- The webinar will start promptly at 12:00 EST
  There will be a Q&A session during the last 10 - 15 minutes of the webinar
- All participants will be on mute
- One day after the webinar has been concluded an email will be sent that will allow you to download a copy of the webinar

- The webinar is being recorded and will also be made available via email
- Please use the “Chat” (see the icon to ask questions for the presenters. Questions will be answered at the end of the webinar. If any questions are missed due to a lack of time, we will follow-up via email after the webinar.

Soil Vapor Extraction
State of the Art Design and Operation

Michael Marley & Dennis Keane
XDD Environmental

August 31, 2021

Why Listen To Us?

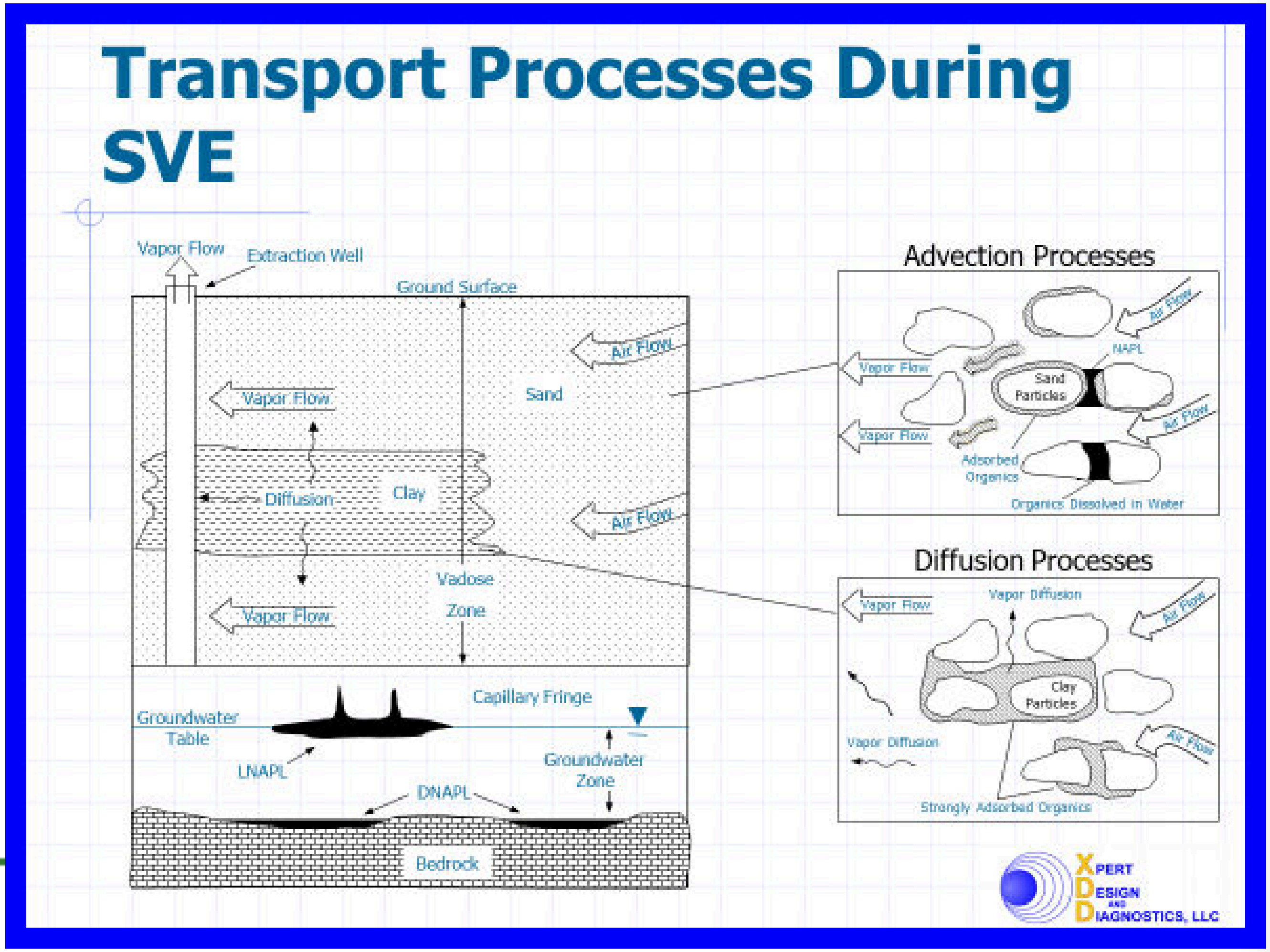
- Have been focused on remediation since early 1980's
- Have been on the forefront of the development of many remediation technologies:
  - Soil vapor extraction
  - Air and oxygen sparging
  - In situ chemical oxidation and reduction
  - Bioremediation
  - Metals stabilization / treatment
  - Thermal remediation
  - Vapor Intrusion Mitigation
- Design and perform treatability testing for end-users, consultants, and contractors
- Wide range of capabilities and experience to solve difficult design and implementation problems

