Tanks Program

- Webinar Series
- L.U.S.T.Line
- National Tanks Conference

LUST CORRECTIVE ACTION WEBINAR SERIES:

AIR SPARGE, SOIL VAPOR EXTRACTION, AND DUAL-PHASE EXTRACTION AT LUST SITES

11/16/2021

TODAY'S SPEAKERS

Edward Tung | ***M.K. Environmental, Inc.***

Matthew Lahvis | ***Shell Global Solutions (US) Inc.***

MK Environmental Inc.

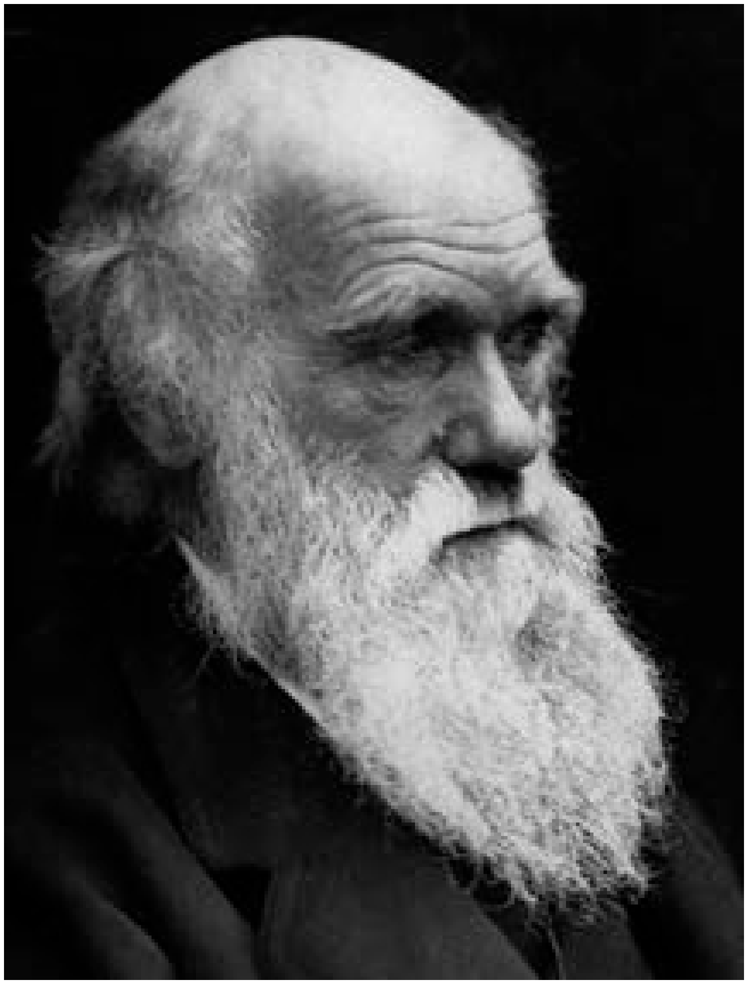
Air Sparge, Soil Vapor Extraction, and Dual-phase Extraction at LUST Sites

Edward Tung, P.E.

MK Company Overview

- Over 1000 packaged UST systems installed
- Sell, Rent and Operate Remediation systems
- Over 1.25 Million hours of direct operational experience @ > 96% uptime, PFP.
- 50 Thermal Remediation Systems (DPVE plus steam and electricity, 200°F)
- Directly invested in success

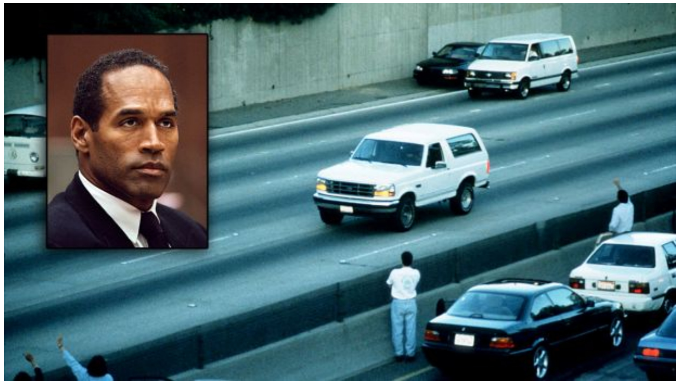
EVOLUTION OF EQUIPMENT SELECTION



- Market Forces
- UpTime demands
- Efficiency
- Reuse/refurbish
- Simultaneous Multiple Technologies
- Software/ algorithms

1994

First Packaged Remediation System



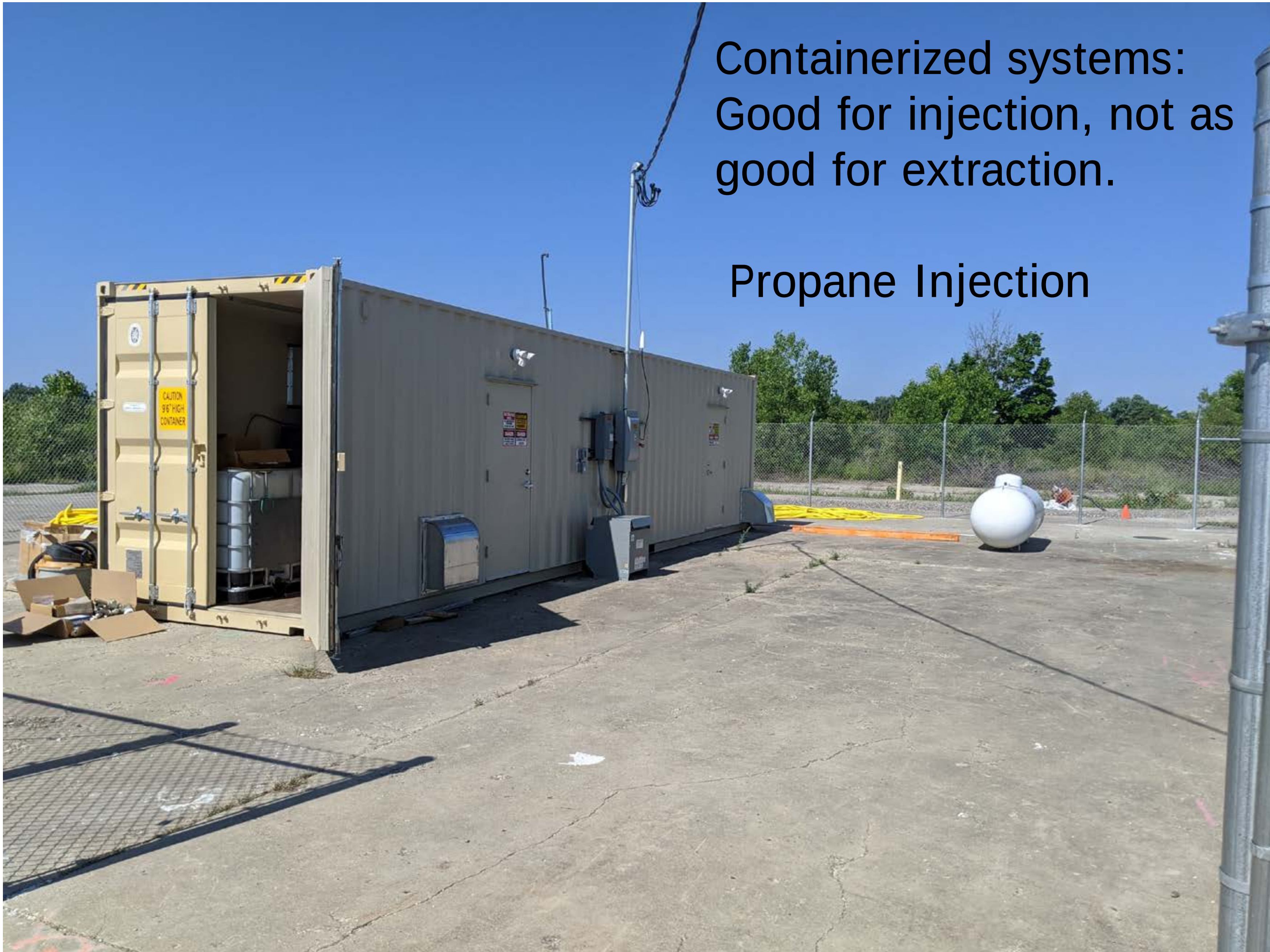
Outdoor Systems

Wooden Shed

Trailerized System

Containerized systems: Good for injection, not as good for extraction.

Propane Injection



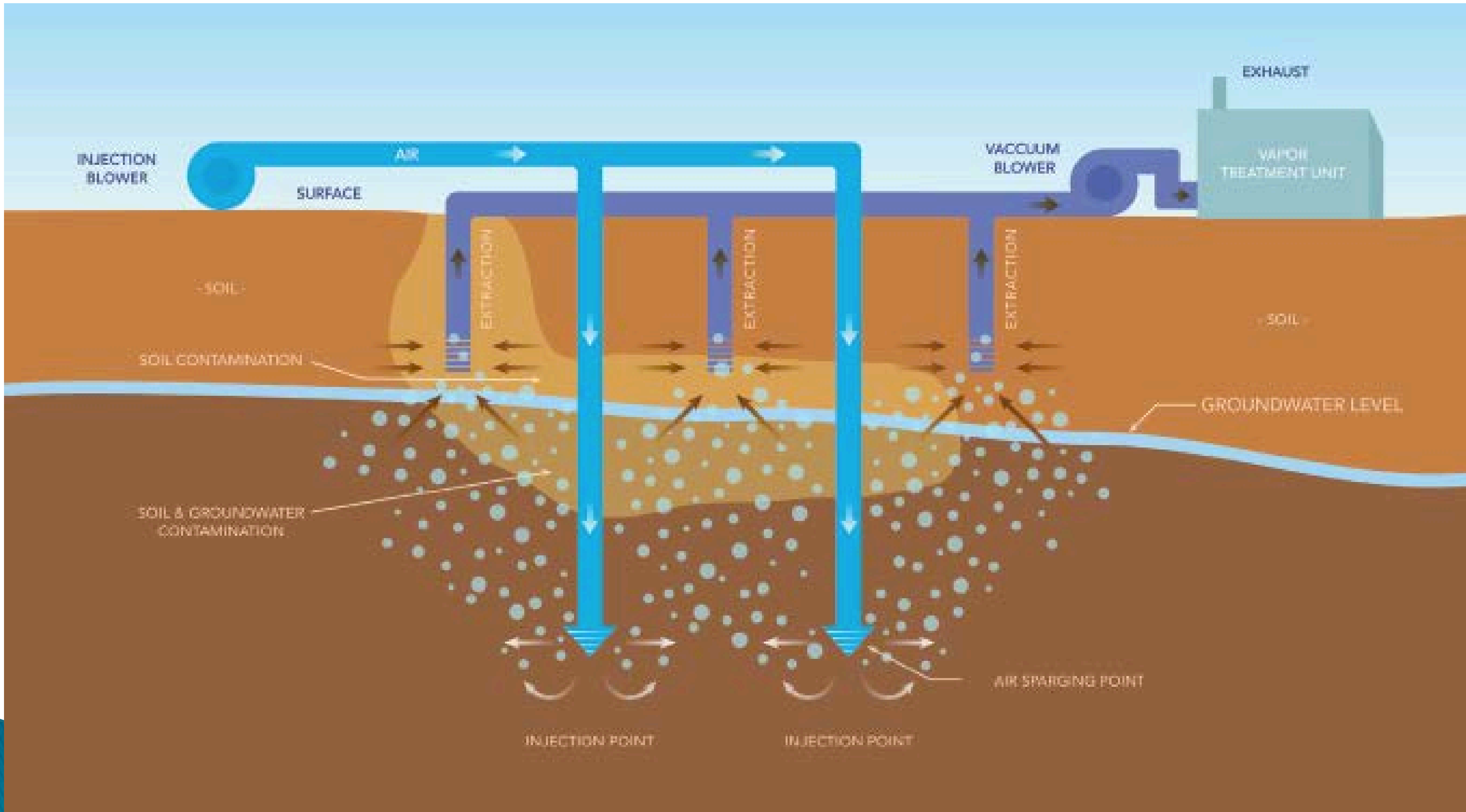
DVPE Pre-fabricated Package

- Small footprint
- Maintenance friendly
- Reuse for multiple site clean-ups

Equipment Procurement :

- New equipment purchase
- Used equipment
- Factory Refurbished equipment
- Rental equipment/pay for service
- General trend is Refurbished, some New, some Rental, very few used.

SVE/AIR SPARGING



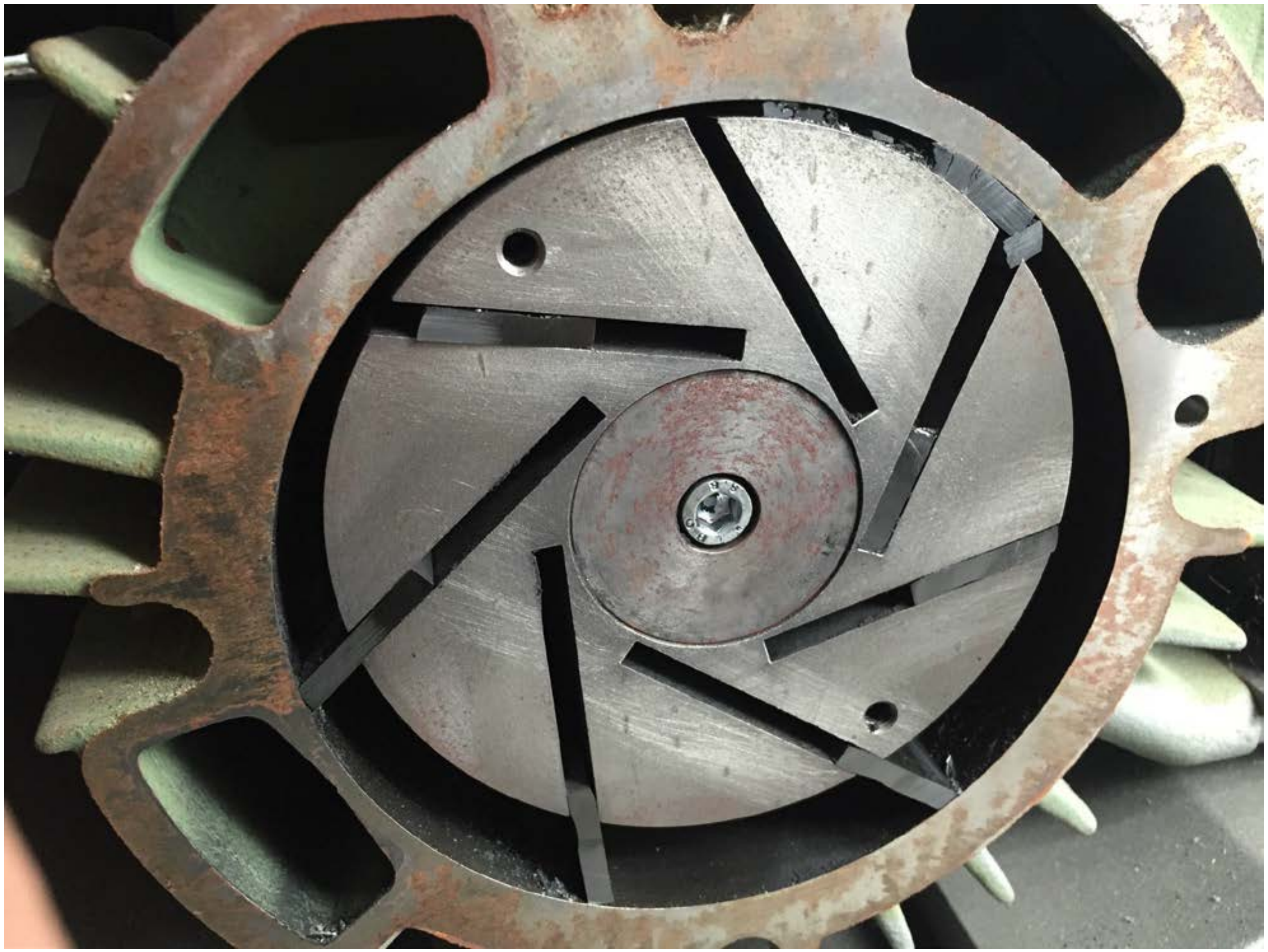
Air Sparge Generalities

- 3-5 CFM per point
- Pressure = water overburden + soil overburden
- Tighter well spacing vs SVE
- ROI ~ depth under contamination
- Size SVE for at least twice the sparge air flow rate

Air Sparge Selection

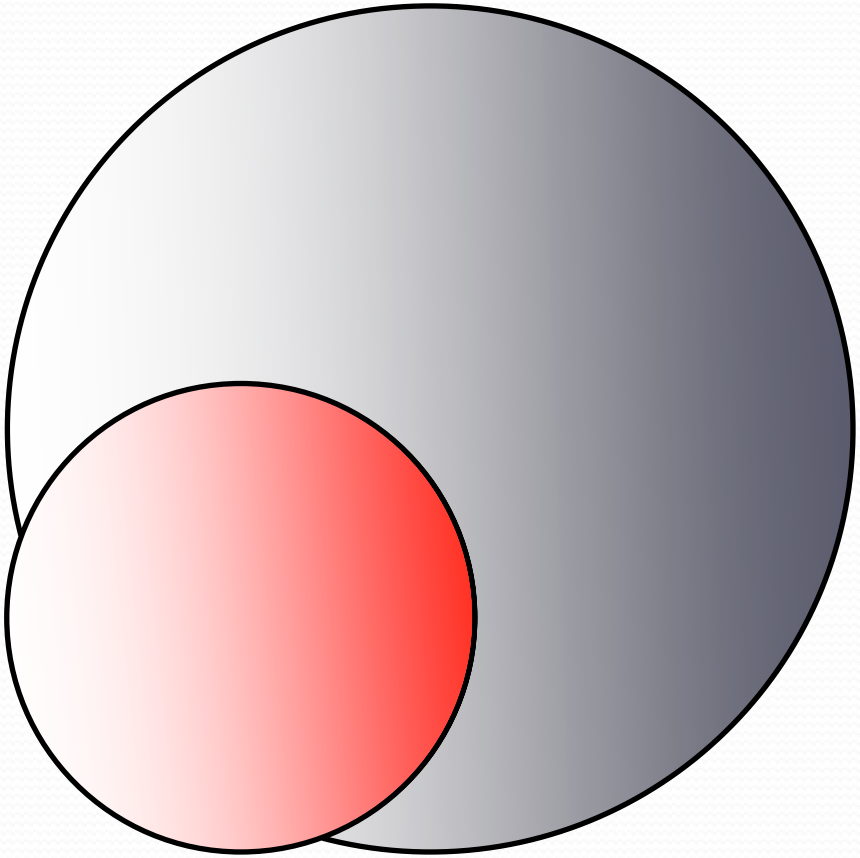
- Rotary Vane: 20 PSI, small, efficient, low cost
- Rotary Lobe: 15 PSI, loud, efficient, low cost
- Rotary Claw: 32 PSI, loud, hot, high cost
- Rotary Screw Compressor: 120 PSI, inefficient, high cost, oil contamination
- Ozone: oxidation technology, generally < 60 PSI, low flow, high cost

Rotary Vane

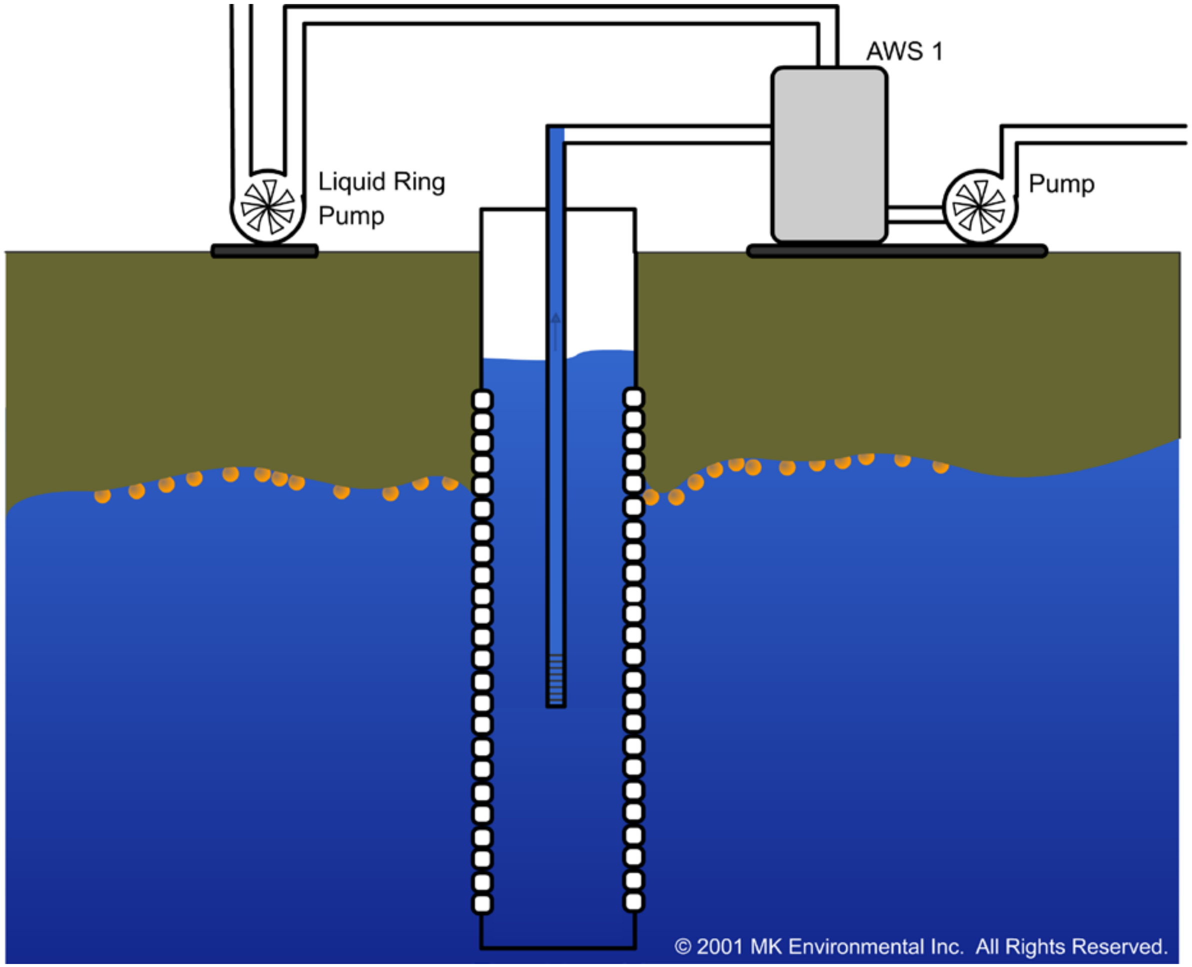


SVE & DPVE: Focus on the Vapor

- Relative pore volumes of Vapor vs Liquid Extracted
- Vapor is Much Easier to Extract Than Liquid From Porous Media
- 90% of the Mass is Recovered in the vapor



