Soil Vapor Extraction Technology Implementation for Vapor Intrusion Mitigation

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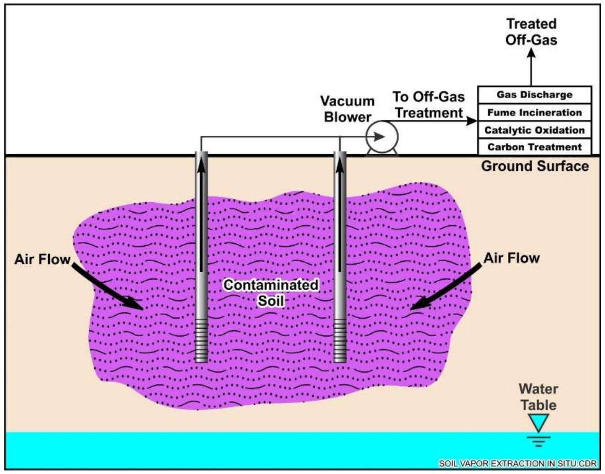
Agenda

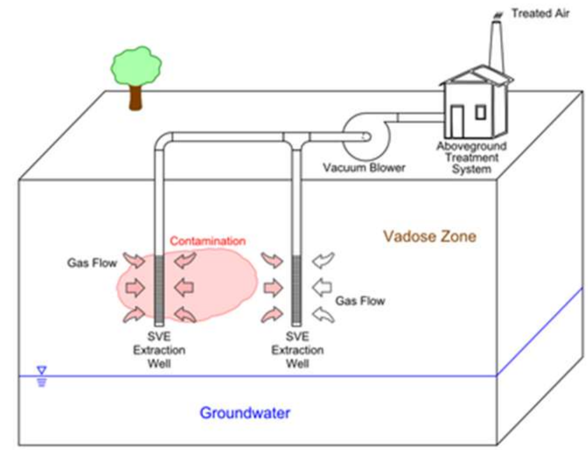


[Technology Screening Matrix | Federal Remediation Technologies Roundtable (frtr.gov)]

1	Background
2	SVE vs. VIM Systems
3	Conditions where SVE for VI may be a preferred approach over conventional SSDS
4	Innovative tools for the design of SVE/VIM systems – Pneumatic Modeling
5	Case Study
6	Conclusions

Background

- SVE is a proven technology for VOC mass removal from the unsaturated and partially saturated (e.g., capillary fringe) zone soils.
- SVE has been applied at more than 285 Superfund sites in the USA, not including other thousands of:
  - State cleanup program sites
  - Brownfield sites
  - Voluntary action cleanup program sites
  - Leaking underground petroleum storage tank sites
- Although, SVE has been applied to control VI, its applicability to VI mitigation remains reluctant among practitioners likely due to the general impression of its robust nature and associated higher costs.



Soil Vapor Extraction (SVE) - Enviro Wiki

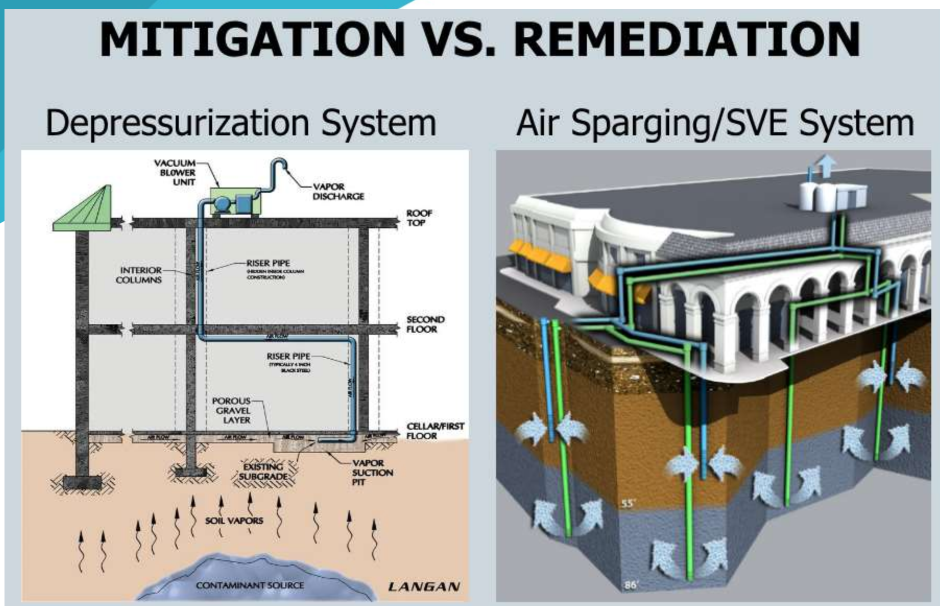
SVE Control Mechanisms

Conceptually, SVE could control vapor intrusion (VI) through multiple mechanisms:

- Depressurization across the slab
- Lowering soil vapor concentrations
- Removal of VOC mass from the unsaturated and partially saturated zone sources and soils
- Interception of VOC vapors migrating from groundwater
- Soil gas dilution effects due to mixing of relatively large volumes of clean air with impacted vapors
- Influencing flow through building entry points

Although, both the SVE and SSDS fundamentally work using similar mechanisms and laws of physics, chemistry, fluid mechanics, and mathematics, the main difference among these is their remedial objective and design basis.

Mitigation vs. Remediation



MITIGATION

Objective:

Create a differential pressure barrier between subsurface and buildings

Design Basis:

Vacuum Gradient = 0.004 – 0.1 IWC

REMEDIATION

Objective:

Remove contaminants from the vadose zone

Design Basis:

Pore Volume (PV) Exchanges

- Sands = 500 PV/year
- Silts = 1,500 PV/year
- Silty Clays/Clays = 2,500 PV/year

