An Analysis of Subsurface Vapor Attenuation Data from Petroleum Hydrocarbon Sites

National Ground Water Association and American Petroleum Institute

Vapor Intrusion Workshop

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Costa Mesa, California

by

Robin Davis, Project Manager

Utah Department of Environmental Quality

Leaking Underground Storage Tank Program

801-536-4177 rvdavis@utah.gov

Purpose

- **Explore why:**
  - **LUST sites have very few reported incidents of vapor intrusion to buildings**
  - **Vapor attenuation is observed in the majority of events, even beneath buildings and in coarse-grained soil**
- **Explore, evaluate and show characteristics of vapor attenuation from existing published data**
- **Evaluate potential for vapor intrusion exposure pathway to be complete** ***(why is there no attenuation beneath some buildings?)***
- **Identify data gaps and needs**

Background

- **Nov. 2002: U.S. EPA published draft guidance "Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils"**
- **Guide uses the Johnson-Ettinger (J&E) Model**
- **J&E Model may be overly conservative for petroleum sites *(no bioattenuation)***
- **2003: U.S. EPA formed a national work group**

  (*comprised of state and federal regulators)*
  - **Determine if Guidance is appropriate for petroleum**
  - **Study the mechanisms of petroleum vapor attenuation in the subsurface**

Scope

- **Reviewed published literature and public domain documents for data containing indicators of bioattenuation**
- **Data compiled and tabulated:**
  - **Multi-depth vapor phase benzene, TPH, oxygen and carbon dioxide**
  - **Depth to groundwater**
  - **Adsorbed and dissolved phase benzene, TPH**
  - **Presence of free product on groundwater**
  - **Type of ground surface cover *(paved, unpaved, presence of overlying buildings)***
  - **Soil type**
  - **Sampling dates**

Scope *(continued)*

- **Developed attenuation ranking system**
  - ***Significant (AF=<0.09)***
  - ***Insignificant (AF=>0.09)***

- **Tabulated multi-depth data and compared common characteristics to 4 published models of behavior** ***(Roggemans, Johnson)***

- **Identified how future data sets can be improved to reduce uncertainties**

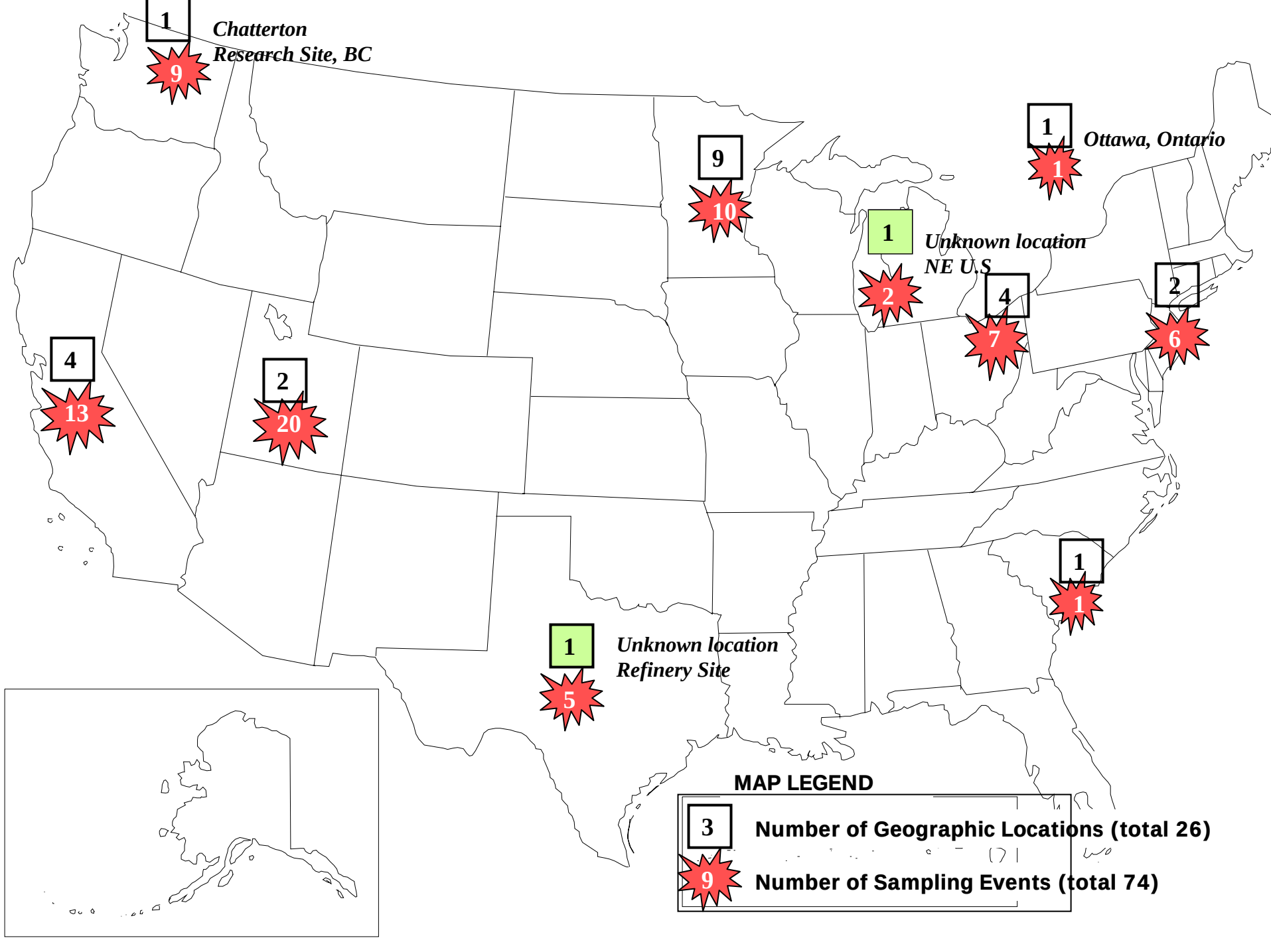
Example of Table of Compiled Sample Data for Evaluating Subsurface Vapor Attenuation at Petroleum-Contaminat

