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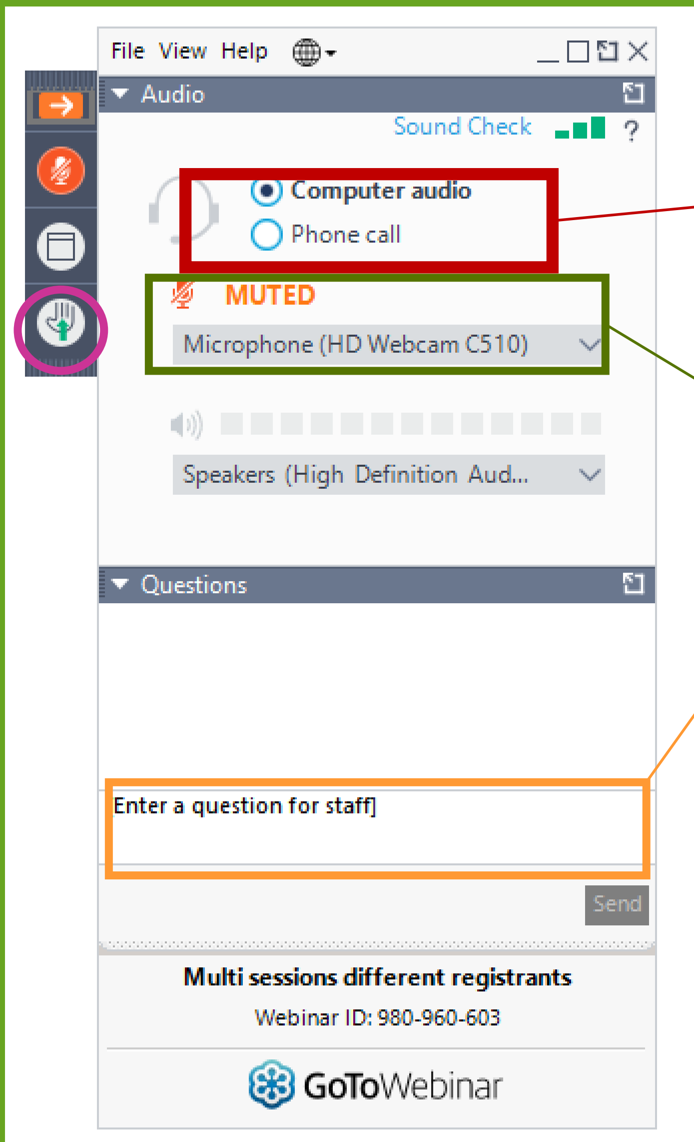

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NE IW PCC

EVALUATING REMEDIATION WORKPLANS

Welcome to NEIWPCC's addition in the LUST Corrective Action Webinar Series

6/8/2020

TODAY'S SPEAKERS

Tom Fox, Environmental Protection Specialist | *Colorado Division of Oil & Public Safety*

Bill Brasher, Water Resource Control Engineer | *California State Water Resources Control Board*

TRAINING OVERVIEW

- Background/References
- Overview of LNAPL CSM
- Remedy Selection
- Performance Metrics and Milestones
- Tips for Common LNAPL Technologies, including
  1. Multi-Phase Extraction
  2. Air Sparging and Soil Vapor Extraction
  3. Injection Technologies
  4. Natural Source Zone Depletion

Framing the Discussion

For today's discussion, we'll focus on the following parameters:

- Underground Storage Tank (UST) Releases
- Fuel Hydrocarbons (i.e., LNAPLs)
    - Gasoline, specifically
- Groundwater impacts
- Oxygenates may or may not be present

References and Resources

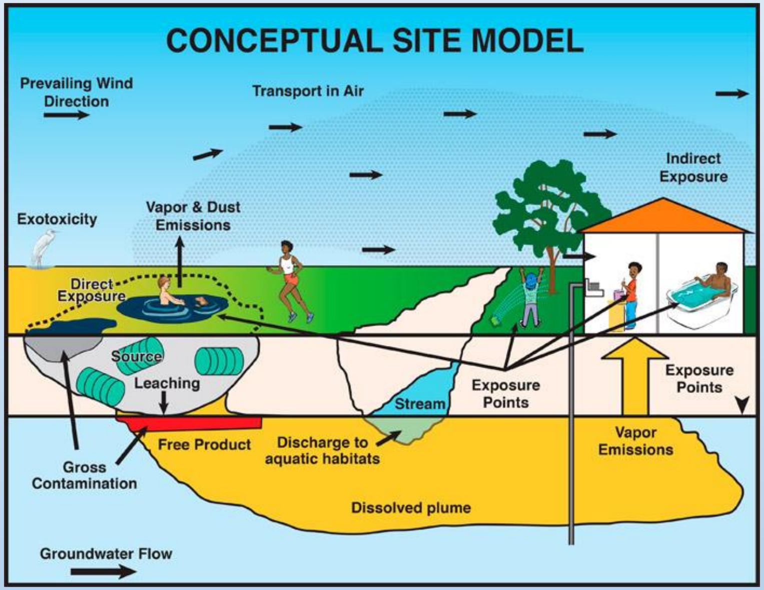
- LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (ITRC 2018)
- Remediation Management of Complex Sites (ITRC 2017)
- How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers (USEPA 2017 update)
- Others, as noted

Regulatory Over-Reach?

- Many states prohibit regulatory agencies from specifying means and methods that a responsible party may use to achieve compliance with cleanup requirements
  - Most do NOT prohibit “suggesting” methods, nor keep the agency from requesting the RP provide adequate basis for their proposal
- Caseworkers should exercise their right to disapprove a remediation proposal if they don’t believe it will be effective, believe another remedy is more appropriate, or simply don’t have enough information to determine efficacy of the proposed remedy.
  - Guide the RP’s representative to gather sufficient basis for remedy being proposed.
  - Remediation proposals may not meet the objectives, but the designer should have enough data to predict the reasonable success of a remediation plan.

Conceptual Site Model

- In California, one of the general criteria for closure under the Low-Threat UST Case Closure Policy is an adequate Conceptual Site Model
  - “A conceptual site model that assesses the nature, extent, and mobility of the release has been developed”
- The word “adequate” is not used in the Policy
  - Used here to underscore the CSM doesn’t necessarily need to be complete to make a remediation decision
- For remediation decision-making, strike a balance between over-investigating and jumping the gun on remediation
  - Need an intermediate point at which investigation may continue, but enough data is available to make an informed decision on remediation



TPH Risk Evaluation at Petroleum-Contaminated Sites (ITRC, 2018)

California State Water Resources Control Board (2012). “Low-Threat Underground Storage Tank Case Closure Policy”.

CSM Terms

"Conceptual Site Model" (CSM): All information known about a site. Site conceptual model (SCM) is another term meaning the same thing.

"LNAPL Conceptual Site Model" (LCSM): All information known about LNAPL at a site.

"Remediation Conceptual Site Model" (RCSM): All information relevant to remediation at a site.

Note: A CSM includes the LCSM and RCSM. So, use of the term LCSM or RCSM is not necessary as long as LNAPL and remediation information are included in the CSM. For the purposes of this seminar, LCSM and RCSM will be considered the same. LCSM will be used going forward.

Why an LCSM?

- Contamination from UST releases has four phases
  1. LNAPL (aka free product)
  2. Dissolved (Groundwater)
  3. Adsorbed (Soil)
  4. Vapor (Soil Gas)
- However, from a risk management standpoint, LNAPL removal is typically all the active remediation necessary
- Recognize the biodegradable nature of petroleum hydrocarbons
  - Residual contamination will not migrate or expand and will continue to degrade naturally

LNAPL Characteristics

LNAPL is problematic at petroleum sites because:

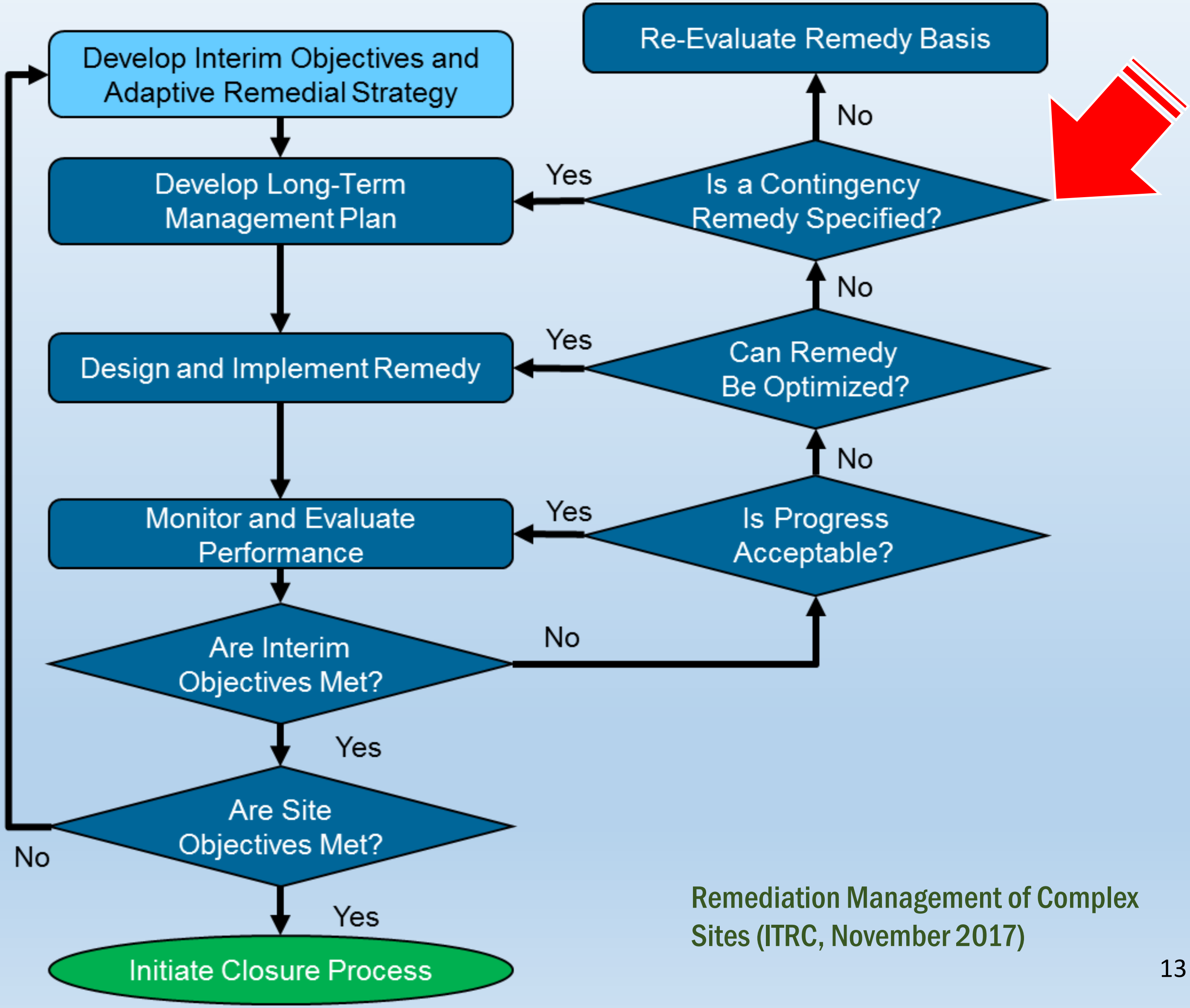
- LNAPL represents the vast majority of the mass of contamination in the subsurface
- LNAPL presents a risk for vapor intrusion into buildings
- LNAPL contacting groundwater maximizes dissolved concentrations (e.g., effective solubility at LNAPL-water interface)
- LNAPL may sustain groundwater plume for extended periods regardless of groundwater remediation efforts

Goals of LCSM

- Understand the nature, extent, and mobility of the contaminants that have been released
- Identify all receptors and understand the potential risk to each (pathways of exposure)
- Define remediation goals and objectives based on local regulations
- **Most important to remediation**: Define the extent of the LNAPL body laterally and vertically. This is essential to the success of any remediation.

- Interim remediation should only be deployed prior to achieving these goals where there is known threat to a receptor.