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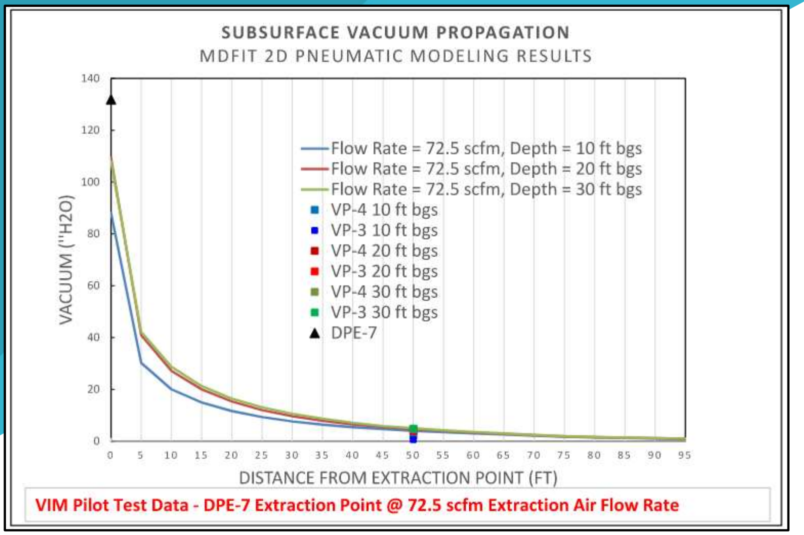
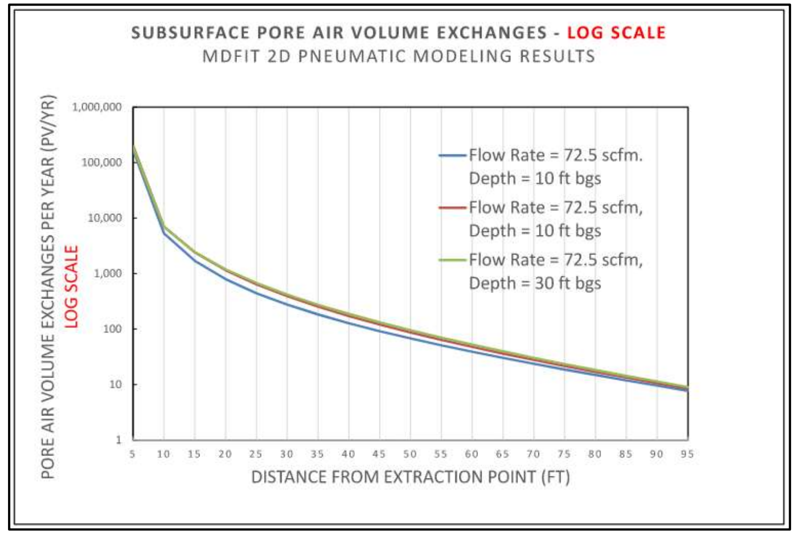
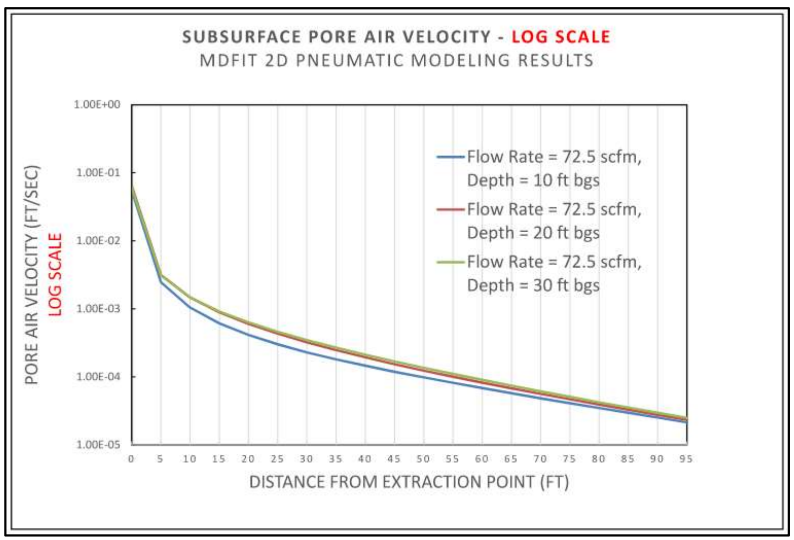
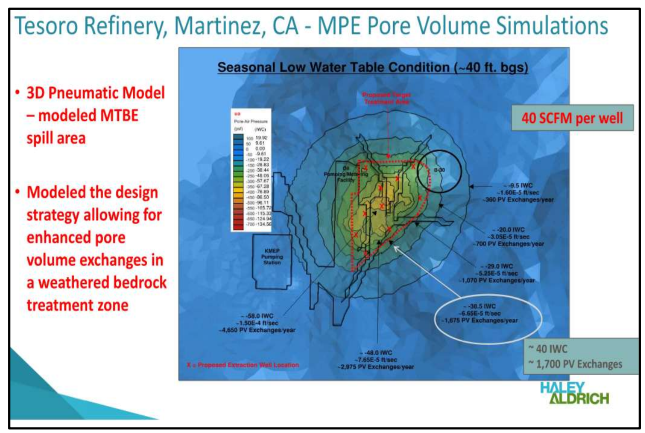
Mitigation vs. Remediation