Sample Site Location and Reference	Depth to GW ft bls	Depth ft bls	Soil Type	CO_2 % vol	O_2 % vol	Vapor TPH ug/m^3	Vapor Benzene ug/m^3	TPH in GW mg/L	Benzene in GW mg/L	Vapor AF for TPH	Vapor AF for Benzene	Vapors Sampled Beneath Paved Areas
Refinery Site, unknown location VW 93 (Roggemans, 1998; Roggemans, et al., 2001)	65	10	Sand and gravel, permeable with fine-to-medium sand from 48.5 to 54.5 feet	5.72	15.84	1.00E+03	0.00E+00			0.00001	0.05	
		15		6.79	15.49	1.90E+04	0.00E+00					
		20		6.34	14.96	7.00E+03	0.00E+00					
		25		3.22	15.66	4.00E+03	0.00E+00					
		30		6.41	14.9	4.00E+03	0.00E+00					
		35		8.18	12.51	2.00E+04	0.00E+00					
		40		9.48	10.24	1.00E+04	1.00E+06					
		45		14.65	1.17	2.39E+07	5.94E+06					
		50		13.37	1.11	4.17E+07	1.04E+07					
		55		13.2	1.11	4.66E+07	1.16E+07					
		60		12.42	1.15	7.84E+07	1.89E+07					
BP, Akron, Ohio VMP-1 (Roggemans, 1998)	13.8	2	Sand, silty sand	0.20	22.00	1.00E+05	4.80E+02			0.001	0.002	X
		4	Sand, silty sand	0.20	22.10	2.10E+05	8.80E+02					
		6	Sand, silty sand	7.80	7.90	1.00E+08	2.70E+05					
		8	Silt, clayey									
BP, Paulsboro, New Jersey Area 1A (Roggemans, 1998; U.S. EPA, 2003)	18 to 20	4	Sand, fine-medium-grained, minor silt and coarse sand	0.4	19.6		5.00E+00		9.6		0.00001	X
		8		0.4	19.2		5.00E+00					
		12		4.1	6.0		2.40E+05					
		16		6.5	6.1		5.00E+05					
		20										
BP, Paulsboro, New Jersey Site D (Roggemans, 1998; U.S. EPA, 2003)	18 to 20	8	Sand, fine-medium-grained, minor silty and coarse sand	6.8	3.5		3.40E+05				0.5	
		12		10.0	1.0		3.90E+05					
		16		12.2	1.0		6.30E+05					
		20										
Port Hueneme, Calif. MP-10, Site 1, dissolved area (Roggemans, 1998)	8	2	Silts and sands	0.49	15.89	1.60E+04				0.3		X
		4		0.41	17.74	4.60E+04						
		6		0.48	17.06	5.70E+04						
Hal's Chevron, Green River, Utah VW-10, 11/20/03 (Secor, 2004)	16	3	Silt, clayey			7.80E+00	1.90E+01	10.8	3.16	0.0002	0.00004	X
		7	Silt			2.70E+01	4.50E+02					
		11	Silt			3.00E+04	1.10E+05					
		15	Silt			3.50E+04	4.70E+05					
Stafford, New Jersey Building #14 and VP-10 (Sanders, et al., 2004)	11 to 14	sub-slab	Sand				3.00E+00		6		0.001	
		3					<8.00E+00					
		6					6.90E+01					
		9					2.10E+03					
		11										

Distribution of the Data Points

Indicators of attenuation available for:

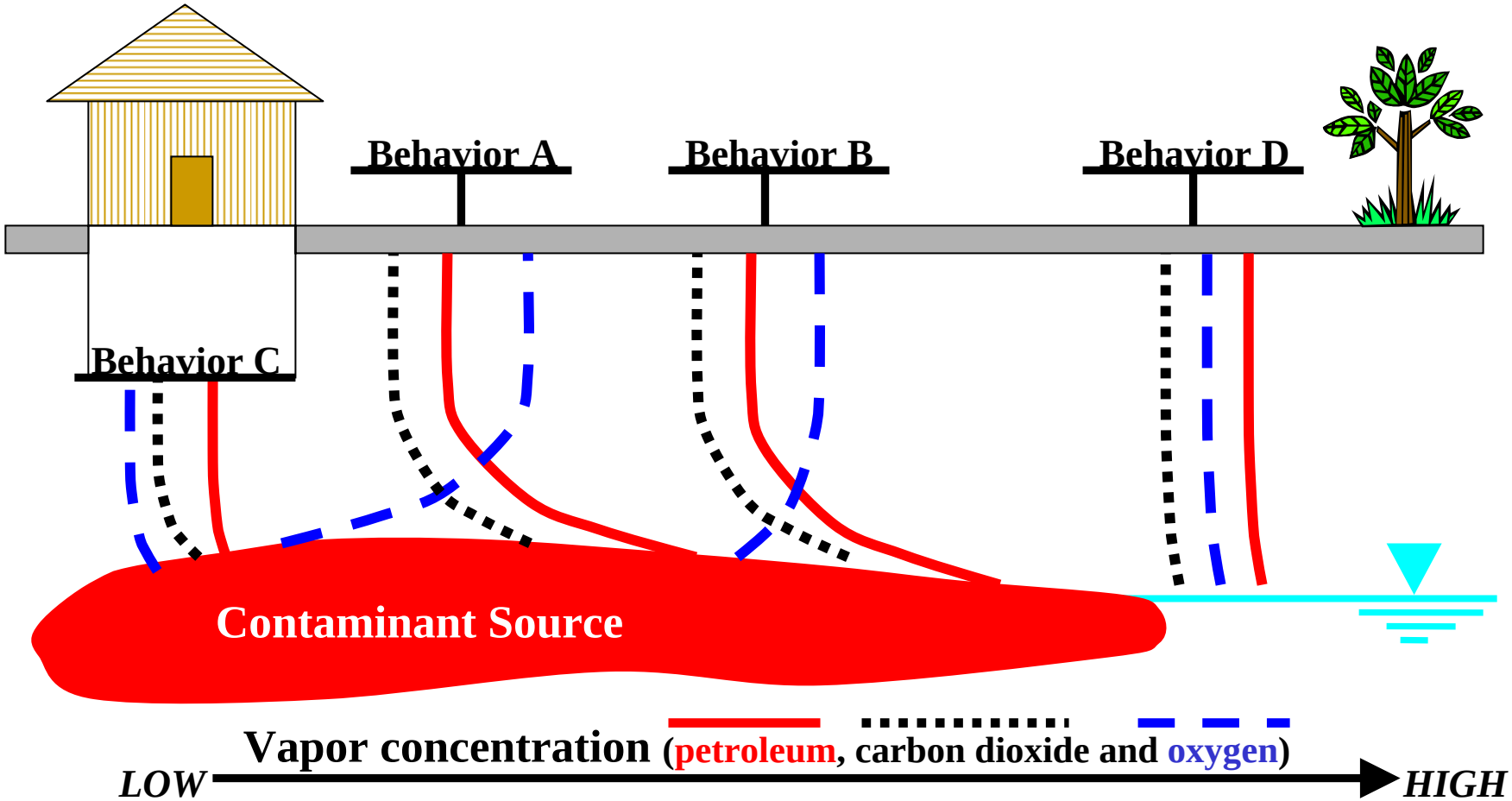
- **26 separate geographic locations in United States and Canada**
- **52 sample points** ***(example: individual nested vapor wells)***
- **74 sample events**


1
Chatterton
Research Site, BC
9
9
10
1
Ottawa, Ontario
1
1
Unknown location
NE U.S
2
4
7
2
6
4
13
2
20
1
1
1
Unknown location
Refinery Site
5
MAP LEGEND
3
Number of Geographic Locations (total 26)
9
Number of Sampling Events (total 74)

Attenuation Ranking System

Attenuation Factors (AF) calculated by dividing the contaminant vapor concentration at shallow depth by that at deepest depth

