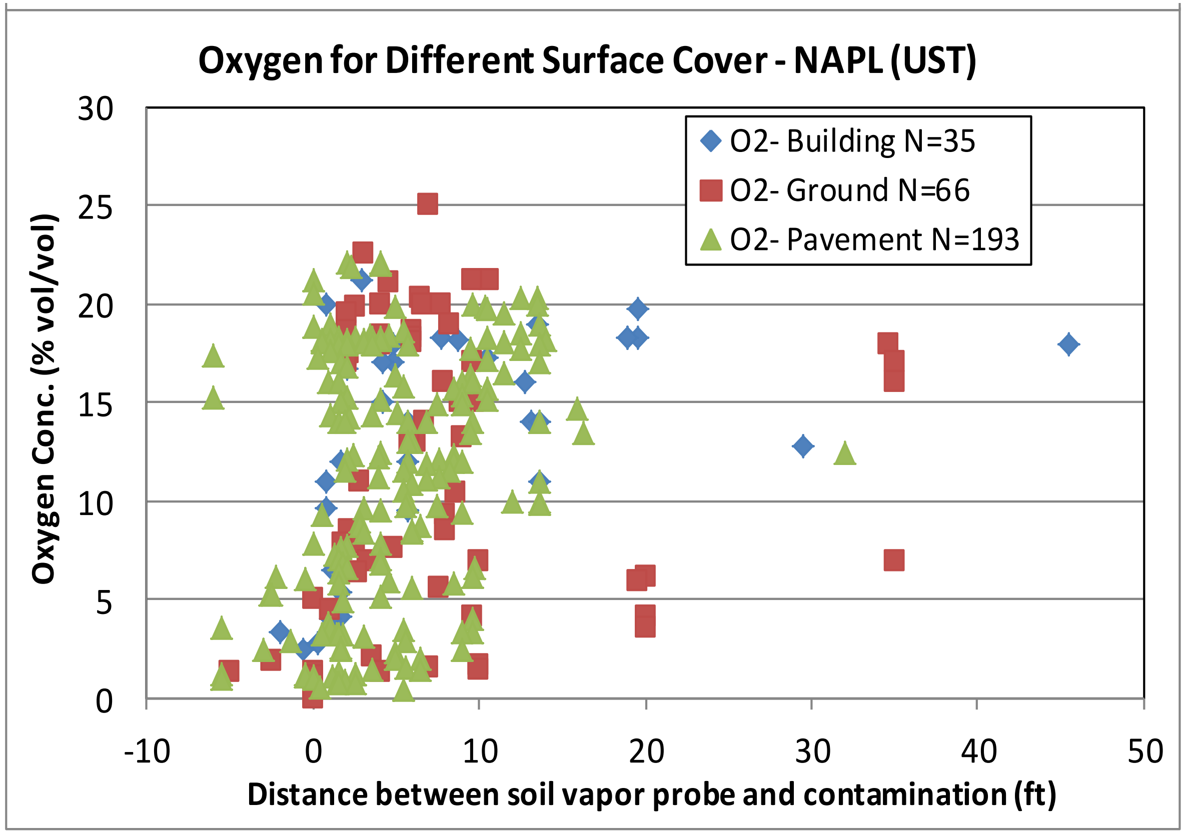
- Verginelli et al. (2016) – Analytical model
  - Pervious slab
  - Distance to contamination source = 16.4 ft. (5 m)
  - TPH C_V = 200 mg/L (gasoline): No O_2 shadow for 20 m by 20 m building (larger building not simulated)

- Knight and Davis (2013); Yao at el. (2014) – impervious slab (not that useful)

KEY POINT:	**Imperious slab studies not useful (gas migration through concrete occurs); Studies inclusive as to building size of concern for O_2 shadow (>30 m by 30 m building?)**