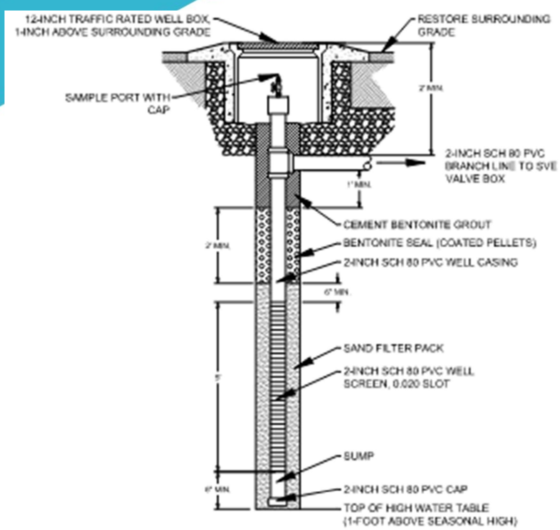




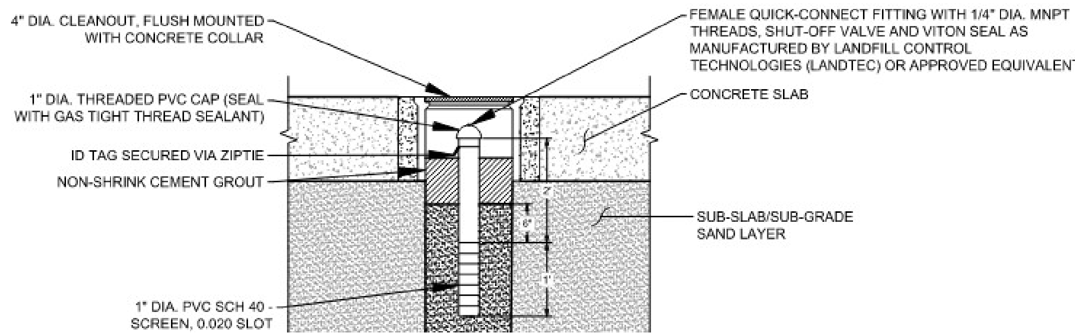




Mitigation vs. Remediation



Typical SVE Well



Typical SSDS Extraction Point

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SVE Approach

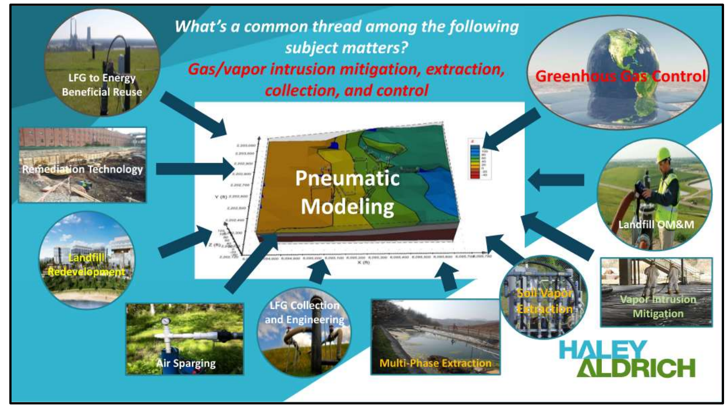
Conditions where SVE for VI may be a preferred approach over conventional SSDS:

- Presence of site logistical constraints such as space restrictions and limited site access in an existing building
- Occurrence of complex sub-slab environments in an existing building such as slab-on-grade foundations, low permeability of the slab subgrade material, anisotropic heterogeneous geologic settings, shallow water table, and varying fate and partitioning behavior of organic contaminants
- Presence of significant mass of contaminant source material requiring the active VI mitigation systems to operate for infinite timeframes
- If VI mitigation is needed at a neighborhood scale due to a single point source.

Pneumatic Modeling for Design of Remediation Systems (Innovative Tool)

WHY DO IT?

- Determine Existing Conditions
- Simulate Proposed Conditions
- Better Predict System Performance
- Cost-Effective and Reliable Remediation Systems
- **Saves Time and Money!**

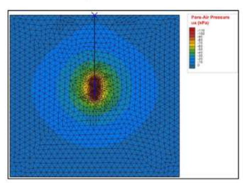


Fundamentals of Pneumatic Modeling

- **Mathematical Description**

The equation for air flow in an unsaturated, unconsolidated porous medium is derived from the conservation-of-mass principle.

$$\frac{\partial}{\partial T}(\rho\theta) = \nabla.(\rho q) = 0$$



Where, ρ is the density of air (g/cm^3)
θ is air-filled porosity (dimensionless)
q is the specific discharge vector for air (cm/sec)
T is time (sec)

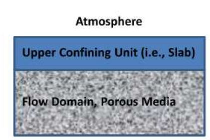
Ref: Baehr and Hult titled "Evaluation of Unsaturated Zone Air Permeability Through Pneumatic Test " (WRR., Vol. 27, No. 10, Pages 2605-2617 October 1991).

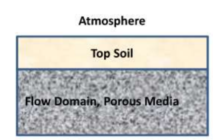
Fundamentals of Pneumatic Modeling

- **Two kinds of air flow problems in porous media**

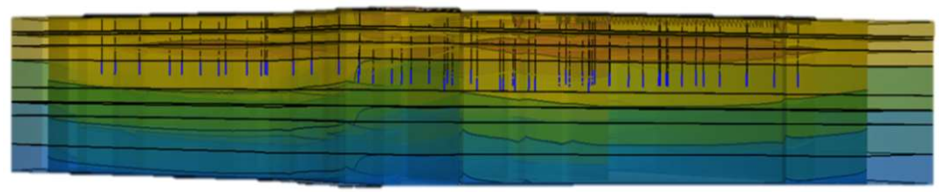
Two analytical solutions for steady state, two-dimensional, axisymmetric airflow to a single well partially screened in the unsaturated zone are developed:

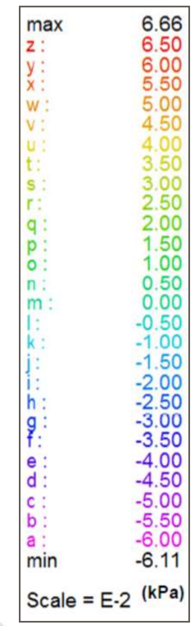
1. Flow domain separated from the atmosphere by a confining unit
2. Flow domain with no confining unit as an upper boundary





Pneumatic Modeling



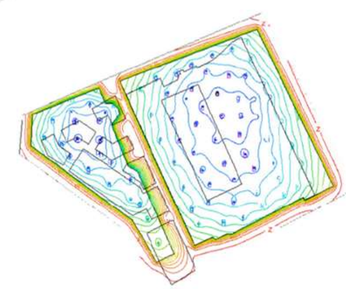


OBJECTIVE:

Predict system performance under current and future conditions

Model Outputs:

- Radius of Influence
- Number and Spacing of SVE Wells
- Anisotropic Conditions
- Air Intrinsic Permeability
- Vacuum Propagation
- Pore Volume Exchanges
- Design SVE Extraction Flow Rates and Vacuum

