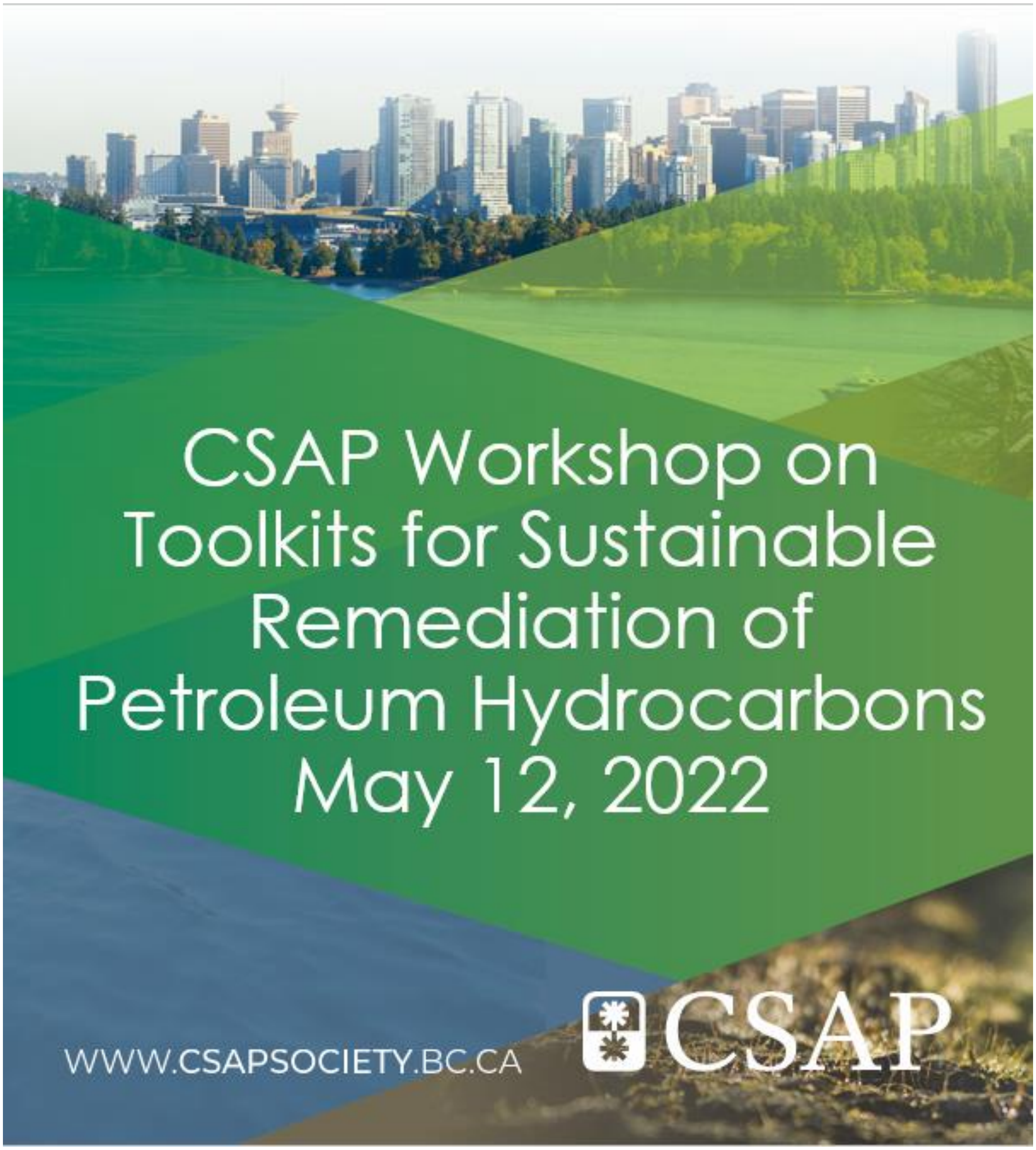
CSAP Workshop on
Toolkits for Sustainable
Remediation of
Petroleum Hydrocarbons
May 12, 2022
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Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons

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

Introduction

This document provides a summary of the Workshop on Toolkits Sustainable Remediation of Petroleum Hydrocarbons, and consists of:

1. Workshop Abstract
2. Summary of Panel Discussion
3. Results of Poll Questions
4. Presentations

Workshop Abstract

The half-day workshop, held on 12 May 2022, was on the **Toolkits for Sustainable Remediation of Petroleum Hydrocarbons**, a four-volume set of tools designed to integrate the latest science into a decision- framework to identify, evaluate and optimize remedial options for petroleum hydrocarbon-contaminated sites. These toolkits include an approach for remedial decision-making that considers the role of natural attenuation processes, and guidance and tools on conducting sustainability evaluations.

The first two toolkits, **Conceptual Site Model (CSM) and Case Studies** (Toolkit 1) and **Methods for Monitoring and Prediction of Natural Source Zone Depletion (NSZD) and MNA** (Toolkit 2), were published in 2016 to help document the latest science on NSZD and natural attenuation. In 2021, **Evaluation of Remediation Technologies for Petroleum Hydrocarbon Sites** (Toolkit 3) and **Methods for Sustainable Remediation** (Toolkit 4) were published (https://csapsociety.bc.ca/csap-toolkits/). The workshop focused on Toolkits 3 and 4, leading participants through an end-to-end process for site management and closure that included:

- developing and building upon an effective CSM
- identifying concerns/risks and remedial objectives
- evaluation of natural attenuation
- selecting remedial measures and performance / transition metrics in context of sustainable approaches
- optimizing remedial approaches, including transition to other remedies or natural attenuation / NSZD and site closure

The workshop described how to incorporate NSZD and MNA into the site remediation process and the benefits of both natural and enhanced attenuation. The principles and basis for sustainable approaches were addressed together with a roadmap for conducting sustainability evaluations, including emerging considerations for resilient sustainable remediation and climate change. Toolkit implementation was discussed from both a technical and regulatory (BC and other jurisdictions) perspective. Workshop presentations are attached including additional materials provided, e.g., best management practices (BMPs) for sustainable remediation. Opening and closing panel sessions were held to frame the workshop and identify current status, possible barriers, and desired future outcomes and needs.

Workshop Presenters:

Ian Hers, Ph.D., P.Eng., CSAP, Hers Environmental Consulting, Inc. (HEC)
Parisa Jourabchi, Ph.D., P.Eng., ARIS Environmental Ltd.
Linda Kemp, P.Eng., WSP Golder

Workshop Panelists and Moderator:

Francois Beaudoin, GHD
Parisa Jourabchi, Ph.D., P.Eng., ARIS Environmental Ltd.
Matthew Lahvis, Ph.D., Shell Oil Products US
David Mitchell, P.Eng., CSAP, Active Earth
Guy Patrick, P.Eng., CSAP, Patrick Environmental (moderator)

Workshop Facilitators:

Nelly Pomareda, CSAP
Dana Bidnall, CSAP

Summary of Panel Comments and Discussion

Common Themes Raised through Comments and Observations by Panelists:

- Existing environmental regulations related to contaminated sites (BC and other jurisdictions) do not sufficiently incorporate sustainability. A regulatory driver is needed to promote use of more sustainable remediation methods.
- There is little consideration of quantification and reduction of greenhouse gas (GHG) emissions currently in site investigation and remediation. Guidance or a framework on this is needed.
- There is low use of quantifiable methods for assessing monitored natural attenuation (MNA) in practice. Parameters are collected, but not capitalised on to put all the information together for quantifiable use.

- We often collect a lot of data but fall short in using and effectively analyzing the data. There are newer data collection techniques and sensors that can improve this process.
- Motivation for sustainable remediation is starting to increase, but it was noted that it has been approximately 10 years since the Sustainable Remediation Forum (SURF) was initiated and too little progress in implementation has been observed since that time.
- There is recent guidance and improved knowledge on sustainable remediation and an increasing number of available tools. There is opportunity to "do better" in incorporating sustainability in our projects.
- The addition of a new ASTM guide for NSZD will help clarify and provide more confidence in NSZD assessments and allow for ease of review for projects where NSZD is used for decision making purposes.
- Sustainability is subjective and we have a ways to go. In particular, how do we incorporate social issues into our assessments? The earlier these concepts are considered in a project the better. May warrant collaboration / consultation with Indigenous communities, planners, stakeholders. A recommendation was made to involve a social scientist early in the discussions to support this side of a project.
- Best practices include appropriate documentation and transparency. Standardization and templates can improve process leading to improved sustainability.
- California has a "low threat" closure policy that is supportive of reduced clean up requirements for low threat sites. There is also the California GeoTracker database (site data including chemistry) which has enabled analysis of remediation timelines and helped promote more sustainable approaches.
- There is opportunity to build on knowledge, to optimize, improve sustainability, more confidently transition to passive remediation approaches. Leaving contamination in place as part of natural attenuation approach may require longer timelines, recognizing that given time natural processes will often take care of the problem.
- There are innovative and more sustainable technologies that can improve remediation (one example provided was soil heating to enhance bioremediation). Research and collaboration are needed to further advance technologies. A recommendation was made to consider how research could be conducted at idle brownfields sites.

Individual Opinion Comments/Observations:

- Sustainable remediation is a key component for sites in northern Yukon where impacts to permafrost need to be considered.
- One individual attendee expects to see larger support from land developers on sustainability if sustainability approaches are regulated.
- One individual reported that a strong driver for sustainability that they had observed was through First Nations involvement on projects.

Summary of Poll Results

Question 1

1. Have you incorporated sustainability assessment in remedial decision making? (Single Choice) *

Yes	(32/58) 55%
No	(22/58) 38%
Not applicable	(4/58) 7%

Question 2

1. How have you incorporated sustainability assessment in remedial decision making? (Single Choice) *

Best Management Practices (BMPs) (e.g., energy use, ...	(13/39) 33%
Carbon footprint assessment	(2/39) 5%
Sustainability assessment tools (environmental, social ...	(10/39) 26%
Not applicable	(14/39) 36%

Question 3

1. For petroleum hydrocarbon sites, have you implemented remediation technologies other than excavation & disposal? (Single Choice) *

Yes	(41/53) 77%
No	(9/53) 17%
Not applicable	(3/53) 6%

Question 4

1. How often have you implemented active remediation other than excavation and disposal or 'pump & treat' of groundwater? (e.g., SVE-AS, multiphase extraction, oxidation, etc.) (Single Choice) *

Rarely (e.g., < 10%)	(24/48) 50%
Sometimes (e.g., 10 < 50%)	(16/48) 33%
Often (e.g., 50 - 100%)	(8/48) 17%

Question 5

1. Are performance evaluation measures and threshold metrics defined and aligned upfront with the regulator *prior* to remedy implementation? (Single Choice) *

Yes (17/43) 40%

No (14/43) 33%

Sometimes (12/43) 28%

Question 6

1. Are performance evaluation results of an existing remediation system used in decision making for remedy transition (site closure or alternate remedial system)? (Single Choice) *

Yes (25/39) 64%

No (5/39) 13%

Sometimes (9/39) 23%

Question 7

1. What do you see as challenges in the incorporation of sustainability assessment tools in remedy selection and design? (select all that apply) (Multiple Choice) *

Lack of practical assessment tools / resources	(11/34) 32%
Lack of regulatory guidance	(21/34) 62%
Regulatory framework not amenable	(21/34) 62%
Lack of consistent standards	(10/34) 29%
Cost considerations	(21/34) 62%

Question 8

1. On a scale of 1 (not important) to 4 (very important), what is the significance of estimating natural attenuation rates at a NAPL site? (Single Choice) *

Not important	(2/40) 5%
Somewhat important	(7/40) 18%
Important	(17/40) 43%
Very important	(14/40) 35%

Question 9

1. Are natural attenuation rates quantified and documented? (Single Choice) *

Yes	(7/42) 17%
No	(16/42) 38%
Sometimes	(19/42) 45%

Question 10

1. What do you see as challenges in estimating natural attenuation rates? (select all that apply) (Multiple Choice) *

Unfamiliarity with the methods / lack of consistent sta...	(25/38) 66%
Uncertainty associated with the measurements	(22/38) 58%
Lack of regulatory guidance on application of the mea...	(23/38) 61%
Current remedies deemed effective	(8/38) 21%
Budgetary constraints	(19/38) 50%

CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
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This meeting is being conducted from the traditional, ancestral, and unceded territory of the Coast Salish peoples, including Squamish, Tsleil-Waututh, and Musqueam

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Agenda and Opening Comments

CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Dr. Ian Hers, HEC

Agenda

Welcome, Agenda and Opening Comments – Dr. Ian Hers (5 min; 8:30-8:35)

Opening Perspectives of the Panel – Panelists TBD, moderated by Guy Patrick (25 min; 8:35-9:00): *Panelists representing regulatory, applied research, approved professionals and consulting, and industry areas will help frame workshop including the current status of sustainable remediation, motivation and need for new approaches (including toolkits) and desired outcomes***.**

Participant Polling Questions and Answers – All (10 min; 9:00-9:10)

Toolkits for Sustainable Remediation – Rationale and Overview – Dr. Ian Hers, HEC (10 min; 9:10-9:20)

Overview of Best Practices for Assessment of Natural Attenuation (Update on Guidance / Methods in Toolkits 1 and 2) – Dr. Parisa Jourabchi, ARIS Environmental Ltd. (25 min; 9:20-9:45)

A New Framework for Efficient, Optimized and Sustainable Site Remediation Process (Toolkit 3) – Dr. Ian Hers, HEC (30 min; 9:45-10:15)

Break – 15 min (10:15-10:30)

Agenda (cont.)

CSAP

Sustainable Remediation – A Framework, Roadmap and Tools (Toolkit 4) – Dr. Ian Hers, HEC (35 min; 10:30-11:05)

Considerations for Application of Toolkits within BC Regulatory Framework – Linda Kemp, Golder Associates (15 min; 11:05-11:20)

Review Poll Answers, Panel Discussion & Participant Q&A – Panelists (45 min; 11:20-12:05)

Panelists representing regulatory, applied research, approved professionals and consulting, and industry areas will discuss what we have learned, current gaps and next steps and answer participant questions.

Closing Comments – (12:05)

Agenda is also at: https://csapsociety.bc.ca/events-2/

Opening Comments

CSAP

1. **Purpose of Toolkits**: Develop systematic approach to optimizing remediation that incorporates risk-based principles, natural attenuation and sustainability.
2. **Goals of workshop**: Share knowledge and experience; identify gaps and possible barriers; identify opportunities to improve practice and next steps.
3. **Context**: Focus is petroleum hydrocarbons, but principles generally apply to contamination; one session will be on BC regulatory framework, while science and issues are broadly applicable across jurisdictions.
4. **Format**: Will include poll questions, opening and ending panel sessions and opportunity to ask questions and provide comments.
5. **Outcome**: Workshop will be recorded and available on the CSAP website. A short workshop report will be prepared that will be broadly shared.