Discussion on State of the Art vs. State of the Practice
(primarily influenced by pricing pressures)

- For majority of technologies developed the state of the practice diverged from the state of the art
- Pressure in the industry for low-cost solutions is a major driver in the state of the practice
  - With the low-cost driver, uncertainty in reaching the desired remedial goals can be high
  - This approach ultimately can result in higher cost to meet the remedial goals due to multiple remedy applications, failures and reevaluations
- For some technologies e.g., soil vapor extraction initial success is evident; however, it can take years of operation before system failure to meet remedial goals or system design limitations come to light
- For others like chemical oxidation and reduction, the failures and limitations are more likely to present themselves in the near-term

Soil Vapor Extraction

- Conceptually simple technology
  - Gas (typically air) is induced to move through the vadose zone
  - VOCs are "stripped" from the soils and soils moisture into the gas stream
  - Gas with VOCs are removed from the vadose zone for treatment / disposal above ground



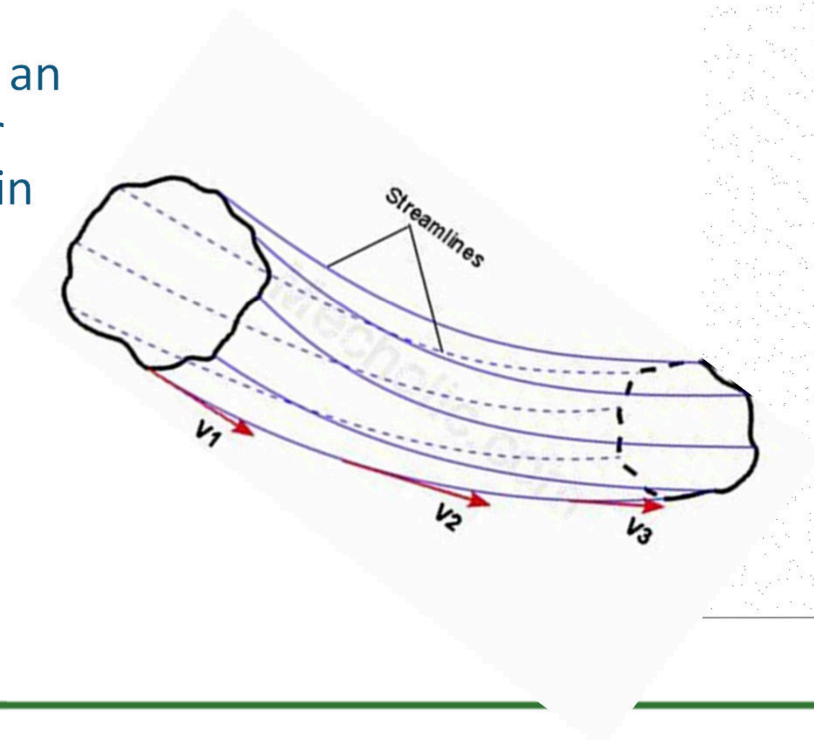
XDD ENVIRONMENTAL
Do it right. Do it once.

Soil Vapor Extraction Design
(Not as Simple)

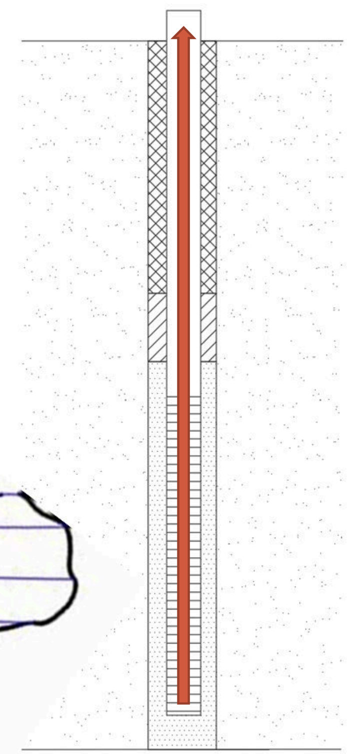
- State of practice (SOP) in SVE design - based on vacuum propagation
  - Example site in CA – 4 to 5 acres – SOP Design
    - Operating from 2002, silty sands and interbedded sands and clays
    - ~400 cfm system
    - High vacuum throughout well field and vapor / vacuum points
    - 10k's lbs. removed since 2002; only ~300 lbs. removed since 2014 – large VOC mass remaining
- State of art (SOA) in SVE design - based on gas pore volume exchanges
  - Example Site in IL ~3 acres – SOA Design – (will discuss in more detail later)
    - Met goals after 2.5 years
    - EPA approved closure

SVE ROI (SOP)

- Vacuum at 0.1 (or other arbitrary number) used traditionally to evaluate radius of influence (ROI) or well spacing
- Radius of vacuum influence is not an effective indicator of adequate air flow and pore volume exchanges in the subsurface