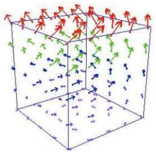


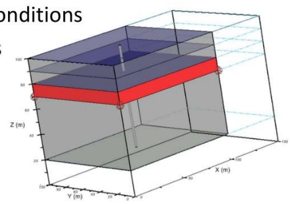
Pneumatic Modeling

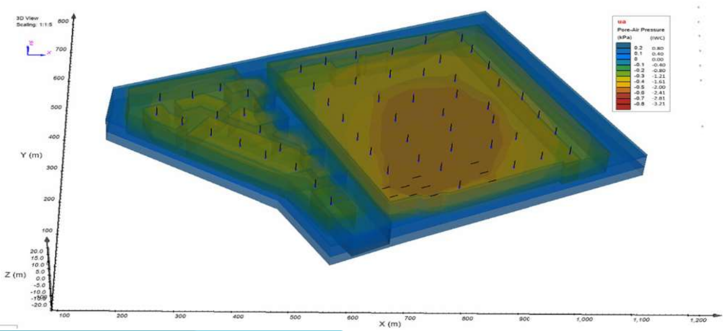
SVAIR™

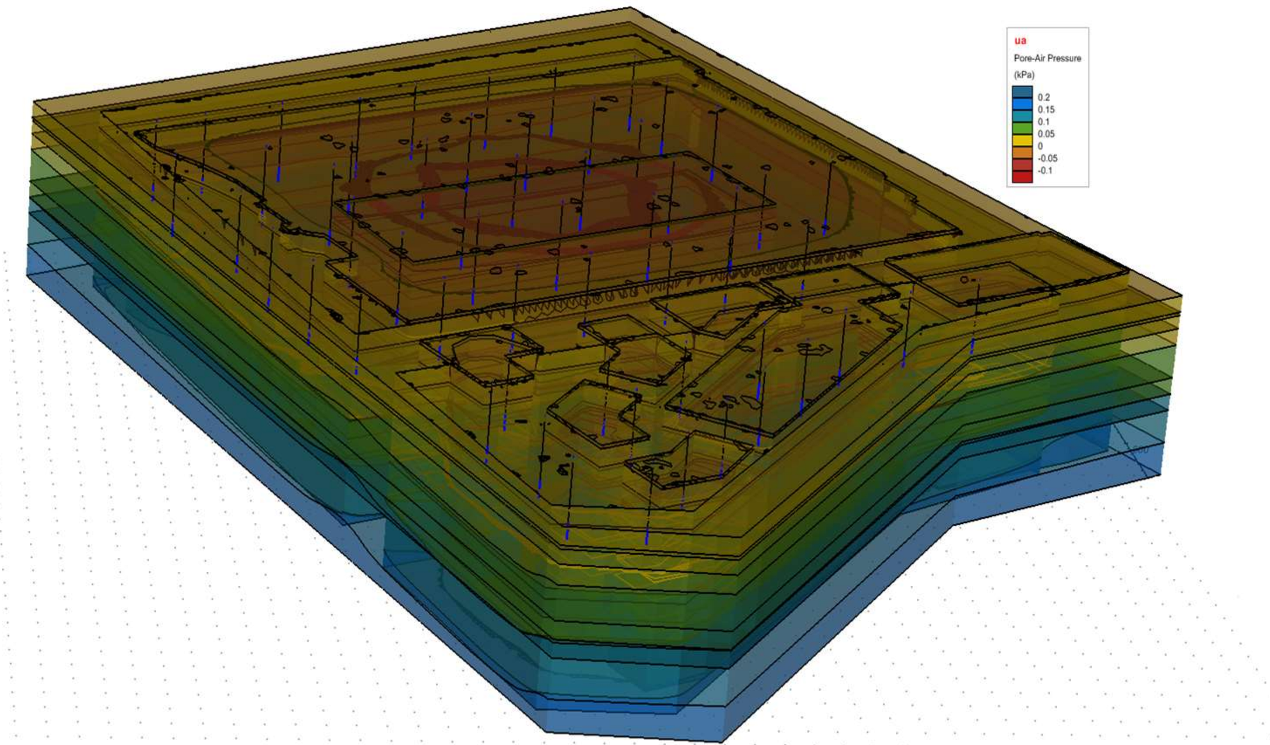
Modeling Procedure

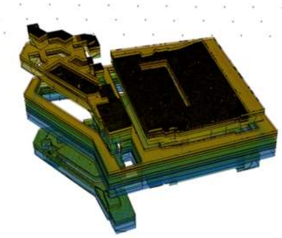
- Step 1 – Establish Regions and Layers
- Step 2 – Specify Initial Conditions
- Step 3 – Define Layer Properties
- Step 4 – Set Boundary Conditions
- Step 5 – Simulation Runs