Welcome and we hope you enjoy the workshop!

Remediation Toolkits Project

A series of 4-toolkits prepared by WSP Golder,
published by CSAP https://csapsociety.bc.ca/csap-toolkits/

#1 Conceptual Site Model (CSM) & Case Studies

Conceptual Site Model → Multi-Site Database Studies → BC Case Studies

Completed 2016

#2 Methods for Monitoring and Prediction of Natural Source Zone Depletion (NSZD) and MNA

Methods for evaluation of natural attenuation and source depletion

Completed 2016

#3 Evaluation of Remediation Technologies for Petroleum Hydrocarbon Sites

Systematic approach for remediation objectives, selection, optimization and transition

Completed 2021

#4 Methods for Sustainable Remediation

Methods & roadmap for implementing sustainable remediation (SR)

Completed 2021

Workshop Facilitators

CSAP

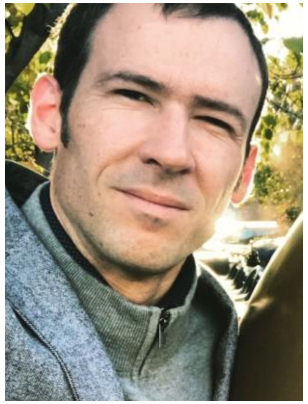
Dr. Parisa Jourabchi*
ARIS
Presenter /
Panelist

Dr. Matthew Lahvis**
Shell
Panelist

Linda Kemp**
WSP Golder
Presenter

David Mitchell
Active Earth
Panelist

Guy Patrick**
Patrick
Environmental
Moderator



Francois Beaudoin*
GHD
Panelist

Dr. Ian Hers*
HEC
Presenter

* Toolkit author; ** Tookit reviewer

Funding by CSAP and Shell is gratefully acknowledged

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Opening Panel

CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Moderated by Guy Patrick, Patrick Environmental

Poll Questions

CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Moderated by Parisa Jourabchi

For sites managed in any jurisdiction, in the last three years…

For sites managed in any jurisdiction, in the last three years…

Funding by CSAP and Shell is gratefully acknowledged

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Thank you to all facilitators and hard work of CSAP operations & communications team (Nelly Pomareda and Dana Bidnall)

THANK YOU FOR ATTENDING

Toolkits for Sustainable Remediation – Rationale and Overview

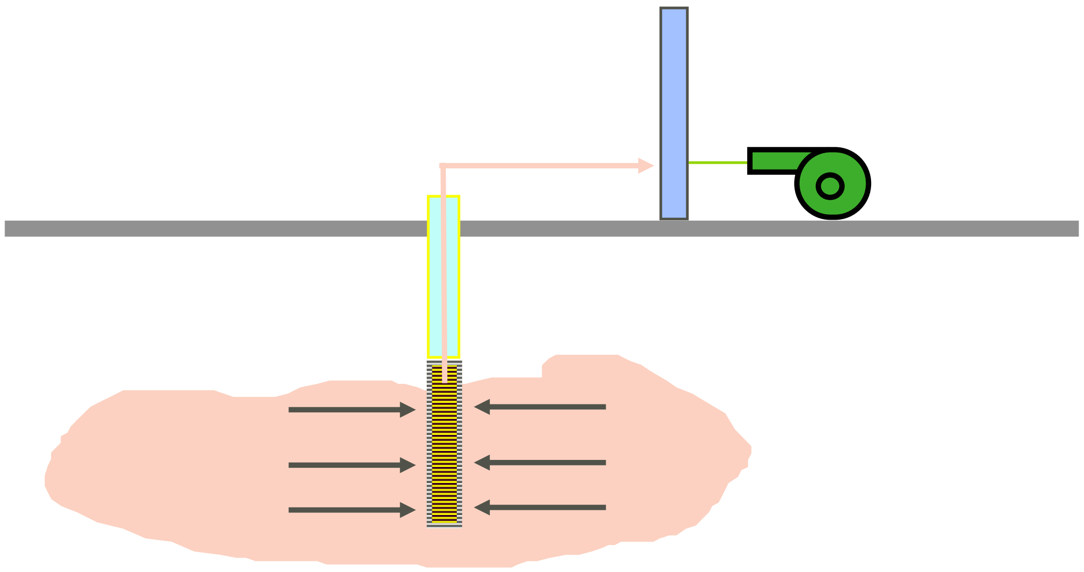
CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Dr. Ian Hers, HEC

Outline

1. A brief history of remediation
2. Learning from petroleum hydrocarbon and light non-aqueous phase liquid (LNAPL) remediation
3. Introduction to natural source zone depletion (NSZD) and natural attenuation (NA)
4. Rationale for Toolkits

1980s & 90s: Pump and Treat - Chronic Failure of the Obvious Solution*



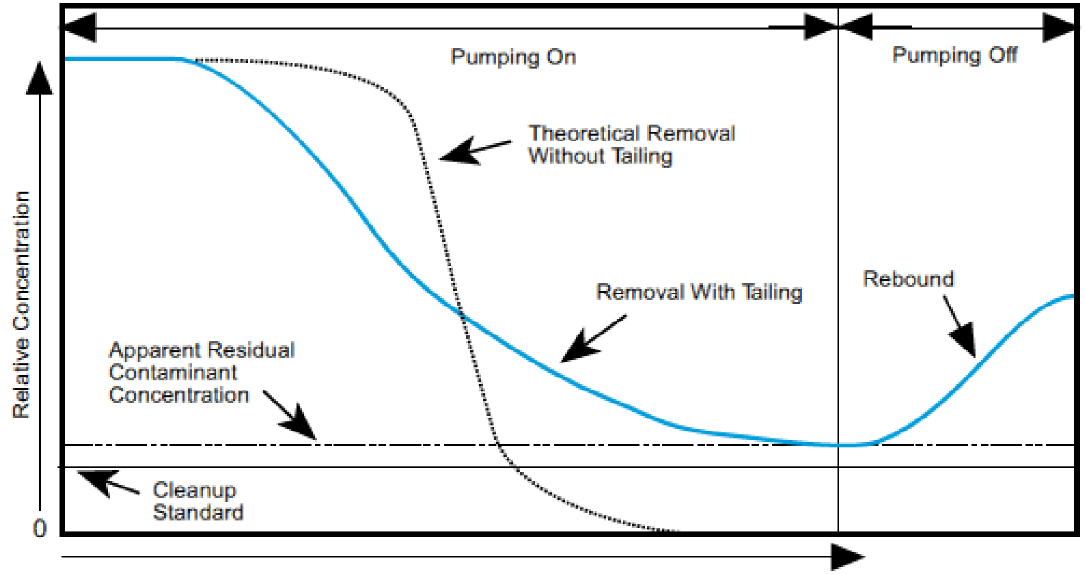


Figure 10. Concentration versus pumping duration or volume showing tailing and rebound effects (Cohen et al., 1994).

EPA/625/R-95/005 (1996)

<u>Problem of rebound and back diffusion:</u> Air-phase technologies such as SVE and air-sparging also affected to varying degrees (our focus has shifted to composition and how risk profile is affected)

HERS Environmental Consulting, Inc.

* Thanks Pete Craig, QM for title

What We Already Knew in 1995:

(a.k.a., The More Things Change, the More They Stay the Same)

Table 1. Categories of Sites for Technical Infeasibility Determinations (NRC, 1994)

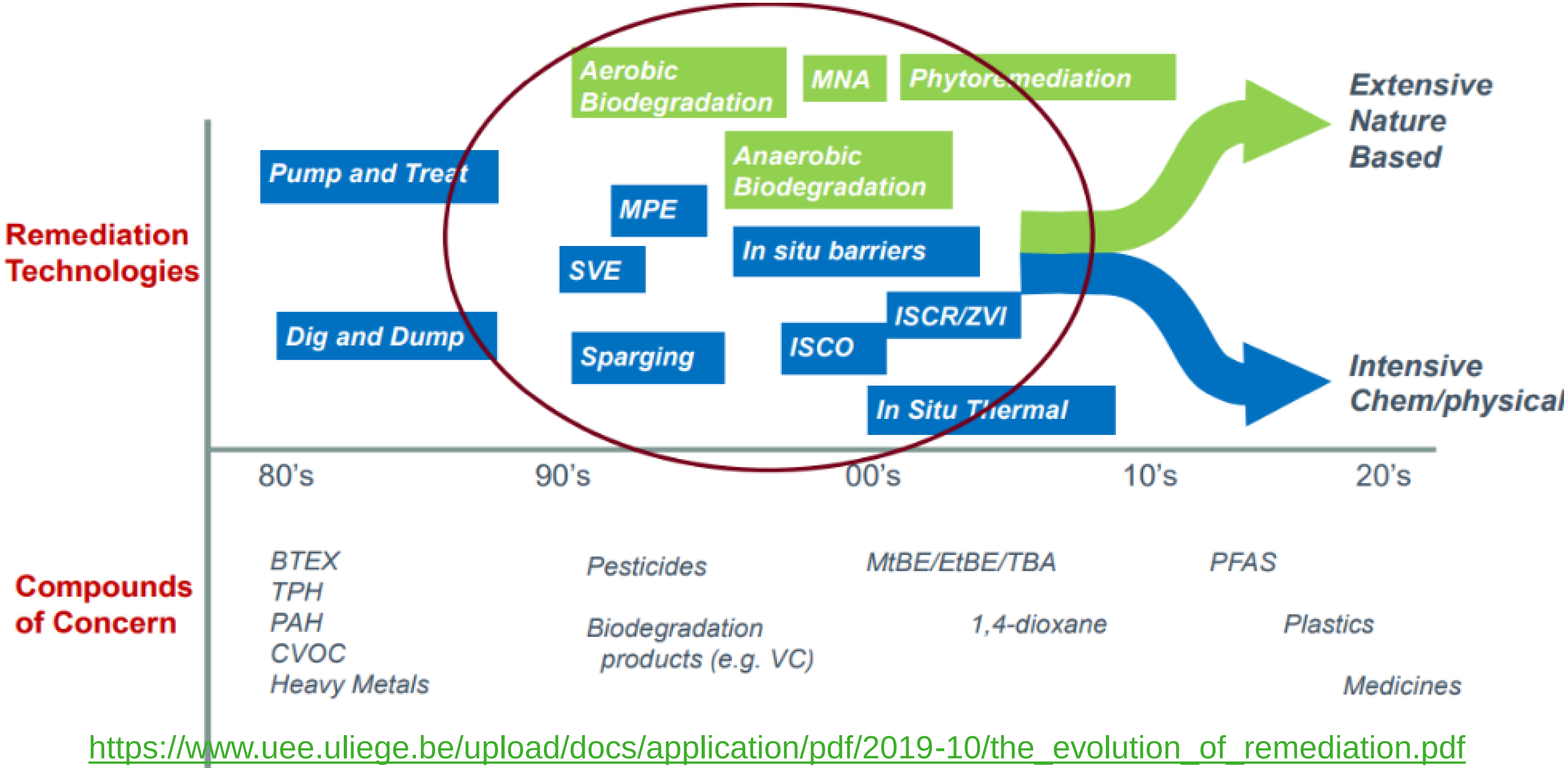
EPA/625/R-95/005

	Contaminant Chemistry					
Hydrogeology	Mobile Dissolved (degrades/ volatilizes)	Mobile, Dissolved	Strongly Sorbed, Dissolved (degrades/ volatilizes)	Strongly Sorbed, Dissolved	Separate Phase LNAPL	Separate Phase DNAPL
Homogeneous, single layer	A (1)	A (1-2)	B (2)	B (2-3)	B (2-3)	B (3)
Homogeneous, multiple layers	A (1)	A (1-2)	B (2)	B (2-3)	B (2-3)	B (3)
Heterogeneous, single layer	B (2)	B (2)	B (3)	B (3)	B (3)	C (4)
Heterogeneous, multiple layers	B (2)	B (2)	B (3)	B (3)	B (3)	C (4)
Fractured	B (3)	B (3)	B (3)	B (3)	C (4)	C (4)

Note: Shaded boxes at the left end (group A) represent types of sites for which cleanup of the full site to health-based standards should be feasible with current technology. Shaded boxes at the right end (group C) represent types of sites for which full cleanup of the source areas to health-based standards will likely be technically infeasible. The unshaded boxes in the middle (group B) represent sites for which the technical feasibility of complete cleanup is likely to be uncertain. The numerical ratings indicate the relative ease of cleanup, where 1 is easiest and 4 is most difficult.

Evolution of Remediation

Paul van Riet, Dow, GQ 2019



New focus
Sustainability
Climate change
Resiliency
GHG emission

https://www.uee.uliege.be/upload/docs/application/pdf/2019-10/the_evolution_of_remediation.pdf

https://www.geodrillinginternational.com/wells-boreholes/news/1385447/to-dig-or-not-to-dig-contamination-that-is-the-question

Insight from Multi Fuel-release Site Plume Studies

O'Conner et al. 2015* Toolkit 1

Summary of Plume Lengths

Parameter	Total Number of sites	Delineation criteria (µg/L)	Weighted mean on 90th and 50th percentile plume lengths (m)
Benzene	165	5	130 / 55

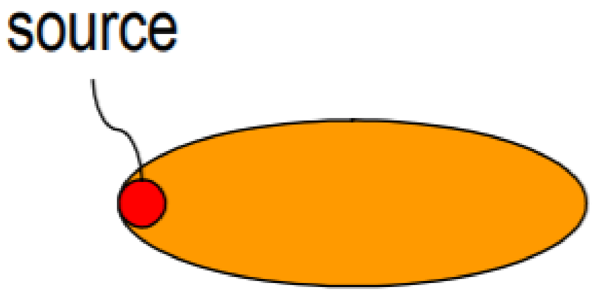
Summary of Stability Condition: Concentrations

Parameter	Total Number of sites	Decreasing concentrations (%)	"Non-increasing" concentrations (%)
Benzene	905	63	92

Summary of Stability Condition: Plume lengths

Parameter	Total Number of sites	Decreasing plume lengths (%)	"Non-increasing" plume lengths (%)
Benzene	566	32	94

Plume-athons!



Stable or Shrinking Plumes

Extensive info on MNA – Toolkit 2, TG 22 references

How would this paradigm apply to other contaminants?

