Evaluating the Vapor Intrusion Pathway

Nationwide Study of Subsurface Petroleum Hydrocarbon Vapor Occurrence & Attenuation

by
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Vapor Intrusion Work Shop & Session, March 16-19, 2008
20th Annual National Tanks Conference, Atlanta, Georgia

Thanks to: NEIWPCC, EPA, ASTSWMO, API

Purpose

- Explore why so many LUST sites exist nationwide, but so few report vapor intrusion to indoor air
- Evaluate mechanisms & show characteristics of subsurface bio-attenuation of petroleum hydrocarbon vapors
- Determine when VI pathway is complete & if further actions are necessary (e.g., sub-slab)
- Apply Subsurface Bio-Attenuation Factors for petroleum hydrocarbons to avoid unnecessary, costly VI investigations

Background…

- **2002, November: EPA OSWER Draft Guide "Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater & Soils"**

  - **Guide uses Johnson-Ettinger (J&E) Model to develop generic screening levels for soil vapor & groundwater to protect VI pathway**

  - **J&E Model does not consider bio-attenuation of petroleum hydrocarbons (works well for non-degradable compounds: solvents)**

  - **Guide therefore recommends it *NOT* be used for VI evaluation at UST sites**

  - **Guide recommends forming work group of EPA & state regulators to further study behavior of subsurface petroleum associated with VI pathway**

Background, continued

- **2003-2005: EPA OUST Work Group for Petroleum Hydrocarbons & VI Pathway, CONCLUSIONS:**

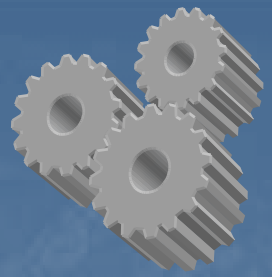
  ➢ **High-quality site data necessary for evaluating petroleum hydrocarbon occurrence & attenuation**

  - **Soil vapor concentrations: multi-depth, sub-slab**
  - **Dissolved concentrations**
  - **Groundwater depth & gradient**
  - **Contaminant source zone extent**
  - **Soil type**

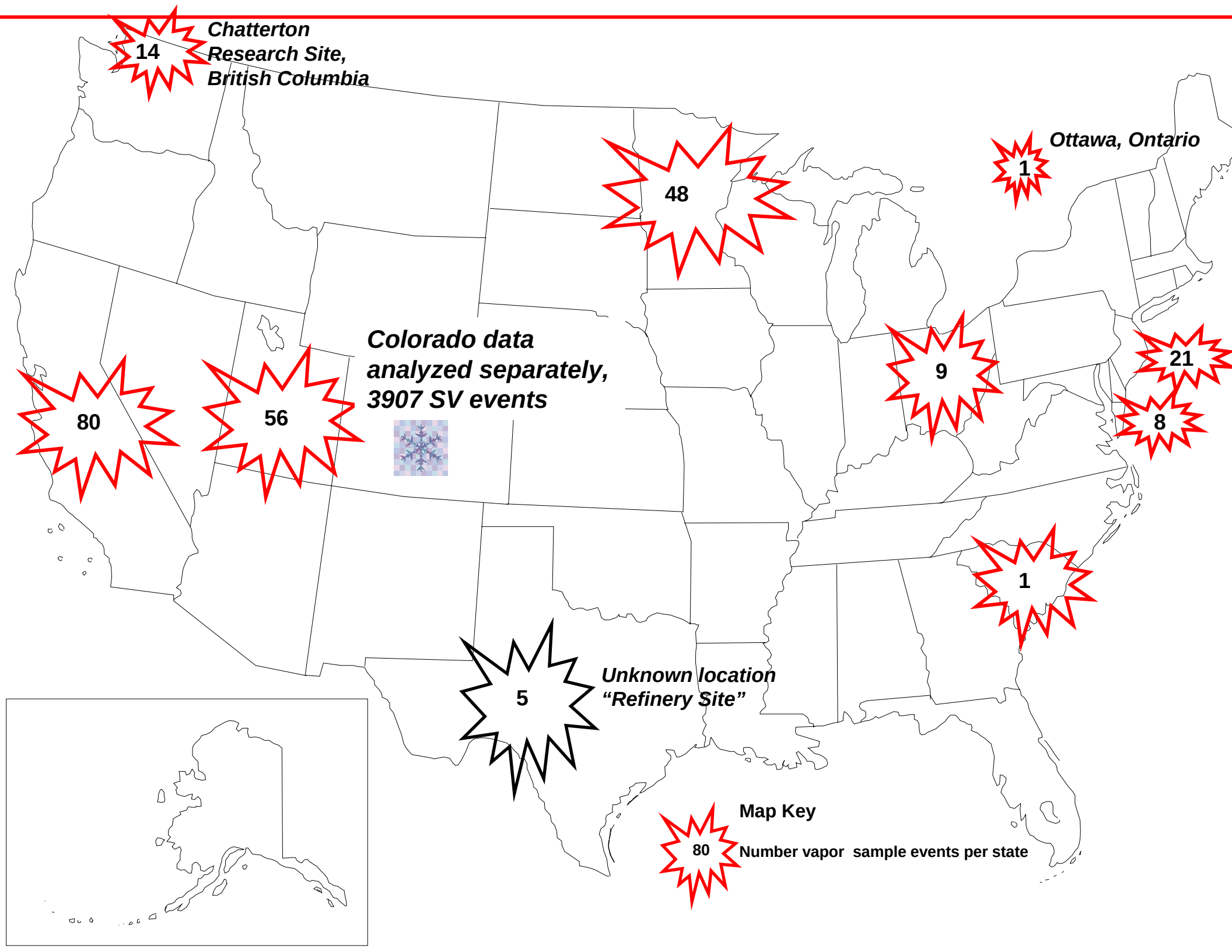
  ➢ **Large volume data necessary to understand trends**

  ➢ **Compile data in a way that yields meaningful interpretations**

SCOPE

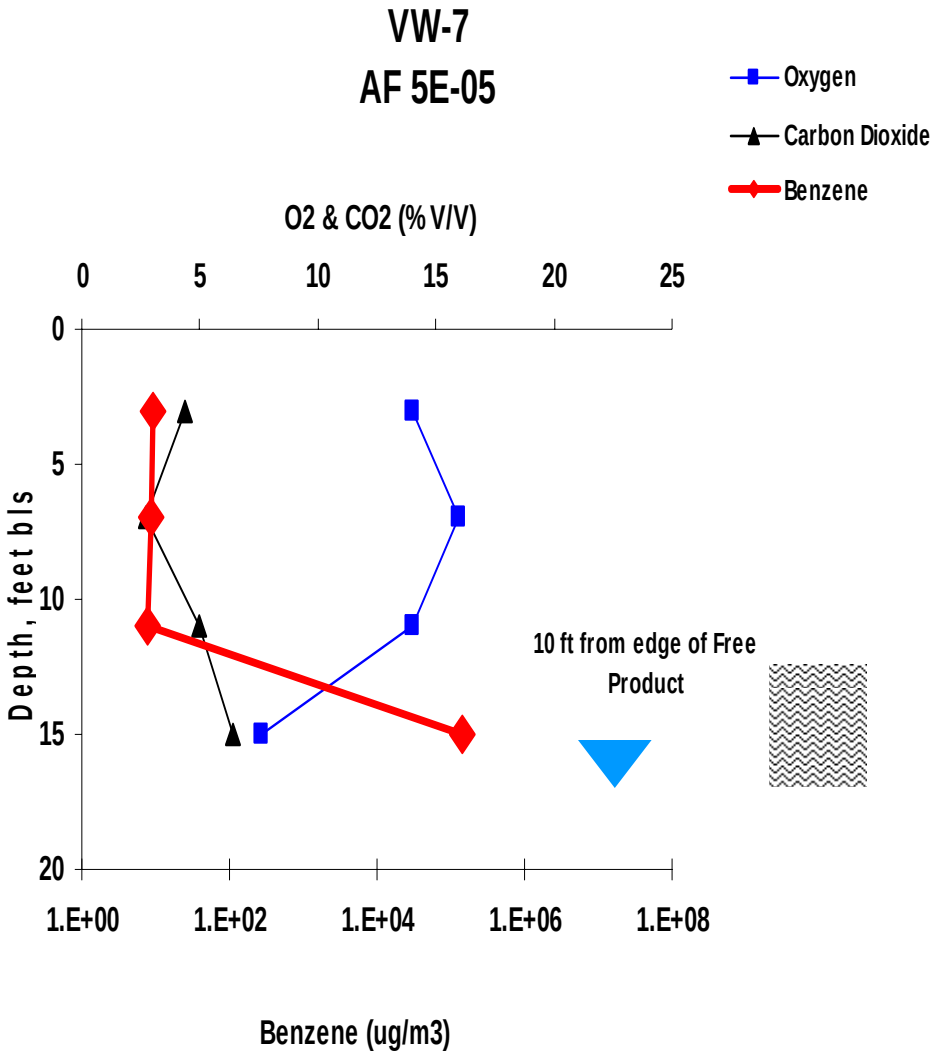


- **Compile & evaluate large volume of nationwide data, high-quality, readily accessible, from well-studied sites:**
  - **243 soil vapor sampling events** ***(82 events since LUSTLine #52, May 2006) (183 soil vapor sample points/wells)***
  - **51 sites/geographic locations nationwide, United States & Canada** ***(Colorado data analyzed separately)***
- **Compare findings at nationwide sites to representative Utah Case Study, Hal's Chevron**
- **Compare nationwide measured vapors to models & quantify differences**


