Evaluating the Petroleum Vapor Intrusion Pathway

Studies of Natural Attenuation of Subsurface Petroleum Hydrocarbons & Recommended Screening Criteria

NEIWPCC Webinar on Petroleum Vapor Intrusion

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11:30 am-2:00 pm MDT

by
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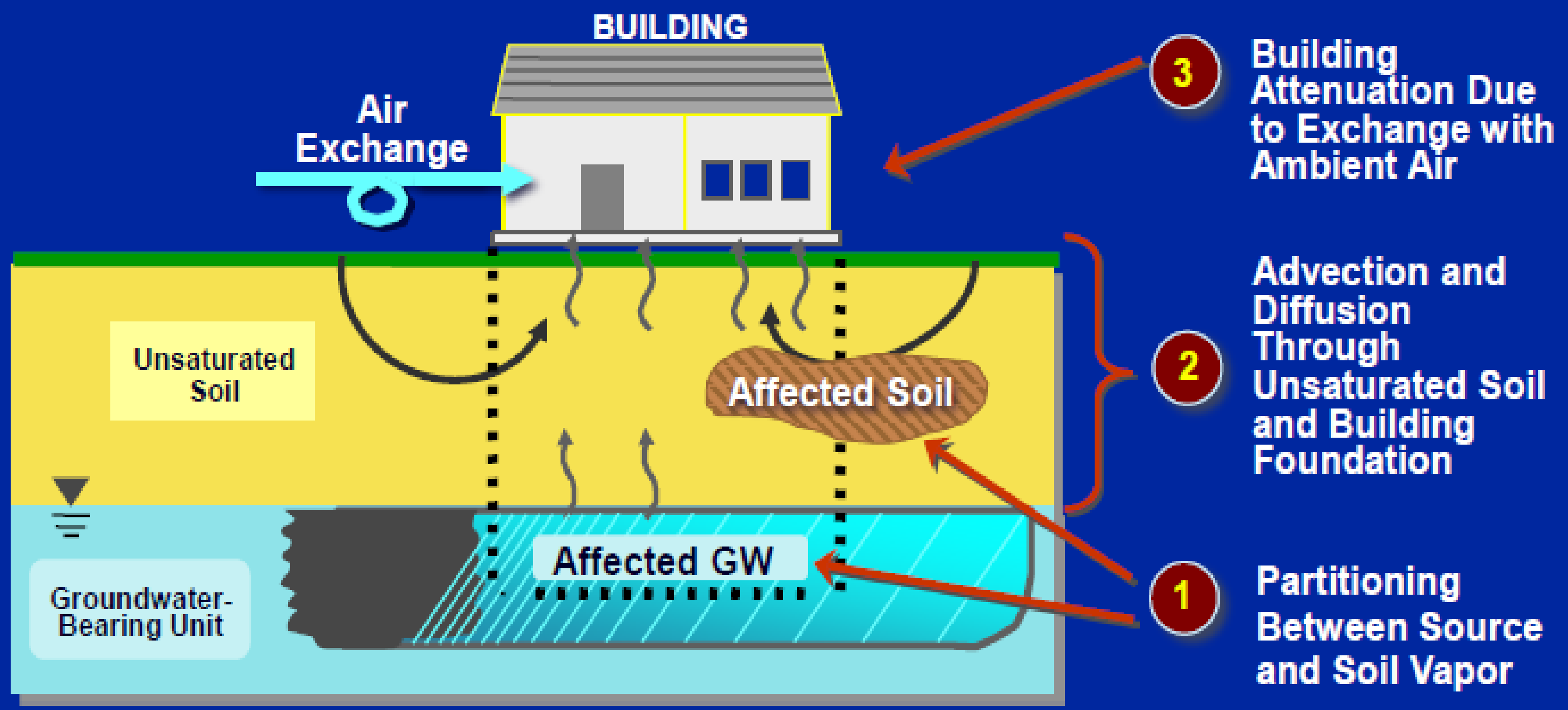
General Conceptual Model for Vapor Intrusion



KEY POINT: **Most VI guidance focused on building impacts due to chlorinated VOC vapor migration.**

Slide provided by Tom McHugh, 2012

OBJECTIVES

- **Understand why there are so many petroleum LUST sites yet petroleum vapor intrusion (PVI) is very rare**
- **Use Screening Criteria to exclude low-risk sites from PVI pathway**

SCOPE

- **Build Petroleum Vapor Database from field studies**

  Soil type, depth to GW, LNAPL presence, contaminant source concentrations

- **Show mechanisms & characteristics of petroleum hydrocarbon vapor biodegradation**

Petroleum Vapor Database

Compilation of concurrent source strength & soil vapor data

~170 Sites

~1000 measurements

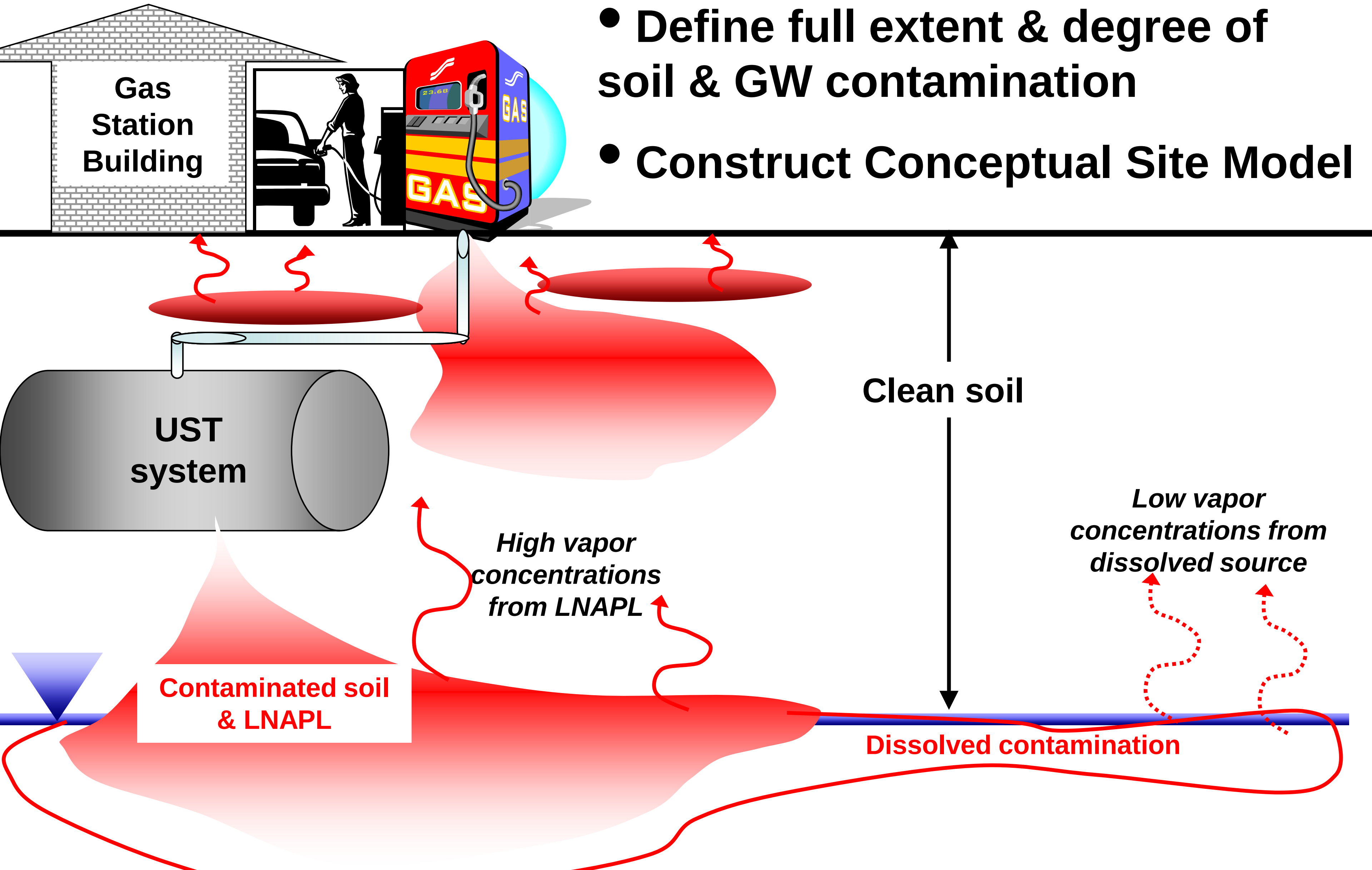
MAP KEY

56 # Geographic Locations (sites) Evaluated

304 # Paired concurrent measurements of benzene subsurface soil vapor & source strength

Characterize Site

- Define full extent & degree of soil & GW contamination
- Construct Conceptual Site Model



Case Study 1

Tesoro #40
Salt Lake City, Utah

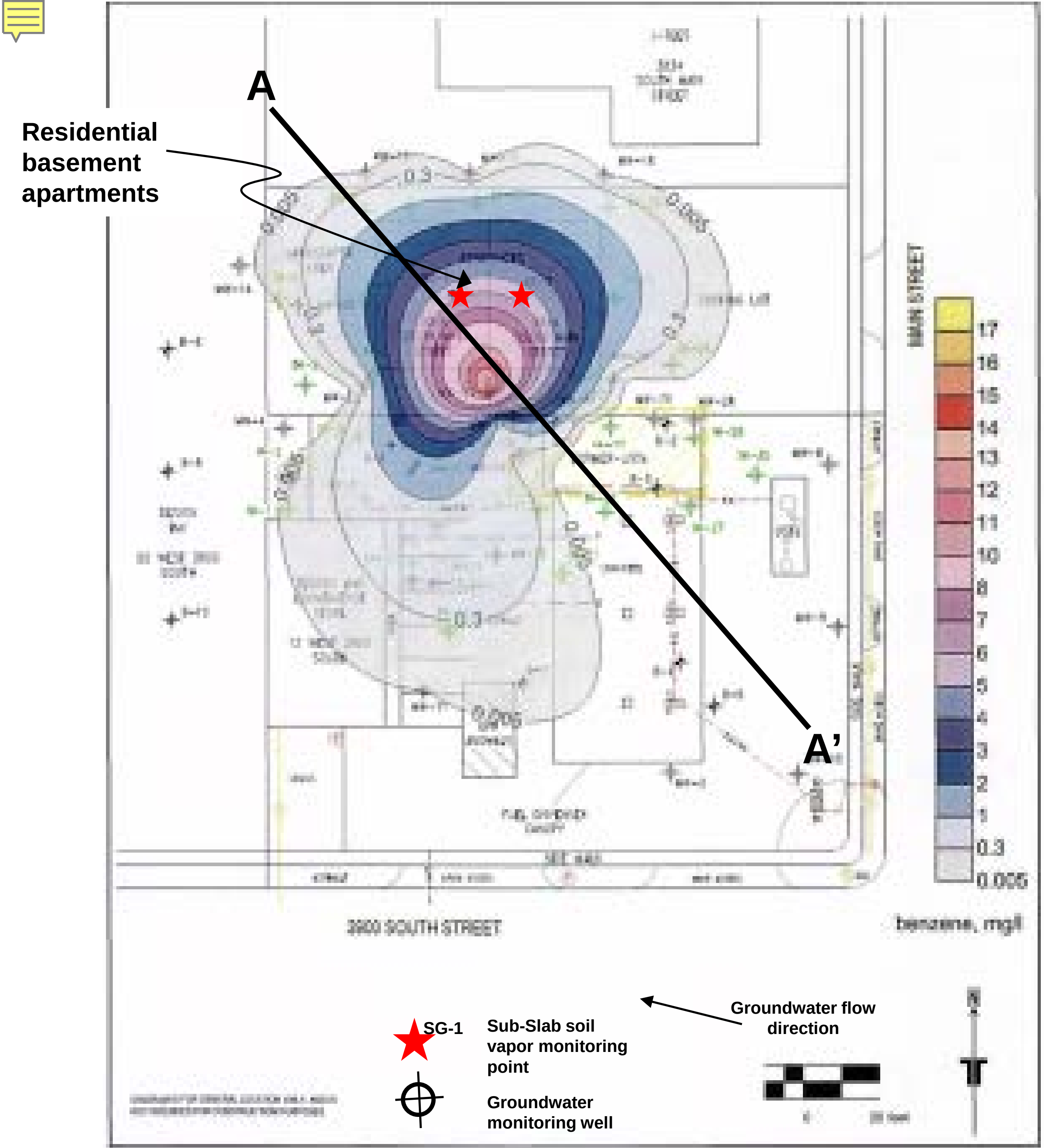
- Very high concentrations of contaminant source in soil & GW <5 feet below apartment building foundation