Adaptive Site Management



Remediation Management of Complex Sites (ITRC, November 2017)

21 Technology "Tools"

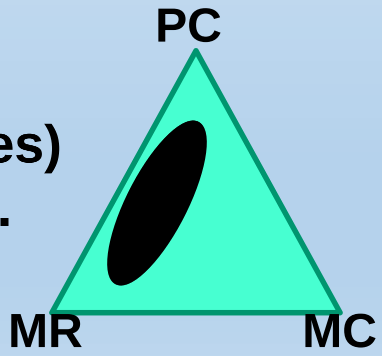
1. Excavation
2. Skimming
3. Vacuum enhanced skimming (LNAPL & vapor)
4. Total liquid extraction (LNAPL & water)
5. Multi-phase extraction (LNAPL, water, & vapor)
6. Water/hot water flooding
7. Surfactant-enhanced subsurface remediation
8. Cosolvent flushing
9. Steam injection
10. Electrical resistance heating
11. Air sparging/soil vapor extraction (AS/SVE)
12. In-situ chemical oxidation
13. Natural source zone depletion (NSZD)
14. Physical or hydraulic containment
15. In-situ soil mixing (stabilization)
16. Thermal conduction heating
17. In-situ smoldering
18. Biosparging/bioventing
19. Enhanced anaerobic biodegradation
20. Activated carbon
21. Phytotechnology

LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (ITRC, March 2018)

LNAPL Remedial Technology Groups

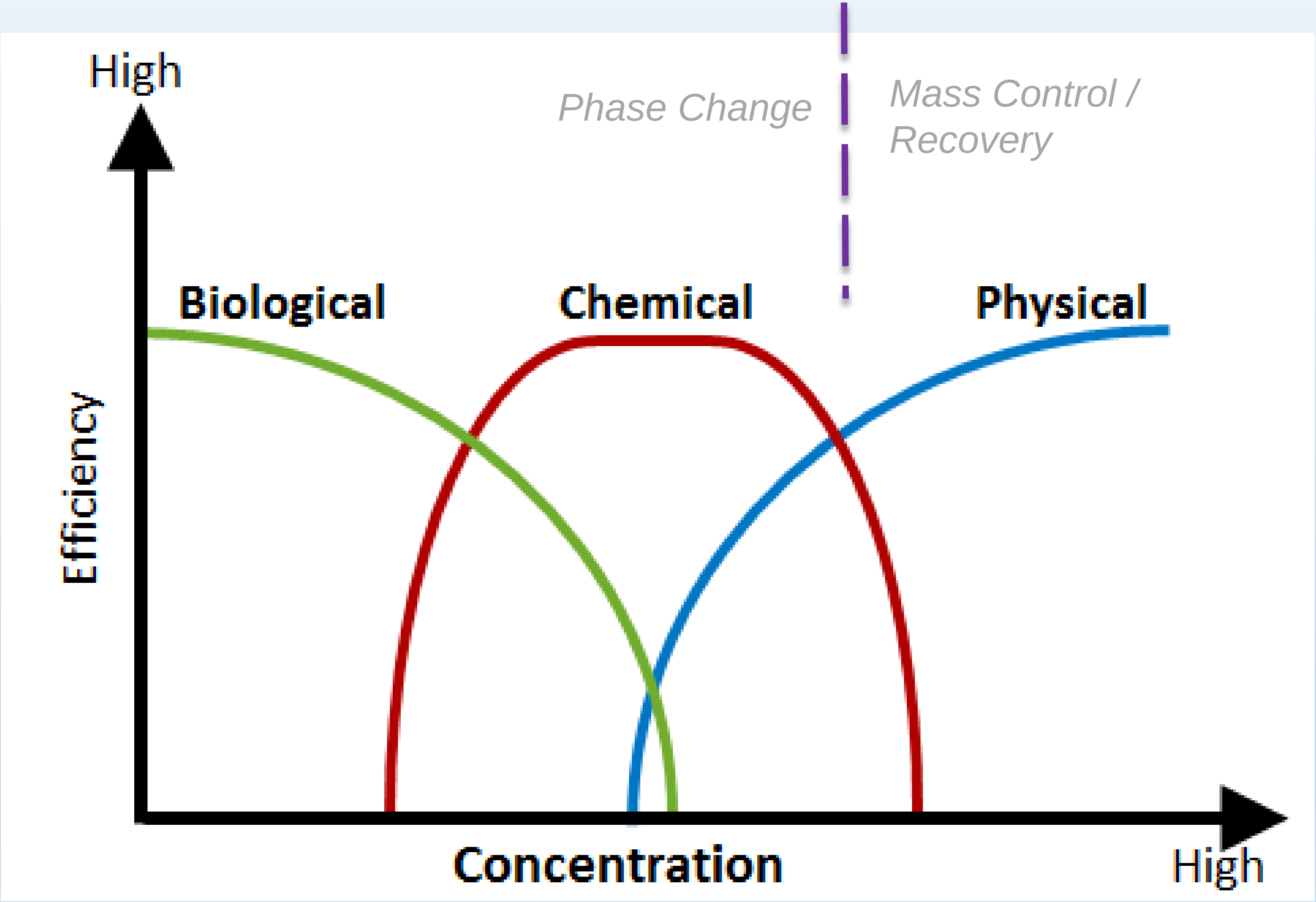
- **Mass Control** - **Contain LNAPL at a defined boundary**
- **Mass Recovery** - **Remove LNAPL mass to limit migration**
- **Phase Change** - **Abate unacceptable COCs**

Technologies (i.e. processes) sometimes overlap groups.



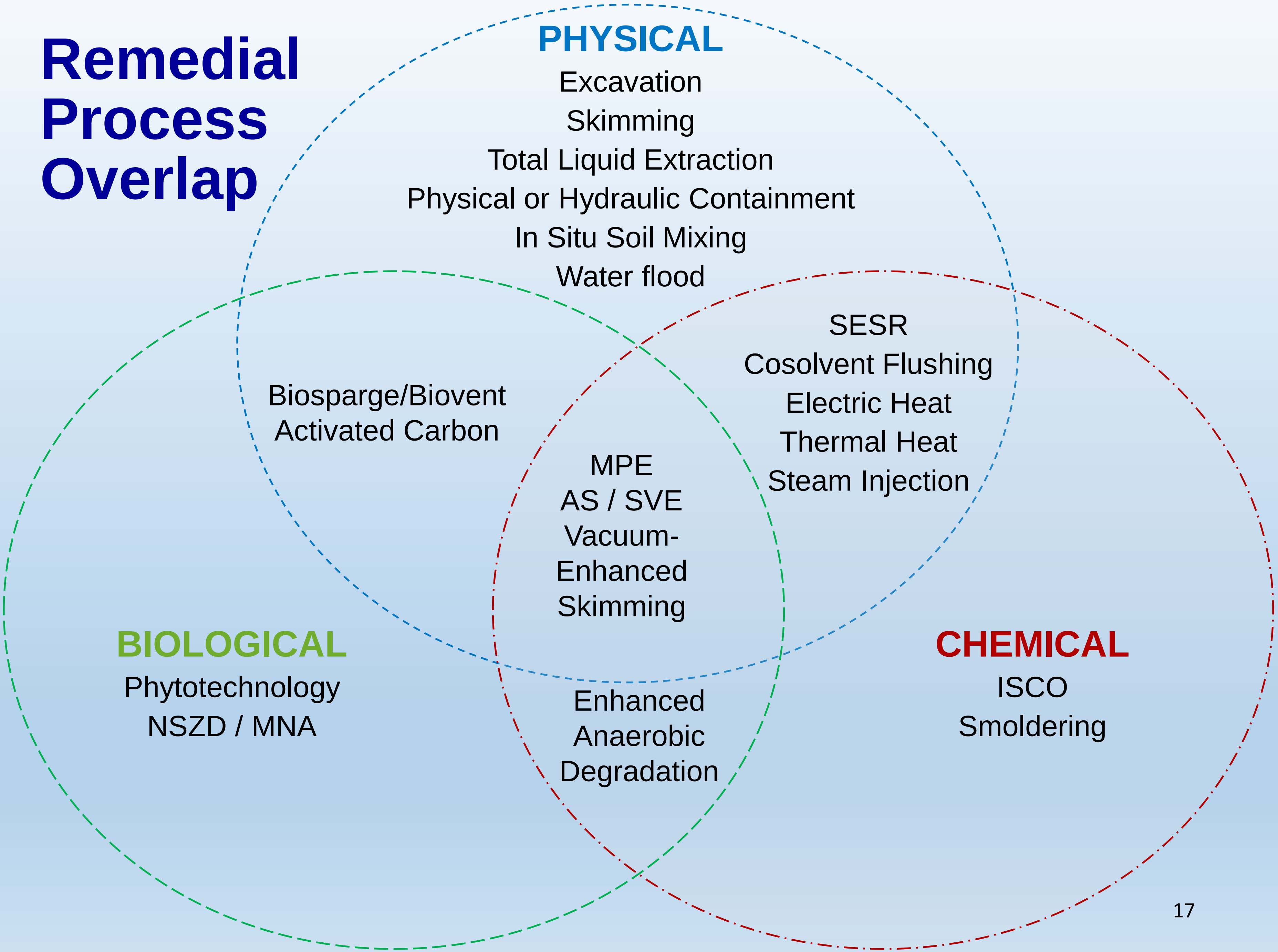
LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (ITRC, March 2018)

Processes



High
Phase Change
Mass Control / Recovery
Biological
Chemical
Physical
Efficiency
Concentration
High

Remedial Process Overlap



Technically Achievable

Examples Include:

Remedial Mechanism		Technically Achievable / Limit
1. LNAPL Recoverability	→	LNAPL Transmissivity (0.1 to 0.8 ft^2/day)
2. Volatilization • AS • SVE	→	Vapor Pressure 10-100X less than gasoline
3. Injection • ISCO • Carbon	→	Soil texture limits delivery of oxidant/other media
4. Biodegradation • Biovent / Biosparge • NSZD/MNA	→	Rate of degradation won't achieve goal in timeframe

“Treatment Train”
(Consecutive Remedies)

- <u>PLANNING</u> to use multiple remedial technologies *in sequence* to achieve closure

- Sequence remedial technologies based on contaminant concerns and remedial objectives
    - Consider starting with a primary technology (excavation?) tailored for higher contaminant mass
    - Continue with a 2nd treatment technology (ISCO?) and possibly a tertiary polishing step (CBI?) to address remaining contaminant mass and to eliminate contaminant concerns

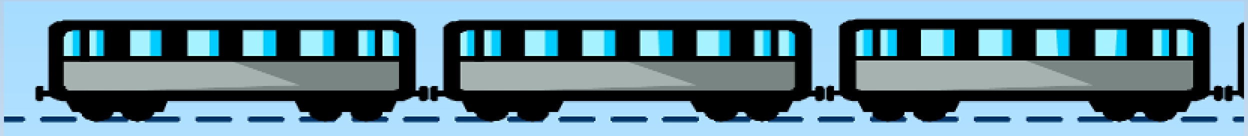
Treatment Trains

Good

- When planned with SMART objectives, metrics for transition, and endpoints
- Orderly implementation

Bad

- Unplanned, lack SMART objectives, metrics for transition, and endpoints
- "Throwing" more technologies at the problem



SMART?

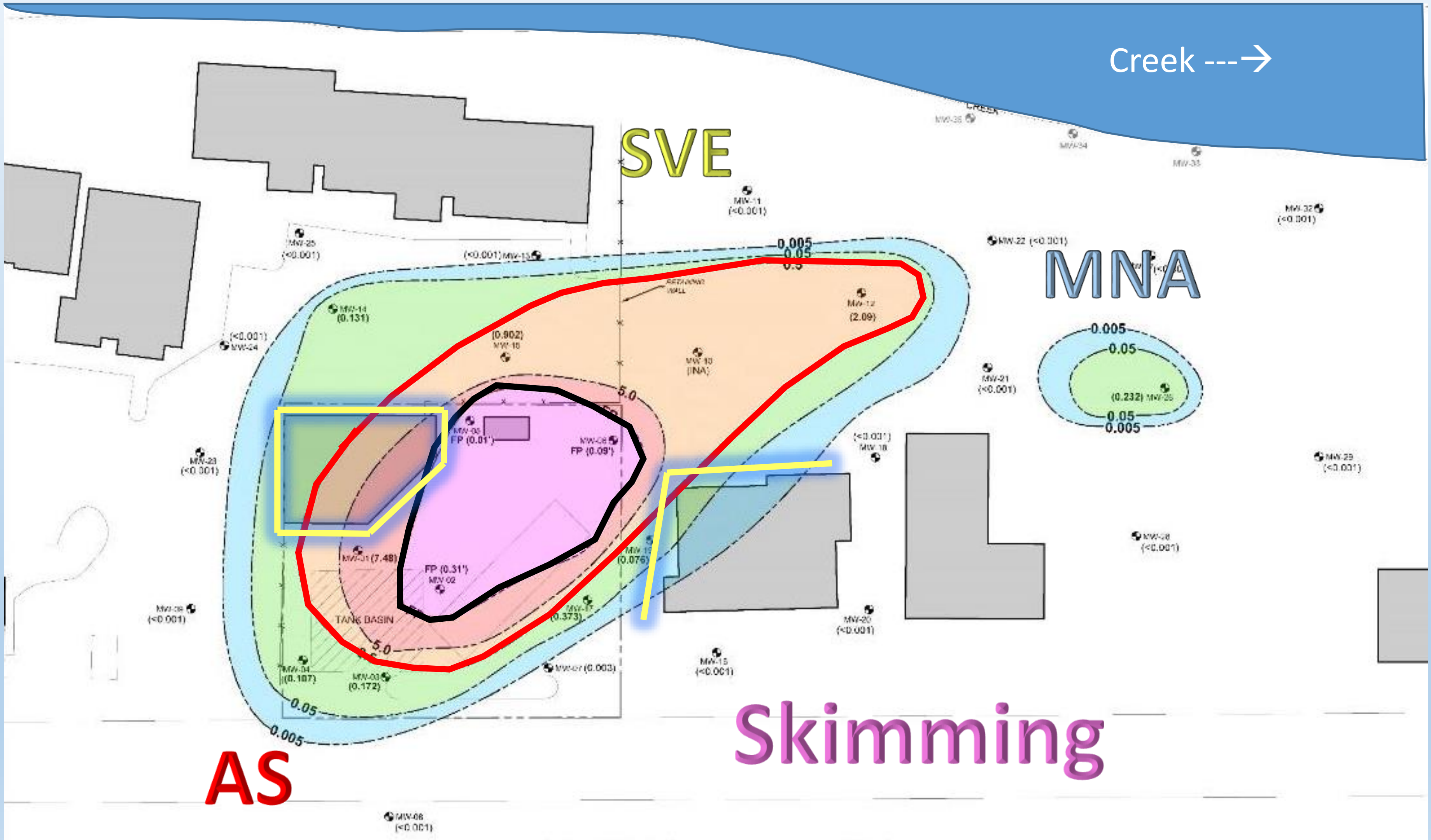
- **S**pecific - Targeted treatment area and technology-specific endpoints are clearly stated
- **M**easurable – Performance metrics that demonstrate progress towards the endpoint
- **A**greed Upon – Concerns, goals, objectives, treatment areas, metrics, endpoints
- **R**ealistic – Demonstrated ability to achieve objective
- **T**ime-Based – Target date of remedial endpoint being achieved

