Evaluating the Petroleum Vapor Intrusion Pathway

Studies of Natural Attenuation of Subsurface Petroleum Hydrocarbon Vapors and Recommended Screening Criteria

Workshop 7
Tuesday March 19, 2013, 6:30 pm – 9:30 pm

Association for Environmental Health & Sciences (AEHS)
23rd Annual International Conference on Soil, Sediment, Water & Energy
San Diego, California

by
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OBJECTIVES

- Understand why so many petroleum sites exist, yet petroleum vapor intrusion (PVI) is very rare.

- Analyze field data to determine thickness of clean soil required to attenuate vapors associated with:
  - **Dissolved sources**
  - **LNAPL & soil sources**

- Develop Screening (Exclusion) Criteria, screen out low-risk sites, avoid unnecessary & costly soil vapor/air sampling

SCOPE

- Petroleum Vapor Database compiled from basic field data:
  - ***Source type & strength (LNAPL, contaminated soil, dissolved-phase), lateral & vertical extent of source, associated vapor concentrations, soil type.***
- Show characteristics, mechanisms, extent & degree/magnitude (vertically & laterally) of petroleum hydrocarbon vapor biodegradation & attenuation

Petroleum Vapor Database

International Compilation of Paired Measurements of Concurrent Contaminant Source Strength & Soil Vapor Data

MAP KEY (e.g. **56/304**)

56	# of geographic locations evaluated
304	# of paired concurrent measurements of benzene subsurface soil vapor & source strength

TOTALS:

170 Sites
925 Measurements

REFERENCES

EPA Jan 2013, 510-R-13-001
Davis, R.V., 2009-2011
Wright, J., 2011, Australian data

NEW !

Jan. 2013

United States Environmental Protection Agency — EPA

EPA 510-R-13-001

Evaluation Of Empirical Data To Support Soil Vapor Intrusion Screening Criteria For Petroleum Hydrocarbon Compounds

U.S. Environmental Protection Agency
Office of Underground Storage Tanks
Washington, DC 20460

http://www.epa.gov/oust/cat/pvi/PVI_Database_Report.pdf

NEW !

Dec. 2012

EPA United States Environmental Protection Agency

Ground Water Issue

An Approach for Developing Site-Specific Lateral and Vertical Inclusion Zones within which Structures Should be Evaluated for Petroleum Vapor Intrusion due to Releases of Motor Fuel from Underground Storage Tanks

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Contents

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ABSTRACT

Buildings may be at risk from Petroleum Vapor Intrusion (PVI) when they overlie petroleum hydrocarbon contamination in the unsaturated zone or dissolved contamination in ground water. The U.S. EPA Office of Underground Storage Tanks (OUST) is preparing *Guidance for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*. The OUST guidance provides general screening criteria that can be used to identify structures that are at risk from PVI. The criteria are used to determine if a structure is included within a lateral or vertical zone where proximity to the contaminant might make the building vulnerable to PVI. If the structure is within a lateral or vertical inclusion zone, then additional investigation is necessary to evaluate and manage exposure to the vapors.

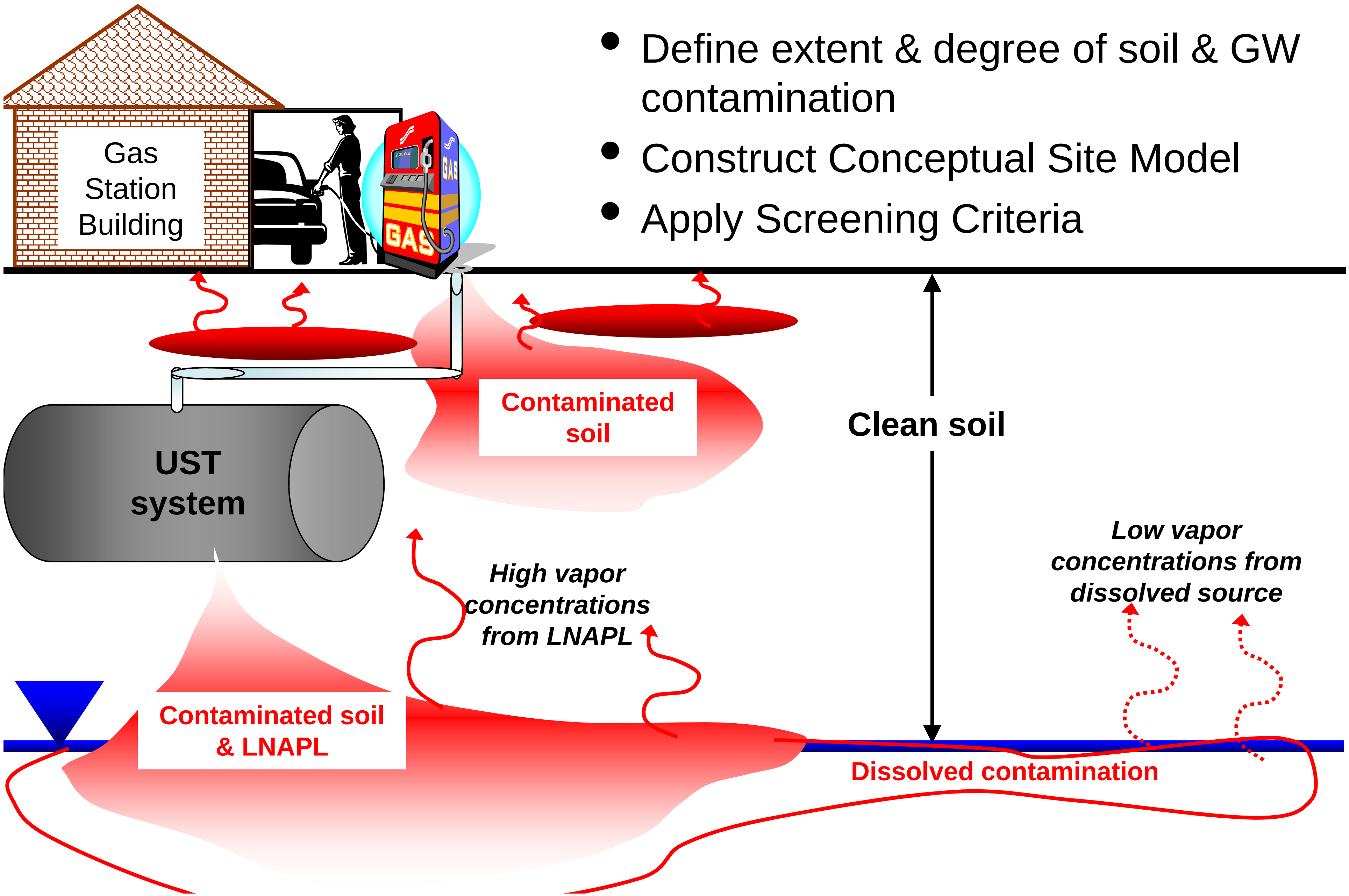
This Issue Paper contains technical suggestions and recommendations proposed by the U.S. EPA Office of Research and Development for applying the criteria provided in the OUST guidance. The Issue paper provides a graphical approach to define a lateral inclusion zone based on the proximity of a structure to the presumed maximum extent of contamination. The presumed maximum extent of contamination is defined by a perimeter of clean monitoring locations that are arranged around the known source of contamination. The lateral inclusion zone is extended past the presumed maximum extent of contamination to allow for uncertainty of the concentrations of contaminants in the space between monitoring locations. The Issue Paper provides instructions and suggestions to use knowledge of ground water flow to refine the lateral exclusion zone, and reduce the area where additional investigation is necessary. The Issue Paper provides recommendations on collecting and analyzing core samples to determine the vertical extent of contamination in the unsaturated zone, and water samples to determine the extent of contamination in ground water. The Issue Paper provides illustrations of the appropriate comparison of the field data to the criteria in the OUST Guidance. In combination, definition of lateral and vertical inclusion zones makes the best use of site characterization data for assessing the risk of PVI to structures at a LUST site. The procedures

EPA/600/R-13/008

Practical Application of Screening Criteria

Characterize Site

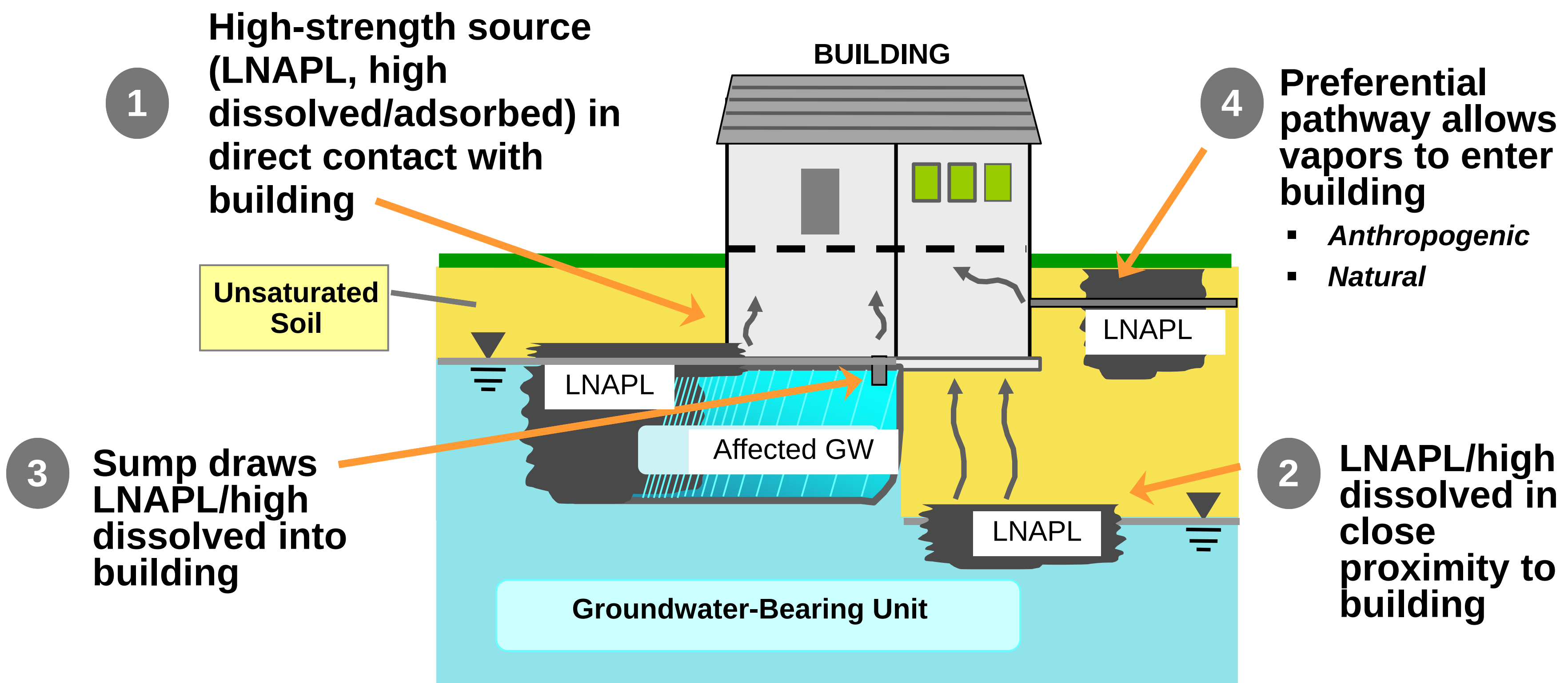
- Define extent & degree of soil & GW contamination
- Construct Conceptual Site Model
- Apply Screening Criteria