- Vapors are biodegraded & fully attenuated within few feet of clean soil overlying the source

- PVI pathway is not complete

Case Study 1: Front View of Apartments

Dissolved Benzene Plume Map



Dissolved source

Benzene 14,000 ug/L

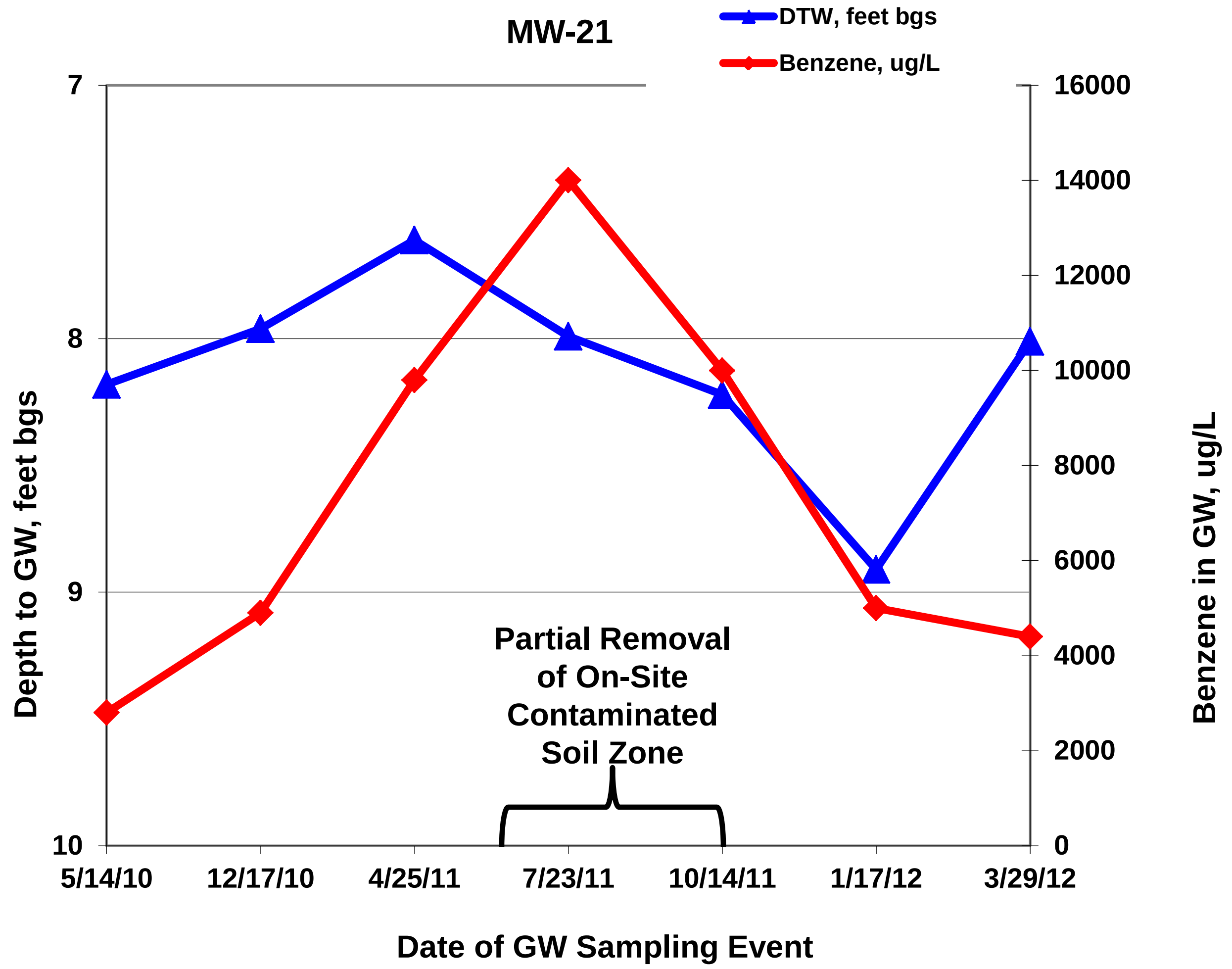
TPH 28,000 ug/L

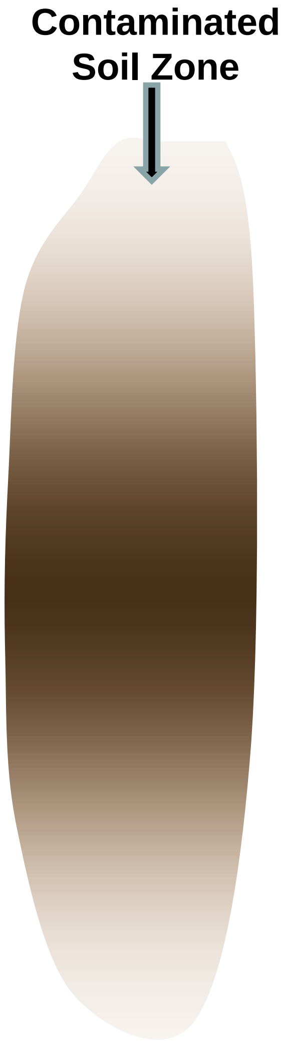
Sub-slab vapors

Benzene 9.9 ug/m3

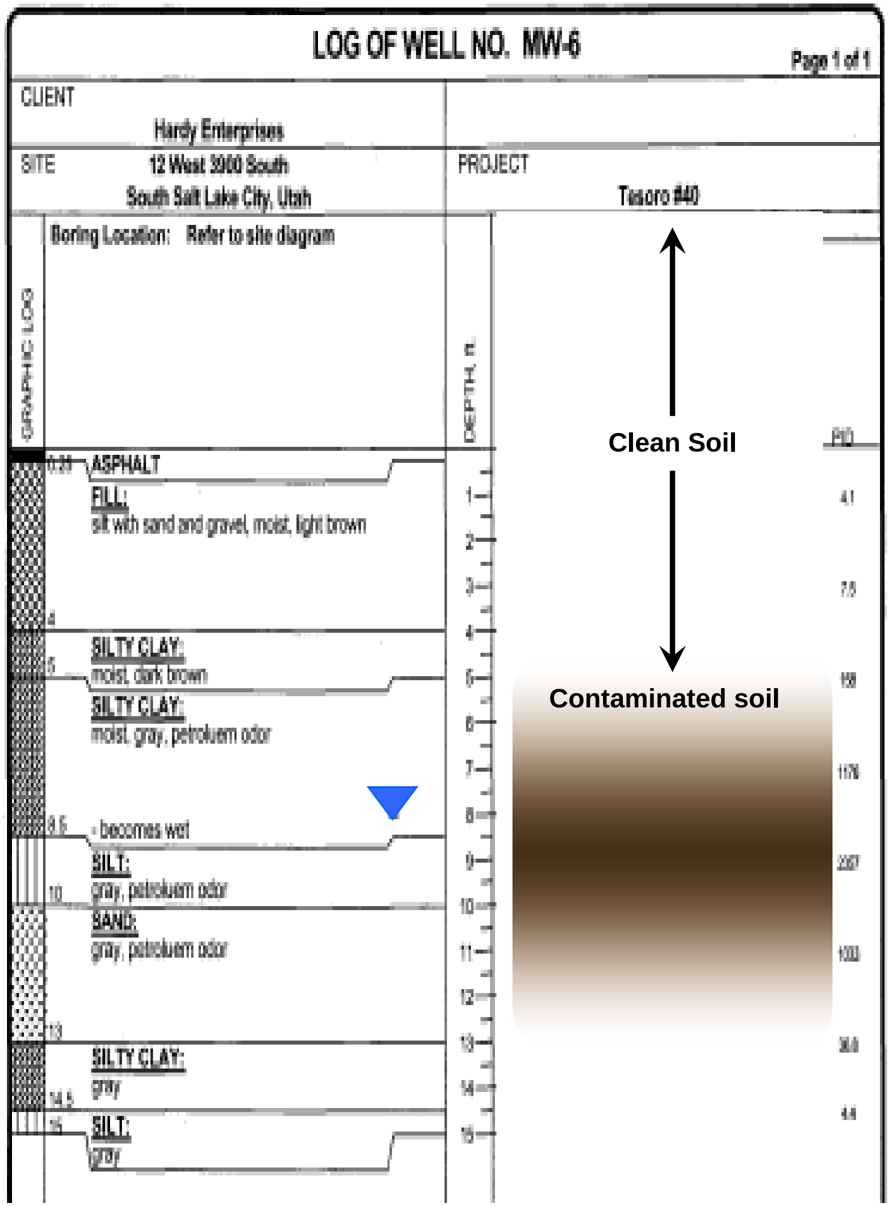
TPH 130 ug/m3

Long-Term GW Monitoring





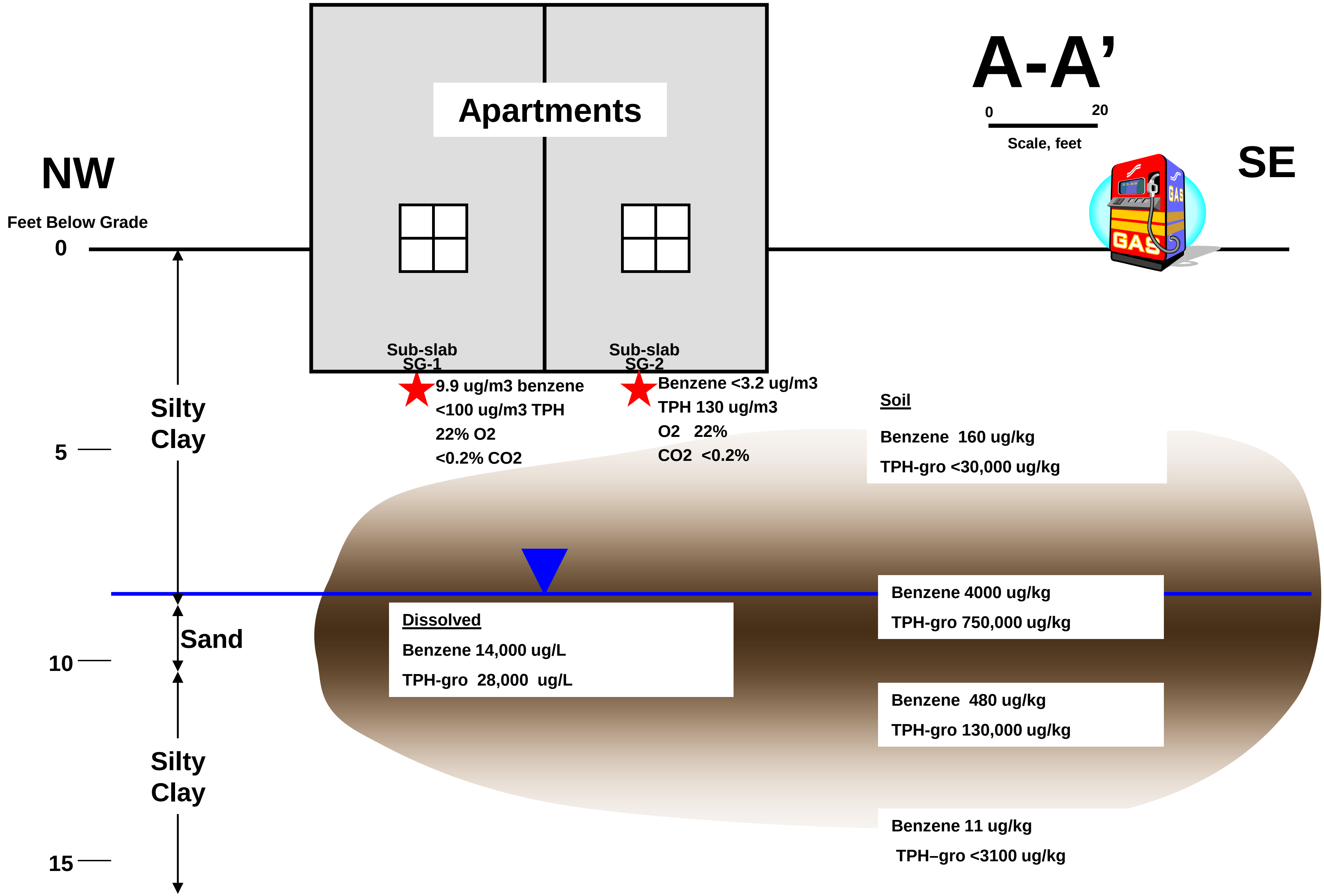
Boring Log near Apartments



PVI Investigation

Cross-Section

A-A'



Case Study 2

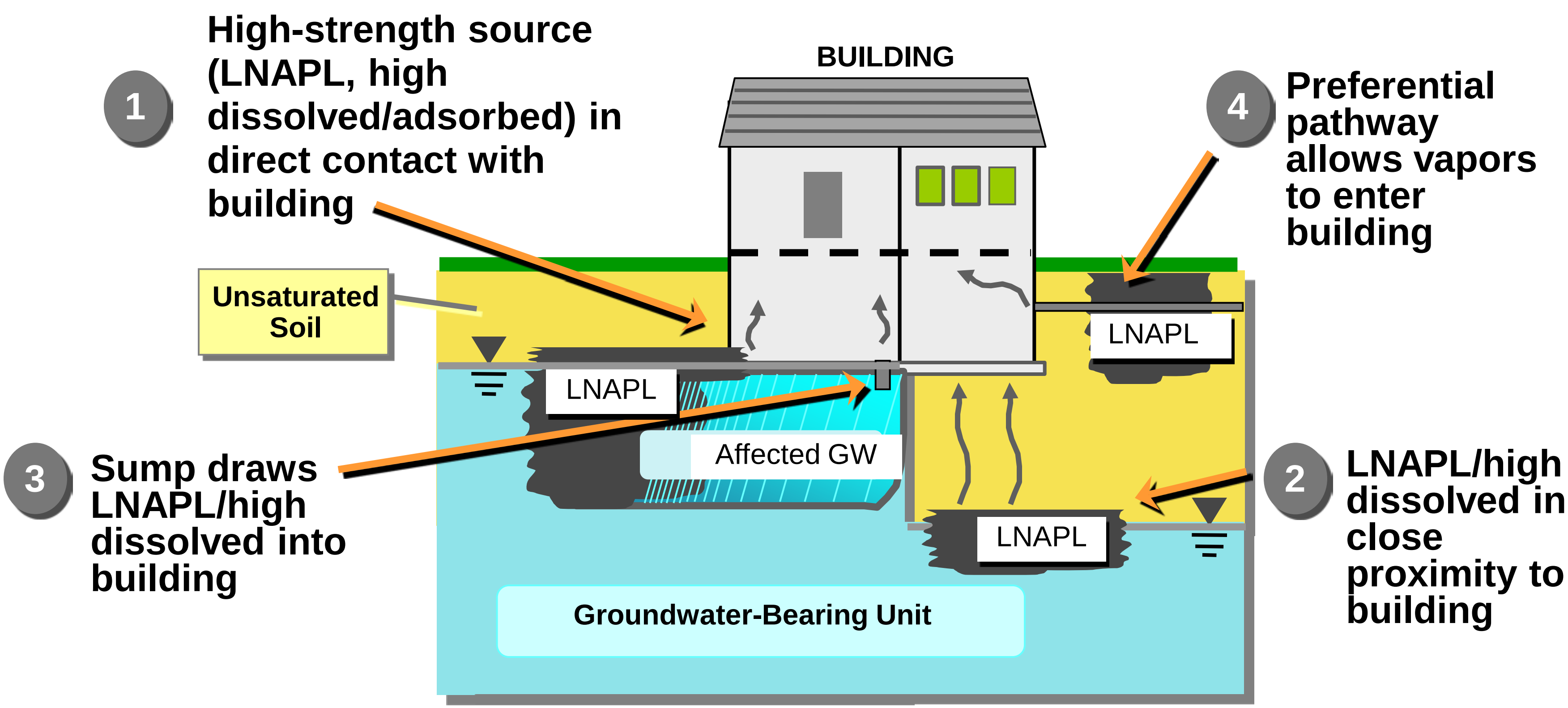
Ogden Mini Mart, Ogden, Utah

Gasoline LNAPL directly beneath building slab, PVI reported by building occupants, mitigation implemented immediately

Results of Field & Published Studies