US EPA PVI Database – Effect of Surface Cover



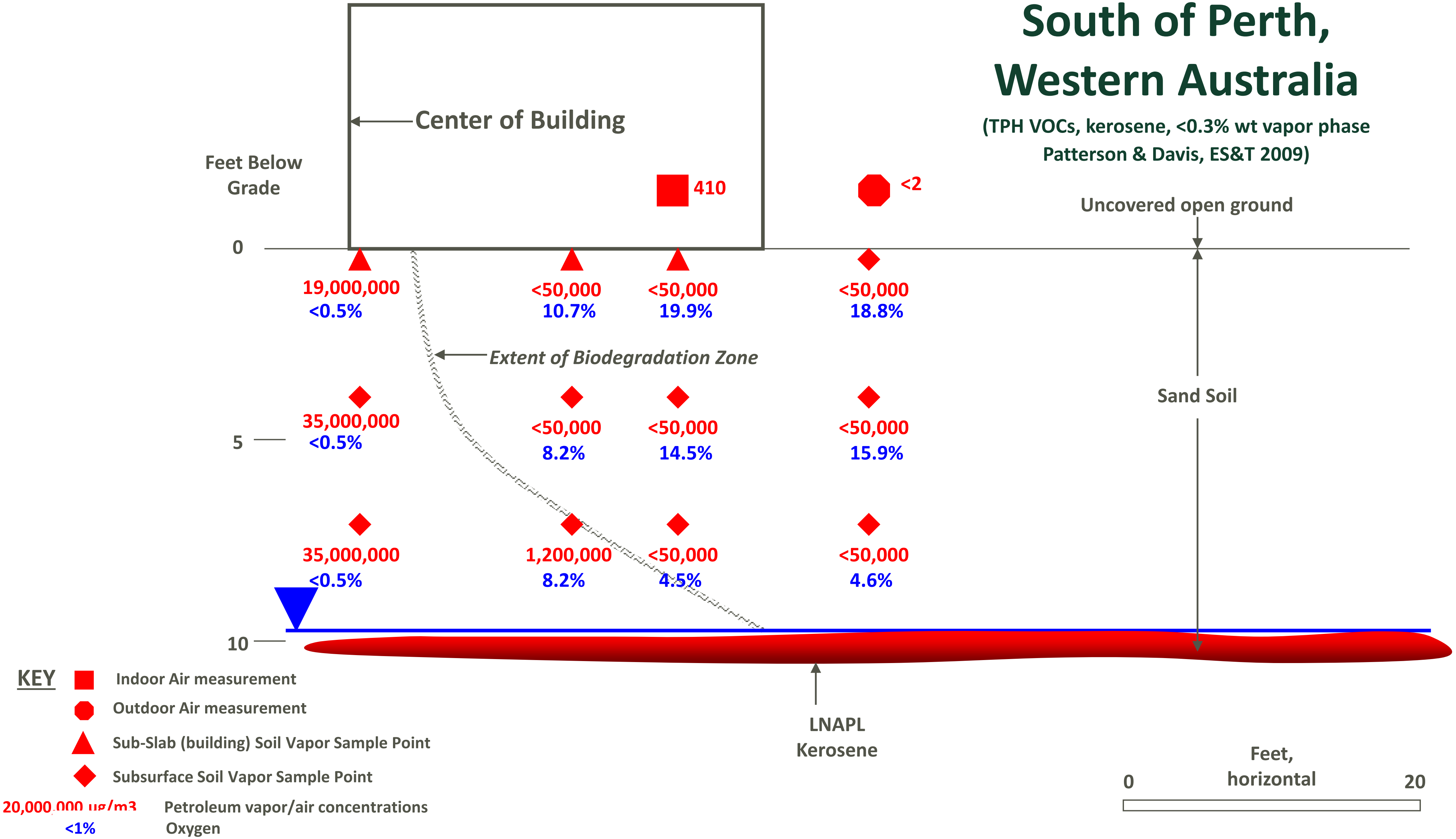


37 sites with below-building soil gas data

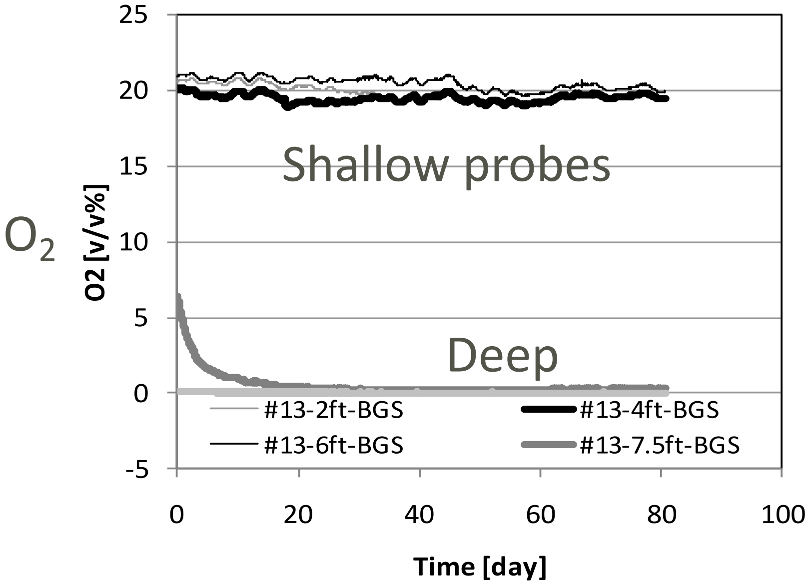
KEY POINT:	**No significant difference in screening distance for sites with building or pavements or oxygen concentrations**