Results of Studies of Subsurface Petroleum Vapor Bioattenuation

- >100 years of published research proves biodegradation of PHCs by 1000s of indigenous microbial species
- Empirical database studies show PHC vapors bio-attenuate within a few feet of clean (oxygenated) surrounding soil
- No cases of PVI from low-strength sources
- Causes of PVI are well-known

Causes of Petroleum Vapor Intrusion

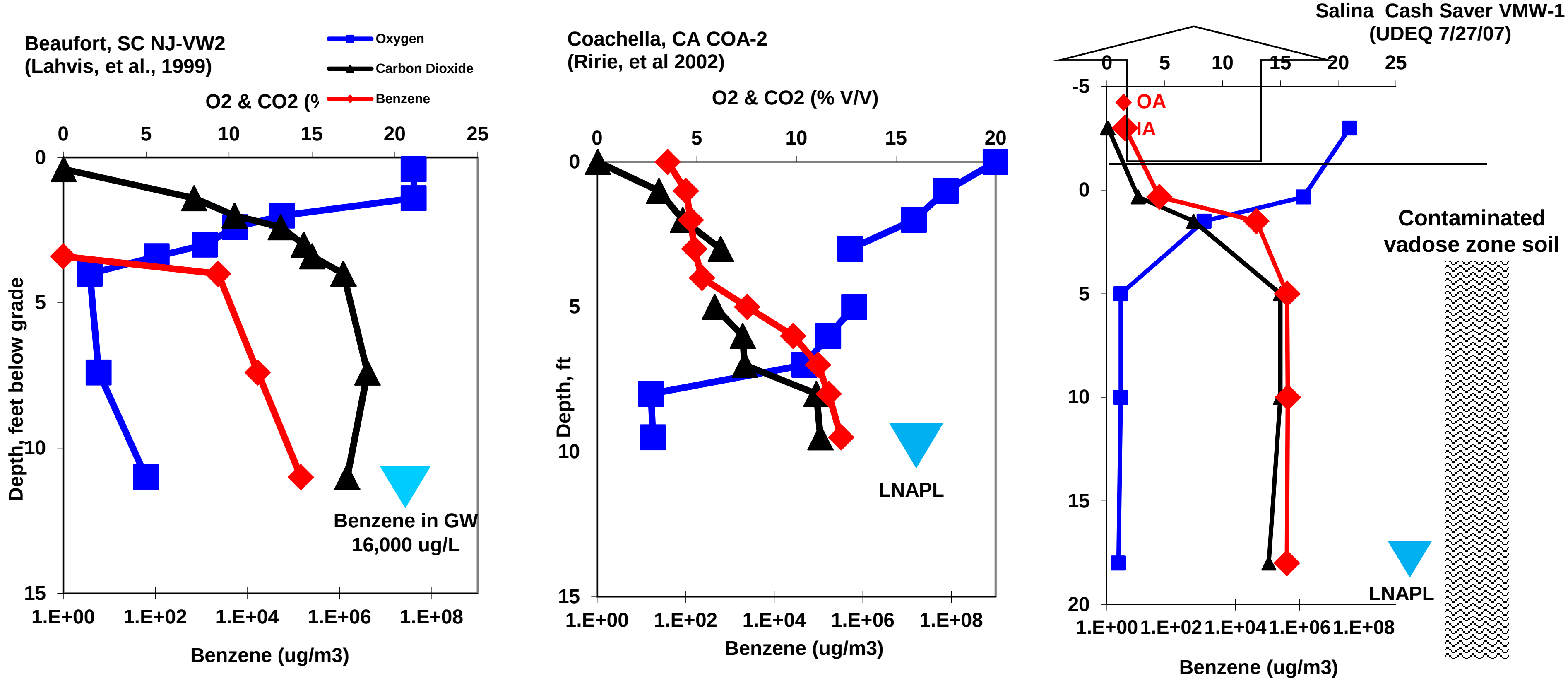


KEY POINTS:

- Vapor intrusion caused by very high-strength sources in direct contact or close proximity to buildings/utilities
- High-strength sources: LNAPL & very high-concentration dissolved & adsorbed sources

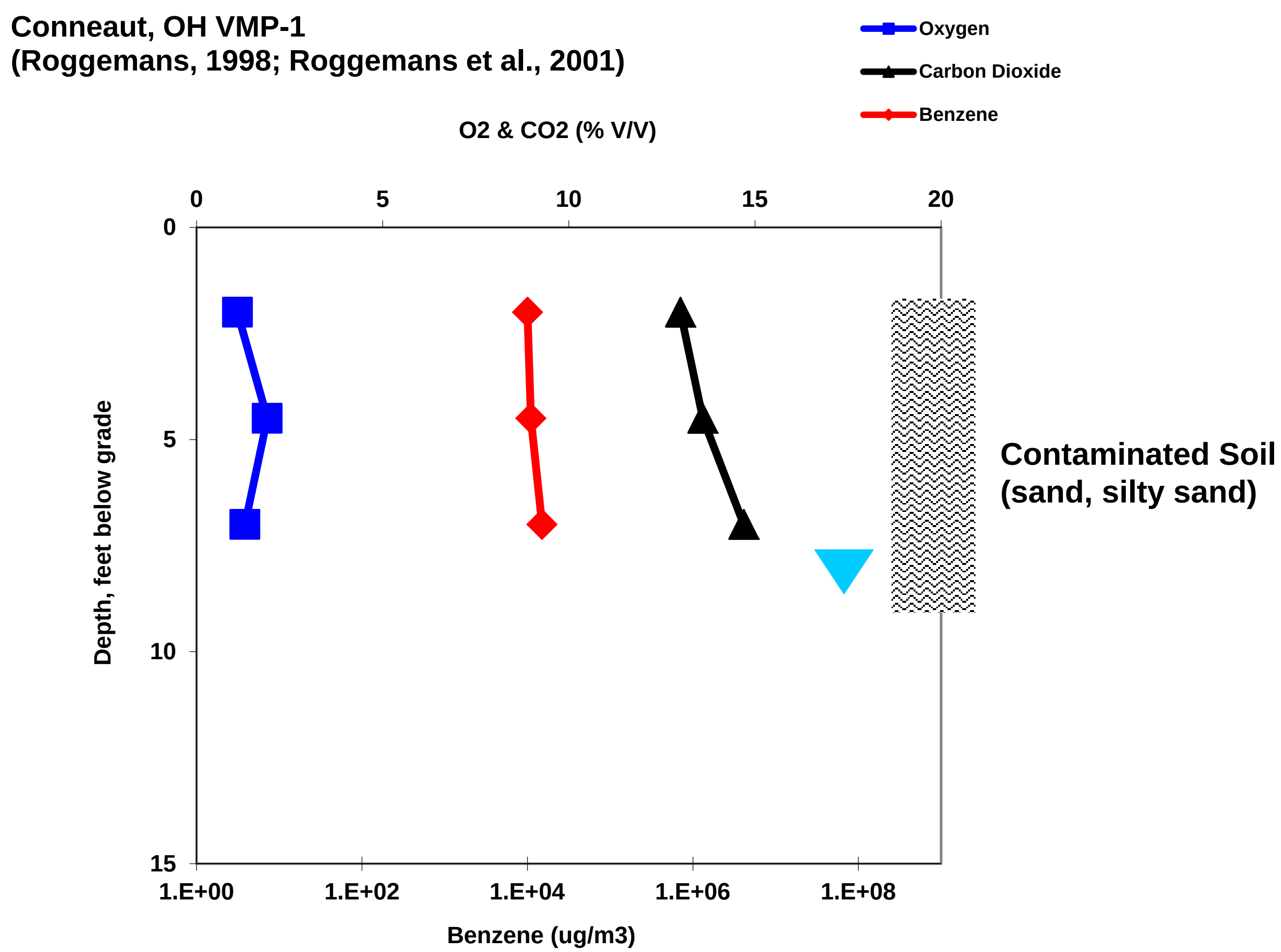
Drawing after Todd Ririe, 2009

Signature Characteristics of Aerobic Biodegradation



- Typical O_2, CO_2, PHC vapor profiles: petroleum vapors naturally biodegrade & attenuate given sufficient thickness of clean vadose zone soil
- 1000's of similar measurements have yielded consistent, predictable results: distance required for vapor attenuation can be quantified and screening criteria developed