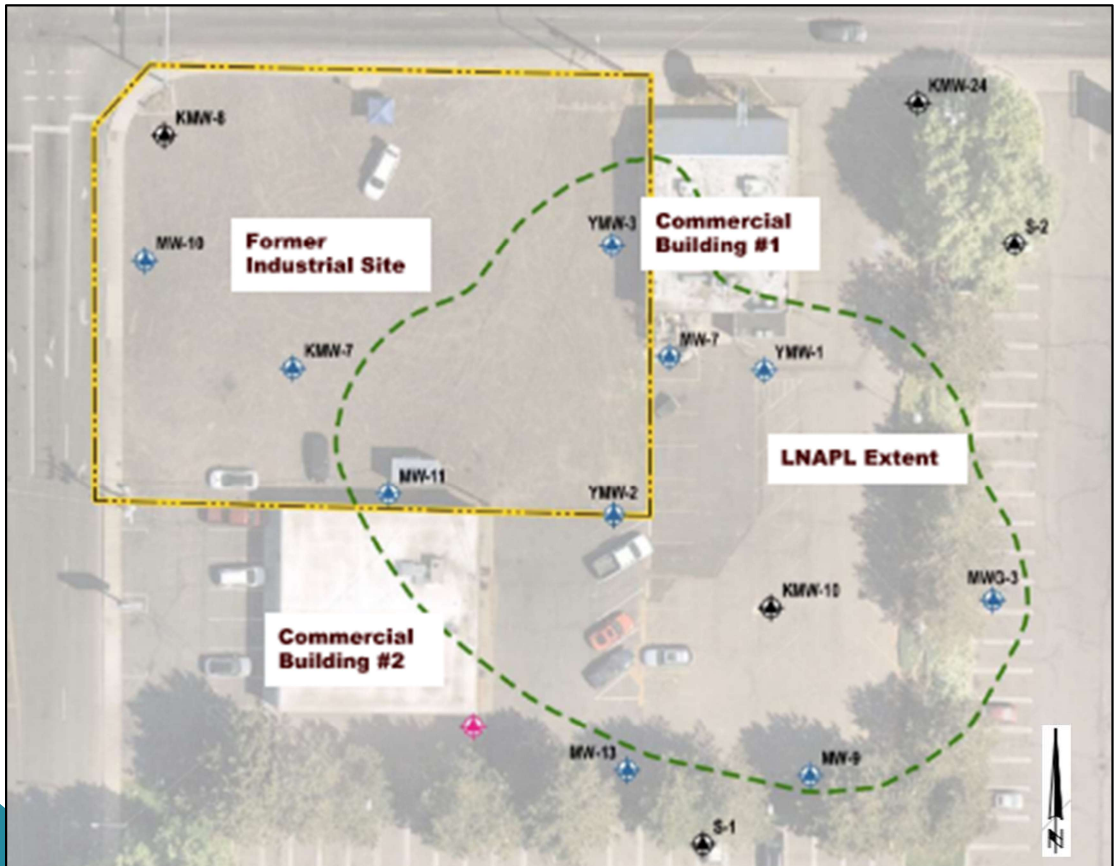






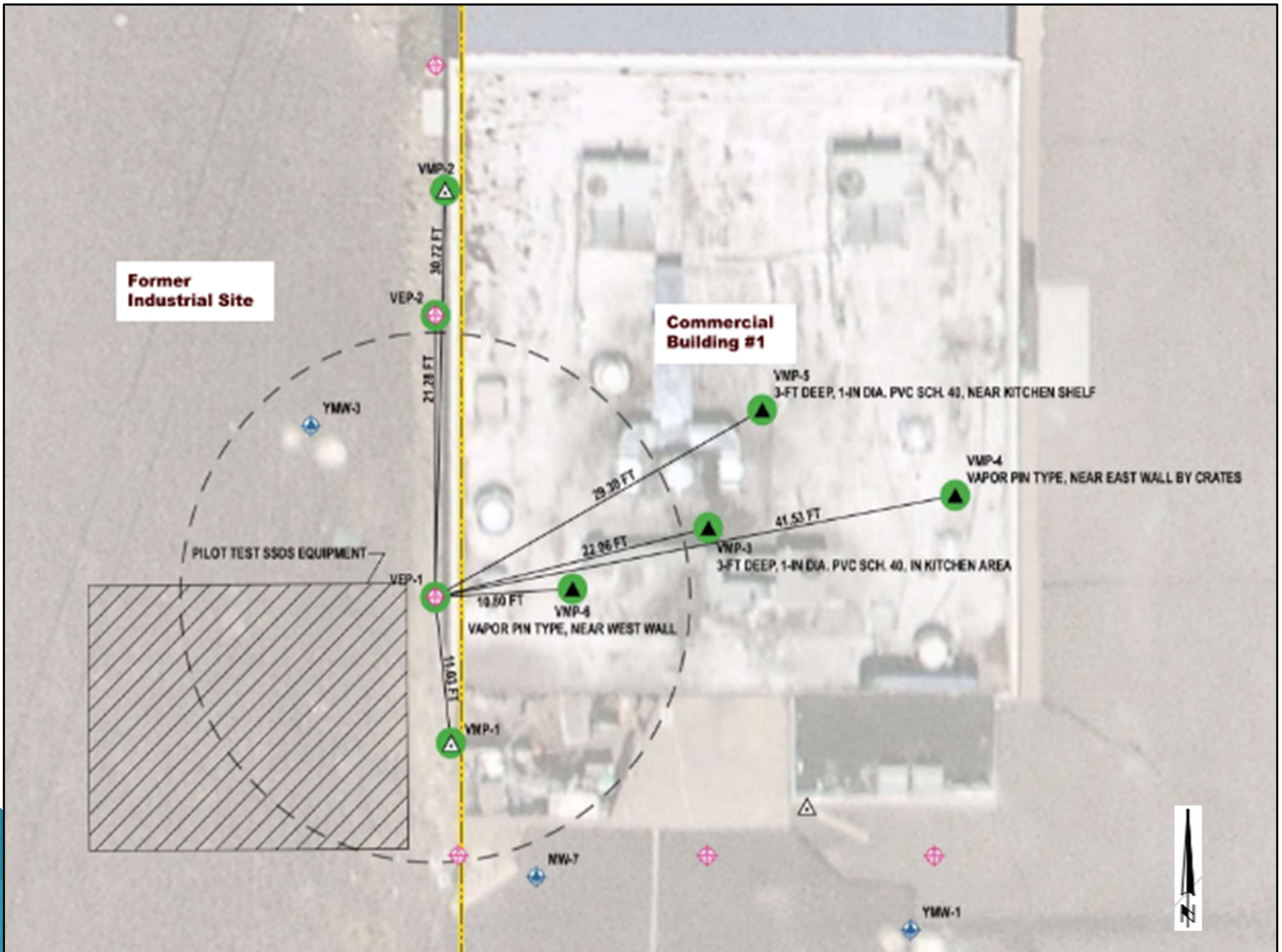


Case Study - Yakima, Washington SVE Approach for VIM



- The site consists of a former oil and gasoline distribution facility with two adjoining business buildings with NAPL presence in the subsurface.
- Extremely high-level indoor air and soil vapor chlorinated VOCc, gasoline range organics (GRO), and petroleum hydrocarbon concentrations.
- Chlorinated VOCs detected in soil vapor and indoor air are from an off-site commingled plume.
- Adjoining buildings comprising of retail businesses and a restaurant with access restrictions for a full-scale SSDS installation.

SSDS Pilot Testing



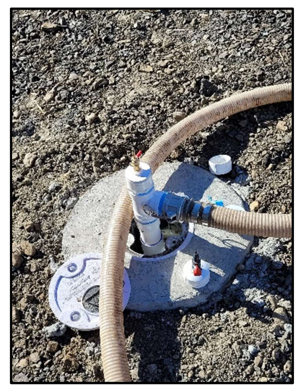
SSDS Pilot Testing







SSDS Pilot Testing



SSDS Pilot Testing Results

- Vapor Extraction Flow Range = 5 – 38 scfm
- Applied Vacuum at Extraction Point = 2 – 14 inches of Hg
- Max. Measured Vacuum at Monitoring Points = 0.2 inches of H_2O
- Radius of Influence = 12 feet max.
- Influent COC Concentrations:

  Benzene: 22 ug/m^3 Toluene: 11,000 ug/m^3

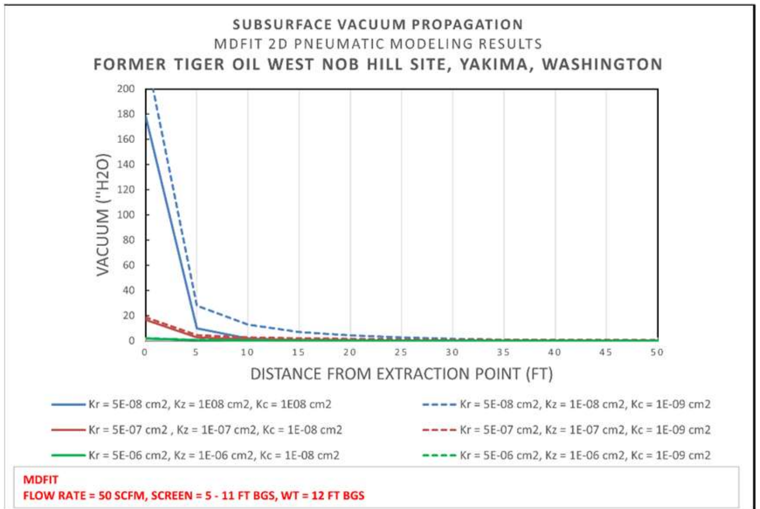
  m,p-Xylene: 8,900 ug/m^3 TPHv: 2,500,000 ug/m^3