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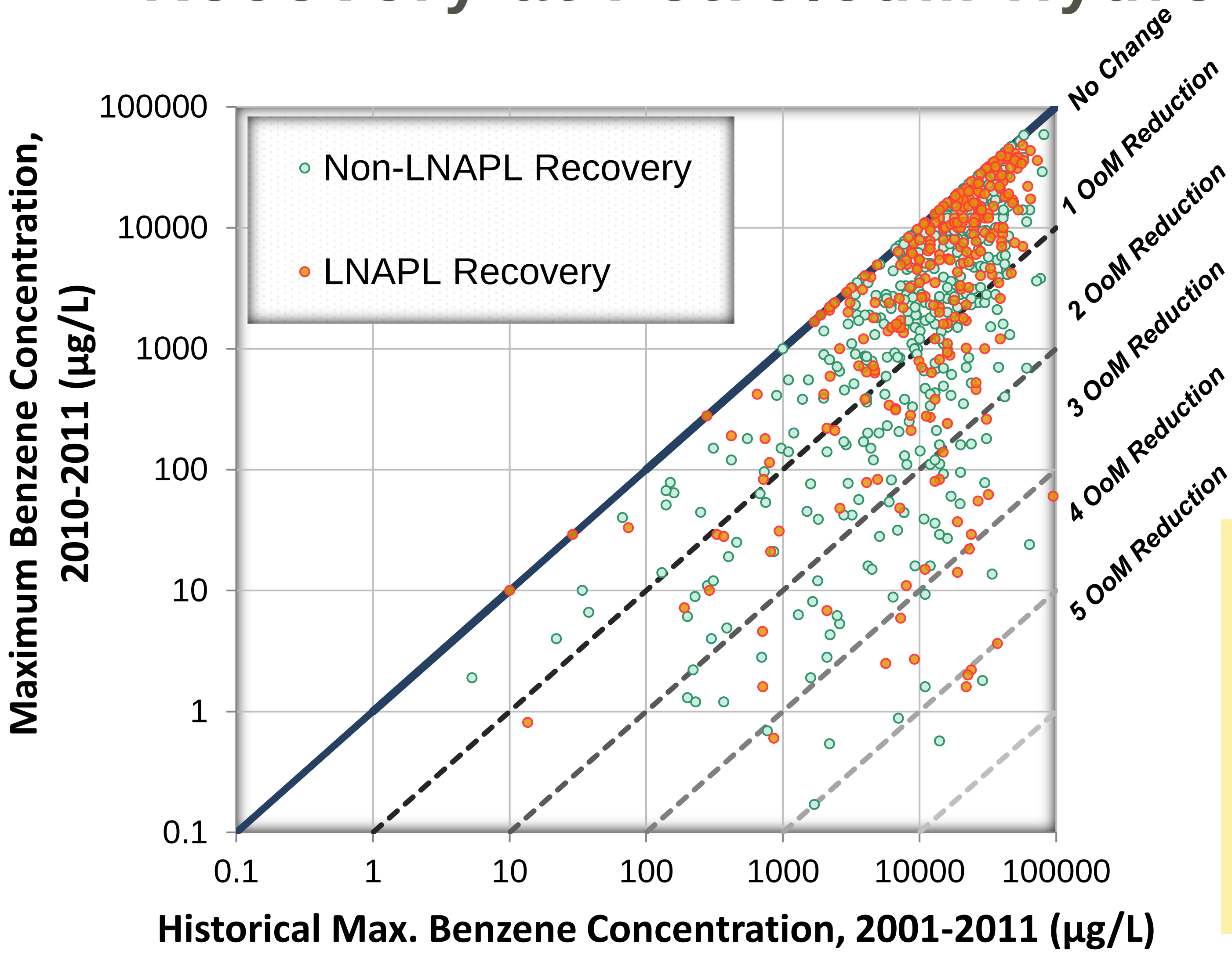
* From review of 13 multi-site or multi-plume studies (references not provided are in toolkits)

Insight from Big Data – Impact of LNAPL Hydraulic Recovery at Petroleum Hydrocarbon Sites



GeoTracker Data

McHugh et al. 2013

Toolkit 1

Key Point: Sites with mobile LNAPL had lower attenuation rates (not shown), but for sites with mobile NAPL, hydraulic recovery had little benefit In increasing attenuation or reducing dissolved BTEX concentrations

HERS Environmental Consulting, Inc.

Insight from Big Data – Comparison of Remediation Approaches at Petroleum Hydrocarbon Sites

McHugh et al. 2014 Toolkit 1

- Data from 4,000 retail gasoline sites in California with monitoring from 2001-2011 with ≥ 4 years of data
- Estimated median benzene attenuation rates:
  - All sites (most with active remediation) = 0.18 yr^{-1}
  - NSZD/MNA only (72 sites) = 0.13 yr^{-1}

Key Point: Slightly faster attenuation rate for active remediation compared to NSZD/NA

California GeoTracker Database "Big-data"

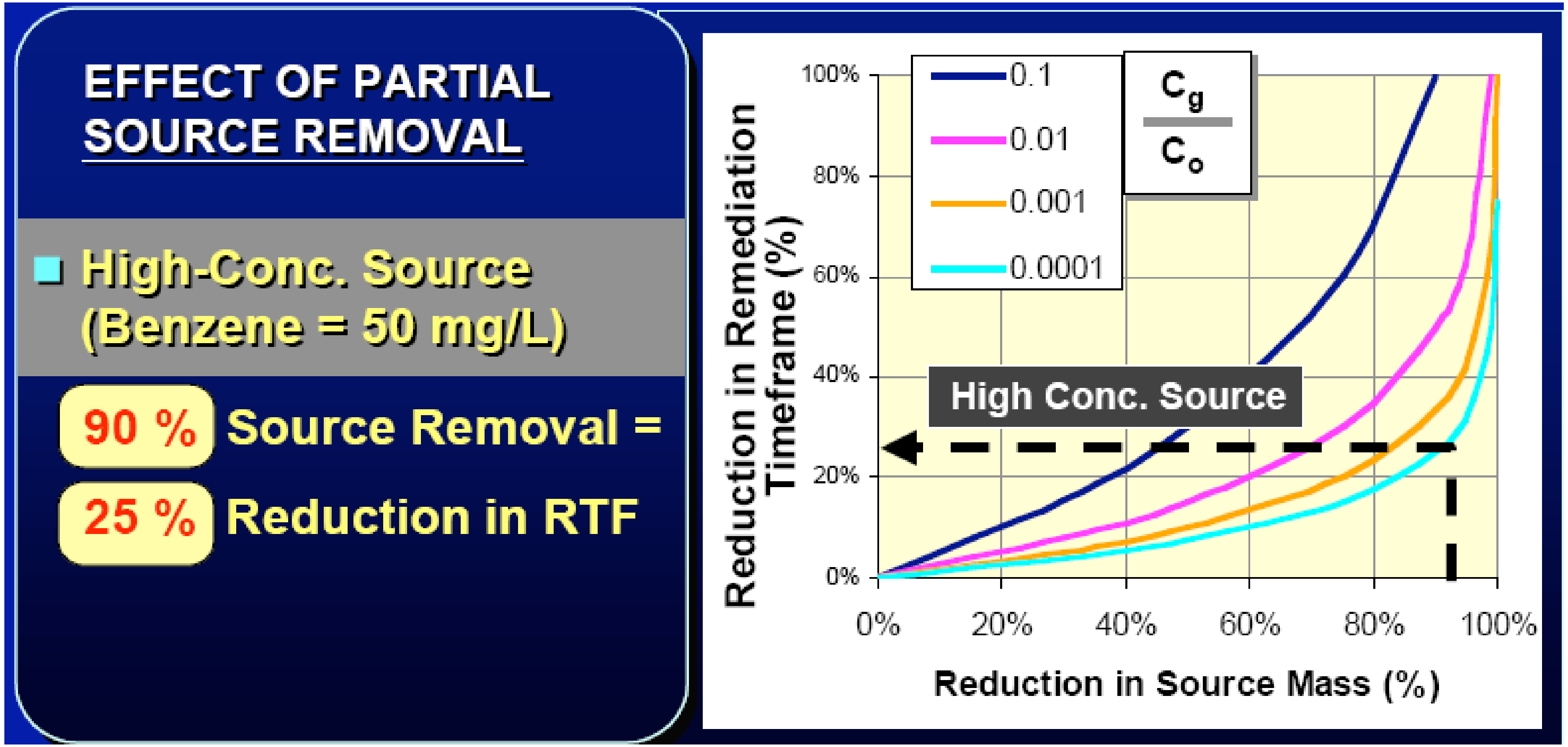
Technology	Constituent	Increase in attenuation rate at wells in/adjacent source zone (%)
SVE	benzene	28
	MTBE	11
Air Sparging	benzene	53
	MTBE	22
Chemical Oxidation	benzene	20
Pump & Treat	MTBE	17

Assuming median benzene attenuation rate = 0.13 yr^{-1} the timeline for attenuation from 10 mg/L to 5 µg/L = 58 years

LNAPL Recovery and Remediation Timeframe Reduction: A Point to Consider (ITRC IBT)

ITRC IBT Training, Slide by Chuck Newell, GSI

Key question: What will be left behind after remediation?



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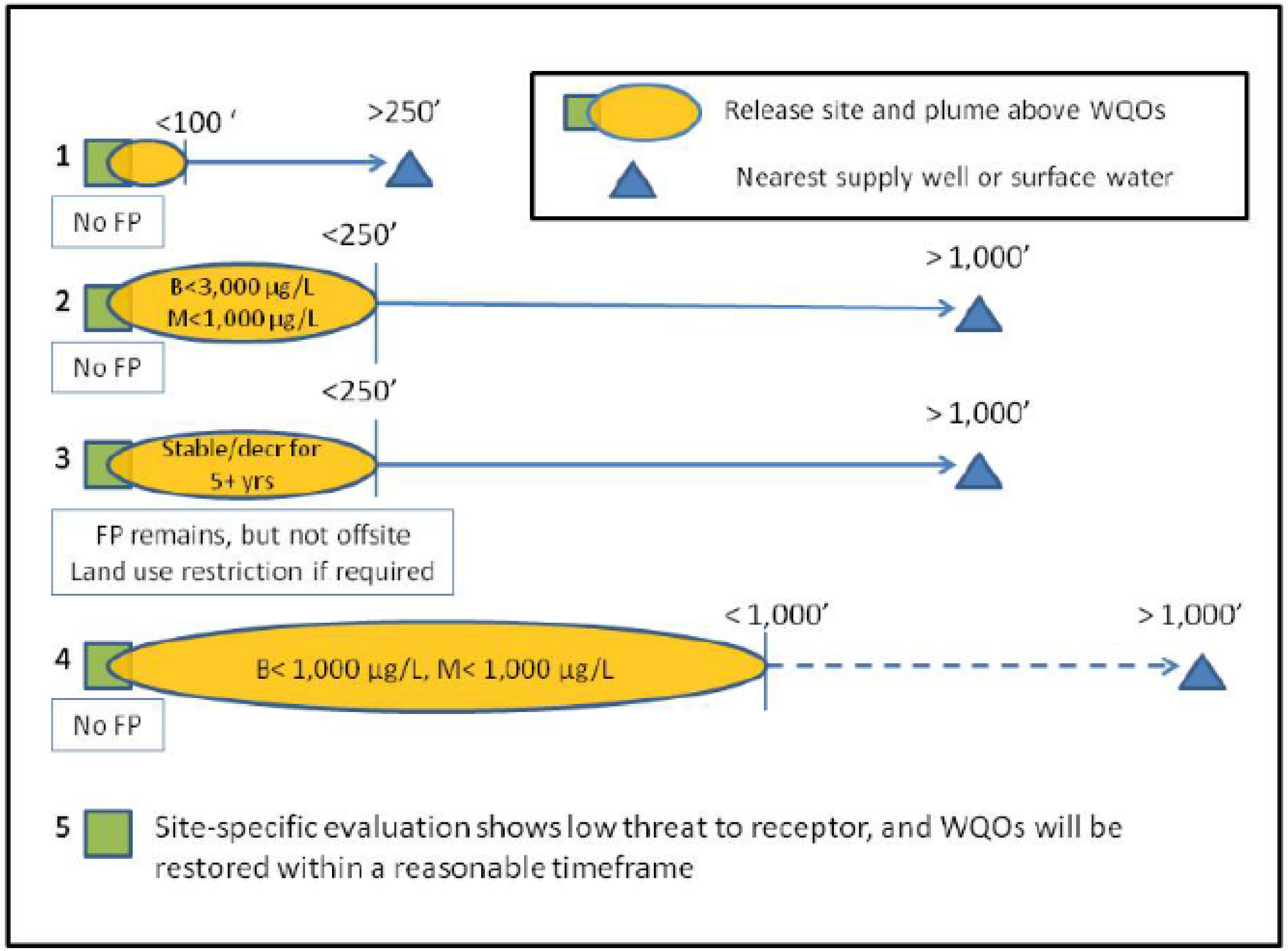
Also see articles by David Huntley and Toolkit 2

California Low Threat Guidance

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



- 5 Pathway Scenarios w/ different allowable distances to receptor based on plume length / strength
  - key COPCs (benzene, MTBE, TPH)
- minimum requirements
  - groundwater plume must be stable or decreasing
  - release stopped; LNAPL removed to max extent practicable

Notes:

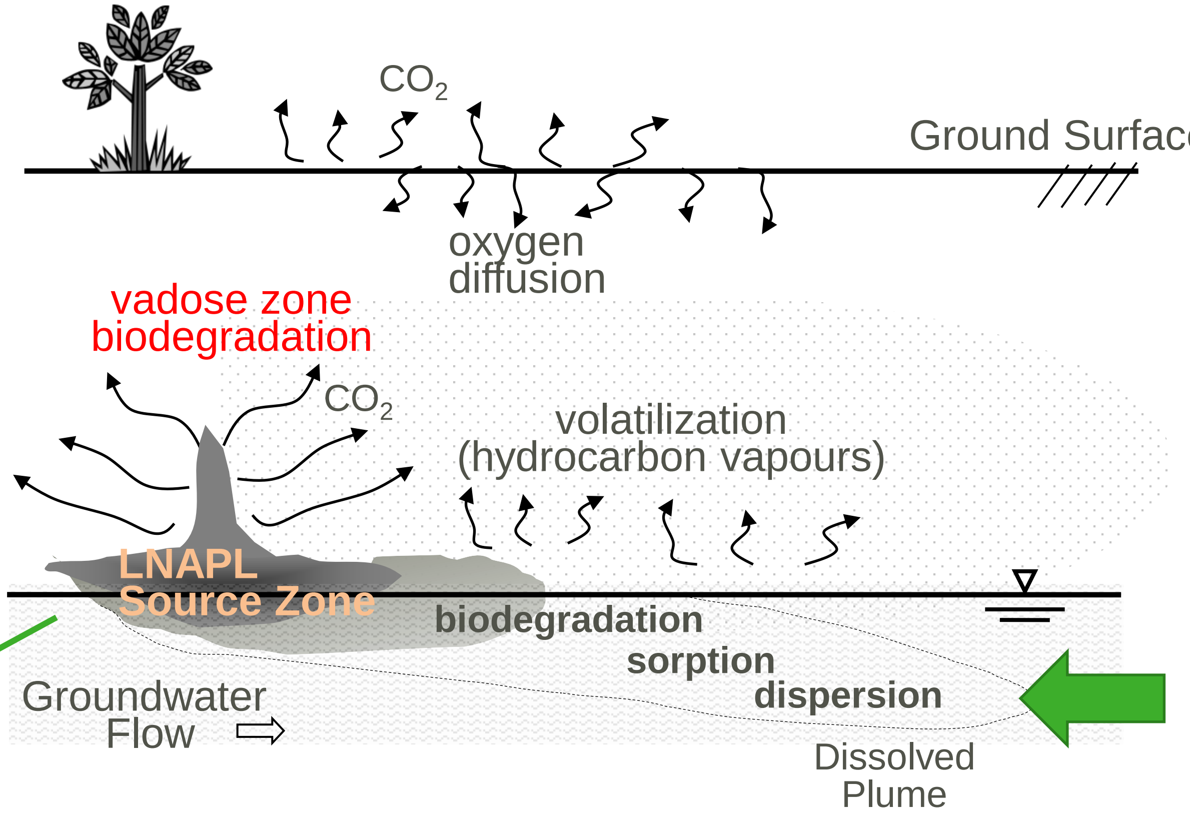
B	Benzene
FP	Free Product
M	Methyl tert butyl ether
Stable/decr	Stable or decreasing in areal extent
WQO	Water Quality Objective

Figure is not to scale

From Lahvis 2013. Balancing Natural Attenuation, Risk-Based Corrective Action and Sustainable Use of Groundwater Resources. Site Remediation In B.C.:From Policy To Practice" Conference.