Dual Phase - Principle of Operation



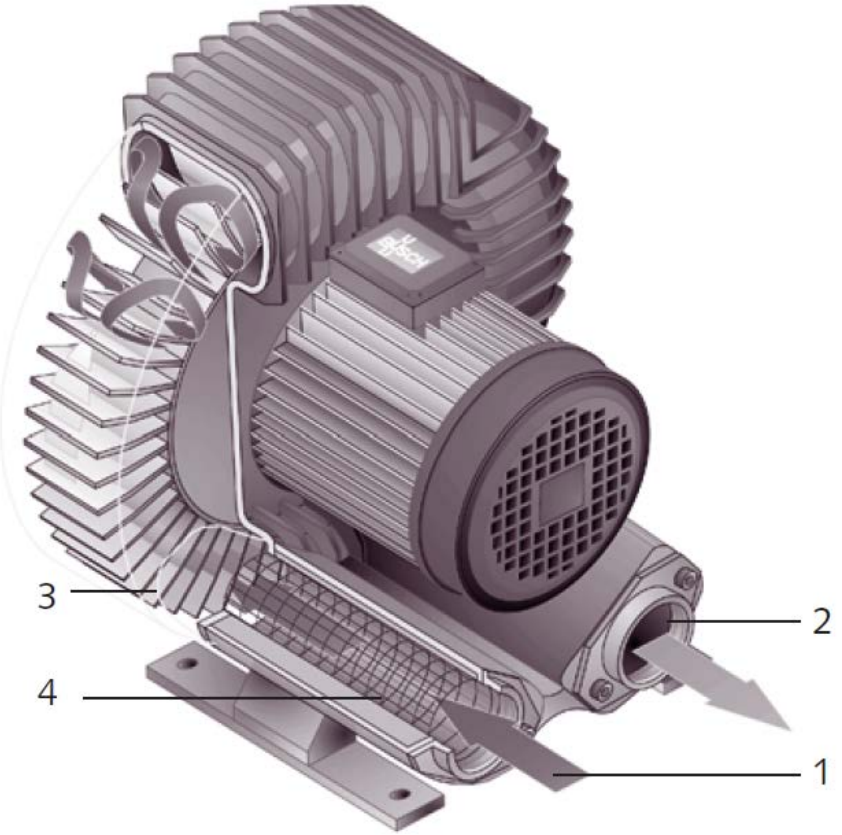
SVE Selection

- Regenerative Blower : 1-7" Hg, small, efficient, low cost. SVE only.
- Rotary Lobe: 1-15"Hg , loud, efficient, low cost
- Liquid ring 15-28"Hg, quiet, large, efficient, high cost
- Rotary Claw: 1- 25"Hg , small, loud, hot, high cost

Regenerative Blower

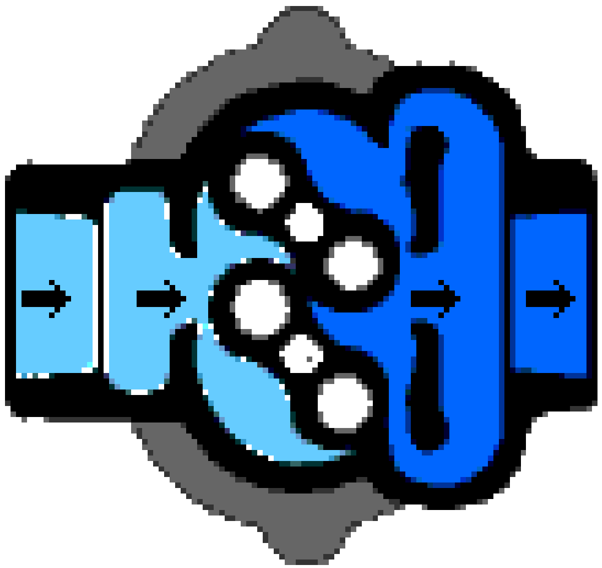
- Up to 7” Hg

Single-stage version



Rotary Lobe Blower

Rotary Lobe Blower



- Typically 15” Hg maximum
- Very noisy
- Hot
- Susceptible to water carry-over

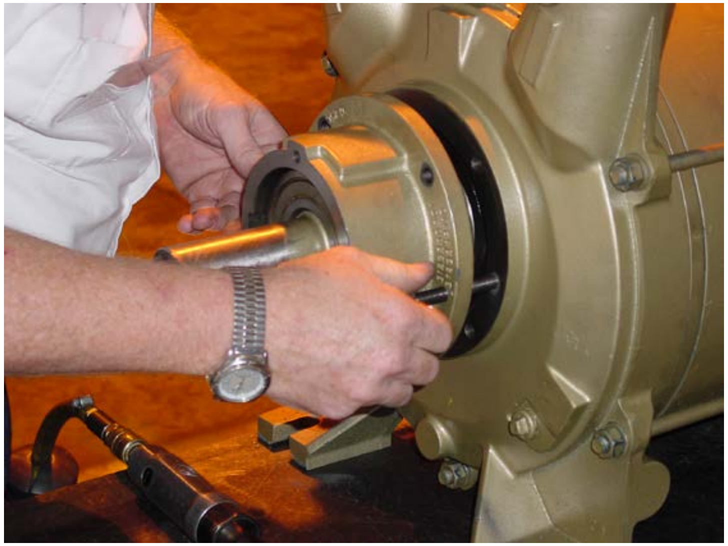
Rotary Claw Blower

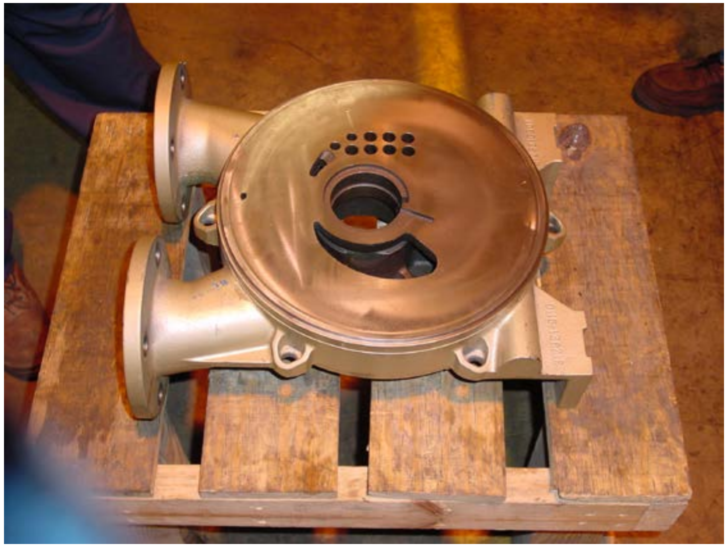
Dual Phase Extraction – Oil Seal

- 40.0 HP LRP SKID
- 500 ACFM AIR FLOW

- AWS-1 CLEAR PVC STILLING WELL & INLET

Inside the Liquid Ring Pump





- SHAFT, SEAL, INLET PLATE & IMPELLER

Oil Sealed Liquid Ring

- **Advantages:**
- Quiet
- No tap water required
- Self Contained
- **Disadvantages:**
- Constant 10-20 PPM oil concentration in exhaust stream
- High operating temperature, typically 180°

DPVE System Montgomery AL

Inefficiencies

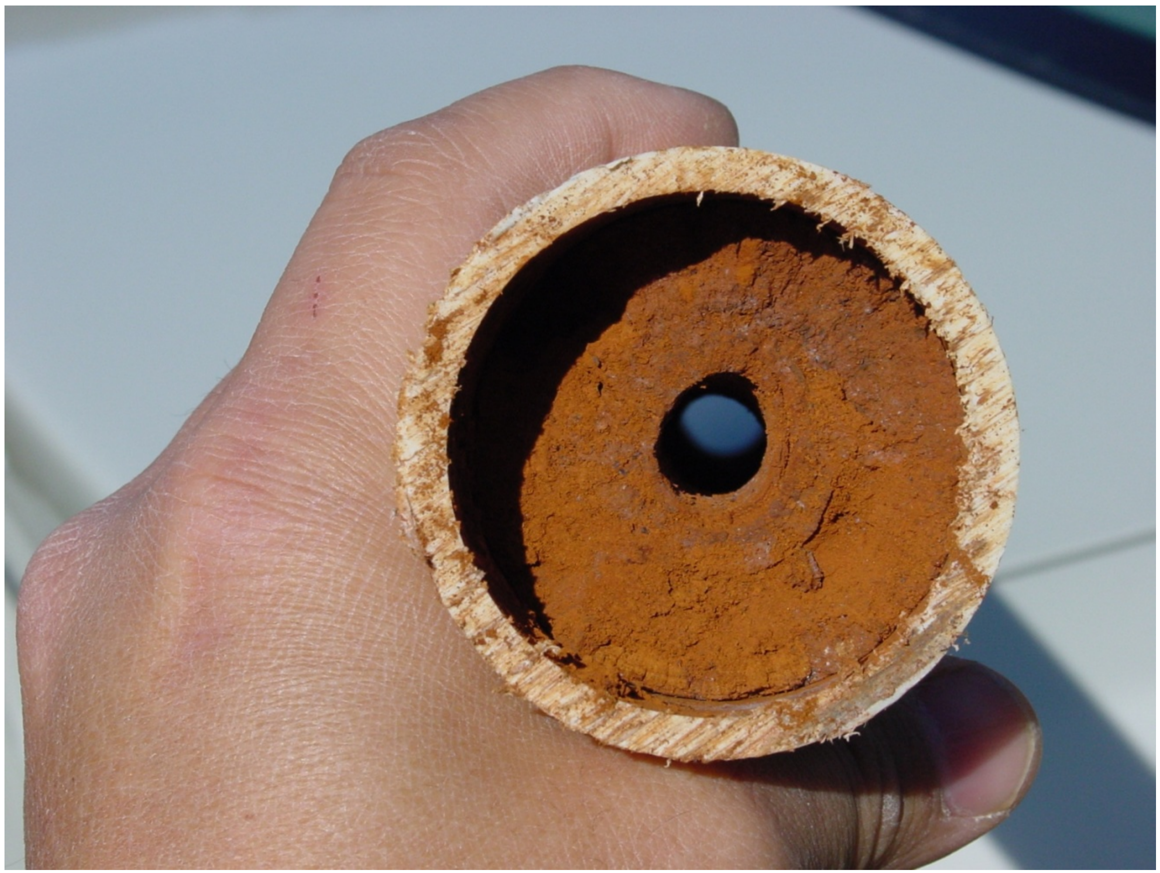
Manifold

Good: Independent flows

Inefficient: competing flows


Use long radius elbows
vs short radius elbows
Bobcat
3500

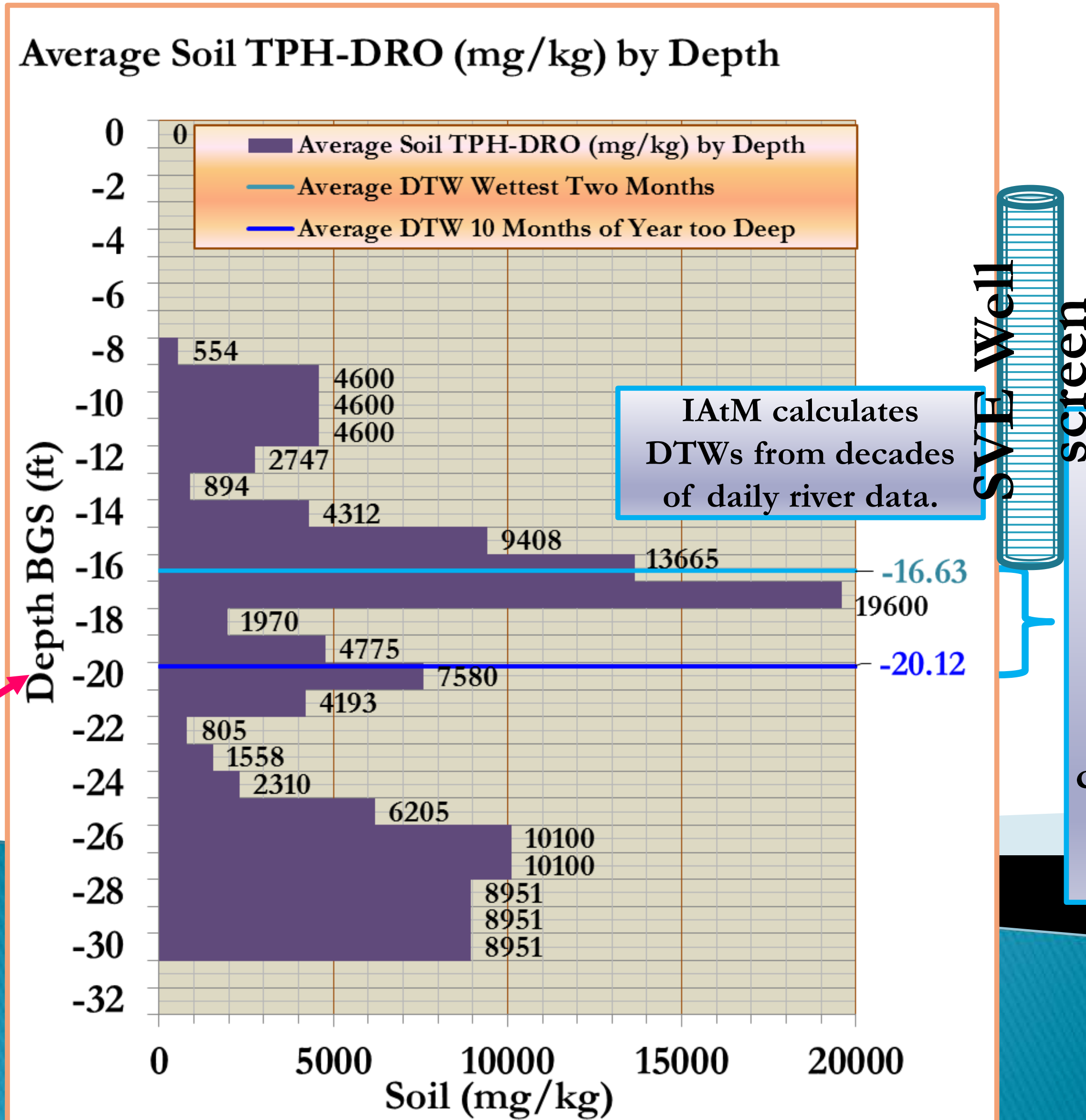
2” PVC PIPE REDUCED TO ½”
93% REDUCTION IN CROSS SECTION AREA



Understanding Gained from IAtM's Advanced Data Analysis (ADA) Assessments at nearly 100 Problem Sites Guides Remedial Selection.

ADA

100% SVE Systems evaluated were less effective at reducing mass in the intermediate vertical interval between the bottom of SVE well screen and lower water levels during the non wettest months.



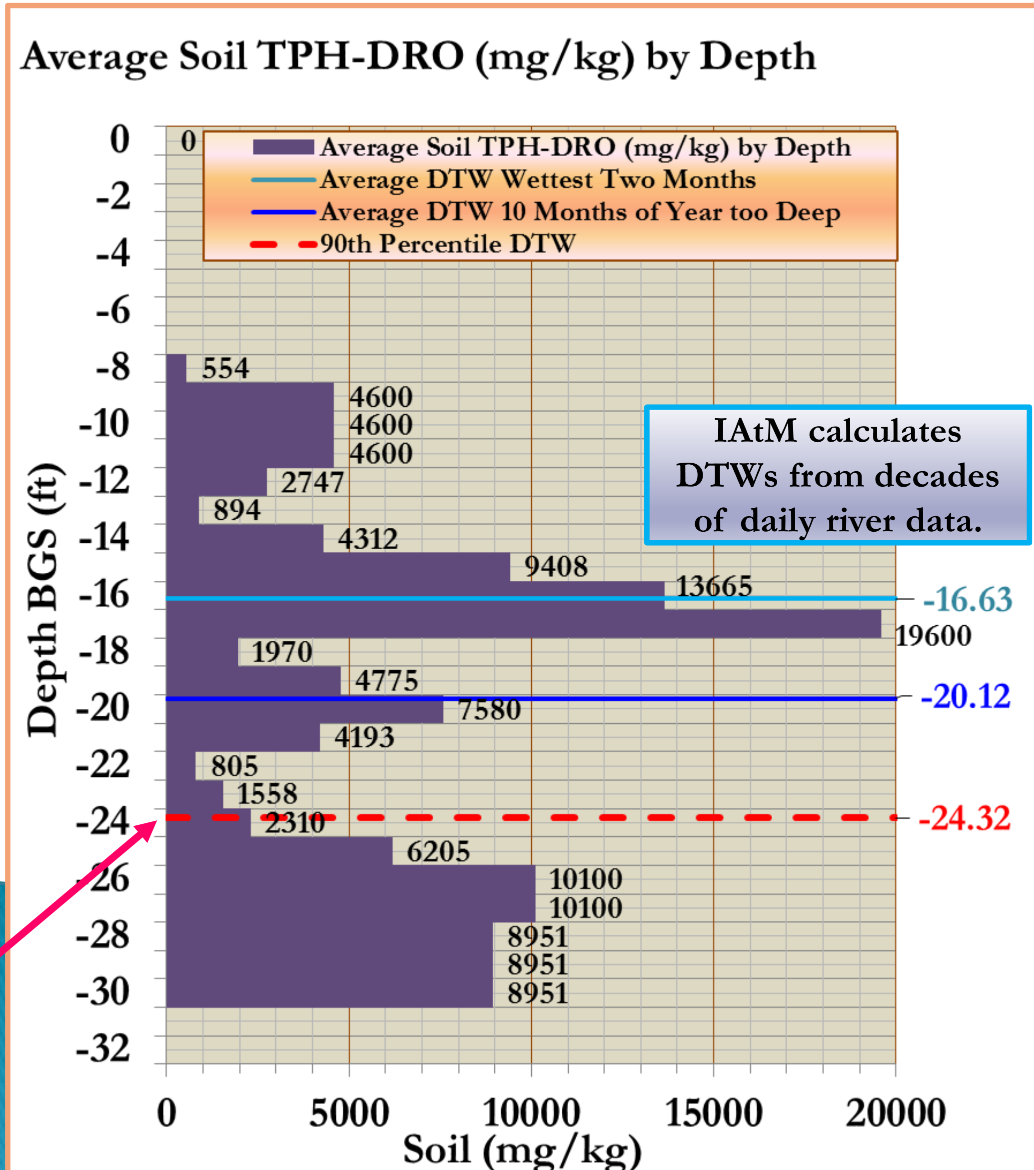
If mass exists above the average DTW during the non wettest months, then deeper wells and a DPE system capable of handling some water is needed.

Louisiana site

IAtM Improved Analysis through Modeling, LLC

Slide

Understanding Gained from IAtM's Advanced Data Analysis (ADA) Assessments at nearly 100 Problem Sites Guides Remedial Selection.



100% of DPE Systems that operated 6+ years missed typically submerged deep mass.
79% of all DPE systems evaluated.

If deep mass exists below the 90th percentile DTW, then an injection technology is also required.

Louisiana site

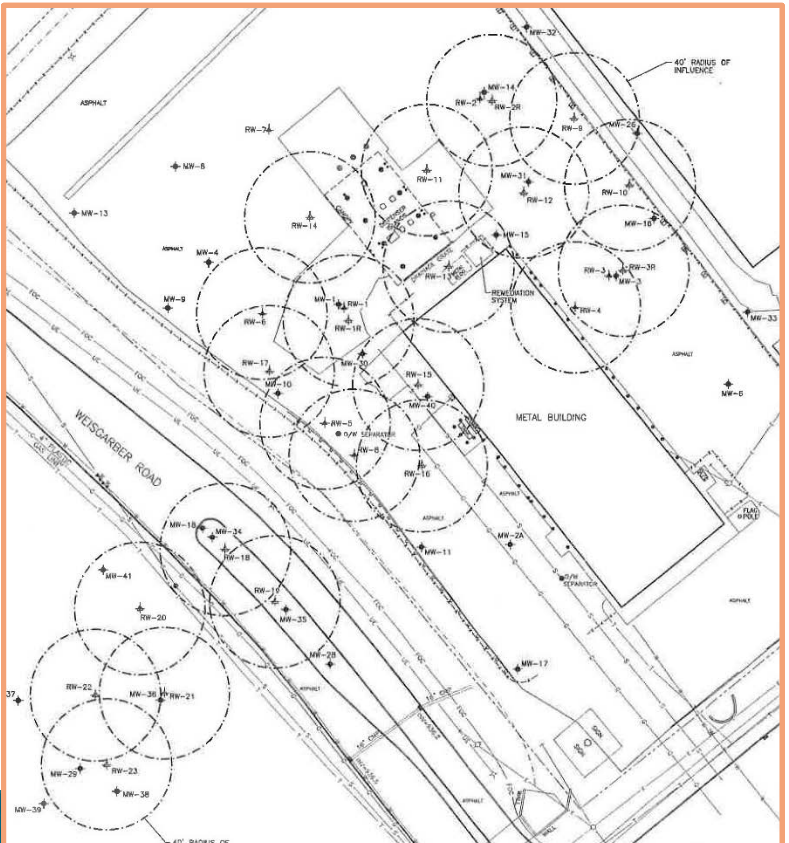
IAtM Improved Analysis through Modeling, LLC

Slide

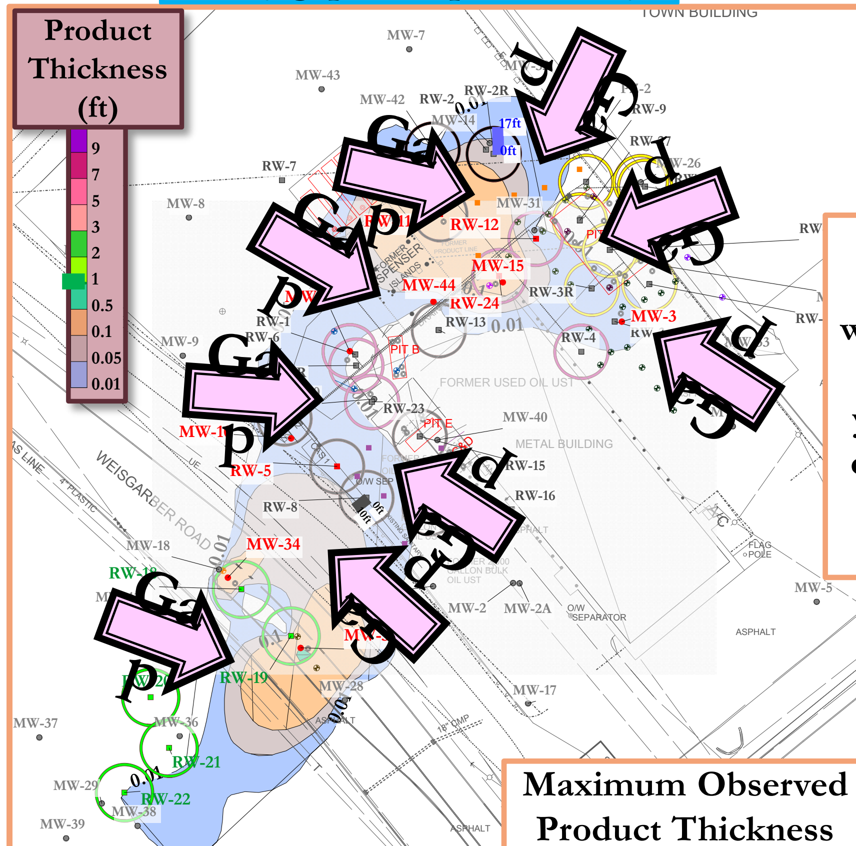
Understanding Gained from IAtM's Advanced Data Analysis (ADA) Assessments at nearly 100 Problem Sites Reveals Common Design Short-falls.