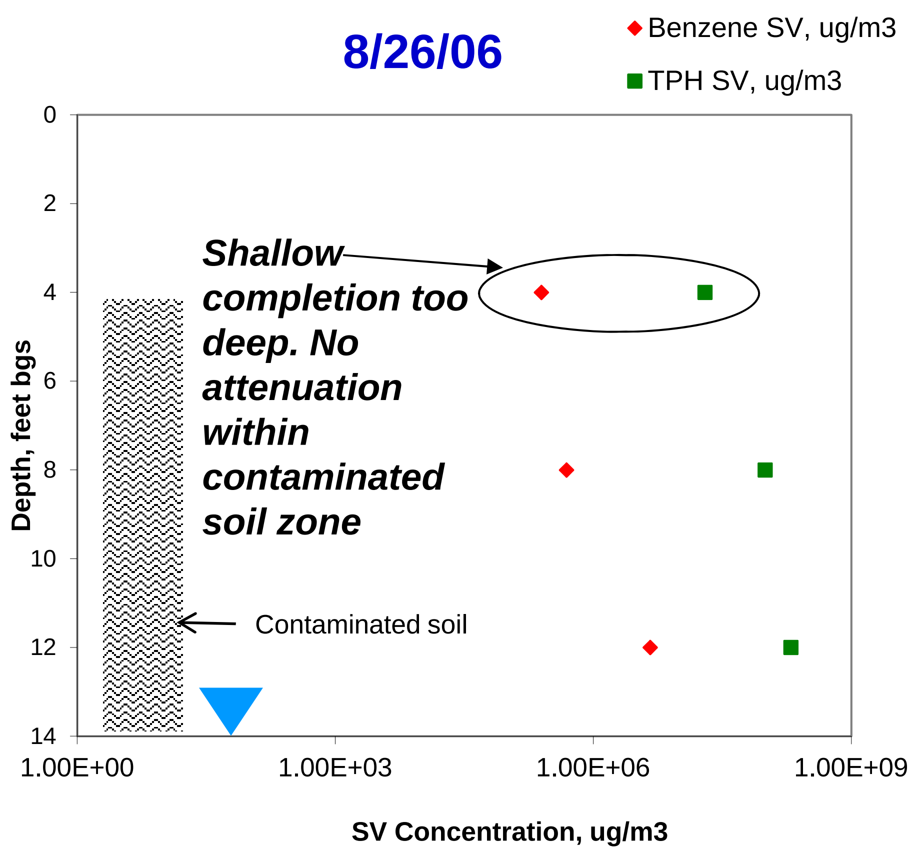
Non-Attenuation of Vapors Due to Lack of Clean Overlying Soil

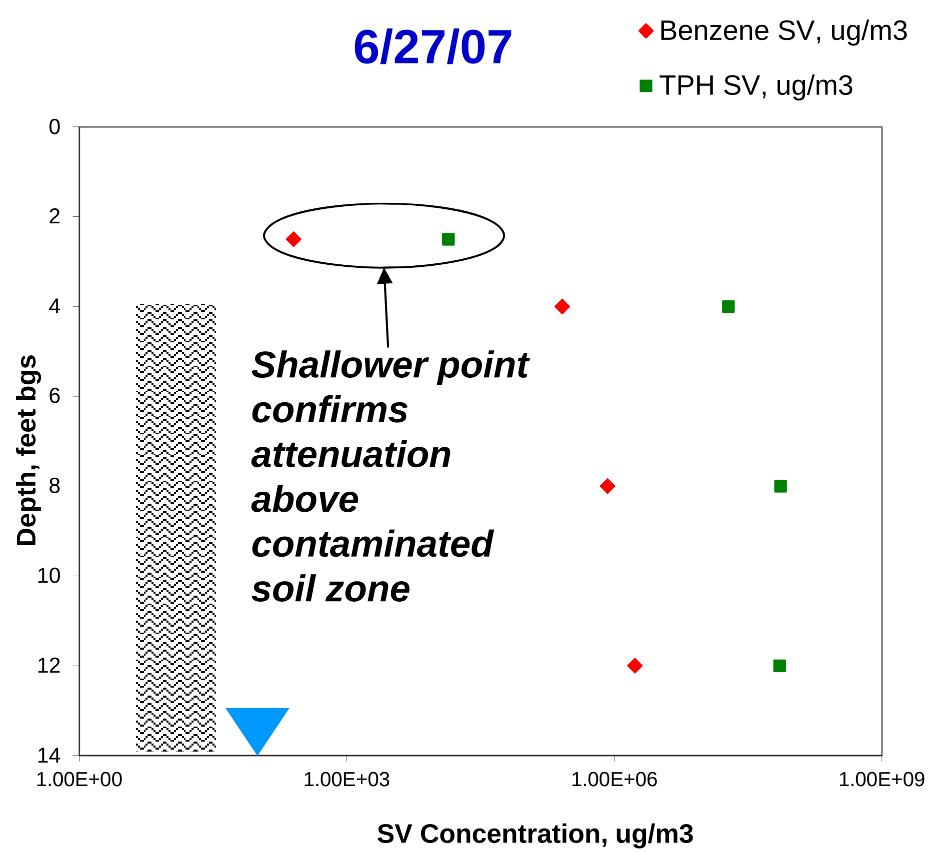


Importance of Shallow Vapor Completion Points

Example of apparent non-attenuation
until shallow soil vapor point installed

VW-11 Hal's, Green River, Utah





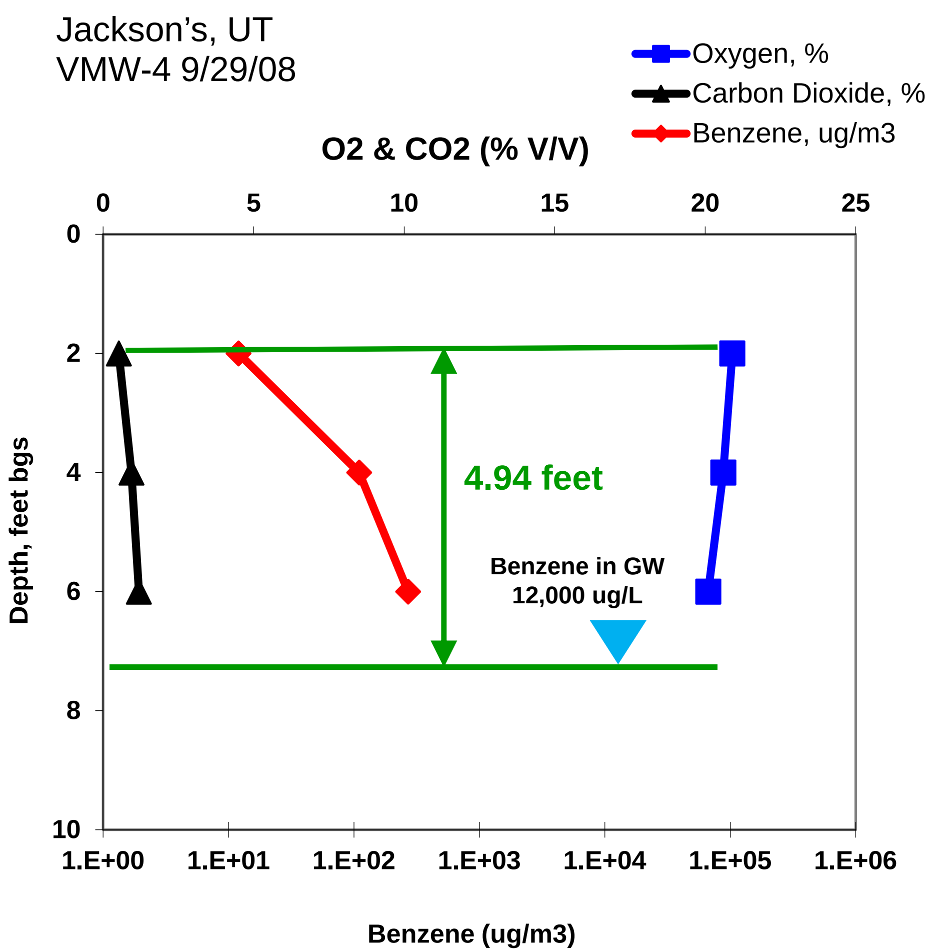
Methods for Developing Screening/Exclusion Criteria

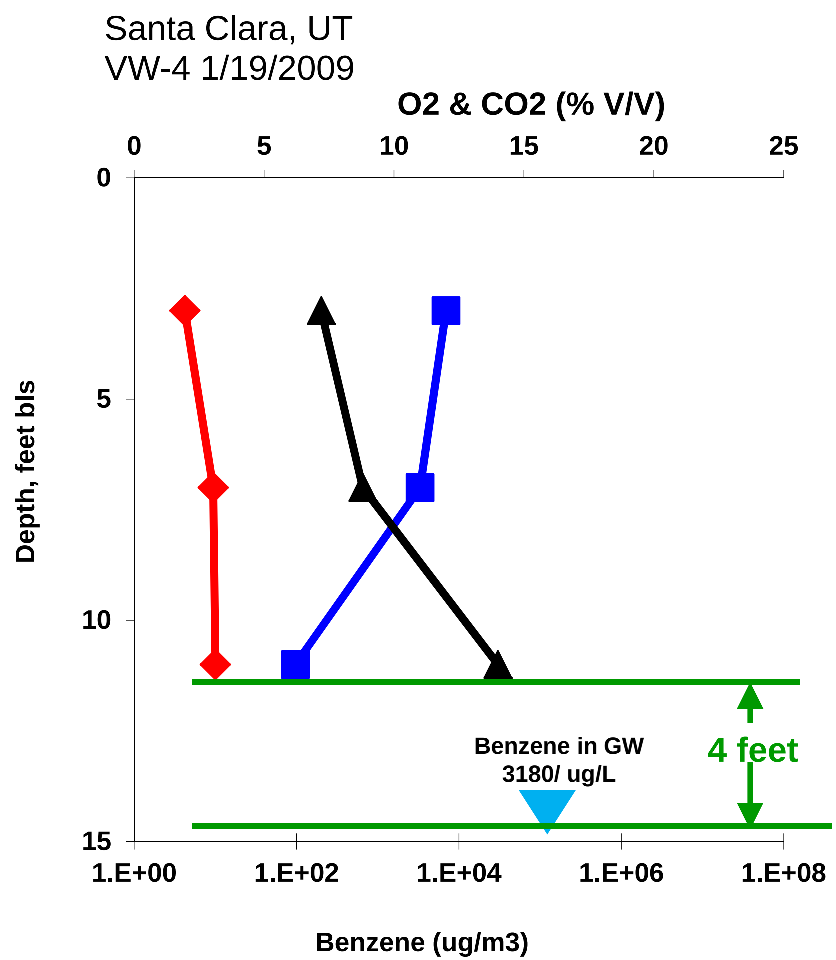
Determine thickness of clean surrounding soil required to attenuate vapors associated with:

- Dissolved sources
- LNAPL and soil sources

Method for Dissolved Sources

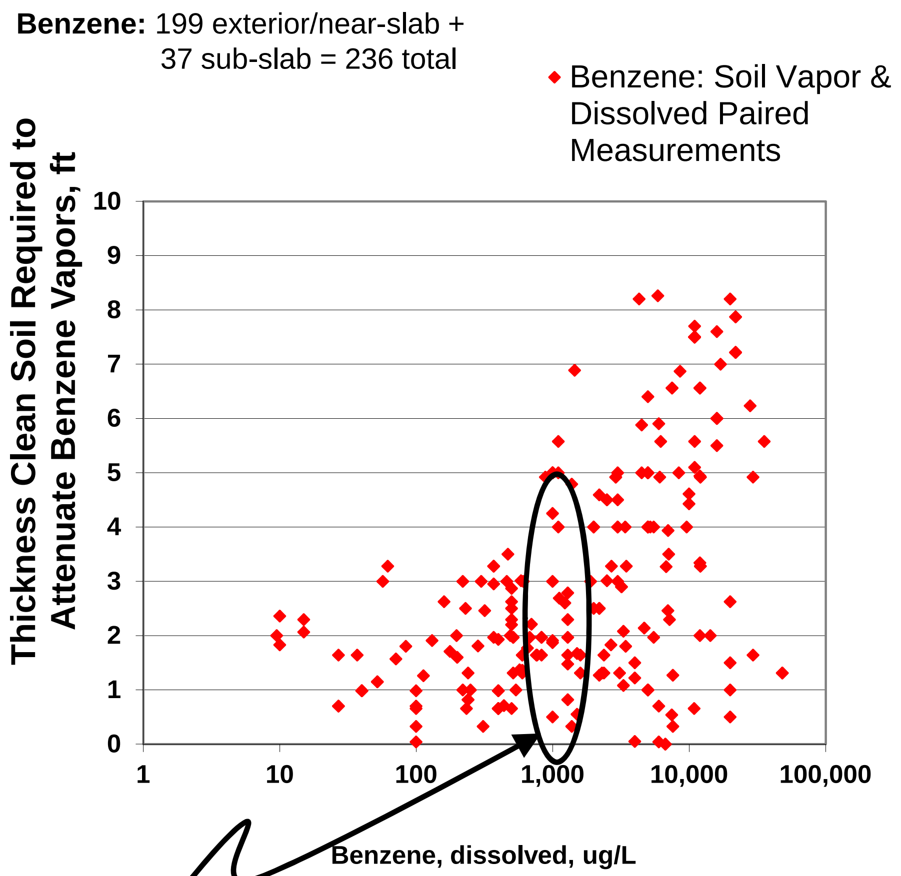
Formula: Distance between top of dissolved groundwater source and deepest clean vapor point = thickness of clean soil (feet) needed to attenuate vapors

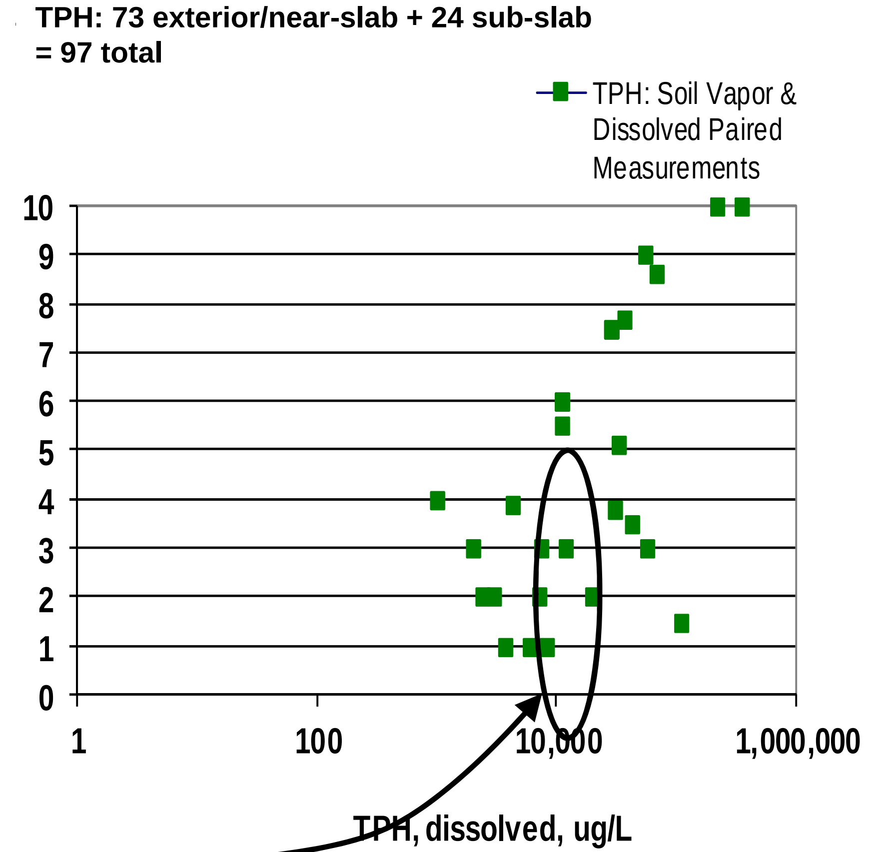




Screening Criteria for Dissolved Benzene & TPH

(Exterior + Sub-Slab, all soil types, UST and non-UST sites)



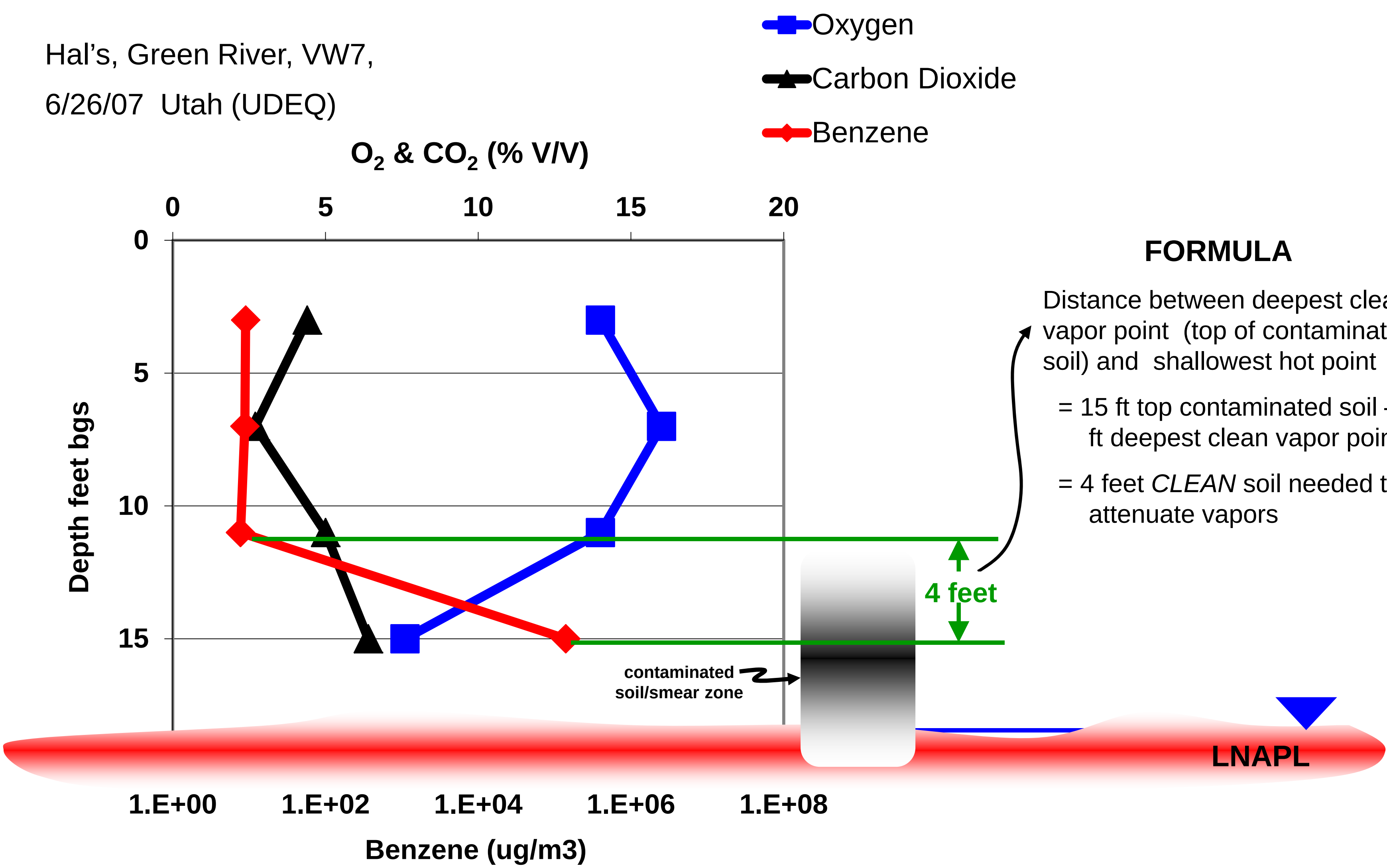


5 ft CLEAN overlying soil attenuates vapors associated with dissolved benzene ≤1,000 ug/L, TPH ≤10,000 ug/L