Natural Source Zone Depletion CSM

Toolkit 1



Natural Attenuation = NA – refers to entire contamination

Natural Source Zone Depletion = NSZD

Plume Natural Attenuation

Key Point: Unsaturated zone rates ~ 1 to 2 orders of magnitude greater than saturated zone rate

Natural Source Zone Depletion (NSZD) Rates

Significantly elevated PHC-NSZD rates at many sites

Toolkit 2

Bulk LNAPL Depletion Rates

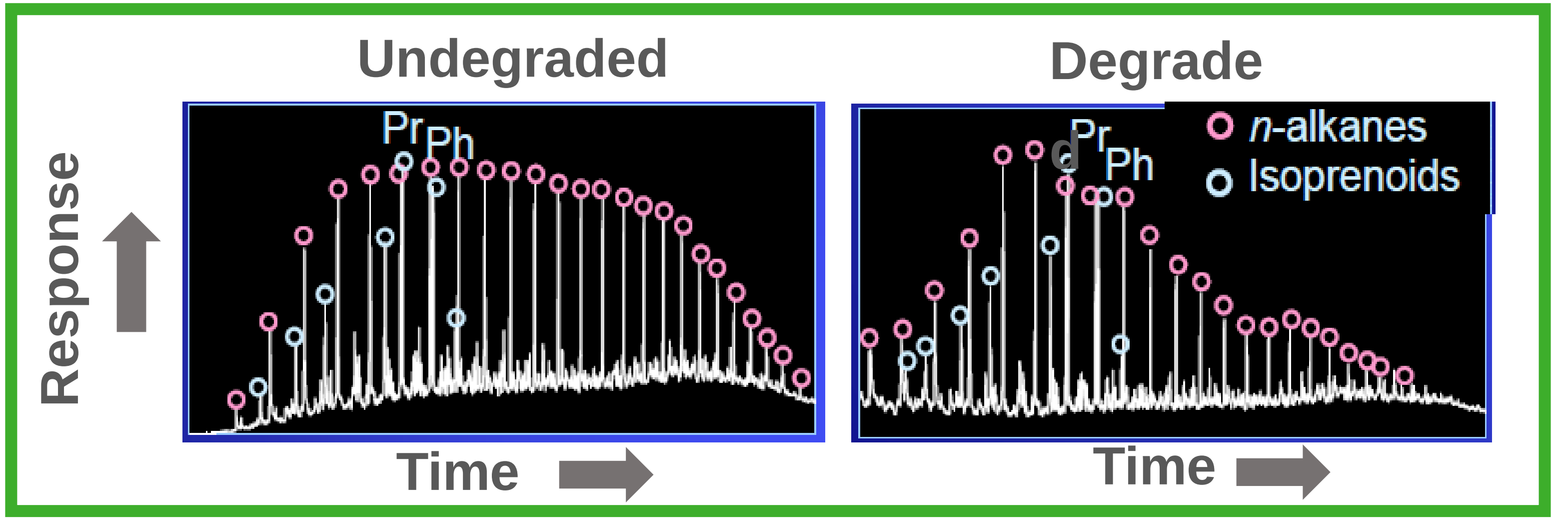
CSAP-Shell Remediation Toolkits 2016: N = 17
Typical range site averages:
500-1500 US gal/acre/yr

Garg et al. 2017 N = 25 sites
Primarily CO_2 efflux method
25^{th},50^{th},75^{th} percentiles =
700, 1100, 2800 US gal/acre/yr

CRC Care 47 2020 N = 6 sites
Highly variable site conditions
Range site average =
240-9,500 US gal/acre/yr

Composition of Source & Plume also Changes Over Time

Bekins et al, 2005



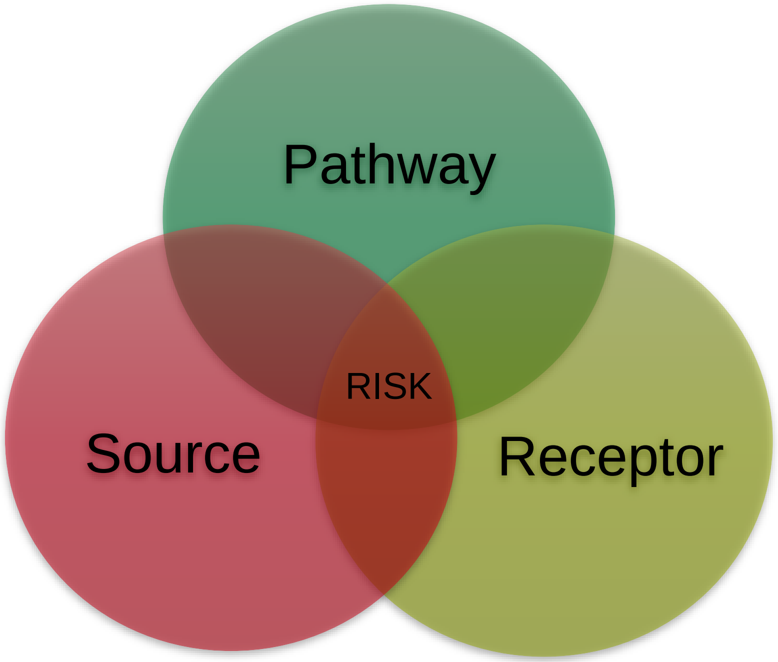
Evidence for direct degassing from oil degradation at Bemidji Site

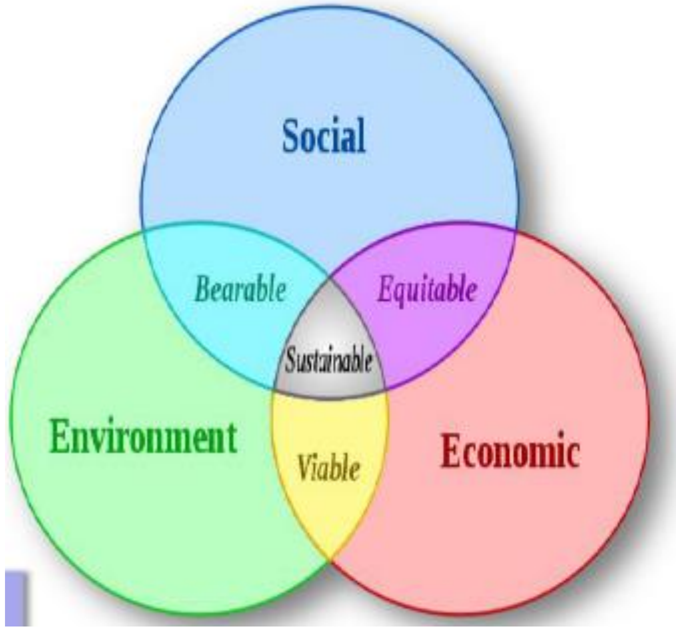
How would this paradigm apply to other contaminants?

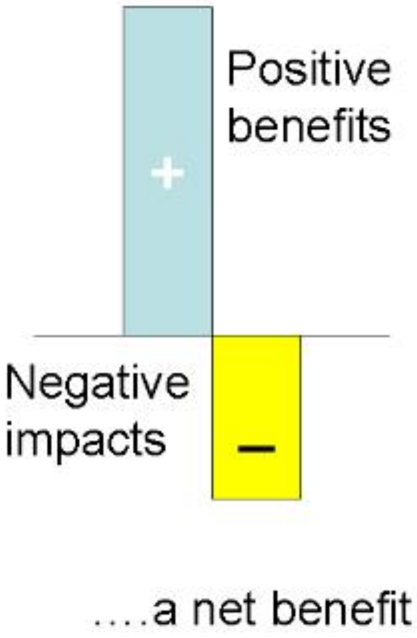
1 USgal/acre/yr = 9.35 L/hectare/yr

Risk and Sustainability Context

Toolkit 4







- Sustainable remediation and concept of net environmental benefit
- Intrusive remediation when no pathway or receptor (or future use) creates a negative effect

Remediation Toolkits Rationale

- Recognition of need to improve remediation through systematic approach & incorporation of sustainability
- Opportunity to document and incorporate new science on natural attenuation and improve confidence in NA
- Improve data collection and how we define remedial concerns and metrics or transition points
- Increase awareness and use of existing tools, and develop new ones
- “non-technical”
  - future land use
  - responsible party’s obligation, regardless

HERS Environmental Consulting, Inc.

Remediation Toolkits Project

A series of 4-toolkits published by CSAP https://csapsociety.bc.ca/csap-toolkits/

#1 Conceptual Site Model (CSM) & Case Studies	Conceptual Site Model → Multi-Site Database Studies → BC Case Studies	Completed 2016
#2 Methods for Monitoring and Prediction of Natural Source Zone Depletion (NSZD) and MNA	Methods for evaluation of natural attenuation and source depletion	Completed 2016
#3 Evaluation of Remediation Technologies for Petroleum Hydrocarbon Sites	Systematic approach for remediation objectives, selection, optimization and transition	Completed 2021
#4 Methods for Sustainable Remediation	Methods & roadmap for implementing sustainable remediation (SR)	Completed 2021

15

Overview of Best Practices for Assessment of Natural Attenuation

(Update on Guidance / Methods in Toolkits 1 and 2)

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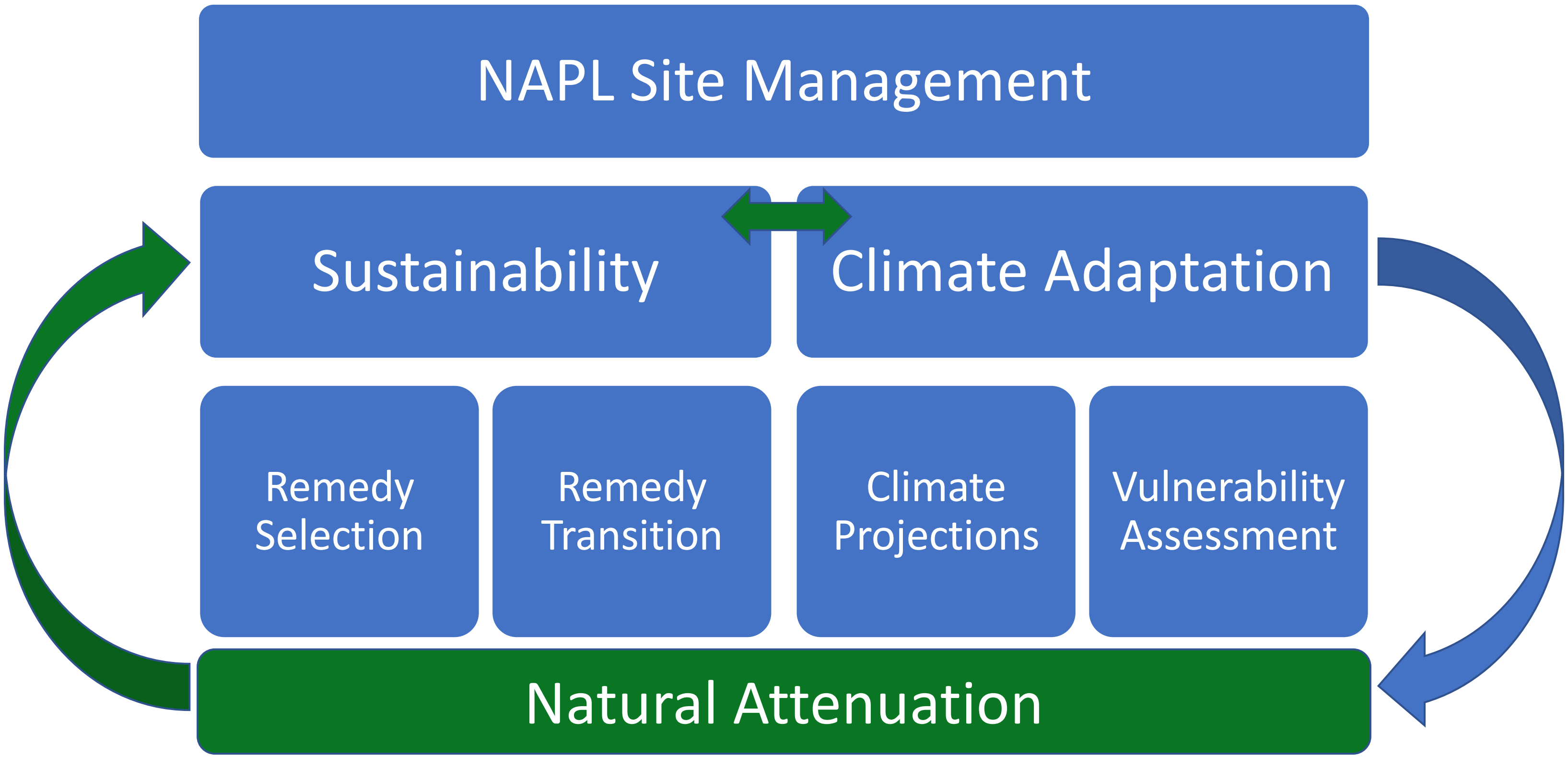
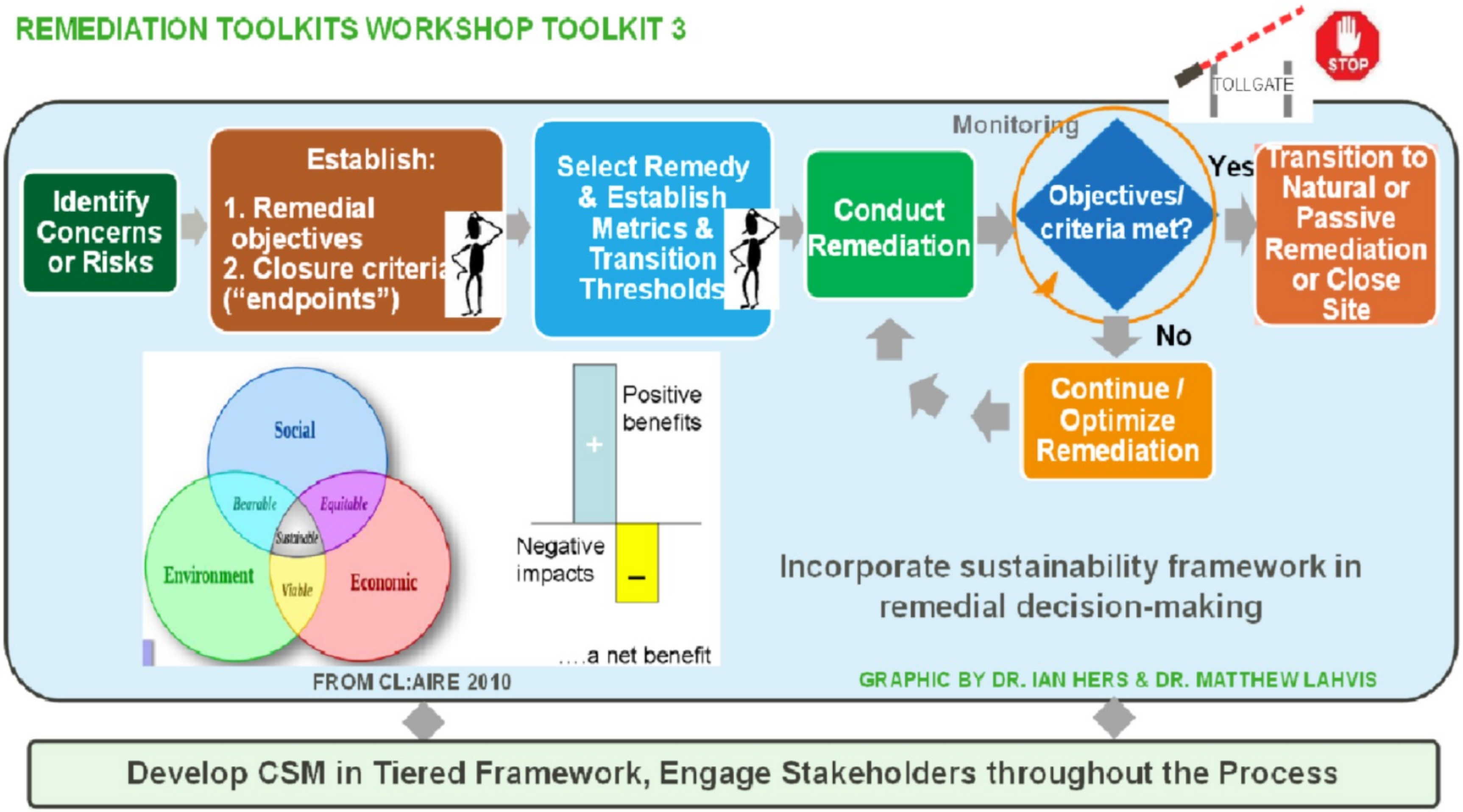
Parisa Jourabchi, Ph.D., P.Eng. (ARIS)
Environmental Engineer