Example: Area 1A, Paulsboro, New Jersey
(sand w/minor silt and coarse sand)
Benzene vapor concentrations:
shallow **(4 feet) = 5 ug/m3**
deep **(16 feet) = 500,000 ug/m3**
AF = 0.00001



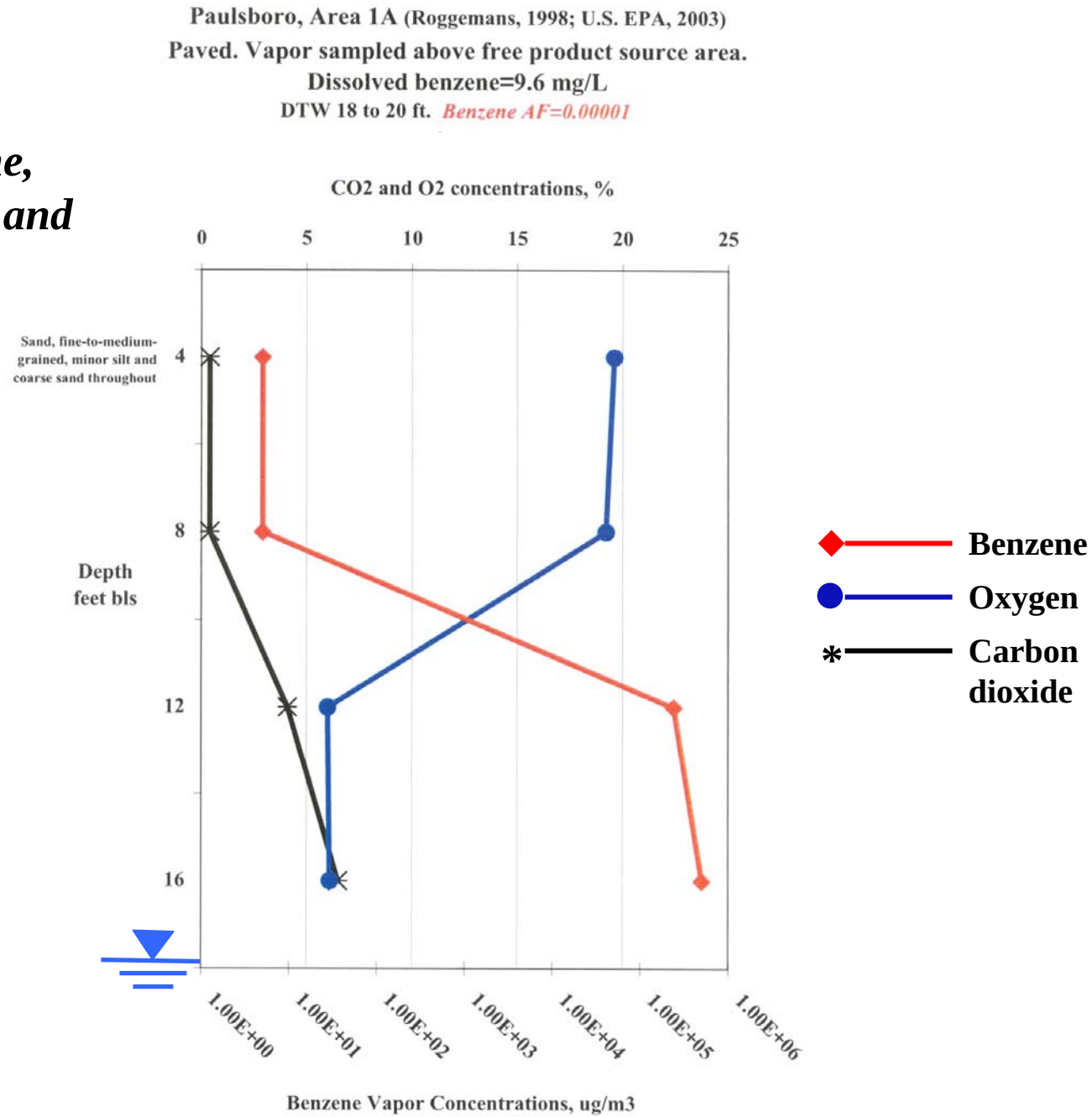
Behavior A:	**Strong anoxic and aerobic zones, and upward attenuation of petroleum**
Behavior B:	**Weak anoxic and aerobic zones, and upward attenuation of petroleum**
Behavior C:	**Anoxic/oxygen-deficient, no upward attenuation of petroleum**
Behavior D:	**Weak hydrocarbon source and constant O2 and CO2 concentrations**

Conceptual Characteristics of 4 Published Models of Attenuation

(***Roggemans, 1998; Roggemans, Bruce, Johnson and Johnson, 2001***)