Achieving a remedial endpoint does not necessarily mean that all contaminant concerns have been eliminated

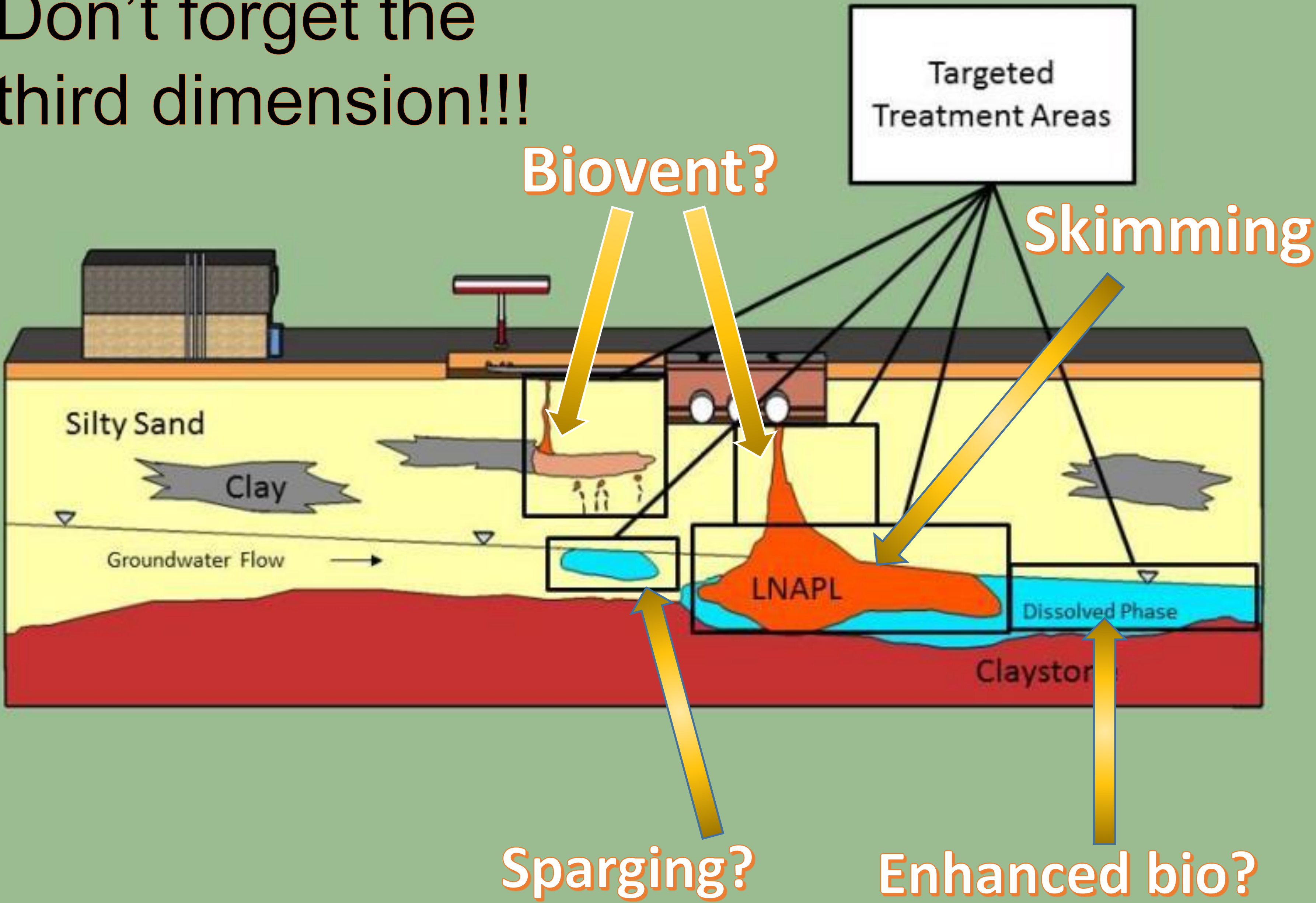
Concurrent Remedies

- Using multiple technologies on a site at the same time, in *different target zones* due to differing contaminant concentrations
  - Use primary technologies in the source area (e.g. excavation).
  - Use secondary or tertiary technologies on <u>periphery</u> of contaminated area, and in deeper zones.
- Still rely on SMART performance metrics to measure remedial progress

Example: Treatment Areas



Don't forget the third dimension!!!

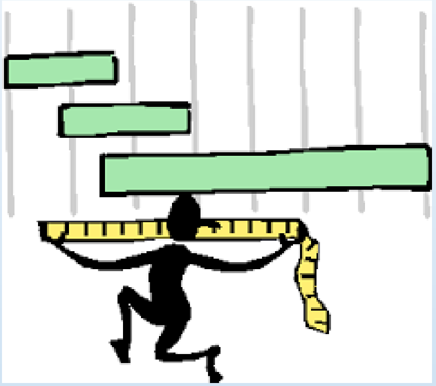


Performance Metrics

<u>Measurable characteristics</u> that track the progress of a selected technology to achieve a remedial objective and abate a contaminant concern

<u>ASK</u>: What conditions do you expect to change as you remediate the site? And how quickly?

Performance Metrics



- Technology-specific!
- Track progress toward endpoint
- Verify that remedy is being implemented effectively
- Allow for mid-course corrections
- Allow for CSM updates

Performance Metrics Examples

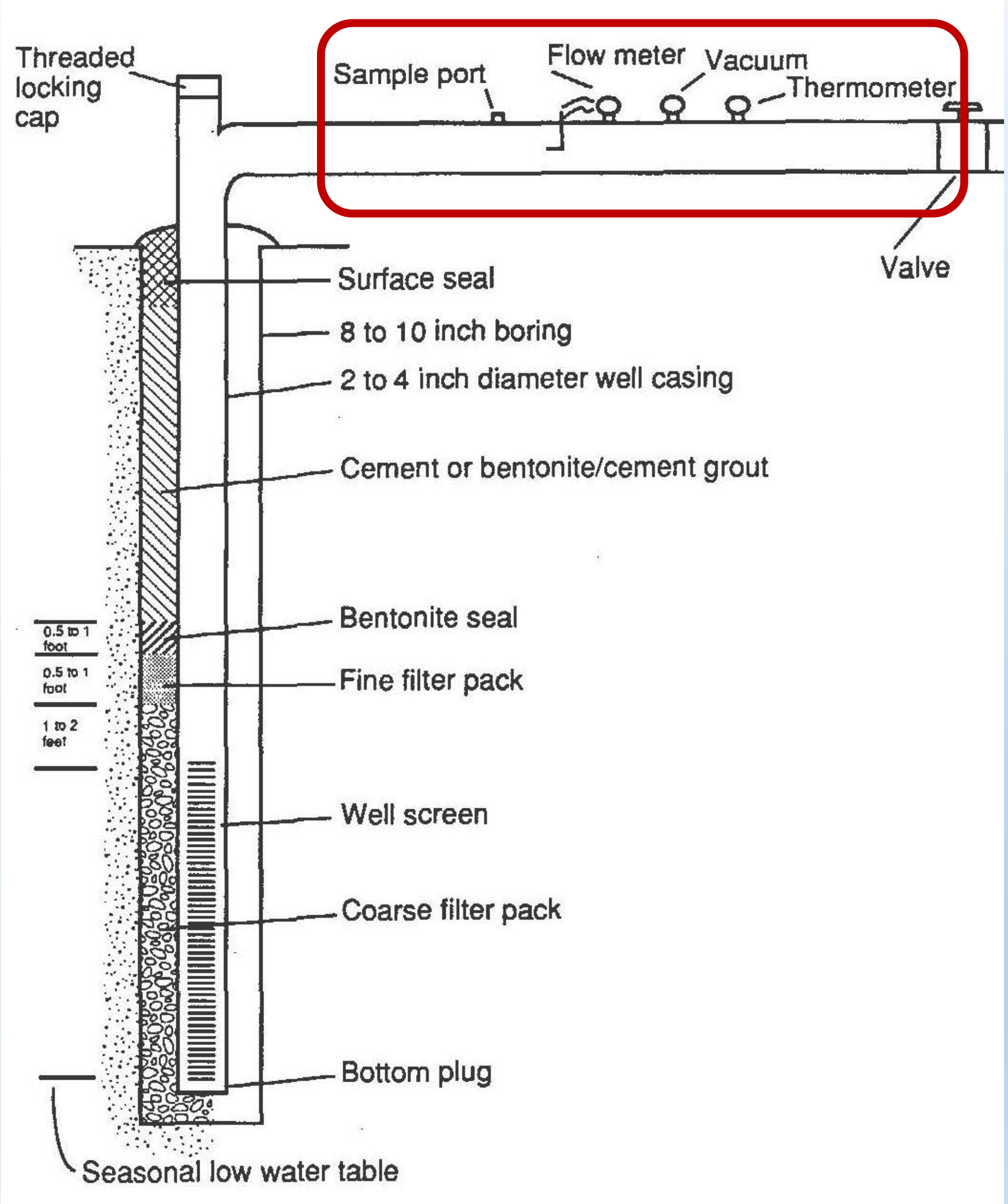
- AS/SVE - Air emission samples to evaluate contaminant recovery; DO in groundwater
- SVE - Interim or final soil confirmation samples
- ISCO - Data to evaluate distribution of an in-situ application (e.g. pH, ORP, DO)
- MNA – Organic/ inorganic/ biological samples

Where To Collect Performance Measurements

Key Point: A common mistake is measuring concentrations (collecting samples) on one side of the blower and flow on the opposite side of the blower

- Vapor conditions are vastly different on the vacuum (upstream) side of the blower versus the pressurized (downstream) side.
- Monitoring remediation systems that extract mass in the vapor phase requires the conversion of vapor flow rates from the field-measured “actual cubic feet per minute” (ACFM) to “standard cubic feet per minute” (SCFM).
- Performance monitoring data (e.g., pressure, flow rate, temperature, etc.) should be measured at as close to the same location as possible to support accurate calculations.

SVE Sampling/Measurement Location



Converting Vapor Flow Rate ACFM to SCFM

$SCFM = ACFM\ (P_A/P_S \cdot T_S/T_A)$

- P_A = Absolute pressure = $P_S + P_{gauge}$
- P_S = Standard pressure
- T_A = Absolute temperature (ºR) = T_A (ºF) + 460
- T_S = Standard temperature

In the absolute scales required by the ideal gas law, **standard atmospheric pressure is 14.7 psi** and **standard temperature is 528 degrees Rankine**, which equals 68 degrees Fahrenheit. Using these values, we obtain:

$SCFM = ACFM\ (P_A/14.7\ psi)\ (528^\circ R/T_A)$
$ACFM = SCFM\ (14.7\ psi/P_A)\ (T_A/528^\circ R)$

P_{gauge} is positive on pressurized side of blower and negative on vacuum side of blower **(see next slide)**

Accounting for Humidity: Because air is not actually an ideal gas, a more accurate relationship between ACFM and SCFM takes into account moisture content of the air. However, relative humidity has a minimal affect on the calculation compared to temperature and pressure and is often neglected. Example: a 70% relative humidity results in a 3% change in SCFM.

Note: Barometric pressure correction is also necessary for elevations > 3,000 feet above sea level (i.e., P_S would have to be adjusted for actual barometric conditions.

Gauge Pressure vs. Absolute Pressure

Gauge pressure and gauge vacuum are typically displayed relative to atmospheric pressure (e.g., 0 psig = 1 atmosphere = 14.6959 psi).