Method LNAPL & Soil Sources

Hal's, Green River, VW7,

6/26/07 Utah (UDEQ)



FORMULA

Distance between deepest clean vapor point (top of contaminated soil) and shallowest hot point

= 15 ft top contaminated soil – 11 ft deepest clean vapor point

= 4 feet *CLEAN* soil needed to attenuate vapors

Results for LNAPL & Soil Sources

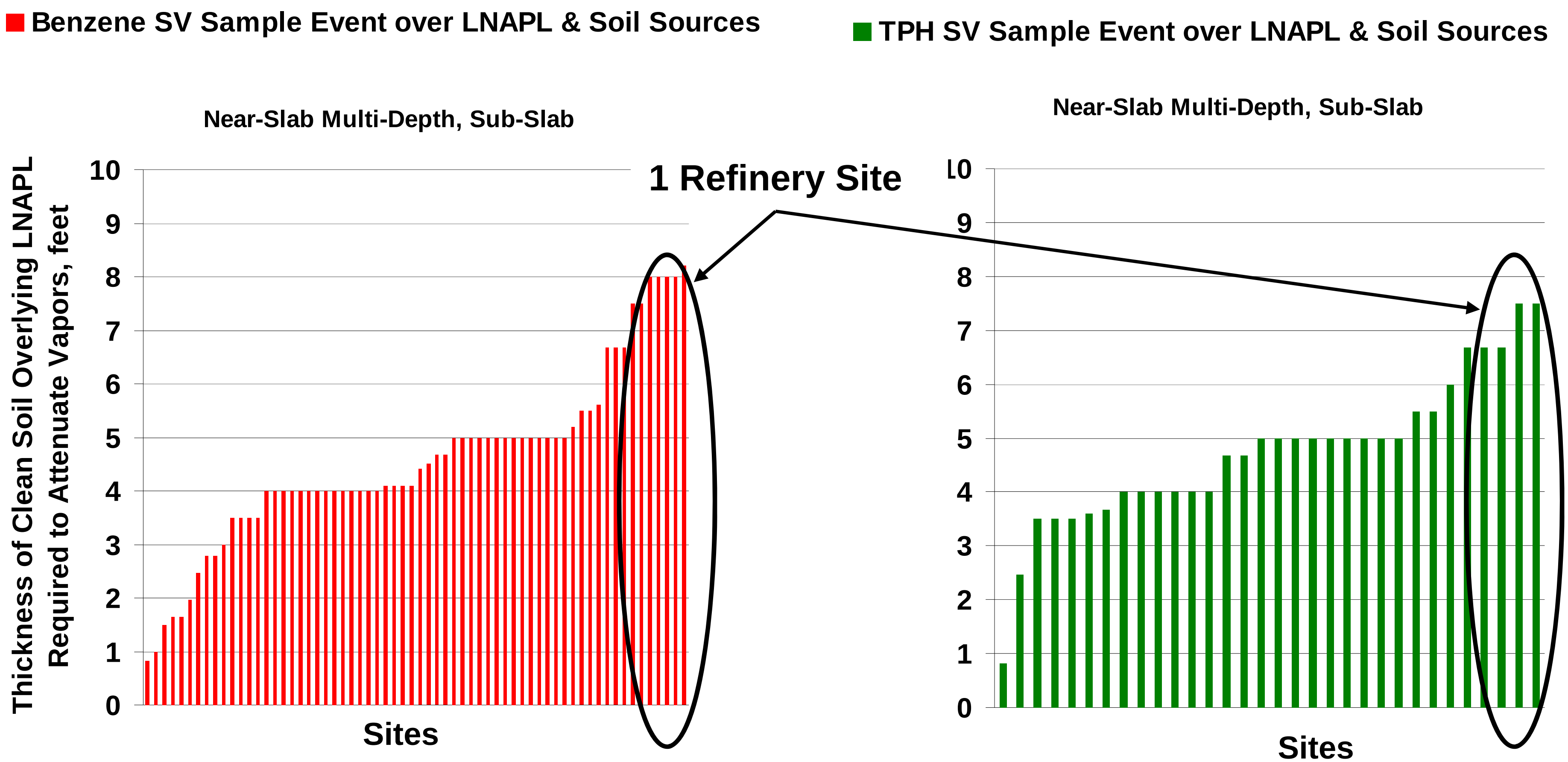
(Exterior + Sub-Slab, all soil types, UST and non-UST sites)

Benzene

48 exterior/near-slab + 23 sub-slab = 71 total

TPH

17 exterior/near-slab **+ 19 sub-slab = 36 total**



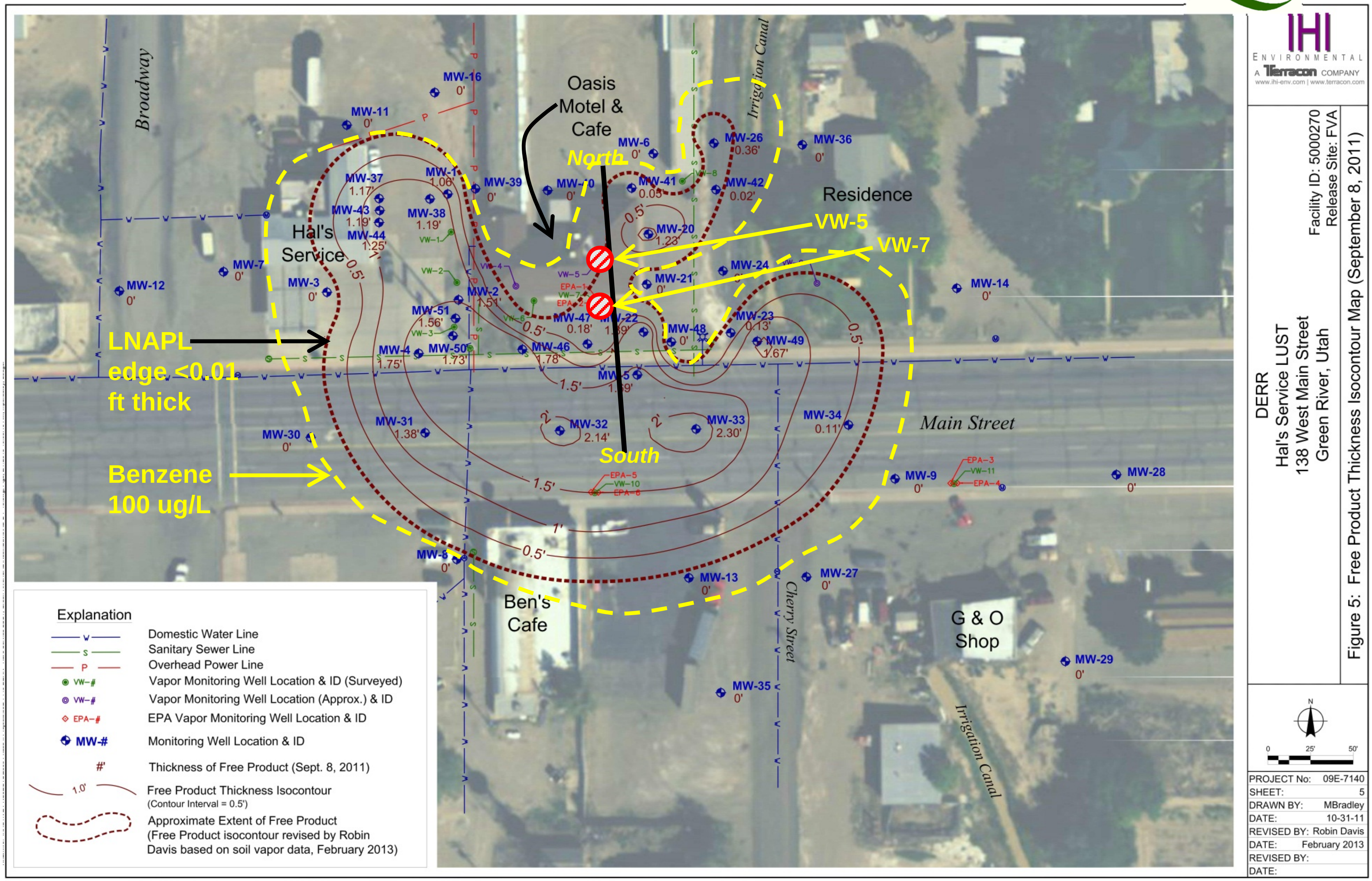
8 ft CLEAN overlying soil attenuates vapors associated with LNAPL and Soil Sources