ADA discovers that 89% of DPE Systems and 80% of all Remedies evaluated overestimated design ROI leaving gaps in spatial coverage.

Design ROI of 40 feet



Actual ROI of 17 feet leaves many gaps in vapor recovery



Product remains at wells near gaps after many years of DPE operation and adding more wells.

Slide

Tennessee site

IAtM Improved Analysis through Modeling, LLC

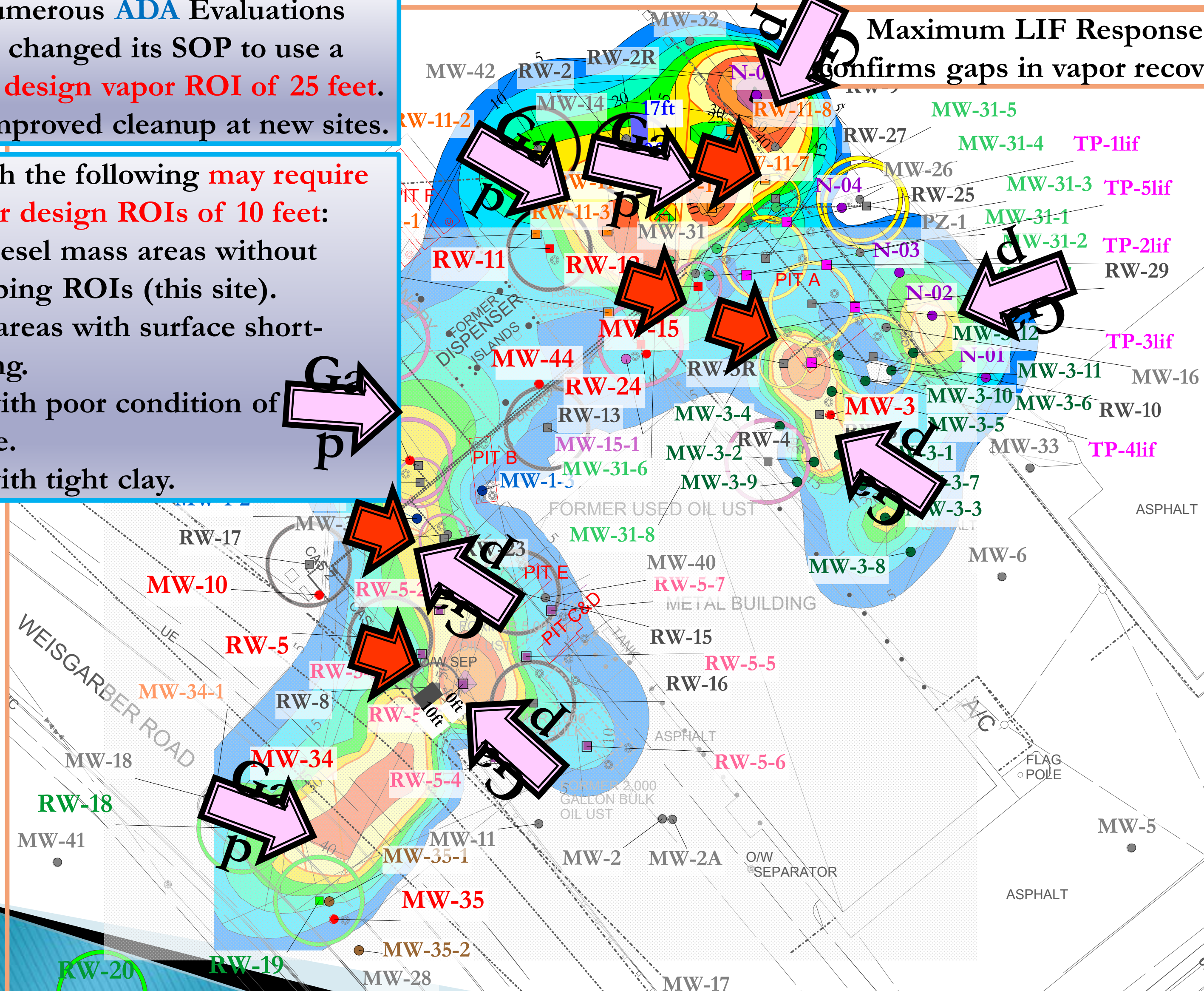
Understanding Gained from IAtM's Advanced Data Analysis (ADA) Assessments at nearly 100 Problem Sites Guides Remedial Design.

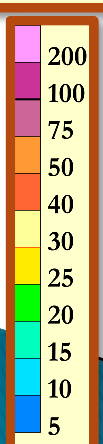
After numerous ADA Evaluations MDEQ changed its SOP to use a maximum design vapor ROI of 25 feet. This has improved cleanup at new sites.

Areas with the following may require smaller design ROIs of 10 feet:

- ✓ High diesel mass areas without overlapping ROIs (this site).
- ✓ Grassy areas with surface short-circuiting.
- ✓ Areas with poor condition of concrete.
- ✓ Areas with tight clay.

Maximum LIF Response confirms gaps in vapor recovery.





ADA

Slide

Tennessee site

IAtM Improved Analysis through Modeling, LLC

HOW MUCH RISK IS ACCEPTABLE?

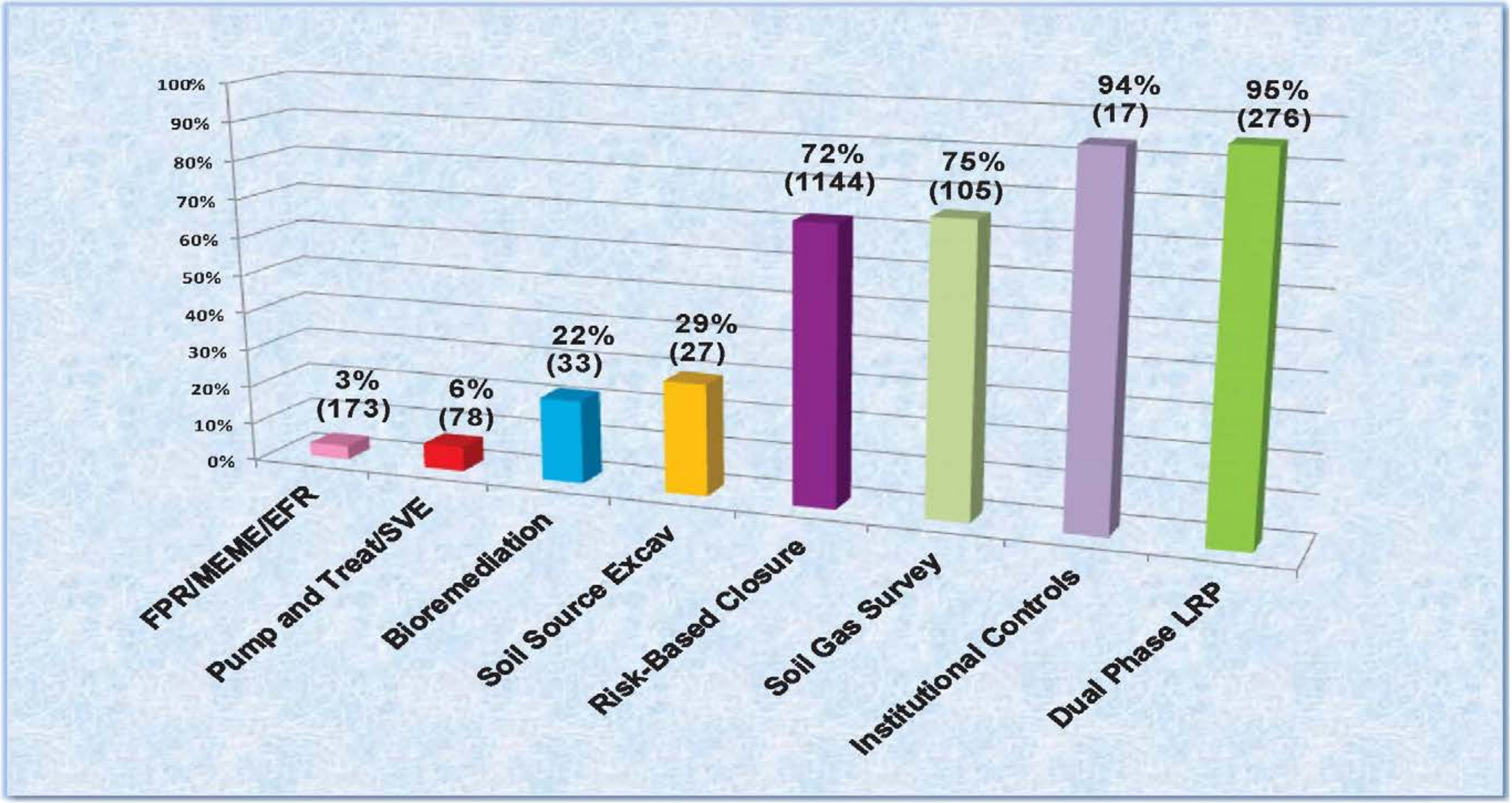
Mississippi Overview Pre 2015

- Approximately 180 systems 2000- 2015
- 95+% Dual Phase
- 20-30 HP average system
- 70% <3.5 years
- 30% >6 years
- Few sites in the middle

Dual Phase Extraction
Evolution of Design

- Changed Standard Operating Procedure
- 25’ ROI maximum, determines qty. of wells
- Well bottom and screen determined by PID readings, NOT current water table.
- Increase HP to 40, 50 or greater
- 3” piping, 4” wells
- Reevaluate at ~2.5 years
- Average clean up has decreased from 3.5 to 2.5 years

TDEC Closure Success Rate Based on Technology (2015)



Courtesy of TDEC

Tennessee DPVE

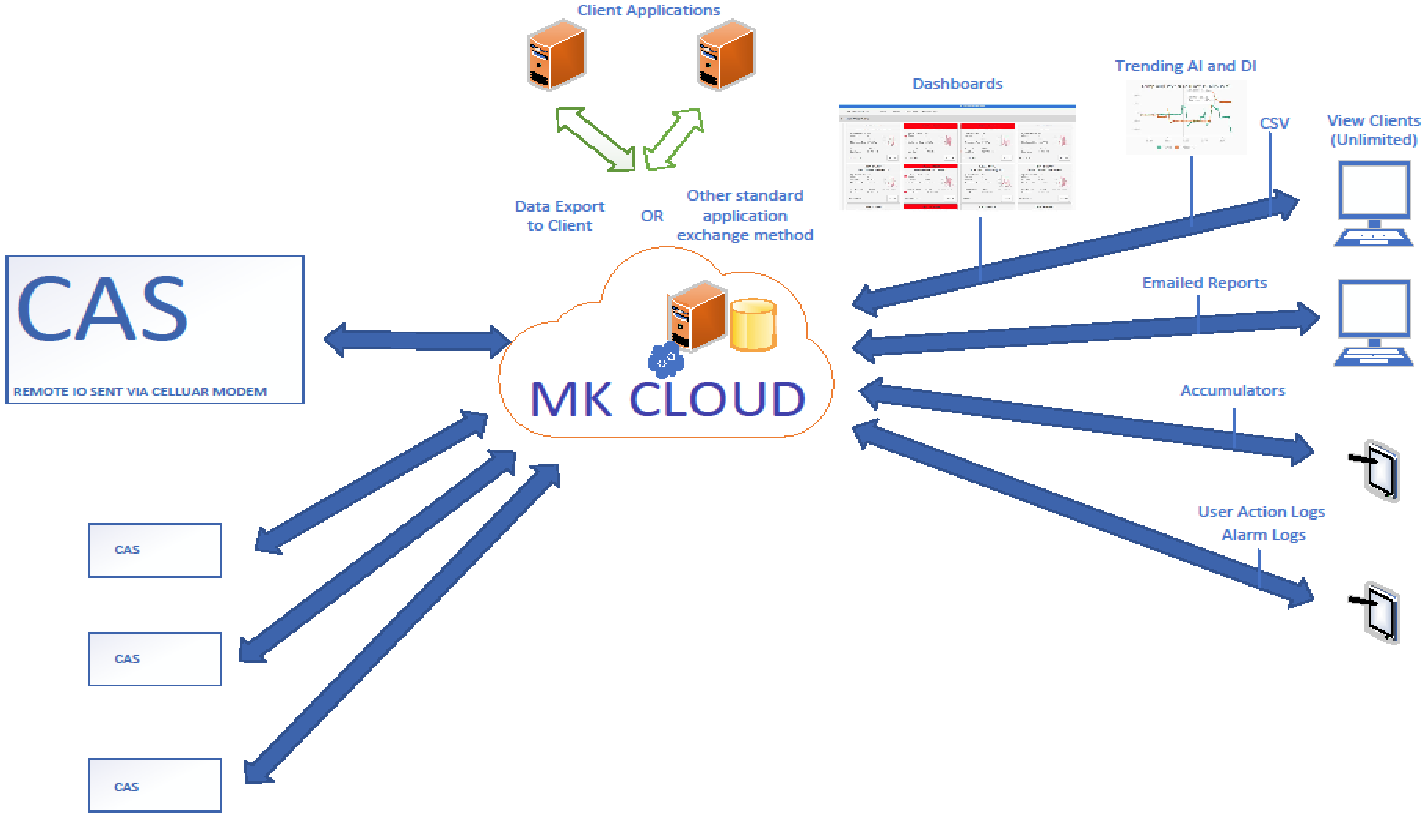
- 2009 - 2015 purchased 190 DPVE (New)
- (83) 25 HP, (38) 30 HP & (69) 40 HP all DVPE (300-500 AFM)
- Trend is towards 40 all HP systems. Two locations with (3) x 40 hp systems in parallel.

Contamination Sites Closed with DPVE

- 187 sites
- (40) were Drinking Water (DW) sites
- (111) were Free Product (FP) sites
- (10) were both DW & FP sites

- Average time to clean-up: **2.64 years**

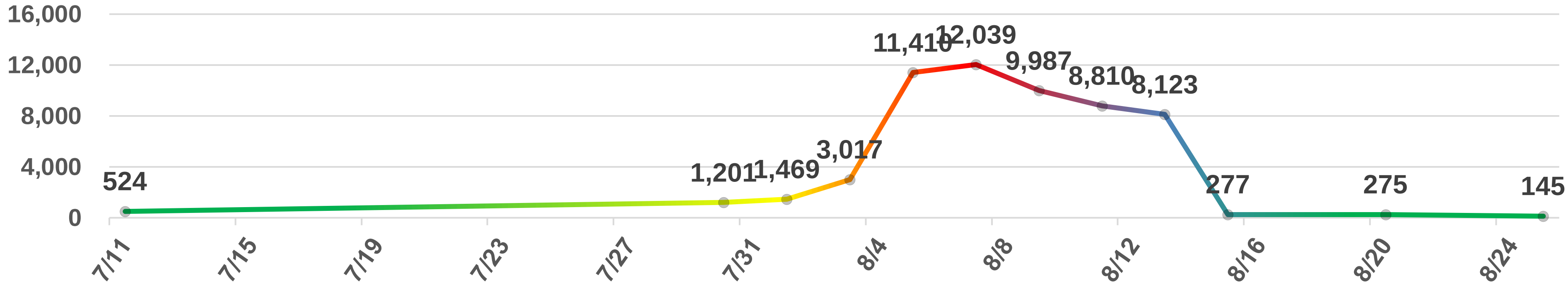
MK SITE OPTIMIZATION SOFTWARE ARCHITECTURE



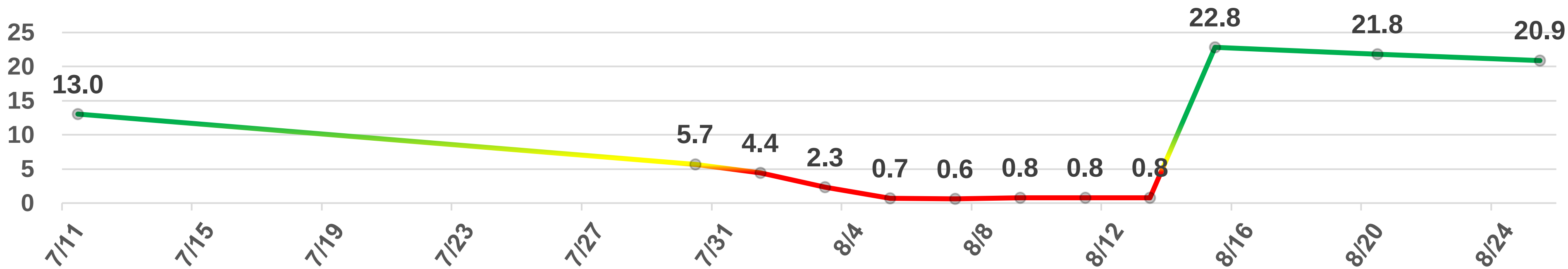
Let’s start instrumenting some sites

SITE OPTIMIZATION SOFTWARE (SOS)

SUMP TRANSFER PUMP CYCLE COUNTS



SUMP TRANSFER PUMP GALLONS/ CYCLE



SITE OPTIMIZATION SOFTWARE (SOS)

PREDICTIVE DATA ANALYSIS

- Early warning indicator of reduced
- Reduce downtime
- Significant Energy Cost savings
- Optimize personnel management
- Assist the Project manager in evaluations

General Trends

- Shorter Duration to Closure
- More realistic ROI and better screen placements
- Larger systems / higher flows. Time is money.
- More durable industrial equipment
- Piping and installation improvements
- Training, improved analytics
- Use of Multiple technologies, simultaneously or in series

MK ENVIRONMENTAL

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Special Thanks to TDEC, MDEQ and IATM

Design, Optimization, and Termination of Air-Based Remediation Technologies

LUST Corrective Action Webinar Series
November 16, 2021
Virtual Conference

Matthew A. Lahvis
Principal Engineer
Shell Global Solutions (US) Inc.

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Outline

- why air-phase remediation
- design considerations
  - soil vapor extraction (SVE)
  - air sparging (AS)
  - multi-phase extraction (MPE)
  - bioventing/biosparging
- “Exit Strategy Toolkits”
  - case for change
  - contents/recommendations

air treatment (thermal oxidizers) for soil vapor extraction (SVE) system - Hartford, Illinois

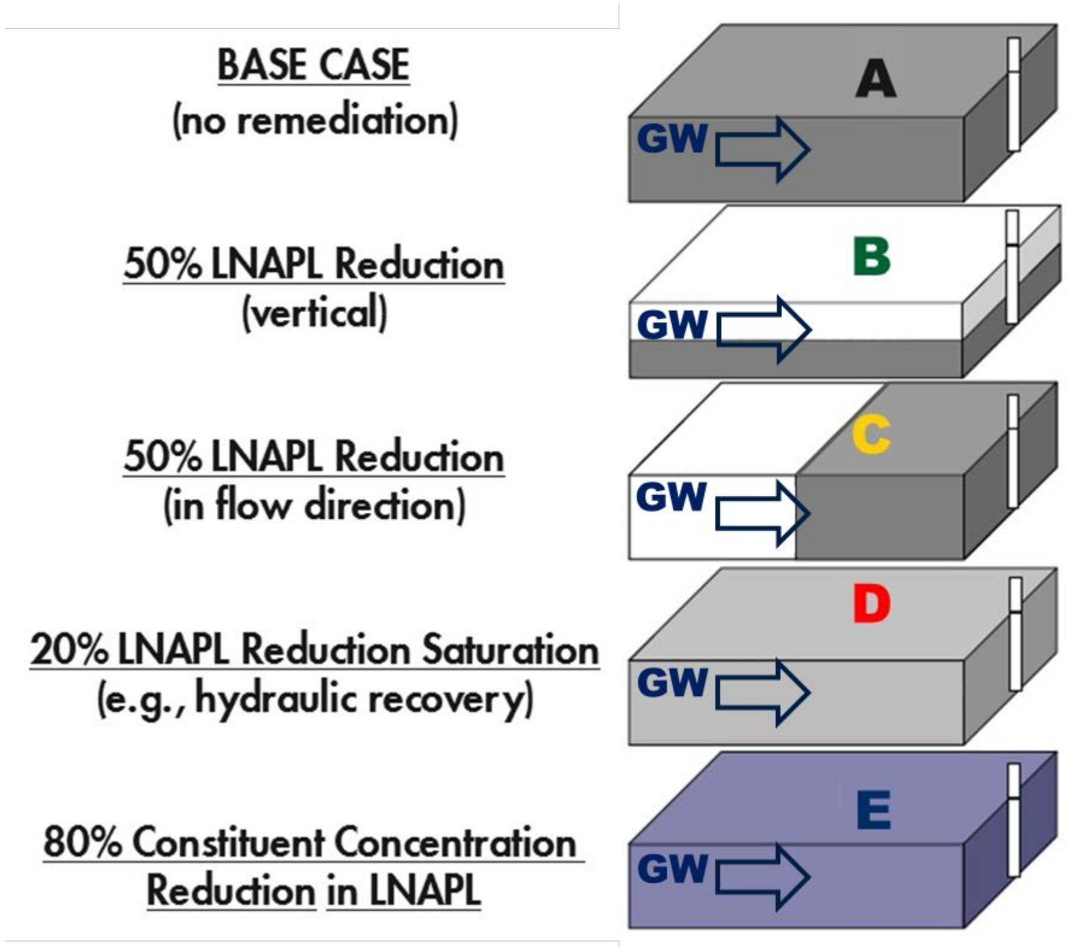
GOALS:

- ✓ **provide a few general design considerations for air-phase remediation**
- ✓ **highlight a sustainable approach to air-phase remediation**

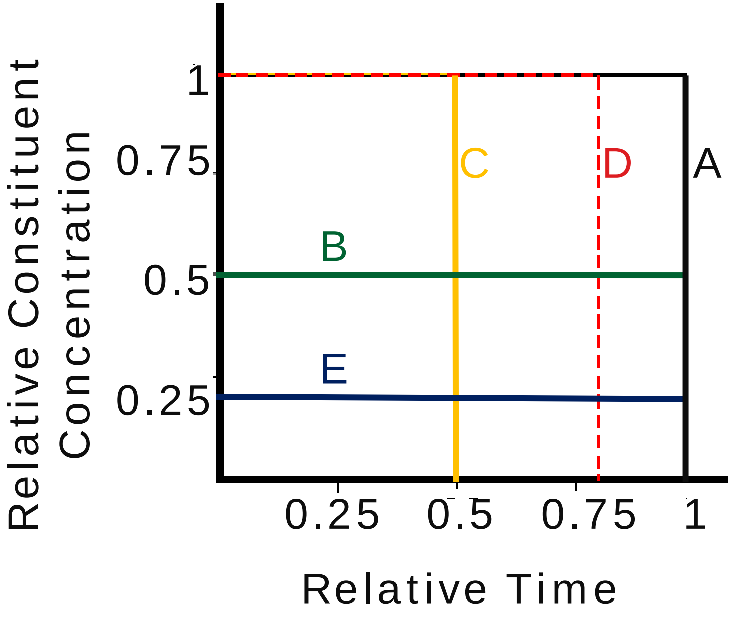
BACKGROUND – AIR PHASE REMEDIATION

1.0

Motivation Behind Selecting Air-Based Technology:
LNAPL Recovery vs. Concentration and Plume Longevity



from ITRC, 2009



*** assumes groundwater flow is left to right, plug flow through the source, equilibrium dissolution, and no biodegradation**