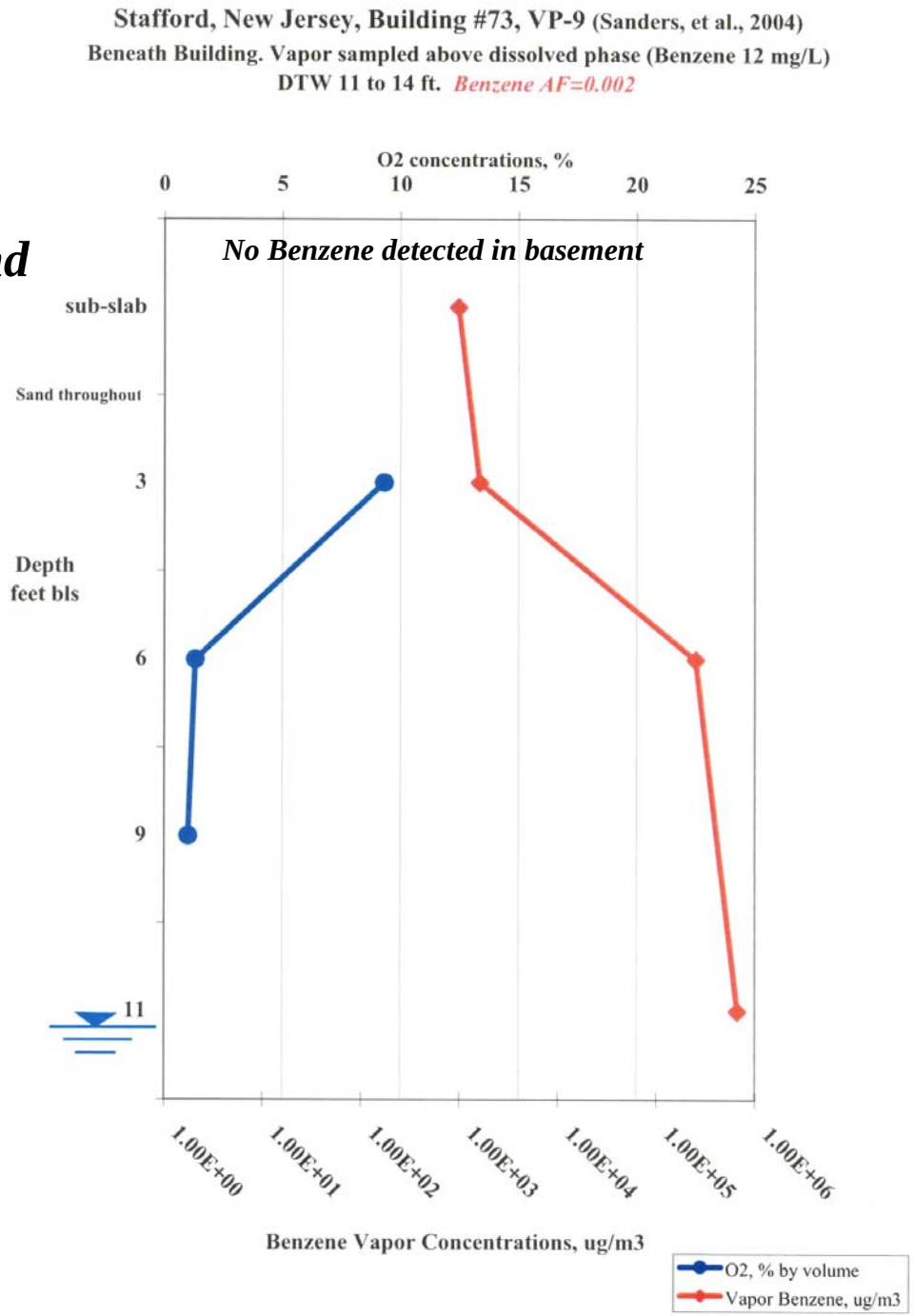
Behavior A

(depleting benzene, strong O2 supply and depletion)



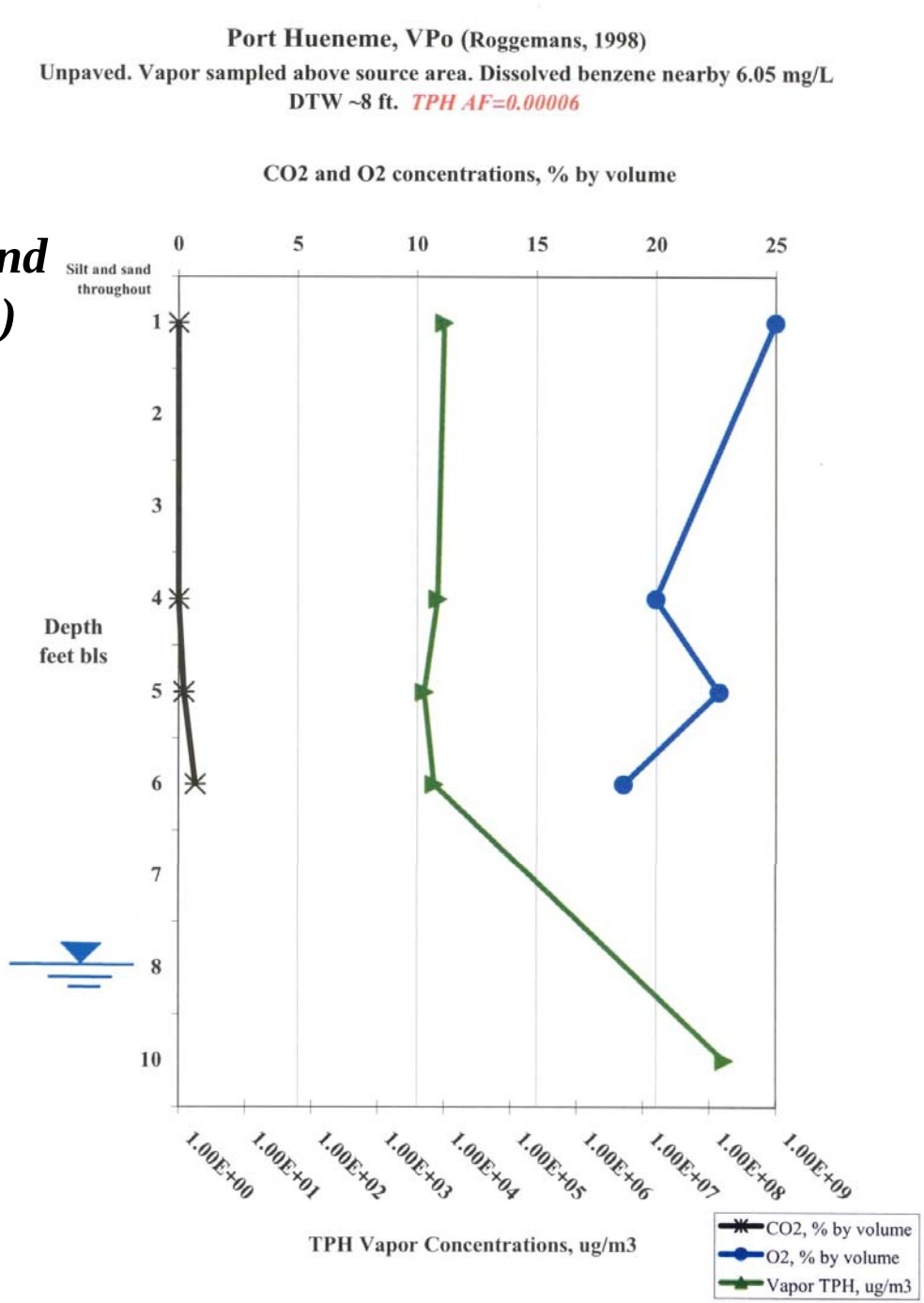
Behavior A

(depleting benzene, strong O2 supply and depletion)