- **Clean soil contains sufficient oxygen needed to biodegrade vapors (aerobic)**
- **A few feet of clean soil provides a natural barrier to PVI**
- **No reported cases of PVI from low-strength sources**
- **Causes of PVI are predictable & well-understood**

Causes of Petroleum Vapor Intrusion



The Science of Petroleum Hydrocarbon Biodegradation & Vapor Attenuation

Aerobic Biodegradation and Oxygen Mass Balance

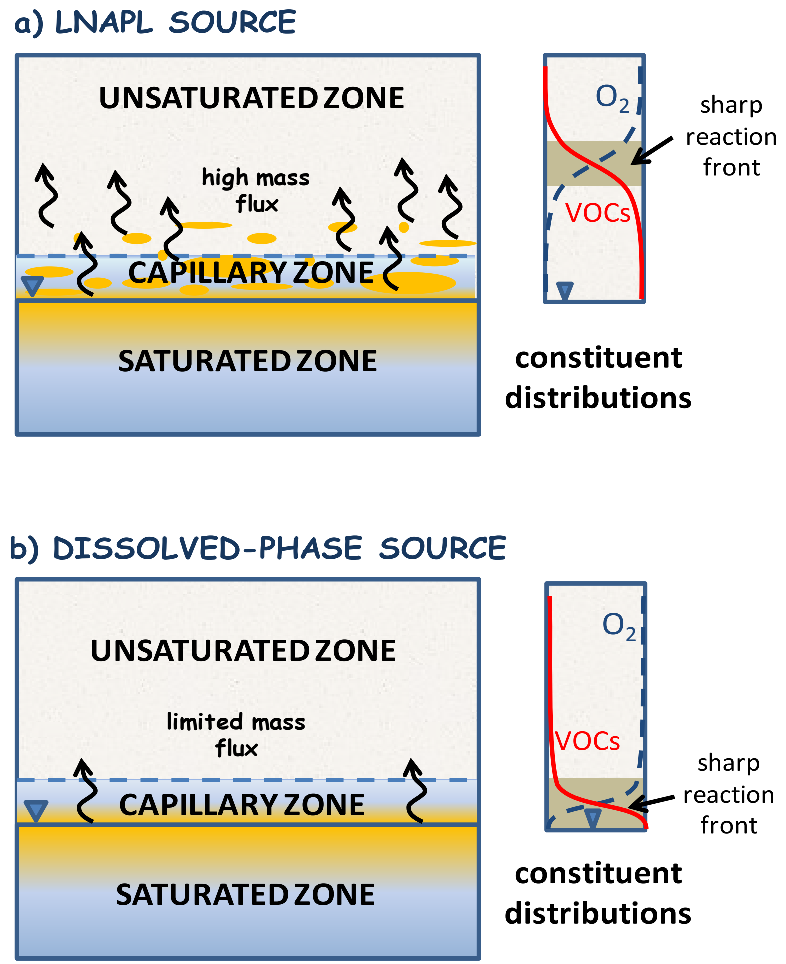
Petroleum Hydrocarbon

$$C_6H_6 \quad + \quad 7.5O_2 \xrightarrow{\text{Aerobic Bacteria}} 6CO_2 \quad + \quad 3H_2O$$

- Aerobic bacteria use oxygen to degrade the hydrocarbon for the carbon.
- The waste product is carbon dioxide and water

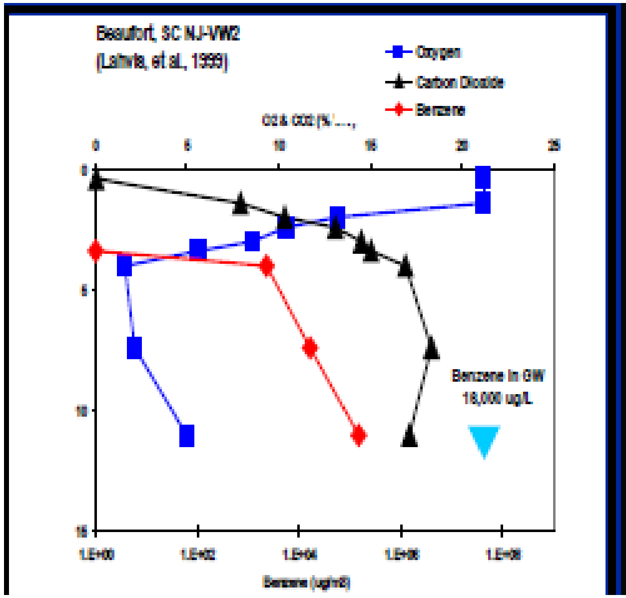
Conceptual Model of Aerobic Petroleum Vapor Biodegradation