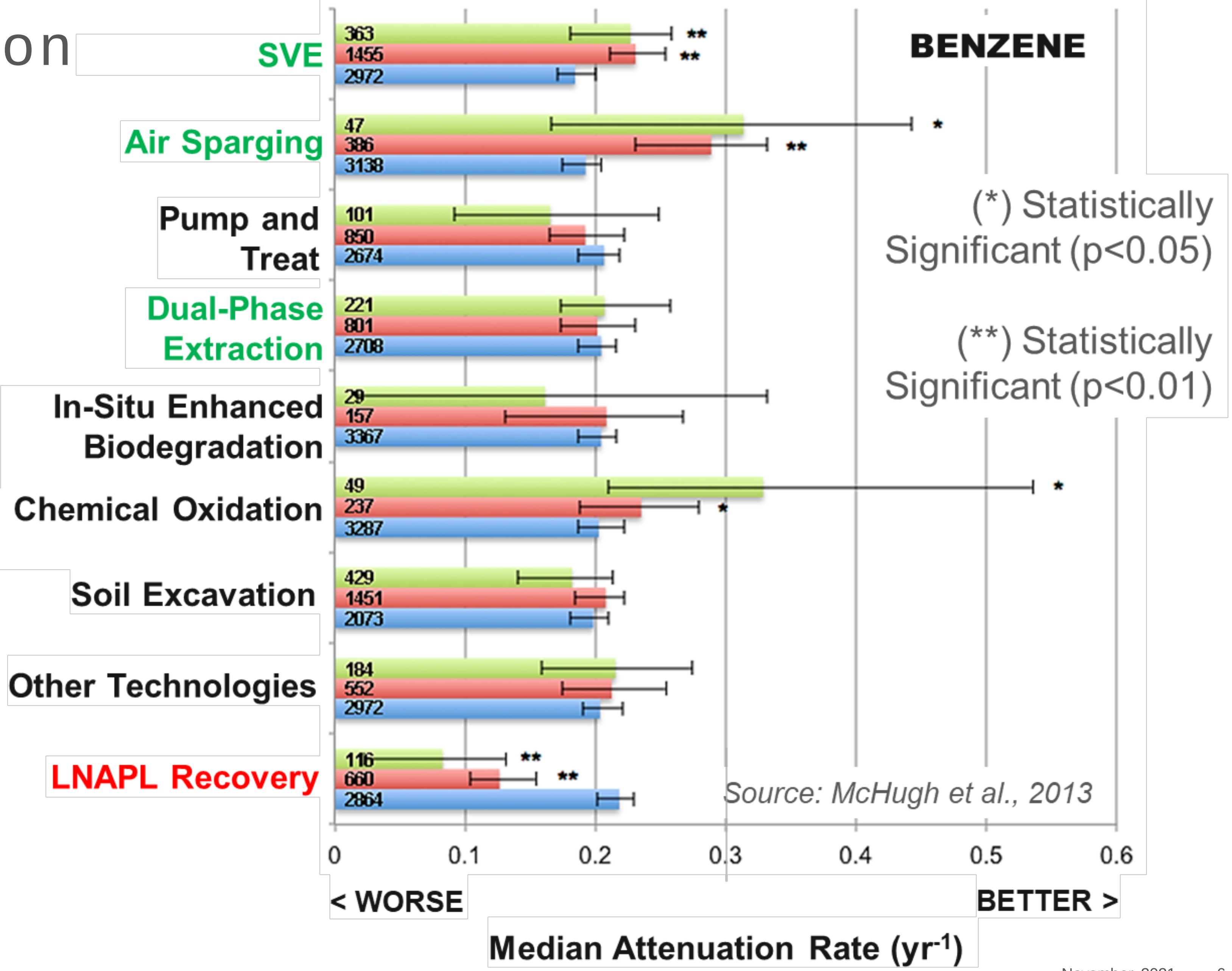
KEY POINT

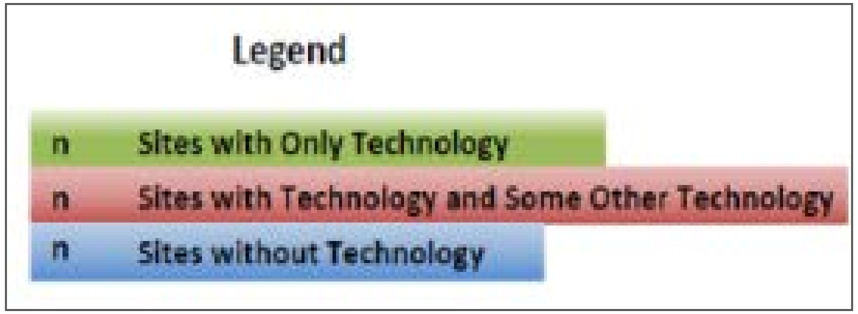
air-based remediation technologies affect composition (risk)

Air-Based Remediation More Effective Than LNAPL Recovery:

Effect of Remediation Technology on Source Attenuation Rate

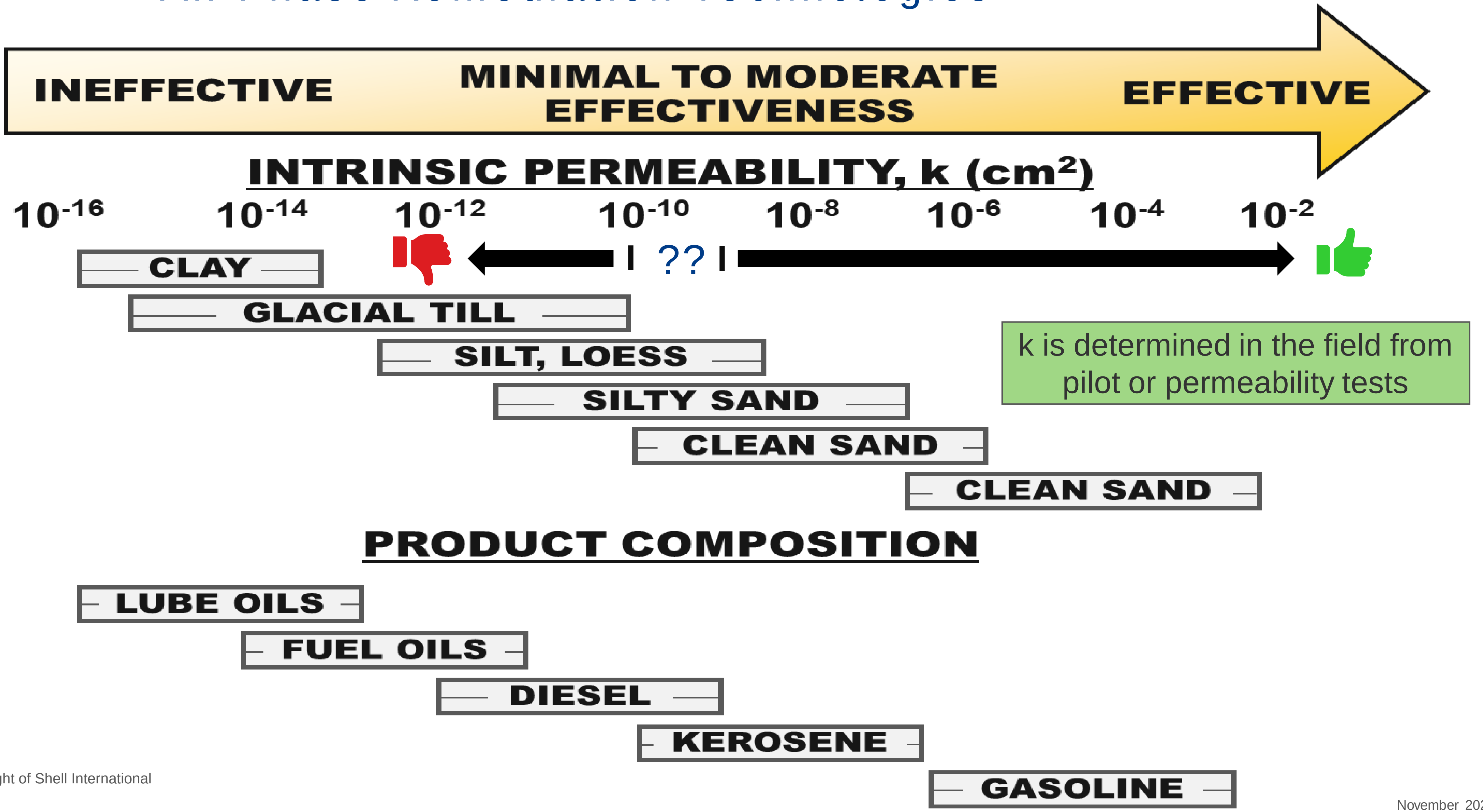
Geotracker Study – 12,000+ sites (McHugh et al. 2013)





KEY POINT air-based remediation technologies enhance attenuation rates

Design Considerations/Issues:
Air Phase Remediation Technologies



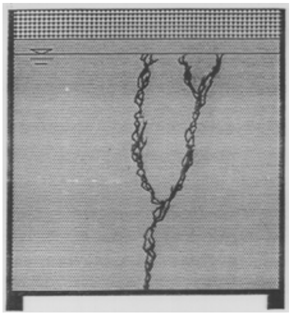
AIR SPARGING

2.0

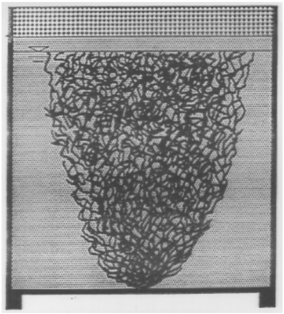
Design Considerations/Issues: Air Sparging

FLOW VISUALIZATIONS

LOW INJECTION RATE



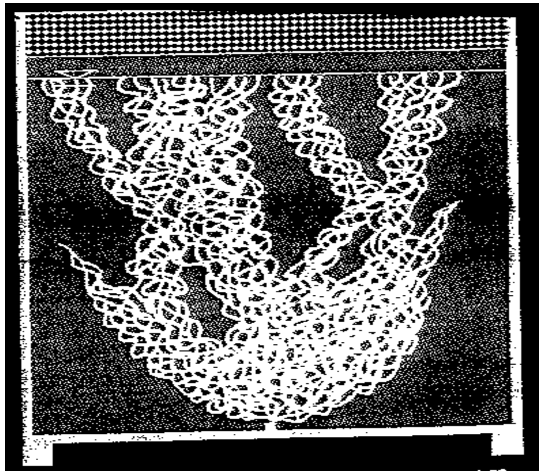
HIGH INJECTION RATE



Ji et al. (1993)

- air channels generally collapse to fewer conduits over time
- can be overcome to a degree by pulsing
- small scale heterogeneities can greatly affect airflow

AIRFLOW AFFECTED BY SMALL-SCALE HETEROGENEITY

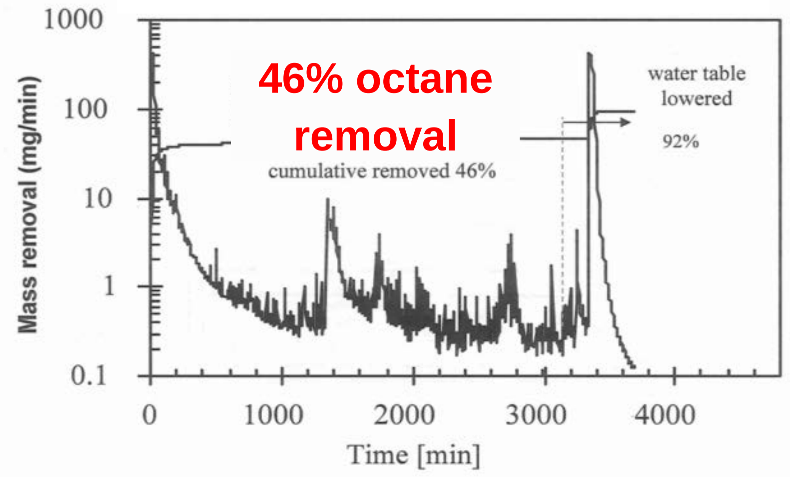


KEY POINT

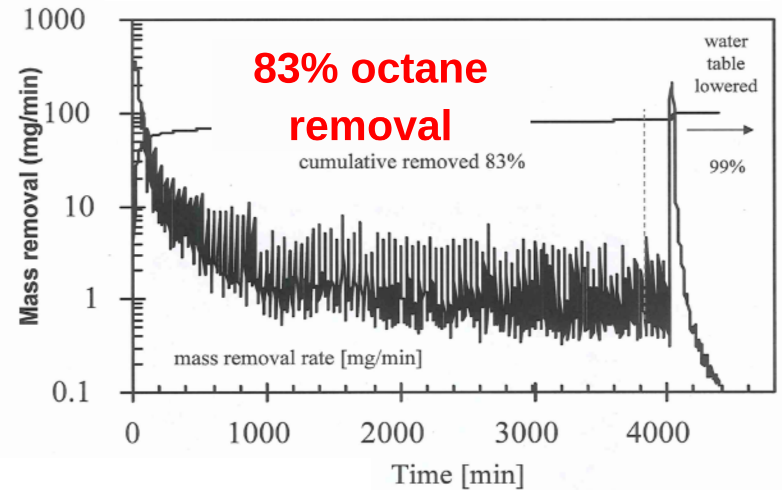
pulsed, high injection-rate sparging (e.g., 1 – 8 pulses/day) generally improves air distribution over continuous sparging

STEADY VS. PULSED

steady sparge



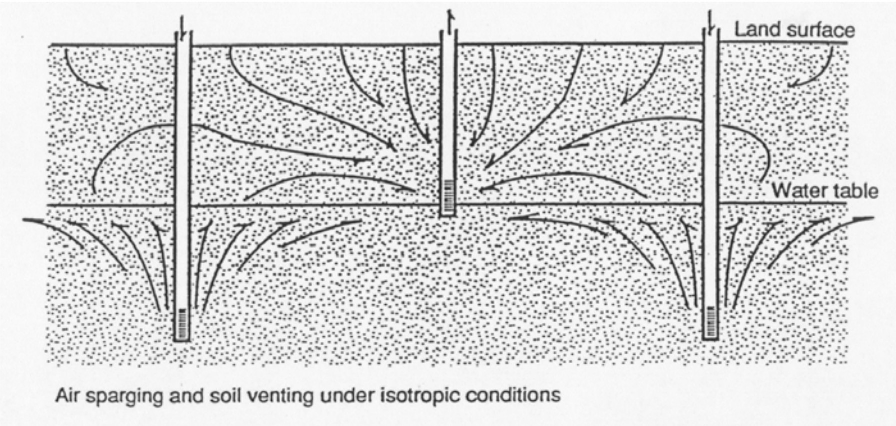
pulsed sparge



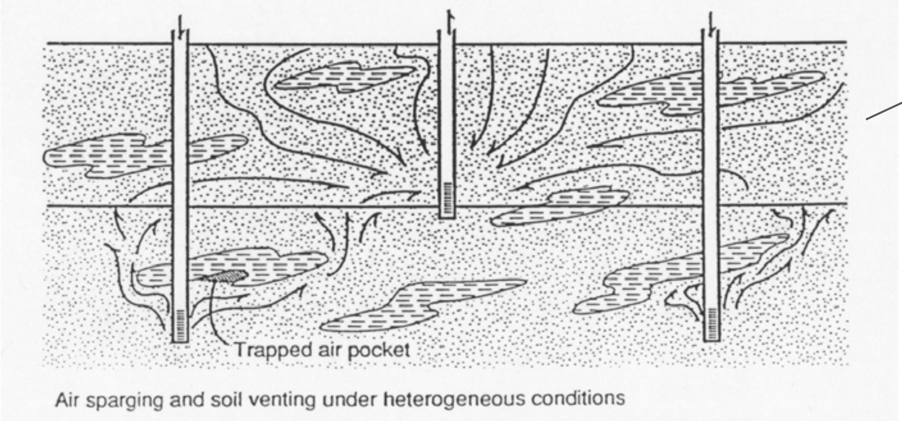
Bruce (written communication)

Design Considerations/Issues: Air Sparging

IDEAL AIR FLOW



REALITY



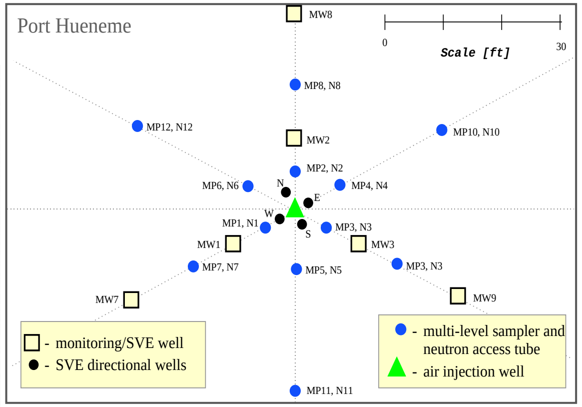


Figure 13. Evidence of IAS Impact

Bruce (written communication)

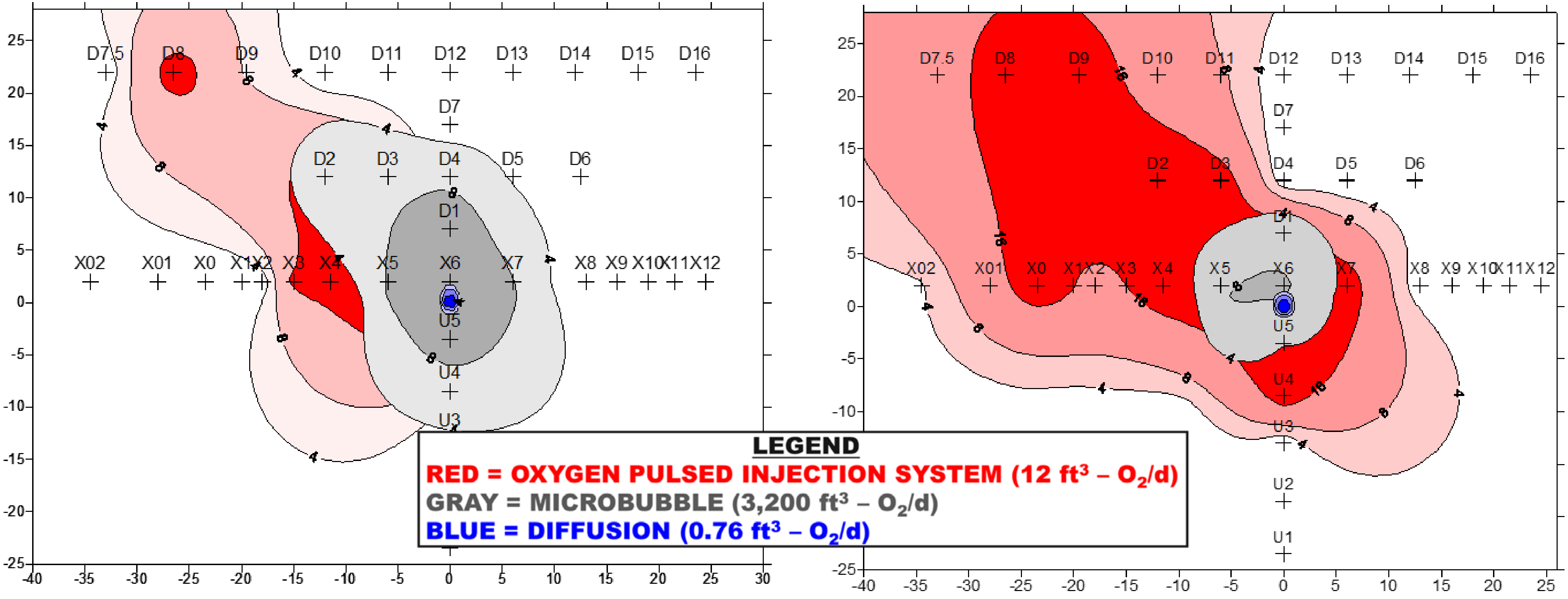
geyser at MW -- took about a month to depressurize after AS turned off…took 6 months for MW located ~1000 ft away from nearest sparge point to depressurize post AS shut down

air distribution is often variable, making monitoring a challenge

Design Considerations/Issues: O_2 Delivery

O_2 Distribution
Shallow Aquifer @ 18 Weeks

O_2 Distribution
Deep Aquifer @ 18 Weeks

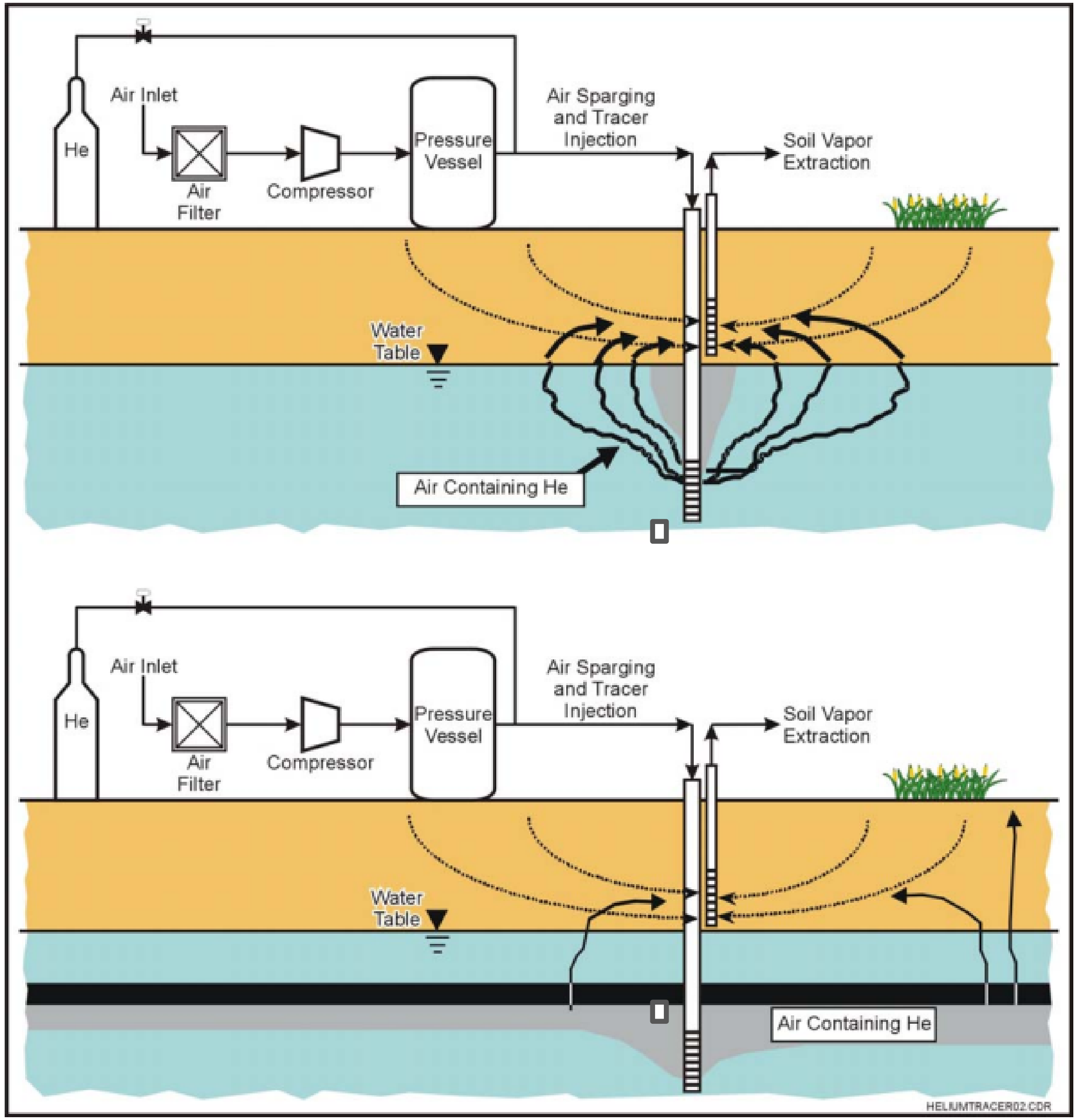


KEY POINT

- must understand O_2 demand
- how you inject is important

Other Design Considerations/Issues: Air Sparging

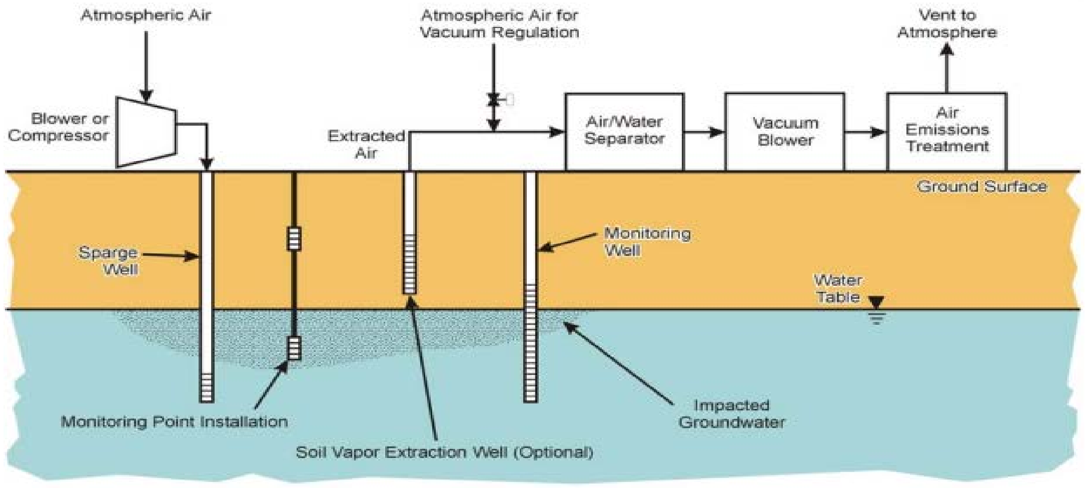
- ✓ **injection wells not properly developed** - often see monitoring wells developed but sparge wells get ignored
- ✓ **injection wells silting up, especially under pulsing conditions** - can be addressed, in part, using blank casing at the bottom of the sparge well
- ✓ **iron precipitation** - can be an issue if concentrations in groundwater exceed 10 – 20 mg/L
- ✓ **well completion not competent, especially for pulsed or biosparging injection** - can be addressed, in part, by completing the wells with a bentonite/cement mixture