Typical SVE Well

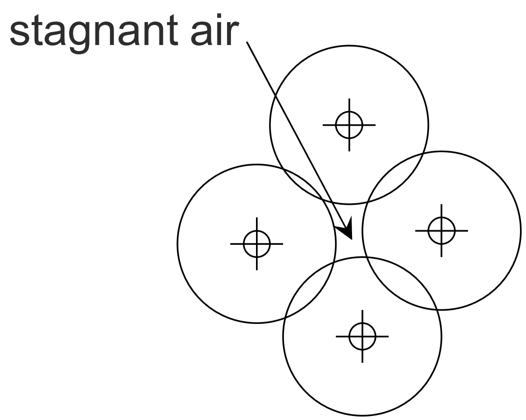


Pore Volume Exchanges
Gas Velocity as Design Criteria

- Pore gas velocities between 0.01 and 0.001 cm/sec recommended
- Pore gas velocities of 0.001 cm/sec or ~3 ft/day (DiGuilio and Ravi 1999)
  - Performance monitoring: vapor probe data used to determine pressure gradients
  - Pressure gradient must be consistent with adequate air velocities through subsurface to assure meeting design criteria
- Pore gas velocity required must be low enough to allow diffusion, but high enough so that excessive buildup of vapors does not occur

Pore volume exchanges / Gas Velocity as Design Criteria

- May be little or no influence at the intersection of ROI of SVE Wells
- Have a "dead zone" of stagnant air due to vacuum
- How to fix?
  - Add passive inlet wells (however, vacuums may be too low to achieve any significant air flow)
  - Active air injection (requires more blower capacity)
  - Vary operation at adjacent wells to "move" the "dead zone" over the period of operation
  - Soil vapor modeling

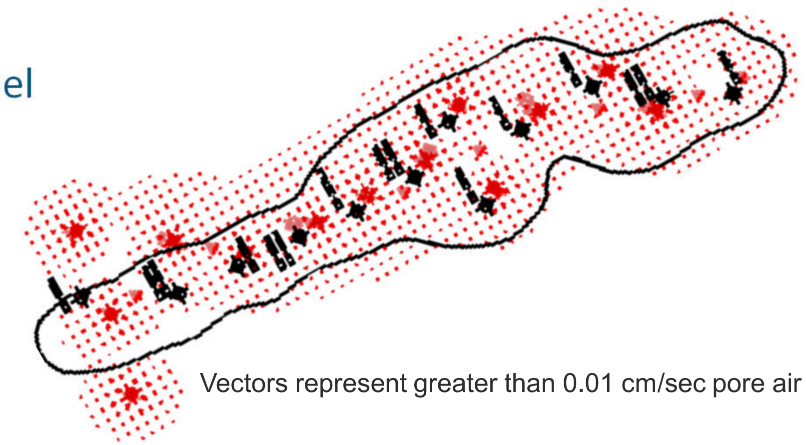


Design – Point Permeability / Pilot Testing

- To design SVE system (SOA or SOP) need to test the site soils to collect data on air flow and vacuum propagation
  - Scale of site dictates scale of testing (see case studies)
- Stratigraphy – test well placement
  - Low or high permeability
  - Layered or stratified system
  - Surface cover
- SVE wells installed in area to be remediated
  - Should limit screen length to 5 ft max!
  - Do not try to screen across entire unsaturated zone
- Soil vapor probes: multi-level
  - Installed in two radial directions minimum
  - Allows to evaluate anisotropy of horizontal plane

Models – Mathematical Solutions

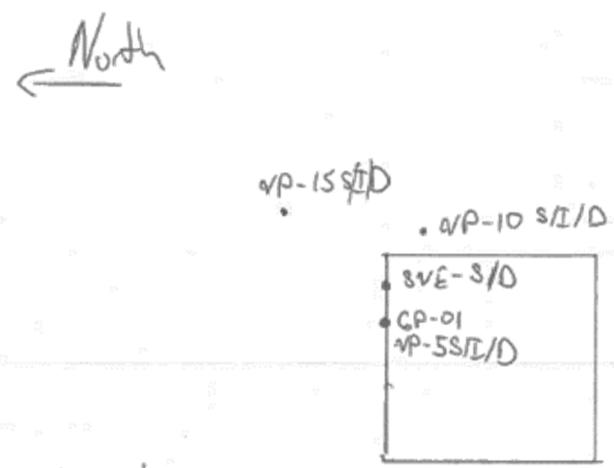
- Analytical Solutions
  - Example: Baehr, A.L., and M.F. Hult. 1991. Evaluation of Unsaturated Zone Air Permeability Through Pneumatic Tests. *Water Resources Research*. Vol. 27, no. 10: 2605-2617.
- Numerical Solutions
  - Example: API Air3D Model



Vectors represent greater than 0.01 cm/sec pore air velocity

XDD ENVIRONMENTAL
Do it right. Do it once.