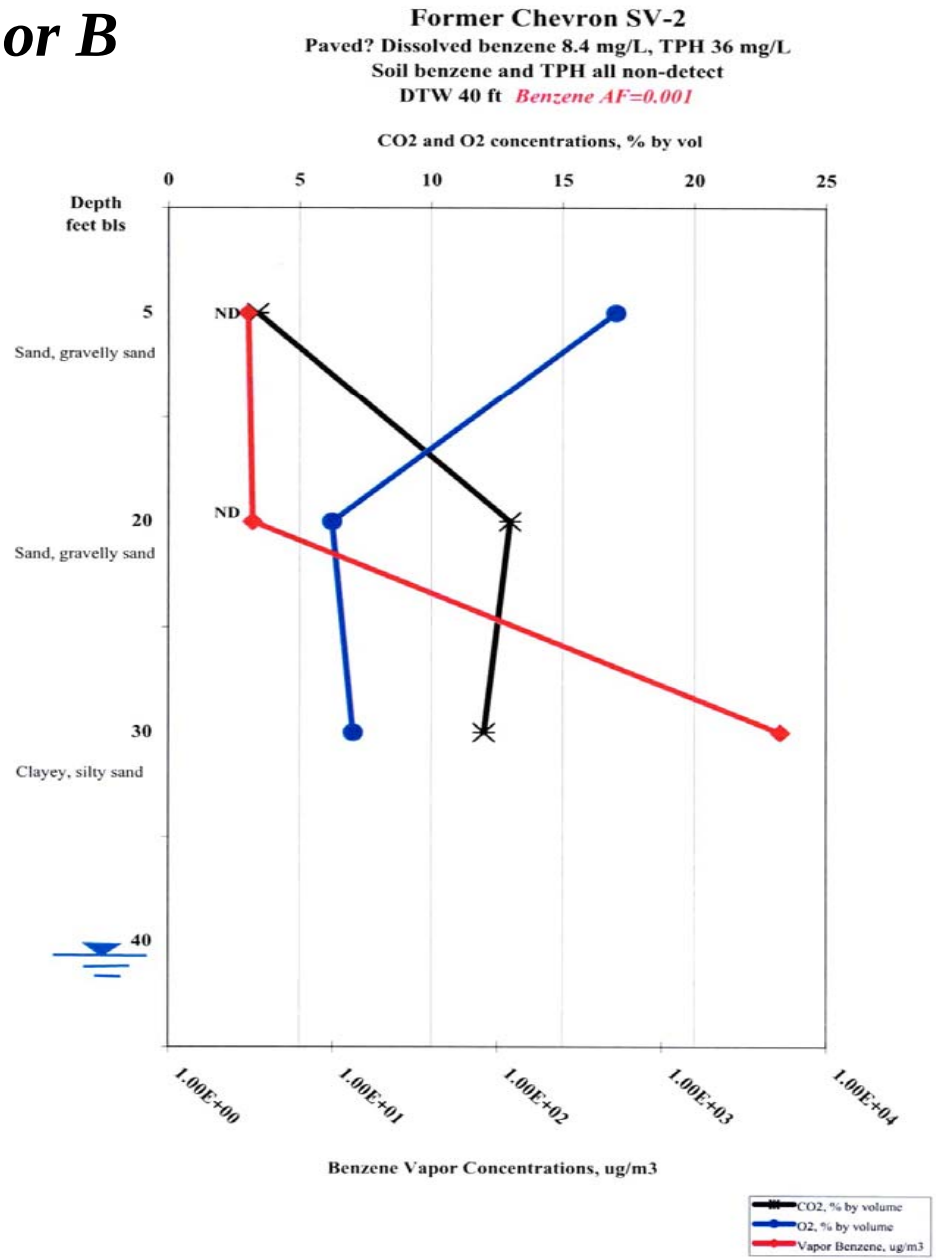


Behavior B

(depleting TPH, strong O2 supply and moderate depletion)