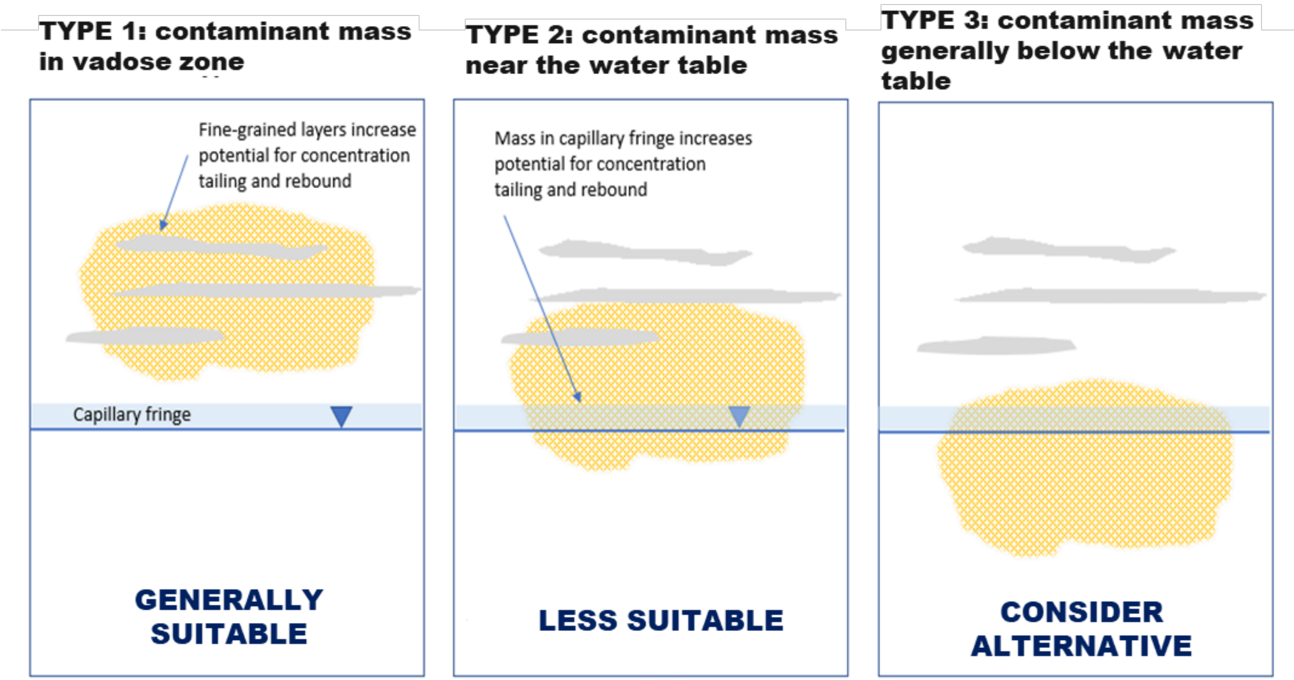
SOIL VAPOR EXTRACTION

3.0

Design Considerations: Soil Vapor Extraction (SVE)



Relative Applicability vs. General Contaminant Mass Distribution



adapted from Truex et al. (2013)

- the more LNAPL mass is distributed above the water table, the better (little remediation of confined/submerged sources – must couple w/ AS)
- difficult to remediate mass in low-permeability soils (rebound) - rebound testing (soil-gas monitoring after system shut down) recommended for validation
- other challenges: GW mounding/large fluctuations in water table, short circuiting, frozen condensate lines
- SVE recommended as an alternative to sub-slab depressurization for VI mitigation

Design Considerations: Soil Vapor Extraction (SVE)

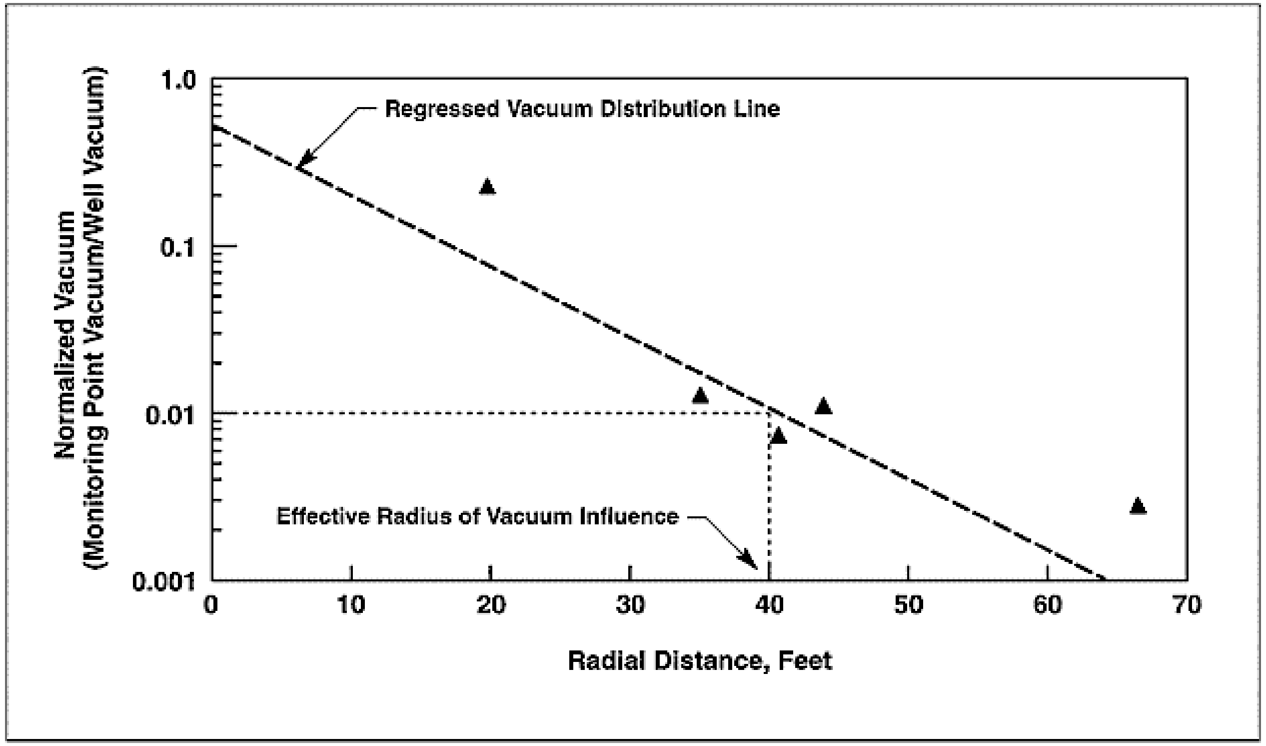
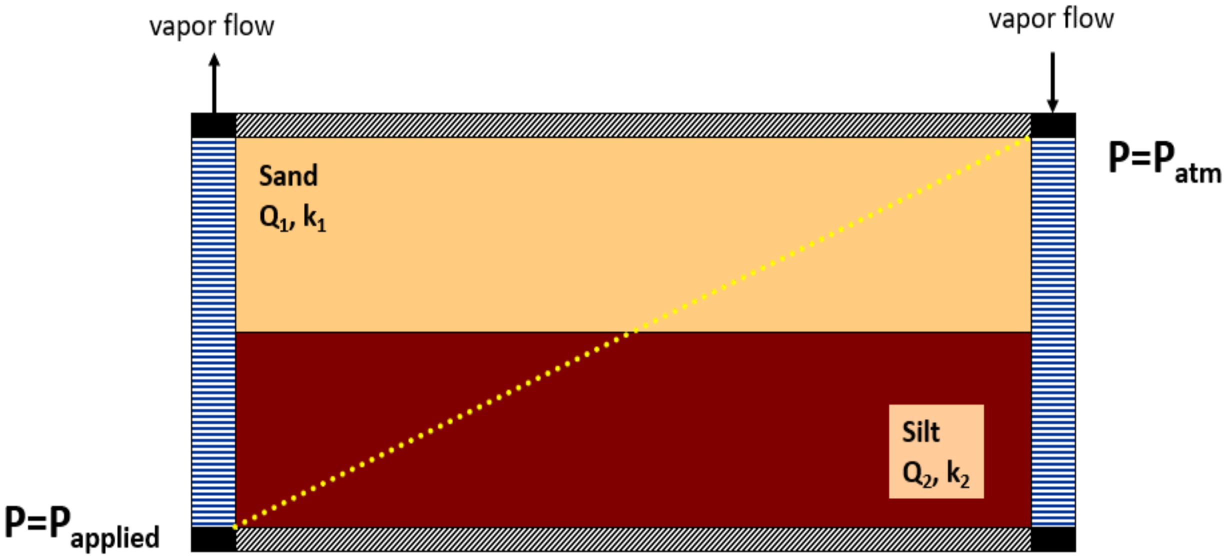


Fig. 7 – Effective Radius of Vacuum Influence Normalized Pilot Test Vacuum Data Plot



KEY POINT

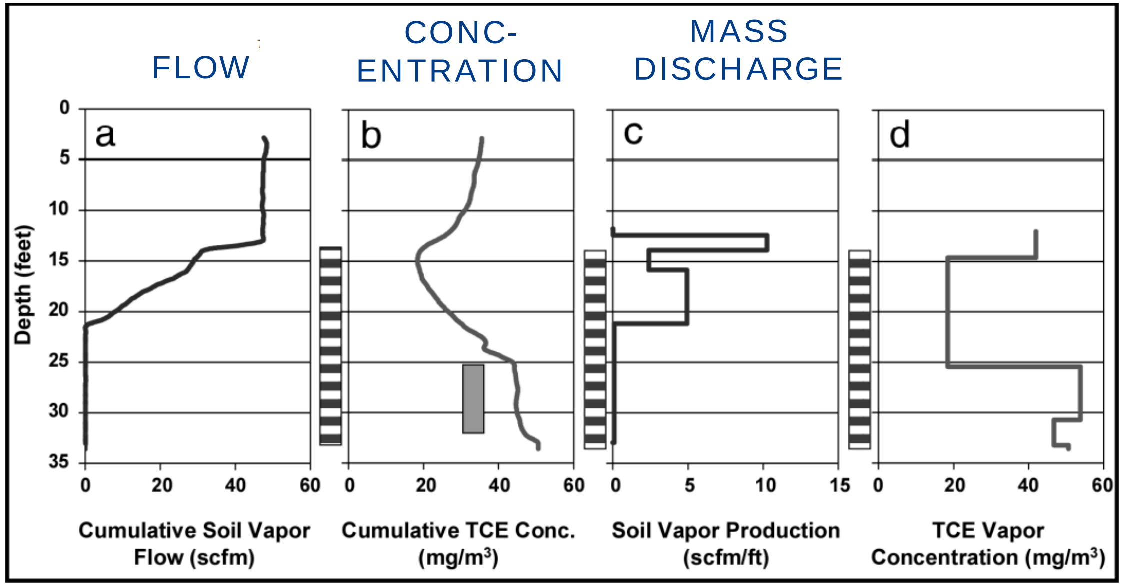
- **vacuum ≠ flow**
- **tracers and temperature measurements can be beneficial for assessing ROI**

- ROI can extend beyond where vacuum is measurable
  - soil-gas (O_2, CO_2, COCs) concs vs. time
  - tracers (He, SF_6) are relatively easy/repeatable
  - temperature can be used as an indicator of ROI and to assess total mass removal (e.g., nested thermistors) monitoring (flow, concs) (Sweeney and Ririe, 2014)

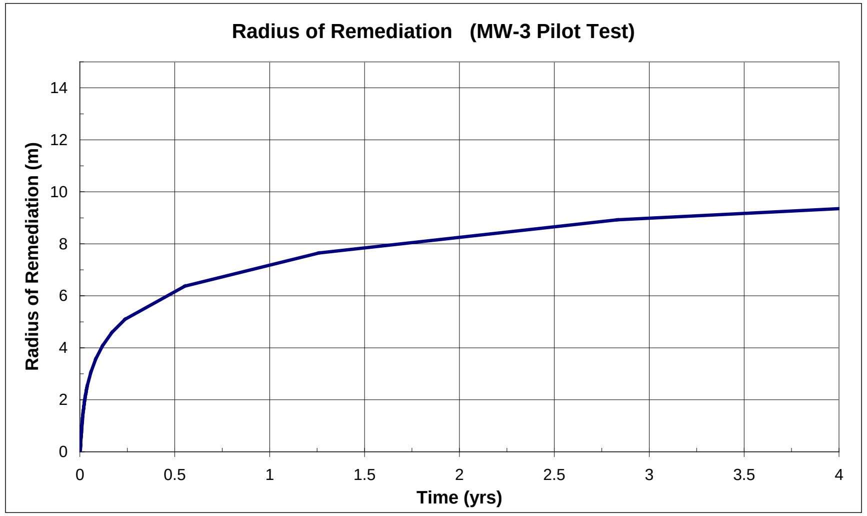
Design Considerations: Soil Vapor Extraction (SVE)

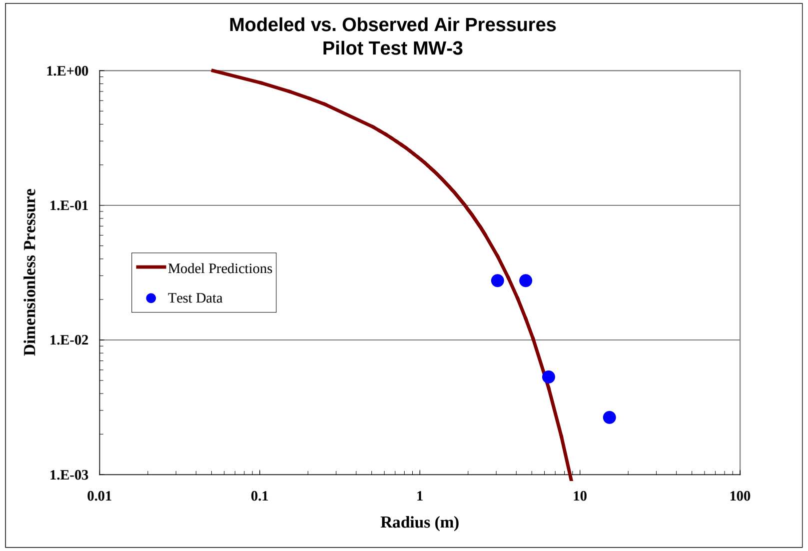
- optimize via extraction well-specific monitoring/regulation (flow, concs)
  - conduct profiling of in-well flow & contaminant concentrations under active extraction
  - pilot testing and simple spreadsheet models to design well configurations

MASS DISCHARGE ESTIMATES
CONCENTRATION & FLOW PROFILING



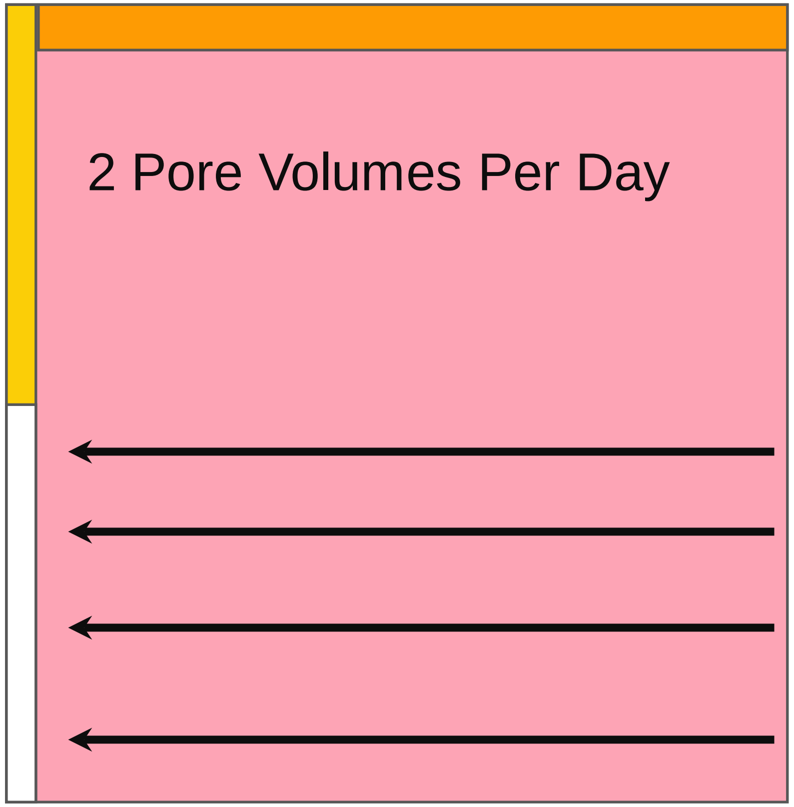
USEPA (2000)



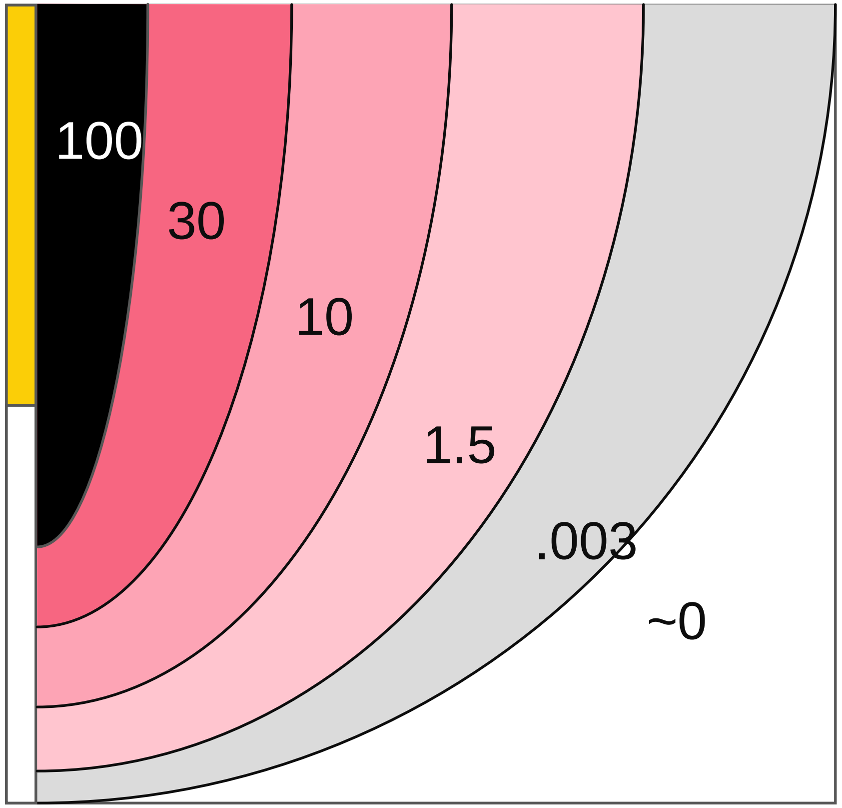


Design Considerations: Soil Vapor Extraction (SVE)