14
Chatterton Research Site, British Columbia
48
1
Ottawa, Ontario
Colorado data analyzed separately, 3907 SV events
80
56
9
21
8
1
5
Unknown location "Refinery Site"
Map Key
80
Number vapor sample events per state

Profile of Multi-Depth Vapor Monitoring Well & Signature Characteristics of Vapor Bio-Attenuation

Hydrocarbon concentrations high in source zone, O2 depleted, CO2 generated. As vapors diffuse upward through clean soil, hydrocarbons deplete, O2 & CO2 return to atmospheric proportions

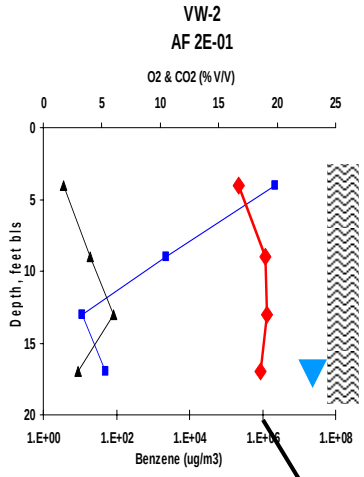


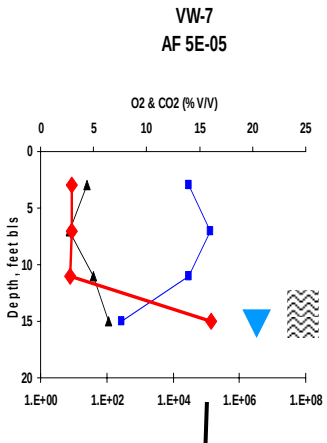
EXPLANATION

- Oxygen, %
- Carbon Dioxide, %
- Benzene, ugm3
- TPH, ug/m3
- Contaminated soil zone
- Depth to groundwater
- Edge of free product 0.1 ft thick
- Benzene 1,000 ug/L
- AF — Subsurface Bio-Attenuation Factor, generally in clean soil: *Shallow SV / Deep SV*

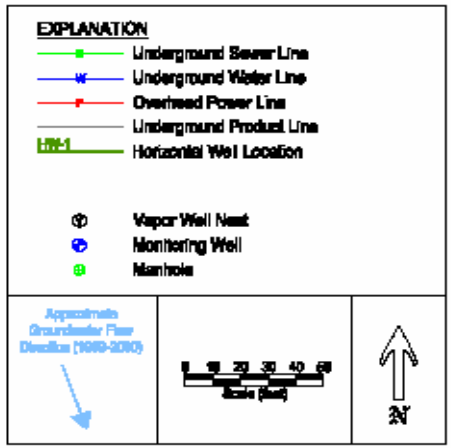
Case Study: Hal's Chevron, Green River, Utah…

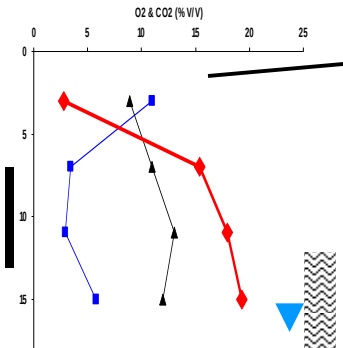
Insignificant AF in shallow source zone. Significant AF overlying strong source with 2-7 feet clean overlying soil.

