Striving for More Sustainable Risk Management at Petroleum Release Sites

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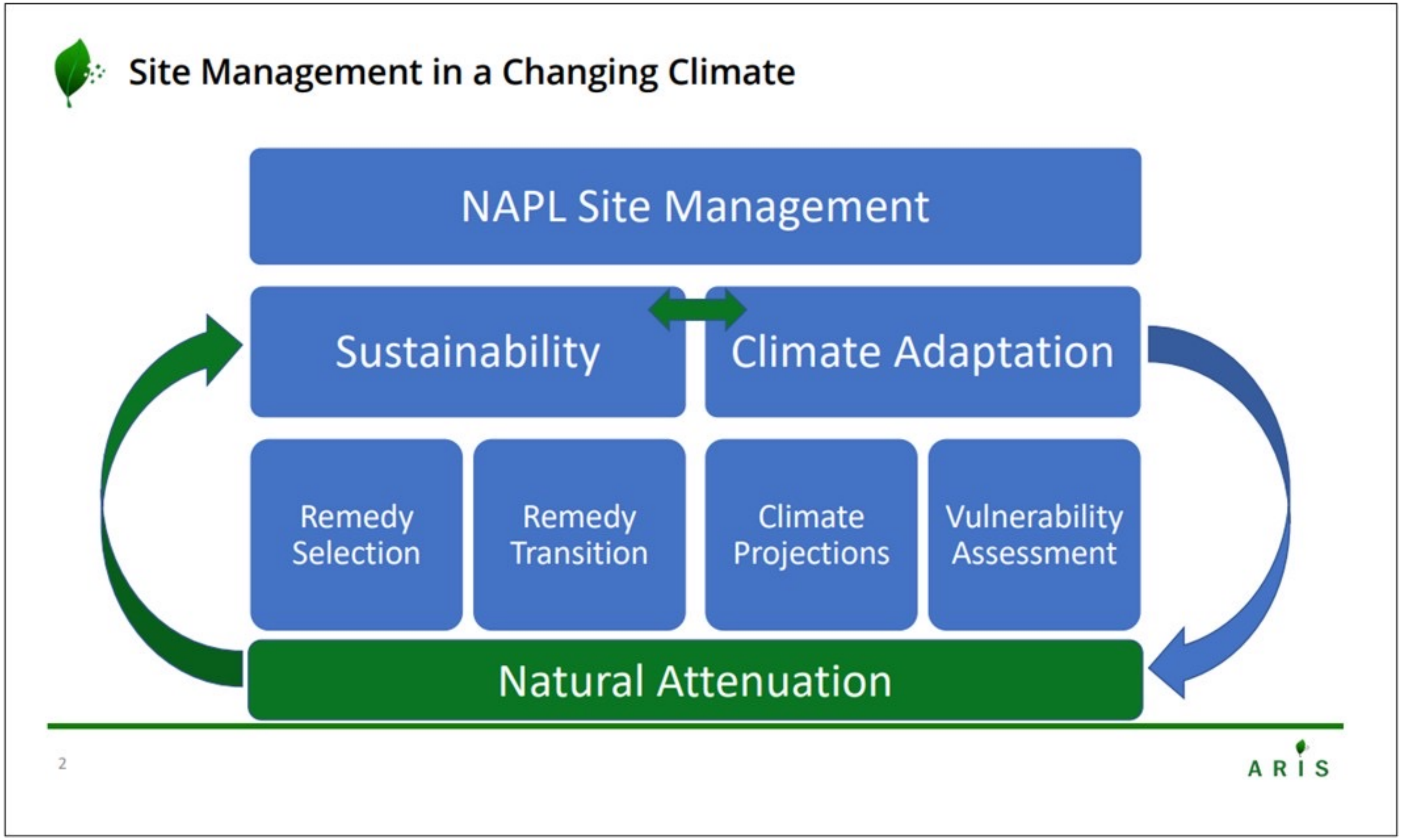
Outline

- Background/Motivation (sustainability, net-environmental benefit)
  - ASTM Guidance (2022) – Standard Guide for Estimating Natural Attenuation Rates for Non-Aqueous Phase Liquids in the Subsurface
  - ASTM Guidance (2024)– Standard Guide for Advancing Stalled (Petroleum Underground Storage Tank) Remediation Sites to Closure
  - Exit Strategy Toolkit (2024)
- Conclusions

GOAL:

- ✓ **promote and put into practice sustainable and resilient approaches to petroleum contaminated land management**
- ✓ **leverage the science on natural attenuation and demonstrate how to meaningfully apply it to support confident remedial decision making**

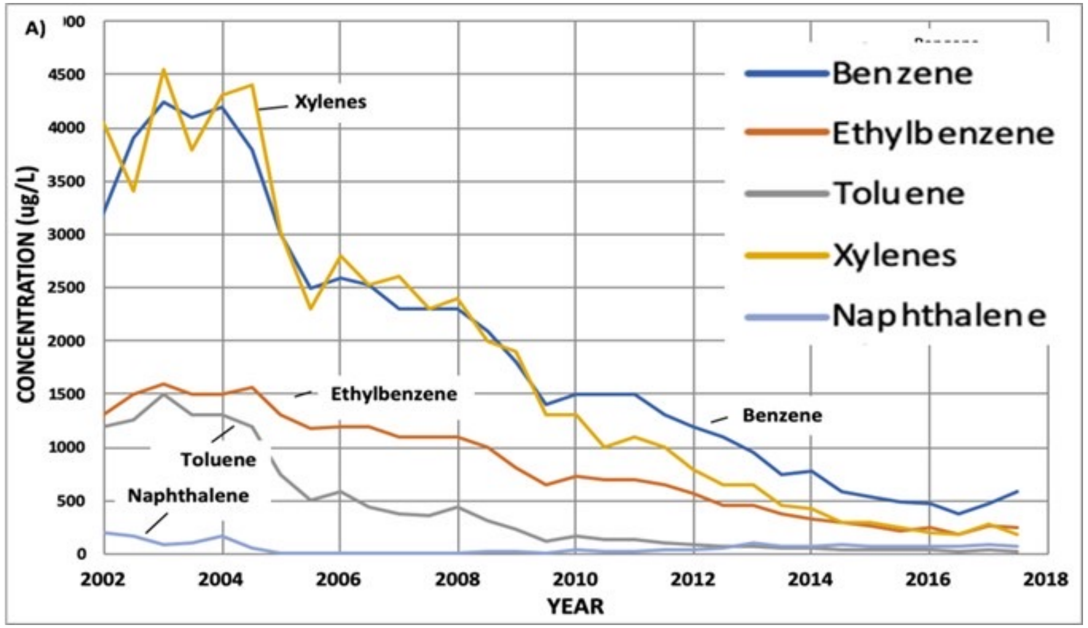
Issue: Navigating the NAPL Site Management Paradigm

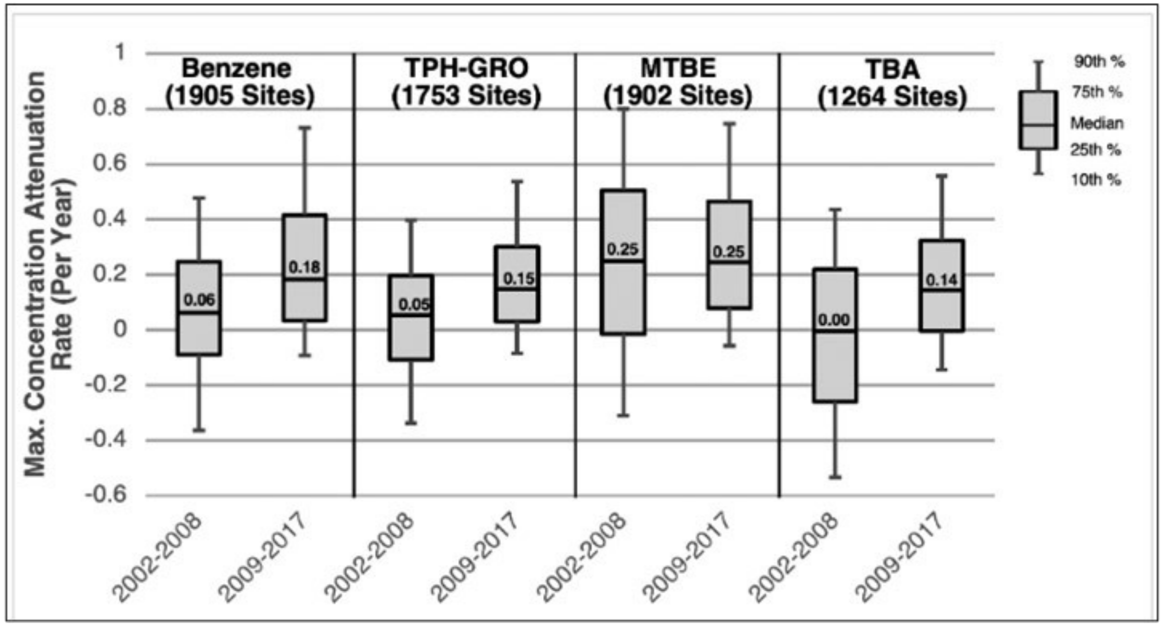


From: Jourabchi, P. , 2022. Natural Source Zone Depletion: Standard Guide for Estimating Natural Attenuation Rates for NAPL in the Subsurface, 27th National Tanks Conference, Pittsburgh, PA September 13 - 15, 2022

Issue: Opportunity for Greater Uptake of Science on Attenuation Rates

Median GW Source Area Concentrations over Time at 1000s of Sites



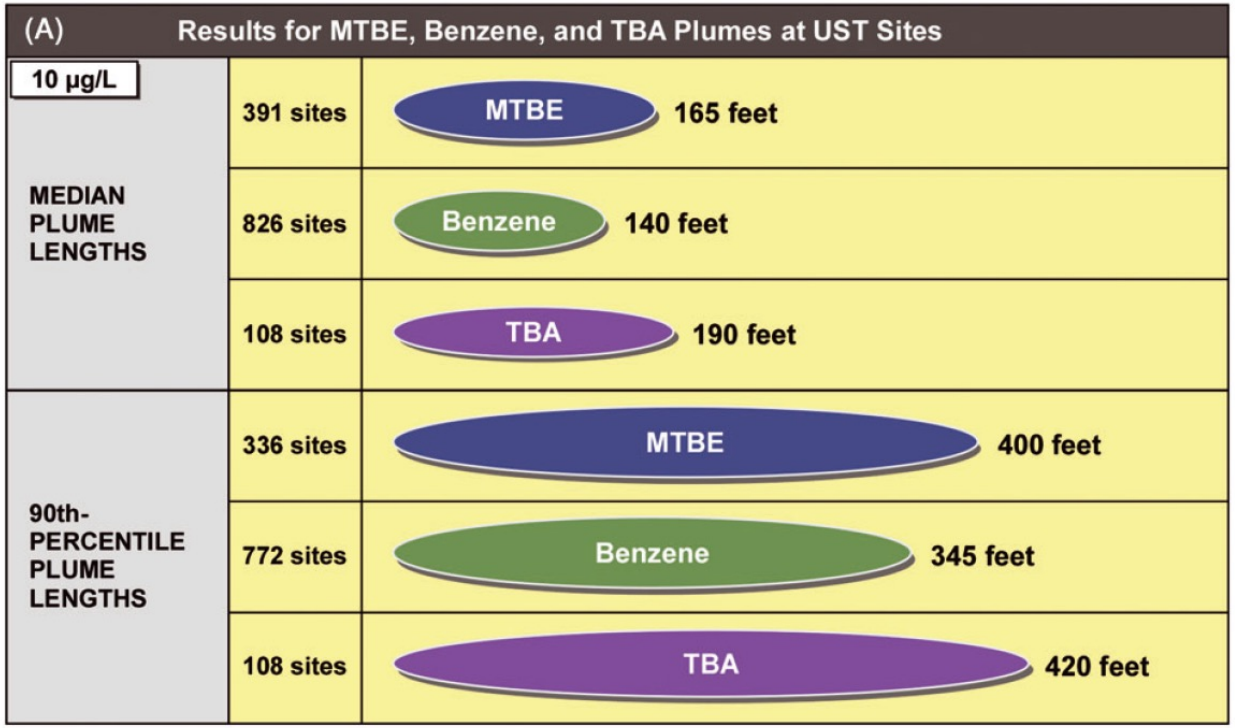


McHugh, T.E., Newell, C.J., Beckley, L.M., Adamson, D.T., DeVaull, G.D., and M.A. Lahvis. 2022. Forecasting groundwater remediation timeframes: Site-specific- temporal monitoring results may not predict future performance. Groundwater Monit. Rem. https://doi.org/10.1111/gwmr.12508