CASE STUDY

Hal’s, Green River, Utah

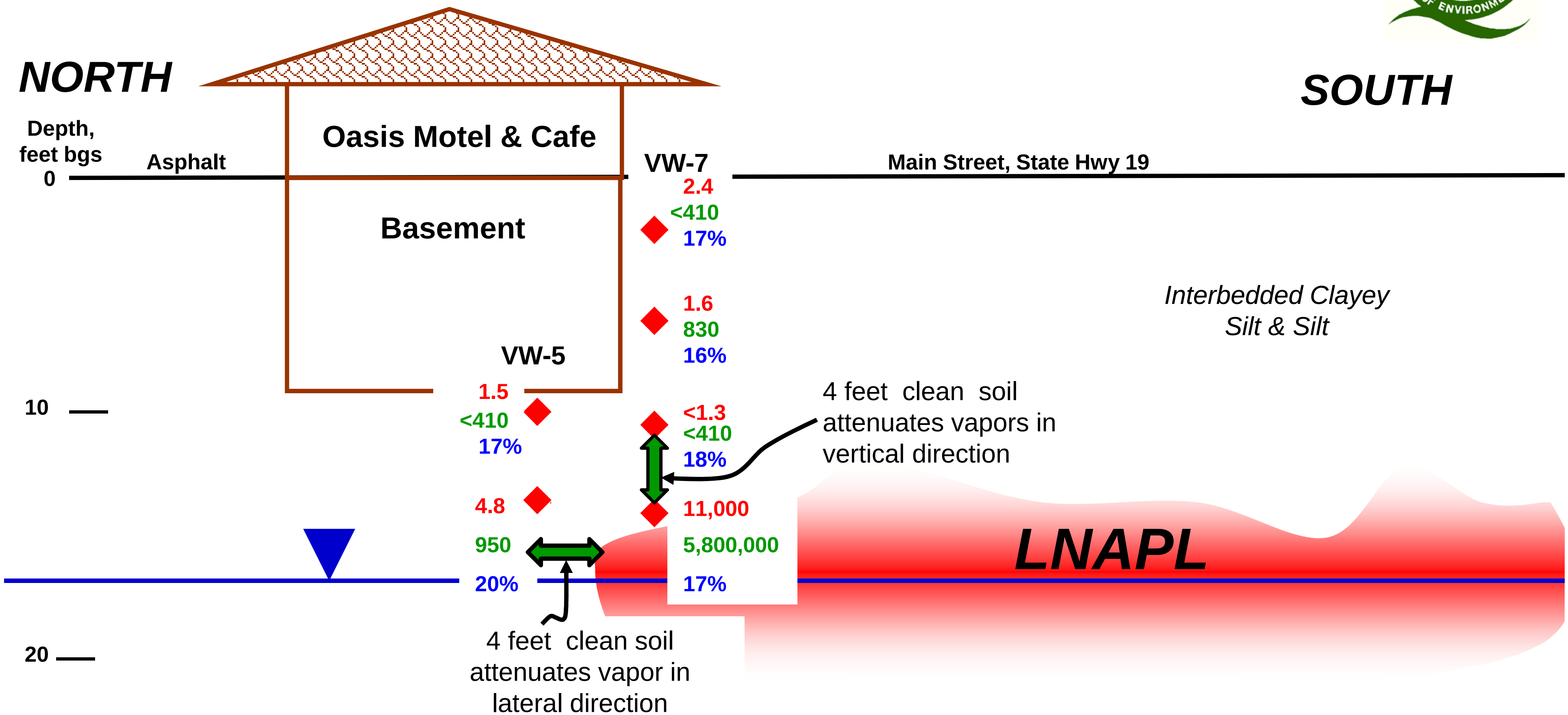
- Well-characterized site
- Extensive LNAPL plume, associated dissolved-phase
- All characteristics of vapor attenuation relative to source strength are shown

Site Map (Hal's Green River, Utah, UDEQ, 9/8/11)



Cross-Section

Hal's Green River



FIELD STUDY RESULTS:

- Vapors associated with LNAPL attenuate vertically & laterally in the same distance.
- Oxygen not occluded by large building or asphalt/concrete area.

KEY

VW-7	Multi-depth vapor monitoring well
◆	Sub-Surface vapor sample point
260,000	Benzene, ug/m3
33,000,000	TPH-gro, ug/m3
2.5%	Oxygen, %

0 50

Feet, horizontal

Comparison of Field Data to Models that Account for Biodegradation & Attenuation

- Abreu & Johnson Numerical Model
- BioVapor Analytical Model

Numerical Model (Abreu & Johnson, Abreu 2009)

Effect of Oxygen-Driven Biodegradation & Magnitude of Subsurface Attenuation of Petroleum Hydrocarbon Vapors Beneath Buildings

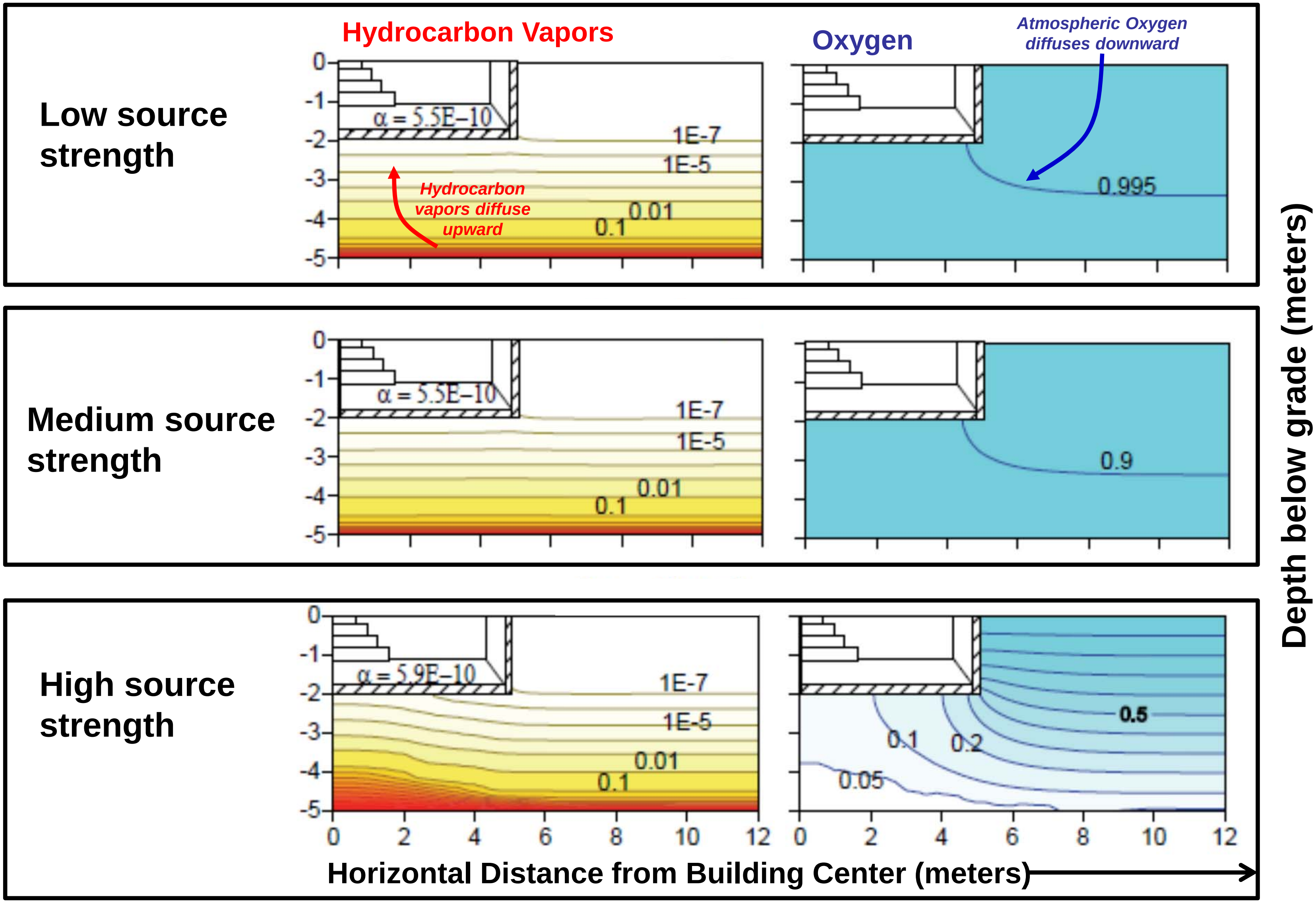


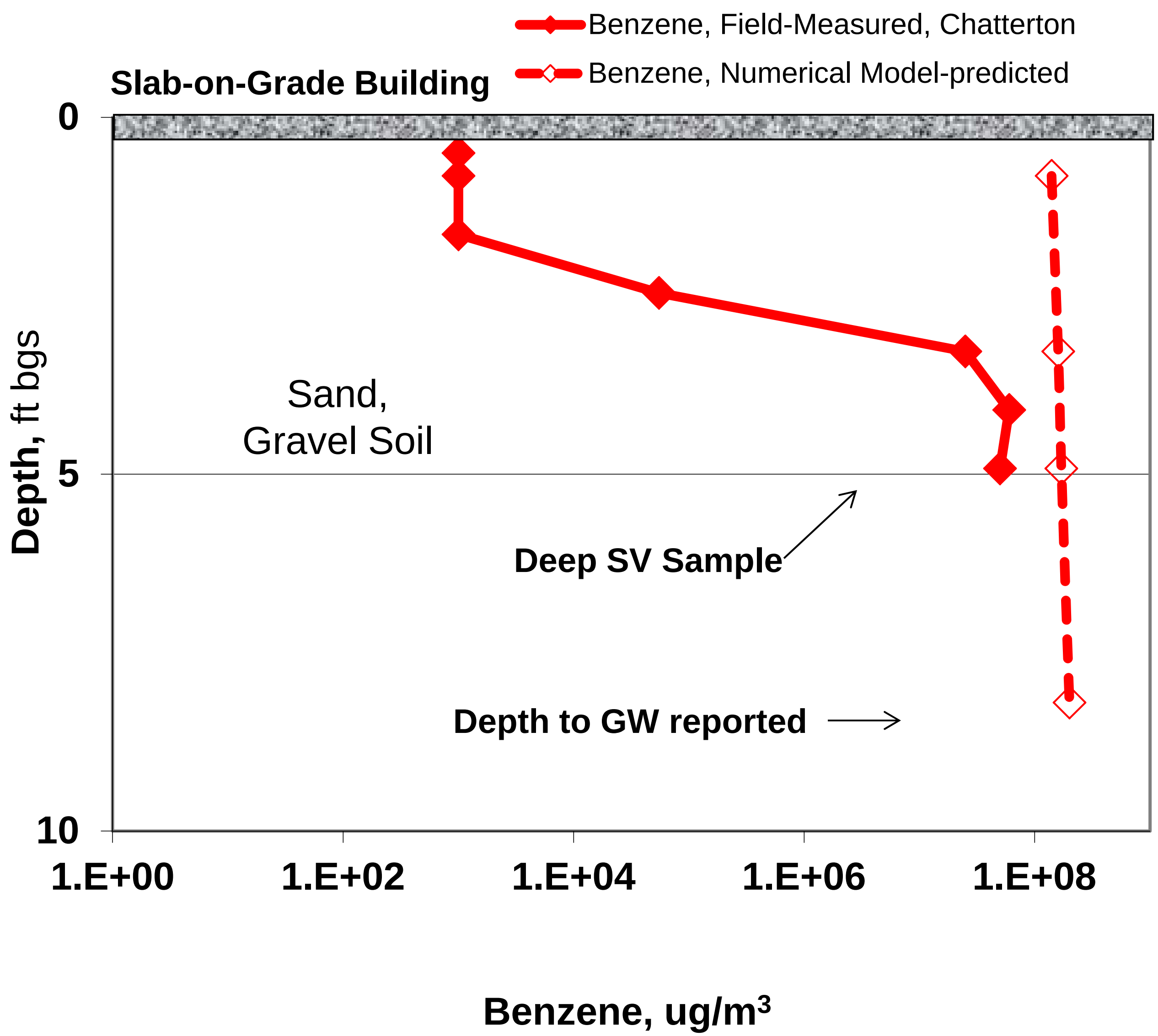
Figure 3—Effect of low vapor source concentration (Cvs) on soil gas concentration distribution and vapor