Positive pressure systems (psi): $P_{abs} = P_{atm} + P_{gauge\ pressure}$

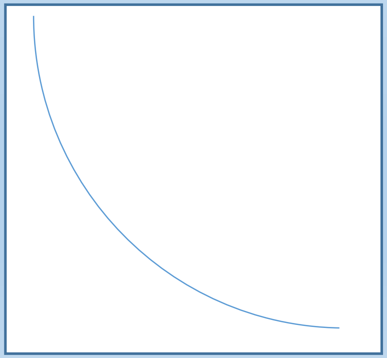
Negative pressure systems (inches Hg): $P_{abs} = P_{atm} - P_{gauge\ vacuum}$

Remedial Milestones
(Interim Objectives)

Anticipated points throughout remediation implementation to evaluate progress towards remedial endpoint (for a performance metric).

Remedial Milestone Examples

- LNAPL reduction = 10% of volume estimate per quarter/month
- Emissions decrease 30% per quarter/month
- Dissolved phase concentrations remediated to 25%, 50%, 75% of endpoint (with timeframe)



Remember!

Declines are exponential, not linear

(90% of the result takes 10% of the time?)

Endpoints

- Also technology-specific!
- Defined as:
  1. LNAPL concern has been addressed, or
  2. Practicable limit of the technology reached

- If technology reaches its practicable limit before LNAPL concern is abated, then the endpoint marks the transition to the next technology in the treatment train

Endpoint Identification
(Final Objective)

- Predetermined value that describes when a technology has achieved the limits of beneficial application
- Should account for expectations of the selected remedial technology
- Does not necessarily eliminate all contaminant concerns described in the CSM

The endpoint may not be your site goal!

Question & Answer

Please address all questions to a speaker

Reference slide number if necessary

EPA UST Cleanup Guide Highlights

- https://www.epa.gov/ust/how-evaluate-alternative-cleanup-technologies-underground-storage-tank-sites-guide-corrective

- Purpose: to help environmental professionals review corrective action plans (CAPs) that propose alternative cleanup technologies
- The guide is designed to enable the professional to answer two basic questions when reviewing a CAP:
  - Has an appropriate cleanup technology been proposed?
  - Does the CAP provide a technically sound approach to the cleanup?

EPA UST Cleanup Guide Highlights (cont.)

- Guide contains 13 chapters on alternative cleanup technologies and 2 appendices

- Each chapter contains the following resources:
  - ✓ <u>**Flow charts** to</u> help the professional <u>understand the review process</u> and decisions for each technology
  - ✓ <u>**Checklists** to</u> help the professional <u>determine whether the CAP contains all of the necessary information and factors</u> needed to evaluate each technology
  - ✓ <u>**Tables** that present advantages and disadvantages</u> of each technology, initial screening criteria, and other data specific to each technology
  - ✓ <u>**References**</u>, which provide sources of <u>additional information</u>

EPA OUST Contacts

- Tom Walker
  - ✓ walker.tom@epa.gov
  - ✓ 1-202-564-0581
- Will Anderson, Supervisor
  - ✓ anderson.will@epa.gov
  - ✓ 1-202-564-1642

Conceptualizing the Remedy

- The consultant should provide a comprehensive “design” of the proposed remedy (chosen technology or combination of technologies)
- Design in this context should not confused with detailed engineering design upon which construction would be performed
- Conceptual design should indicate how technical parameters of chosen technology would be executed to target the LNAPL body in order to most effectively mitigate it
- Recommended this basis of design be presented in a formal Remedial Action Plan, or equivalent document.
- The conceptual design needs to incorporate a reasonable understanding of the operational theory of whatever technology is selected to demonstrate that the consultant understands how to effectively implement it.

Pulling Together The Elements

- The targeted LNAPL body must be fully defined by the LCSM
  - It is extremely important the LNAPL extent be defined both laterally <u>and</u> vertically; relatively precise LNAPL geometry should be established.
- The remedy is the one selected during an exhaustive feasibility evaluation
- Utilize the design parameters gathered during pilot testing or otherwise presumed based on technology guidance

Basis of Design

- This concept is recommended to provide the best chance of success implementing the remedy
  - We, as regulators, should push RPs (and their consultants) to “prove” their design will have the best chance of meeting remediation objectives
  - RPs, in turn, should want us to demand this in order to ensure the most effective stewardship of cleanup funds (private or public)
- This document would guide the final engineering design by tying together the elements of the LCSM, pilot test data, and equipment specifications
- Tying all of these together conceptually should maximize the chance the LNAPL body will be mitigated to the maximum extent practicable

Key Design Elements

- Extraction/Injection Well Details
  - Well array locations
  - Well designs (size, depths, screen intervals, slot sizes)
- Equipment and materials
- Utility connections and other logistical constraints
- Permitting compliance and constraints
- Operational Plan
  - Performance monitoring parameters and schedule
  - System optimization and rebound testing
  - Shutdown targets and goals

LNAPL Remedy Selection

For the majority of gasoline UST releases, the technology evaluation for remediating LNAPL bodies most often leads to choosing one of two technologies:

- Multi-phase extraction (MPE); and
- Air sparging with soil vapor extraction (AS/SVE).

Which of these two technologies chosen is mainly dependent on soil type:

Multi-phase extraction may be an effective remedy if the LNAPL smear zone can be dewatered easily

Air sparging with soil vapor extraction is likely a better remedy where hydraulic conductivity is high and groundwater drawdown produces large volumes of water and/or limited or no drawdown

Excavation

Quick reminder: Soil excavation should not be ignored or forgotten as a potential LNAPL remedy.

- There is no better way to mitigate an LNAPL source than digging it out in the right situation:
  - Relatively shallow (<~20 feet bgs to the bottom of the) LNAPL body, including submerged source
  - No physical constraints (buildings, roads, etc.) overlying or adjacent to the area of LNAPL body
    - Even an LNAPL body extending off-site can be removed if there are no physical impediments and right of access can be obtained
  - Enough laydown room for excavated soil and other equipment
  - Relatively easy logistics for transport and disposal of excavated materials

Soil Vapor Extraction (SVE) Concepts

- SVE alone is feasible for VOC mass located in the vadose zone
  - Need to enhance SVE to affect groundwater cleanup
- Can't discuss MPE or AS/SVE without first talking about SVE since it is a key component of both technologies.
- SVE alone will not be enough to mitigate a submerged LNAPL source:
  - Groundwater depression added to expose previously saturated smear zone and mitigate impacts to groundwater (i.e., MPE).
  - Air injection (sparging) may act to strip LNAPL from saturated interval into vadose zone where it can be collected by SVE wells (i.e., AS/SVE).

Multi-Phase Extraction

Multi-phase extraction (MPE): Vacuum applied during drawdown of liquids (groundwater and LNAPL, if necessary) to induce gradient toward recovery well. Drawdown exposes more LNAPL to air, increasing volatilization (primary) and biodegradation (secondary).

- Extracted vapor and liquids are treated, or collected for disposal.
- After recoverable LNAPL is extracted, MPE is primarily a vapor remediation technology with dewatering only to facilitate vapor-phase recovery.

MPE Terminology

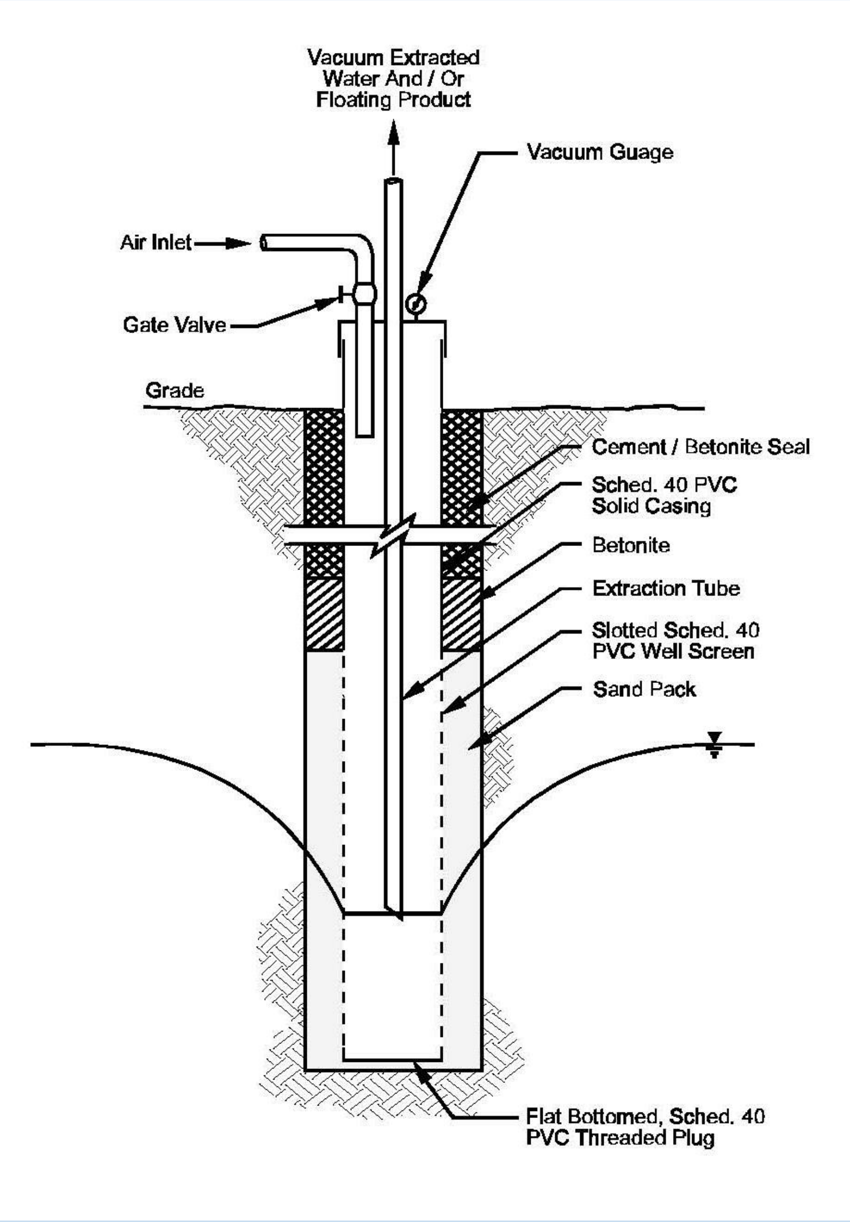
There are many different terms used to describe various MPE equipment configurations. Regardless of the terminology used, **understanding the configuration being used is essential** for monitoring and troubleshooting performance.

The most common MPE configurations are:

- <u>Single Pump Extraction</u>: Recovery of liquids and vapors together as a single waste stream (ex situ separation is common). Single pump configuration with "stinger" or drop-tube for extracting all fluids.
- <u>Multiple Pump Extraction</u>: Recovery of liquids and vapors as separate waste streams. Dual pump configuration with submersible pump for extracting liquids. A third pump could also be used to extract free product.

MPE Configurations

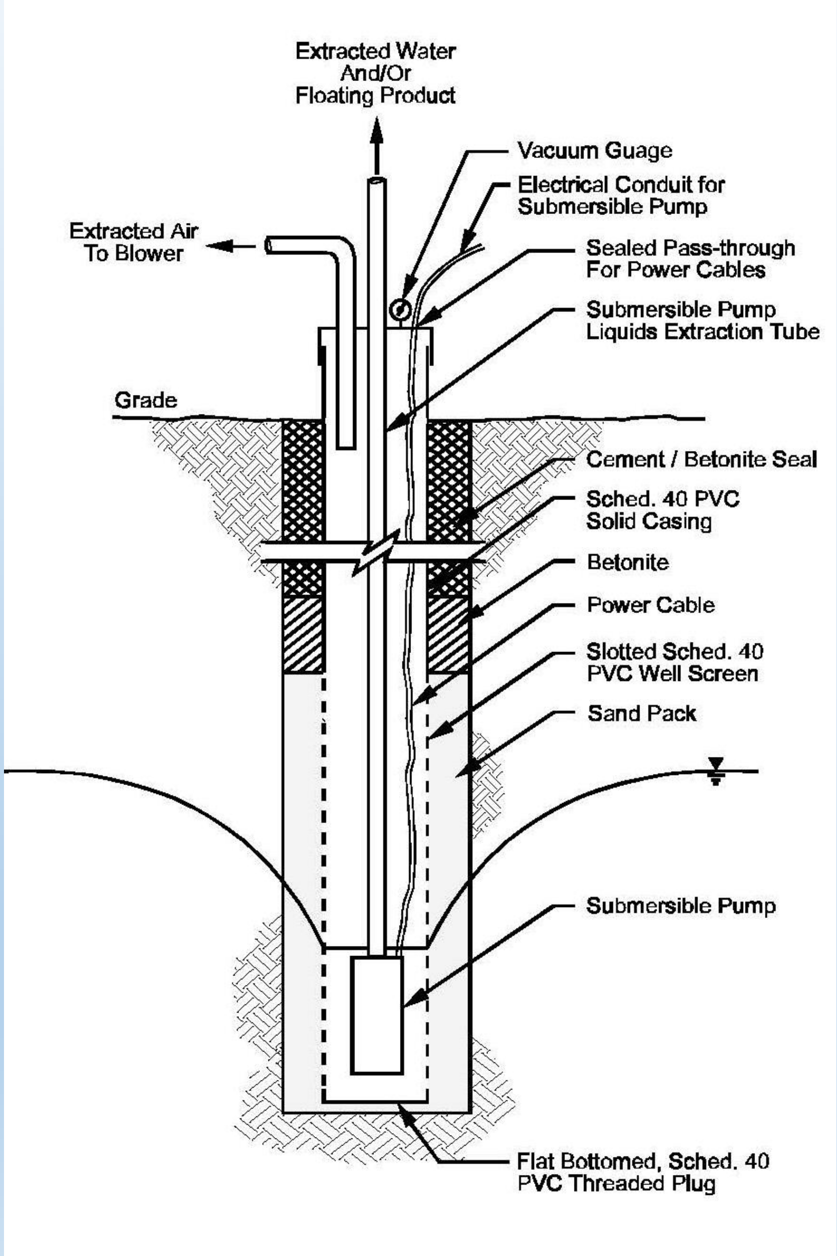
Single pump configuration with an aboveground vacuum pump connected to drop tubes (i.e., “stingers”) inserted into each of the extraction wells to extract LNAPL, vapor, and groundwater in a mixed stream.