Pilot Layout Small Site (Case Study 1)



SVE-S = 3' to 8' BGS

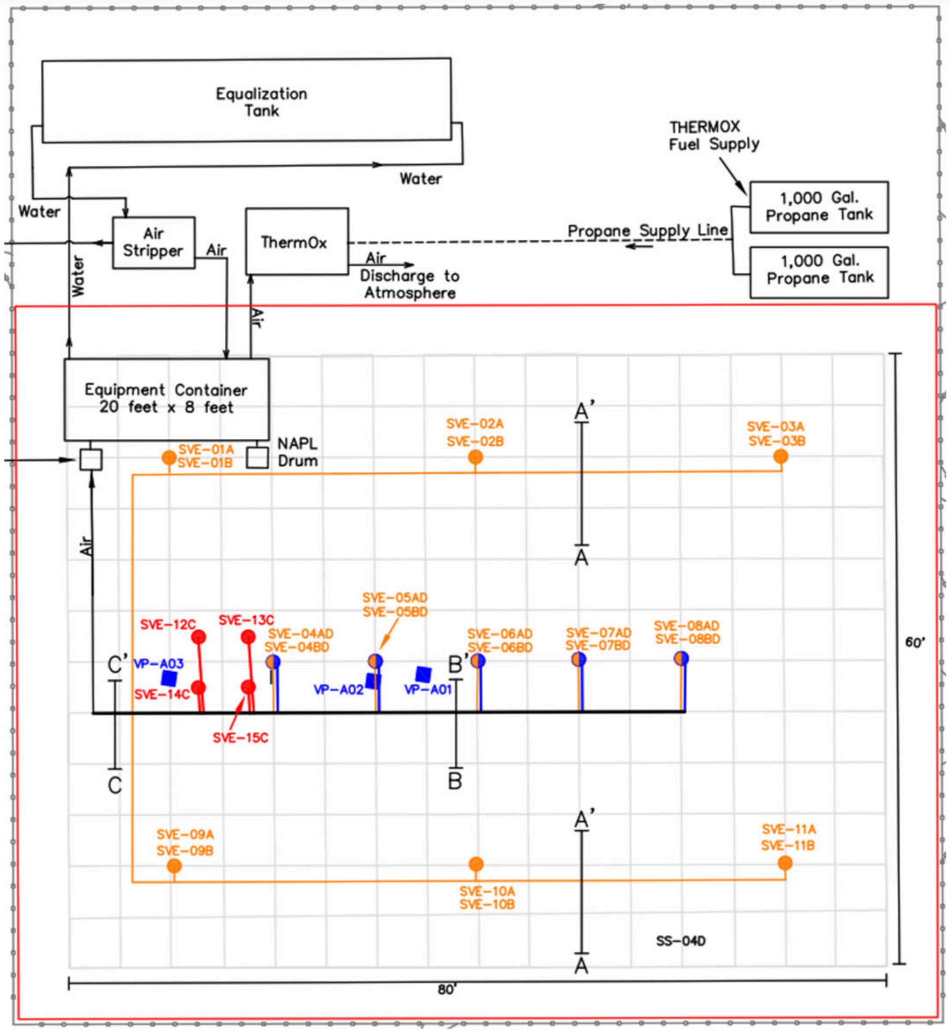
SVE-D = 13 to 18' BGS

VP-#S - center of SVE-S screen = 5.5' BGS

VP-#D - center of SVE-D screen = 15.5 BGS

VP-#I - at elevation of lower perm. materials observed @ GP-01
construct VP-5I with sand pack fully isolated
in fine sand + silt layer observed ~~from~~ in GP-01-07
+ GP-01-13.

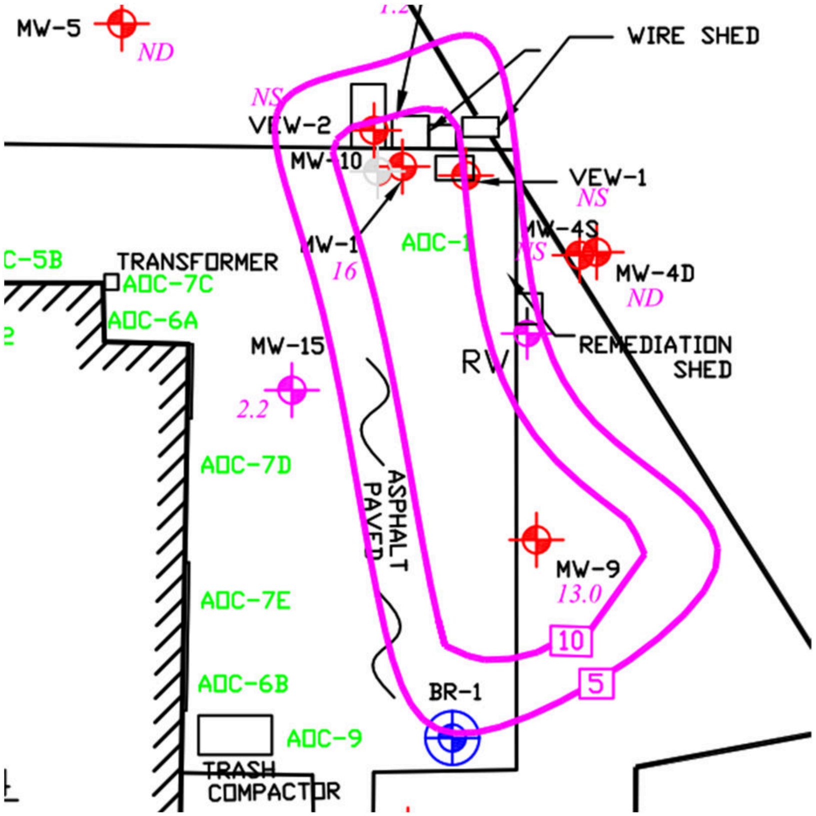
Pilot Layout Large Site (Case Study 2)