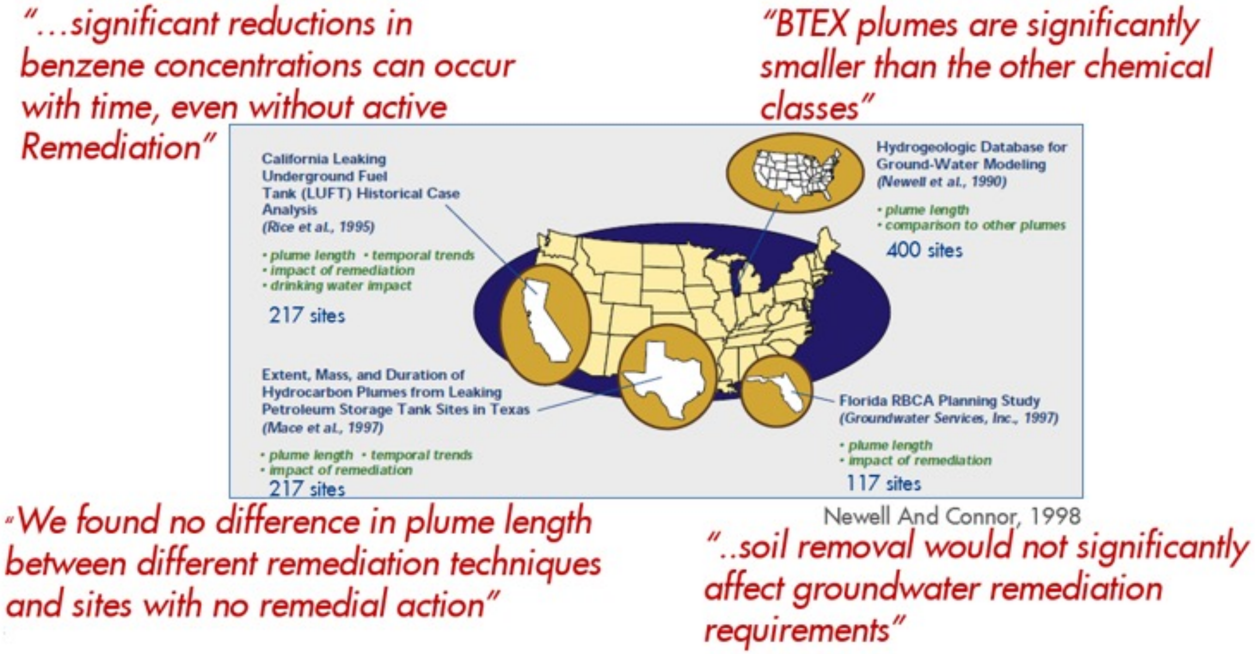
KEY POINT

- median half-lives of 1 - 2 yrs (median source concentrations decrease by 50% every 1-2 yrs)
- concentration reductions a combination of a) mitigation/remediation, b) improved leak prevention and detection, and c) natural attenuation

Issue: Opportunity for Greater Uptake of Science on Plume Lengths



Connor, J.A., Kamath, R., Walker, K.L., and T.E. McHugh. 2015. Review of quantitative surveys of the length and stability of MTBE, TBA, and benzene plumes in groundwater at UST sites. Groundwater Monit. Rem. 53, 195-206. https://doi.org/10.1111/gwat.12233

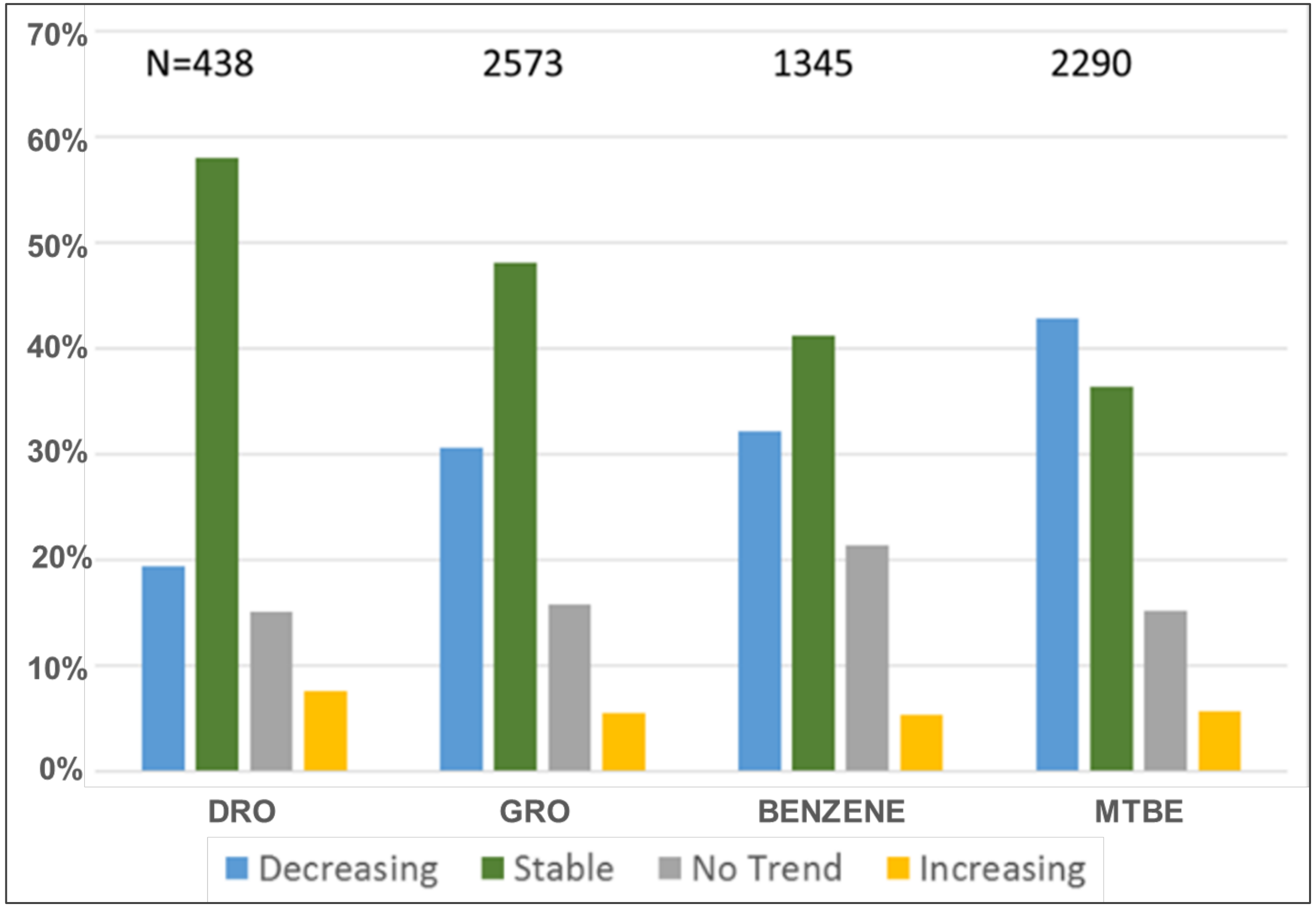


Newell, C.J., and J.A. Connor. 1998. Characteristics of dissolved petroleum hydrocarbon plumes: Results from four studies. American Petroleum Institute Soil and Groundwater Bulletin 8. Washington, DC: American Petroleum Institute.

KEY POINT

- good understanding of plume lengths from published groundwater plumeathon studies (1,000s of sites)

Issue: Opportunity for Greater Uptake of Science on Plume Stability

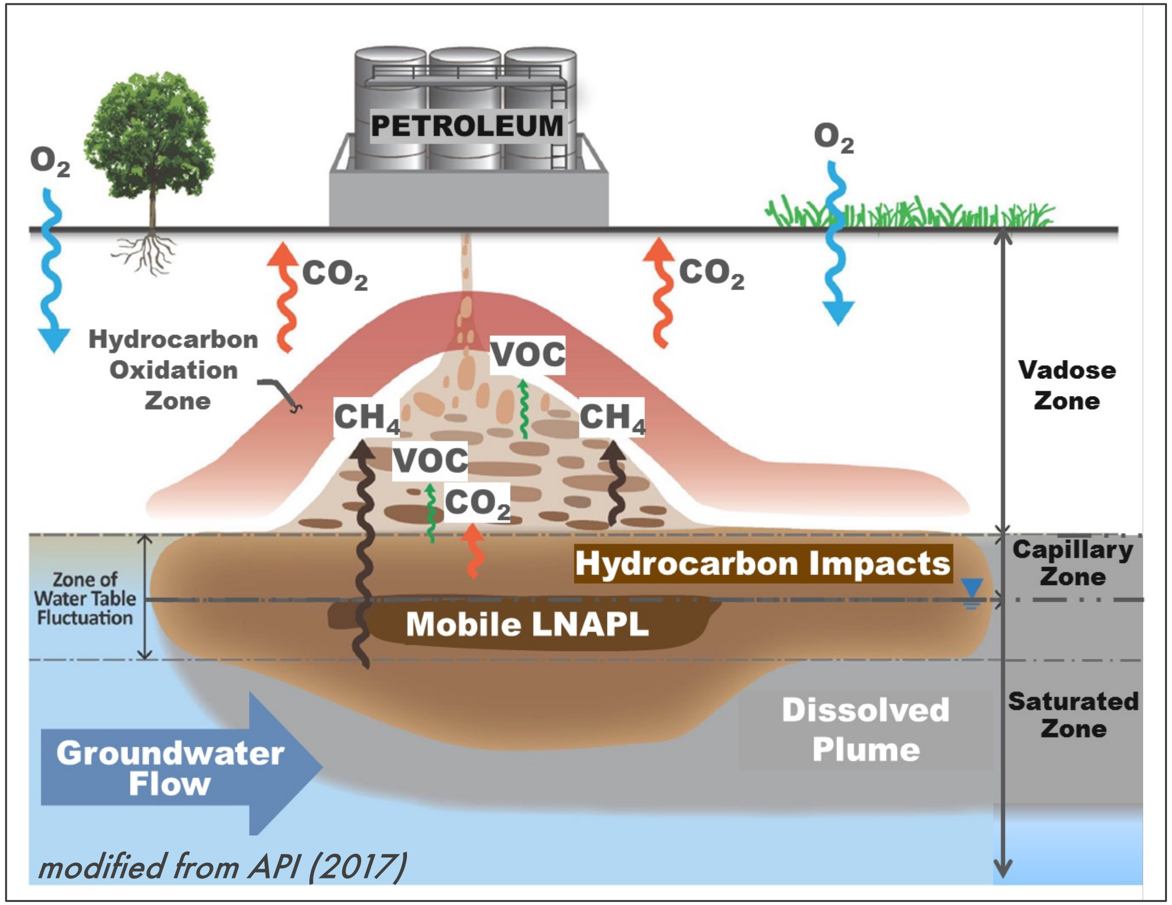


Adapted from: O'Reilly, K., M.A. Lahvis, DeVaull, G.E., and A.M. Deines. 2021. A comparative plume study of DRO, GRO, benzene and MTBE: Implications for risk management. Groundwater Monit. Rem., 41, 58-64. https://doi.org/10.1111/gwmr.12441