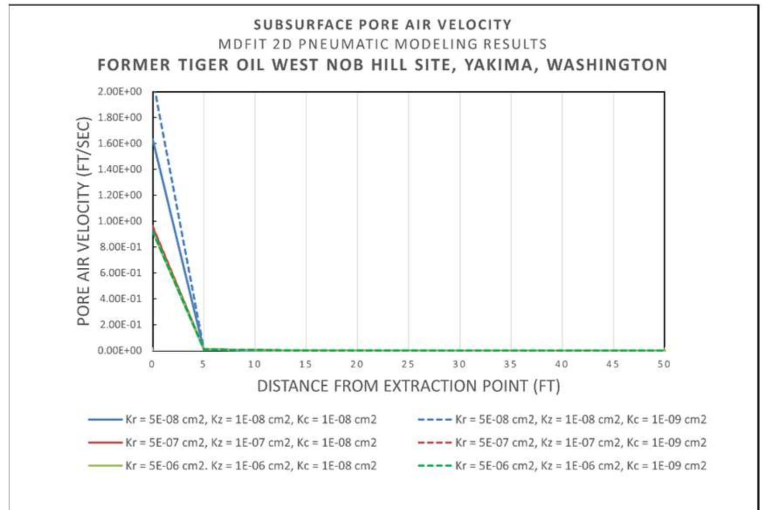
- **Conventional SSDS approach may not be feasible for the site, hence considered a barrier SVE/VIM/SSDS design approach.**

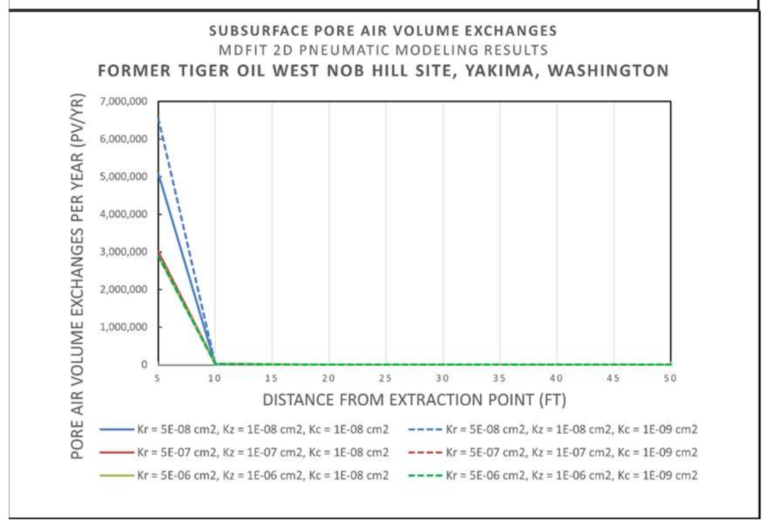
SSDS Pilot Test Air Emission Calculations

Methods	Indoor Air Sampling Results (July 2021)		EPA AF	Calculated Soil Vapor Concentrations	Extraction Flow Rate	Vapor Emissions	Total Vapor Emissions	Safety Factory/SVE Extraction Efficiency	Total Vapor Emissions	**Total Vapor Emissions After Carbon Treatment (80% Removal Efficiency)**
	COC	ug/m3		ug/m3	scfm	lbs/day	lbs		lbs	**lbs**
Method 1[1] - Site Specific Data	Benzene	0.58	0.03	19.3	200	0.00035	0.00035	10	0.003	**0.0007**
	GRO	630	0.03	21,000	200	0.378	0.378	10	3.78	**0.76**
Method 2[2] - Literature Review	Total TVOCs (Literature Gasoline Headspace Concentrations) = 35,100 mg/m3			35,100,000	200	631	631	30	21.0	**4.21**
Method 3[3] - Literature Review	Literature Assumed Total TVOC Concentration of 100 ppmv = 409 mg/m3		na	409,000	200	7	7	na	7	**1.47**

2D Pneumatic Modeling for SSDS Design





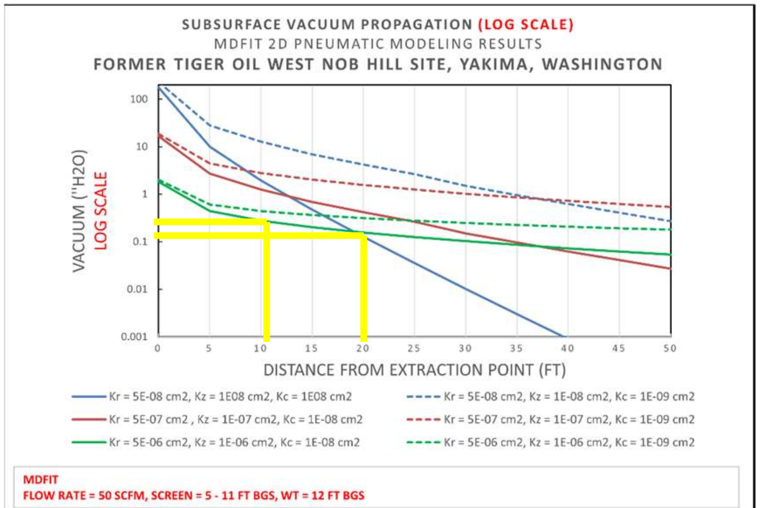


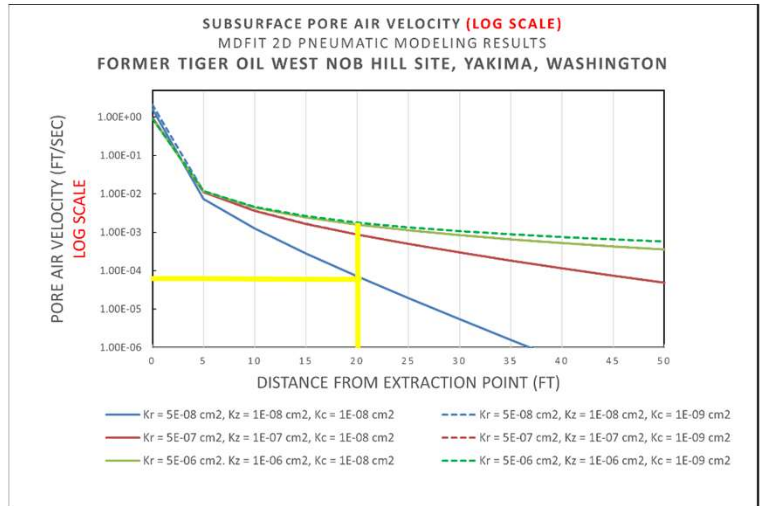
Air Intrinsic Permeability Estimation:

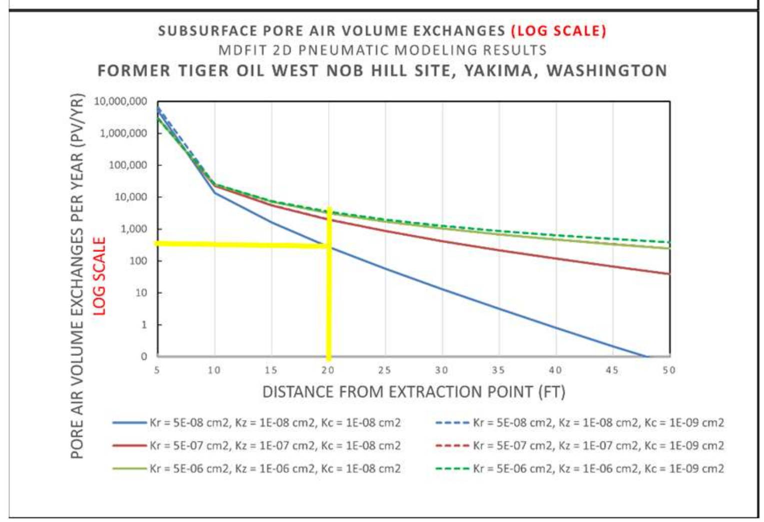
- **K_R = Horizontal Air Intrinsic Permeability (Silty Sand w/ Sand & Gravel Layers)**
- **Kz = Vertical Air Intrinsic Permeability (Silty Sand w/ Sand & Gravel Layers)**
- **Kc = Upper (Surface) Confining Layer Air Intrinsic Permeability (Gravel Surface)**
- **n = Assumed Porosity = 0.35**

(MDFIT™, Mike Marley, XDD)

2D Pneumatic Modeling for SSDS Design







Air Intrinsic Permeability Estimation:

K_R = 5E-08 cm2 - 5E-06 cm2 (Silty Sand w/ Sand & Gravel Layers)

Kz = 1E-08 cm2 - 1E-06 cm2 (Silty Sand w/ Sand & Gravel Layers)

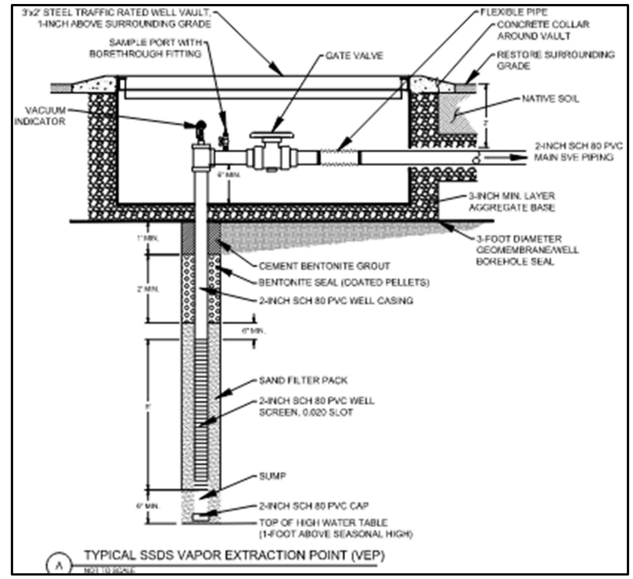
Kc = 1E-09 cm2 - 1E-08 cm2 (Gravel Surface)

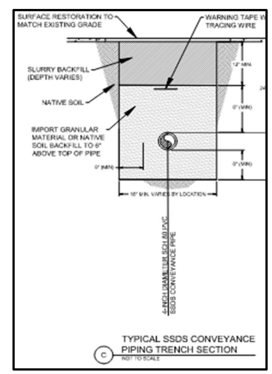
n = Assumed Porosity = 0.35

(MDFIT^{TM}, Mike Marley, XDD)

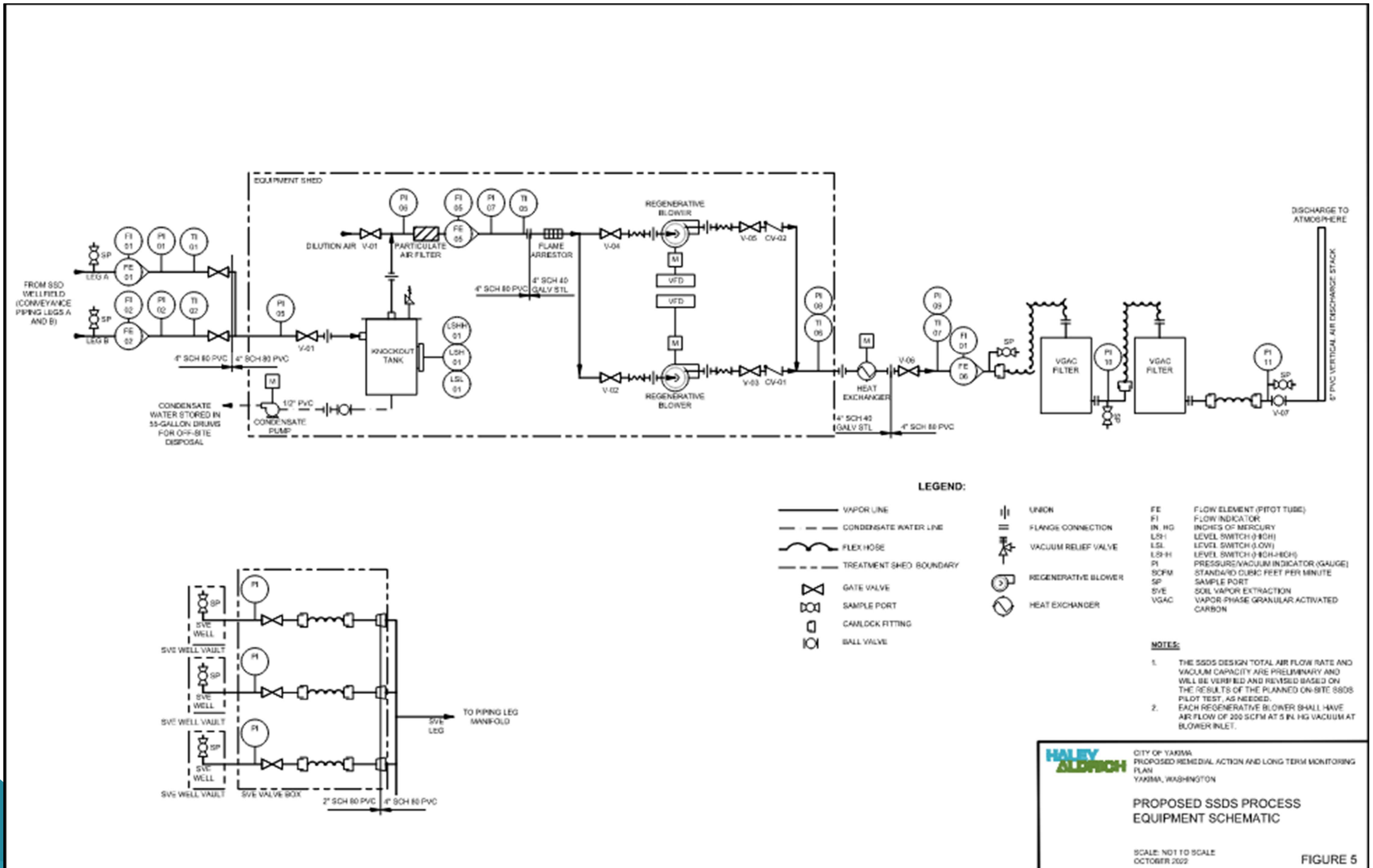
The literature permeability values for the silty sand w/ sand & gravel layers target lithology (i.e., 5E-08 to 5E-06 cm2) were taken from the "Groundwater" Handbook by Freeze and Cherry, 1979, Table 2-2, page 29.