SEALED SURFACE



OPEN SURFACE

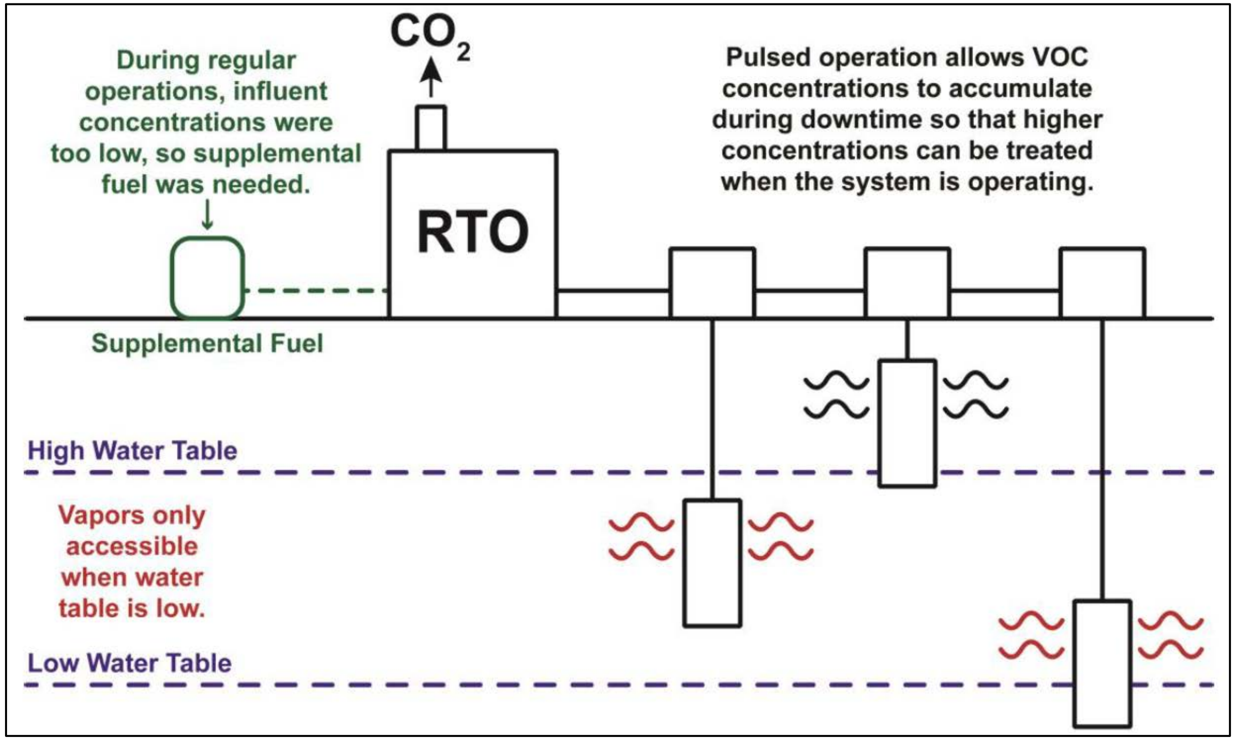


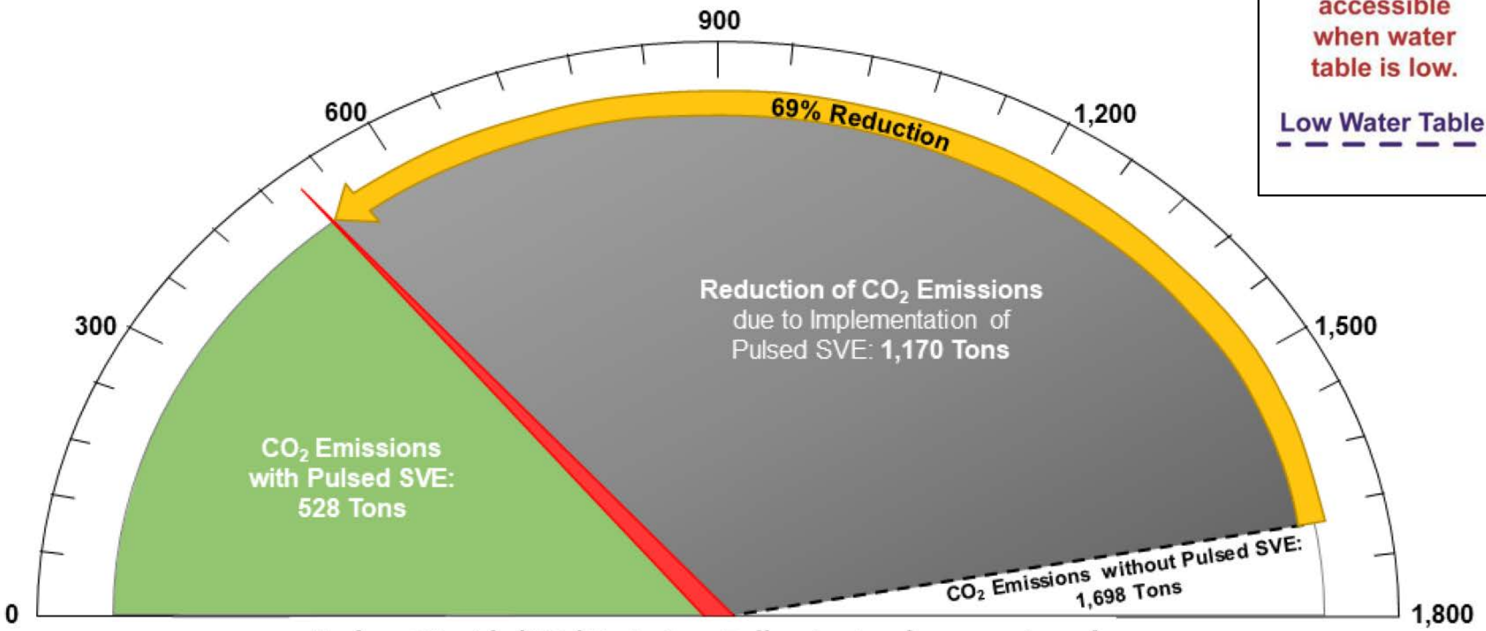
KEY POINT | **surface cover, soil layering can greatly affect air distribution and clean-up times**

Pulsed SVE: A Sustainable Remediation Alternative

- CO_2 emissions (~1 year, 1 site)
  - without pulsed SVE = 1,698 tons CO_2
  - with pulsed SVE = 528 tons CO_2

69% reduction in CO_2 emissions





Carbon Dioxide (CO_2) Emissions Following Implementation of Pulsed Soil Vapor Extraction (SVE)
May 8, 2020 to June 28, 2021

MULTI-PHASE EXTRACTION

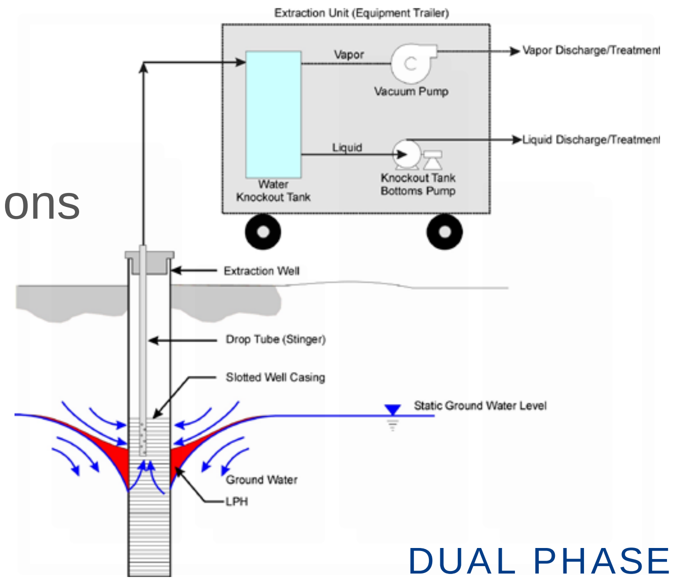
Dual Phase Extraction, Bioslurping, Vacuum Extraction/Groundwater Extraction (VE/GE), Vacuum-Enhanced Recovery or Skimming

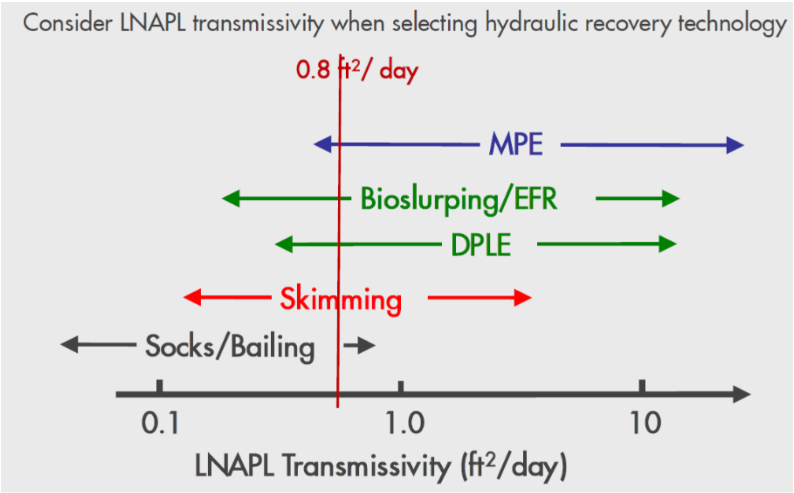
4.0

MPE: General Applications and Observations

GENERAL APPLICATIONS

- submerged LNAPL (dewater)
- relatively thick, lower-permeability formations
- confined LNAPL
- lower-volatility LNAPL
- interim remedy (emergency response)

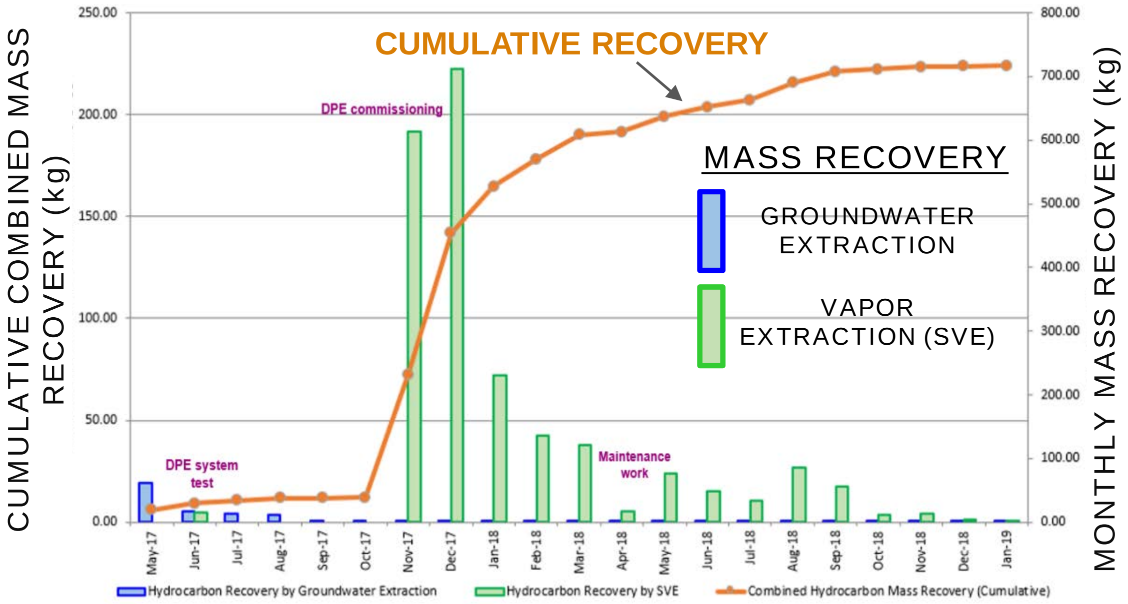




GENERAL OBSERVATIONS

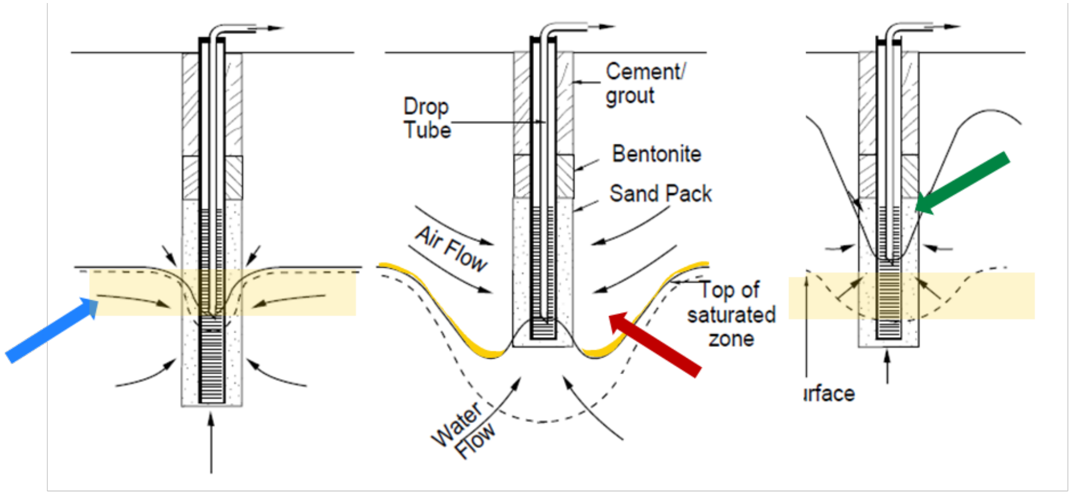
- difficult to operate (stinger/drop tube adjustment)
- relatively costly O&M (instrumentation, uptime, adjustments over time, treatment of multiple fluids, LNAPL/water emulsification in treated liquids w/ single pump configurations)
- most mass loss through vapor extraction - difficult to pull liquids (vs. air w/ SVE) through formations
- liquid removal does not affect risk, only timeline

DUAL PHASE EXTRACTION (DPE) MASS RECOVERY



Design Considerations (MPE): What Can Go Wrong?

- inadequate dewatering – too much or too little
- difficulty in optimizing in real-time (permanent installations)
- inability to pull LNAPL through low permeability formations
- LNAPL recovery can easily diminish once water fills pore space adjacent extraction well (water is the wetting fluid vs. LNAPL)
- noise pollution

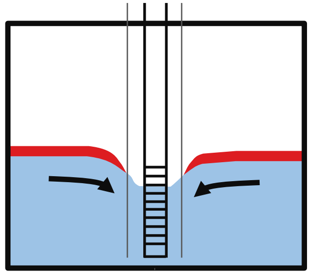


- Permeability too high
- No drawdown
- Too much water extracted

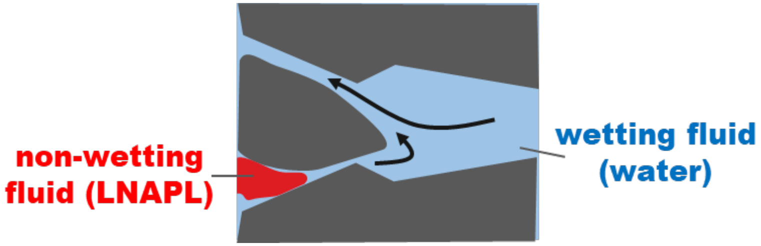
- Good air flow through exposed, impacted soil

- Permeability too low
- No expansion of the vadose
- No soil gas flow

MACRO-SCALE



PORE SCALE



LNAPL arteries can easily be “snapped” or by-passed during extraction making LNAPL recovery difficult

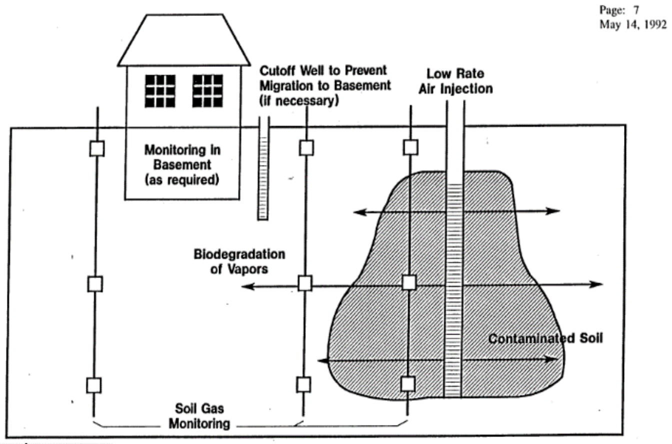
BIOVENTING/BIOSPARGING

5.0

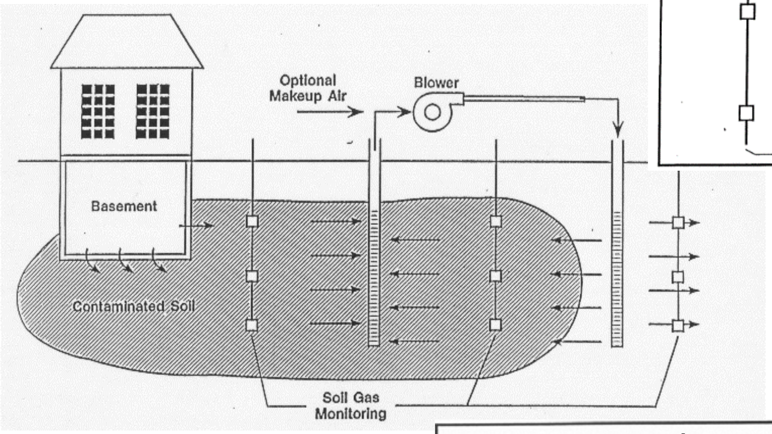
Bioventing/Biosparging

- more sustainable than SVE or AS (O&M, CO_2 footprint – no treatment)
- targets aerobically biodegradable & volatile COCs (e.g., < C_9)
- effectiveness monitoring (other than COCs): pressure, temperature, DO, alkalinity, pH, redox, EC, anions/cations (Fe, S, Mn), soil-gas (O_2, CO_2, CH_4) concentrations
- smaller ROI than AS/SVE (deep sources – ‘ e.g., > 50 ft bgs can be challenging)

Bioventing - Air Injection



Bioventing - Air Extraction

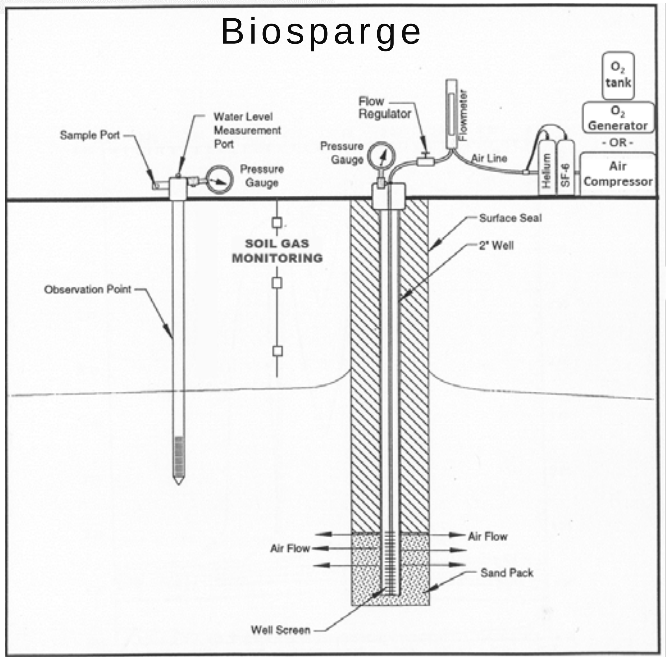


From Hinchee et al. (1992)

Biosparging

- O_2 as alternative to air @ sites w/ high O_2 demand (LNAPL sources)
- injection wells can be clogged by elevated TPH concentrations (e.g., > 50,000 ppm) from biofouling or high (e.g., > 10 mg/L) dissolved Fe^{+2} (precipitation)
- again, pulsing limits channelization (e.g., 1 – 8x/day)

Biosparge



Bioventing/SVE:
In Situ Respirometry Test

- rates of hydrocarbon (C_nH_m – e.g., benzene C_6H_6) degradation are proportional to rates of O_2 utilization and CO_2 production (*assuming conditions in the vadose zone are aerobic*)

$$C_nH_m + (n + 0.25m)\ O_2 \rightarrow n\ CO_2 + (0.5\ m)\ H_2O$$

- assess site specific biodegradation rates by
  - measure O_2, CO_2 before test (test well or soil-gas probes)
  - extract air (bioventing/SVE)
  - shut system off and monitor O_2, CO_2 rebound (test well or soil-gas probes)
  - evaluate biodegradation rates by fitting a line through the data (slope) or applying a simple analytical solution


ISSN 1047-3289 J. Air Waste Manage. Assoc. 42: 1305–1312

A Rapid In Situ Respiration Test for Measuring Aerobic Biodegradation Rates of Hydrocarbons in Soil

Robert E. Hinchee and Say Kee Ong
Battelle
Columbus, Ohio

An in situ test method to measure the aerobic biodegradation rates of hydrocarbons in contaminated soil is presented. The test method provides an initial assessment of bioventing as a remediation technology for hydrocarbon-contaminated soil. The in situ respiration test consists of ventilating the contaminated soil of the unsaturated zone with air and periodically monitoring the depletion of oxygen (O_2) and production of carbon dioxide (CO_2) over time after the air is turned off. The test is simple to implement and generally takes about four to five days to complete. The test was applied at eight hydrocarbon-contaminated sites of different geological and climatic conditions. These sites were contaminated with petroleum products or petroleum fuels, except for two sites where the contaminants were primarily polycyclic aromatic hydrocarbons. Oxygen utilization rates for the eight sites ranged from 0.02 to 0.99 percent O_2/hour. Estimated biodegradation rates ranged from 0.4 to 19 mg/kg of soil/day. These rates were similar to the biodegradation rates obtained from field and pilot studies using mass balance methods. Estimated biodegradation rates based on O_2 utilization were generally more reliable (especially for alkaline soils) than rates based on CO_2 production. CO_2 produced from microbial respiration was probably converted to carbonate under alkaline conditions.

Implications

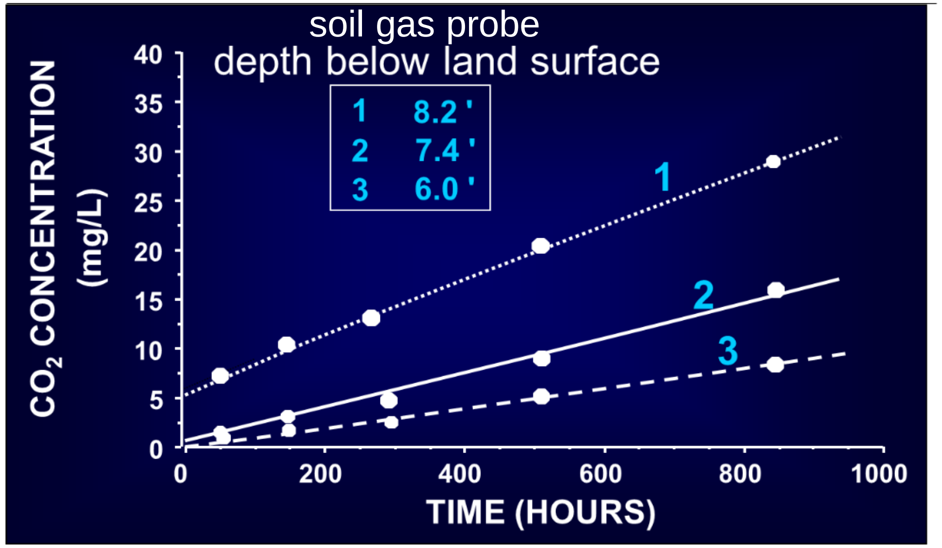
This paper describes a short-term field treatability test that has been developed for application to potential bioventing sites. Bioventing is an emerging technology which is gaining wider application for remediation of petroleum hydrocarbon-contaminated sites. Bioventing was highlighted ...

The U.S. Environmental Protection Agency (EPA) has estimated that about 25 percent of the two million underground storage tank (UST) systems located at 700,000 facilities in the United States may be leaking.[1] Release of chemicals from UST systems has a significant environmental impact on groundwater resources and may also pose a potential risk to human health. Types of chemicals released range from low-molecular-weight, highly volatile organics such as benzene and chlorinated solvents to high-molecular-weight organics with low volatility such as polycyclic aromatic hydrocarbons. Releases may include inorganic contaminants such as heavy metals. Under the Superfund Amendments and Reauthorization Act (SARA) of 1986, EPA and state agencies were given the authority to clean up releases from UST systems or to require owners and operators to do so. In response to this legislative action, several remediation technologies with varying degrees of remedial effectiveness have been developed.