KEY POINT

- COPC plumes at 1000s of sites are generally stable or decreasing after monitoring is initiated; an indicator that biodegradation is significant in affecting risk profile

Issue: Opportunity for Greater Uptake of Science on NSZD Rate Estimates



- NSZD is critical hydrocarbon mass-loss pathway:
  - 70% of hydrocarbon can directly outgas to vadose zone (Ng et. al., 2015)
  - rates consistent w/ some engineered remediation (700 – 4,000 gal/acre-yr - - Garg et al., 2017)

KEY POINT

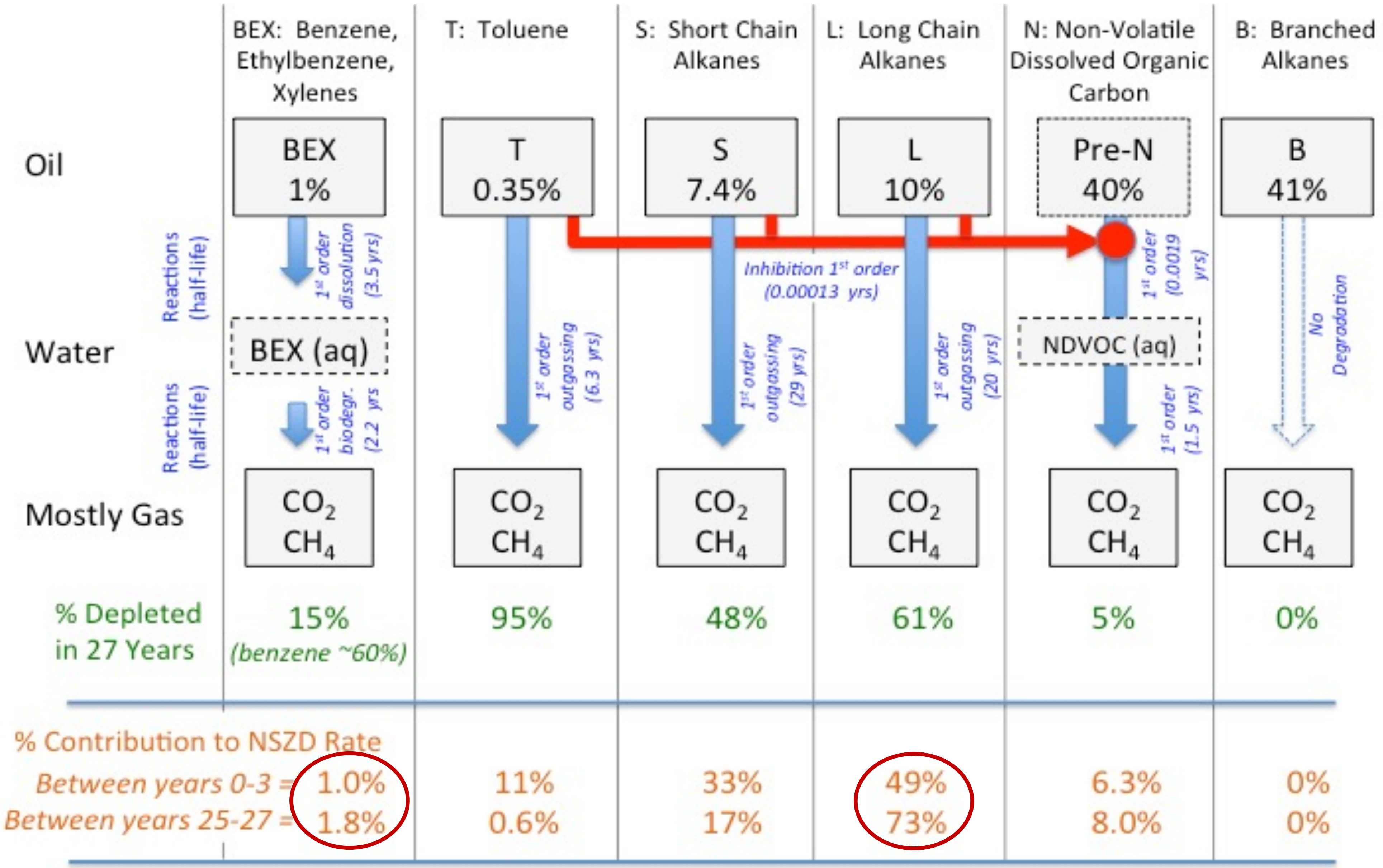
- **How do we leverage NSZD science in remedial decision making?**
- **An opportunity to optimize active remediation?**

API, 2017. Quantification of vapor phase-related natural source zone depletion processes. American Petroleum Institute Publication #4784. API Publishing Services, 1220 L. Street, NW, Washington, DC. May 2017.

Garg, S., C.J. Newell, P.R. Kulkarni, D.C. King, D.T. Adamson, M.I. Renno, and T. Sale. 2017. Overview of Natural Source Zone Depletion: Processes, Controlling Factors, and Composition Change. Groundwater Monit. Rem. 37, 62-81. https://doi.org/10.1111/gwmr.12219

Ng, G.-H.C., Bekins, B.A., Cozzarelli, I.M., Baedecker, M.J., Bennett, P.C., Amos, R.T., and W.N. Herkelrath, 2015. Reactive transport modeling of geochemical controls on secondary water quality impacts at a crude oil spill site near Bemidji, MN, Water Resour. Res., 51, 4156–4183, http://doi:10.1002/2015WR016964

NSZD Rate vs. Composition



KEY POINT

- NSZD (TPH) rate integrates biodegradation and volatilization rates for range of hydrocarbons (COPCs)
- bulk rates don't necessarily reflect attenuation of key risk drivers (e.g., BTEX)

total mass recovery or COPCs?

Issue: Opportunity for Greater Uptake of Science on Methods and Rate Estimation

Application of Four Measurement Techniques to Understand Natural Source Zone Depletion Processes at an LNAPL Site

https://doi.org/10.1111/gwmr.12398

by Poonam R. Kulkarni, Charles J. Newell, David C. King, Lisa J. Molofsky, and Sanjay Garg

Refinement of the gradient method for the estimation of natural source zone depletion at petroleum contaminated sites

Iason Verginelli [*], Renato Baciocchi

https://doi.org/10.1016/j.jconhyd.2021.103807

Laboratory of Environmental Engineering, Department of Civil Engineering and Computer Science Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133 Rome, Italy

Natural source zone depletion (NSZD) insights from over 15 years of research and measurements: A multi-site study

Poonam R. Kulkarni [a,*], Kenneth L. Walker [a], Charles J. Newell [a], Kayvan Karimi Askarani [b], Yue Li [a], Thomas E. McHugh [a]

https://doi.org/10.1016/j.watres.2022.119170

Overview of Natural Source Zone Depletion: Processes, Controlling Factors, and Composition Change

https://doi.org/10.1111/gwmr.12219

by Sanjay Garg, Charles J. Newell, Poonam R. Kulkarni, David C. King, David T. Adamson, Maria Irianni Renno, and Tom Sale

Tracking NSZD mass removal rates over decades: Site-wide and local scale assessment of mass removal at a legacy petroleum site

G.B. Davis [a,*], J.L. Rayner [a], M.J. Donn [a], C.D. Johnston [a], R. Lukatelich [b], A. King [c], T.P. Bastow [a], E. Bekele [a]

https://doi.org/10.1016/j.jconhyd.2022.104007

A comparison of three methods to assess natural source zone depletion at paved fuel retail sites

https://doi.org/10.1144/qjegh2021-00

Jonathon J. Smith[1], Enrique Benede[2], Birgitta Beuthe[3,4], Manuel Marti[2], Amaya Sayas Lopez[2], Brad W. Koons[5], Andrew J. Kirkman[4,6], Luis A. Barreales[7], Thomas Grosjean[4,8] and Markus Hjort[4*]

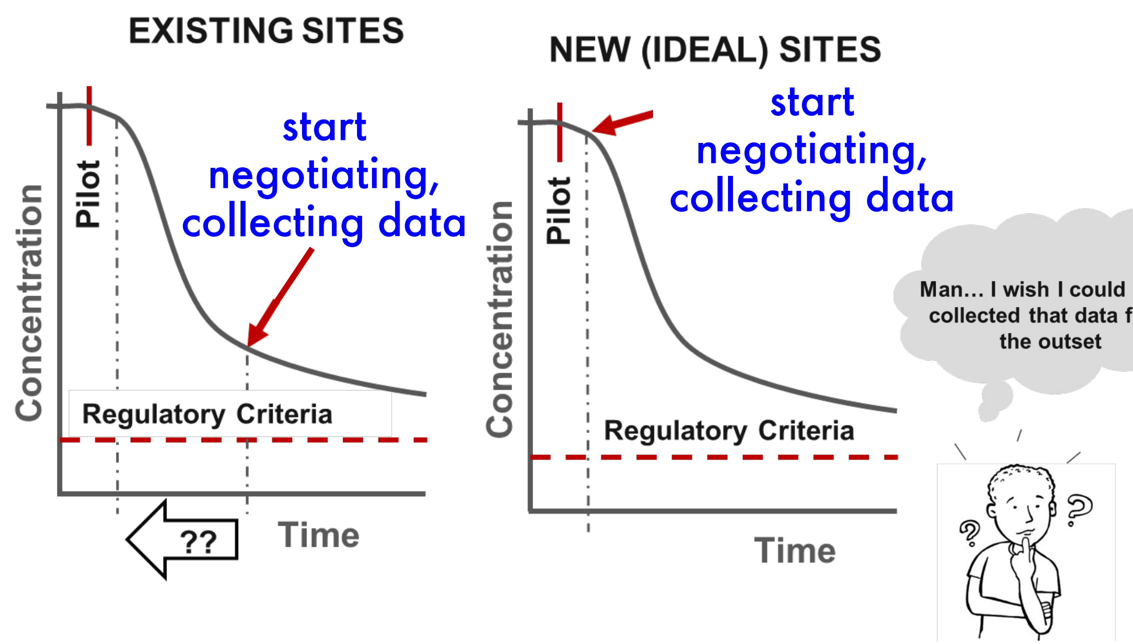
Multiple Lines of Evidence for Estimating NSZD Rates Overlying a Shallow LNAPL Source Zone

Anne Wozney, Ian Hers, Krista Stevenson, Calista Campbell, Nick Nickerson, Colleen Gosse