How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers (USEPA 2017 update)

MPE Configurations

Two pump configuration using submersible pump to extract groundwater and an aboveground vacuum pump/blower connected to each of the extraction well casings to extract soil vapor. Skimmers may also be included (either passive or active [3rd pump]).



How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers (USEPA 2017 update)

Multiple Pump better than Single Pump?

- Single pump is typically only feasible at extraction rates <0.5 gpm/well and depth < 25 feet
  - Greater volumes of water will use too much of the energy (i.e., vacuum) to mover water and hinder vapor-phase mass removal
- Single pump systems much more difficult to operate
  - Fluctuations in recharge rates could overwhelm stingers, cutting off flow from well(s) and potentially shutting down the system
  - System restarts typically require manually lowering stinger to bottom of each well
  - Possibly requires a liquid-ring pump (blower)
- System shutdowns will eliminate drawdown already achieved in formation
  - Each well/system restart means drawdown is starting over

Beware Mobile (Rental) MPE Services

- Noted many cases where mobile (rental) equipment-based remedies have been selected, but the cost estimates are not accurately compared with the cost of a fixed remediation system
  - Timeframe/effort is typically underestimated
  - Effectiveness overestimated
- MPE rental equipment is often not operated long enough to achieve adequate dewatering of smear zone
- Generally operated on one well at a time
  - Less effective at dewatering a more-expansive LNAPL smear zone).
- Mainly operated in a single-pump configuration.
- Short-term rental of mobile remediation systems often has a narrow cost-effective window (e.g., single-well, very small and localized source area).

MPE Pilot Testing Objectives

MPE testing objectives (in order of importance):

1. Determine feasibility of dewatering LNAPL "smear zone" to allow LNAPL vapor-phase recovery
2. Determine potential mass removal rate in vapor-phase
3. Determine potential groundwater volumetric extraction rate
   - MPE generally infeasible at higher water production rates
4. Determine vacuum radius of influence
5. Determine full-scale system design parameters

MPE Pilot Testing Tips

- Often testing is performed on too many wells for too short a timeframe
  - Test one well at a time
  - Test should be performed for several days
- Proper selection/installation of wells, including observation wells
  - Need closely-spaced observation wells to evaluate drawdown
- Recommend testing using two pump configuration (with submersible pump)
- During testing, ensure that extraction well stays fully dewatered
- Too much focus on groundwater extraction
- Too much focus on vacuum radius of influence

MPE Implementation

- Choose quantity and locations of MPE wells adequate to mitigate entire LNAPL source area
- Design MPE wells (depths, diameters, screen intervals) based on:
  - CSM data
  - Pilot testing results
  - MPE configuration chosen
- Equipment must be sized large enough to allow extraction from at least one well at a time
- Maximize vacuum/vapor-phase mass removal by controlling the number of wells operated at the same time:
  - May require operation of as few as one well at a time
- Monitor mass removal for each well (vacuum, vapor flow, and concentration data)
  - Difficult if not impossible for single pump configuration because of mixed media in extraction pipe
- Monitor vapor concentrations frequently with field instrument, but regularly verify concentrations by laboratory analysis of samples.
- Calculate mass removal values using laboratory analytical data

MPE Measures of Success

Primary measures of MPE success in general order of importance are:

- Reduction in vapor concentrations;
- Reduction in LNAPL transmissivity; and
- Reduction in groundwater concentrations within the treatment area.

Key point: Large mass removal rates may not be effective mass removal. Effective mass removal is removing mass within the entire smear zone that directly impacts groundwater concentrations. The system must be designed to address the entire smear zone (laterally and vertically) identified in LCSM.

MPE System Shutdown

- Operate individual MPE wells until the mass removal rate has reached low-level asymptotic rates (indicates recoverable mass in well vicinity has been removed to the maximum extent practicable).
- Shut down individual wells where vapor-phase mass has been removed to the maximum extent practicable.
- System shutdown should occur when all wells have achieved asymptotic low mass removal rates; indicating all readily extractable mass has been removed and mass recovery has become diffusion limited.
- Rebound testing at the end of operation (e.g., recovery < 10 lb/day) should not be required if system optimization is ongoing.

Question & Answer

Please address all questions to a speaker

Reference slide number if necessary

Air Sparging with Soil Vapor Extraction

Air Sparging with Soil Vapor Extraction (AS/SVE): Injecting air below the water table to strip VOCs from groundwater, soil, and LNAPL smear zone. Vapors are captured by SVE system and treated prior to discharge.

- AS/SVE is generally applicable to higher transmissivity soils than MPE. If MPE is deemed infeasible because the smear zone cannot be dewatered, then AS/SVE generally be applicable.
- Air injection is achieved through vertical, horizontal, and directional wells or sparging probes (i.e., small wells dedicated to injecting air).
- Oxygen added to groundwater and vadose zone may also enhance biodegradation of contaminants.

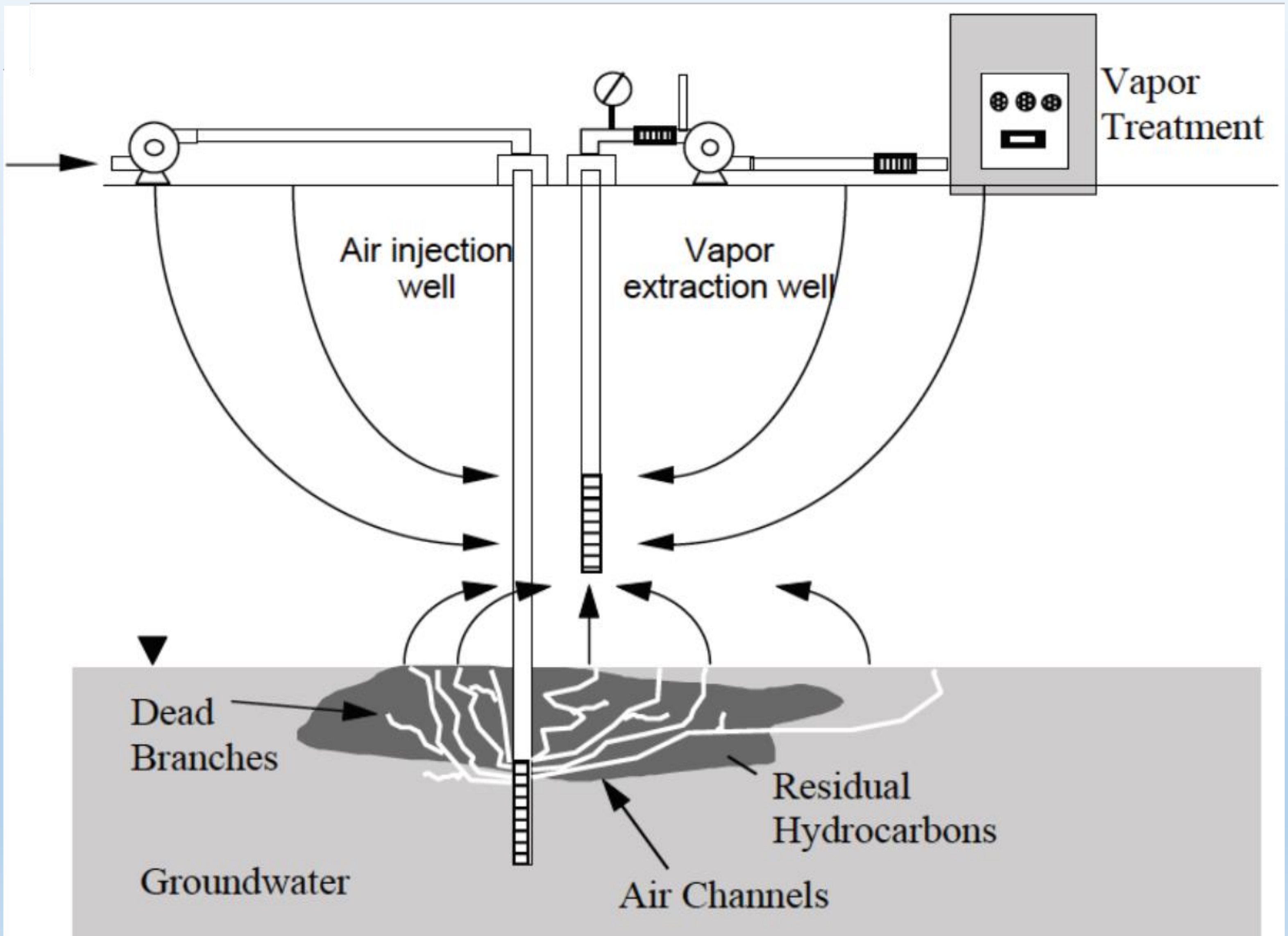
AS in Presence of “Free Product”

Most guidance (EPA OUST, California LUFT Manual, etc.) rejects the concept of performing AS in the presence of mobile LNAPL. We urge a more open-minded approach to AS when mobile LNAPL is present.

- Most guidance referenced is over 20 years old; mechanisms of AS more well known today
- Concern was due to apparent mounding caused by AS. However, mounding is:
  - Localized
  - Temporary
  - Cycled operation further reduces risk
- AS will actually mitigate LNAPL more than push it away

- AS should not be implemented:
- When migrating LNAPL is present
- If free product measurements >~6 inches
- If free product has not been removed to the maximum extent practicable (LNAPL transmissivity <0.8 ft^2/day)
- Directly beneath occupied buildings

Air Sparging with Soil Vapor Extraction (AS/SVE)

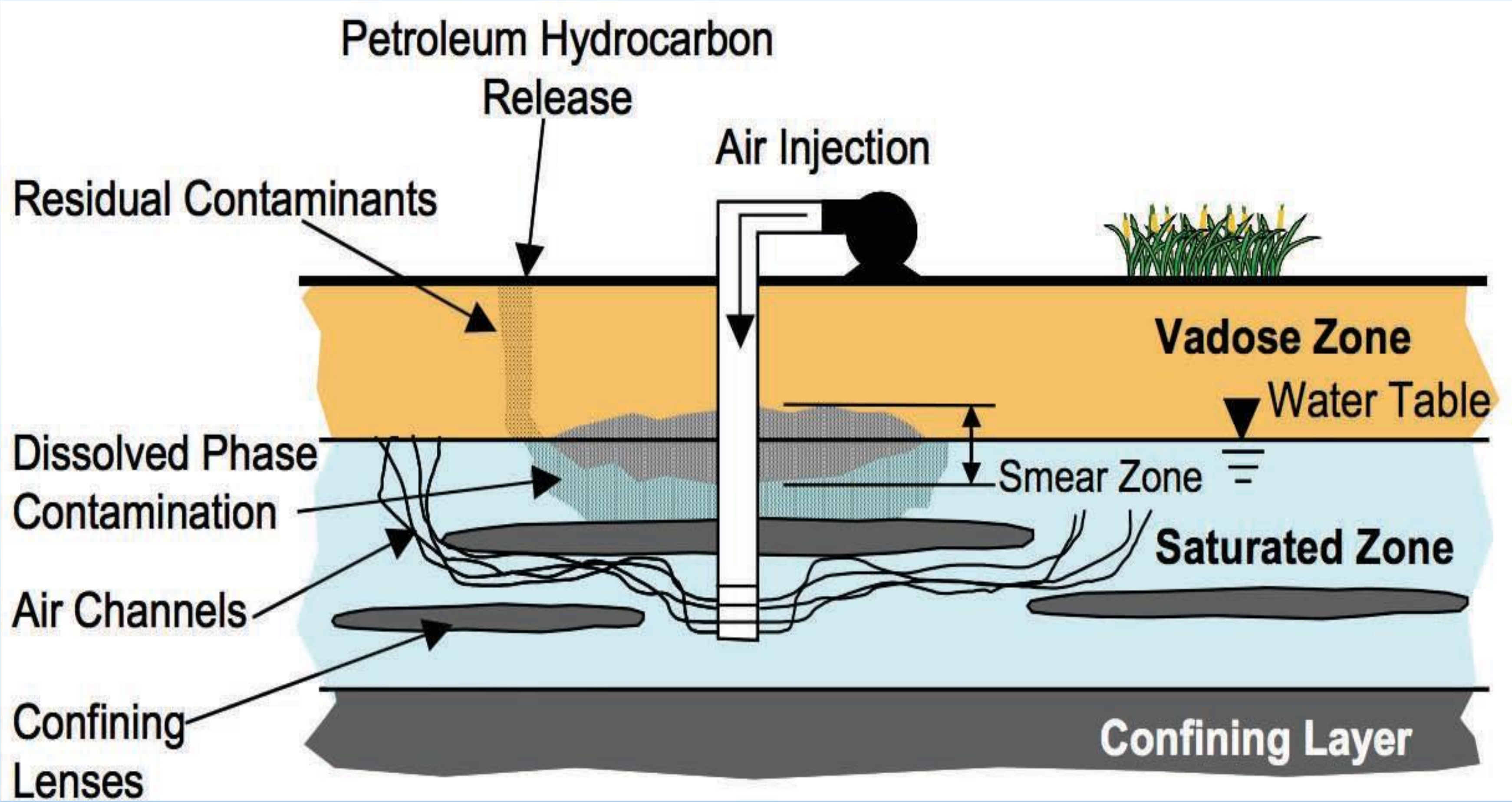


"A Citizen's Guide to Soil Vapor Extraction and Air Sparging". EPA 542-F-12-018 (USEPA, 2012)