Site Management in a Changing Climate

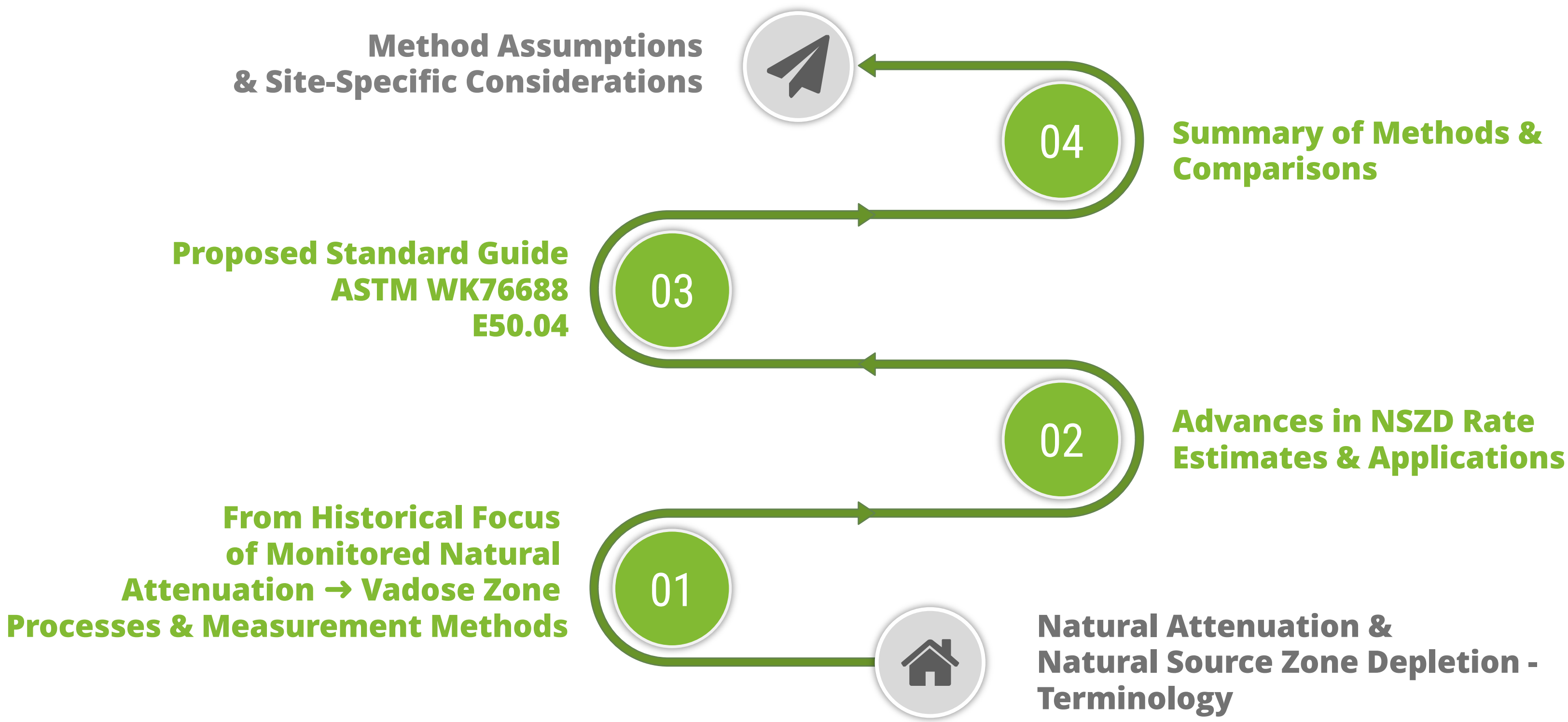


GENERALIZED FRAMEWORK FOR REMEDIAL DECISION MAKING

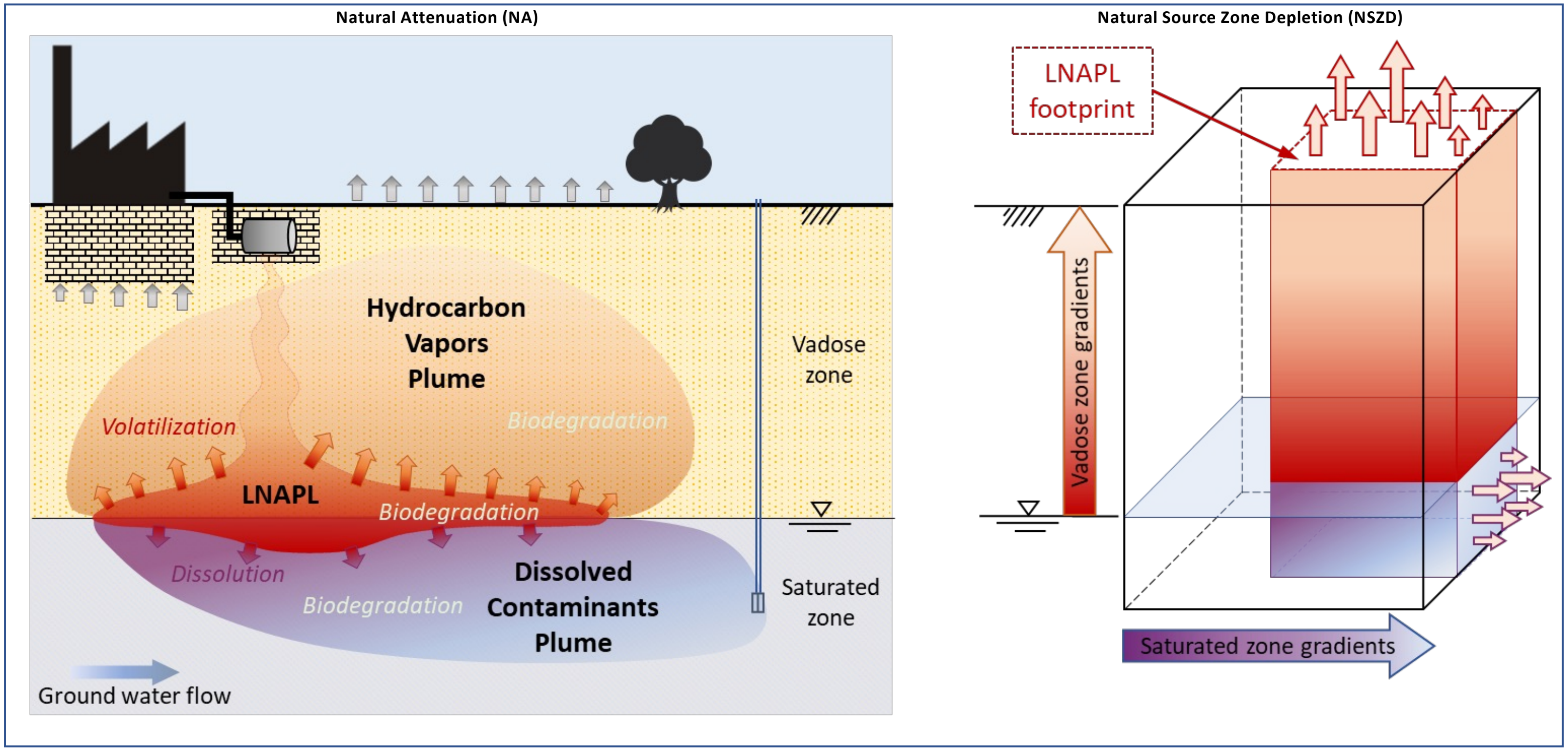
REMEDIATION TOOLKITS WORKSHOP TOOLKIT 3



Presentation Roadmap



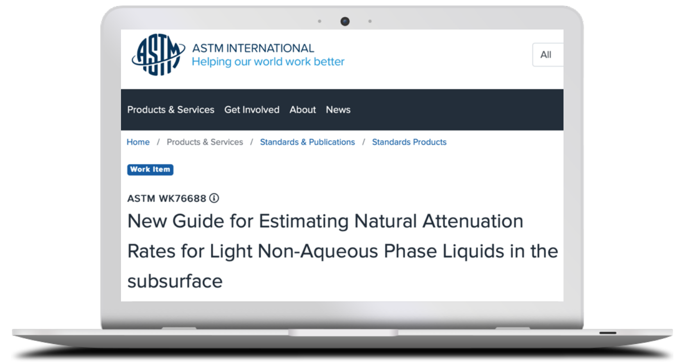
Natural Attenuation & Natural Source Zone Depletion (NSZD)



ARIS

Terminology: NA & NSZD

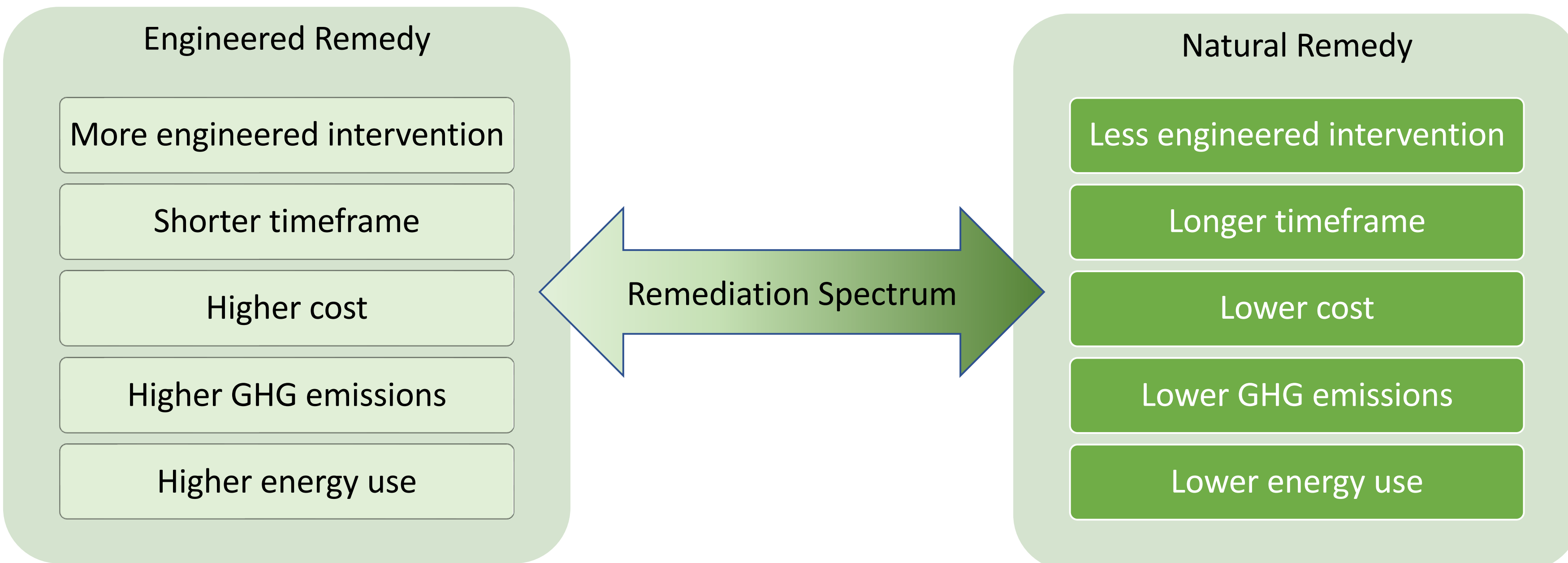
Natural Attenuation (NA): The naturally occurring mass loss of hydrocarbons in various phases and media (NAPL, vapor, soil, and groundwater) within a volume of soil or groundwater contamination.



https://www.astm.org/workitem-wk76688

Natural Source Zone Depletion (NSZD): The naturally occurring mass loss of hydrocarbons in NAPL source zones as a result of dissolution, volatilization, and biodegradation.