First published: 04 June 2022 | https://doi.org/10.1111/gwmr.12533

Issue: Opportunity for Greater Uptake of Science by Practitioner Community

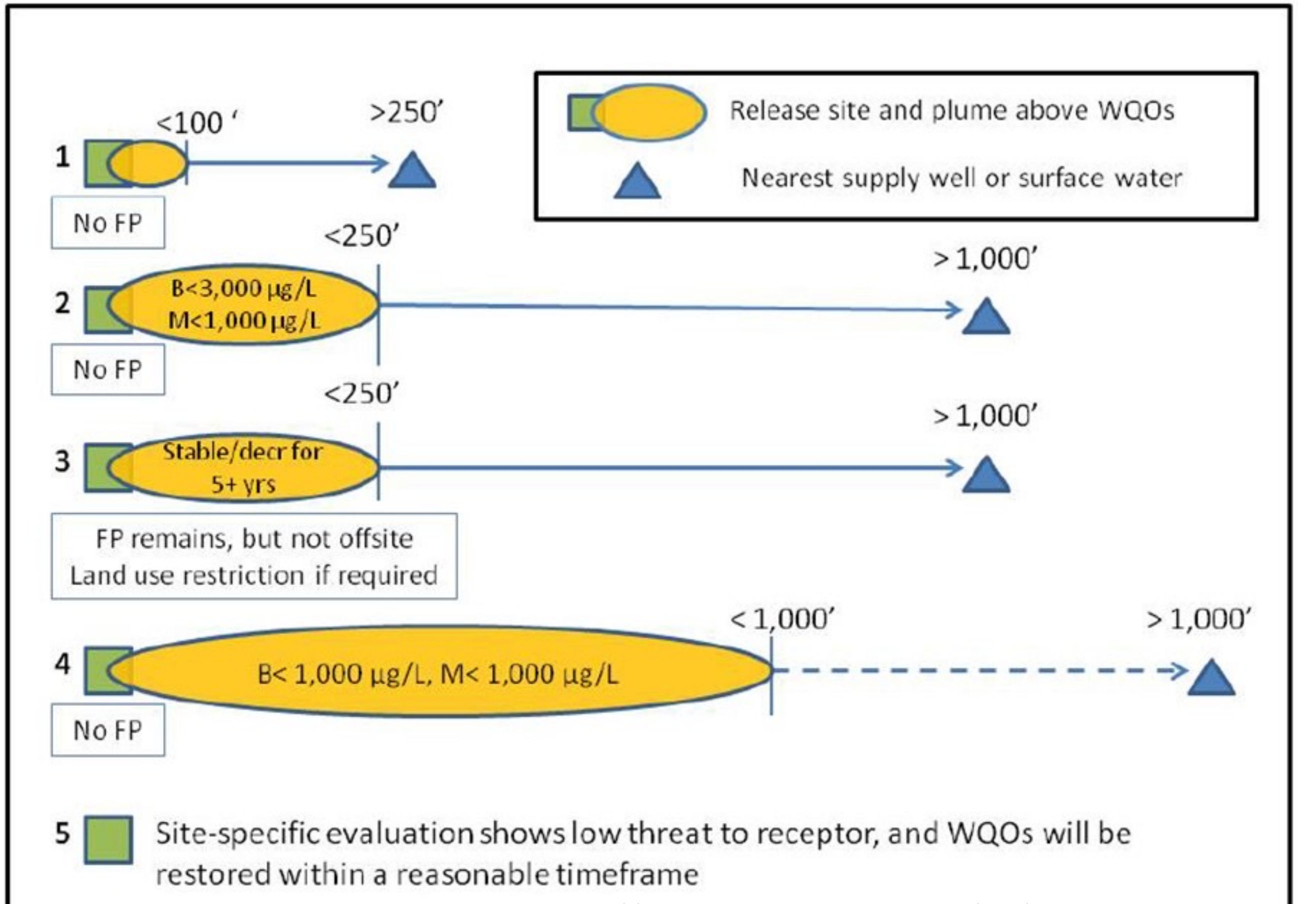
- active remediation systems are often operated beyond where they reduce risk or provide net environmental benefit:
  - failure to set and agree remedial performance criteria
  - little consideration of available tools
  - uncertainty in the ability of natural attenuation to achieve regulatory clean-up levels



- not clear on societal benefits (e.g., Brownfield redevelopment):
  - economic growth
  - job creation
  - betterment of community

Issue: Opportunity for Greater Uptake of Science by Regulators (e.g., California Low-Threat Tank Closure Policy – 2012)

Figure 17-1: Groundwater Plume Classes for Low-Threat UST Case Closure Policy



https://www.waterboards.ca.gov/ust/lt_cls_plcy.html

Notes:

B	Benzene
FP	Free Product
M	Methyl tert butyl ether
Stable/decr	Stable or decreasing in areal extent
WQO	Water Quality Objective

Figure is not to scale

KEY POINT

- science on plume lengths and stability is being used to ID low-threat sites and underpin sustainable, risk-based policy

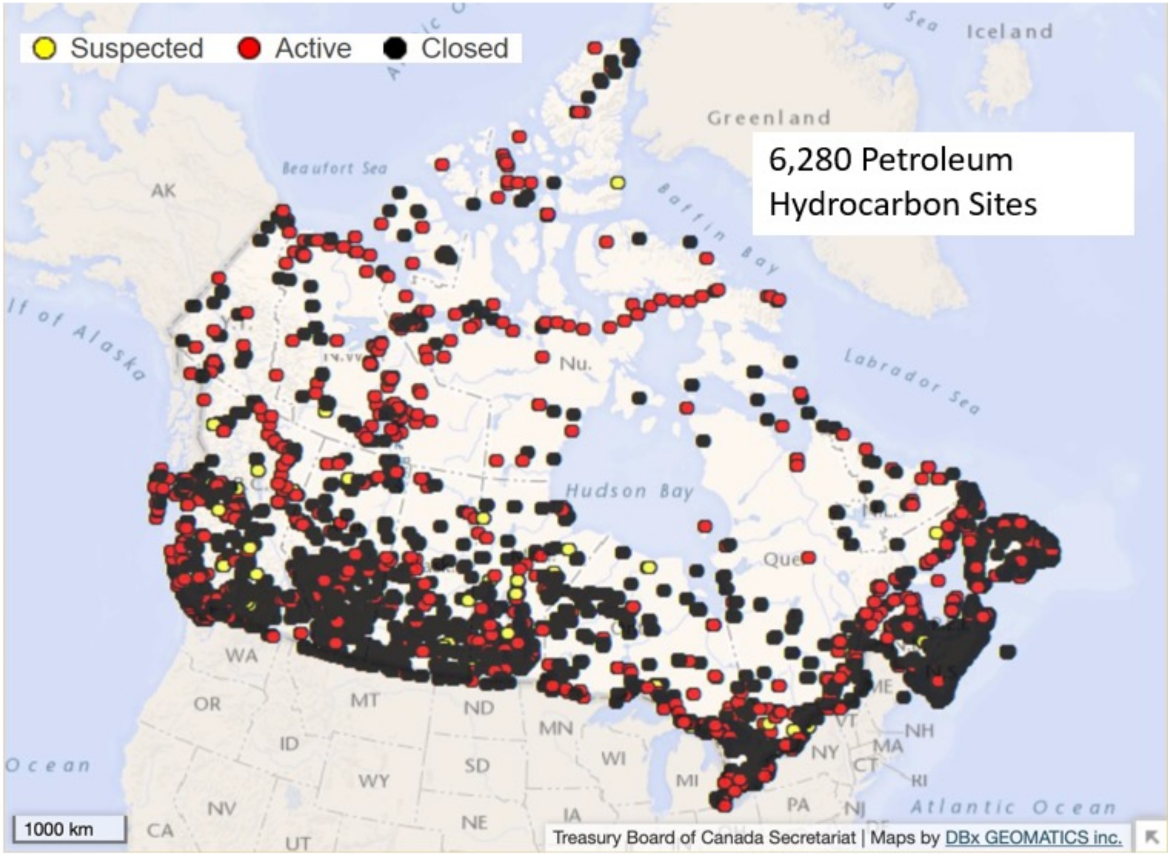
Issue: Need for Improved LNAPL Management is Growing

Federal Contaminated Sites Inventory

How many federal contaminated sites are there in Canada?

Total of 23,078 federal sites:

- 5,337 active contaminated sites
- 2,355 suspected sites
- 15,386 closed (remediation is complete or because no action was necessary following assessment)



- Federal contaminated sites
- Investigation sites from past use
- Non-federal sites for which Government of Canada has accepted some or all financial responsibility

3

https://www.tbs-sct.gc.ca/fcsi-rscf/numbers-numeros-eng.aspx?qid=2121830

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Applied Research for Innovative Solutions

From: Jourabchi, P. , 2019. Compendium of tools and methods for systematic approach to sustainable sites closure for petroleum hydrocarbon sites. Remediation Technologies Symposium RemTech2019, Banff, Alberta, October 17, 2019.

Issue: Closure Criteria Needed by Regulators

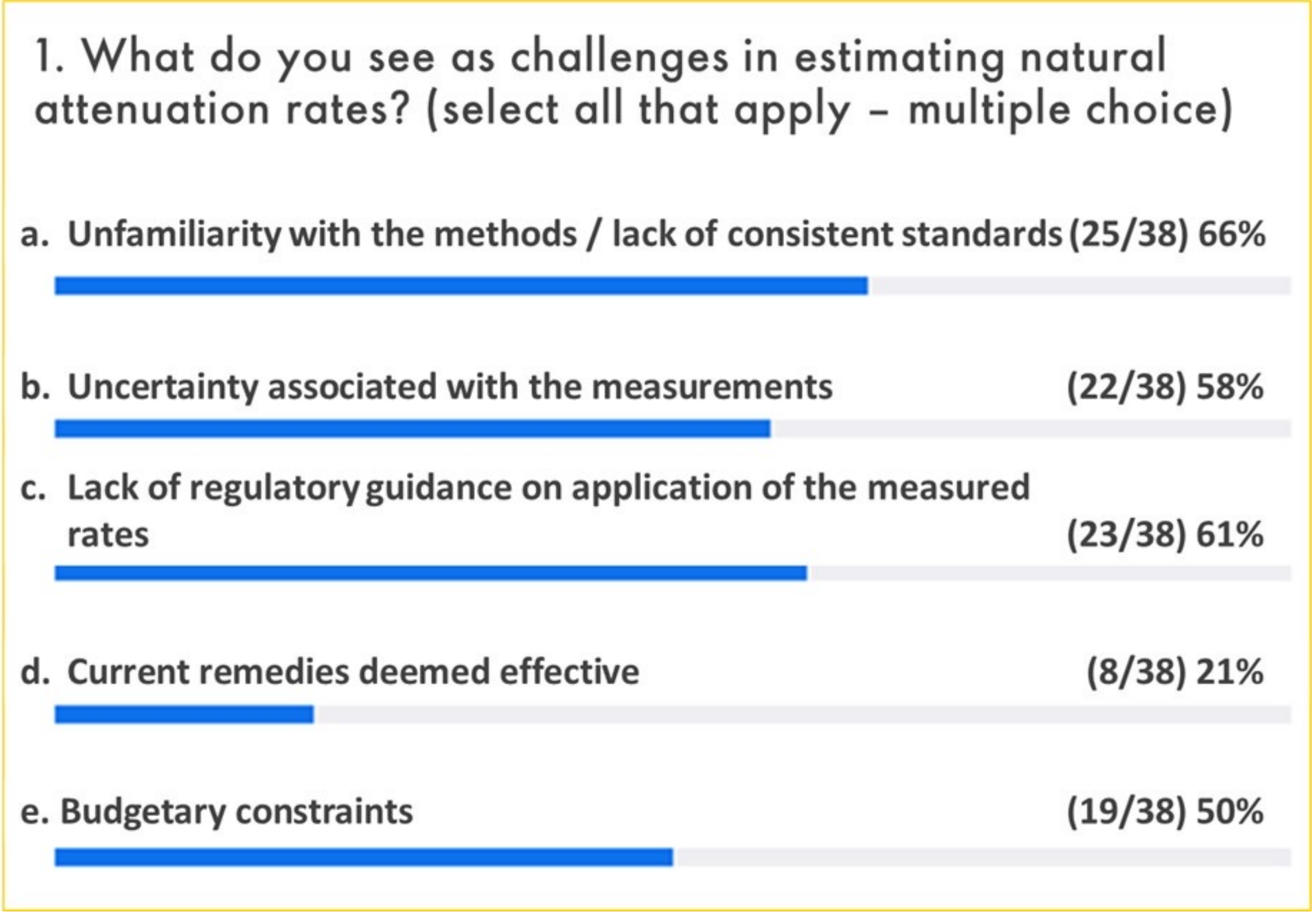
RESULTS

What elements to include in an ASTM Standard?

- ✓ 75% state suggested criteria for closure decisions
- 72% state best practices for managing orphaned sites
- 72% state examples or success stories
- 69% state outreach and training on best practices
- 69% state periodic review of remedial effectiveness

From: Dunn, G. , 2022. Taking the mystery out of closing LUST remediation projects, 27th National Tanks Conference, Pittsburgh, PA September 13 - 15, 2022

Issue: Barriers Remain to Greater Uptake of NSZD



* Results from workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons,

May 12, 2022 (Virtual)
Sponsored by Contaminated Sites Approved Professional Society (CSAP) of BC and Shell

Targeted Guidance to Facilitate More Consistent Uptake & Implementation of Natural Attenuation and NSZD

1).