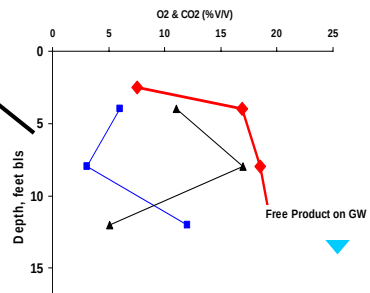




Tour de Plume

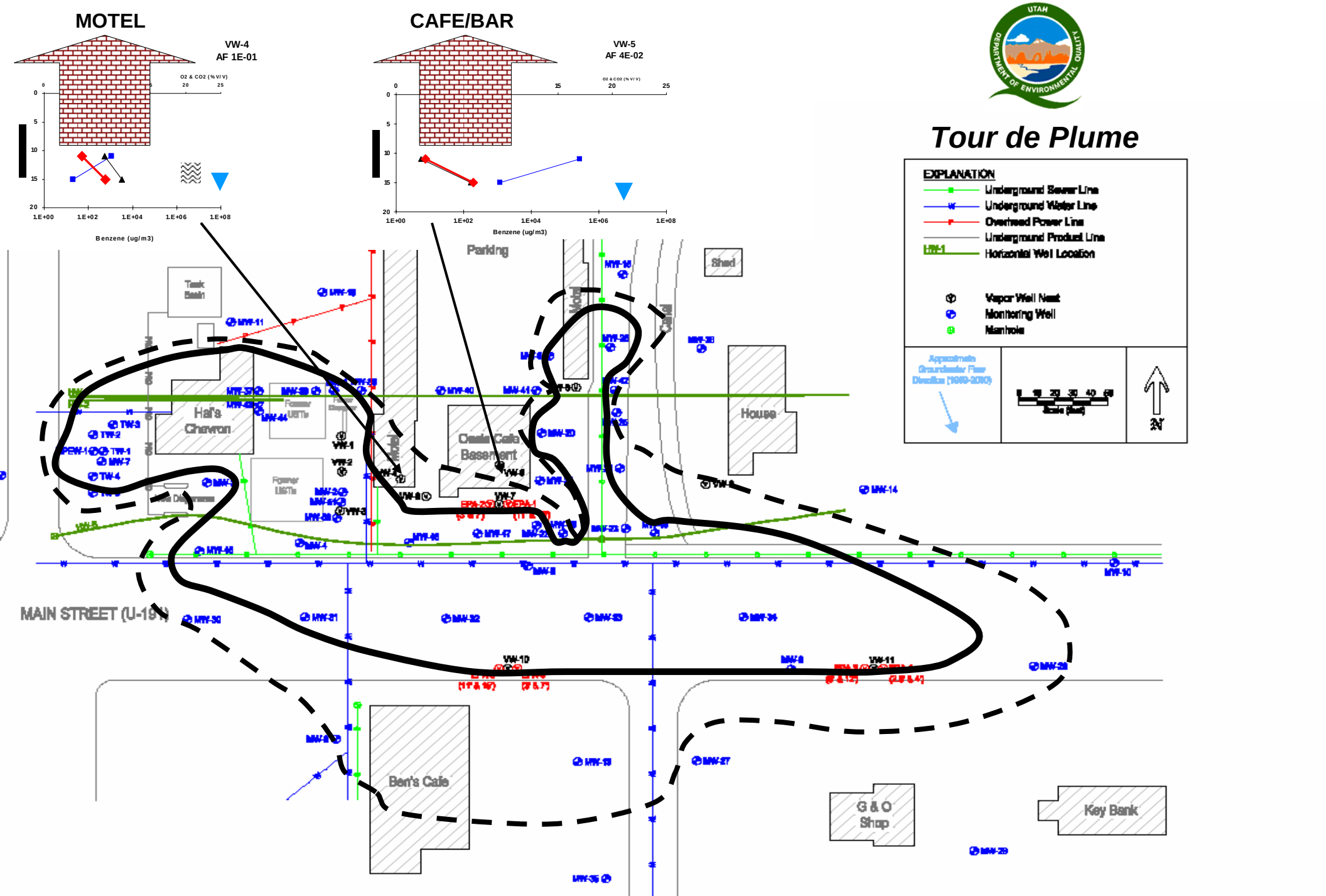






Case Study: Hal's Chevron, Green River, Utah, continued

Insignificant AF overlying weak dissolved plume where benzene 1000-5000 ug/L

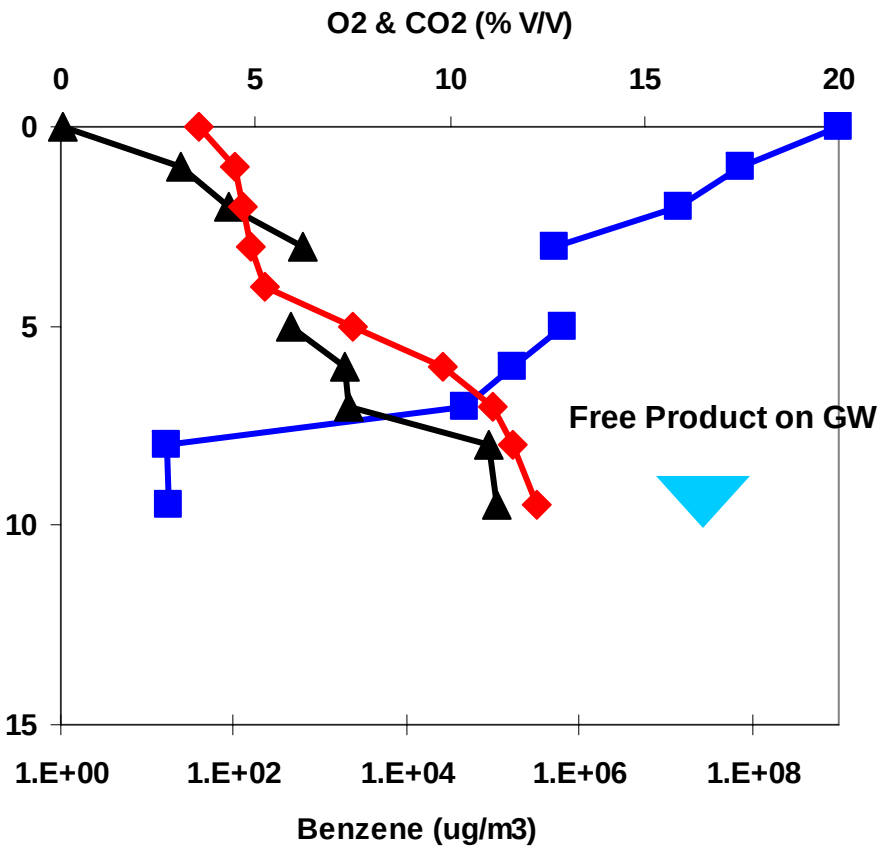


Nationwide Examples of Significant Attenuation

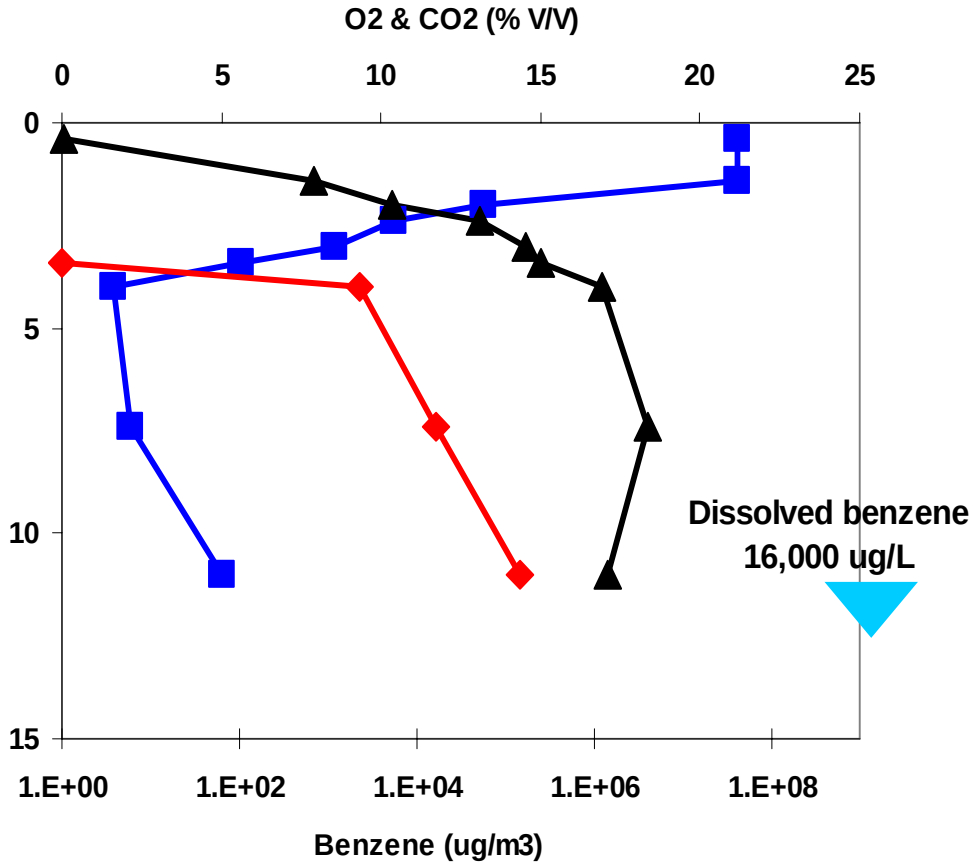
AF 1E-04 to 1E-05

Very Strong Sources with 5 to 7 feet Clean Overlying Soil

Coachella, CA COA-2
(Ririe, et al 2002)
AF 1E-04



Beaufort, SC NJ-VW2
(Lahvis, et al., 1999)
AF 1E-05

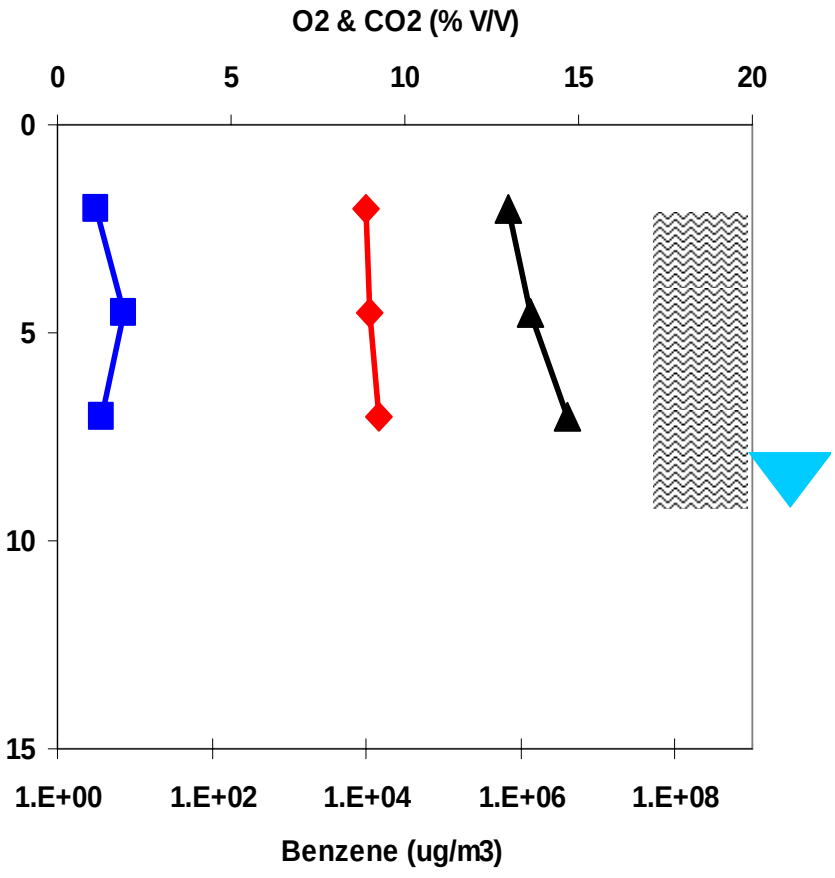


Nationwide Examples of Insignificant Attenuation…

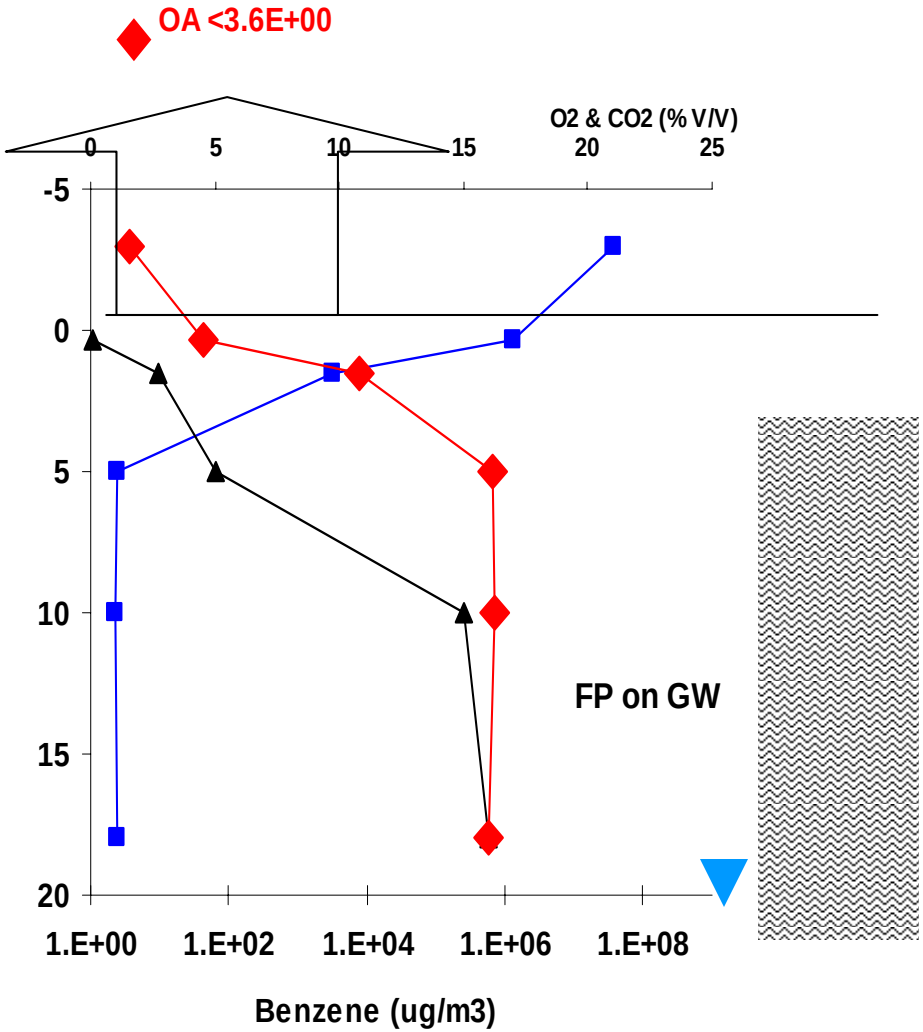
AF ~1E+00 to 1E-01

Very Strong, Shallow Sources, Little Clean Overlying Soil

Conneaut, OH VMP-1
(Roggemans, 1998; Roggemans et al., 2001)
AF 7E-01



Salina Cash Saver VMW-1
Utah DEQ, 7/07
AF 1E-01 (excludes sub-slab)