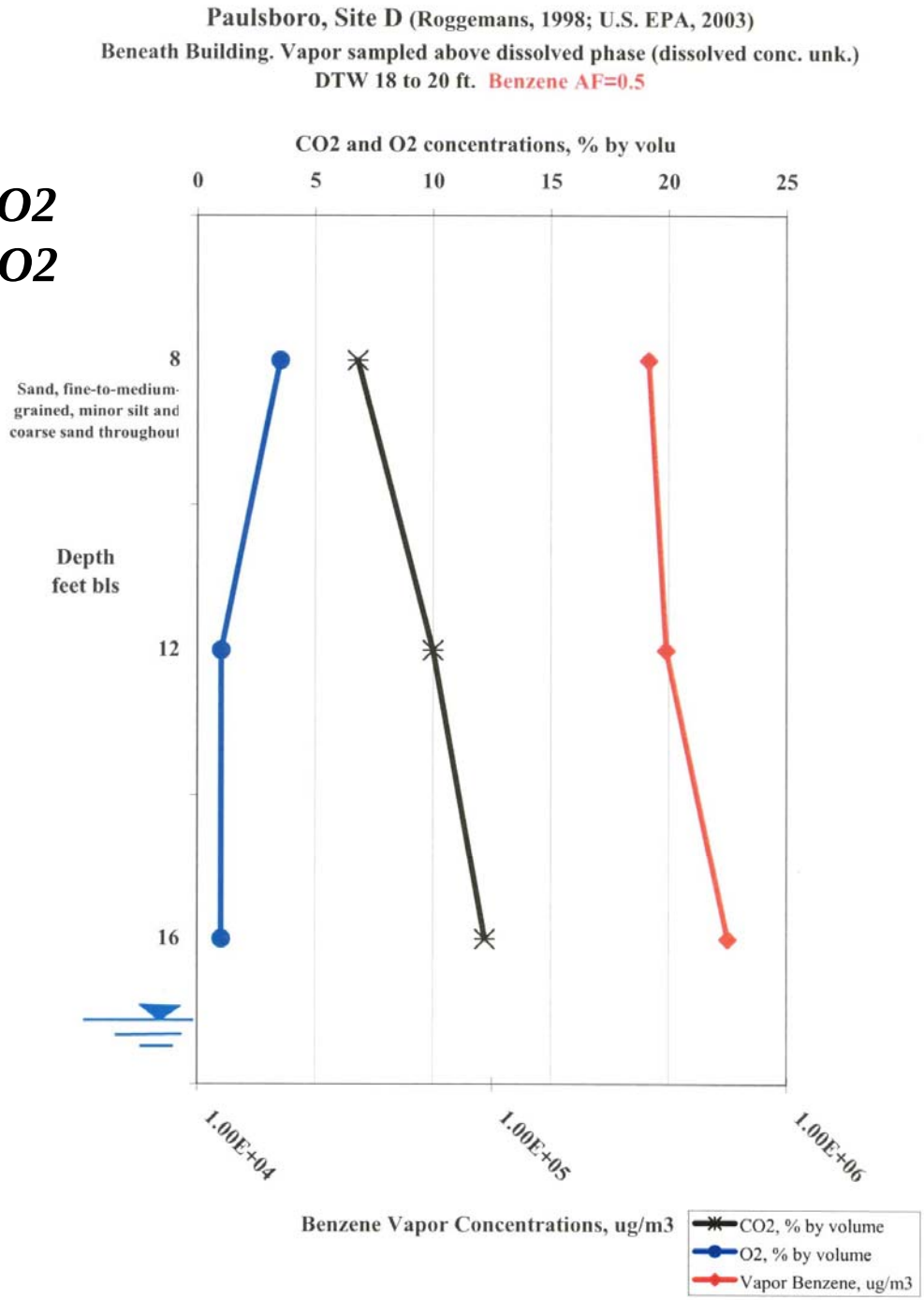


Behavior A or B



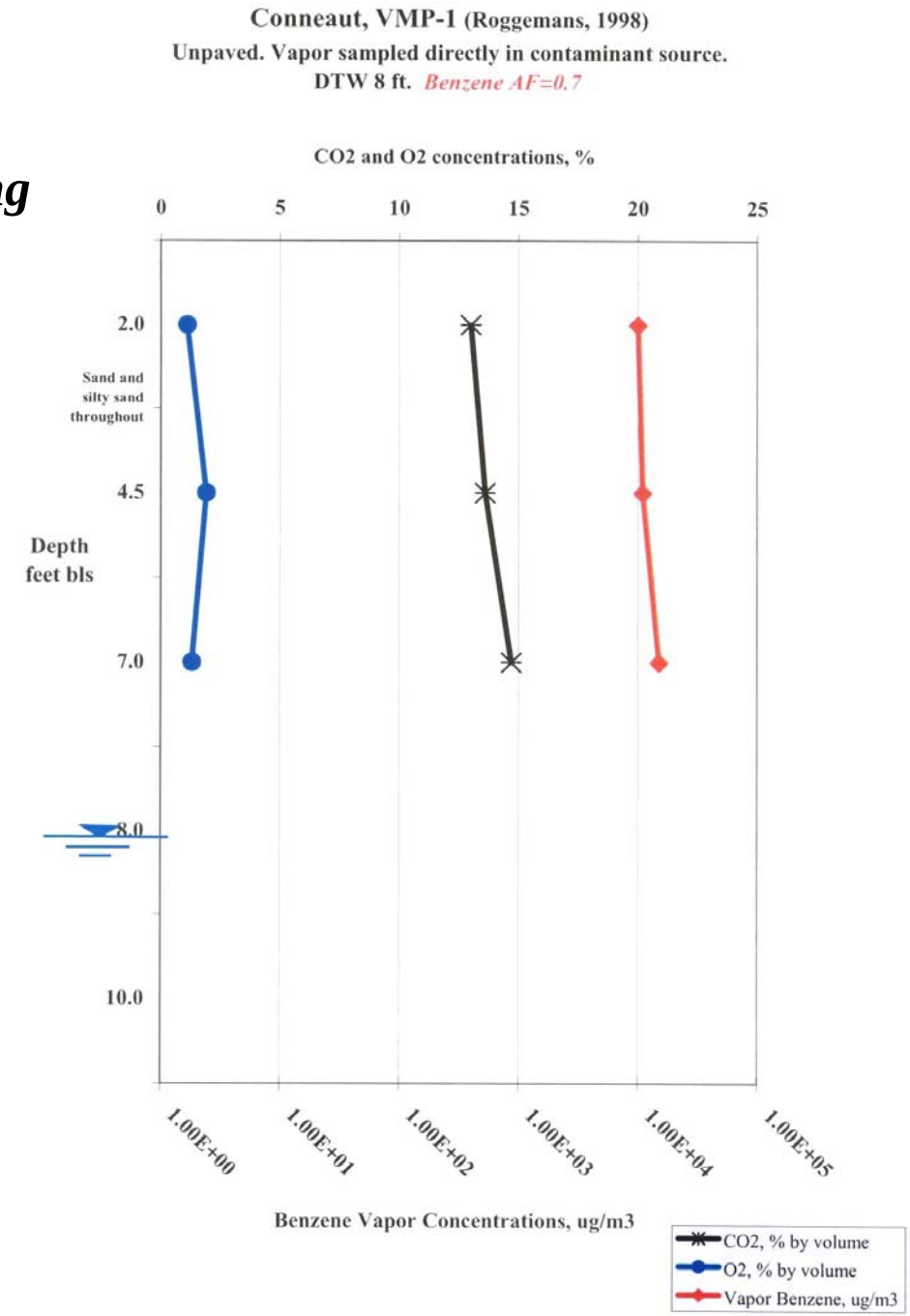
Behavior C

(constantly high benzene, strong O2 depletion with CO2 enrichment)



Behavior C

(constantly high benzene, and strong O2 depletion with CO2 enrichment)



Findings…

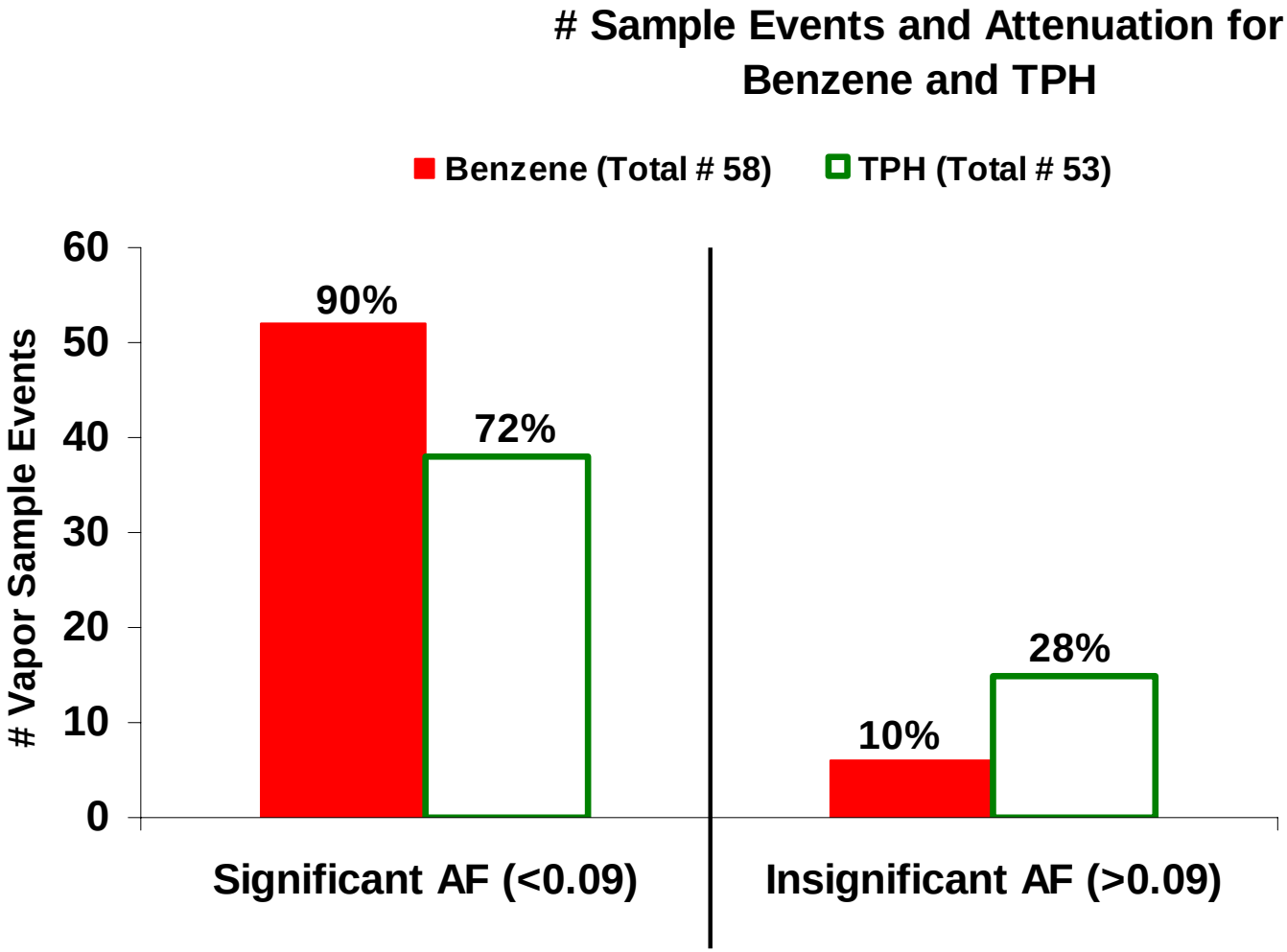
Indicators of Significant Attenuation

- **AF = ≤ 0.09**
- **AFs range from 0.09 to 0.00001**
  - **90 % benzene events fit that range**
  - **72 % TPH events fit that range**
- **Clean soil (at least 2 feet) overlies contaminant source**
- **Petroleum vapor concentration decreases significantly vertically away from source**
- **O_2 depletion and CO_2 enrichment near the source, and O_2 enrichment and CO_2 depletion with increasing distance from the source**
- **O_2 range 5% to 10%**