Field-Measured Data Compared to Numerical Model

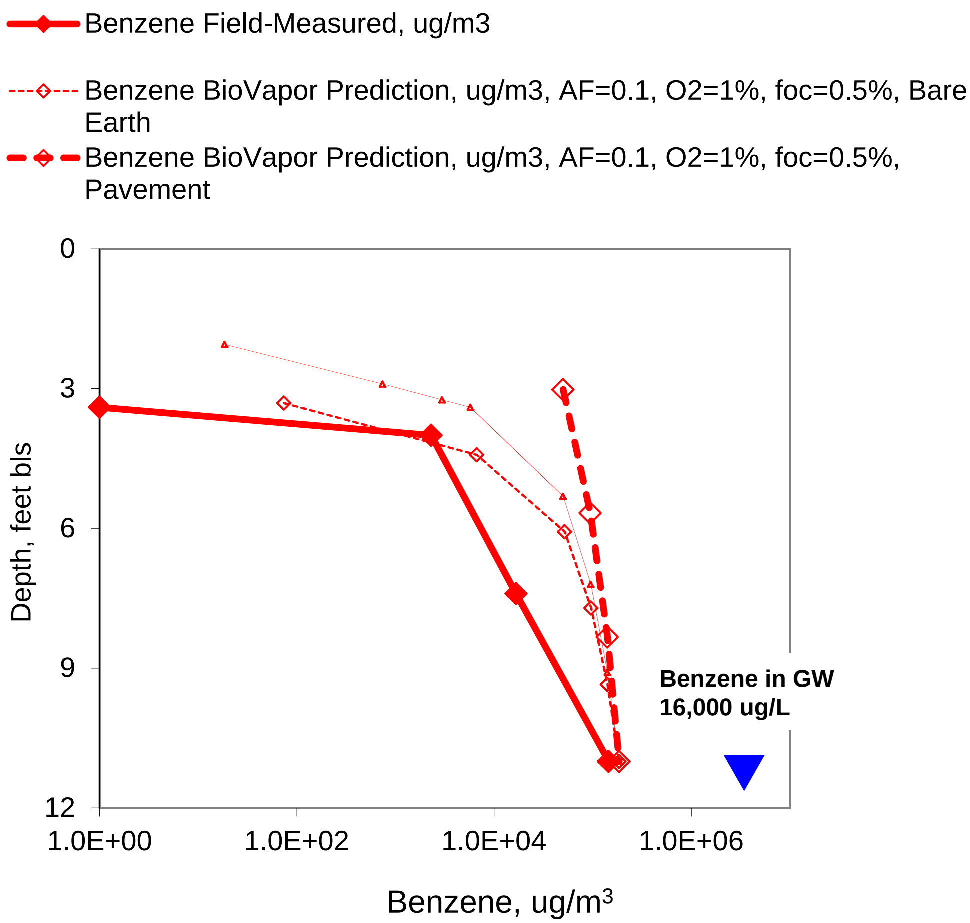
Chatterton Research Site, British Columbia, Canada
(Hers et al 2000)

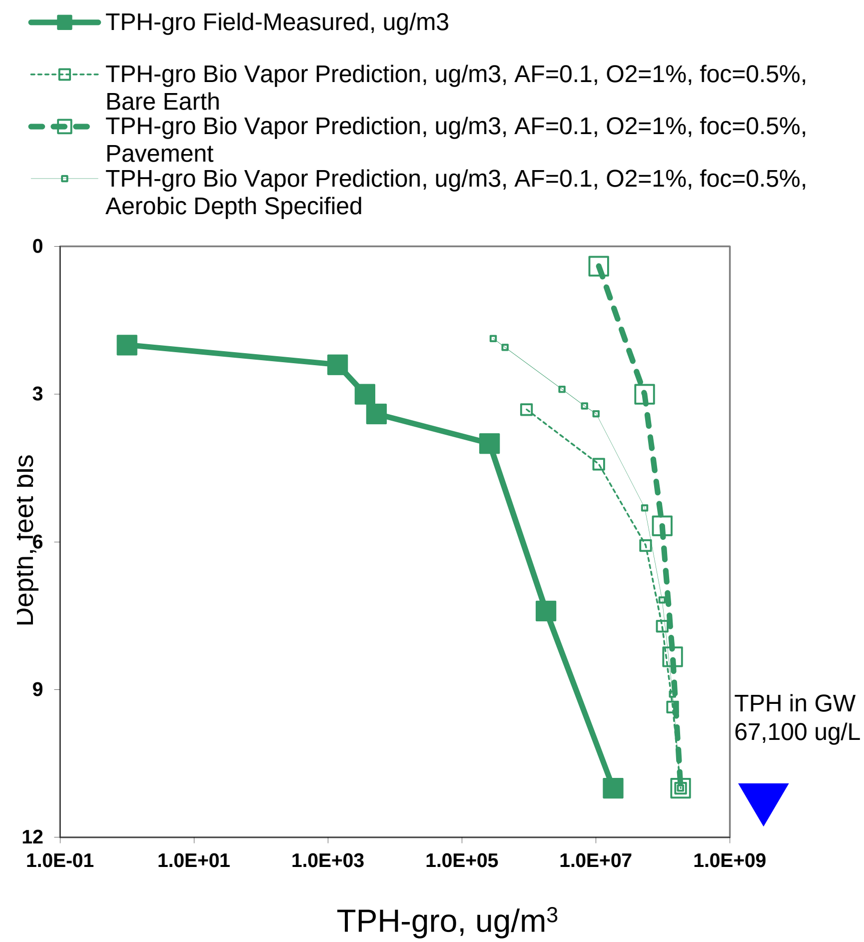
RESULTS:

- Field data show O_2 is NOT occluded, biodegradation NOT impeded by small building located ~9 ft above LNAPL source
- Model under-predicts attenuation by up to 10,000x (>1E+4)



Beaufort, South Carolina (Lahvis et al 1999) Compared to BioVapor Model





RESULTS BioVapor Model under-predicts subsurface attenuation by 100x to 10,000x

Conclusions from Models

- Models under-predict attenuation by >>100x = conservative estimation of natural processes

- Low-to-medium source strength vapors beneath average-size buildings attenuate with a few feet of clean overlying soil

- Oxygen occlusion beneath building only with high vapor concentrations at shallow depths

Method for Measuring Magnitude of Subsurface Vapor Attenuation

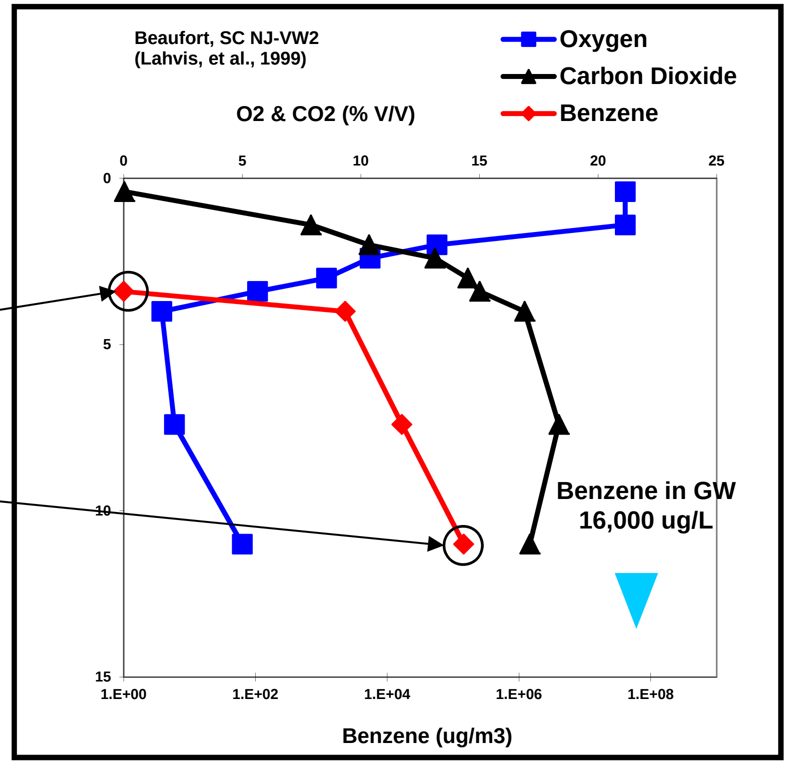
"Attenuation Factor" AF
= Ratio of Shallow Vapor Concentration Divided by Deep

$$AF = \frac{\text{Shallow SV Benzene, ug/m}^3}{\text{Deep SV Benzene, ug/m}^3}$$