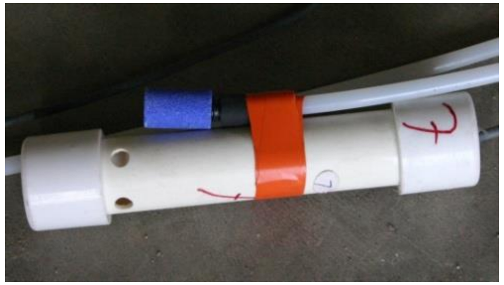
South of Perth, Western Australia

(TPH VOCs, kerosene, <0.3% wt vapor phase
Patterson & Davis, ES&T 2009)



Golder Cold Climate VI Research Study





>50 O_2 sensors

- Do cold temperatures and frost/ snow reduce biodegradation?
- High resolution O_2, pressure, soil moisture, weather
- Numerical modeling (MIN3P-DUSTY)

USEPA PVI database includes sites in colder climate area including Canada (4 sites) plus Maine, Minnesota, North Dakota, New York

KEY POINTS: **No reduction in biodegradation activity during cold winters; snow not a barrier to O_2 migration**

Hers, I., P. Jourabchi et al. 2014. Evaluation of Seasonal Factors on Petroleum Hydrocarbon Vapor Biodegradation and Intrusion Potential in a Cold Climate. GWMR. 34, no. 4/ Fall 2014/pages 60–78

New Screening Distance Publication (September 2019)

Groundwater Monitoring&Remediation

Vertical Screening Distance Criteria to Evaluate Vapor Intrusion Risk from 1,2-Dichloroethane (1,2-DCA)

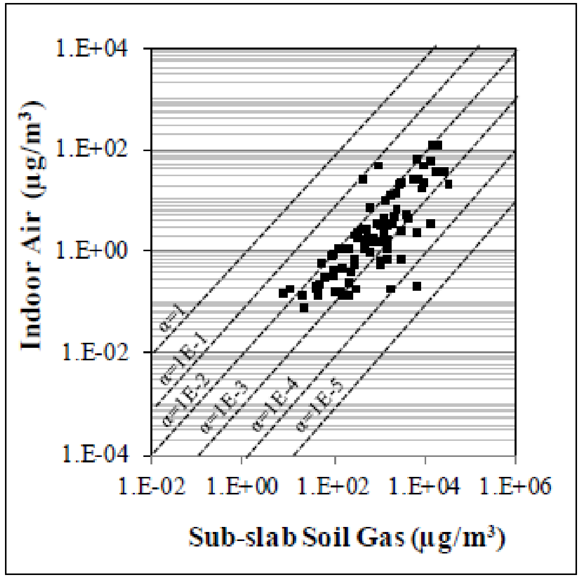
by Ravi V. Kolhatkar, Matthew A. Lahvis, Ian Hers, John T. Wilson, Emma (Hong) Luo and Parisa Jourabchi