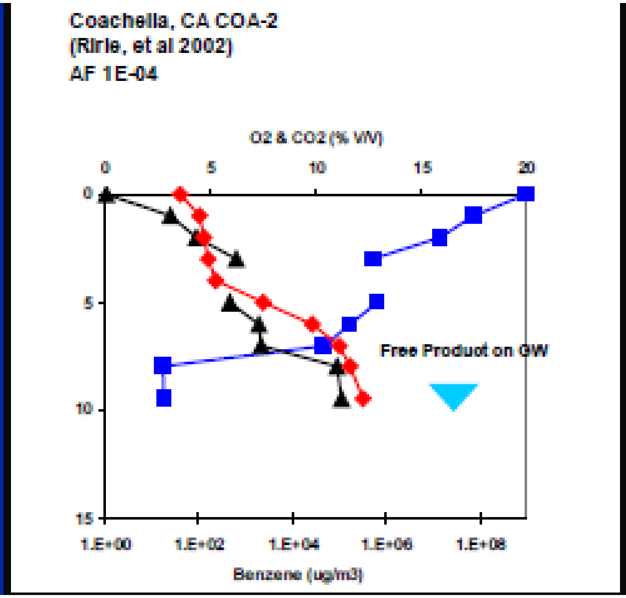
- **Aerobic biodegradation is a robust & rapid process**
- **Clean/uncontaminated soil is sufficiently aerobic to biodegrade & attenuate vapors**
  - 8 feet for LNAPL
  - 5 feet for dissolved

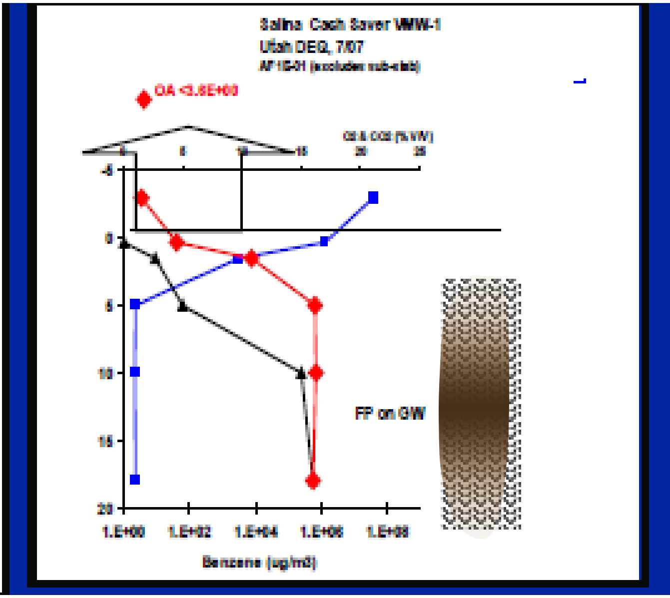


Lahvis, Hers, Davis, Wright, DeVaull (2012, in process)

Signature Characteristics of Aerobic Biodegradation

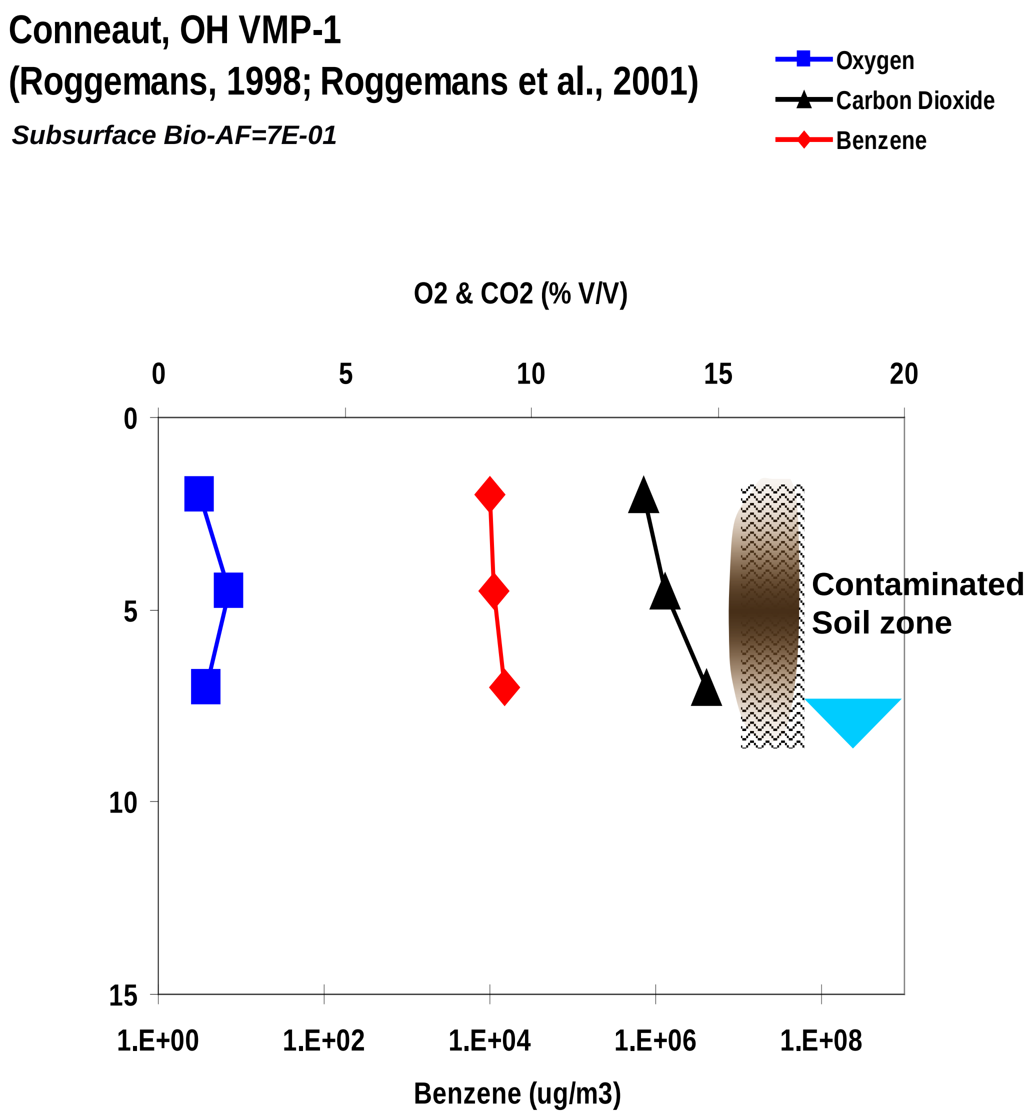






Typical O2, CO2, PHC vapor profiles as petroleum vapors are naturally biodegraded & attenuated with sufficient thickness of clean vadose zone soil

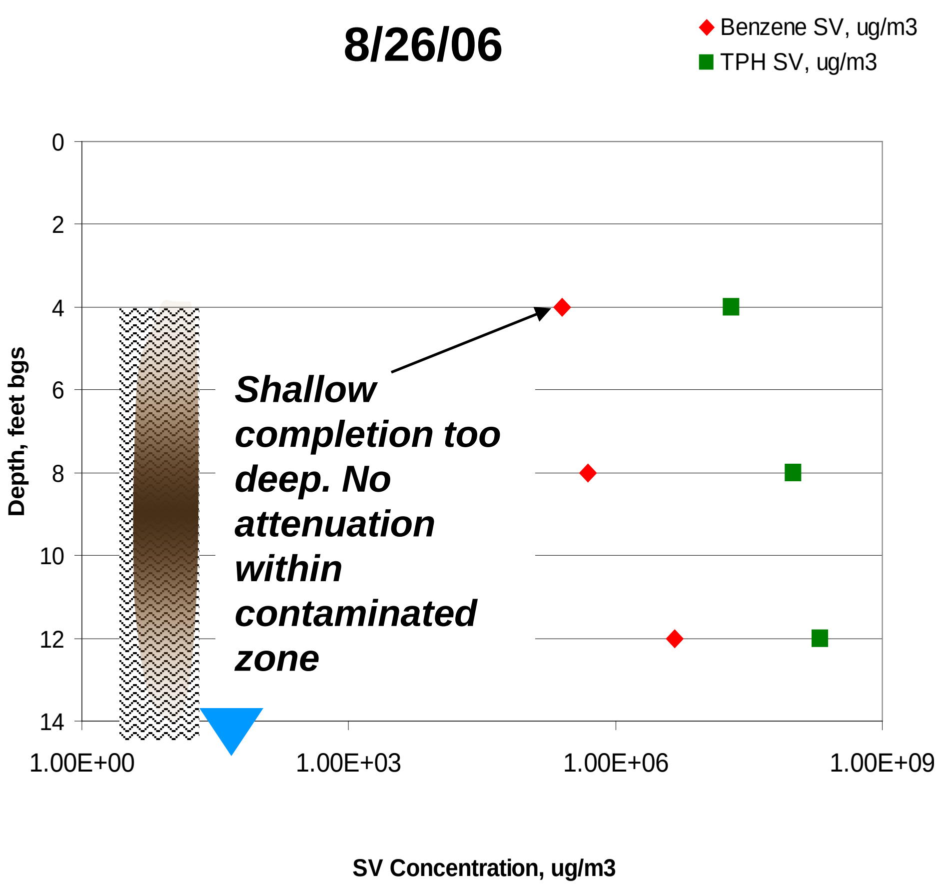
Non-Attenuation of Vapors due to Lack of Clean Overlying Soil