AS/SVE Pilot Testing

- Often, the choice for a mechanical remediation technology at a site with a submerged LNAPL body usually boils down to a choice between MPE and AS/SVE.
- Unless the geology at a site makes it obvious that AS/SVE is the choice, then a MPE pilot test would probably be performed.
- Even if MPE proves infeasible, the pilot test will likely provide sufficient data to determine the design parameters for the SVE system.
- The AS element of this remediation technology can either be determined using established guidance or from minimal pilot testing.
- If pilot testing is still needed, the primary objective for SVE is to determine design parameters for the SVE portion of the system.
- Even then, AS pilot testing may only be required to determine whether air can be injected into the saturated zone at or below the base of the LNAPL smear zone at a sufficient rate of injection.
    - Radius of influence is nearly impossible to estimate for air sparging due to complex air channel formation (this is the primary reason AS pilot testing is not as highly recommended).

Air Sparging and Geology Challenges



Note: Confining layers may increase lateral movement of air, which may or may not be beneficial (more or less smear zone contact).

"Air Sparging Guidance Document". NFESC, Technical Report, TR-2193-EN. (NAVFAC, 2001).

AS/SVE Design

- According to the “Air Sparging Design Paradigm”, it is acceptable to use a Standard Design Approach, wherein AS wells are spaced on 15-foot centers throughout the area of residual LNAPL impact
  - Results from pilot testing could be used to derive spacing greater than 15-foot centers, if that spacing is cost-prohibitive
- Design well screens (and sand pack) for AS wells to be located completely (several feet) beneath the base of the LNAPL smear zone (~2 ft long screens)
  - 5 feet of blank casing recommended below sparging screen to catch sediment that may accumulate in well.
  - Take into account historic and seasonal water table fluctuations
- Properly design air sparge blower
  - Capable of delivering 10 to 20 scfm per well to at least one well at a time
  - At a pressure capable of overcoming the pressure head in each well (typically at least 10 to 15 psig).
  - Be conscious of formation fracture pressure threshold
- Choose quantity and spacing of SVE wells and SVE blower/treatment equipment adequate to fully capture VOCs liberated from the saturated zone by air sparging

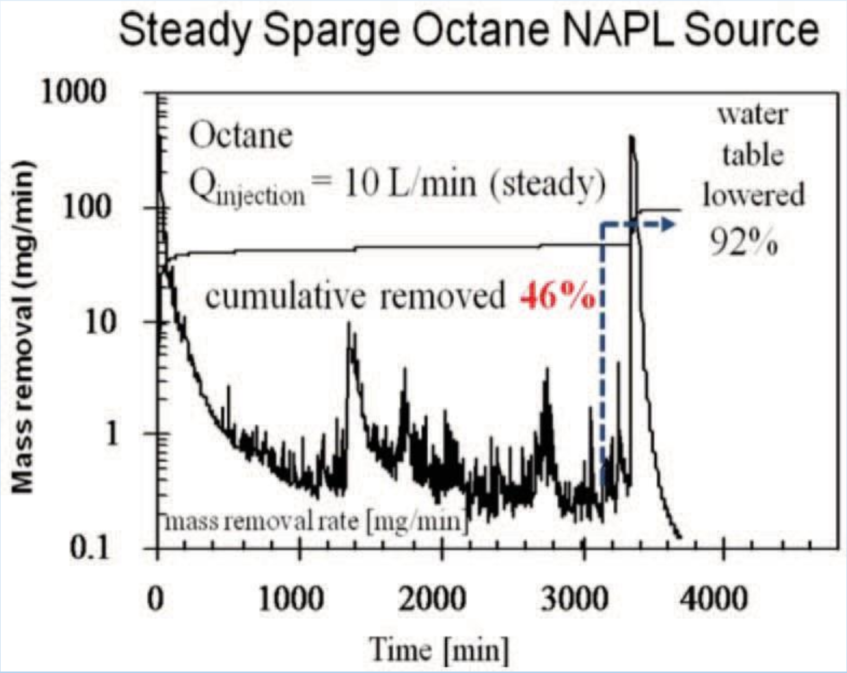
AS System Operation

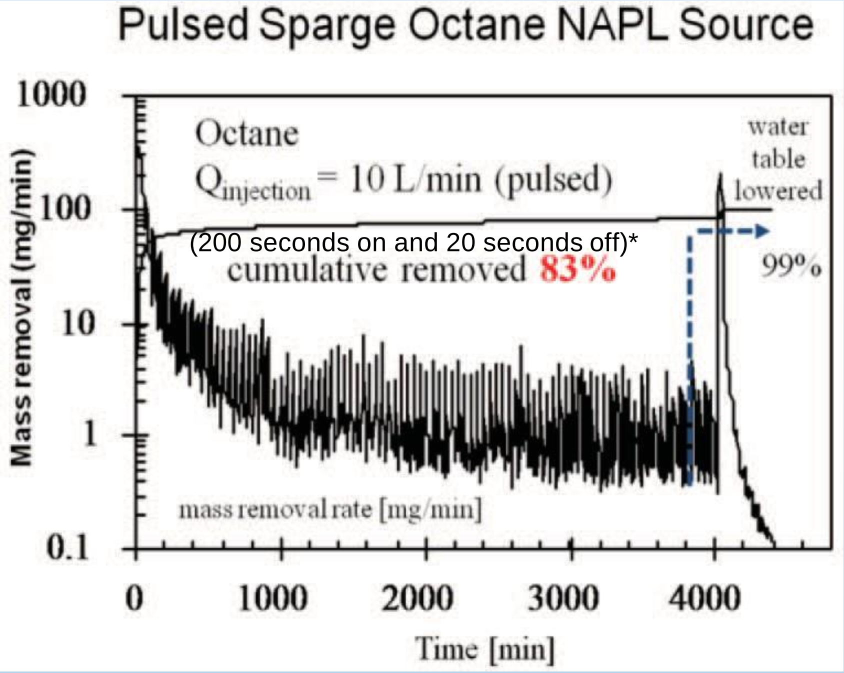
- Initiate AS operation once effective SVE system operation is established
- Only inject air into AS wells if there are sufficient SVE wells being operated to capture the injected air
- AS system should be programmed to shut off if SVE operation ceases

- Key Operational Element: Cycle air injection on and off between wells to allow water to collapse back into air pathways between air injection periods (this dramatically improves mass removal!).

Steady vs. Pulsed Air Sparge

Bench-Scale Air Sparge Example





***Note: These data are from bench-scale studies. Optimal pulse duration is site-specific and generally increases with sparging depth. Typical sparge durations are a few hours (e.g., 2 – 4 hours).**

"Effect of Flow Rate Changes and Pulsing on the Treatment of Source Zones by In Situ Air Sparging" (Environ. Sci. Technol. 33(10): 1726-1731, Johnson, P.C., A. Das, and C.L. Bruce, 1999).

AS/SVE Measures of Success

Primary measure of AS/SVE success is reduction in dissolved concentrations within the treatment area.

- System should be shutdown periodically to collect groundwater samples for analysis.
- System may continue to reduce groundwater concentrations at low mass recovery rates and continued operation may be justified (e.g., <10 lb/day).
- Groundwater concentrations are better indicators of performance than mass recovery rates.

AS/SVE System Shutdown

- System shutdown should be based on reducing dissolved concentrations to below cleanup objectives
- Rebound testing should be performed periodically, and the system can remain off if dissolved concentrations remain below cleanup objectives
- While groundwater concentrations stay above cleanup objectives, the SVE system should continue to operate until vapor-phase mass removal approaches zero
  - With AS/SVE, vapor-phase mass removal reaching a low asymptote is not necessarily an indicator the system has reached the end of its effectiveness.
- As vapor-phase mass removal approaches zero, the SVE portion of the system could be shut down and the AS system transitioned to biosparging

Remediation System Troubleshooting

Reasons why remediation systems fail to meet performance objectives:

1. CSM is incomplete and source mass is not adequately defined
2. Design is insufficient to address entire LNAPL smear zone or plume
3. Installation not as designed
4. Operation not as designed (operators may adjust system to keep it running at the expense of performance)
5. Maintenance is required or equipment is not functioning properly

Rebound Testing

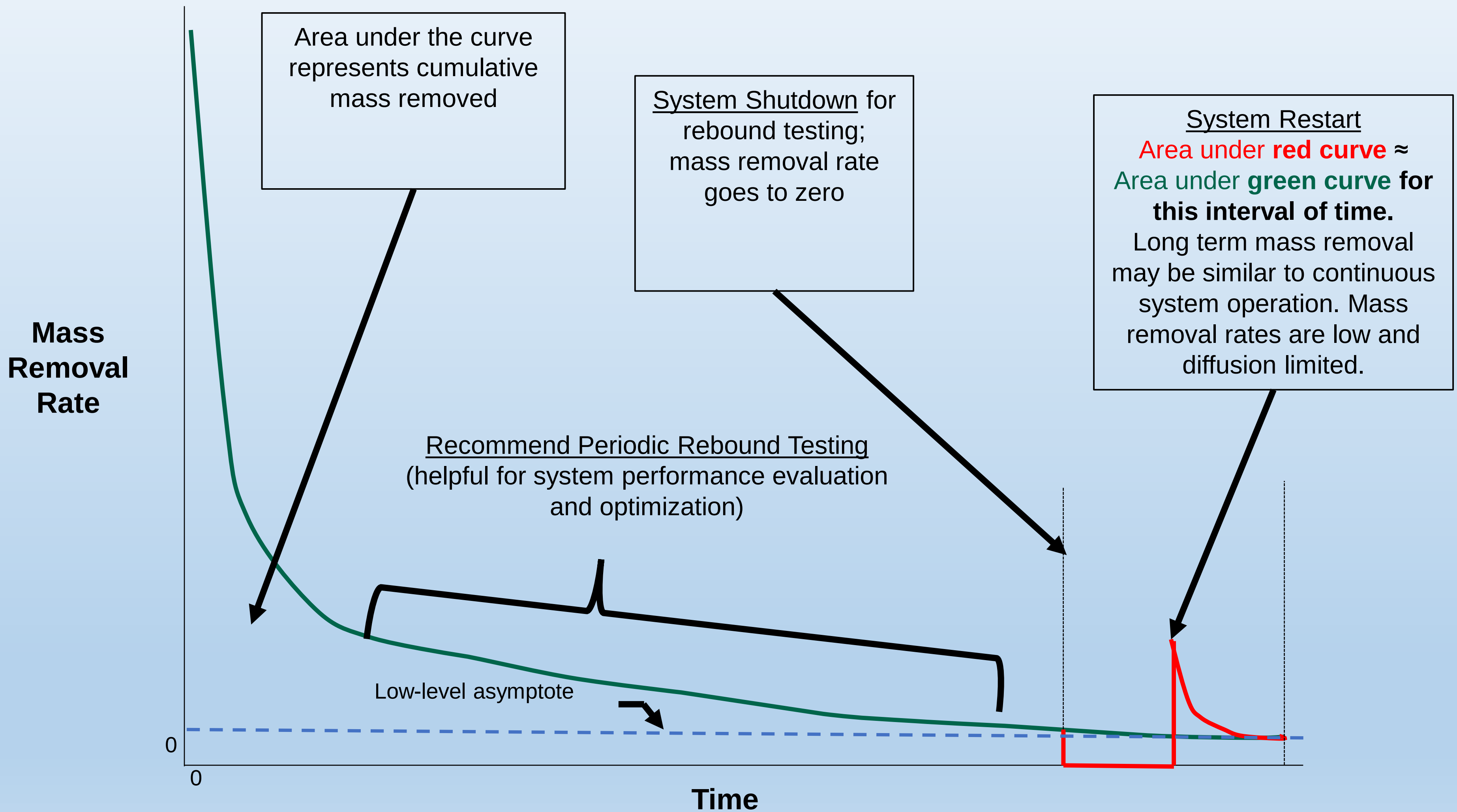
There are two types of rebound tests that could be employed to measure the success of mechanical remediation or to determine the need for further operation, and even possibly the need for modifications to the system:

- Vapor-phase mass removal rebound testing
- Dissolved plume concentration rebound

Most rebound testing is performed when the system has apparently met its operational goals; however, that may be too late. Interim rebound testing is recommended to determine whether residual LNAPL mass is located outside the radius of influence of extraction wells.