Remedy Transition



Natural Attenuation Guidance

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: E1943 – 98 (Reapproved 2015)

Standard Guide for
Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites[1]

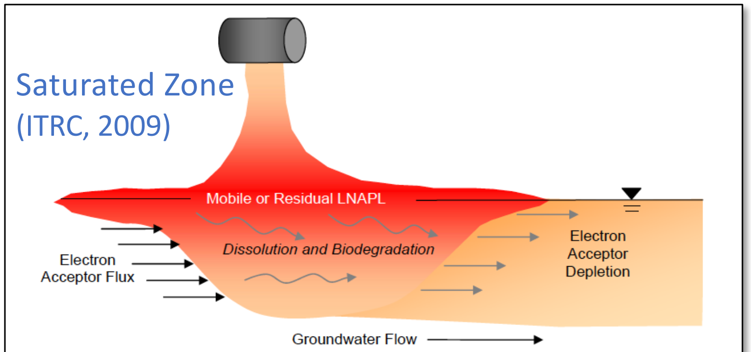
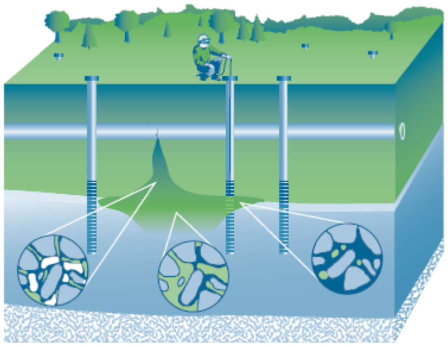


Figure 2-1. Groundwater transport–related NSZD processes.

Technology Overview

Evaluating Natural Source Zone Depletion at Sites with LNAPL



April 2009

ARIS

GW Monitoring Tools for Management of Petroleum Hydrocarbon Sites

- Guidance documents on LNAPL assessment, characterization and remediation

(FCSAP, US EPA, ITRC, API, …)

- Mass flux estimates

(iFlux Technology, GSI Mass Flux Toolkit, ITRC guida

- Groundwater monitoring of natural attenuation geochemical parameters

(FCSAP, ITRC Control Volume Approach)

- Modeling of contaminant fate and transport in groundwater

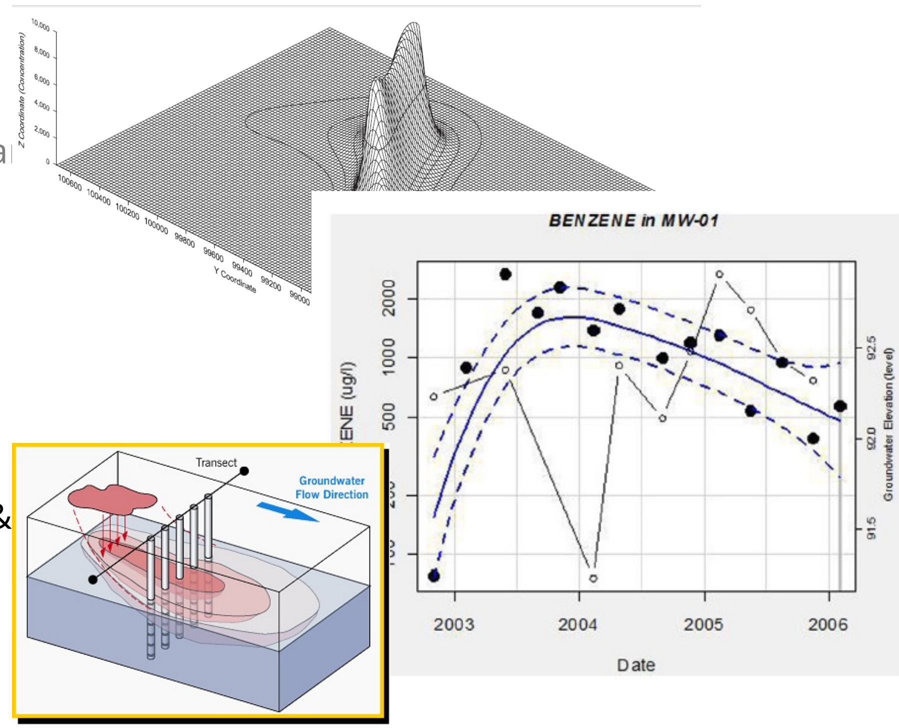
(US EPA BIOSCREEN, REMFuel, API LNAST, …)

- Groundwater plume stability, LNAPL footprint, & visualization

(API GWSDAT, Ricker Method, …)

- Trend analysis and plume stability

(US EPA ProUCL, AFCEE MAROS, …)



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Mass Depletion Processes

Biodegradation, Dissolution and Volatilization

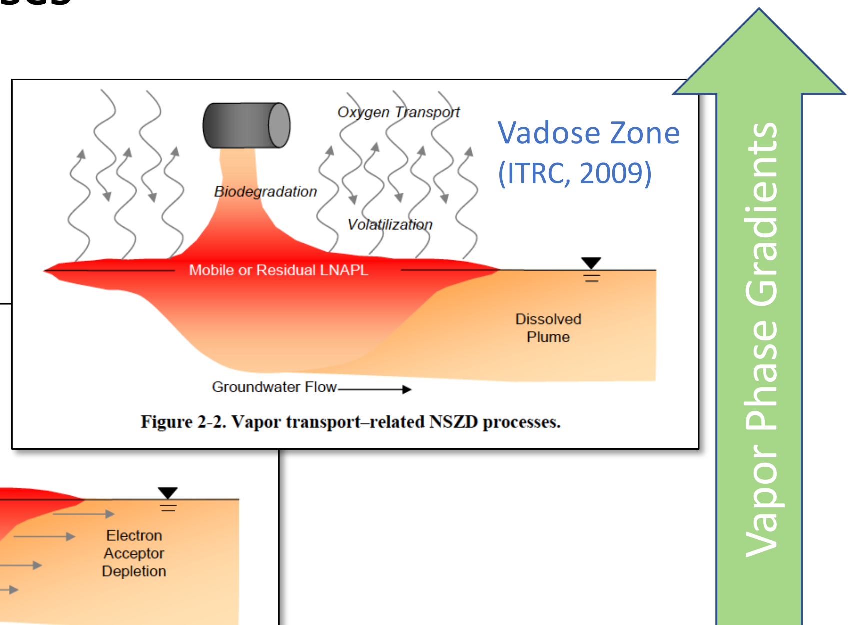


Figure 2-2. Vapor transport–related NSZD processes.

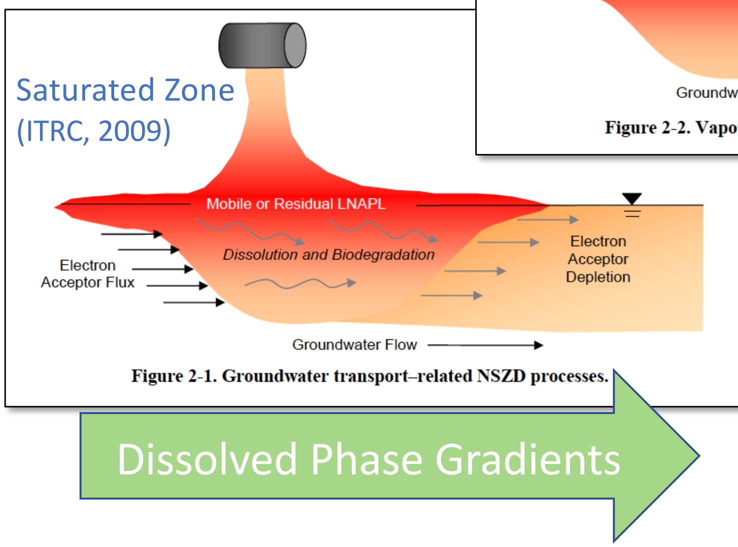


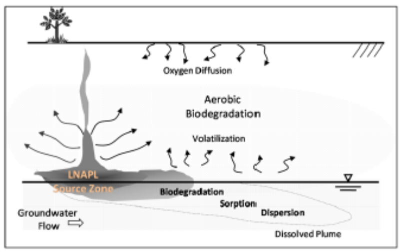
Figure 2-1. Groundwater transport–related NSZD processes.

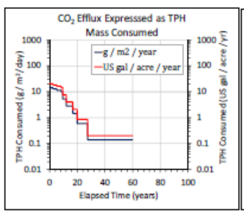
Natural Attenuation Guidance

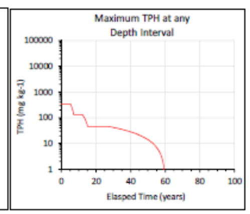
8 July 2016

REPORT

Toolkits for Evaluation of Monitored Natural Attenuation and Natural Source Zone Depletion







Submitted to:
Contaminated Sites Approved Professional Society
and Shell Global Solutions

Report Number: 1417511-001-R-Rev0

Golder Associates

Groundwater Monitoring&Remediation

2017

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

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

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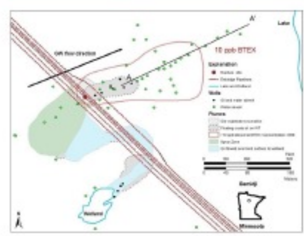
Featured article / Natural Attenuation in Source Zone and Groundwater Plume - Bemidji Crude Oil Spill



Enviro Wiki Highlights

NO-PURGE/PASSIVE GROUNDWATER SAMPLING

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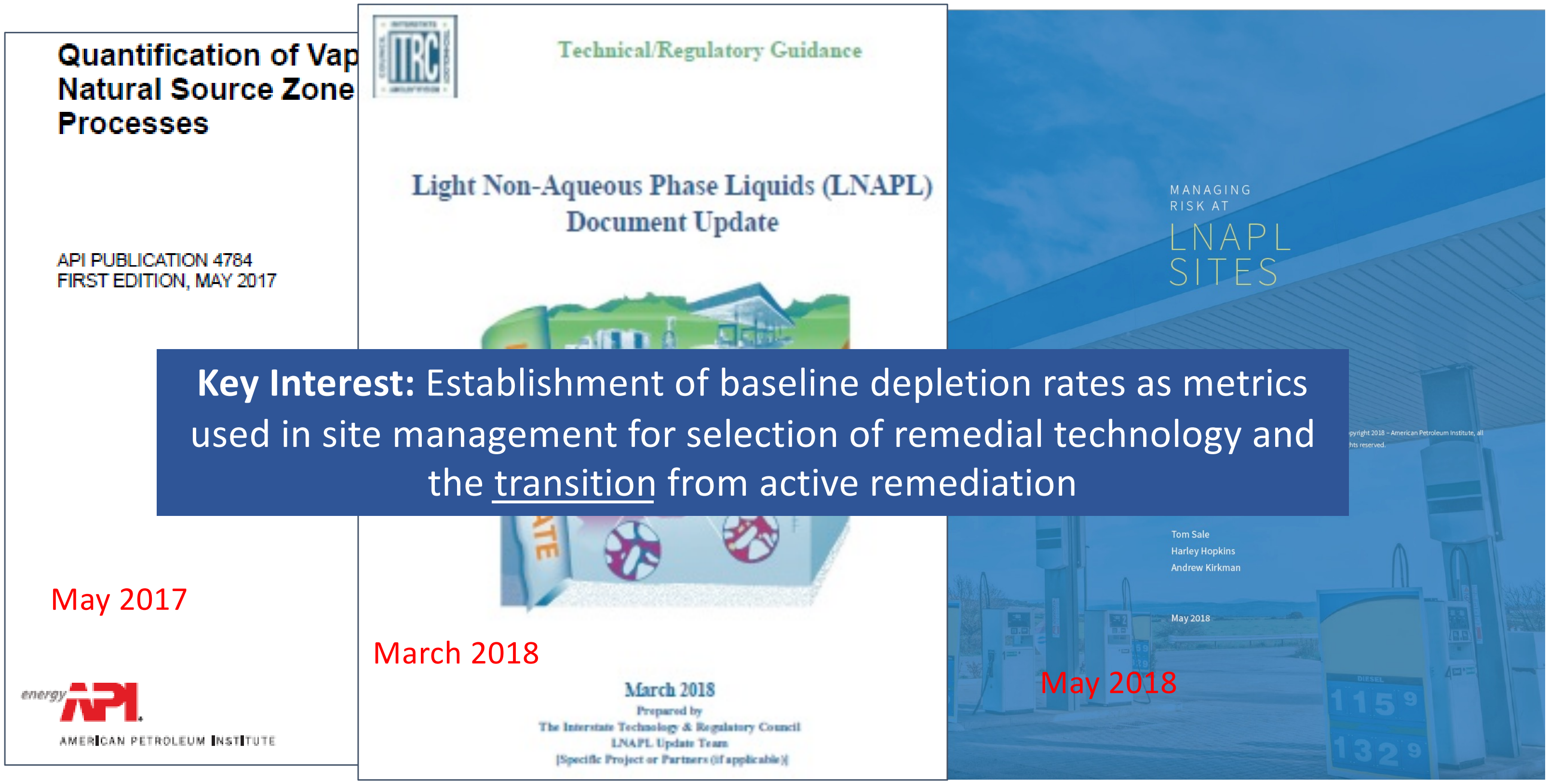
NSZD in 2017 and Beyond



Key Interest: Establishment of baseline depletion rates as metrics used in site management for selection of remedial technology and the transition from active remediation

ARIS

Communicating Role of NSZD in the CSM & Site Management

CL:AIRE technical bulletin
TB 20 (June 2019)

CL:AIRE technical bulletins describe specific techniques, practices and methodologies relevant to sites in the UK. This bulletin introduces the concept of natural source zone depletion. It includes a description of the processes controlling depletion rates, how these rates are measured and outlines its potential significance at UK LNAPL sites.

An Introduction to Natural Source Zone Depletion at LNAPL Sites

1. INTRODUCTION

Sources of hazardous chemicals in the subsurface may pose significant risks to human health and the environment. Of particular concern are light non-aqueous phase liquid (LNAPL) source zones that may contain considerable chemical mass, and pose potential risks via direct exposure to LNAPL, vapour migration / intrusion and dissolved-phase impact to controlled waters. Spills of hydrocarbon fuels and oils form the most common examples. Remediation of such sites requires effective source zone management to achieve successful outcomes.