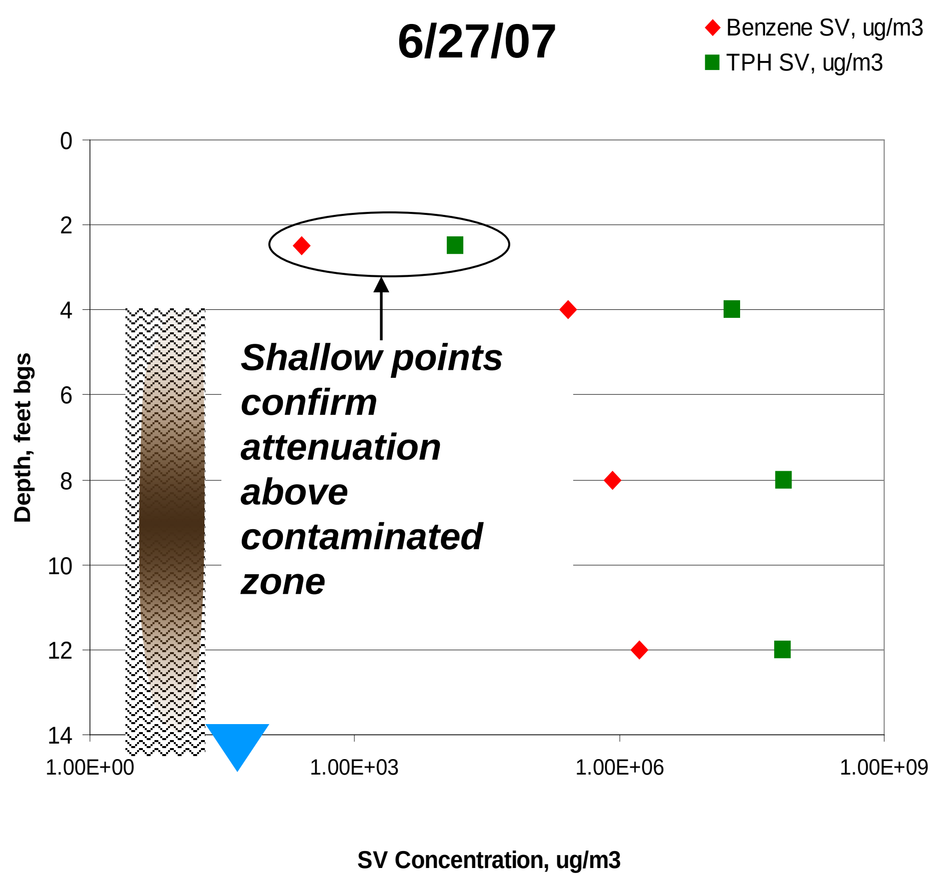


Importance of Shallow Vapor Completion Points

Example of apparent non-attenuation due to no shallow soil completion point, attenuation shown in later sample points

VW-11
Hal's, Green River, Utah





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

- **Abreu & Johnson Numerical Model**
(Abreu & Johnson)

- **BioVapor Analytical Model** **(DeVaull & McHugh)**

Numerical Model

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

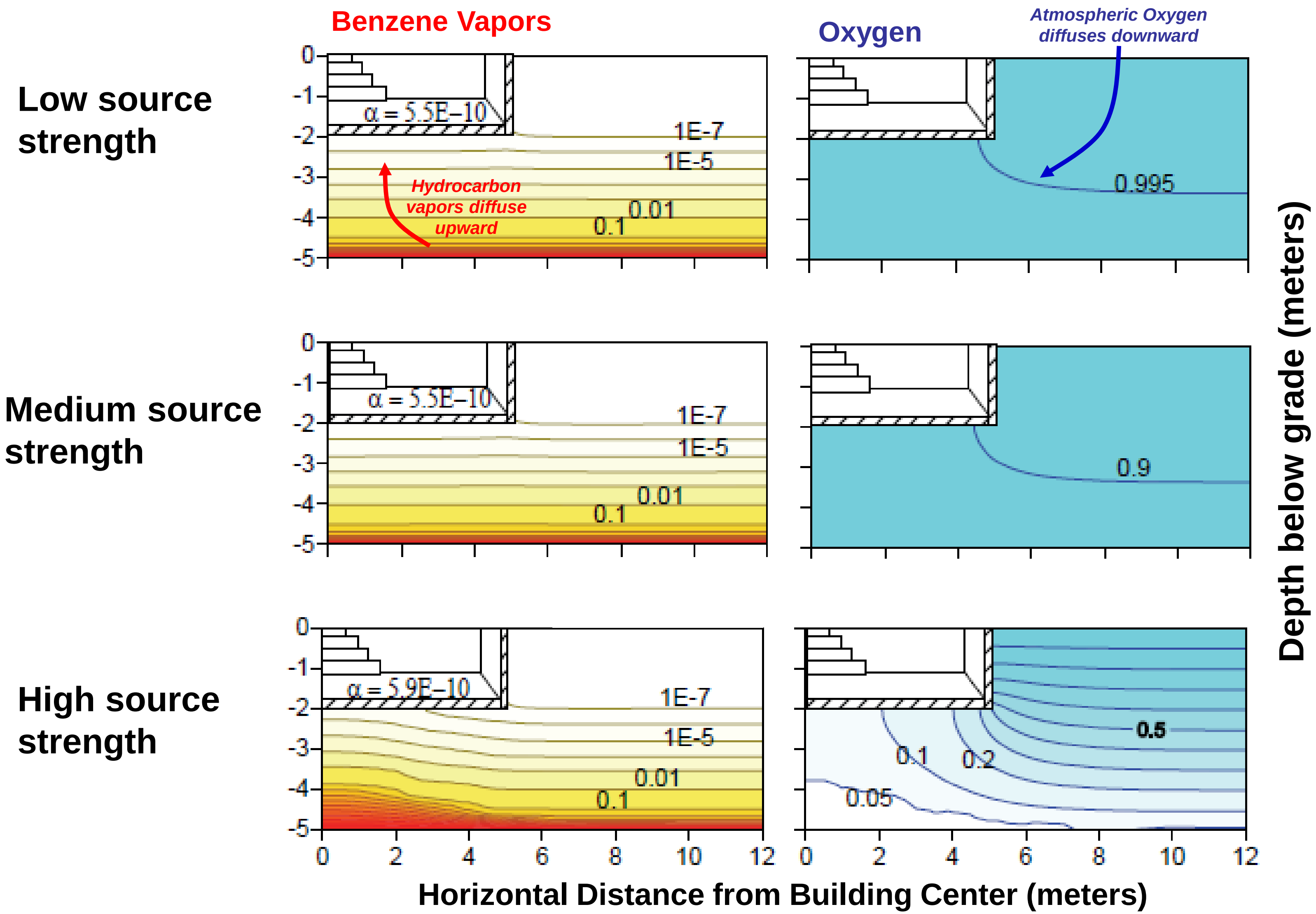
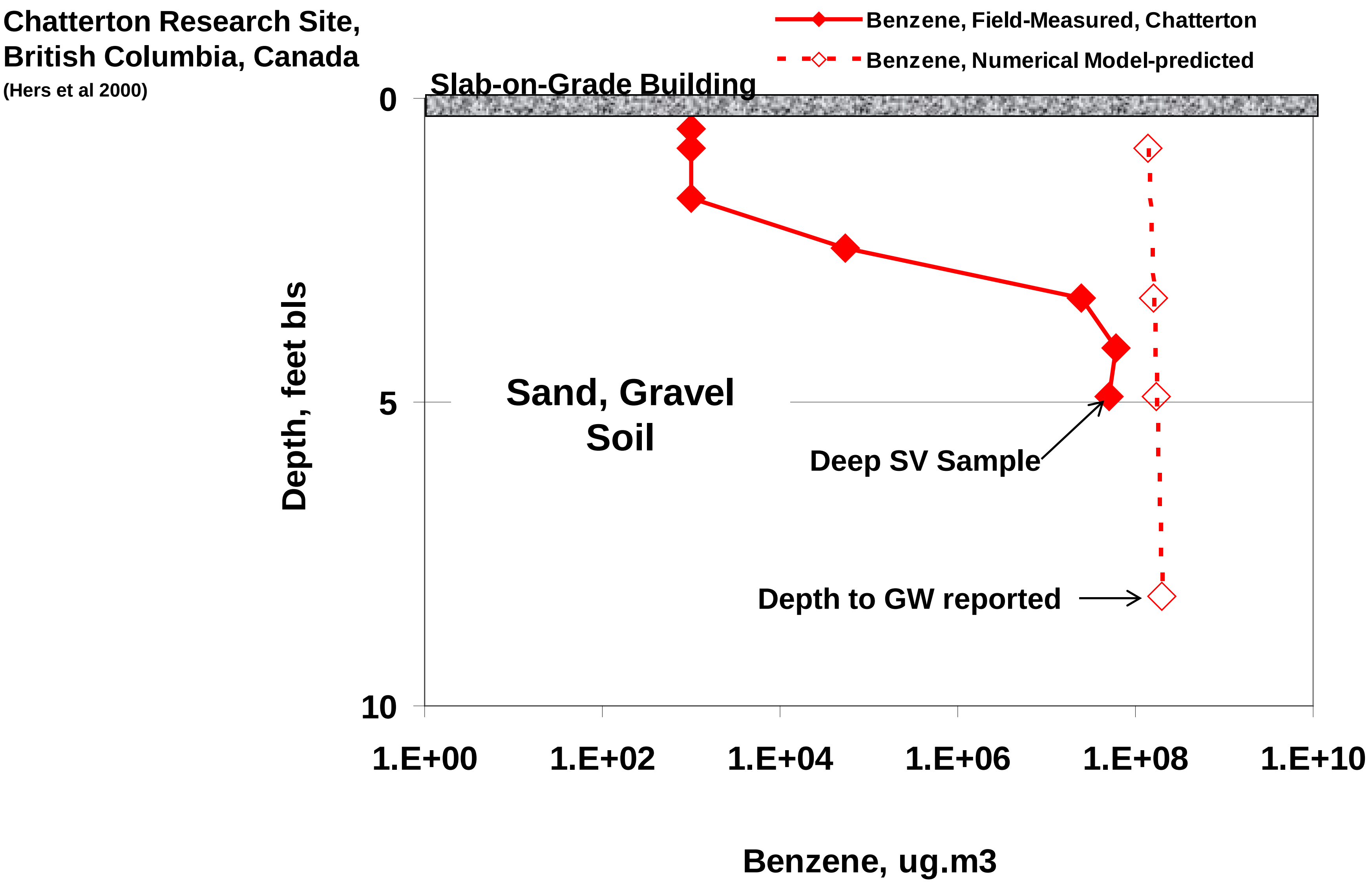


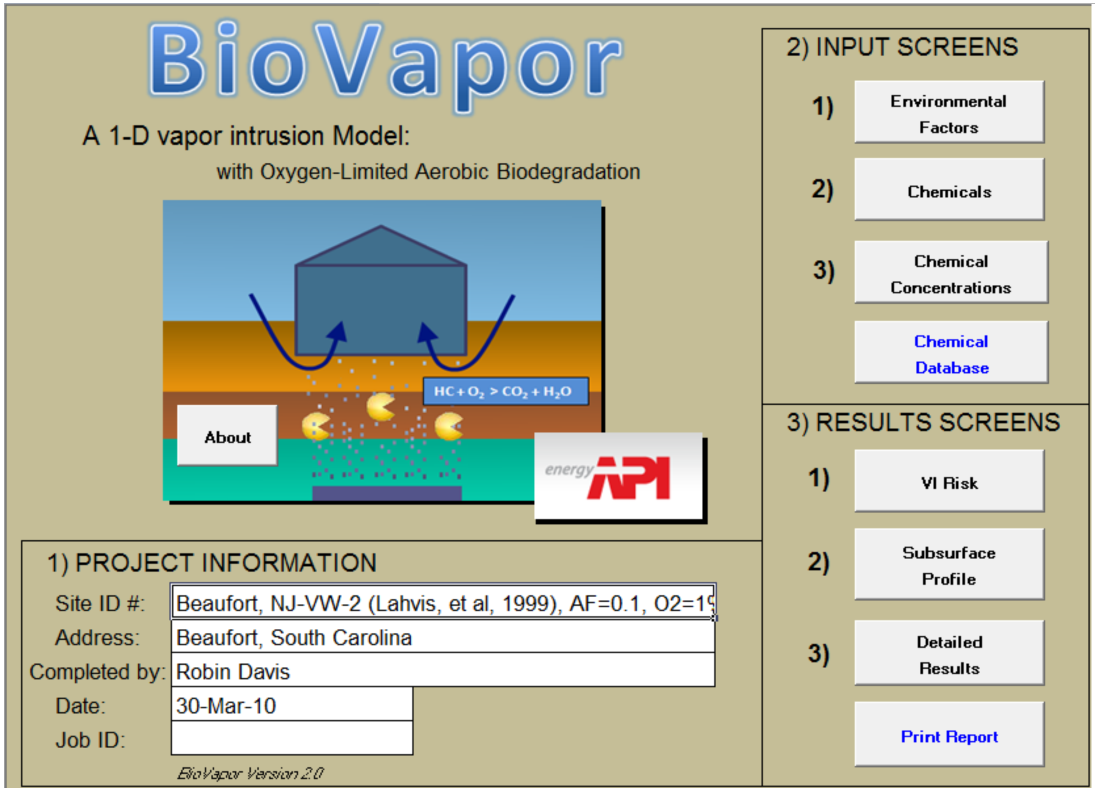
Figure 3—Effect of low vapor source concentration (Cvs) on soil gas concentration distribution and vapor