- If additional extraction wells or other system upgrades are required, they should be implemented as soon as possible.
- Don’t wait until the end of operation to perform rebound testing to avoid wasting time and financial resources (see graph on next slide).

Mass Removal, Asymptotes, and Rebound Testing



Question & Answer

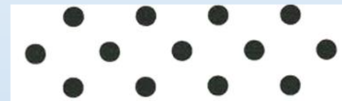
Please address all questions to a speaker

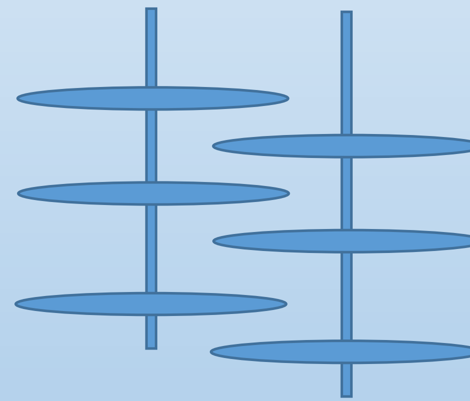
Reference slide numbers if necessary

Injection of Amendments

- Liquids or slurries (in most cases)
- Need HRSC to locate target intervals
- Best for:
  - Small areas
  - Open access
  - >10 feet below grade
  - Often require permits to inject
  - Ability to direct push injection rods?
  - Fairly homogeneous geology with no preferential pathways (e.g. utilities, poorly plugged boreholes)

Other considerations

- Pilot tests required (monitor for rebound)
- Offset grid pattern 
- Short injection intervals, offset from others (into flux zones)
- Top down vs. bottom up?
- Experienced crew needed
- Materials often hazardous



Side view

In Situ Chemical Oxidation

Injection of oxidant to destroy organic compounds

- ISCO may treat dissolved plume, soil, or LNAPL
- Oxidation occurs in dissolved phase (dose accordingly)

Common oxidants

1. Persulfate
2. Percarbonate
3. Activated hydrogen peroxide
4. Permanganate (not for benzene)
5. Ozone (injected into the vadose zone or sparged)

Dissolved LNAPL constituents often increase after initial application!

ISCO Applicability

- ✓ **Destructive technology**
- ✓ **Short remedial timeframes (typically < 1 year)**
- ✓ **Most applicable to residual LNAPL situations (contact more certain)**
- ✓ **Ozone gas is especially well suited for sparging and vadose zone remediation (also promotes biodegradation after O_3 breaks down into O_2)**
- ✓ **Low carbon footprint for injection-only systems**

ISCO Limitations

- **Rebound frequently occurs** (desorption, unknown mass, TOC)
- **Effects last 45-60 days, multiple treatments needed**
- **Usually not economical on large LNAPL volumes or high LNAPL saturation**
- **Requires bench testing** to determine efficacy and dosing of oxidant
- **Daylighting of oxidant may occur** (especially in shallow or high pressure injections)
- **May generate excessive heat and gases** (especially hydrogen peroxide)
- **Can cause metals issues** (iron, chromium) **and sulfate precipitation**
- **High pH can be detrimental to further biodegradation**

ISCO References

- USEPA 2017 update (Chapter 13)
- In Situ Chemical Treatment: A Love-Hate Relationship, Suthersan et al, GWMR (Winter 2017)
- In Situ Chemical Oxidation: Lessons learned at multiple sites, Pac et al, Remediation (2019)

And many others…

Activated Carbon

Added to excavations/trenches in granular form, or injected into the subsurface in powdered (slurry) or nano (colloidal)-scale (liquid) form.

Absorbs hydrocarbons (and other things)

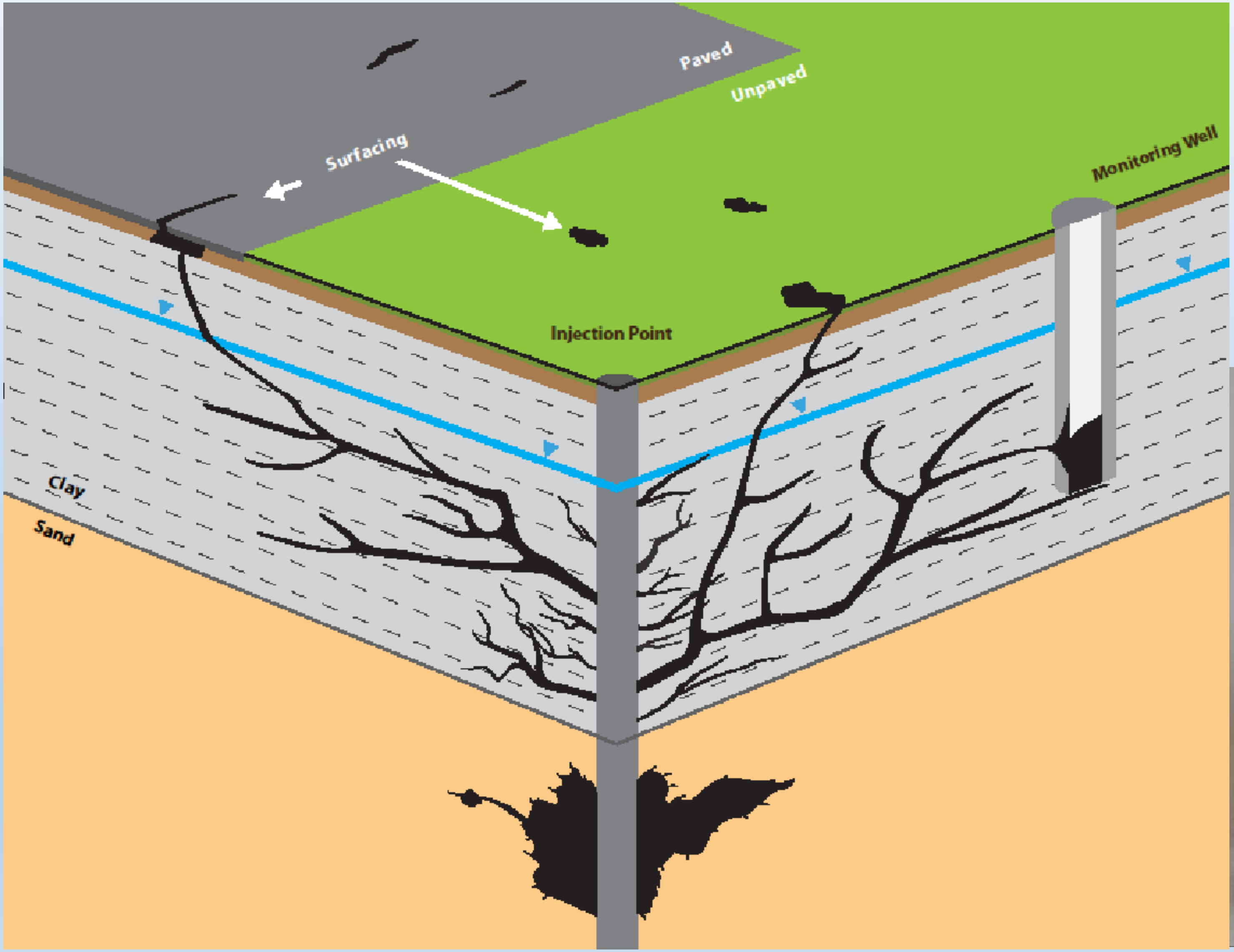
Activated Carbon Applicability

- ✓ Phase change technology
- ✓ Unused, food-grade, coal-based activated carbon is recommended for use
- ✓ Chemical or biological amendments may be added to enhance degradation (add piping to excavations to replenish amendments)
- ✓ Sorptive capacity of carbon increases with aqueous concentrations (to a point)
- ✓ Carbon sorption is effectively instantaneous

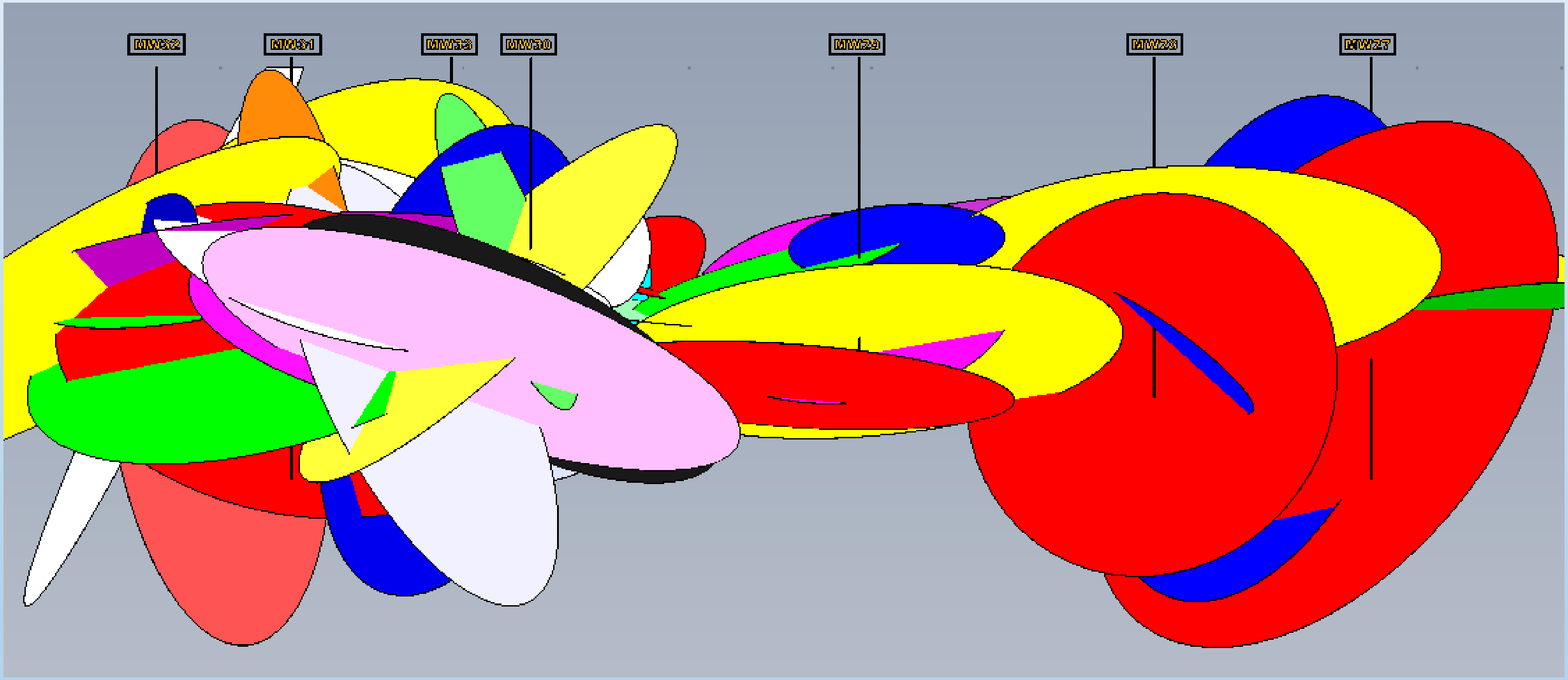
AC Applicability (cont.)

- ✓ Best used in excavations where distribution can be controlled (granular AC)
- ✓ Applicable to low to moderate dissolved concentrations
- ✓ Biodegradation of sorbed contaminants can occur if conditions are favorable (e.g., aerobic)
- ✓ Biostimulation (addition of oxygen or sulfate, heat, etc.) will improve destruction of sorbed contaminants
- ✓ Wide variety of injection options ranging from gravity feed to fracturing with carbon as a proppant

Distribution issues



Fracture propagation



Activated Carbon Limitations

- Sorption is competitive, which may limit sorption of target contaminants (e.g., xylene and PAHs outcompete benzene)
- Sorption is reversible (unless biodegradation occurs)
- Adequate carbon mass and proper placement are critical for success
- Carbon injection performance affected by particle size and hydrogeology
- Carbon is impossible to remove from monitoring wells and will create negative sampling bias (need new wells)

Activated Carbon References

- NEIWPCC September 2016 webinar
- Current state of in situ subsurface remediation by activated carbon-based amendments, Fan et al, Jour. Envir. Mgmt. v. 204, p. 793 (2017)
- Remedial Technology Fact Sheet – Activated Carbon-Based Technology for In Situ Remediation (EPA 542-F-18-001, April 2018)

What Data Should You Ask For?