ASTM INTERNATIONAL

Designation: E3361 – 22

https://www.astm.org/e3361-22.html

Standard Guide for
Estimating Natural Attenuation Rates for Non-Aqueous Phase Liquids in the Subsurface[1]

This standard is issued under the fixed designation E3361; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

2).

Work Item

CELEBRATING 125 YEARS

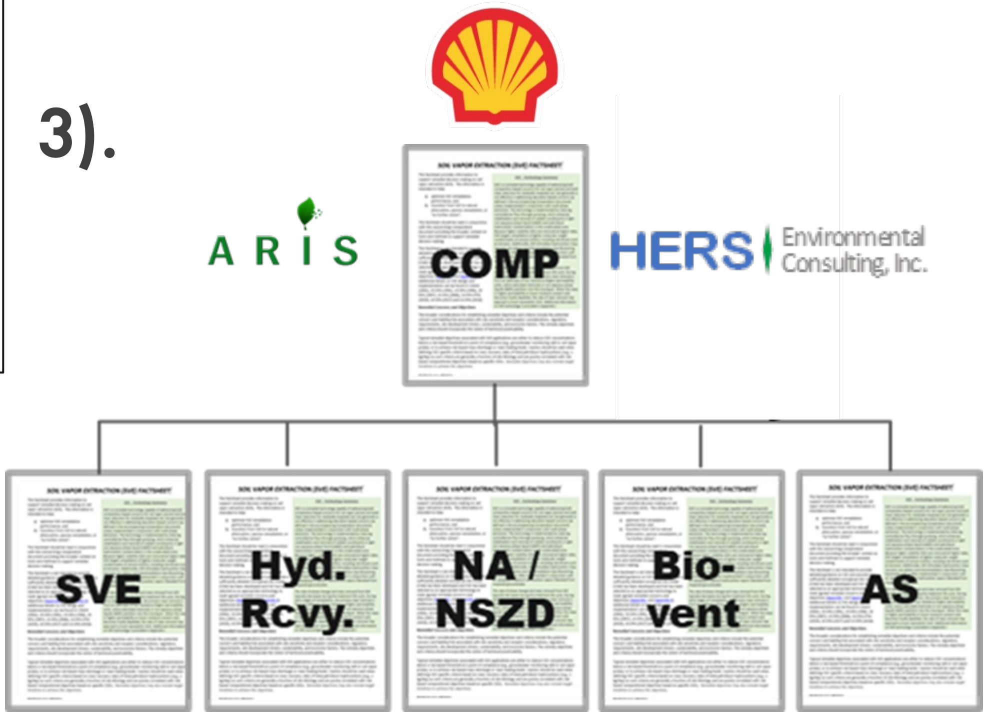
ASTM WK78667

https://www.astm.org/workitem-wk78667

New Guide for Advancing Stalled Corrective Action Sites Toward Site Closure

3).

Exit Strategy Toolkit



ASTM Standard Guide for Estimating Natural Attenuation Rates for Non-Aqueous Phase Liquids in the Subsurface (2022)

Natural Attenuation Estimation Methods

1. CO_2 Efflux Method
2. Temperature Gradient Method
3. Soil Gas Gradient Method
4. Groundwater Monitoring Method
5. NAPL Composition Method

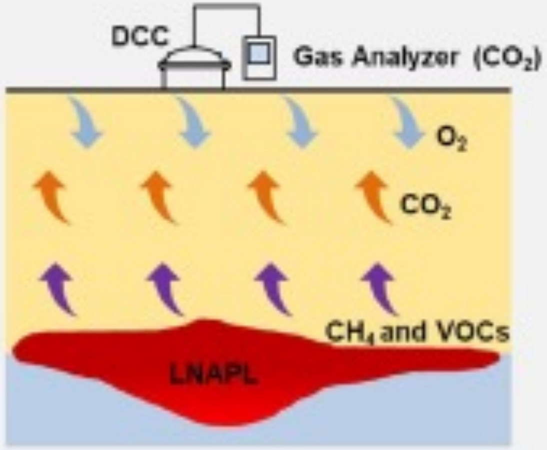
For each method, the standard provides:

- description
- assumptions
- applicability (site conditions), issues (e.g., background correction) and implementation
- screening or feasibility assessment
- data interpretation and key considerations and challenges

Multiple technologies & approaches for data collection & interpretation for each method...

Step-by Step Process for Implementation

CO_2 Efflux Method



Method: upward flux of CO_2 measured with DCC at the ground surface above the LNAPL footprint is used to estimate the NSZD rate. DCC (Dynamic Closed Chambers) are open-bottom containers in which the vapors emitted from the subsurface are accumulated over time. The concentration increase in the chamber (dC/dt) is continuously measured with a gas analyzer (e.g. IR sensor).

Step 1 – Install the DCC: Before the installation of the chambers, the portion of the soil area selected for the monitoring must be cleaned by any grass that could alter the emission of vapors from the subsurface.

Step 2 – Estimate the CO_2 flux: On the basis of the concentration increase in chamber (dC/dt) that is continuously measured with the gas analyzer, it is possible to estimate the total CO_2 flux (J_{CO2}), e.g., by linear interpolation of the measured CO_2 concentration vs. time.

$$J_{CO_2} = \frac{dC}{dt} \cdot \frac{V}{A}$$

J_{CO2} = Total CO_2 flux (μmol CO_2/m^2/s)
dC/dt = CO_2 increase over time (μmol CO_2/m^3/s)
V/A = DCC height (m)

Method Selection Varies Based on Whether Concern is Saturation or Composition

NAPL Composition Method – New Guidance Content

Groundwater Monitoring&Remediation

DeVaull et al. (2020)

Petroleum NAPL Depletion Estimates and Selection of Marker Constituents from Compositional Analysis

by George E. DeVaull, Ileana A. L. Rhodes, Emiliano Hinojosa, and Cristin L. Bruce

at $(t = 0)$ for total NAPL $(k_{eff,T}(t = 0)$; per year)

or individual constituents $(k_{eff,i}(t = 0)$; per year)

Or the half-life, $t_{half} = \frac{-\ln(0.5)}{k_{eff}}$ (years)

Step 1. Identify the relevant constituents
Step 2. Analyze data on mass fractions of NAPL constituents
Step 3. Identify potential markers
Step 4. Refinement on identifying potential markers
Step 5. Estimate the effective rates

$$Remaining\ fraction\ at\ time, t = \frac{\chi_{A,q}(0) + (1 - \chi_{A,q}(0))e^{-\kappa_{A,q}t}}{\chi_{A,i}(0) + (1 - \chi_{A,i}(0))e^{-\kappa_{A,i}t}}$$

mass fractions

relative rates

48

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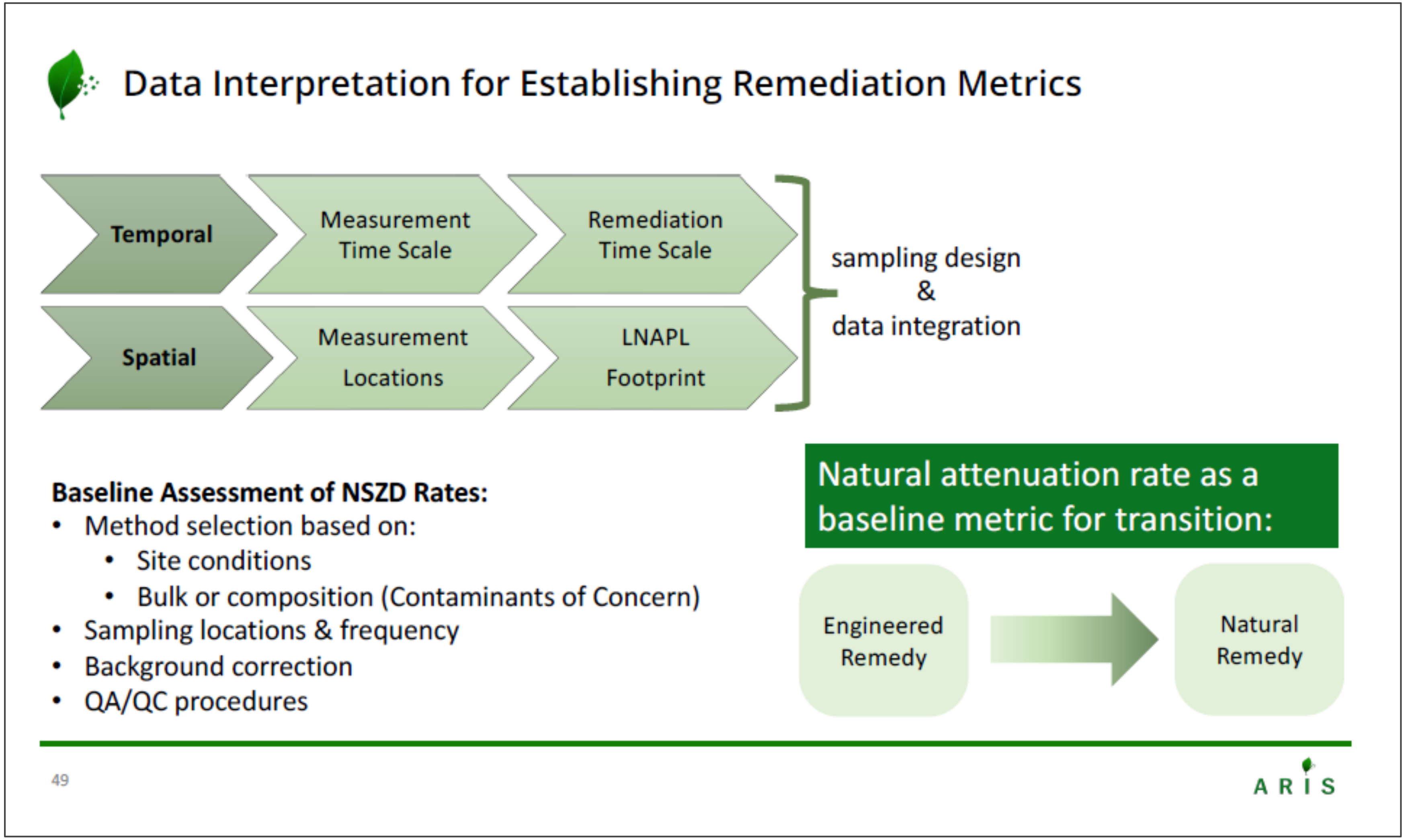
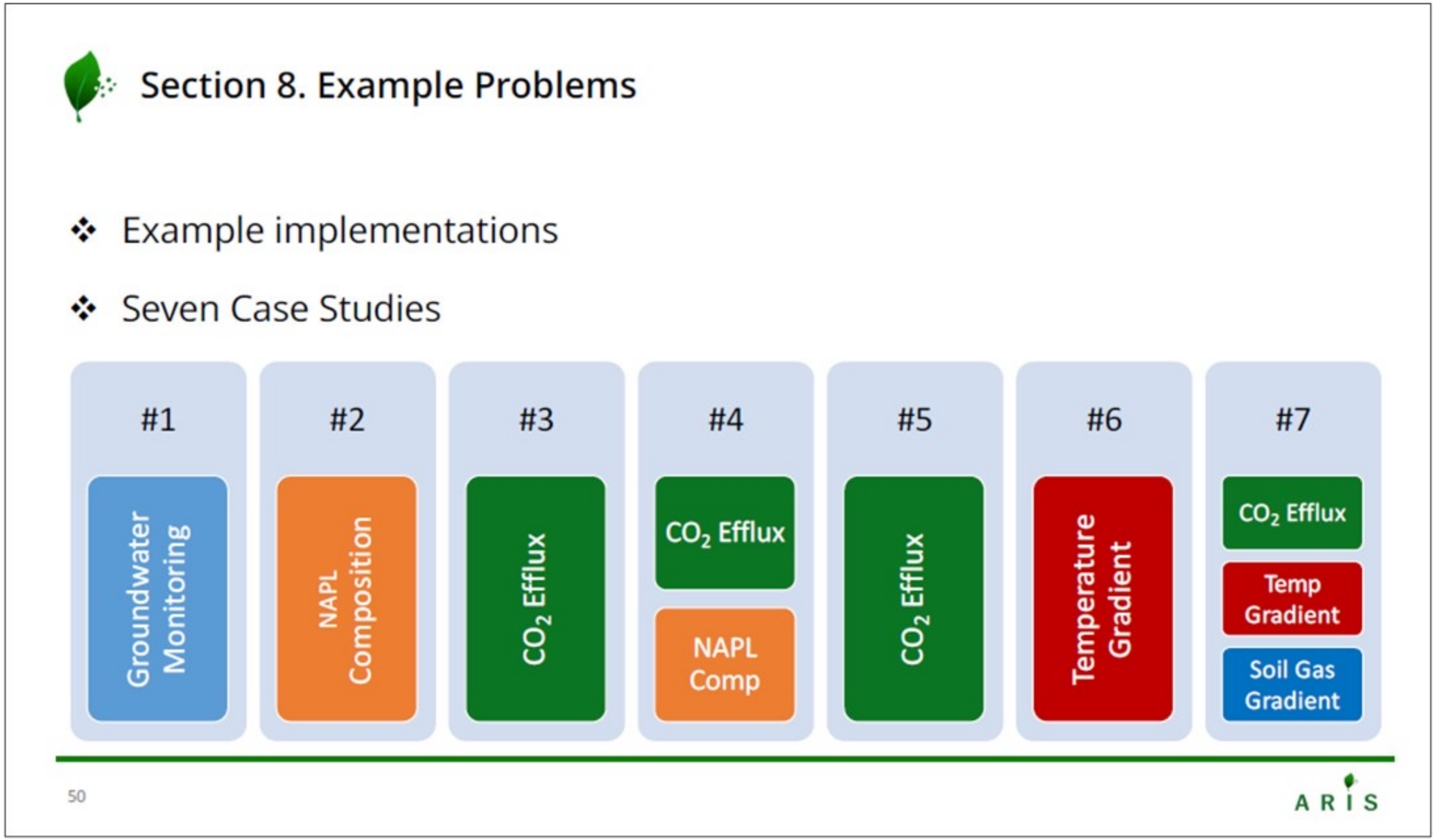
From Jourabchi, P, 2022. ASTM International Session 6 = Natural Source Zone Depletion (NSZD): Standard Guide for Estimating Natural Attenuation Rates for NAPL in the Subsurface. RemTech Europe, September 20, 2022.