Field Example:

$$AF = \frac{\sim 1\ \text{ug/m}^3}{145{,}000\ \text{ug/m}^3} = 7E\text{-}06$$

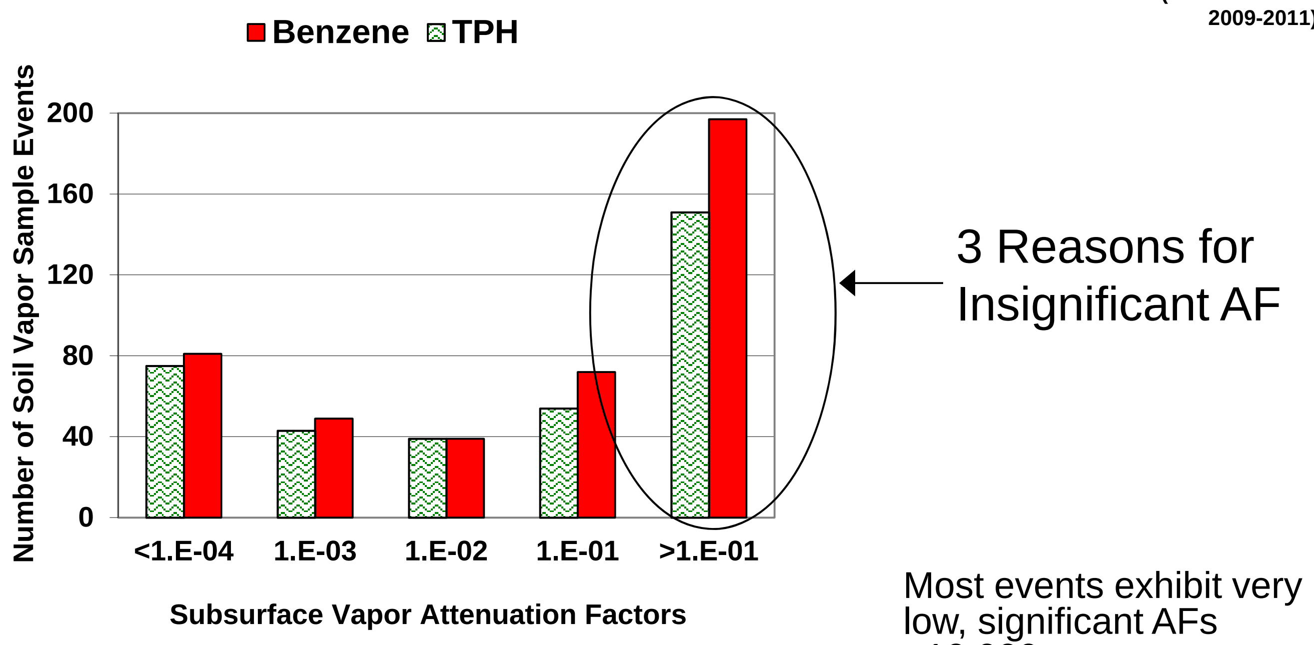
~1,000,000x contaminant reduction

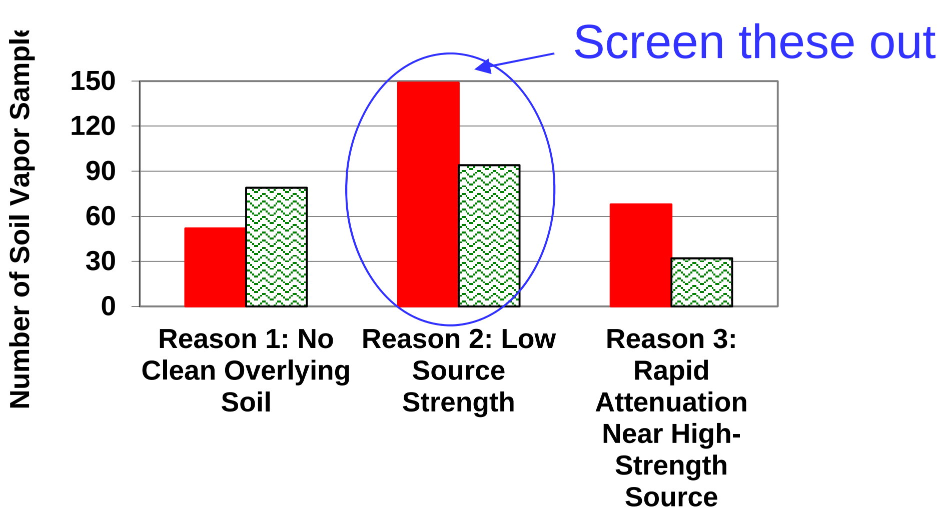


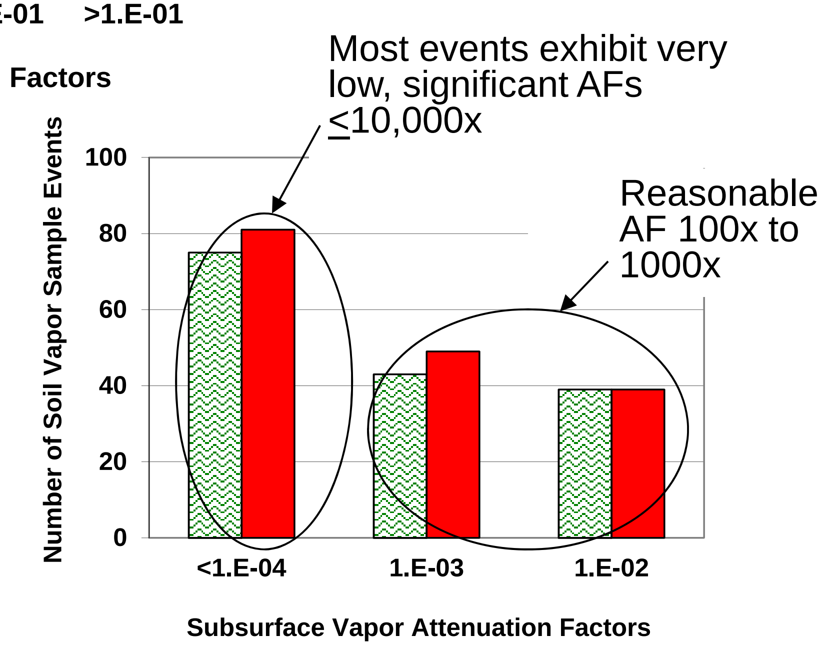
Low AF Value
= High Attenuation of Contaminant Concentrations
= "Significant Attenuation"
= If AF $\leq$ 0.001 then Attenuation $\geq$1000-fold

Distribution of Magnitude of Subsurface Petroleum Vapor Attenuation Factors

(RV Davis database, 2009-2011)







Screening Criteria–Published & Cited Values (after Lahvis & DeVaull, 2011)

Reference	Database & Site Type	Benzene SG Screening Level (ug/m^3)	Screening/ Exclusion Distance (feet)	Screening/Exclusion Concentration Benzene, TPH (ug/L)	Other Criteria
EPA OUST 510-R-13-001	International Petroleum Vapor Database	50,100	5.4 13.5-15	≤5000, ≤30,000 LNAPL	UST sites. 18 ft for non-UST LNAPL sites. Clean soil <250 mg/kg TPH
Davis, R.V. (2009-2012)	International Petroleum Vapor Database	Non-detect (0-<1000)	5 8	≤1000, ≤10,000 LNAPL	UST and non-UST sites.
Lahvis et al (2013)	R.V. Davis & J. Wright	30, 50, 100	0 13	<15,000 LNAPL	Dissolved phase only, BTEX <75,000 ug/L. UST retail sites only
McHugh et al (2010)	Empirical database (Colorado, Davis 2006), & published literature		10 30	<1000, 10,000 LNAPL	
Peargin & Kolhatkar (2011)	Chevron, all sites		0 15	≤1000 >1000	
Wright, J. (2011)	Australia & U.S. sites, UST+ refineries	10, 50, 100, 1000	5 30	≤1000 LNAPL	
California	various references, R.V. Davis, McHugh et al	50, 100	5 5 10 30	<100 <1000 <1000 LNAPL	no SG Oxygen measured with SG Oxygen measured ≥4% no SG Oxygen measured
Indiana	various references, (RV Davis 2009-2010, McHugh et al 2010)		5 30	≤1000 LNAPL	- no SG Oxygen requirement - AFs for GW & SG - Distances apply vertically & horizontally
			5	<100	no SG Oxygen measured

Conclusions

No Further PVI Investigation Necessary When the Following Conditions Exist:

Clean Soil

- TPH <250 mg/kg, PID <100 ppm-v (gasoline), <10 ppm-v (diesel) contains the necessary O_2 to biodegrade PHCs (> 1% O_2)

Dissolved Sources

- 5 feet clean soil between receptor and groundwater with benzene ≤1,000 ug/L or TPH ≤10,000 ug/L

LNAPL & Soil Sources

- 8 feet to 15 feet clean soil between receptor and LNAPL smear zone and/or LNAPL soil sources

Soil Vapor Sampling

- PHC vapors are attenuated before reaching the receptor
- If measuring soil vapor, analyze O_2, CO_2, methane, and ALL COCs
- Apply 1000-fold subsurface bio-attenuation factor to vapor concentrations if evidence of bio-attenuation is supported by O_2 and CO_2 measurements