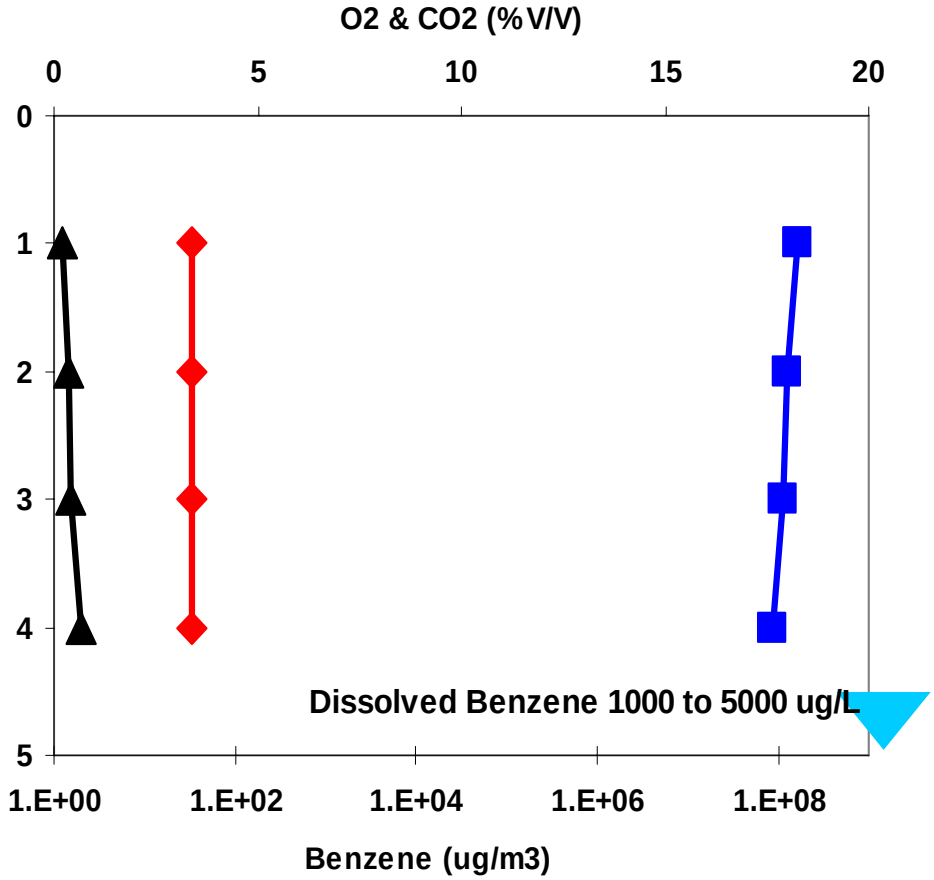


Nationwide Examples of Insignificant Attenuation

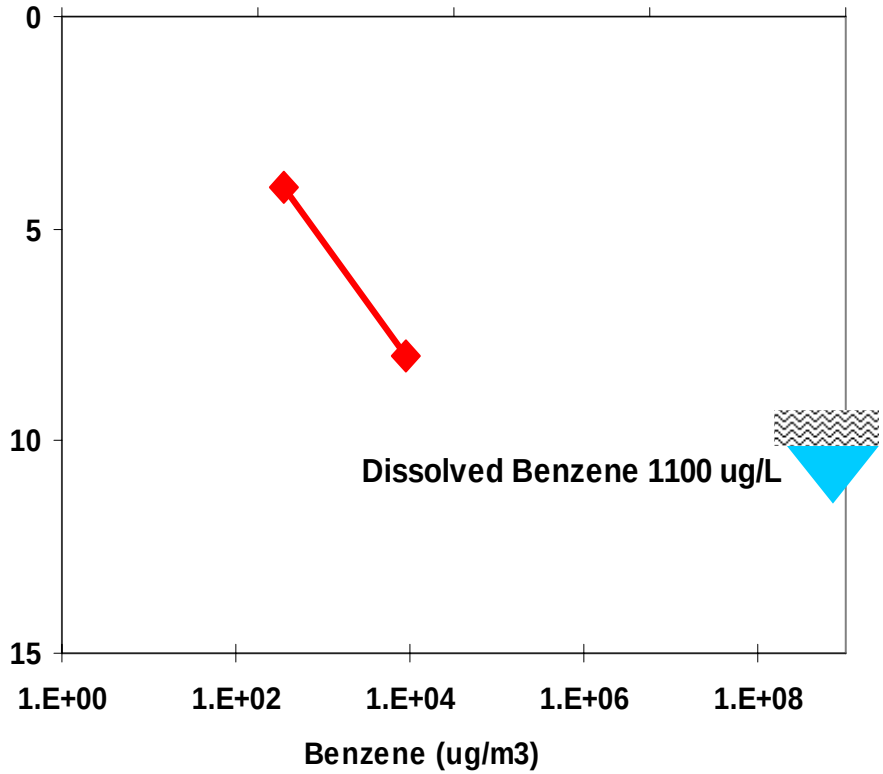
AF 1E+00 to 4E-02

Very Weak Source Strength, Little Hydrocarbon to Degrade

Newport Beach, CA (Ririe, et al 2002)
NB-2
AF 1



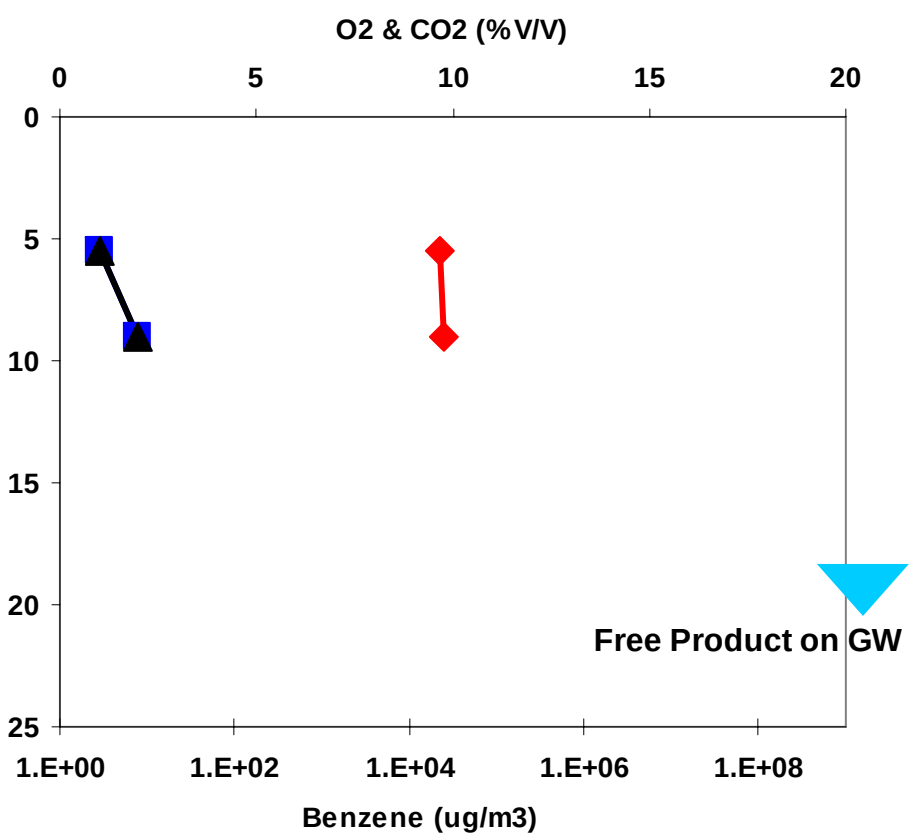
Side Lake Store, MN
(Minnesota Pollution Control, 2004)
VP-1
AF 4E-02