Importance of Establishing Remediation Metrics



From Jourabchi, P, 2022. ASTM International Session 6 = Natural Source Zone Depletion (NSZD): Standard Guide for Estimating Natural Attenuation Rates for NAPL in the Subsurface. RemTech Europe, September 20, 2022.

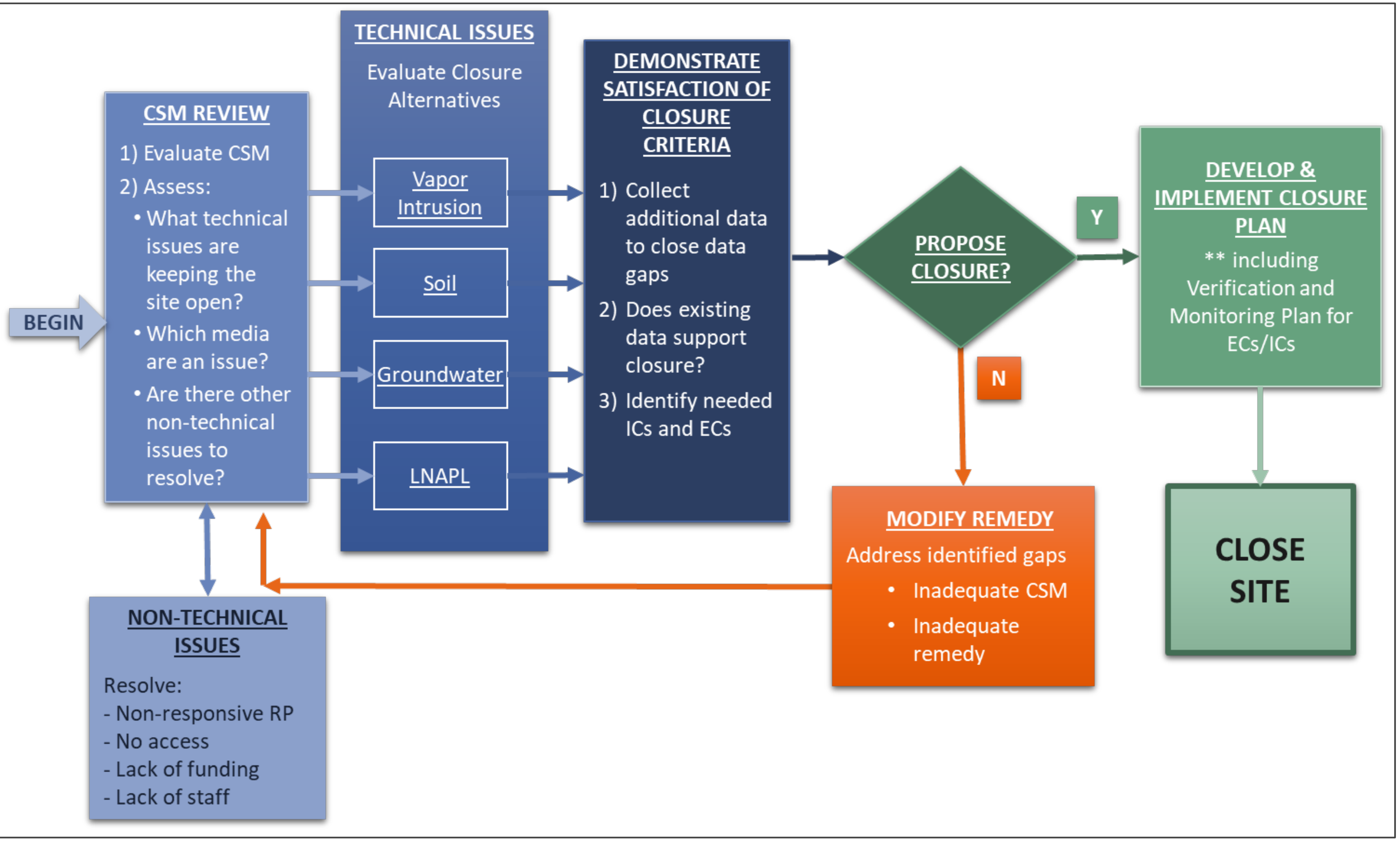
Example Problems and Case Studies



From Jourabchi, P, 2022. ASTM International Session 6 = Natural Source Zone Depletion (NSZD): Standard Guide for Estimating Natural Attenuation Rates for NAPL in the Subsurface. RemTech Europe, September 20, 2022.

ASTM Standard Guide for Advancing Stalled Remediation Sites to Closure (2024)

ASTM Guidance: Contents

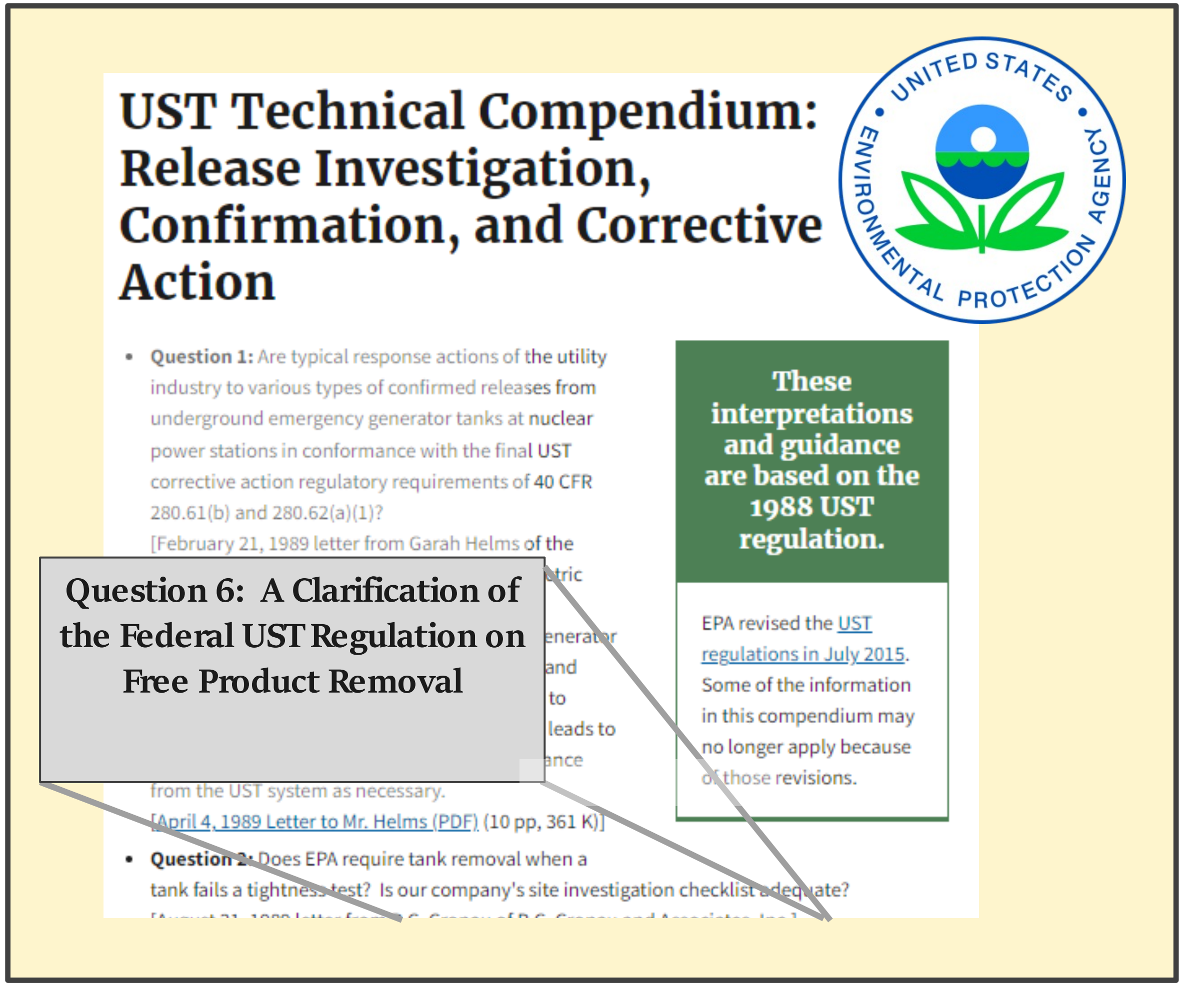


Closure Alternatives

- description
- closure criteria
  - distance-based
  - concentration-based
  - mass-flux based
- CSM data needs
- uncertainties
- engineering controls
- institutional controls

LNAPL – Closure Criteria

- focus on migration – consistent w/ US EPA clarification of 1988 Federal Underground Storage Tank (UST) regulation… LNAPL recovery is no longer required unless LNAPL is migrating or poses a risk to human health or environment
- example criteria:
  - stable/decreasing LNAPL footprint over time
  - stable or decreasing concentrations of LNAPL-related COCs in groundwater or plume lengths over time
  - LNAPL transmissivities < 0.8 ft^2/day
  - residual LNAPL located beyond where LNAPL appears in monitoring wells



https://www.epa.gov/ust/ust-technical-compendium-release-investigation-confirmation-and-corrective-action

Groundwater – Closure Alternatives

Type	Description
Distance-Based Assessments	Lateral separation distances between the leading edge of a COC plume and a current and future receptor are sufficient to allow COCs to attenuate below action levels before reaching a receptors (e.g., supply well, surface water body).
Concentration-Based Assessments	Attenuation rates of COCs in groundwater are sufficiently rapid to achieve background concentrations or site-specific clean-up goals prior to the expected use of any affected groundwater.
Mass-Limited (Flux/Discharge)-Based Assessments	Mass of COCs in groundwater are sufficiently small to prevent COC concentrations from exceeding background or regulatory target levels at points of exposure (e.g., supply wells or surface water bodies)
Engineering Controls	Application of land use management measures (physical controls and barriers) prevent current and future threats from COCs in groundwater.
Institutional Controls	Application of legal and administrative tools reduce the risk of current or future exposures from COCs in groundwater.