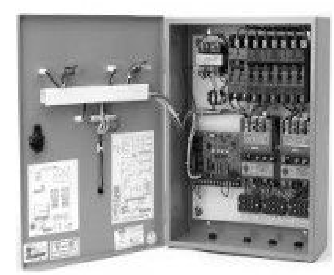
Full-Scale Barrier SVE – VIM Design Approach





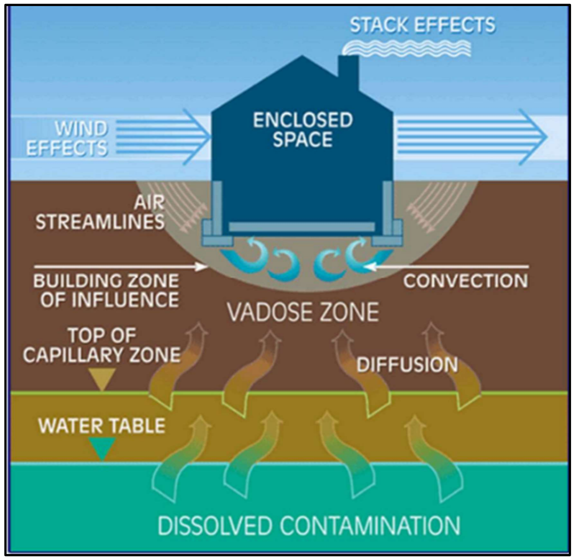
Full-Scale Barrier SVE – VIM Design



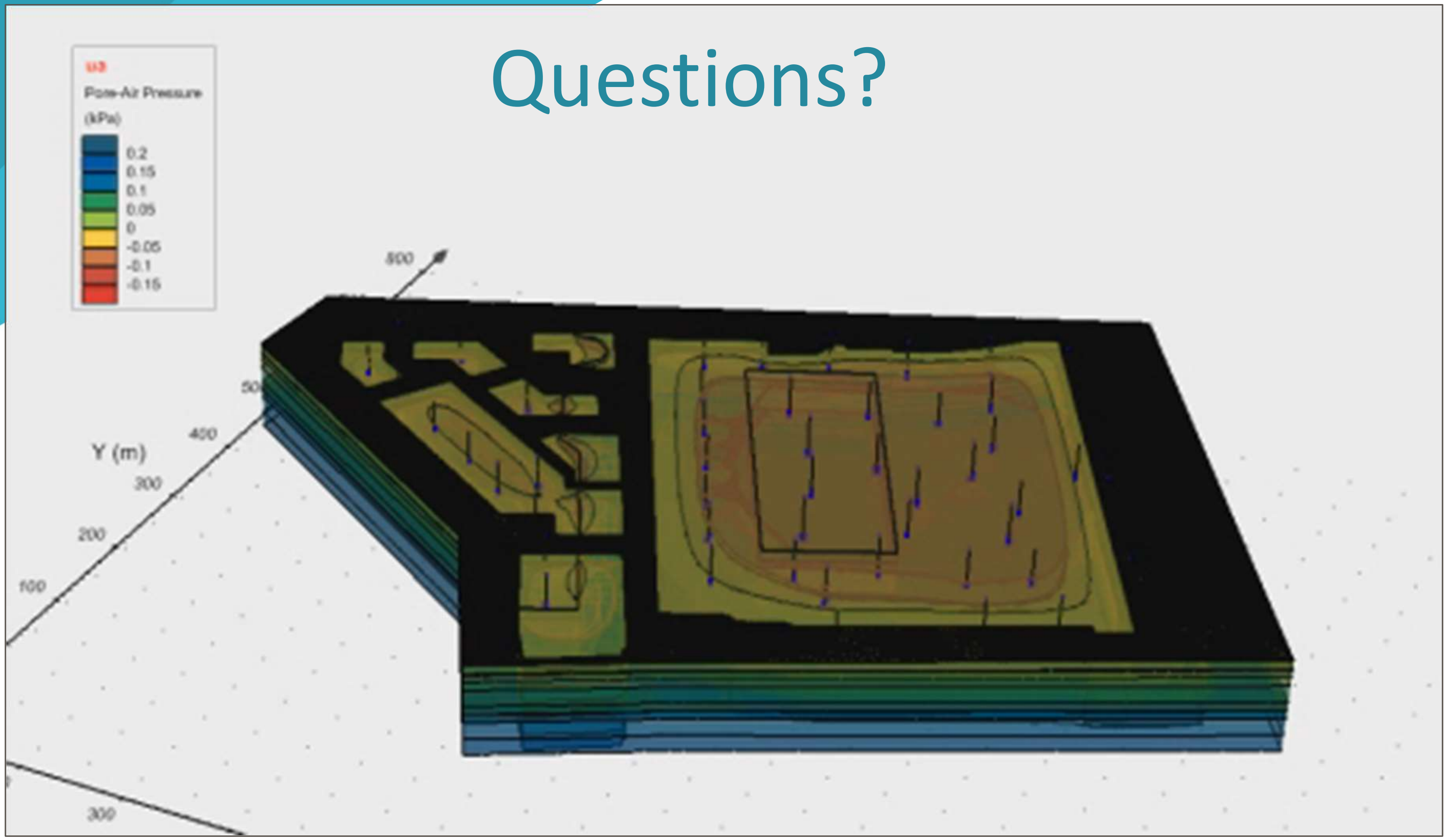


Conclusions

- Conventional SSDS are not always an option due to site-specific constraints.
- SVE, when tailored for VI mitigation, can be an effective alternative to SSDS.
- Pneumatic modeling supported by pilot test data are critical for designing SVE systems for VI mitigation purposes.
- Designing and operating an SVE system for VI mitigation (low flow rate and long operation time) differs from conventional SVE systems (high flow rate and shorter duration).
- If VI mitigation is needed at a neighborhood scale due to a single point source, compared to multiple single-building SSDS, a centralized SVE-based system can
    - Require less intrusive property access,
    - Provide VI control for multiple neighboring homes or buildings,
    - Facilitate more efficient control of off-gas, and
    - Can be more cost effective.



Questions?



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