Comparison of Field-Measured Soil Gas Data to Numerical Model (LNAPL example)



Comparison of Field-Measured Soil Gas Data to BioVapor Analytical Model

Beaufort, NJ-VW-2 (Lahvis et al, 1999) AF=0.1, O2=1%, foc=0.5%

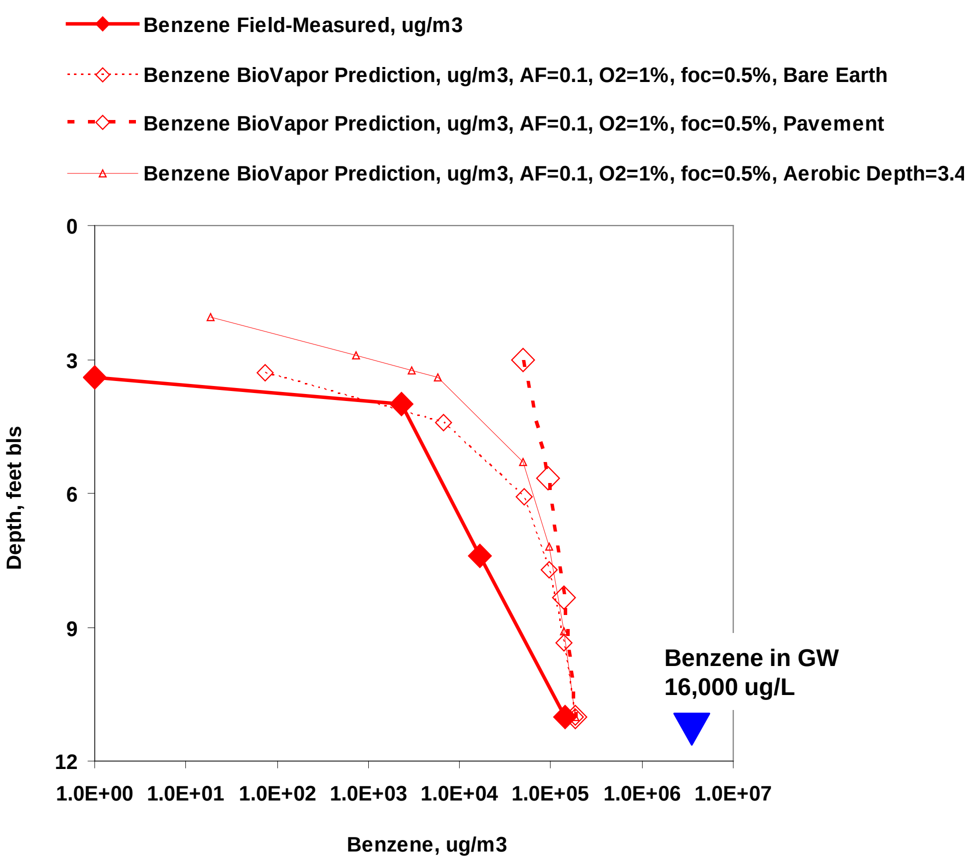


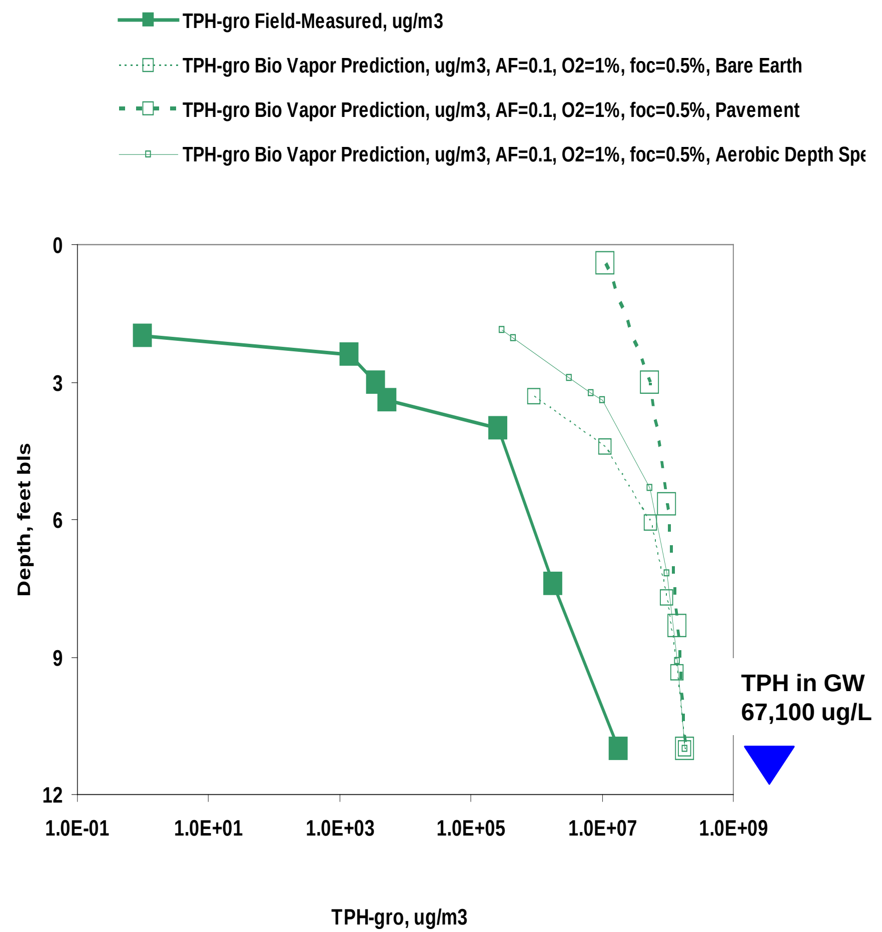
Find it at: api.org

BioVapor Model Compared to Dissolved Site,

Beaufort, South Carolina (Lahvis et al 1999)

- Soil vapors associated with Dissolved Benzene 16,000 ug/L, TPH-g 67,100 ug/L
- BioVapor Model under-predicts subsurface attenuation by 100x to 10,000x