Abstract

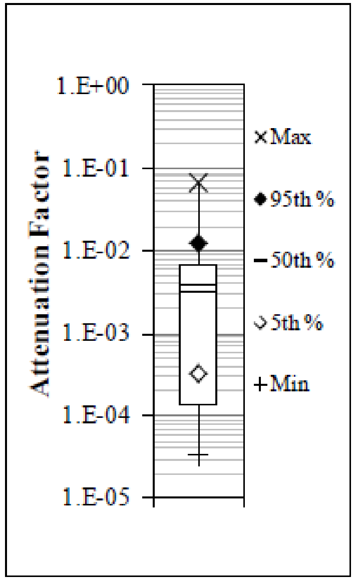
Vapor intrusion (VI) involves migration of volatile contaminants from subsurface through unsaturated soil into overlying buildings. In 2015, the US EPA recommended an approach for screening VI risks associated with gasoline releases from underground storage tank (UST) sites. Additional assessment of the VI risk from petroleum hydrocarbons was deemed unnecessary for buildings separated from vapor sources by more than recommended vertical screening distances. However, these vertical screening distances did not apply to potential VI risks associated with releases of former leaded gasoline containing 1,2-dichloroethane (1,2-DCA), because of a lack of empirical data on the attenuation of 1,2-DCA in soil gas. This study empirically evaluated 144 paired measurements of 1,2-DCA concentrations in soil gas and groundwater collected at 47 petroleum UST sites combined with BioVapor modeling. This included (1) assessing the frequency of 1,2-DCA detections in soil gas below 10^{-6} risk-based screening levels at different vertical separation distances and (2) comparing the US EPA recommended vertical screening distances with those predicted by BioVapor modeling. Vertical screening distances were predicted for different soil types using aerobic biodegradation rate constants estimated from the measured soil-gas data combined with conservative estimates of source concentrations. The modeling indicates that the vertical screening distance of 6 feet (1.8 m) recommended for dissolved-phase sources is applicable for 1,2-DCA below certain threshold concentrations in groundwater, while 15 feet (4.6 m) recommended for light nonaqueous phase liquid (LNAPL) sources is applicable for sites with clay and loam soils in the vadose zone, but not sand, if 1,2-DCA concentrations in groundwater exceed 150 µg/L. This dependence of the predicted vertical screening distances on soil type places added emphasis on proper soil characterization for VI screening at sites with 1,2-DCA sources. The soil-gas data suggests that a vertical screening distance of 15 feet (4.6 m) is necessary for both dissolved-phase and LNAPL sources.

Subslab to Indoor Air Vapour Attenuation Factors

CCME (2014) Soil Vapour Guidelines



Statistics	AF Value
Min	3.4E-05
5th %	3.3E-04
25th %	1.4E-03
50th %	3.4E-03
75th %	5.9E-03
95th %	1.2E-02
Max	6.7E-02
Sample Count*	92 (90CHC+2PHC)
No. of Site	5



*: sample number for Chlorinated Hydrocarbons (CHC) and for Petroleum Hydrocarbon (PHC)
[1]: samples collected in all buildings, labelled as commercial, residential/commercial, commercial/residential, school/commercial

- Subslab AF = 0.01 for commercial/industrial buildings (95th percentile USEPA database)
- Small dataset, typically small commercial buildings
- Overly conservative based on recent studies

Current Research Commercial/Industrial

- AFs expected to vary widely depending on building size/type/HVAC
- Hers (2018) summarize AF studies:
  - US DOD recommended AF based on multiple buildings: **1E-3** for soil vapor and **1E-4** for groundwater
  - Golder data: Geometric mean AF based on multiple samples for individual buildings ranges from **7.7E-05** to **2.2E-03**
- California and Michigan in process of compiling subslab AF data
- Would benefit from obtaining data from Canadian sites
- Modeling also useful to bracket range in AFs (e.g., Brewer et al. 2014)

Hers 2018. Improved Approaches for Vapor Intrusion Assessment of Non-residential Buildings. AWMA Conference on Vapor Intrusion, Remediation, and Site Closure, Phoenix, Arizona December 5 - 6, 2018

Conclusions

- Different approaches needed for petroleum and chlorinated solvent chemicals
- Vertical exclusion distance approach supported based on field data, modeling studies and empirical database studies
- Vertical screening distance approach consistent with science
- Empirical database studies performed by US EPA and CRC Care (Australia) consisting of thousands of data points, which support vertical screening distances of
  - 5 ft (1.5 m) for dissolved-phase sites
  - 15 ft (4.6 m) for LNAPL – UST/AST sites
- Important to consider precluding factors
- Opportunity to incorporate vertical screening distances (or hybrid bioattenuation factor/distance) approaches in Canadian regulatory frameworks
- Gaps include improved knowledge of bioattenuation for colder climate site conditions (although already a sizeable data set) and different building sizes/types

Question: Would vertical screening distance approach be useful?
Proposed R&D project: Collaborative multi-stakeholder/organization effort to assess 1) PHC bioattenuation and screening distances and 2) subslab to indoor air attenuation factors. Data sources could include US EPA database (e.g., select sites in northern states) and additional data from Canadian sites. Seeking interest of individuals/organizations to participate and provide data.

Thank You!

Ian Hers (ihers@golder.com)