Findings, *continued*

Indicators of Insignificant Attenuation

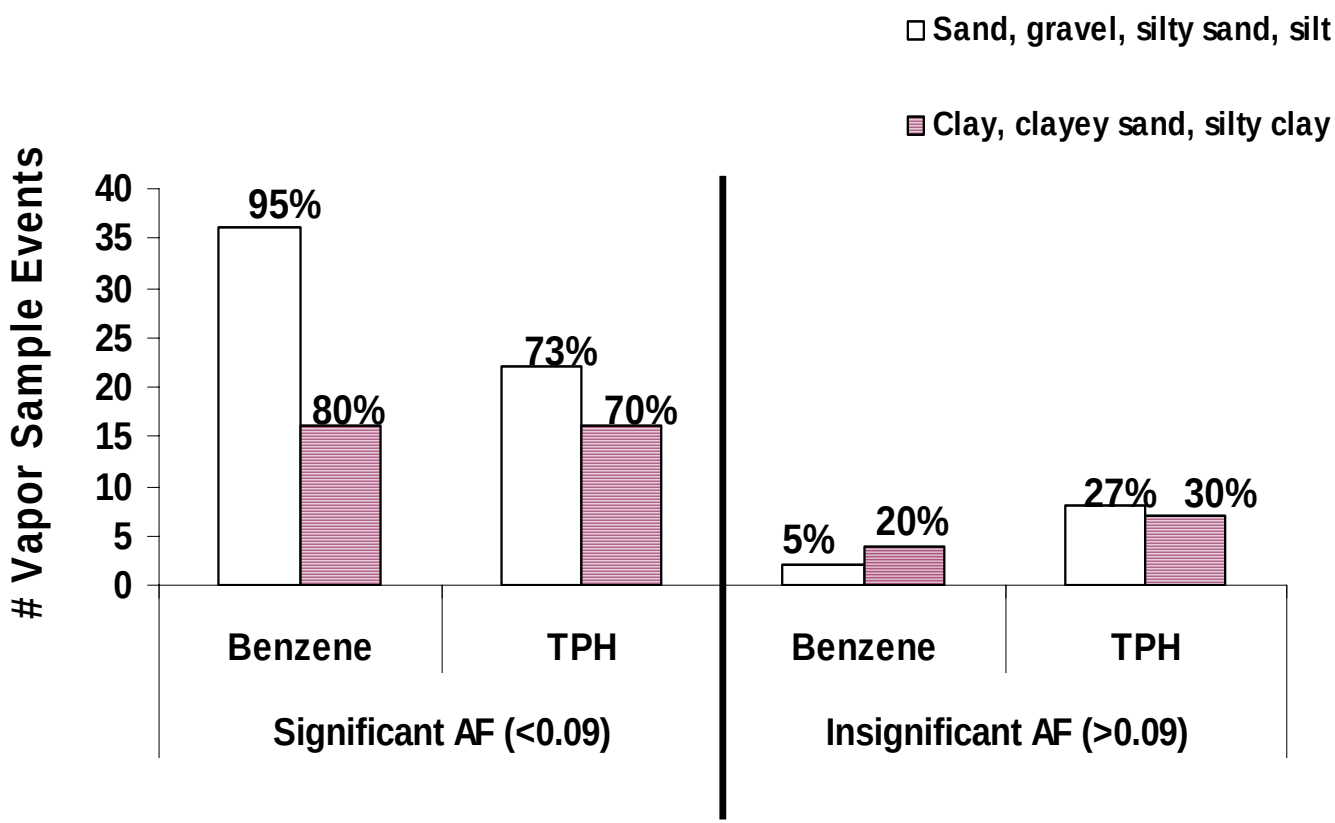
- **AF = > 0.09**
- **AFs range from 0.1 to over 1.0**
  - **10 % benzene events fit that range**
  - **28 % TPH events fit that range**
- **Lack of clean soil overlying contaminant source**
- **Constant petroleum vapor concentration**
- **Constant O_2 depletion and carbon dioxide enrichment**
- **O_2 < 5%**


Sample Events and Attenuation for Benzene and TPH
Benzene (Total # 58)
TPH (Total # 53)
Vapor Sample Events
60
50
40
30
20
10
0
90%
72%
10%
28%
Significant AF (<0.09)
Insignificant AF (>0.09)