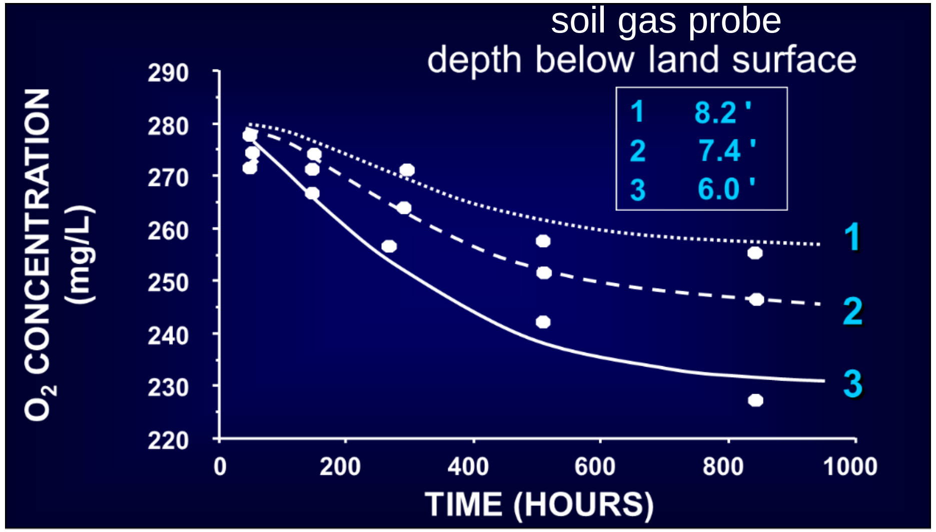
The soil venting technology has been shown to be a cost-effective and simple technique for physical removal of volatile organics in situ from contaminated soil in the unsaturated zone. Soil venting is the process of aerating the subsurface soils to stimulate in situ volatilization of low-molecular-weight compounds. However, in most soil venting remediation treatments, the introduction of a continuous source of oxygen will also promote biodegradation of organic compounds.[2,3] A variation of the soil venting technology is a bioventing technology that seeks to maximize

Hinchee and Ong (1992)

CO_2 Rebound Following SVE



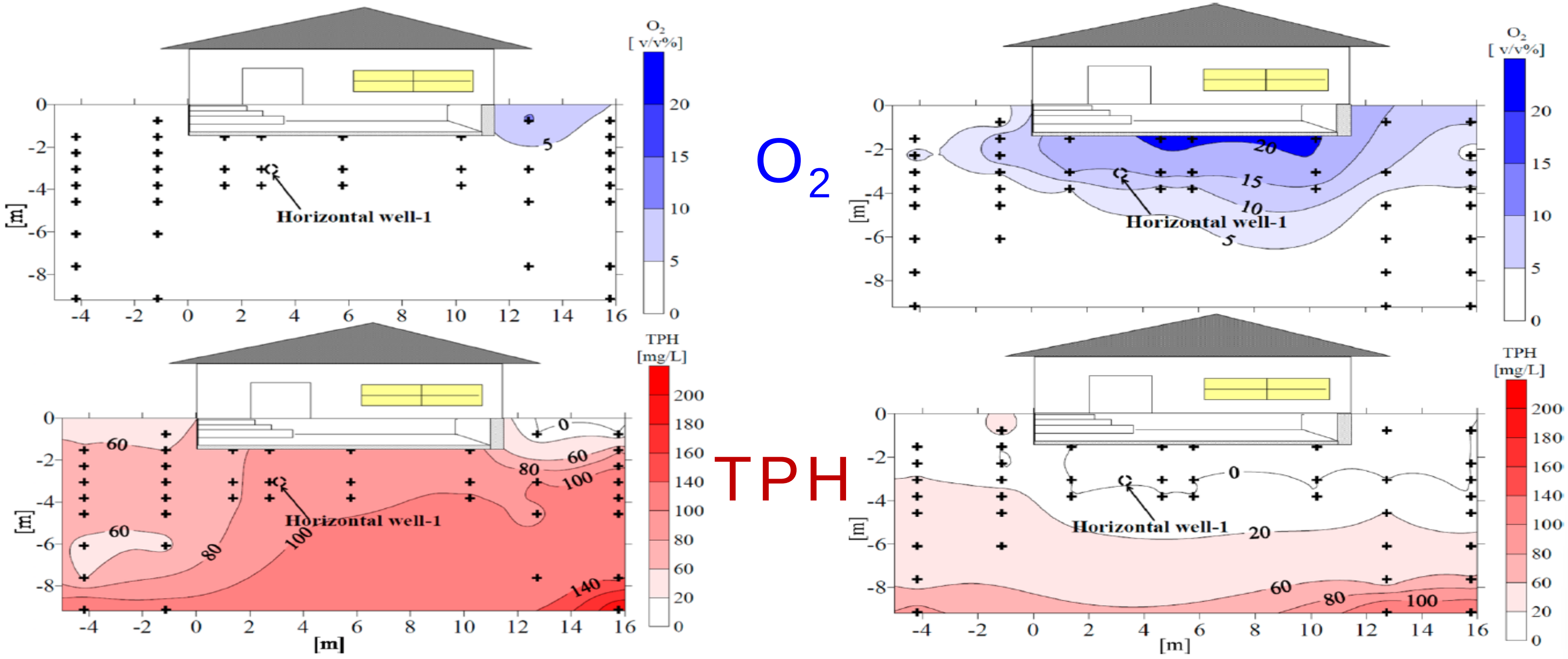
O_2 Rebound Following SVE



Lahvis and Baehr (1996)

Bioventing (Injecting Air):
A PVI Mitigation/Remediation Technology

SOIL-GAS
DISTRIBUTION



PRE – VENTING

Luo et al. (2013)

AFTER 60 DAYS

Aerobic Vapor Migration Barrier (AVMB)

ITRC Technology Information Sheet
Vapor Intrusion Mitigation Team | January 2020

Aerobic Vapor Migration Barrier (AVMB)
Applicability as a method of vapor intrusion mitigation and remediation

This ITRC Technology Information Sheet describes a novel method for vapor intrusion (VI) mitigation involving the delivery of atmospheric (ambient) air around and beneath a building foundation that serves as an aerobic biodegradation barrier preventing hydrocarbon vapor migration from the subsurface to indoor air. The method is relevant for many hydrocarbons of concern for VI that are susceptible to aerobic biodegradation, namely petroleum hydrocarbons. The method can also promote the remediation of shallow subsurface sources. The method is generally a more sustainable, cost effective alternative to other VI mitigation and remediation (e.g., soil-vapor extraction and sub-slab depressurization) because mitigation and remediation occurs in-situ (i.e., the technology does not require expensive off-gas treatment). This Technology Information Sheet is intended to provide basic information to assist the practitioner in VI mitigation decision making.

Overview

Aerobic vapor migration barrier (AVMB) is an in-situ VI mitigation and remediation technology that involves the slow delivery of atmospheric (ambient) air at low pressure below and around a building foundation through either sub-slab vents or horizontal wells installed below the building foundation (see Figure 1). The delivery of ambient air creates elevated oxygen (O_2) conditions in the shallow soil around the foundation that are favorable for aerobic biodegradation. Hydrocarbons that are susceptible to aerobic biodegradation (e.g., petroleum hydrocarbons) are biodegraded before entering the building foundation. The technology can remediate shallow vapor sources and thus serve as a dual remediation and mitigation technology in certain cases. The technology represents a cost-effective alternative to soil vapor extraction (SVE), multi-phase extraction (MPE), and sub-slab depressurization (SSD) and ventilation technologies that can involve expensive off-gas treatment and intrinsically safe equipment for certain (e.g., petroleum) hydrocarbons. The technology is described in greater detail in Luo et al. (2013).

Figure 1. Conceptualization of an Aerobic Vapor Mitigation Barrier.

Design Considerations

Conceptually, AVMB involves the injection of ambient air (O_2) below and around a building foundation to create and maintain an aerobic biodegradation barrier that prevents certain reactive (e.g., petroleum) hydrocarbons from migrating to indoor air. The technology is also applicable in mitigating acute VI issues related to methane (i.e., flammability). The aerobic biodegradation of most petroleum hydrocarbons of concern for VI (and methane) has been well documented. Such hydrocarbons generally biodegrade aerobically in the subsurface at rates that exceed rates of

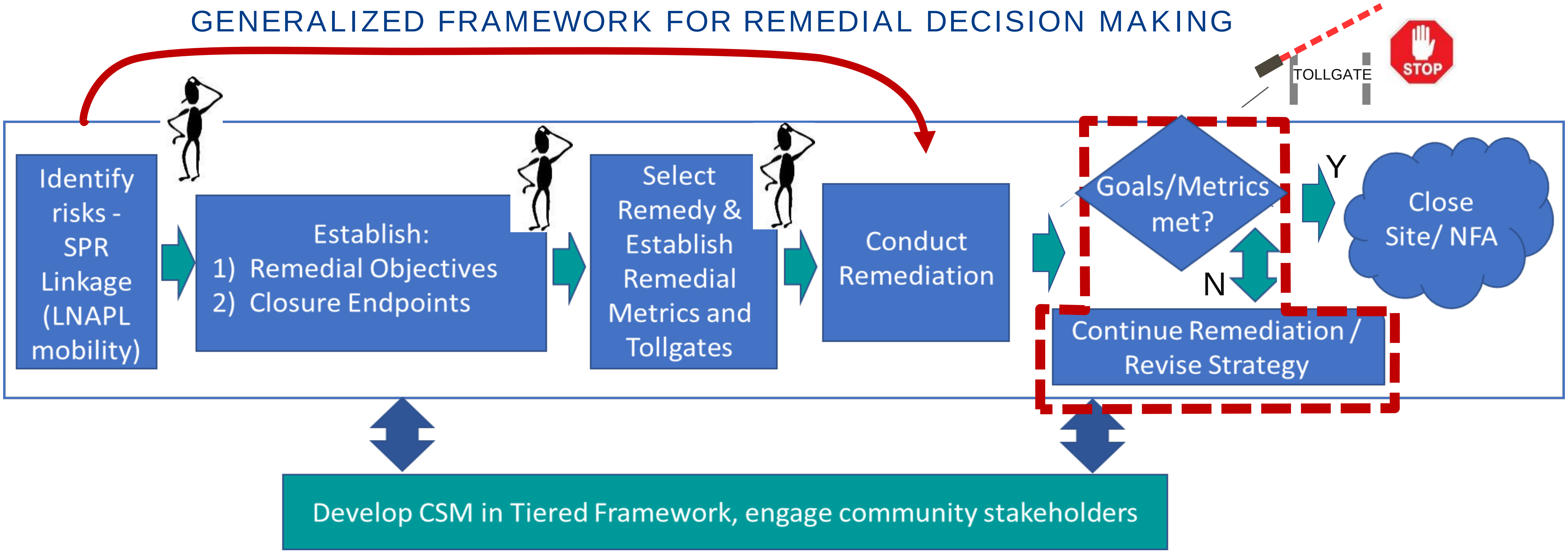
Regulatory Acceptance for New Solutions
Documents, free Internet-based training, contact information: *www.itrcweb.org*

https://vim-1.itrcweb.org/aerobic-vapor-mitigation-barrier-avmb-tech-sheet/

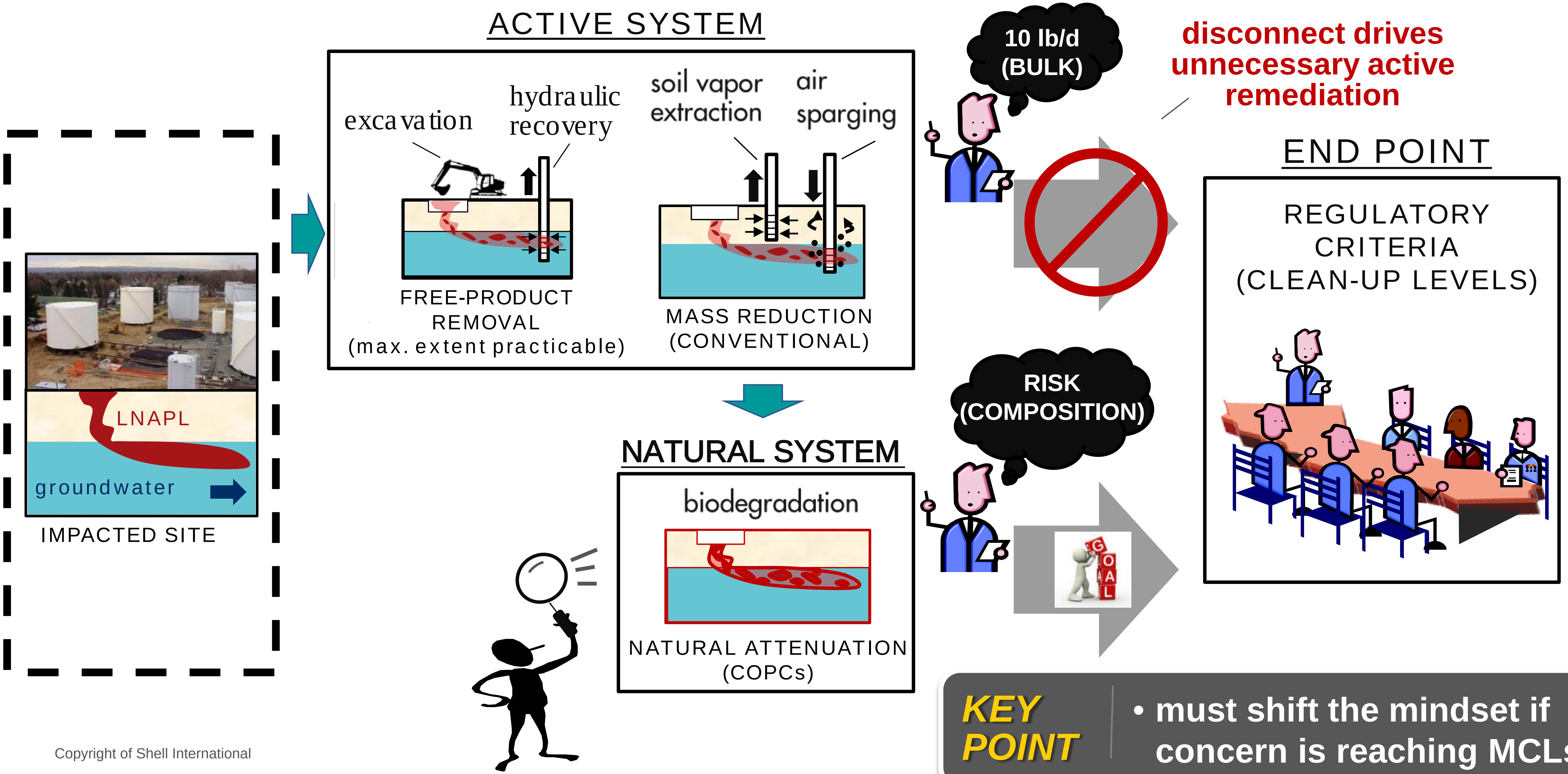
“GETTING TO CLOSURE”… MORE CONFIDENTENTLY, MORE SUSTAINABLY

6.0

Case for Change:
Improving Remedial Decision Making



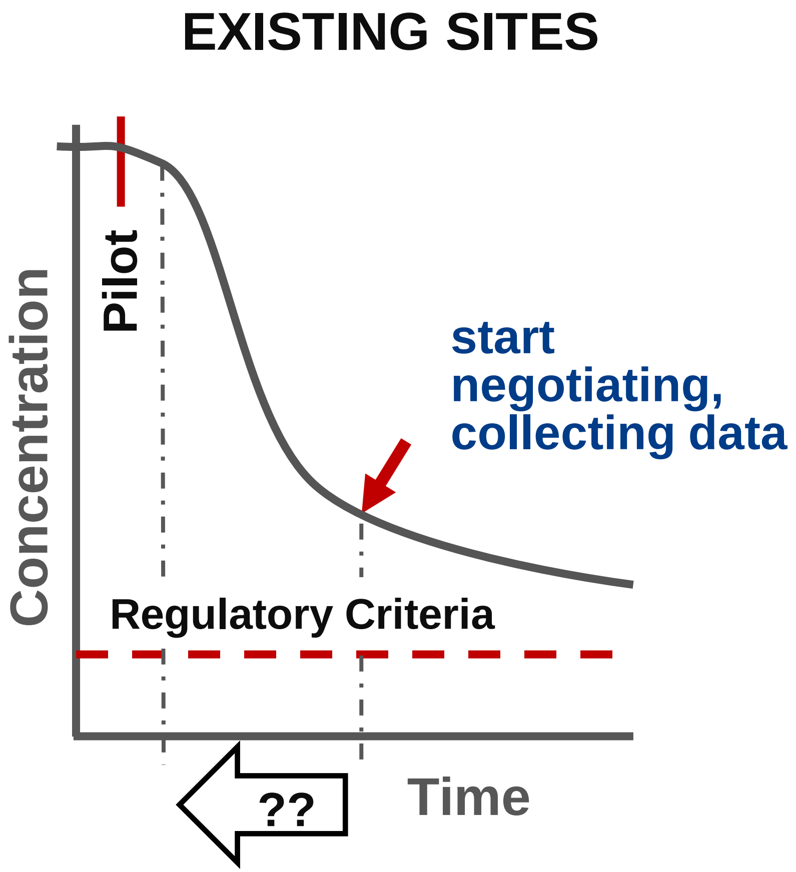
Case for Change: Poorly Defined Remedial Concerns

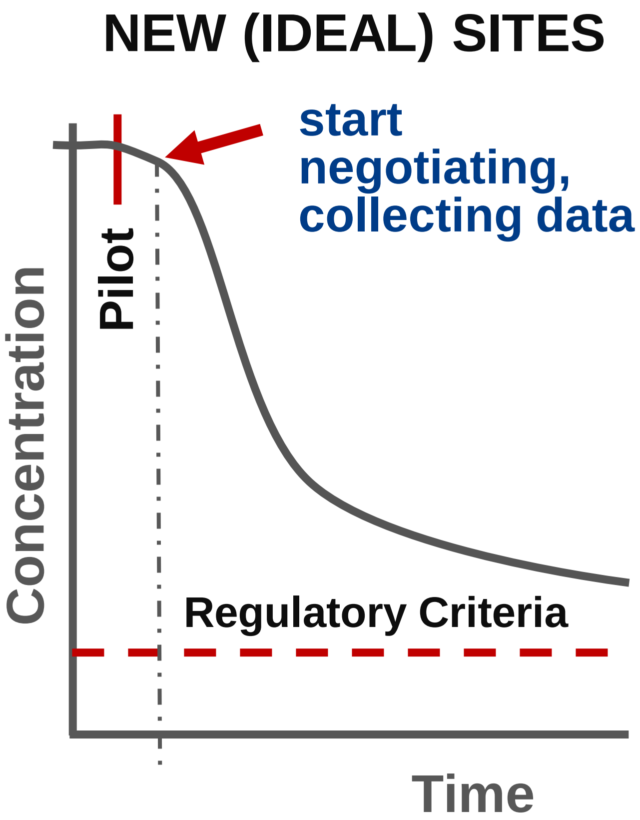


KEY POINT

- **must shift the mindset if concern is reaching MCLs**

Case for Change: No Alignment Upfront on Key Metrics/Tollgates, Knowing What Data to Collect … When

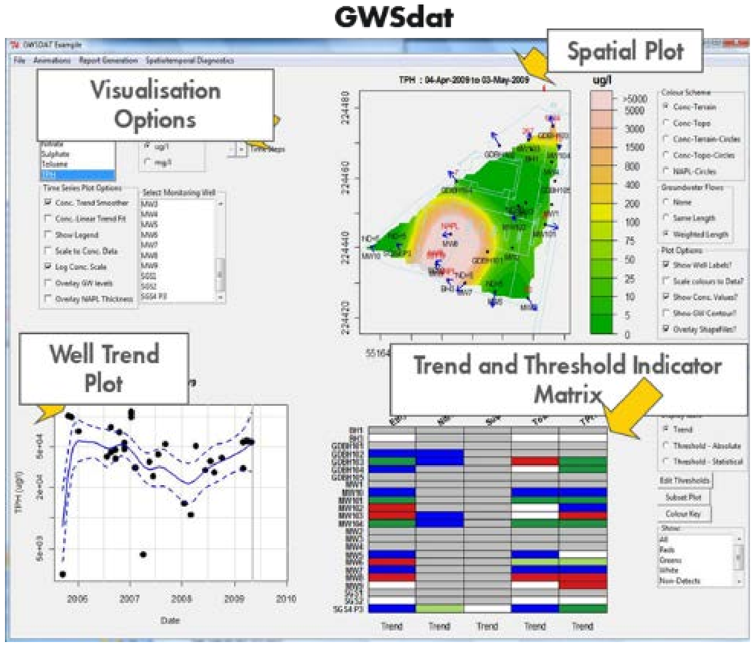




"Exit Strategy" Toolkits:

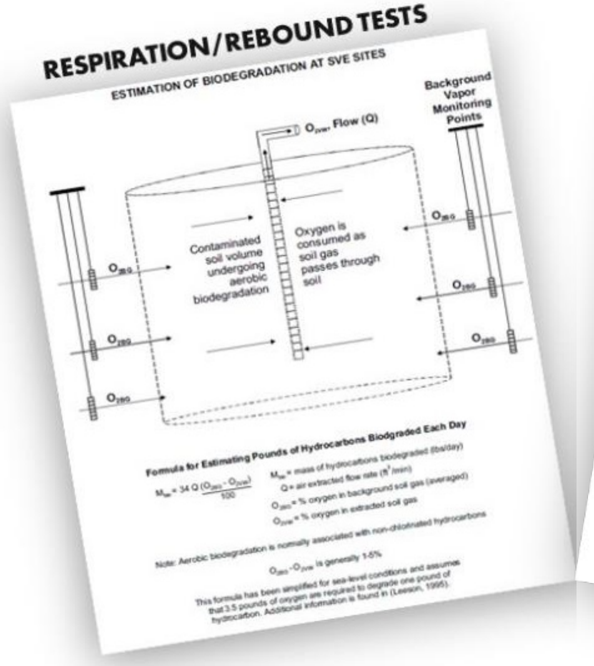
"Getting to Closure" More Efficiently

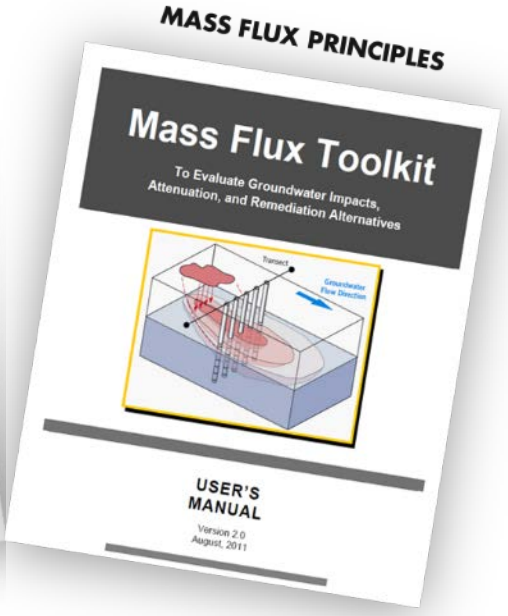
- **<u>ISSUE:</u> active remediation poorly optimized or operated beyond beneficial life (risk reduction/sustainability)**
  - limited upfront agreement on
    - remedial objectives
    - <u>performance metrics</u> (data collection needs, analyses, metrics, tollgates)
    - <u>transition thresholds</u>
  - missed opportunities to collect key data (no documentation of <u>baseline condition</u> – e.g., natural attenuation rates)
  - limited use of available tools
  - practical guidance is lacking



GWSdat - http://gwsdat.net/home/

- **<u>GOAL:</u>**
  - ✓ systematic MLE approach to initiating/ evaluating / terminating active remediation
  - ✓ optimized (less "unnecessary) active remediation
  - ✓ more confident remedial decision making
  - ✓ more successful stakeholder communication





https://clu-in.org/download/contaminantfocus/ER-0430-MassFluxToolkit.pdf

"Exit Strategy" Toolkits:
Getting to "Closure" More Efficiently

Technology Specific Factsheets:

- Compendium (general framework)
- SVE
- Bioventing
- LNAPL Hydraulic Recovery
- Natural Attenuation / Natural Source Zone Depletion (NSZD)

Format:

- generally short (4 – 8 pages)
- illustrative (plots, tables, figures)
- links to further information
- highlight data collection/analyses (not a checklist)
- post CSM (remedial decision making)

What's Different (Key Elements):

- **baseline** natural attenuation rate / NSZD assessment
- **performance metrics**
- **transition thresholds**
- **validation criteria**
- multiple lines of evidence (MLE)
- sustainability focused (technical, economic, social)

HERS Environmental Consulting, Inc.