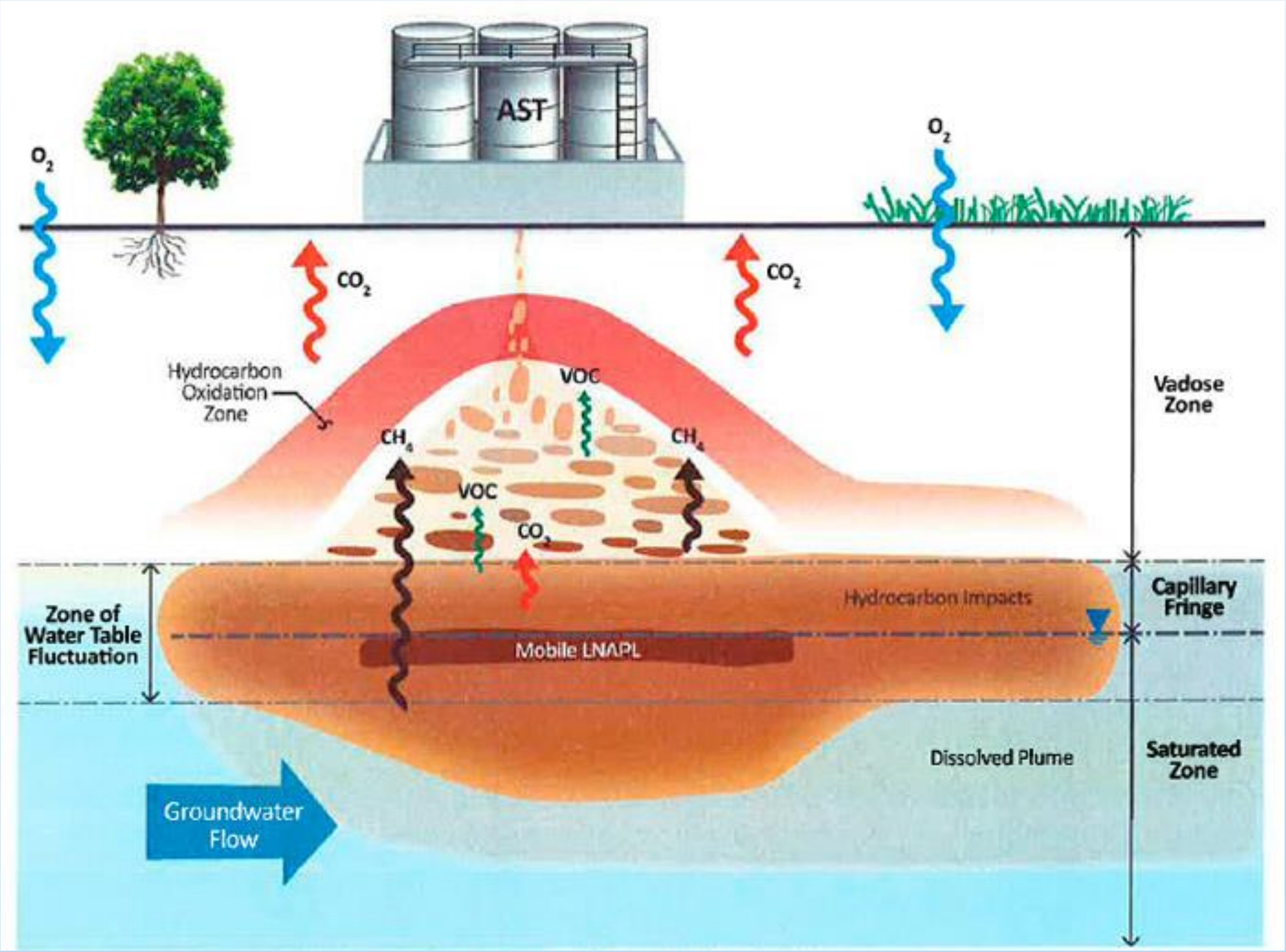
1. HRSC data showing flux zones, locations of hydrocarbon mass (soil borings expected for confirmation)
2. Bench test: choice of oxidant or other amendments (for biostimulation), dosing,
3. Pilot test: pressure, flow, length of activity (rebound assessment) and spacing estimate (indirectly?)
4. Post-injection: soil borings (AC), COC monitoring, evaluate well conditions (AC or scaling), consider pH adjustments (ISCO)

Natural Source Zone Depletion (NSZD)

LNAPL mass reduction via naturally occurring volatilization, dissolution and biodegradation

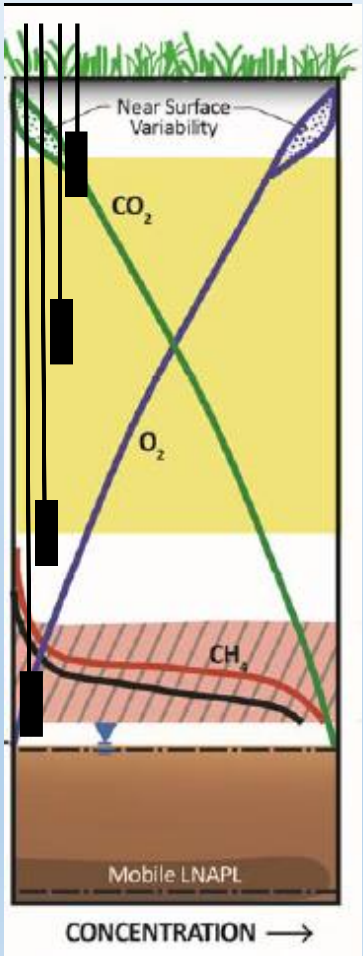
- Typically destroys 100s to 1000s of gallons/acre/year
- Microbes solubilize hydrocarbons from LNAPL or utilize intracellular diffusion to assimilate LNAPL
- Site-specific LNAPL mass loss rates via NSZD can be estimated via soil gas monitoring (e.g., CO_2 and CH_4)
- Process is ubiquitous and accounts for most plume's stability

NSZD Processes



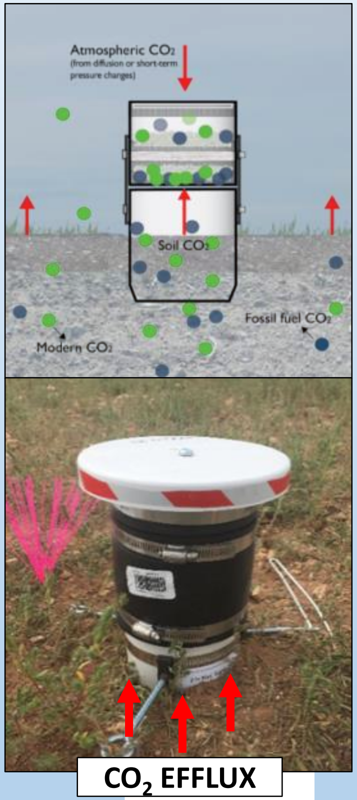
Four Methods to Measure NSZD

1. Gradient Method



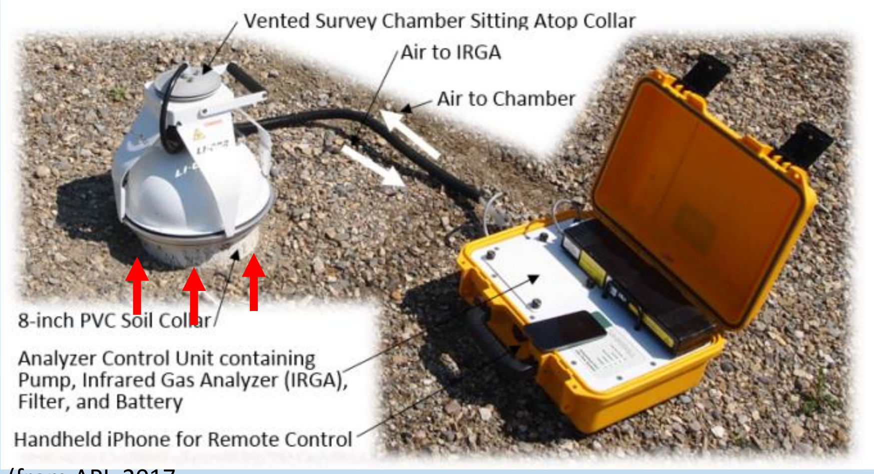
(from API, 2017, http://www.techstreet.com/standards/api-publ-4784?product_id=1984357)

2. Passive Flux Trap



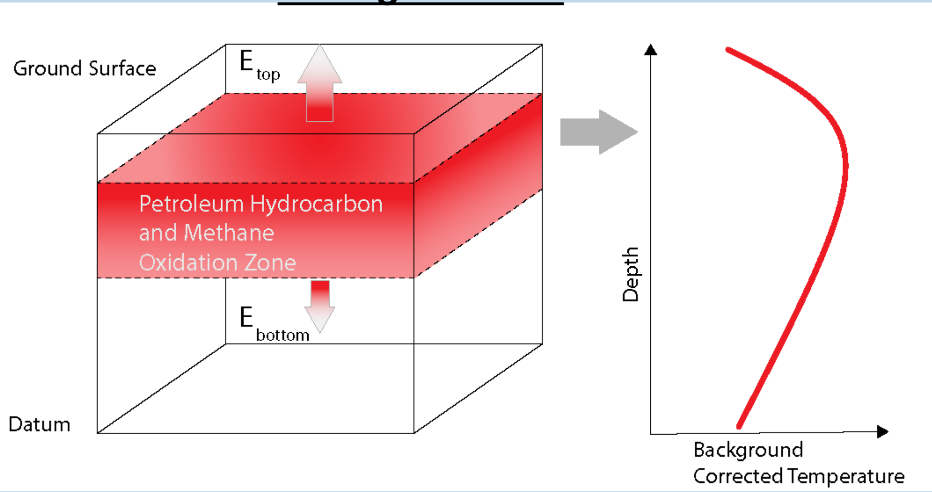
(from E-Flux, LLC, 2017, http://soilgasflux.com/main/home.php)

3. Dynamic Closed Chamber



(from API, 2017, http://www.techstreet.com/standards/api-publ-4784?product_id=1984357)

4. Biogenic Heat



NSZD Applicability

- ✓ Applicable at sites with limited access
- ✓ LNAPL body and dissolved phase plume are delineated and stable
- ✓ No unacceptable exposures, or exposures can be controlled
- ✓ LNAPL removal is shown by transmissivity to be impractical
- ✓ Remedial timescale is acceptable to stakeholders
- ✓ Passive destruction (the ultimate ‘green’ remedy?)

NSZD Limitations

- Less effective in soil with low vapor permeability (e.g., fine grained soil with high moisture content)
- NSZD is controlled by volatilization, dissolution, intracellular diffusion, and biodegradation rates
- NSZD is often slower with increasing LNAPL saturation
- Institutional controls may be required limiting site use
- Less public acceptance than active remediation

NSZD Red Flags

May cause additional cost, effort, or reduced performance:

- Groundwater plume is expanding.
- PVI is a risk (i.e. receptors don't screen out)
- Vapor concentrations are increasing
- Active remediation is desired by concerned community (may rule out NSZD or require more frequent monitoring and reporting)
- Rapid cleanup is desired

What Data Should You Ask For?

- NSZD mass destruction rates (estimated from CO_2 and methane discharge)
- Smear zone temperature profile vs. background (microbial activity increases temperature)
- Plume length: shrinking or stable

<u>Expect increased concentrations</u> of less volatile, less soluble, and less biodegradable LNAPL components in air/water over time as LNAPL composition changes

NSZD References

- ITRC LNAPL 3, Appendix B
- The role of NSZD in the management of LNAPL contaminated sites, CRC CARE Tech. Rpt. 46 (2020) (Cooperative Research Centre for Contamination Assessment and Remediation of the Environment)
- Natural Source Zone Depletion (NSZD): What is it and where does it fit into petroleum NAPL site management? (AIPG webinar 5/13/20)

Question & Answer

Please address all questions to a speaker

Reference slide number if necessary

THANK YOU FOR YOUR PARTICIPATION

LUST Corrective Action Series: https://neiwpcc.org/our-programs/underground-storage-tanks/lust-training-resources-corrective-action/webinar-archive-corrective-action/

UST Inspector Training Series: https://neiwpcc.org/our-programs/underground-storage-tanks/ust-training-resources-inspection-leak-prevention/webinar-archive-inspector-training/

LUST Line: https://neiwpcc.org/our-programs/underground-storage-tanks/l-u-s-t-line/

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LUST Corrective Action Webinar Series

Evaluating remediation Workplans-6/8/2020

Moderated by Nick Bissonnette- Environmental Analyst, *NEIWPCC*

THANK YOU FOR YOUR PARTICIPATION