Case Study
Small-Scale SVE

Site Summary

- Connecticut facility with a history of metal manufacturing and halogenated solvent use.
- Low site concentrations
- Low soil concentrations (vadose and saturated)



Pre-Design Activities

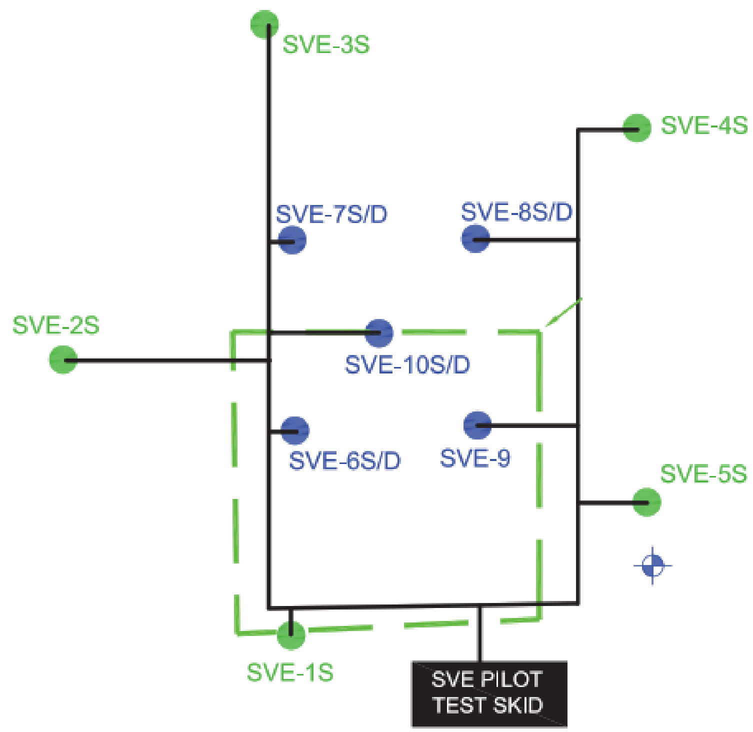
- Delineation (via direct push) to determine the vertical and horizontal extent of impacts
  - Low soil concentrations suggest remnant vapor concentrations are primary source
  - Soil gas delineation in "source" area indicated maximum tetrachloroethylene (PCE) in vapor in the range of 100 ppmv
    - Single digit ppmv along outer edges
  - Soil gas was determined to be negatively impacting groundwater and exceeding drinking water standards
- Soil vapor well and vapor probe installation
- Point permeability testing to determine SVE design parameters

Point Permeability and Design Calculations

- PPT results
  - Intrinsic permeability ranged 1.0 – 9.0 x 10^{-7} cm^2 (clean medium sand)
  - Equivalent to 1.0 – 9.0 x 10^{-2} cm/s hydraulic conductivity
- Analytical model (Baehr, A.L., and M.F. Hult. 1991)
  - Low soil concentrations suggest the need to sweep away PCE in soil vapor
  - Extraction rate: 13 – 17 standard cubic feet per minute
  - 10-foot radius of influence in central - more impacted area
    - 1,000 pore volume exchanges per year
  - 30-foot radius of influence in outer - less impacted area
    - 100 pore volume exchanges per year

SVE Application

- Five shallow/deep nested central SVE wells
- Five shallow outer SVE wells
- Geotextile to prevent water infiltration
- Designed for seasonal operation
- Operated for 2 seasons
- Optimization completed based on:
  - Pre-startup soil vapor sampling
  - Operational monitoring
  - Rebound monitoring



Summary

- System operated for two seasons
- Rebound soil vapor concentrations met shutdown criteria
  - Shutdown criteria determined via Henry's Law
  - Predicted PCE concentrations in vadose zone pore water < 0.5 ug/L