Example of Overlooked Significant Attenuation

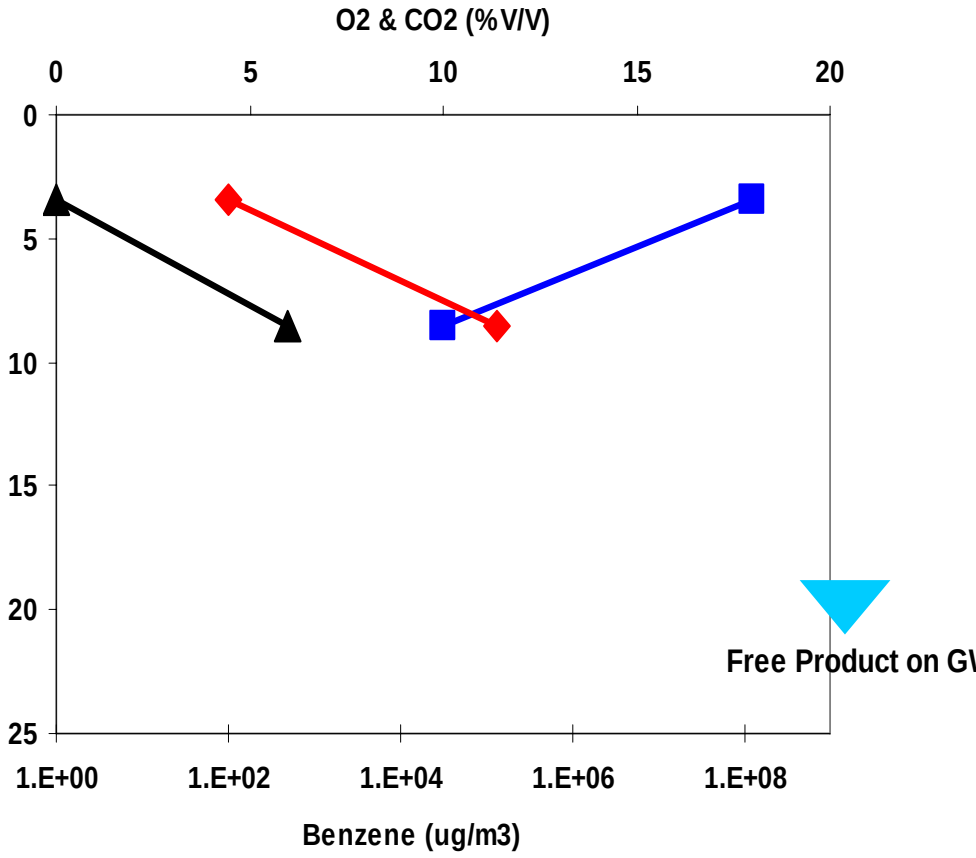
Shallow vapor point set too deep at 5 feet shows insignificant attenuation

Mission Valley Terminal, San Diego, CA
TA-03
AF 1E+00



Shallow vapor point in nearby well set ~2 feet higher shows significant attenuation

Mission Valley Terminal, San Diego, CA
SV-16-AS,AMS 2/23/2004
AF 1E-03



KEY FINDINGS FROM FIELD DATA

- **Characteristics of vapor occurrence & attenuation at Hal's Chevron Case Study are consistent with 242 other events nationwide**

- **Significant vapor bio-attenuation with 2 to 7 feet clean overlying soil**
  - **AF 1E-02 to 1E-05**

- **Insignificant vapor bio-attenuation over weak dissolved plumes & in areas with no clean overlying soil**
  - **AF >1E-02**

- **Weak dissolved plumes with clean overlying soil, vapor intrusion pathway not complete:**
  - **Benzene ≤5,000 ug/L**
  - **TPH ≤10,000 ug/L**

Compare Nationwide Field Data to Results Predicted by Johnson-Ettinger Model (1991)

- **J&E excellent screening tool, cautious, biological degradation not considered**

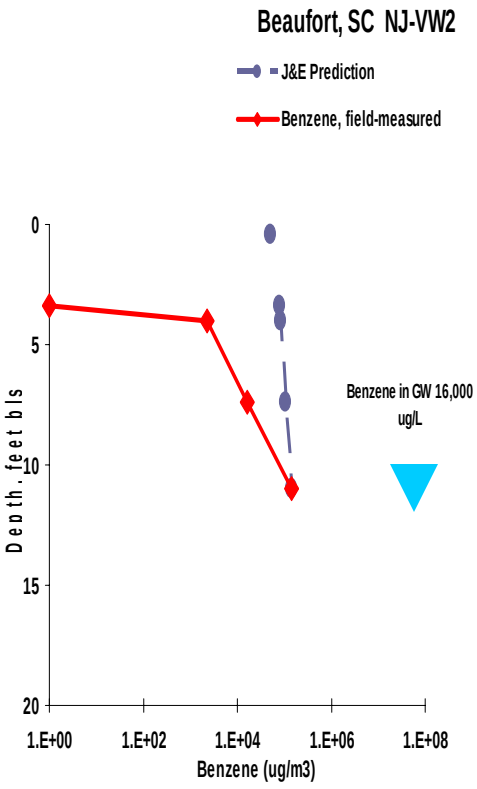
Model assumes vapors migrate by diffusion through vadose zone, vapor concentrations decrease upward to predicted sub-slab concentrations. Those sub-slab vapors migrate across foundations & enter overlying buildings by advection. Indoor vapors are diluted according to building air exchange rate.

- **Run model based on field data to obtain J&E predictions, plot & compare predicted results to field data**

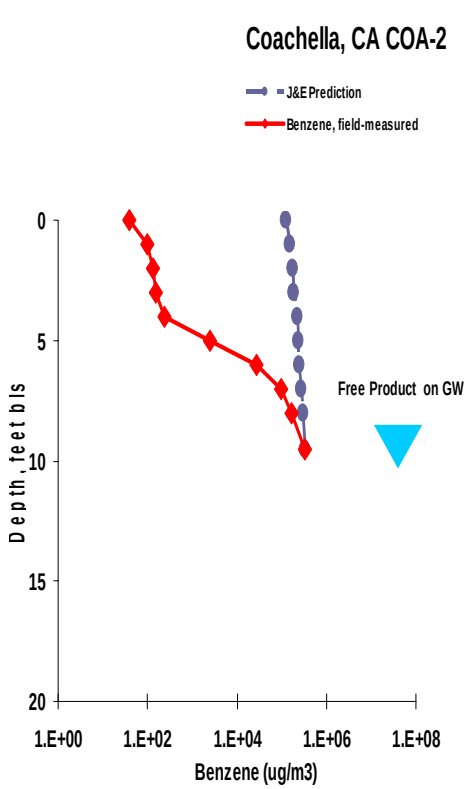
Very Strong Sources with 4 to 7 feet Clean Overlying Soil