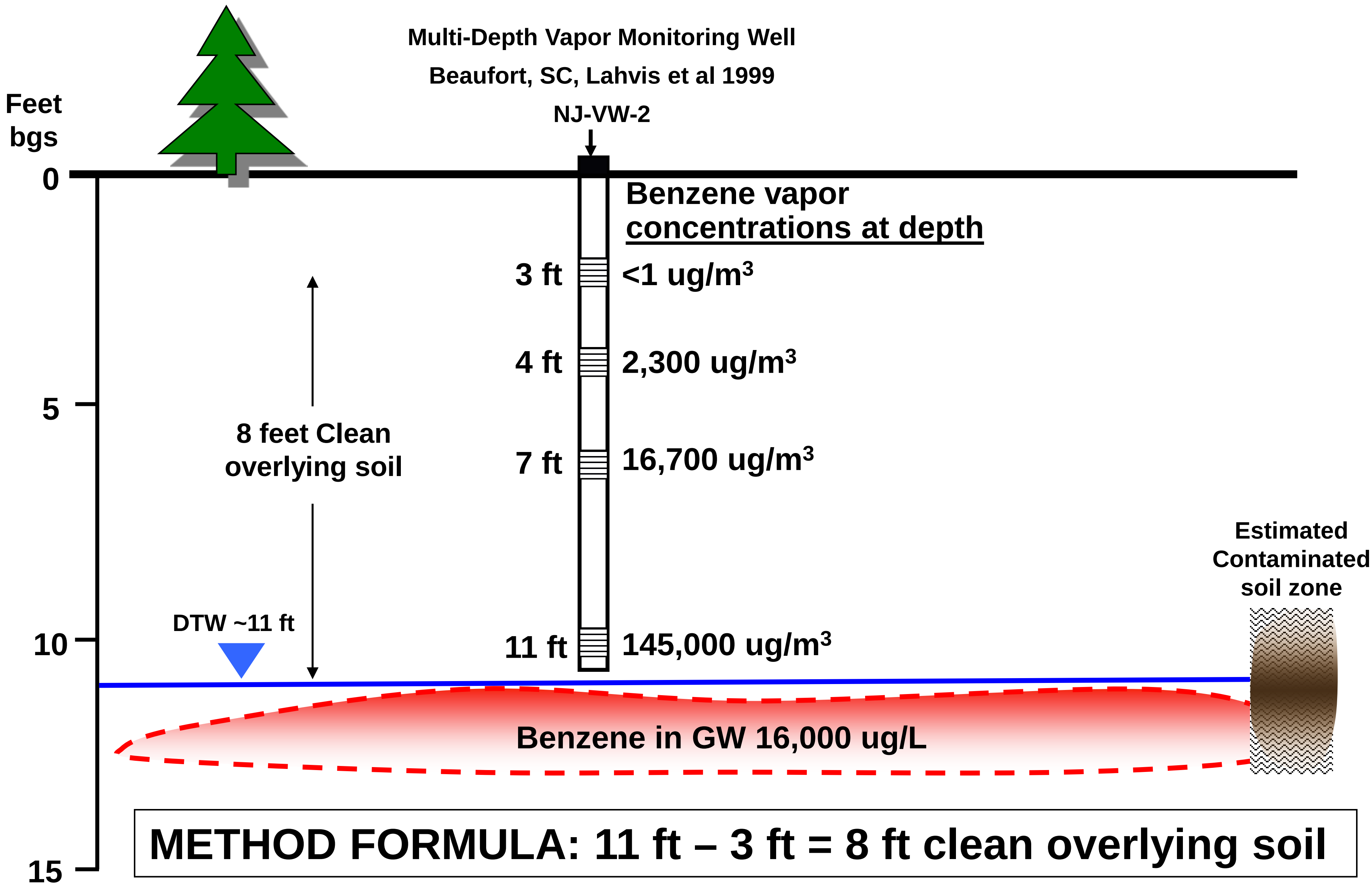
Conclusions from Models

- UNDER-predict subsurface attenuation by 10xxxx

- OVER-predict PVI by 10xxxx

Developing Screening/Exclusion Criteria to Screen Out PVI Low-Risk Sites

Method for Developing Screening Criteria for Dissolved Sources



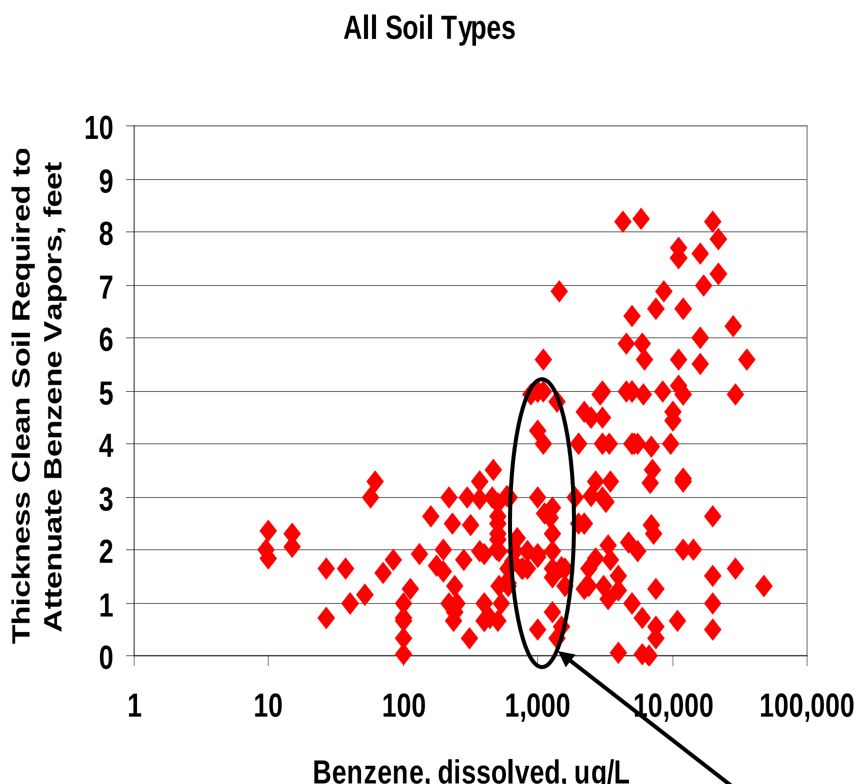
METHOD FORMULA: 11 ft – 3 ft = 8 ft clean overlying soil

Screening Criteria for Dissolved Benzene & TPH

(Exterior + Sub-Slab)

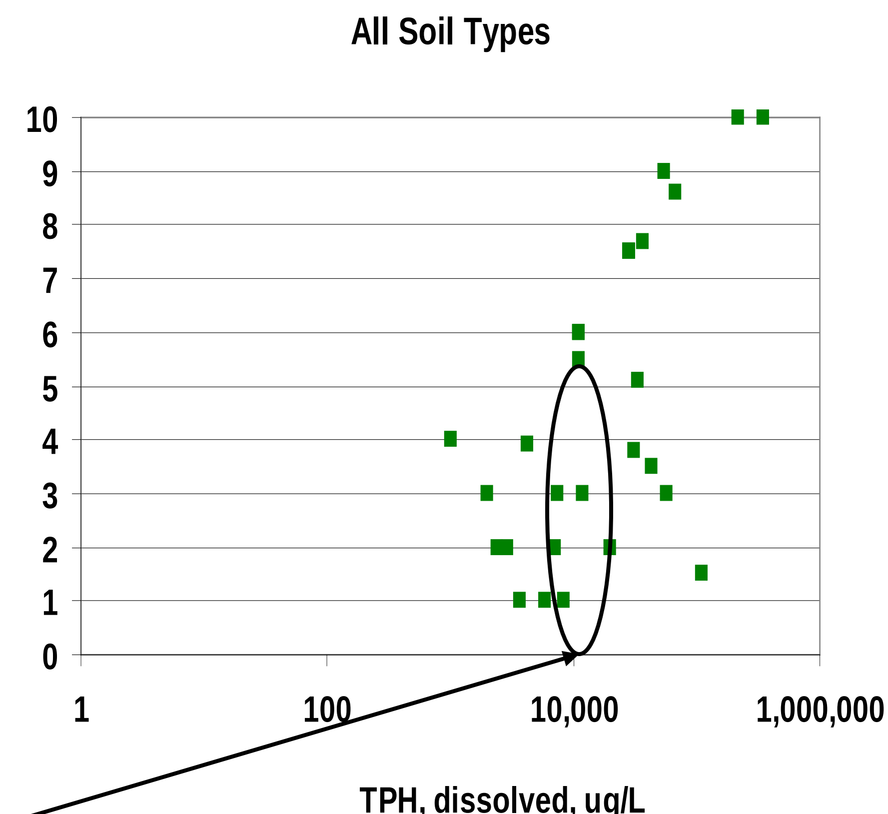
♦ Benzene: Soil Vapor & Dissolved Paired Measurements

Benzene: 199 exterior/near-slab + 37 sub-slab = 236 total



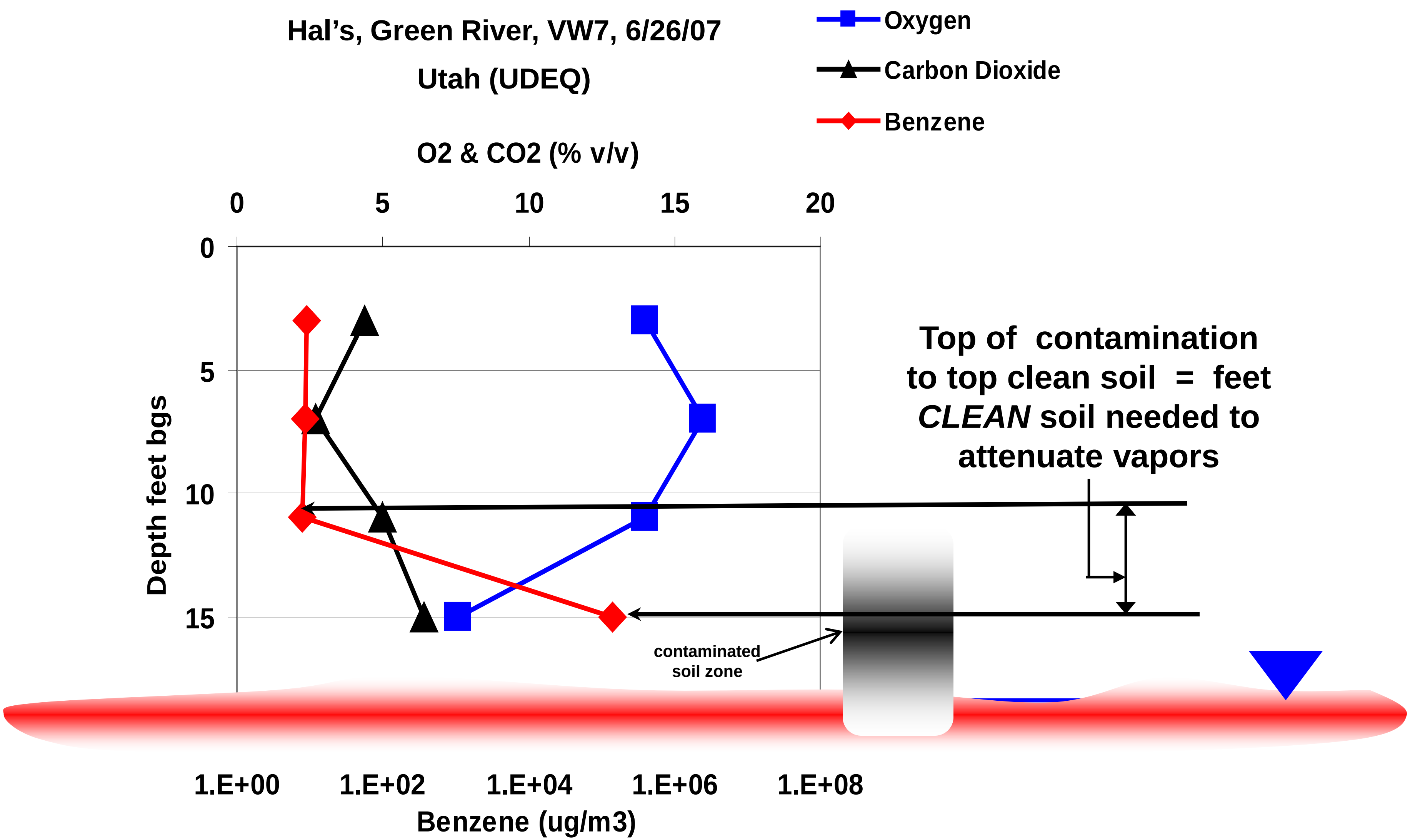
TPH: Soil Vapor & Dissolved Paired Measurements

TPH: 73 exterior/near-slab + 24 sub-slab = 97 total



5 ft Clean Overlying Soil Attenuates Vapors Associated with Dissolved Benzene ≤1,000 ug/L, TPH ≤10,000 ug/L

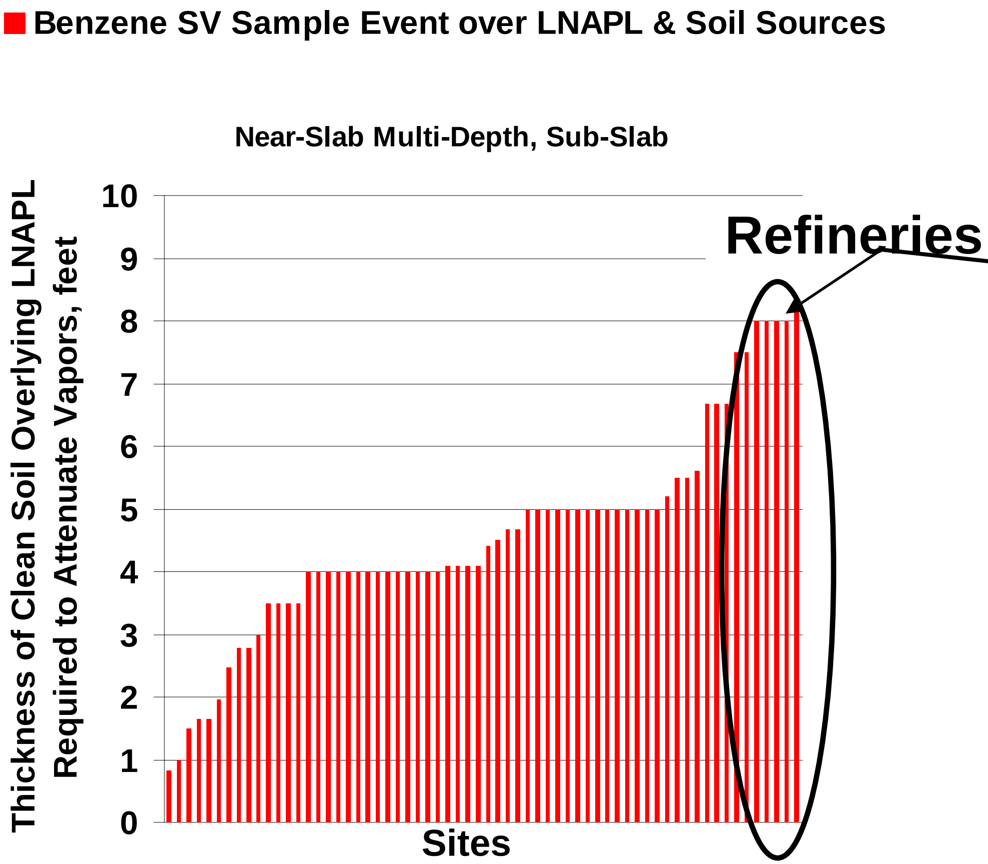
Method for Developing Screening Criteria for LNAPL & Soil Sources



