Exit Strategy Toolkit: "Getting to Closure" More Confidently and More Sustainably

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ISSUES

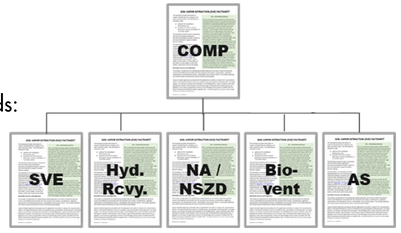
- active remediation systems are often operated at petroleum UST sites beyond where they reduce risk or provide net environmental benefit because of:
  - failure to set and agree remedial performance criteria
  - little consideration of available methods to inform remedial decision making
  - uncertainty in the ability of natural attenuation to achieve regulatory clean-up levels within a "reasonable" time period for key constituents of concern (COCs)

OBJECTIVES

- develop a systematic approach to:
  - improve understanding of remedial concerns, tools, methods, and data needs
  - establish & implement remedial metrics throughout the lifecycle of active remediation
  - incorporate natural attenuation (e.g., natural source-zone depletion - NSZD) into the remedial paradigm

APPROACH

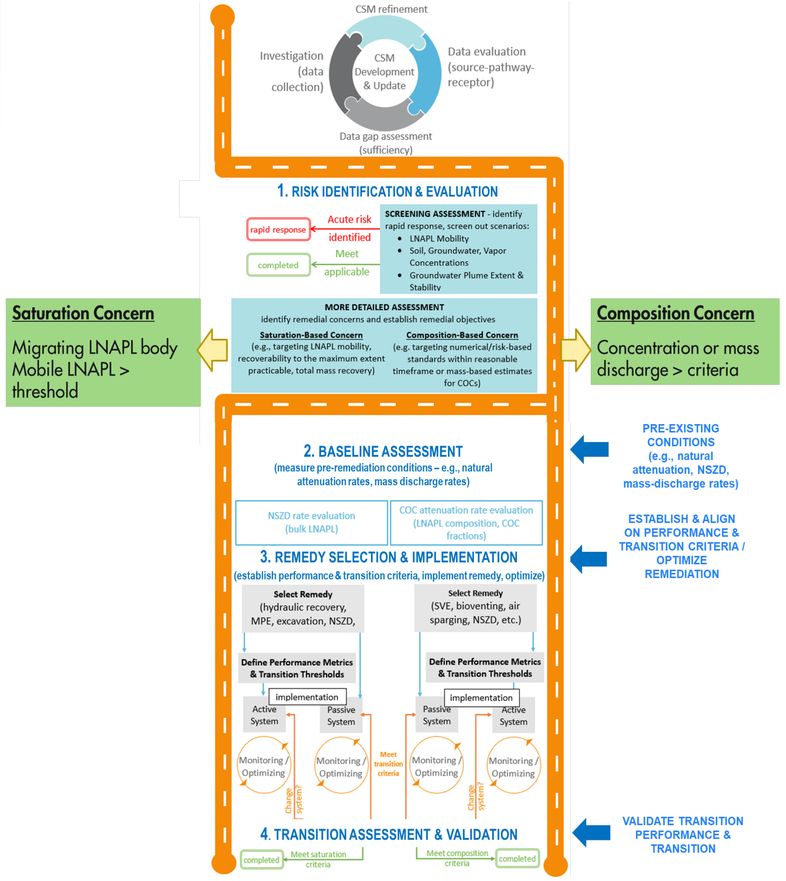
- an Exit Strategy (ES) Toolkit was developed to provide a systematic, non-prescriptive approach to improve sustainable, risk-based decision
- the Toolkit consists of a Compendium & 5 Remediation Factsheets:
  - SVE
  - LNAPL Hydraulic Recovery
  - Bioventing
  - Air Sparging
  - Natural Attenuation & NSZD methods:
    - CO_2 Efflux
    - Temperature Gradient
    - Soil-Gas Gradient
    - Groundwater Monitoring
    - LNAPL Composition



- assuming the CSM is well understood, the Toolkit recommends:

1) baseline assessments to quantify existing rates of hydrocarbon attenuation (i.e., natural attenuation and NSZD rates) prior to active remediation
2) performance metrics to assess whether active remediation is performing as intended and providing a net environmental benefit
3) transition thresholds to inform the transitions between active remediation systems or to monitored natural attenuation (MNA) or no-further action (NFA)
4) validation testing to confirm transitions to MNA or NFA

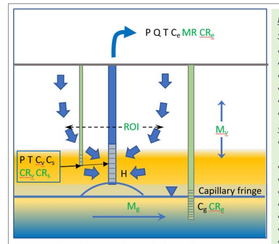
Roadmap to Exit Strategy Toolkit Implementation



Baseline Assessment (e.g., NSZD, MNA, Mass Discharge, LNAPL Tn Estimates)

- document mass loss/discharge/LNAPL recoverability prior to active remediation to confirm need and support optimization (set remedial goals & targets, transition thresholds)

Performance Metrics



Calculated metrics are indicated in green

Performance Metrics

Subsurface:

- C_s = Soil concentration
- C_g = Groundwater concentration
- C_v = Soil vapor concentration
- CR_s CR_g CR_v = Concentration ratios
- M_g = Groundwater mass flux or discharge
- M_v = Soil vapor mass flux or discharge

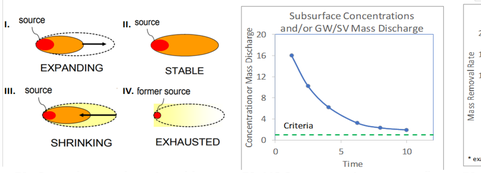
System:

- C_w = Soil gas concentration in extracted gas
- Q = Flow rate
- P = Pressure
- T = Temperature (optional)
- H = Water level mounding
- MR = Mass removal rate ($Q \times C_w$)
- CR_s = Concentration ratios
- ROI = radius of influence

Table 2. Performance Metrics for Saturation-Based Concern

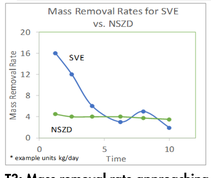
Metric	Methods	Relative Cost	References/Tools
SUBSURFACE METRICS			
LNAPL transmissivity	Bail-down or skimming test Oil-water ratio Other methods	Low to moderate	ITRC LNAPL Guidance (2018) ASTM E2856-13 API Transmissivity Guide
LNAPL footprint (presence/absence in wells)	Time-series measurements in perimeter 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 below)

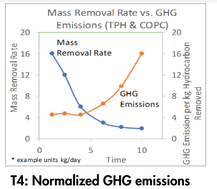


T1: Groundwater plume is stable or shrinking

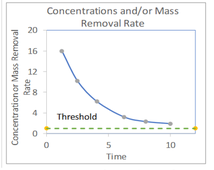
T2: VOC concentration or mass flux approaching asymptote or criterion



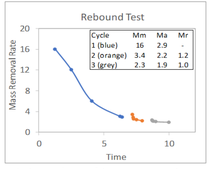
T3: Mass removal rate approaching or less than NSZD rate



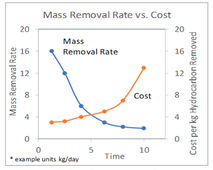
T4: Normalized GHG emissions greatly exceeding mass removal



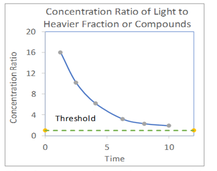
T5: Mass removal rate (or soil-gas concentrations) approaching asymptote or RBSL



T6: No rebound in concentrations after system shutdown



T7: Normalized cost greatly exceeding mass reduction



T8: Concentration ratio approaching asymptote

Validation Testing

- System: turn system off and monitor concentrations and mass recovery after restart
- subsurface: turn system off and measure VOC concentrations @ specific locations over specified times w/ alignment on duration, locations, metrics (concentrations, flux)

CONCLUSIONS

- application at sites w/ planned or existing active remediation is expected to:
  - ✓ provide systematic approach to initiating, optimizing, & terminating active remediation
  - ✓ minimize unnecessary active (i.e., lower costs, carbon dioxide (CO_2) emissions)
  - ✓ facilitate uptake of existing tools and science (e.g., NSZD)
  - ✓ provide more confident remedial decision making
  - ✓ focus limited resources on sites posing the greatest risk