'Natural source zone depletion' (NSZD) describes the naturally occurring processes that collectively result in the depletion of chemical contaminant mass from a (LNAPL) source zone. Over time, source zone depletion typically results in decreased receptor risks and eventual source exhaustion. Dissolution and vapourisation physically deplete the LNAPL by mass transfer of chemical constituents to the aqueous (groundwater) and gaseous (soil gas) phases. Degradation of NAPL constituent chemicals may also occur due to chemical reaction or biodegradation; hydrocarbon fuel/oil constituents are particularly susceptible to the latter.

Recent research in North America has prompted interest to more thoroughly assess LNAPL NSZD occurrence and evaluate its potential significance to LNAPL site management[1]. Underestimation of NSZD rates, due to neglecting the gaseous contribution to depletion, has been a key driver. Substantial quantities of gas may be emitted from anaerobic petroleum hydrocarbon biodegradation processes, especially methanogenesis (Garg *et al.*, 2017; Lundegard and Johnson, 2006). Several guidance documents on the assessment of NSZD occurrence and its potential significance to remediation programmes have been recently published (API, 2017; ITRC, 2018 (updating ITRC (2009); CRC CARE, 2018).

The purposes of this bulletin introducing NSZD at LNAPL sites are to:

- Introduce and raise awareness of NSZD and outline its potential significance;
- Outline the key processes controlling NSZD rates and recent research advances;
- Outline recent approaches to measuring NSZD, particularly the gaseous component;
- Consider the varied roles of emerging NSZD technology use in the remediation life cycle; and
- Review the challenges and needs yet to be overcome.

2. SIGNIFICANCE OF NSZD OCCURRENCE

Assessing the rates and timescales of NSZD occurrence is critical to managing LNAPL-contaminated sites since the contributing processes of dissolution, vapourisation and biodegradation may:

- Significantly reduce impacts over time due to reductions in source zone LNAPL mass, LNAPL saturation of the pore space, and the mobility of the LNAPL;
- Assist definition of a more precise conceptual site model (CSM) and key physical, chemical, and biological processes that control contaminant transport and potential impacts;
- Progressively lower risks arising from the mobility of the LNAPL, for instance, risks of subsurface LNAPL discharge to a receiving water course;
- Progressively reduce contaminant fluxes that sustain both the subsurface vapour and groundwater plume thereby leading to reduced receptor risks and gradual plume shrinkage;
- Influence the timeframes over which plume remediation options such as monitored natural attenuation (MNA) or other *in situ* technologies need to be employed to protect receptors; and
- Influence decision-making on the need for active remediation technologies that may deliver faster (but partial) source zone removal, but may not generate significant risk-reduction when compared to natural depletion processes alone.

3. KEY PROCESSES CONTROLLING NSZD EXPRESSION

Understanding the key processes that control NSZD rates and their individual relative contribution to source-mass depletion are considered a priority for remediation selection and design, for risk assessors and/or regulators. The key processes - dissolution, vapourisation, volatilisation and biodegradation for LNAPL sites - are illustrated in the LNAPL CSM shown in Figure 1. It is convenient to consider here the overall expression of NSZD by segregating source depletion contributions to (Palaia and Fitzgibbons, 2017):

- the aqueous expression of NSZD below the water table, and
- the gaseous expression of NSZD above the water table.

Some of the key processes influencing each expression are introduced below with a greater focus on the gaseous expression where current research advances have been made.

[1] LNAPL NSZD is broadly similar in concept to the 'engineered bioreactor' concept applied in waste management to generate methane from landfills (often for energy production) and accelerate stabilisation of degradable wastes, and on which research has been undertaken in UK and Europe over a number of decades.

If you would like further information about other CL:AIRE publications please contact us at the Help Desk at www.claire.co.uk

Natural Source Zone Depletion (NSZD)

A Key Part of the LNAPL Conceptual Site Model

by Jenna DiMarzio, M.Sc. and Julio Zimbron, Ph.D. (E-Flux)

Following a Light Non-Aqueous-Phase Liquid (LNAPL) spill, characterization activities, including high-resolution site characterization (HRSC), are often used to determine the spatial extent of the contaminant, the location of the source, and the severity of the impacts on both soil and groundwater. After this initial characterization, the site owner must confront the crucial question: What's next? Most site owners and regulators will at this point turn their attention to remediation design, with the legitimate goal of restoring the site to its previously pristine condition.

While we environmental professionals are busy planning our responses to spills, natural soil processes are already underway. Soil microbial populations begin to adjust to the introduction of LNAPL compounds, resulting in the awakening of metabolic pathways capable of using the energy stored in LNAPL. These microbial mechanisms ultimately result in the biodegradation of petroleum, yet are often ignored or overlooked by site owners. However, biodegradation processes, collectively called Natural Source Zone Depletion (NSZD) have recently been recognized as crucial to the contaminated site's life cycle and are a key part of the formulation of the LNAPL conceptual site model (CSM).

NSZD includes microbially driven processes that result in the transformation of petroleum contaminants into dead-end inorganic products. This conversion, called *mineralization*, relies on the presence of microbes capable of degrading the contaminants, as well as the availability of electron acceptors like oxygen. Alternative electron acceptors (e.g., sulfate, nitrate, iron, manganese oxides) typically present in soil can be used by microbes for anaerobic pathways when oxygen is not available until they, too, are depleted. Because oxygen is preferentially used by microbes as an electron acceptor and soil has a limited oxygen transport capacity, it is typically absent near the LNAPL source.

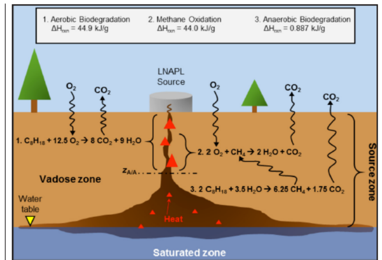


Figure 1. *Schematic depiction of subsurface processes at an LNAPL spill*

Although aerobic biodegradation is traditionally considered to be faster than anaerobic biodegradation, the relative importance of both processes at a site might be determined by the extent of contact between electron acceptors and the contaminant. Both aerobic and anaerobic pathways ultimately result in the production of carbon dioxide (CO_2). This LNAPL-derived CO_2 will rise through the soil column and eventually escape into the atmosphere.

In addition to those processes using "external" electron acceptors (i.e., those migrating toward the contaminant due to air or gas transport), many LNAPL-contaminated sources undergo methanogenesis, which results in the degradation of petroleum products into methane (CH_4) and CO_2. This reaction, which does not require external electron acceptors, takes place below the aerobic/anaerobic interface within the soil column. As the upward-moving CH_4 reaches this interface and contacts oxygen, it is typically rapidly oxidized to CO_2. If the flux of biodegradable carbon sources (including CH_4) exceeds the soil's oxygen transport capacity, incomplete CH_4 oxidation might occur. This situation, which can result in explosion hazards and increased risk of vapor intrusion, has been observed at a large ethanol-containing biofuel spill (Sihota et al., 2013).

Why Are These Processes Important?

Acknowledging the interactions between soil microbes and petroleum contaminants has strong implications. First, it helps us better understand local soil and groundwater geochemistry in the context of a contaminated site. Second, it helps us realize that these processes will result in the in-situ mass depletion of organic contaminants.

From a practical viewpoint, NSZD can be a useful tool at all stages of a contaminated site's life cycle. Using NSZD principles (i.e., increased CO_2 emissions from contaminated soils) to identify a geochemical footprint in the vadose

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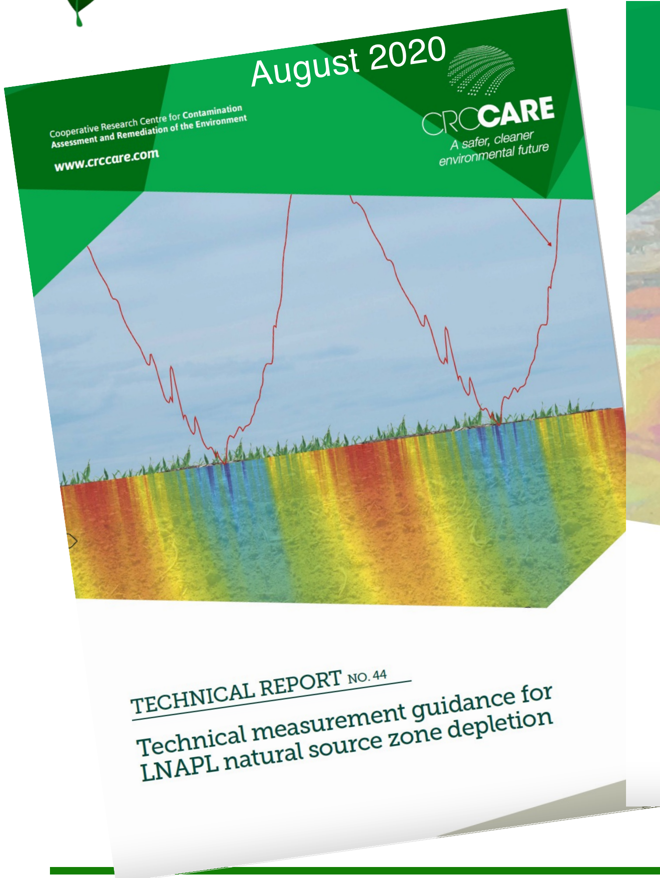
Australian Guidance



ARIS

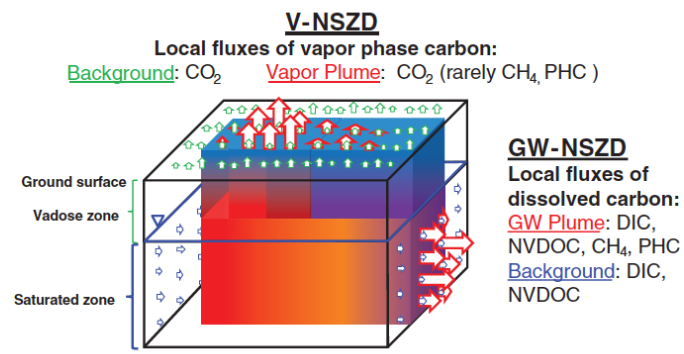
Advances in NSZD Rate Estimates

Groundwater Monitoring&Remediation — Technical Notes

Groundwater Monitoring & Remediation 41, no. 1/ Winter 2021/pages 99–105

Method to Estimate Thermal Conductivity of Subsurface Media

by Kayvan Karimi Askarani, Sam Gallo, Andrew J. Kirkman, and Tom C. Sale



Thermal estimation of natural source zone depletion rates without background correction

Water Research 169 (2020) 115245

Kayvan Karimi Askarani, Thomas Clay Sale*

Civil and Environmental Engineering Department, Colorado State University, 1320 Campus Delivery, B01, Fort Collins, CO. 80523-1320, USA

Mackay et al. (2018) Comparing natural source zone depletion pathways at a fuel release site. Groundwater Monitoring & Remediation

Example Publications…not an exhaustive list…

ARIS

Advances in NSZD Rate Estimates

Groundwater Monitoring&Remediation

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

NAPL Composition Method

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

Groundwater Monitoring & Remediation 40, no. 3/ Summer 2020/pages 75–88

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

Soil Gas Gradient Method

Journal of Contaminant Hydrology 241 (2021) 103807

Iason Verginelli *, Renato Baciocchi

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

Example Applications - Published

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

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

Groundwater Monitoring & Remediation (2020)

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

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*]

Quarterly Journal of Engineering Geology & Hydrogeology (2021)

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

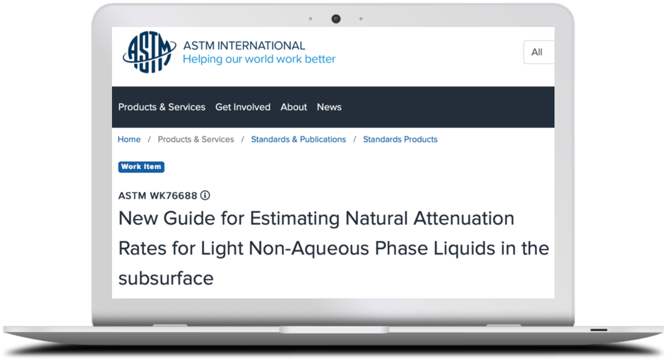
G.B. Davis [a,*], J.L. Rayner [a], M.J. Donn [a], C.D. Johnston [a], R. Lukatelich [b], A. King [c], T.P. Bastow [a], E. Bekele [a]

Journal of Contaminant Hydrology (2022)

Example Publications…not an exhaustive list…

Natural Attenuation Processes & Pathways

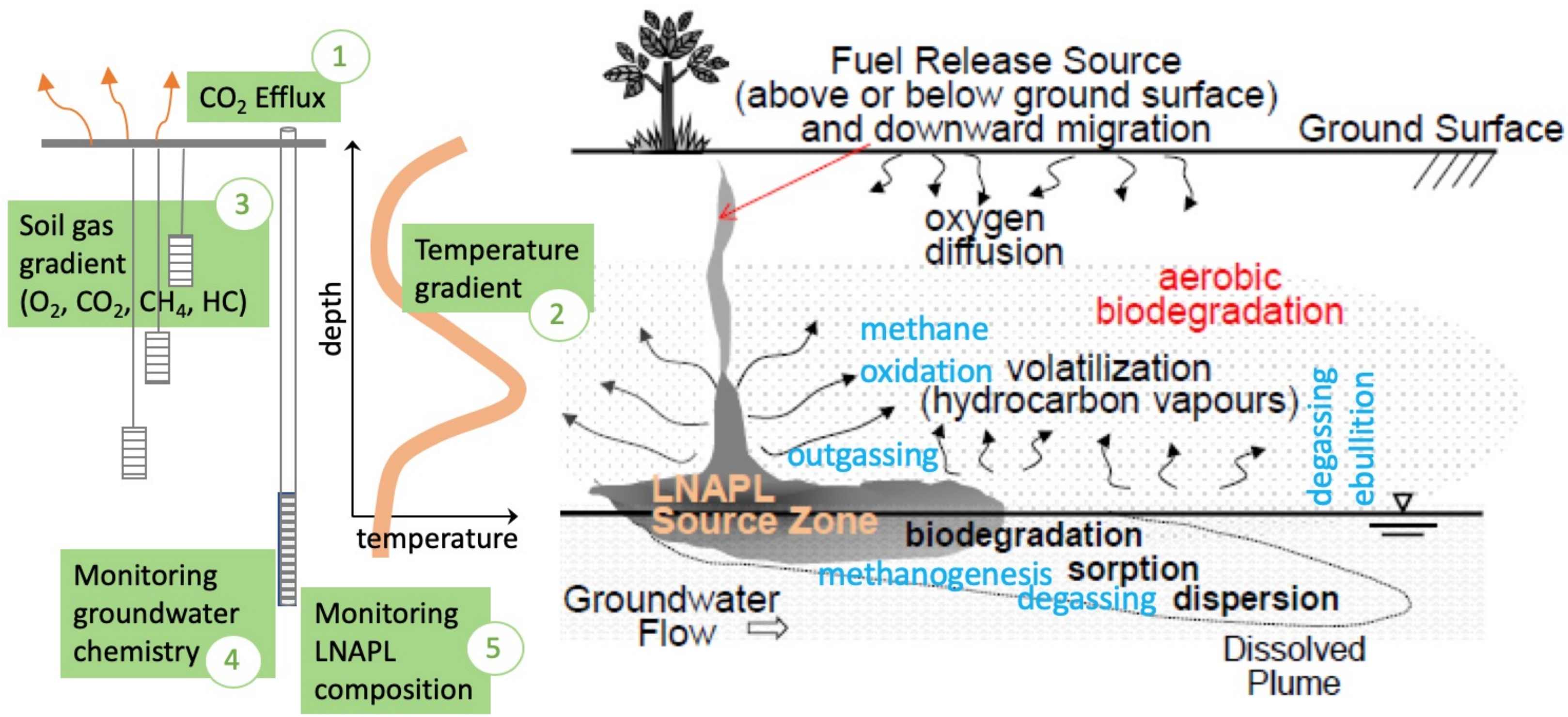
1. CO_2 Efflux Method
2. Temperature Gradient Method
3. Soil Gas Gradient Method
4. Groundwater Monitoring Method
5. NAPL Composition Method



https://www.astm.org/workitem-wk76688

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

Natural Attenuation Processes & Pathways



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Methods in the Proposed Standard

1. CO_2 Efflux Method:

A method for quantifying the natural source zone depletion rate that relies on measurements of CO_2 released from NAPL biodegradation in the subsurface and transported through diffusion and advection to the ground surface.