Soil – Closure Alternatives

Type	Description
Distance-Based Assessments	Vertical separation distances between a soil source and a current and future receptor are sufficient to prevent exposure to a receptor (atmospheric air, groundwater).
Concentration-Based Assessments	Attenuation rates of COCs in soil are sufficiently rapid to achieve background concentrations or site-specific clean-up goals prior to the expected use of any affected soil.
Mass-Limited Based Assessments	Mass of COCs in soil are sufficiently small to prevent COC concentrations in air or groundwater from exceeding background or regulatory target levels.
Engineering Controls	Application of land use management measures (physical controls and barriers) prevent current and future threats from COCs in soil.
Institutional Controls	Application of legal and administrative tools are implemented reduce the risk of current or future exposures from COCs in soil.

Vadose Zone – Closure Alternatives

Type	Description
Distance-Based Assessments	Lateral and vertical separation distances between a COC source in soil or groundwater and a current and future receptor are sufficient to allow COCs to attenuate below screening levels before reaching indoor air.
Concentration-Based Assessments	Concentrations of COCs in soil gas or groundwater are below screening or site-specific target levels.
Mass Limited (Flux)-Based Assessments	Mass of COCs in soil or groundwater is sufficiently small to prevent COC concentrations in indoor air from exceeding background or regulatory target levels.
Engineering Controls	Application of land use management measures (physical controls and barriers) prevent current and future human health and ecological exposures.
Institutional Controls	Application of legal and administrative tools prevent current and future human health and ecological exposures.

Exit Strategy Toolkit
(IN PRESS)

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

Technology Specific Factsheets:

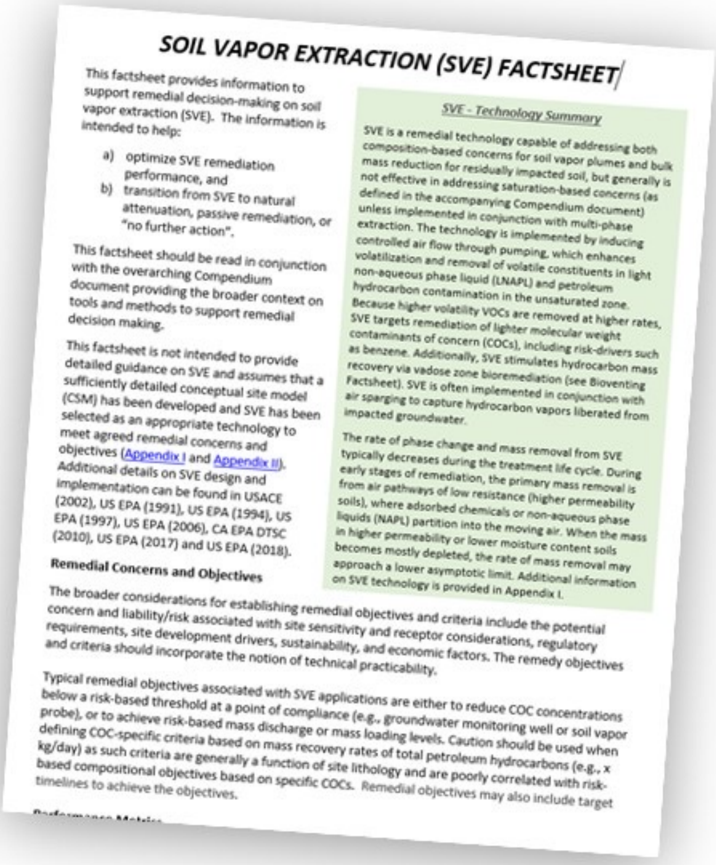
- Compendium (general framework)
- SVE
- Bioventing
- LNAPL Hydraulic Recovery
- Natural Attenuation / Natural Source Zone Depletion (NSZD)

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:

- baseline natural attenuation rate / NSZD assessment
- performance metrics
- transition thresholds
- validation criteria
- upfront stakeholder alignment
  - metrics/thresholds/criteria
  - saturation vs. composition
  - tollgates
- multiple lines of evidence (MLE)
- latest science is leveraged
- environmental & sustainability focus (technical, economic, social)



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

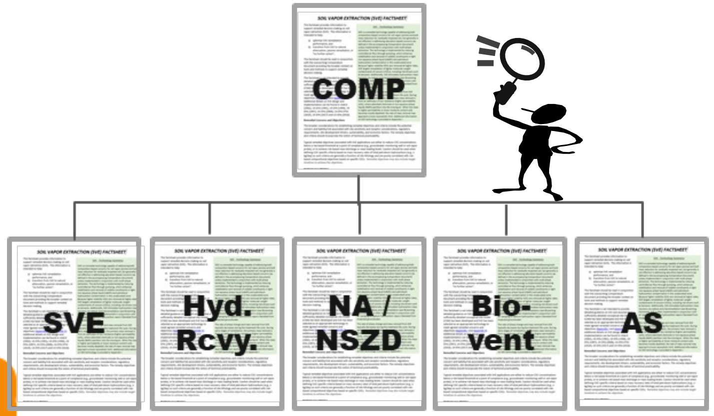
The broader considerations for establishing remedial objectives and criteria include the potential concern and liability/risk associated with site sensitivity and receptor considerations, regulatory requirements, site development drivers, sustainability, and economic factors. The remedy objectives and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

Goal

- ✓ systematic MLE approach to initiating, evaluating, terminating active remediation
- ✓ optimized (less "unnecessary) active remediation
- ✓ more confident remedial decision making
- ✓ more successful stakeholder communication

Compendium Roadmap (1/2)



1. RISK IDENTIFICATION & EVALUATION

SCREENING ASSESSMENT - identify rapid response, screen out scenarios:

- LNAPL Mobility
- Soil, Groundwater, Vapor Concentrations
- Groundwater Plume Extent & Stability

Acute risk identified → rapid response

Meet applicable → completed

MORE DETAILED ASSESSMENT

identify remedial concerns and establish remedial objectives

Saturation-Based Concern

(e.g., targeting LNAPL mobility, recoverability to the maximum extent practicable, total mass recovery)

Composition-Based Concern

(e.g. targeting numerical/risk-based standards within reasonable timeframe or mass-based estimates for COCs)

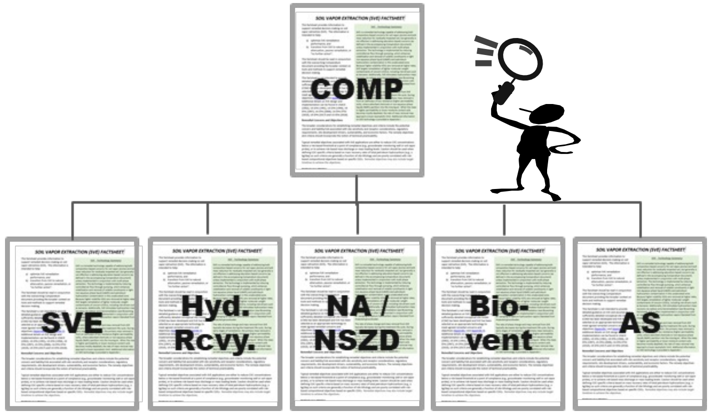
Saturation Concern

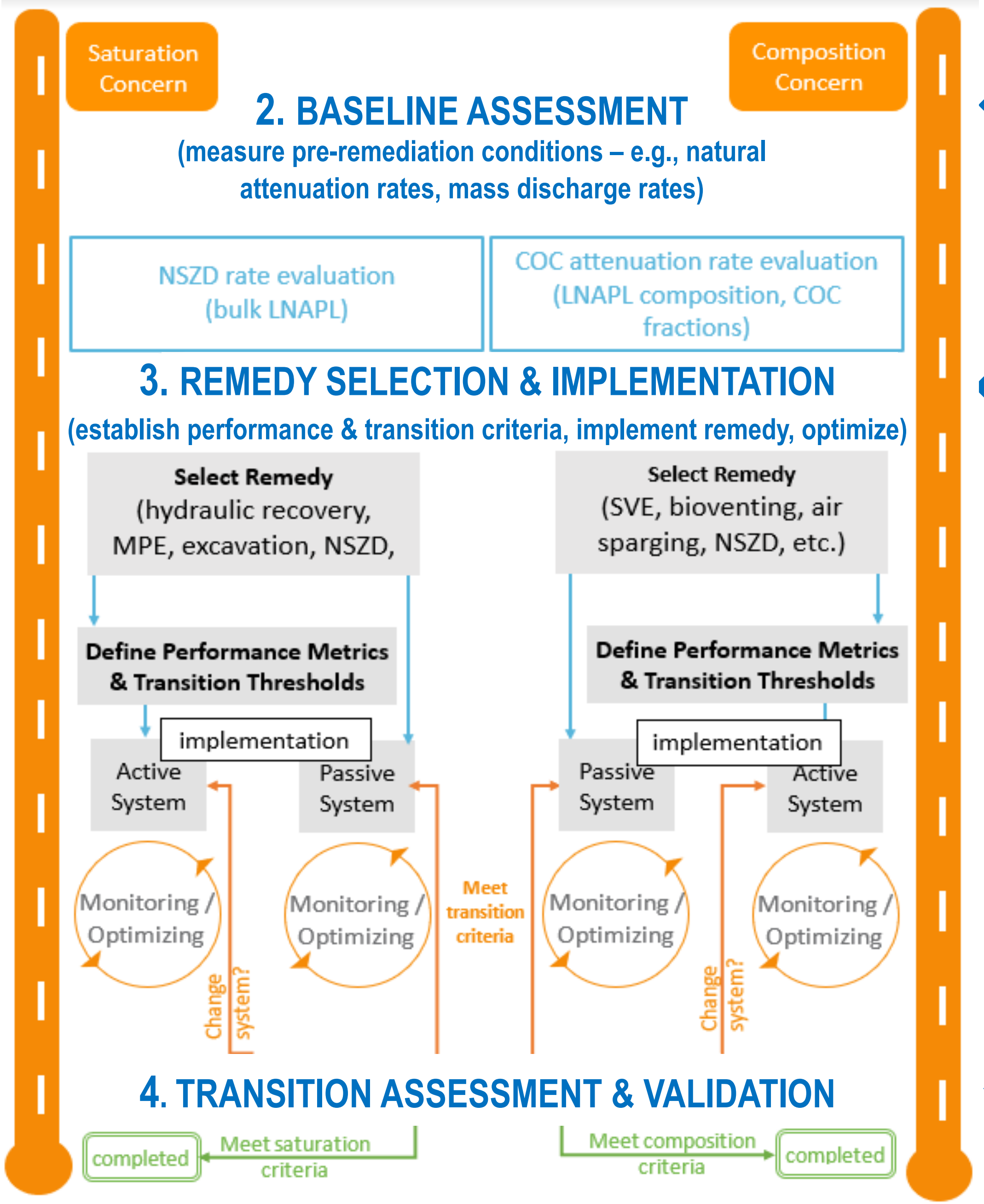
Migrating LNAPL body
Mobile LNAPL > threshold

Composition Concern

Concentration or mass discharge > criteria

Compendium Roadmap (2/2)





MEASURE/ASSESS PRE-EXISTING CONDITIONS (e.g., natural attenuation, NSZD, mass-discharge rates)