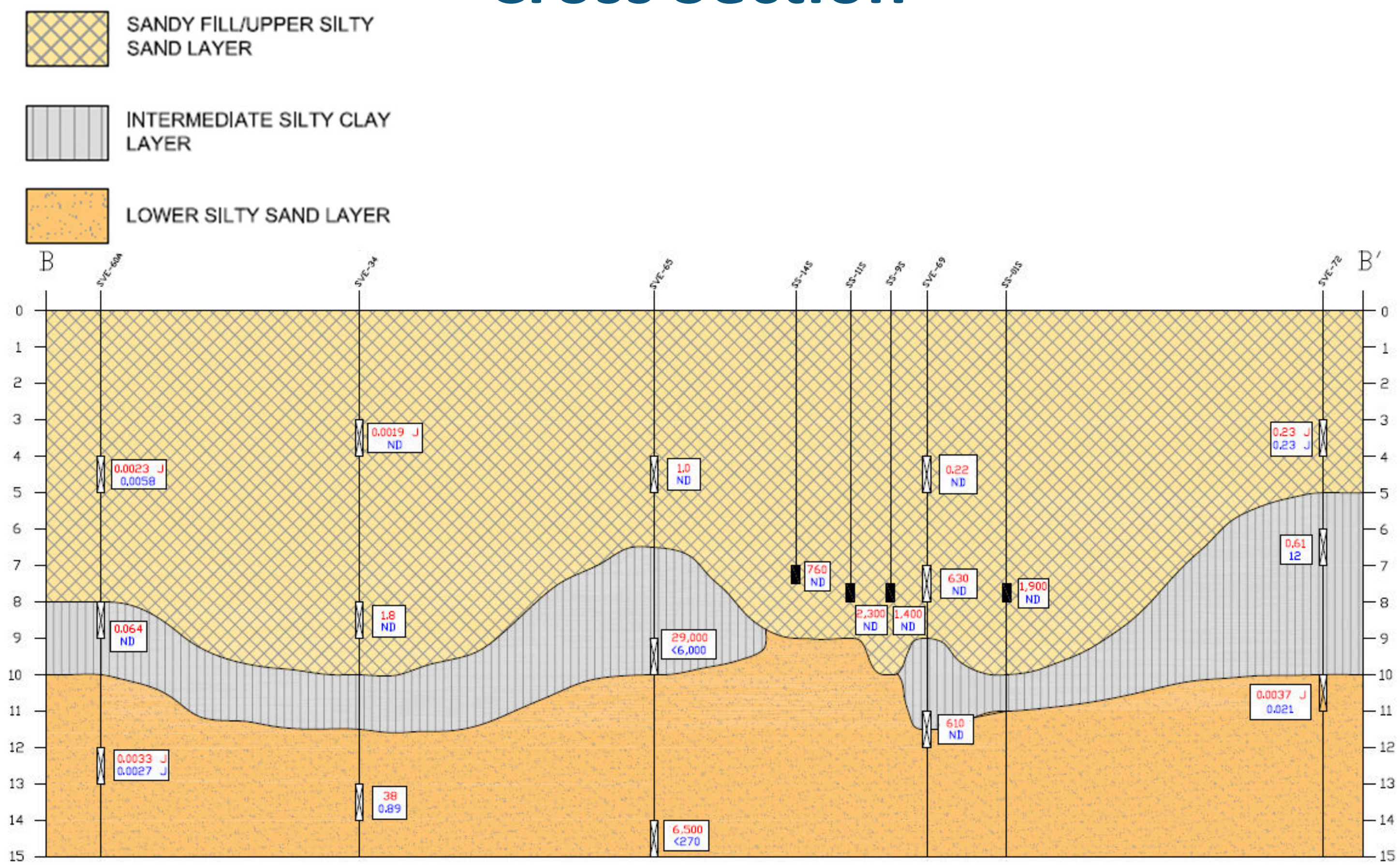
Case Study
Large-Scale SVE

Introduction

- ❑ Site is in a historically urban industrial setting
  - Originally incorporated in 1926
  - Contains multiple industries:
    - Ethanol manufacturing
    - Zinc
    - Chemical manufacturing
  - Total Population: 249
- ❑ Two-million-gallon benzene storage tank operated from 1960 to 2000

XDD ENVIRONMENTAL
Do it right. Do it once.

Cross Section



XDD ENVIRONMENTAL
Do it right. Do it once.