ARIS

Shell

SOIL VAPOR EXTRACTION (SVE) FACTSHEET

This factsheet provides information to support remedial decision-making on soil vapor extraction (SVE). The information is intended to help:

a) optimize SVE remediation performance, and
b) transition from SVE to natural attenuation, passive remediation, or "no further action".

This factsheet should be read in conjunction with the overarching Compendium document providing the broader context on tools and methods to support remedial decision making.

This factsheet is not intended to provide detailed guidance on SVE and assumes that a sufficiently detailed conceptual site model (CSM) has been developed and SVE has been selected as an appropriate technology to meet agreed remedial concerns and objectives (Appendix I and Appendix II). Additional details on SVE design and implementation can be found in USACE (2002), US EPA (1991), US EPA (1994), US EPA (1997), US EPA (2006), CA EPA DTSC (2010), US EPA (2017) and US EPA (2018).

SVE - Technology Summary

SVE is a remedial technology capable of addressing both composition-based concerns for soil vapor plumes and bulk mass reduction for residually impacted soil, but generally is not effective in addressing saturation-based concerns (as defined in the accompanying Compendium document) unless implemented in conjunction with multi-phase extraction. The technology is implemented by inducing controlled air flow through pumping, which enhances volatilization and removal of volatile constituents in light non-aqueous phase liquid (LNAPL) and petroleum hydrocarbon contamination in the unsaturated zone. Because higher volatility VOCs are removed at higher rates, SVE targets remediation of lighter molecular weight contaminants of concern (COCs), including risk-drivers such as benzene. Additionally, SVE stimulates hydrocarbon mass recovery via vadose zone bioremediation (see Bioventing Factsheet). SVE is often implemented in conjunction with air sparging to capture hydrocarbon vapors liberated from impacted groundwater.

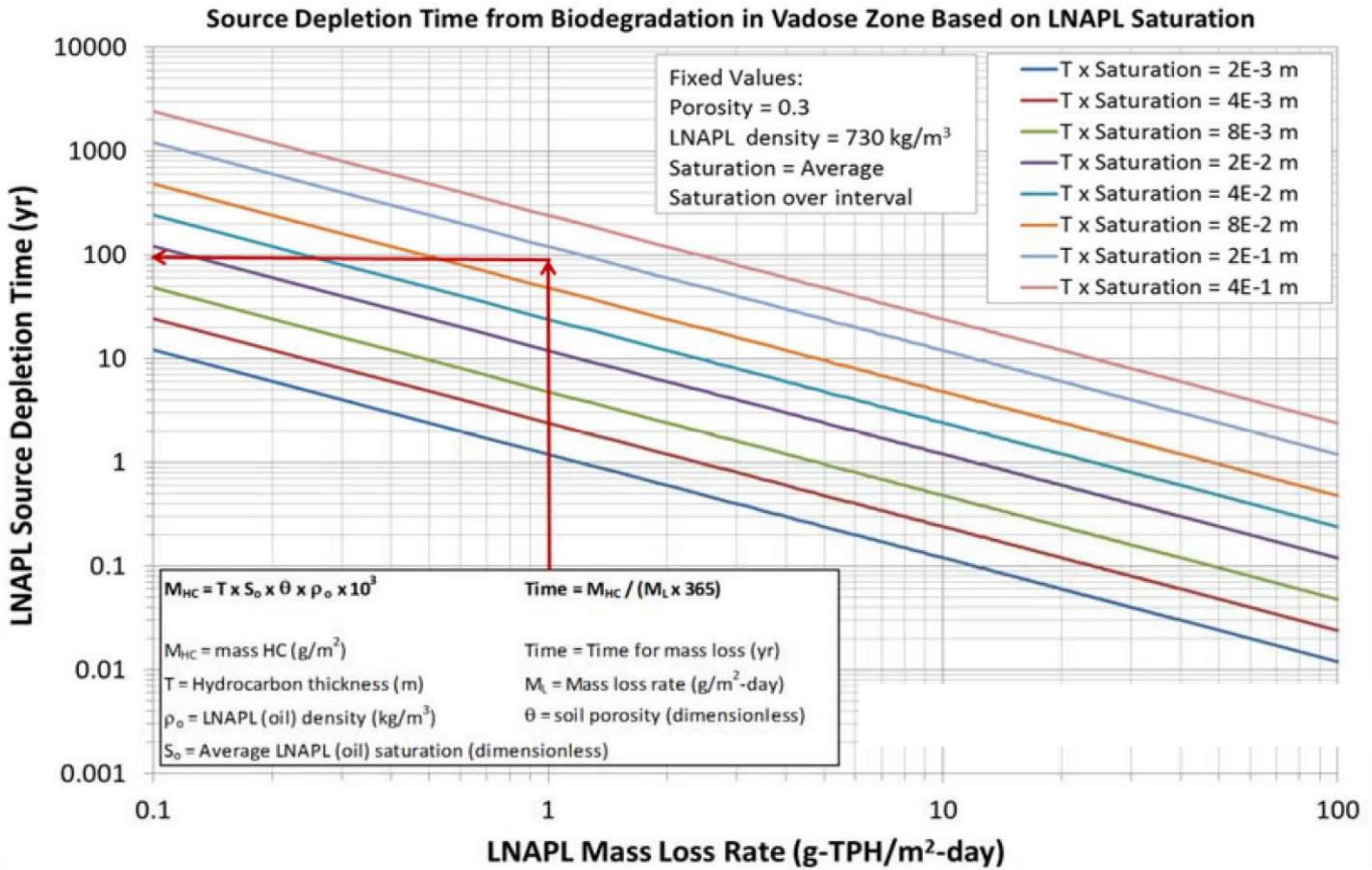
The rate of phase change and mass removal from SVE typically decreases during the treatment life cycle. During early stages of remediation, the primary mass removal is from air pathways of low resistance (higher permeability soils), where adsorbed chemicals or non-aqueous phase liquids (NAPL) partition into the moving air. When the mass in higher permeability or lower moisture content soils becomes mostly depleted, the rate of mass removal may approach a lower asymptotic limit. Additional information on SVE technology is provided in Appendix I.

Remedial Concerns and Objectives

The broader considerations for establishing remedial objectives and criteria include the potential concern and liability/risk associated with site sensitivity and receptor considerations, regulatory requirements, site development drivers, sustainability, and economic factors. The remedy objectives and criteria should incorporate the notion of technical practicability.

Typical remedial objectives associated with SVE applications are either to reduce COC concentrations below a risk-based threshold at a point of compliance (e.g., groundwater monitoring well or soil vapor probe), or to achieve risk-based mass discharge or mass loading levels. Caution should be used when defining COC-specific criteria based on mass recovery rates of total petroleum hydrocarbons (e.g., x kg/day) as such criteria are generally a function of site lithology and are poorly correlated with risk-based compositional objectives based on specific COCs. Remedial objectives may also include target timelines to achieve the objectives.

Baseline Assessment:
NSZD Measurements – Predicting Time for Source Depletion



- requires initial mass/concentration estimate and extrapolation of measured attenuation rates (challenging)
- can predict using a model
- current options for dissolved phase:
  - Source DK[1]
  - US EPA RemFUEL[2]
  - uncertainty in source discharge model and source zone biodegradation
  - likely underpredicts attenuation when significant anaerobic biodegradation is occurring

order of magnitude estimates

[1] https://www.gsienv.com/product/natural-attenuation-tool/

[2] https://www.epa.gov/water-research/remediation-evaluation-model-fuel-hydrocarbons-remfuel

Performance Metrics (SVE): Saturation-Based Concern (Subsurface Metrics)

Table 2. Performance Metrics for Saturation-Based Concern

Metric	Methods	Relative Cost	References/Tools
SUBSURFACE METRICS			
LNAPL transmissivity	Bail-down or skimming test Oil-water ratio Other methods	Low to moderate	ITRC LNAPL Guidance (2018) ASTM E2856-13 API Transmissivity Guide
LNAPL footprint (presence/absence in wells)	Time-series measurements in perimeter wells	Low	ITRC LNAPL Guidance (2018)
LNAPL thickness in wells	Time-series measurements in LNAPL body wells	Low	ITRC LNAPL Guidance (2018)
Mobile LNAPL	Compare actual to residual LNAPL saturation; estimated from vertical equilibrium (VEQ) model or lab measurements)	Moderate to high	API LDRM ITRC LNAPL Guidance
LNAPL saturation profile	Estimate from saturation in soil samples or estimate from TPH and/or Estimated from VEQ model during or after system operation	Moderate to high	ITRC LNAPL Guidance (2018)
LNAPL velocity	Estimate from transmissivity or VEQ model	Moderate to high	API Interactive Guide API LDRM
NSZD rate (bulk)	Unsaturated zone biodegradation rate (CO_2 efflux, soil gas gradient, temperature methods)	Low to high	Natural Attenuation – Overview and related Factsheets
LNAPL movement in sediment (aquatic environment)	Metrics for advective NAPL movement: measurements to assess pore scale mobility; and/or evaluate migration	Low to high	ASTM E3282 Reyenga (2021)
Subsurface rebound test	Turn system off temporarily and monitor response (e.g., LNAPL thickness in wells, transmissivity)	Moderate to high	See Compendium Factsheets ITRC LNAPL Guidance CRC Care 2015
Geochemical parameters (e.g. O_2, CH_4) indicative of natural attenuation	Soil gas and/or groundwater sampling and analysis	Low to moderate	Remediation Toolkits[2] ITRC LNAPL Guidance (2018)

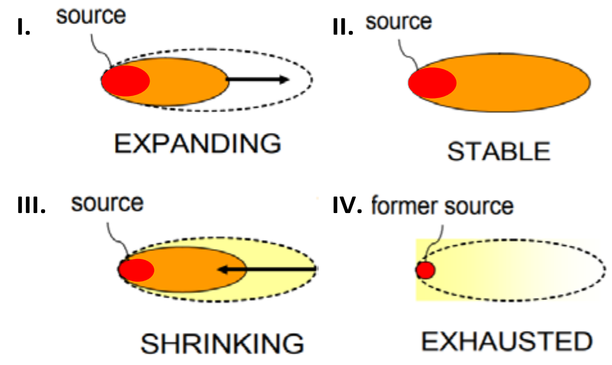
Transition Thresholds: Examples

KEY
S = Saturation-based
C = Composition-based

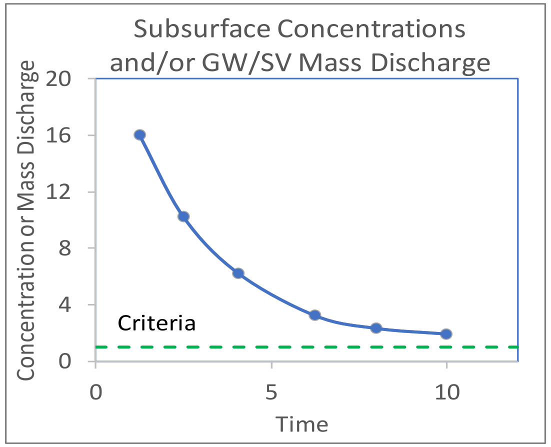
- ✓ recovery of 95% of LNAPL based on decline curve analysis (S)
- ✓ LNAPL transmissivity below ITRC (2018) threshold of 0.1 to 0.8 ft^2/day (S)
- ✓ concentrations or mass discharge at or approaching criteria within accepted statistical certainty (C)
- ✓ active mass recovery rates similar to or less than NSZD or natural attenuation rates (S) (C)
- ✓ ratio of GHG emissions per unit reduction in mass or concentration is rapidly increasing (S) (C)
- ✓ ratio of costs per unit reduction in mass or concentration is rapidly increasing (S) (C)

multiple lines of evidence are used to increase confidence in transition to alternative remediation or monitored natural attenuation

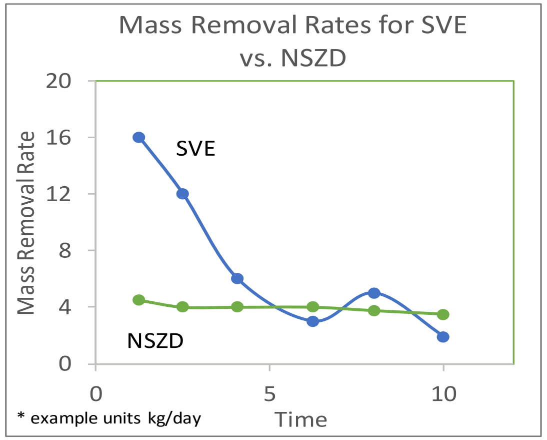
Transition Thresholds: Examples



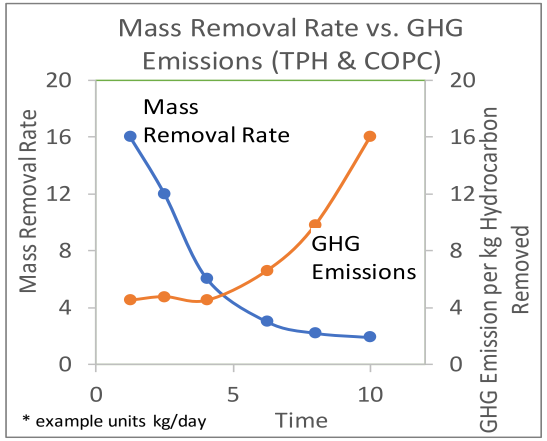
T1. Groundwater Plume is Stable or Shrinking (see Toolkit 2)



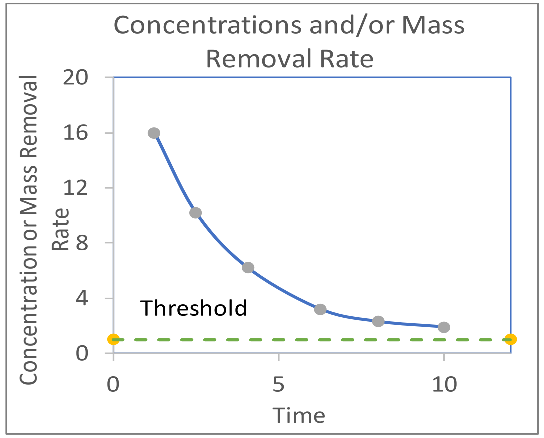
T2. Concentration/Mass Flux Approaching Asymptote or Criteria (see Toolkit 2)



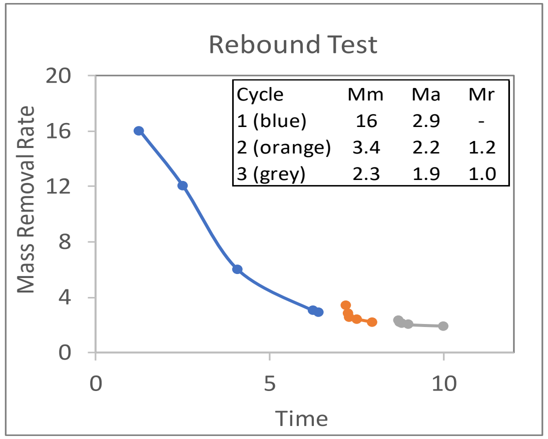
T5. Active Mass Removal Rate Approaching or is Less than NSZD Rate (see this Compendium)



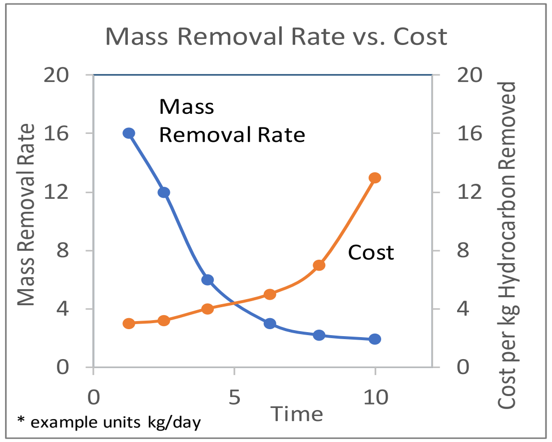
T6. Normalized GHC Emissions (or other metric) Increasing with Little Benefit from Continued Operation (see Toolkit 4)



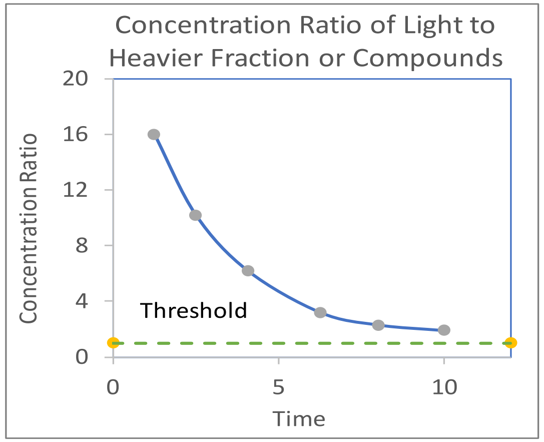
T3. Extracted Soil Gas Concentration/ Mass Removal Rate Approaching Asymptote or Risk-based Threshold (see Toolkit 2)



T4. Acceptable Mass Discharge and Mass Removal Rate (see this Compendium - - Appendix III)

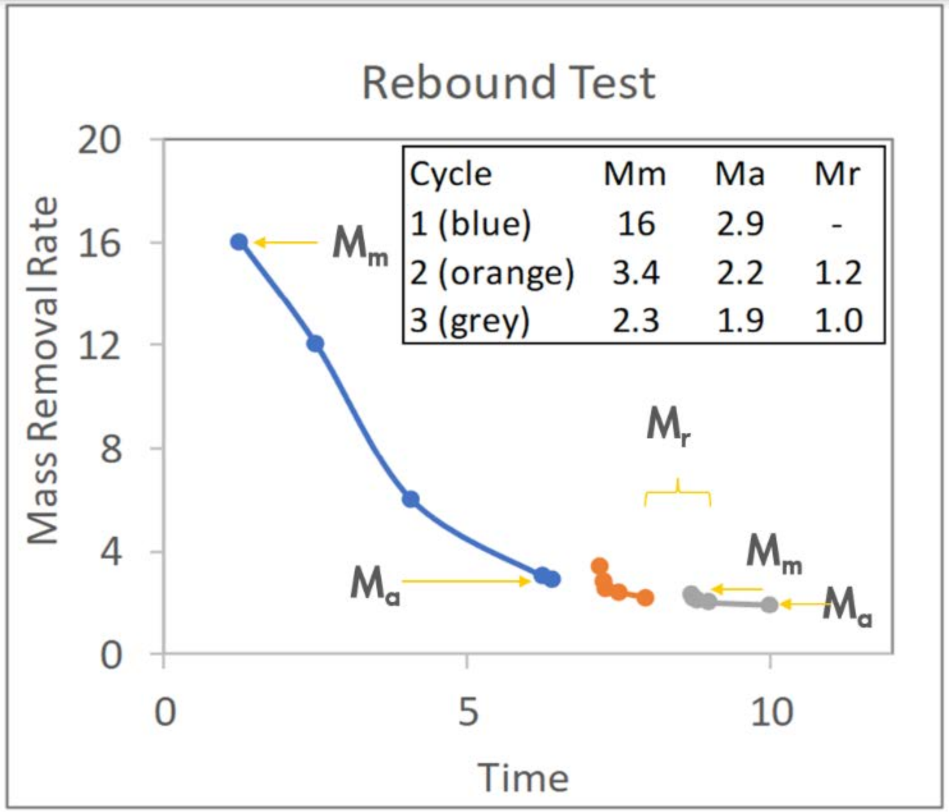


T7. Normalized Cost Increasing with Little Benefit from Continued Operation (see Toolkit 4)



T8. Concentration Ratio Approaching Asymptote or Risk-based Threshold (this Compendium)

Validation: Rebound Testing



Simple models (Brusseau et al. 2010; Truex et al. 2013)

- 1st pore volume of mass that is removed after system restart:

$$M_{pv} = \sum_{i=1}^{n} (C_i - C_a) Q_i \Delta T_i$$

M_{pv} = mass removed 1st pore volume after start up; C_i = conc. system turned on; C_a = conc. at end of previous cycle; ΔT_i = time 1 pore volume; T = rebound period

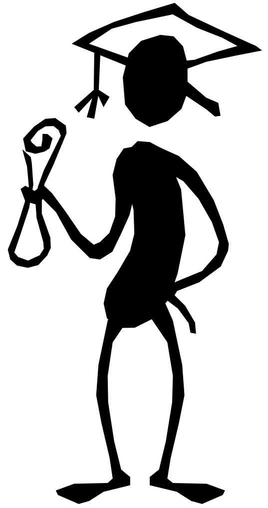
- average mass during rebound (M_r) often occurs from low permeability zones: $M_{rF} = \frac{M_{pv}}{T}$, where T = rebound period
- convergence in rebound flux M_r (diffusive) with active flux M_a suggests approaching end of operational life

More complex models:

- "SVEET" quantifies mass discharge and impact of remaining vadose zone contaminant sources on groundwater https://bioprocess.pnnl.gov/SVEET_Request.htm
- "VIETUS" quantifies mass discharge on soil vapour intrusion into building https://bioprocess.pnnl.gov/VIETUS_Request.htm

Key Take Aways

- air-based remediation (SVE, MPE, AS) preferred for petroleum hydrocarbon remediation (risk reduction/attenuation rate standpoint)
- biosparging/bioventing are generally underutilized – potential sustainable alternatives to end-of-life, underperforming engineered systems (SVE, AS, MPE)



- we can do better w/ respect to operating air-phase (or any) remediation systems more sustainably & improving remedial decision making
  - aligning on remedial concerns and goals
  - aligning on baseline, performance, transition, and validation metrics (and associated data needs, tollgates)
  - incorporating the natural assimilative capacity into remedial paradigm
  - taking advantage of the myriad of tools available

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Questions and Answers

Q&A

Thank You, Speakers!

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Thank you for your participation!