Model Under-Predicts Attenuation by 100x to 100,000x

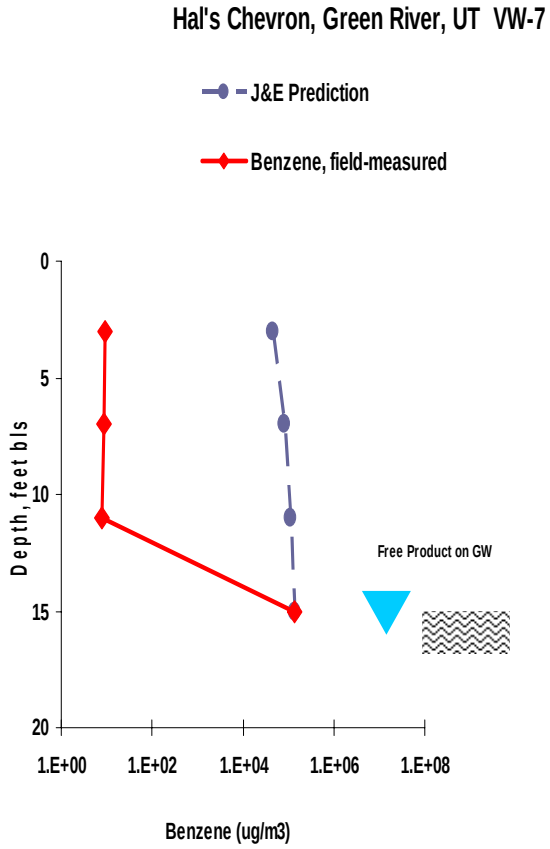
100x to 80,000x



100x to 1000x

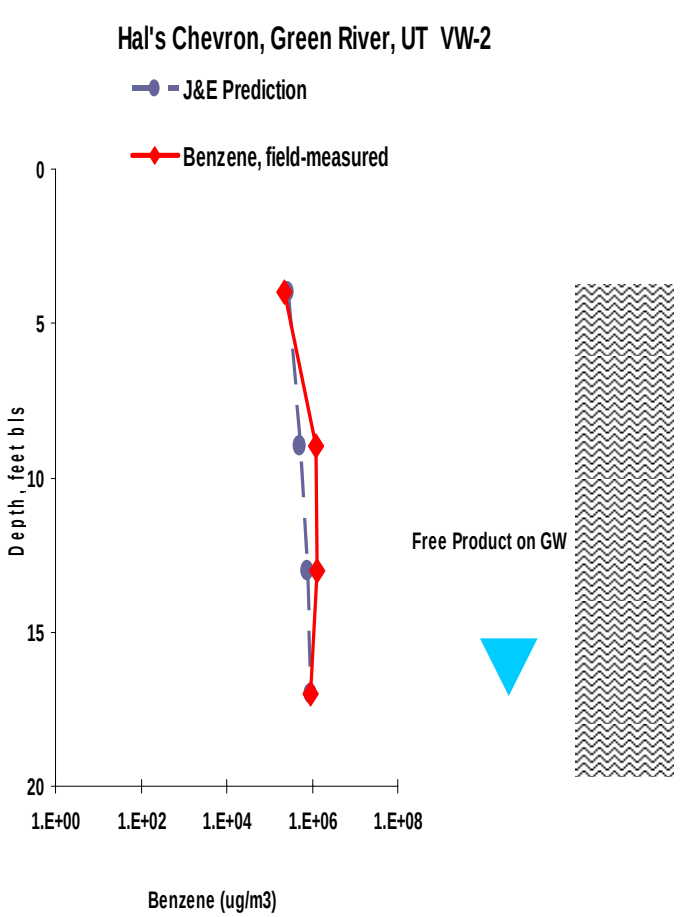


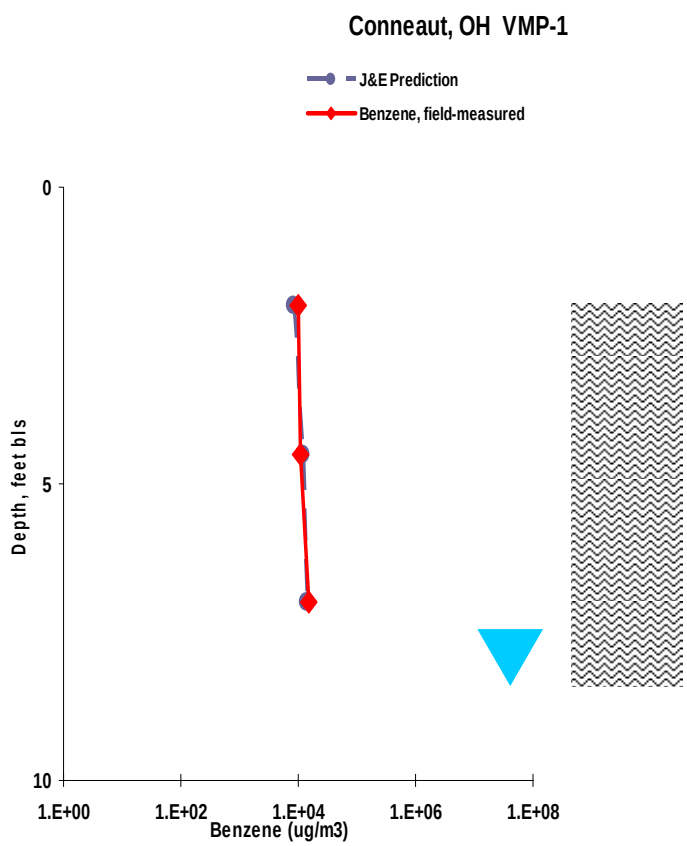
100,000x

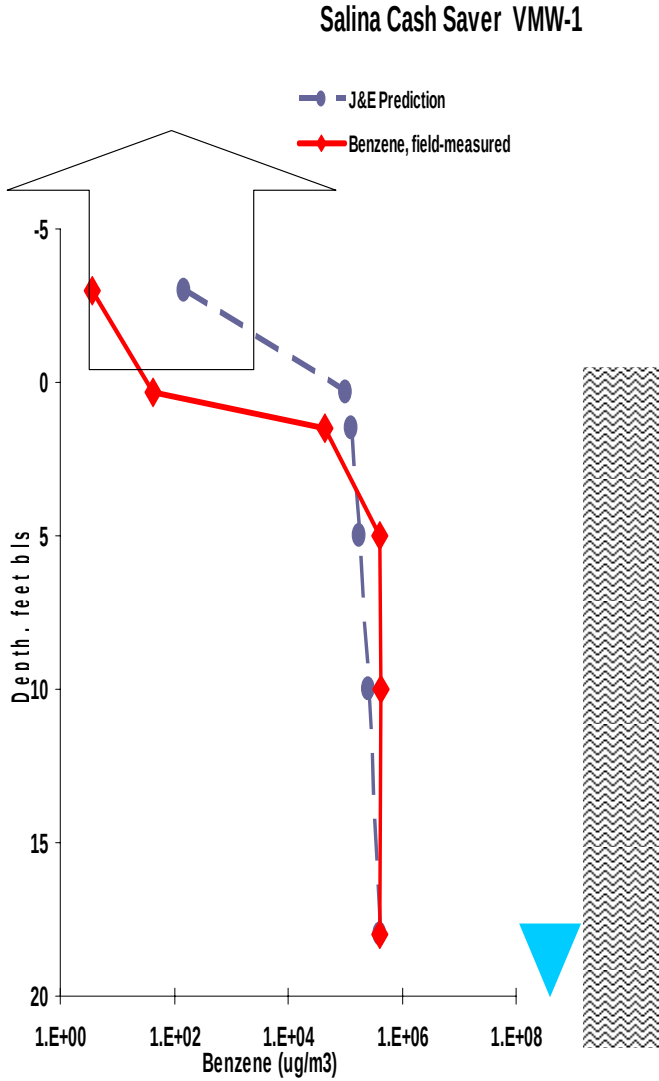


Very Strong Sources with No Clean Overlying Soil

Model Closely Predicts Attenuation

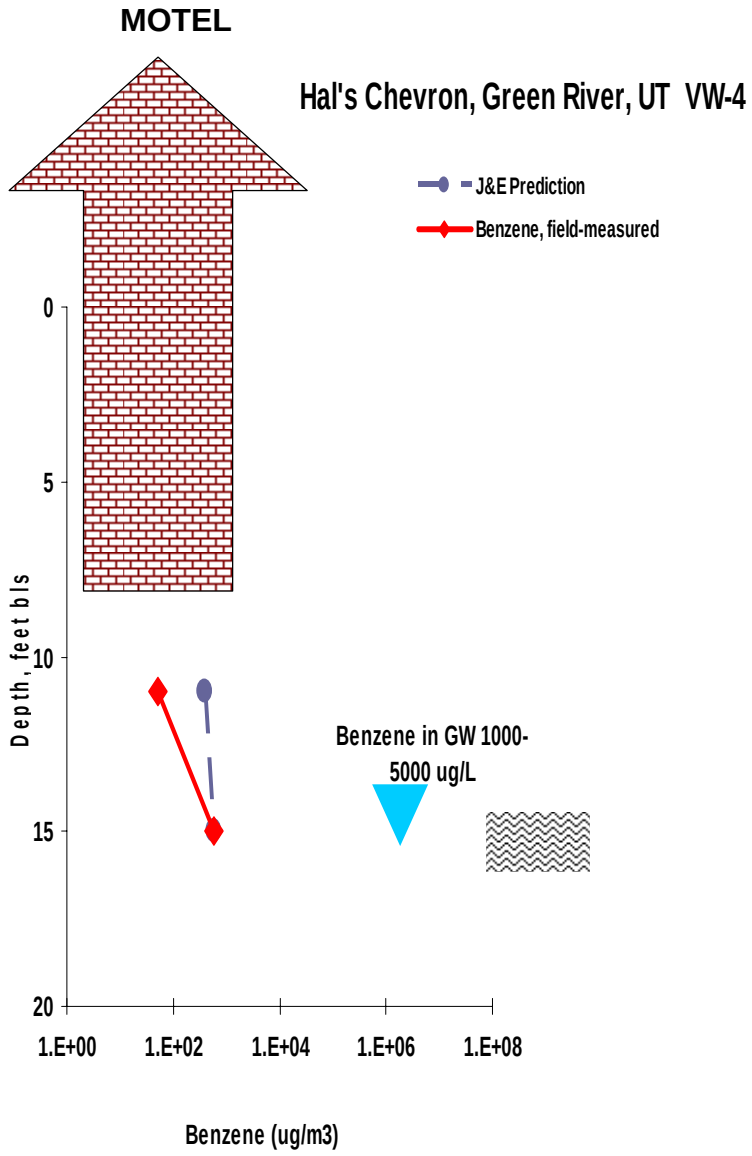


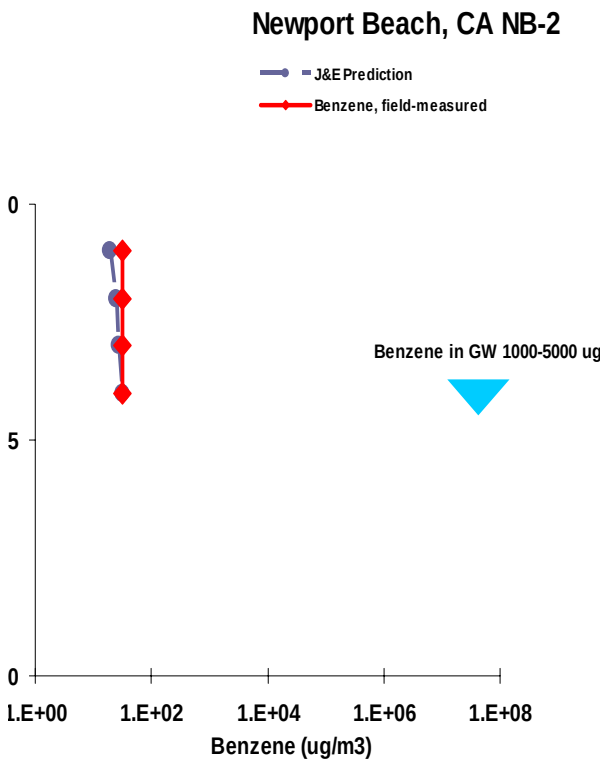


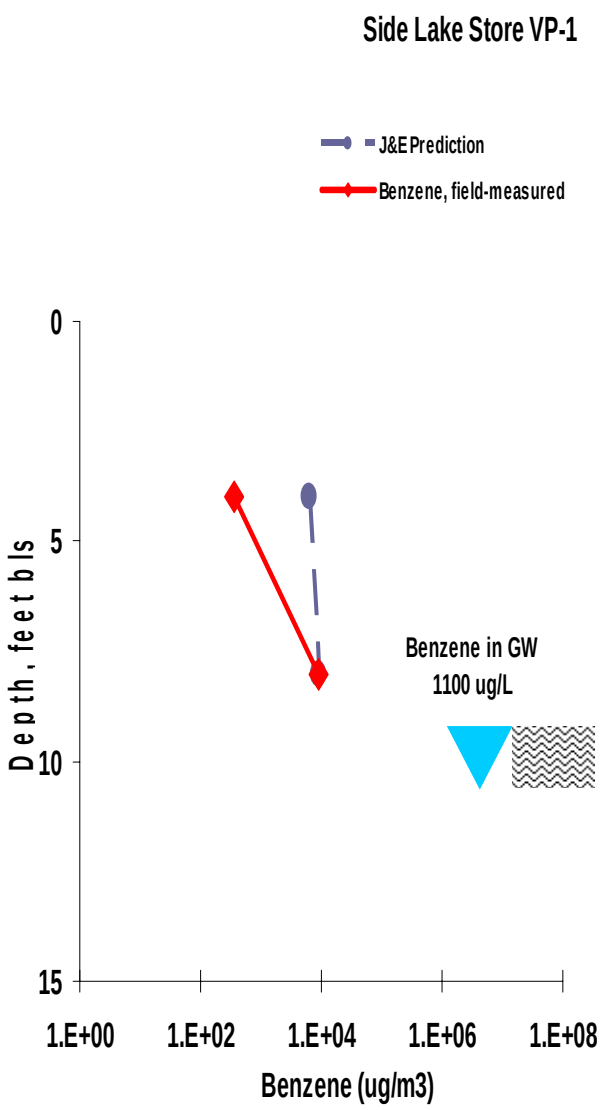


Weak Sources with Little Hydrocarbon to Attenuate

Model Under-Predicts Attenuation by 1x to 100x



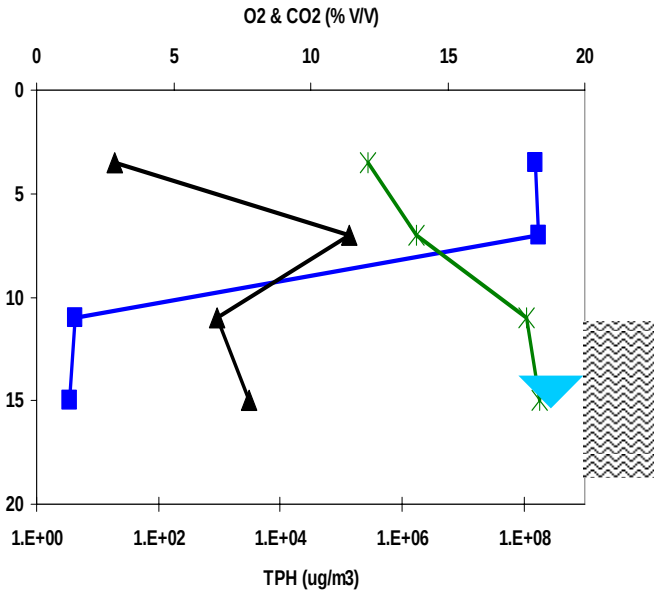