Soil Vapor Extraction – Design Parameters

Point permeability

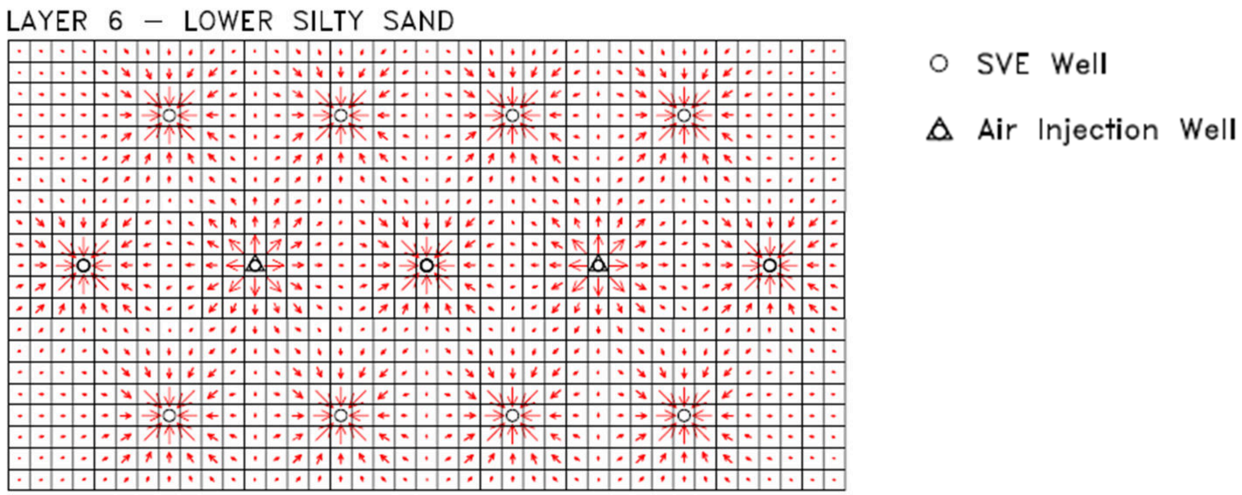
- Upper and Deep Intervals Approx: 5.0×10^{-8} cm^2
- Intermediate silty clay: 1.3×10^{-9} cm^2

Soil vapor (PID) > 9,999 ppmv

Pilot testing

- Testing (Feb – May 2010) conducted in Sandy Fill/Upper Silty Sand Layer
  - Benzene soil mass reduced by 17,000 lbs (21% reduction)
  - Estimated benzene soil vapor removed 15,600 lbs
- No measurable air flow was expected or achieved in the intermediate silty clay layer
- Soil Permeabilities estimated at 3.9×10^{-7} cm^2

Air3D Modeling and Design



- Pore volume exchanges estimated at 1,000/yr @:
  - ROI of 20 – 25 ft
  - Flowrate (per well) of 25 – 30 scfm
  - Estimated remedial timeframe of 3 – 4 years