Results for LNAPL & Soil Sources

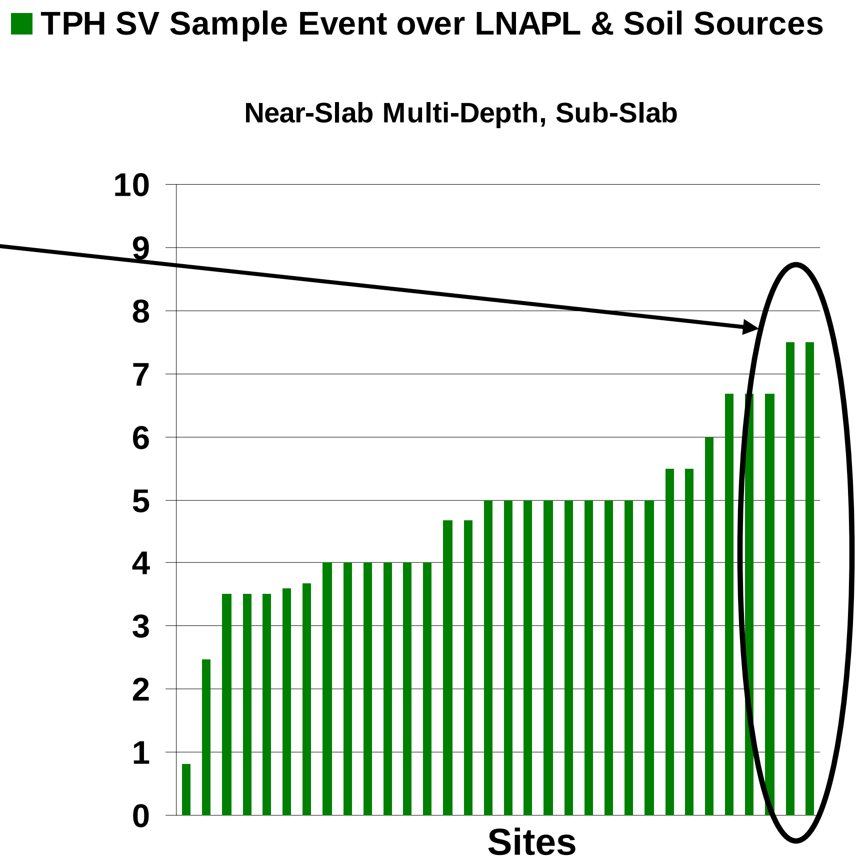
Benzene

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/Soil Sources

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

Reference	Database & Site Type	Benzene Soil Gas Screening Level (ug/m3)	Screening/Exclusion Distance (feet)	Screening/Exclusion Concentration Benzene (ug/L)	Other Criteria
Davis, R.V. (2009, 2010)	International Petroleum Vapor Database	Non-detect	5	≤1000	5 feet for TPH ≤10,000 ug/L
			8	LNAPL	30 ft poorly-characterized sites
Lahvis et al (2012)	R.V. Davis & J. Wright (retail sites only, no refineries)	100	0	<15,000	Dissolved phase only, BTEX <75,000 ug/L
			15	LNAPL	
McHugh et al (2010)	various publications, professional judgement		10	Dissolved phase only	
			30	LNAPL	
Peargin & Kolhatkar (2011)	Chevron, all sites	300	0	≤1000	
			15	>1000	
Wright, J. (2011)	Australia & U.S. sites, all sites + refineries	10, 50, 100, 1000	5	≤1000	
			30	LNAPL	
California	various references, R.V. Davis, McHugh et al	50, 100	5	<100	no SG Oxygen measured
			5	<1000	with SG Oxygen measured ≥4%
			10	<1000	no SG Oxygen measured
			30	LNAPL	
Indiana	various references, (RV Davis 2009-2010, McHugh et al 2010)		5	<1000	no SG Oxygen requirement AFs for GW & SG Distances apply vertically & horizontally
			30	LNAPL	
New Jersey	various uncited references		5	<100	no SG Oxygen measured
			5	<1000	with SG Oxygen measured ≥2%
			10	<1000	no SG Oxygen measured
			100/30	LNAPL/Gasoline	Horizontal & vertical distance
Wisconsin	Davis, R.V., 2009 , Luo et al 2009, McHugh et al, 2010	NONE	5	<1000	Exclusion distances apply vertically & horizontally
			20	>1000	
			30	LNAPL	

Screening Criteria
EPA OUST PVI Guide (3-15-12 draft)

Table 3. Required Vertical Separation Distance Between Contamination and Building Foundation, Basement, or Slab.

Media	Benzene	TPH	Vertical Separation Distance (feet)*
Soil (mg/kg)	NA	≤1,000	5
	NA	1,000 to 100,000 (LNAPL?)	10
	NA	>100,000 (LNAPL)	15
Groundwater (ug/L)	≤ 1,000	≤10,000	5
	>1,000 to 10,000 (LNAPL?)	>10,000 to 50,000 (LNAPL?)	10
	>10,000 (LNAPL)	>50,000 (LNAPL)	15

*Vertical separation distance represents the thickness of clean (TPH ≤ 100 mg/kg), biologically active soil between the source of PHC vapors (LNAPL, residual LNAPL, or dissolved PHCs) and the lowest (deepest) point of a receptor (building foundation, basement, or slab).

Conclusions

PVI pathway not complete when following criteria apply:

Dissolved Sources

- **5 feet CLEAN soil overlying Benzene ≤1,000 ug/L, TPH ≤10,000 ug/L**
- **>5 feet CLEAN soil overlying Benzene >1,000 ug/L, TPH >10,000 ug/L`**

LNAPL Sources

- **8 feet CLEAN soil overlying top of LNAPL smear zone or soil sources**

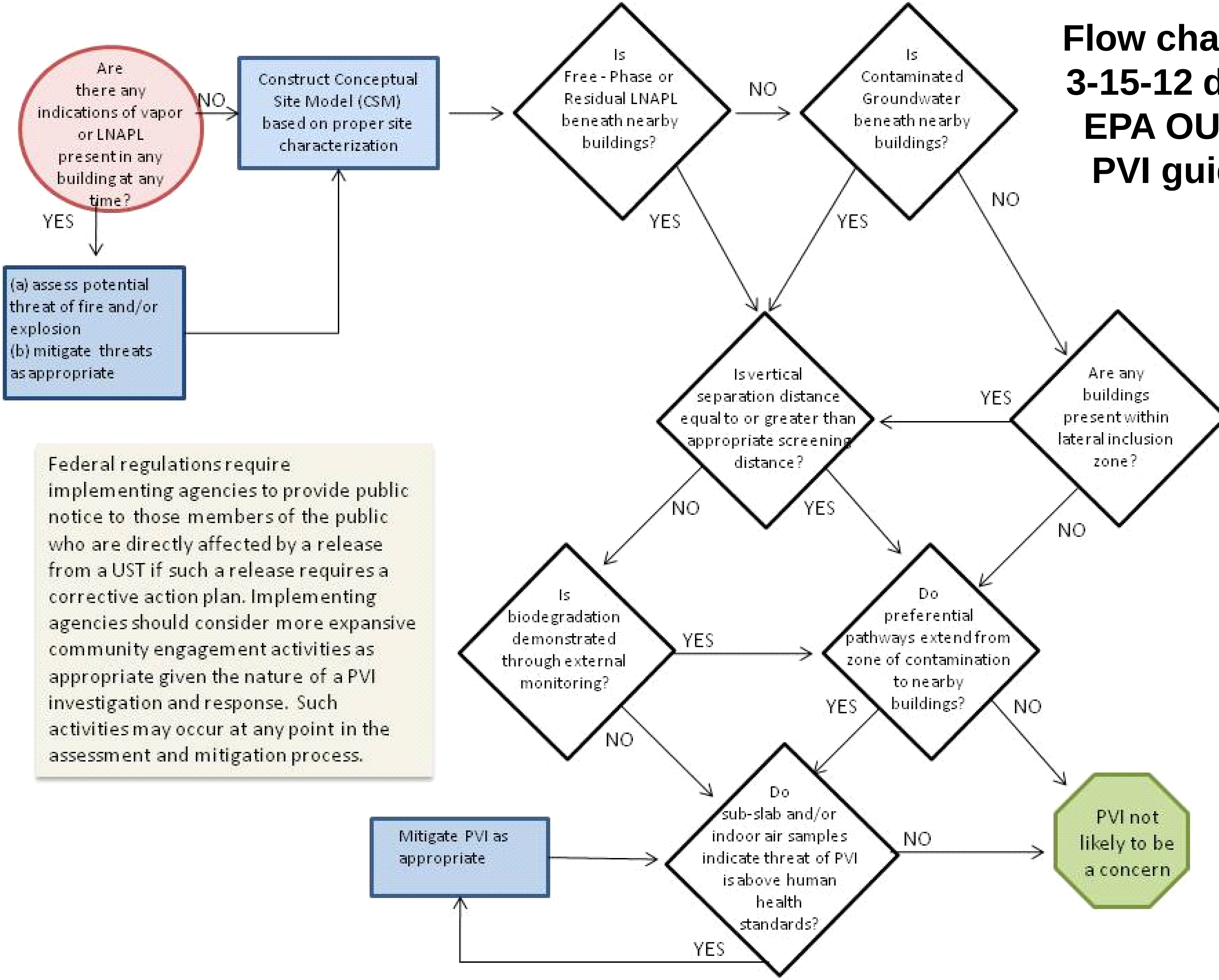
Soil Sources

- **5 feet CLEAN soil = TPH <100 mg/kg, PID <100 ppm-v (gasoline), <10 ppm-v (diesel)**

Vapor Sources

- **Petroleum vapors are attenuated below the receptor**
- **If measuring soil vapor, analyze ALL COCs, O2, CO2, methane, others**
- **Oxygen to Carbon Dioxide ratios demonstrate petroleum biodegradation**

Flow chart in 3-15-12 draft EPA OUST PVI guide



Recommendations

- **Fully characterize sites, determine full extent, degree of contamination**
- **Collect basic field data to assess PVI pathway**
- **Apply Screening/Exclusion Criteria in deciding if PVI investigation is necessary**