ESTABLISH & ALIGN ON PERFORMANCE & TRANSITION CRITERIA / OPTIMIZE REMEDIATION

VALIDATE TRANSITION PERFORMANCE & TRANSITION

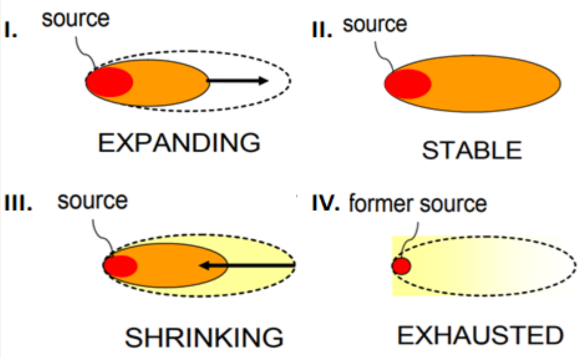
Performance Metrics: (Examples for Saturation-Based LNAPL Concern)

Methods, cost, and where to learn more are provided for each performance metric

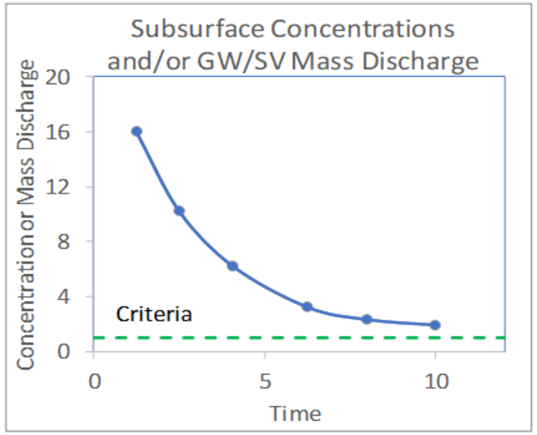
Table 2. Performance Metrics for Saturation-Based Concern

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 ASTM – Natural Attenuation Rates for NAPLs
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)

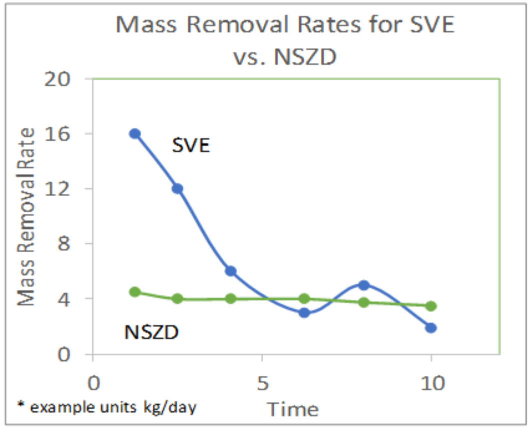
Transition Thresholds: (Examples: SVE)



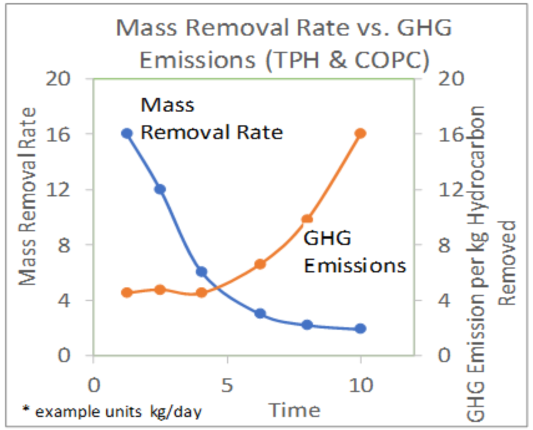
T1. Groundwater Plume is Stable or Shrinking (see Toolkit 2)



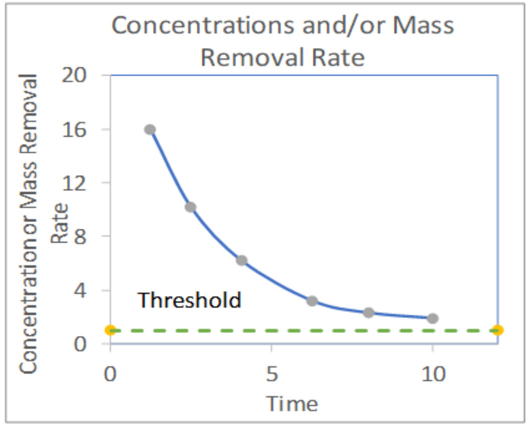
T2. Concentration/Mass Flux Approaching Asymptote or Criteria (see Toolkit 2)



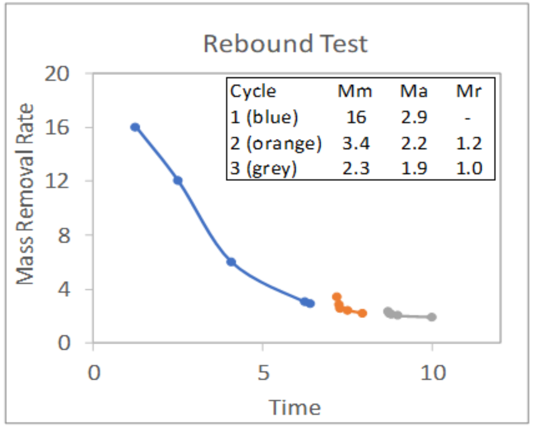
T5. Active Mass Removal Rate Approaching or is Less than NSZD Rate (see this Compendium)



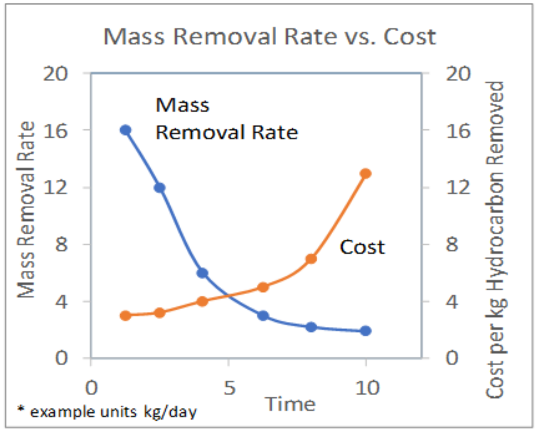
T6. Normalized GHC Emissions (or other metric) Increasing with Little Benefit from Continued Operation (see Toolkit 4)



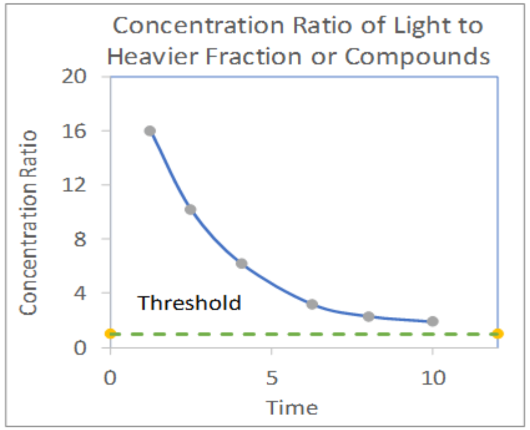
T3. Extracted Soil Gas Concentration/ Mass Removal Rate Approaching Asymptote or Risk-based Threshold (see Toolkit 2)



T4. Minimal or acceptable rebound



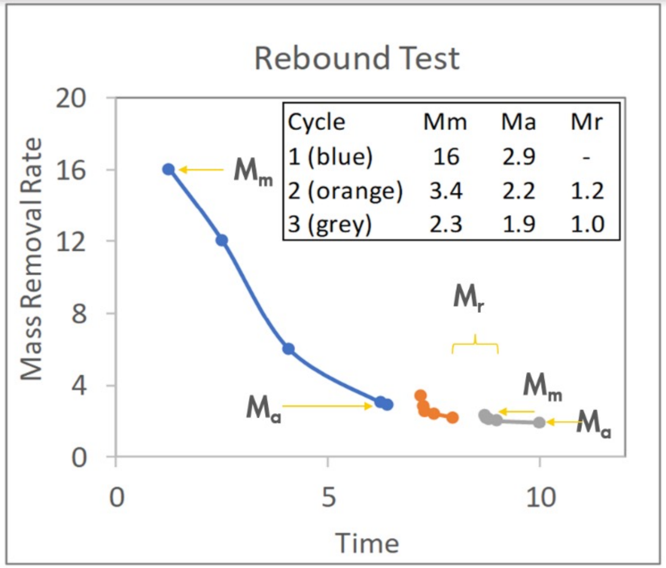
T7. Normalized Cost Increasing with Little Benefit from Continued Operation (see Toolkit 4)

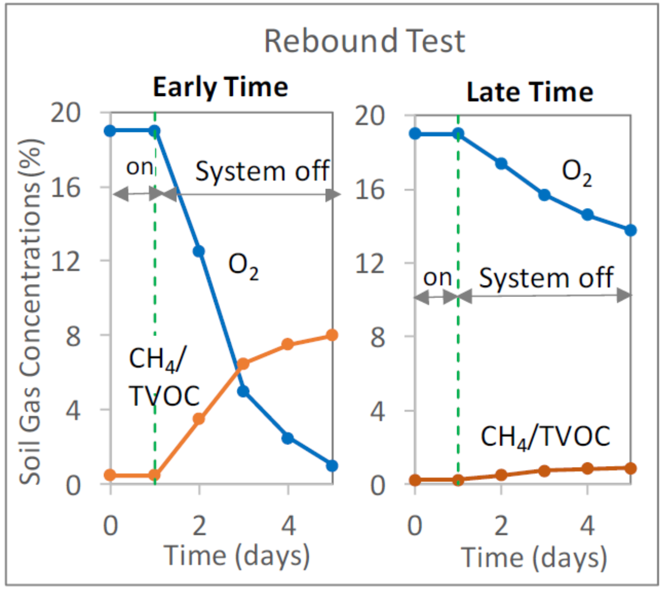


T8. Concentration Ratio Approaching Asymptote or Risk-based Threshold (this Compendium)

Transition thresholds illustrated to facilitate data needs and analyses

Validation: Rebound Testing





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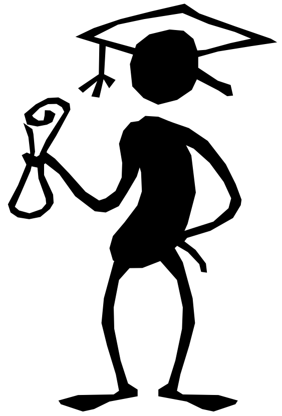
- **SYSTEM**: turning system off and measuring concentrations & mass recovery after initial system restart
  - simple models (Brusseau et al. 2010; Truex et al. 2013)
  - more complex models
    - SVEET (https://www.pnnl.gov/projects/remediation-performance-assessment/soil-vapor-extraction)
    - VIETUS (https://clu-in.org/download/issues/vi/VI-ER-201125-UG.pdf)
- **SUBSURFACE** - monitoring changes in VOC concentrations in soil gas or GW at specific locations over specified time period…requires upfront stakeholder alignment on:
  - duration
  - locations
  - threshold metrics (concentration, flux)
- phased system shut down may be preferrable

Brusseau, M. L., V. Rohay, and M.J. Truex. 2010. Analysis of soil vapor extraction data to evaluate mass-transfer constraints and estimate source-zone mass flux. Ground Water Monitoring and Remediation, 30(3), 57-64. https://doi.org/10.1111/j.1745-6592.2010.01286.x.

Truex, M.J., Becker, D.J., Simon, M.A., Oostrom, M., Rice, A.K., and C.D. Johnson. 2013. Soil vapor extraction system optimization, transition, and closure guidance, Pacific Northwest National Laboratories Publication # PNNL-21843, RPT-DVZ-AFRI-006, February 2013. (https://www.frtr.gov/matrix/documents/Soil-Vapor-Extraction/2013-SVE-System-Operation-Transition-and-Closure-Guidance.pdf)

Take Aways

- quantification of natural attenuation rates is critical for improved, more sustainable, and confident risk-based/remedial decision making
- recent and developing guidance documents target:
  - systematic approaches to documenting and leveraging rates of natural attenuation in remedial decision making
    - initiating, evaluating, terminating active remediation
    - optimization (i.e., less "unnecessary active remediation)
    - greater confidence
- we can do better – all practitioners!



Q&A