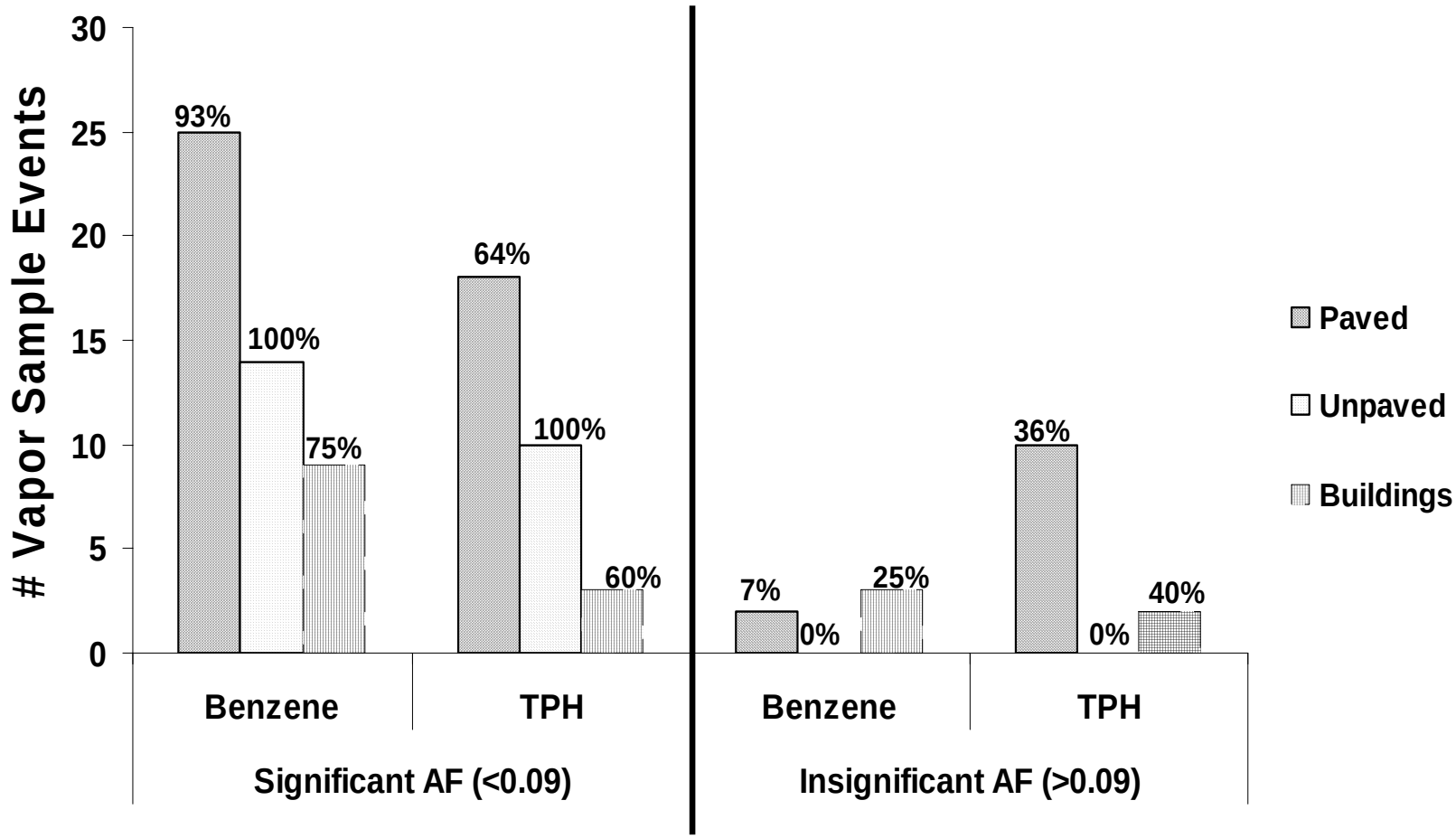
Findings, *continued*

- **Attenuation occurs in gravel, sand and silt in 95% of the benzene events, and 73% TPH events**
- **No correlation of attenuation to ground surface cover**

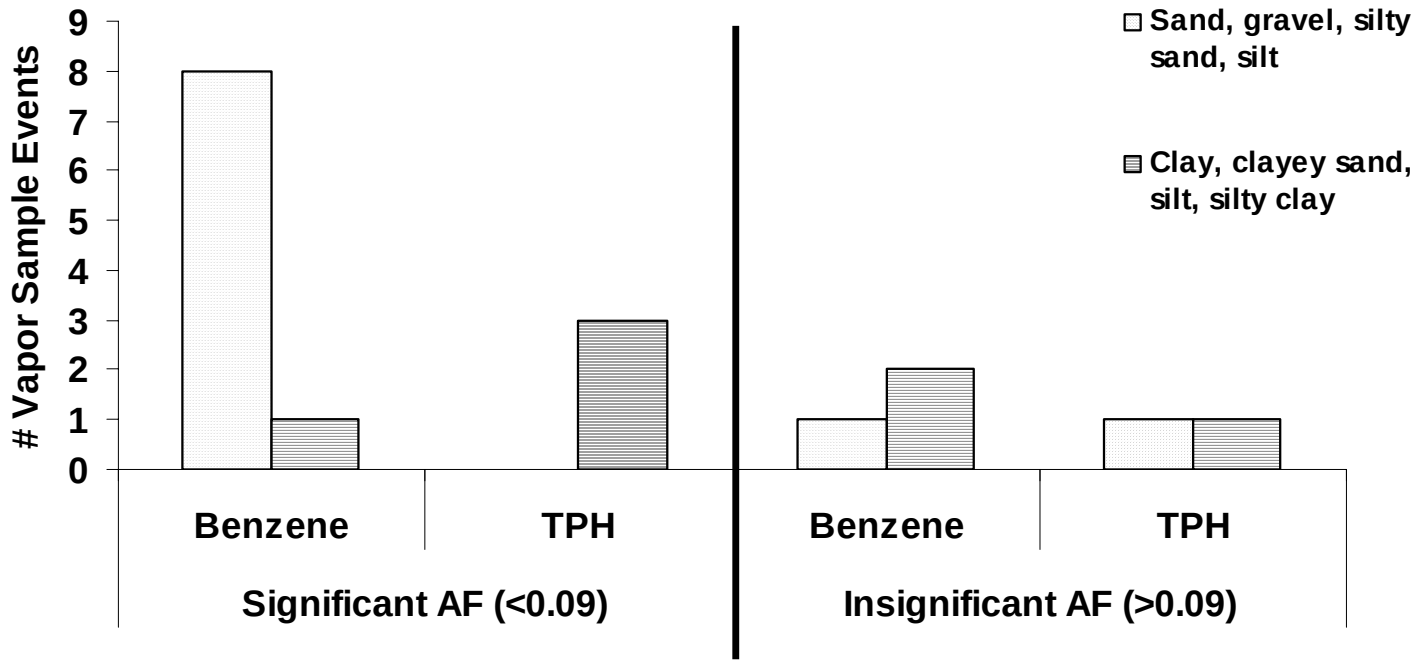
Attenuation Factors Compared to Soil Type



Attenuation Factors Compared to Ground Cover



Attenuation Factors Compared to Soil Type Beneath Buildings



Conclusions…

- **Newly reviewed data, since March 2005, *continue* to support petroleum hydrocarbon bioattenuation**

- **Findings of this study are *still* consistent with other similar studies**

Conclusions, *continued*

- **Signature characteristics of bioattenuation:**
  - **At least 2 feet of clean soil overlie contaminant source**
  - **Petroleum concentrations decrease upward from contaminant source**
  - **Oxygen depletion/carbon dioxide enrichment near the source, oxygen enrichment/carbon dioxide depletion away from contaminant source**
  - **O_2 range 5% to 10%**
- **Determining if vapor intrusion pathway is complete remains a site-specific decision**

Data Needs to Reduce Uncertainties…

- **Greater geographic diversity to capture regional variability of subsurface soil types and climate**
- **Attempts to correlate vapor attenuation to source strength require detailed characterization of contaminant source zone**

(why not take soil samples during vapor probe installation?)

- **Consistency in measuring dissolved / FP phases and DTW during vapor sample collection**

Data Needs to Reduce Uncertainties, *continued*

- **Consistency in analyzing vapor phase benzene, TPH, O_2 and CO_2 at all depths for each sample point and event**

- **More sampling events per point to understand temporal variability in attenuation**

- **Better understanding of the potential for vapors to accumulate beneath and enter buildings**

Additional Data Needs

Latest Findings since March 2005 LUSTLine

- **Data continues to lack consistent reporting of:**
  - **Constituents analyzed**
  - **Source terms**
    - **depth to GW and soil source, distance from vapor point, extent, source strength**
  - **Soil type**
  - **O2/CO2**
    - ***it really helps explain the nature of vapor attenuation, even if some of the above elements are unknown !***

- **Data evaluation is subject to interpretation:**
  - **very low vapor concentrations ~ no attenuation**
    - ***what concentration constitutes vapor contamination?***
  - **data QA/AC concerns**
    - ***is anyone triple-checking the raw data against the input data?***

EPA Work Group's Continuing Efforts

The Work Group is continuing its process of:

- **Requesting that states and private entities share their data with the Work Group**
- **Compiling and evaluating data as it trickles in …**

Acknowledgements…

The data gatherers and authors who collect and publish their data ***(you know who you are !)***

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The End

Thank you

Your comments, observations and data are welcome !