Total Petroleum Hydrocarbon Vapor Evaluation

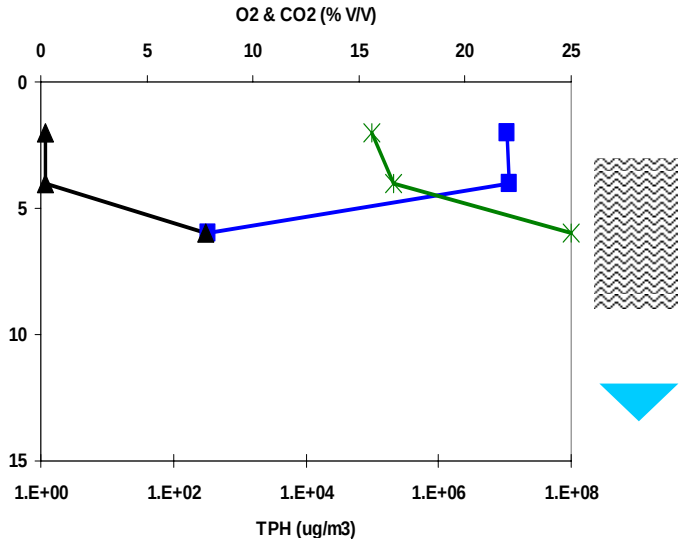
Very high source strength, TPH 180,000,000 ug/m3

Kent, OH VMP-1
(Roggemans, 1998; Roggemans et al., 2001)
AF 2E-03



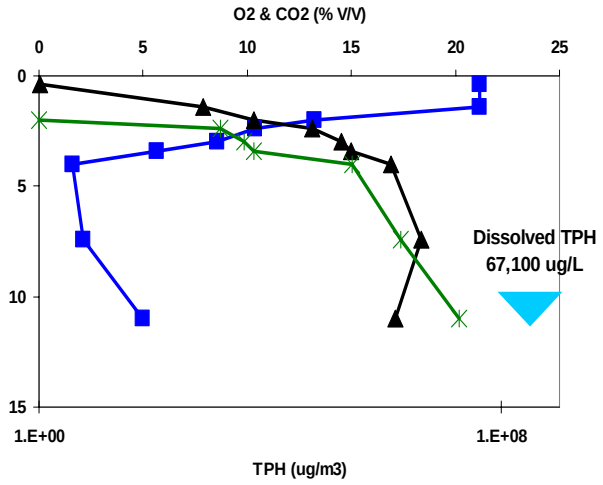
High source strength, TPH 100,000,000 ug/m3

Akron, OH VMP-1
(Roggemans, 1998; Roggemans et al., 2001)
AF 1E-03



Beaufort, SC NJ-VW2
(Lahvis, et al., 1999)
AF 8E-05

Moderate source strength, TPH 18,000,000 ug/m3

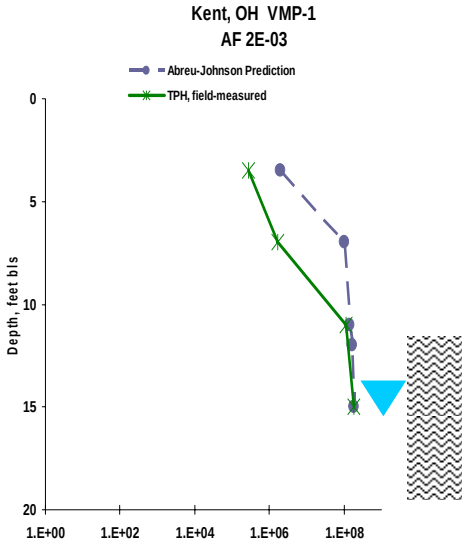


Comparison of TPH Field Profiles to 3-D Numerical Model

Abreu and Johnson, 2005. Med-fine sand.