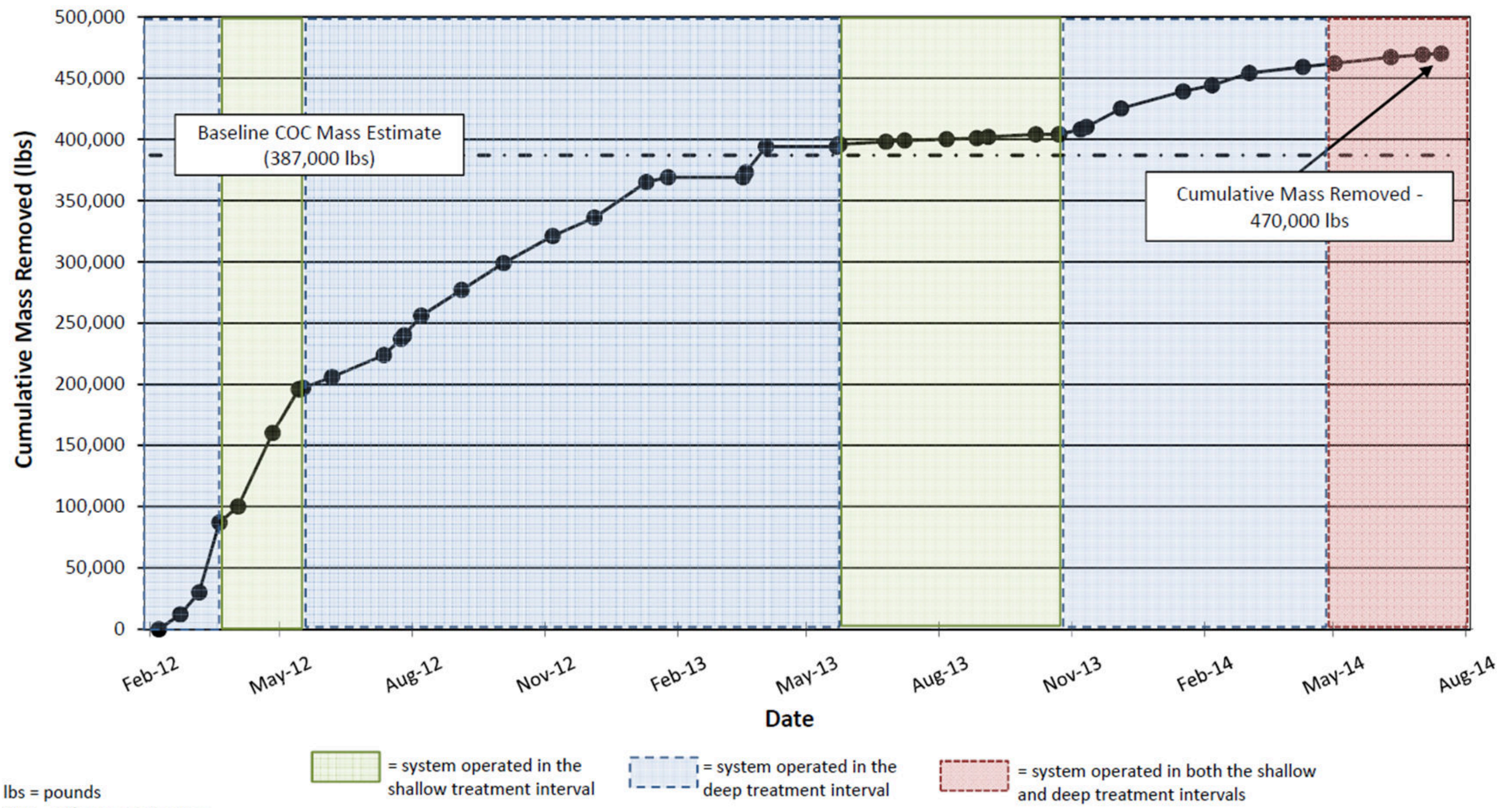
System Design Specifications

- SVE: 2,250 scfm @ 10” Hg
- Air injection: 1,500 scfm
- Two thermal oxidizers
  - Temporarily sited two (2,000 and 1,000 scfm) oxidizers.
  - 1,000 scfm unit moved after one year due to declining concentrations.
- 75 shallow and 82 deep SVE wells (2.5-acre site)
- Thermal alarm and interlock for elevated soil vapor temperatures
- Baseline mass removal rates:
  - Shallow and Deep baseline at 160 and 115 lbs./hr. or
  - 22 gal/hr. or 9.5 drums/day

Constructed Full-Scale SVE System

XDD ENVIRONMENTAL
Do it right. Do it once.

System Performance



lbs = pounds
SVE = soil vapor extraction
COC = contaminant of concern (benzene and chlorobenzene)

Your groundwater is impacting my vadose zone, No your vadose zone is impacting …..

- ❑ Benzene concentrations in groundwater immediately below treatment area 750 mg/L
- ❑ Would additional treatment beyond the closure protocol yield additional benefit to groundwater?

XDD ENVIRONMENTAL
Do it right. Do it once.

Additional Conceptual Model Work

- Was source zone contributing to groundwater or was groundwater now impacting the source zone? Processes included:
  - Smearing from groundwater table fluctuations
  - Mass associated with soils in the saturated zone
  - Overall net flux from saturated zone into unsaturated zone

Location	Benzene Soil Mass Estimate (lbs)	
	Unsaturated (0-15 ft bgs)	Saturated (16-21 ft bgs)
SB-36	4,300	45,200
SB-64	3,400	2,000
SB-65	100	4,900
SB-69	4,100	10,400
Total	11,900	62,500
Pounds per Foot	1,000	12,500

Presented by:

Mike Marley
marley@xdd-llc.com

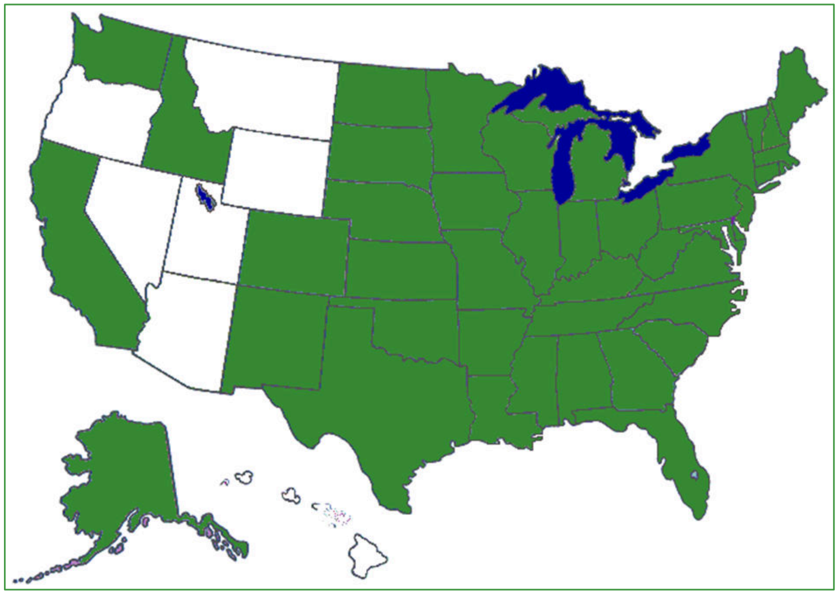
Dennis Keane
keane@xdd-llc.com

1-800-486-3575

www.xdd-llc.com

Follow XDD:
XDD Environmental

States in which we had Projects



ENVIRONMENTAL
Do it right. Do it once.