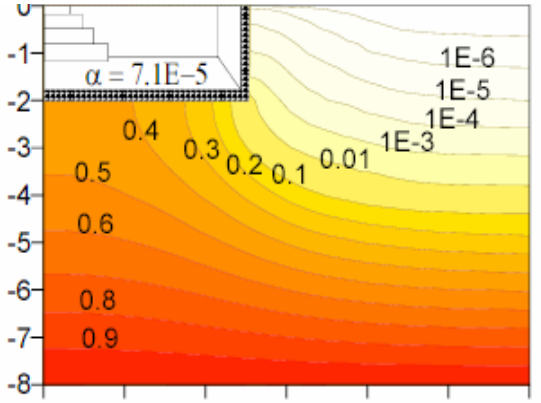
Very Strong Vapor Source →

Model under-predicts attenuation 10x to 100x



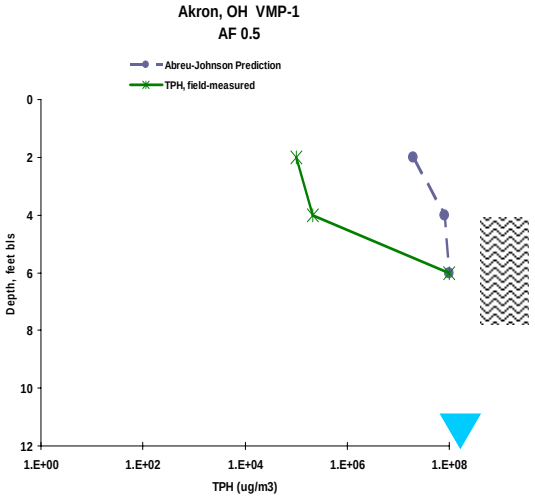
Hydrocarbon

Csource = 200,000,000 ug/m3

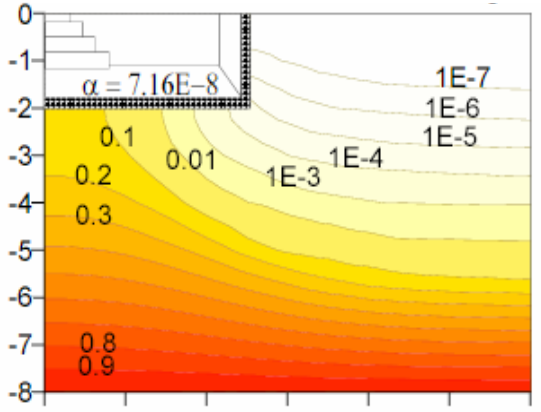


Strong Vapor Source →

Model under-predicts attenuation 100x

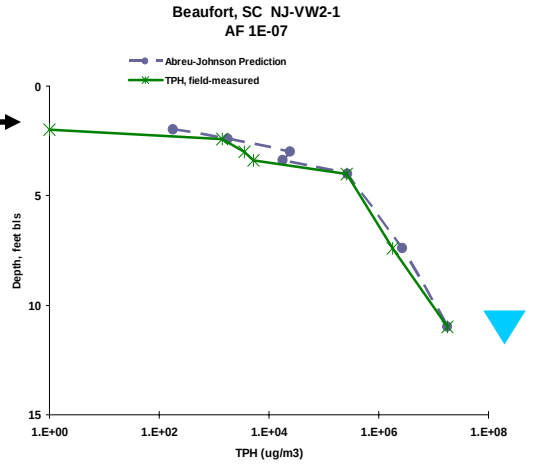


Csource = 100,000,000 ug/m3

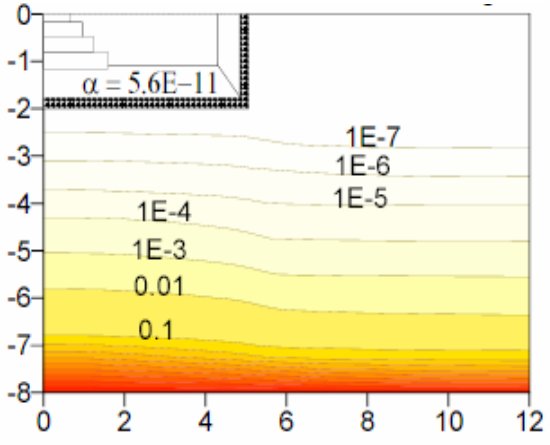


Moderate Strength Vapor Source, common at most LUST sites →

Model under-predicts attenuation ≤10x



Csource = 20,000,000 ug/m3



Comparison of High-Quality Field Data to 2 Models

- **J&E Model**
  - Under-predicts benzene vapor attenuation up to 100,000x in strong source areas with up to 7 feet clean overlying soil
  - Accurate prediction, under-prediction by ≤10x in weak source areas & in strong source areas with little clean overlying soil
  - CONCLUSION: Partitioning from free- & dissolved phase to vapor phase greatly over-predicted (Henry's Law Constant)
- **Abreu & Johnson Model**
  - Fairly accurate predictions in moderate strength sources with as little as 5 feet clean overlying soil, under-predicts vapor attenuation by <10x
  - Under-predicts vapor attenuation by 10x to 100x in high strength sources, <7 feet clean overlying soil required

RECOMMENDED 100-FOLD ATTENUATION FACTOR TO EPA 2002 OSWER GUIDE (residential)

COARSE-GRAINED SOIL

Chemical	Depth feet bls	Soil Gas Concentrations ug/m3		Groundwater Concentrations ug/L	
		J&E Predicted	Proposed	J&E Predicted	Proposed
Benzene	≤5	3.1	310	2.31	231
	>5	31	3,100	2.8	2,800
TPH (1,3,5-trimethlybenzene)	≤5	60	6,000	25	2,500
	>5	600	60,000	98.7	9,870

RECOMMENDED 1 TO 10-FOLD ATTENUATION FACTOR TO EPA 2002 OSWER GUIDE (residential)

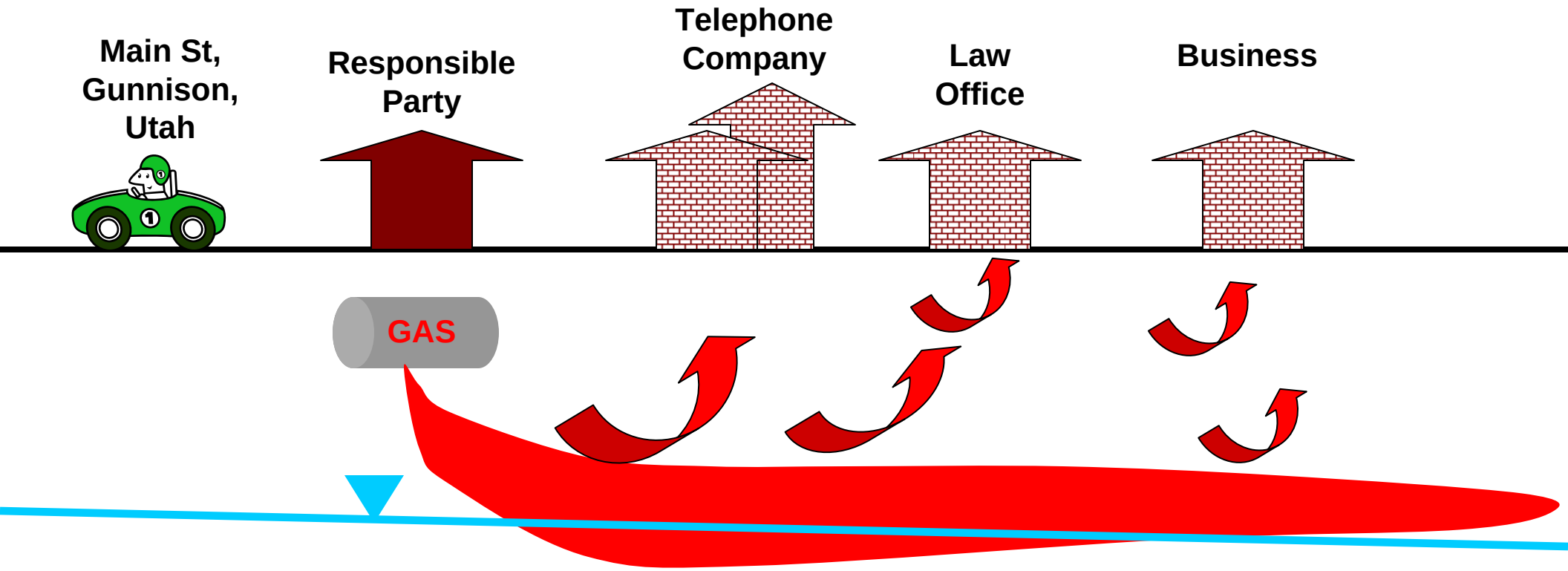
FINE-GRAINED SOIL

Chemical	Depth feet bls	Soil Gas Concentrations ug/m3		Groundwater Concentrations ug/L	
		J&E Predicted	Proposed	J&E Predicted	Proposed
Benzene	≤5	300	300	31.2	312
	>5	500	5,000	32.3	3,230
TPH (1,3,5-trimethlybenzene)	≤5	5,000	5,000	1,020	1,020
	>5	9,000	90,000	1,060	10,600

WHEN DOES VAPOR INTRUSION OCCUR?

Catastrophic petroleum releases

Sudden release cannot displace water-saturated soil, vapors transport quickly



WHEN DOES VAPOR INTRUSION OCCUR?

Modified building HVAC systems, not to code, no air exchange

VAPOR INTRUSION WORK GROUPS

- **API-funded contractor (GSI) compiling & analyzing national petroleum vapor data in Access database (includes Colorado data)**

- **ASTM Vapor Intrusion Task Group E 50.02.06**
  - ***"Assessment of Vapor Intrusion into Structures on Property Involved in Real Estate Transactions," final March 3, 2008***
  - ***VERY CAUTIOUS: Requires assessment of VI pathway for petroleum hydrocarbons within 528 feet (1/10 mile) of property***

- **EPA OUST put Work Group for Petroleum Hydrocarbons "on hold"**


THANK YOU…