2. Temperature Gradient Method:

A method for quantifying the natural source zone depletion rate based on measurements of temperature and estimates of heat flux resulting from aerobic biodegradation of the NAPL and byproducts (methane) in the subsurface.

3. Soil Gas Gradient Method:

A method for quantifying the natural source zone depletion rate based on measurements of changes in soil gas composition with depth (vertical gradient) in the vadose zone resulting from biodegradation and transport of terminal electron acceptors (TEAs) and reaction byproducts (mainly O_2, CO_2, hydrocarbons, and CH_4).

4. Groundwater Monitoring Method:

A method for quantifying natural attenuation rates that relies on groundwater sampling and analyses.

5. NAPL Composition Method:

A method for assessing natural source zone depletion based on monitoring and data analysis of changes in NAPL composition over time.

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

Example: CO_2 Efflux Method

Tools	Products / Instruments
Dynamic closed chamber Active air flow connected to infrared detector Measurement time scale: snapshot (minutes) ^{14}C correction	LI-COR Biosciences Automated Soil Gas Flux System 
Static trap Sorbent material to passively capture CO_2 Measurement time scale: weeks (~1 to 4 weeks) ^{14}C correction	E-Flux Fossil-Fuel Trap 
Forced diffusion dynamic chamber Flow regulated by gas permeable membrane Measurement time scale: snapshot (minutes) continuous monitoring	Eosense eosFD soil CO_2 flux sensor 

ARIS

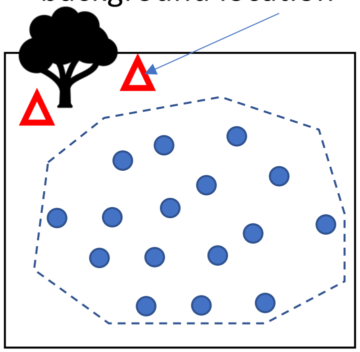
Background Sources of CO_2

- CO_2 produced from natural soil respiration

CO_2 Efflux = Contaminant Soil Respiration + Natural Soil Respiration

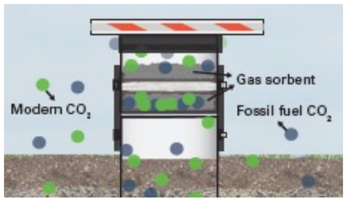
- Two general approaches:
  - Sampling background locations
  - Sampling & analysis of radiocarbon (^{14}C)
- Design of program for background correction is site specific:
  - Heterogeneity in surface cover & vegetation
  - Heterogeneity in hydrogeologic conditions over the LNAPL footprint

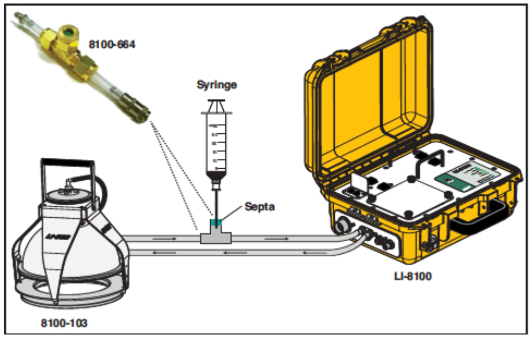
background location



Sampling for ^{14}C Analysis

Contemporary (modern) organic carbon is ^{14}C-rich, while fossil fuel carbon is ^{14}C-depleted





Summary of Methods

Method	Type of Attenuation Measured[1]	Location of Processes & Pathway	Measurement Location
1. CO_2 Efflux	Bulk NAPL	Vadose zone[2]	Ground surface
2. Temperature Gradient	Bulk NAPL	Vadose zone[2]	Vertical profile mostly in the vadose zone & straddling the capillary fringe above the source zone
3. Soil Gas Gradient	Bulk NAPL & COCs	Vadose zone[2]	Vertical profile in the vadose zone above the source zone
4. Groundwater Monitoring	Bulk NAPL & COCs	Saturated zone	Profile along the groundwater flow path up- and down-gradient from the source zone; includes monitoring of dissolved gases
5. NAPL Composition	COCs	NAPL Source zone	Source zone

[1]The depletion rate of bulk NAPL directly addresses saturation-based concern. While estimates of COC attenuation rates have a more direct impact on composition-based concern, both bulk depletion of NAPL and COC attenuation impact the extent and longevity of the COCs in soil vapor and groundwater.
[2]Includes the transport of methane and other hydrocarbons produced from the biodegradation of NAPL in the saturated zone; and methane oxidation at the aerobic/anaerobic interface.

Method Assumptions & Site-Specific Considerations - CO_2 Efflux Method

Underlying Assumptions	Site Conditions
• Attenuation of NAPL constituents through biodegradation • Complete mineralization of NAPL constituents to CO_2 • CO_2 transport in soil gas from the source to the ground surface (point of measurement) • Background source: CO_2 produced from natural soil respiration • Estimate the portion of CO_2 efflux attributable to contaminant biodegradation	• Ground surface cover • Vegetation • High natural organics (e.g., peat) • High permeability soils and barometric pumping • Low gas permeability soils • Preferential pathways (e.g., utilities)

Example Implementation – CO_2 Efflux

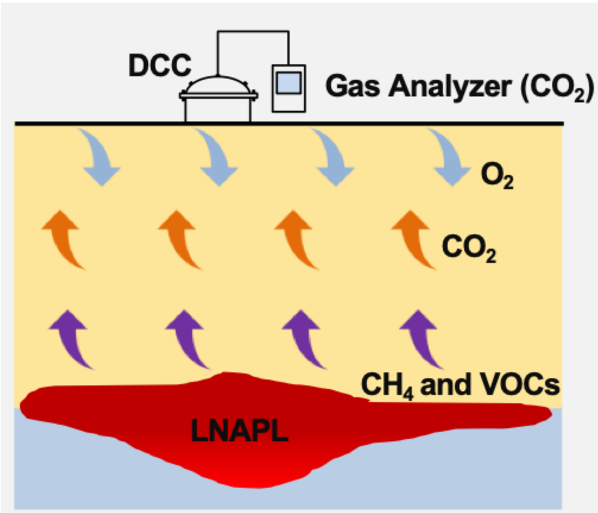


Figure from Iason Verginelli (2021)

Step 1. Install DCC
Step 2. Estimate the CO_2 Efflux, J_{CO2}
Step 3. Correct for background sources

$$J_{CSR} = J_{CO_2} - J_{NSR}$$

J_{CSR} = attributed to NAPL soil respiration (μmol CO_2/m²/s)
J_{CO2} = total measured (μmol CO_2/m²/s)
J_{NSR} = attributed to natural soil respiration (μmol CO_2/m²/s)

Step 4. Estimate the NSZD Flux

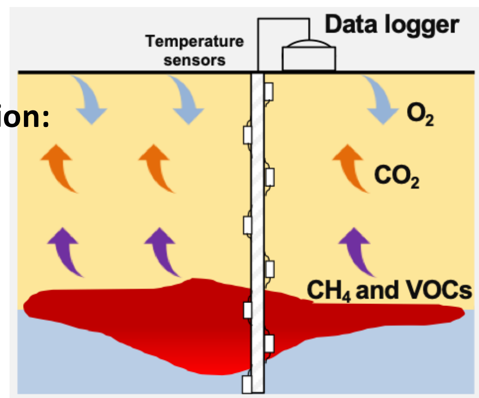
$$J_{NSZD} = J_{CSR} \frac{M_w S_{HC:CO2} U}{\rho_o}$$

J_{NSZD} in gallons/acre/year.
M_w = Molar weight of hydrocarbon (g/mol)
$S_{HC:CO2}$ = Stoichiometric ratio of a mole of hydrocarbon degraded per mole of CO_2 produced
ρ_o = Density of hydrocarbon (kg/L)
U = Unit conversion factor = $33.7 \frac{s}{year} \times \frac{kg}{\mu g} \times \frac{m^2}{acre} \times \frac{gallon}{L}$

Method Assumptions & Site-Specific Considerations – Temperature Gradient Method

Underlying Assumptions	Site Conditions
• Attenuation of NAPL constituents through aerobic biodegradation and oxygen availability • Production of biogenic heat from aerobic oxidation of hydrocarbons (notably methane) • Background correction for heat exchange with the atmosphere and other sources of heat in the subsurface	• Low gas permeability surface cover that could limit soil gas transport[1] • High natural organics (e.g., peat) • Confined NAPL conditions (ASTM E2856) • Geologic or anthropogenic sources of heat not related to the NAPL

Example Implementation:



Step 1. Identify the temperature profile
Step 2. Correct for background sources (select from three approaches)
Step 3. Estimate the NSZD Flux, J_{NSZD}

Method Assumptions & Site-Specific Considerations – Soil Gas Gradient Method

Underlying Assumptions	Site Conditions
• Spatial Changes in soil gas composition – vertical profile in the vadose zone resulting from biodegradation of NAPL constituents • Vertical gradients in O_2, CO_2, or hydrocarbon concentrations in soil gas • Diffusive gas transport in the vadose zone	• Low gas permeability surface cover that could limit O_2 ingress[1] • Low gas permeability soils • Soil gas advection from barometric pumping effects or high methane concentrations

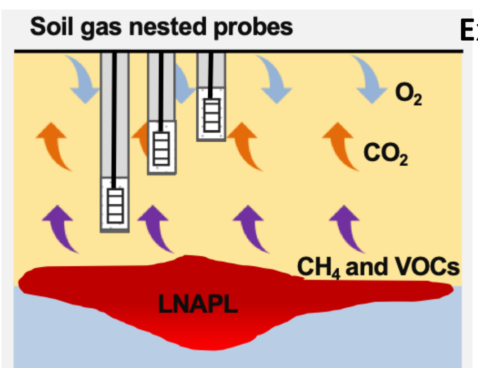


Figure from Dr. Iason Verginelli (2021)

Example Implementation:

Step 1. Identify the O_2 concentration profile in soil gas
Step 2. Estimate the concentration gradient of O_2 in soil gas
Step 3. Estimate the reaction length
Step 4. Estimate the diffusion coefficient
Step 5. Estimate the mass flux
Step 6. Correct for background sources (select from two approaches)
Step 7. Estimate the NSZD Flux, J_{NSZD}

$$J_{NSZD} = J_{CSR} S_{HC:O2}$$

J_{NSZD} in gallons/acre/year
$S_{HC:O2}$ = Stoichiometric mass ratio of g of hydrocarbon degraded per g of O_2 consumed

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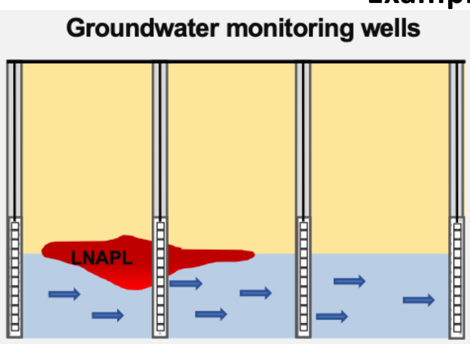
Method Assumptions & Site-Specific Considerations – Groundwater Monitoring Method

Underlying Assumptions	Site Conditions
• Spatial (up-and down-gradient of the source) changes in the groundwater chemistry including dissolved gas concentrations resulting from biodegradation of NAPL constituents in the saturated zone • Dissolution and flow of NAPL constituents in groundwater	• Availability of groundwater monitoring data and hydrogeologic parameters • Assessment of confined NAPL conditions (ASTM E2856) for data interpretation

Example Implementation:



Step 1. Estimate source mass depletion due to dissolution & flow
Step 2. Estimate the assimilative capacity, A_c, based on groundwater monitoring data
Step 3. Assess conditions for **degassing & calculate A_c accordingly**
Step 4. Estimate the rate of biodegradation in the saturated zone
Step 5. Estimate the total rate in the saturated zone, R_{sat} (kg/day)

$$R_{sat} = R_{sat-dis} + R_{sat-bio}$$

R_{sat} = total mass loss of hydrocarbons in the saturated source zone combination of dissolution and flow of the hydrocarbons ($R_{sat-dis}$) and the rate of hydrocarbons biodegraded ($R_{sat-bio}$).

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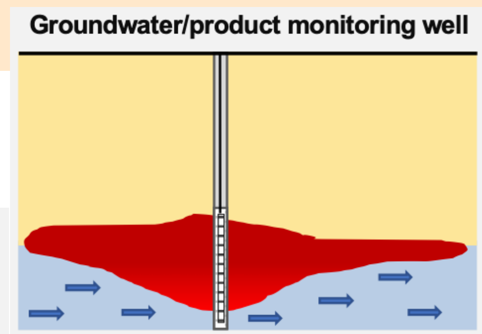
Method Assumptions & Site-Specific Considerations – NAPL Composition

Underlying Assumptions	Site Conditions
• Changes in the composition of NAPL constituents over time • NAPL sampled consecutively from a single location is representative of the same NAPL body over time (monitoring period)	• Finite NAPL mass with no additional releases during the assessment period • Availability of NAPL compositional data over time (minimum of approximately four years and 9 to 10 NAPL samples) • Conversion of fraction/percent rates into volumetric rates will require an estimate of total NAPL volume at the onset of the monitoring period

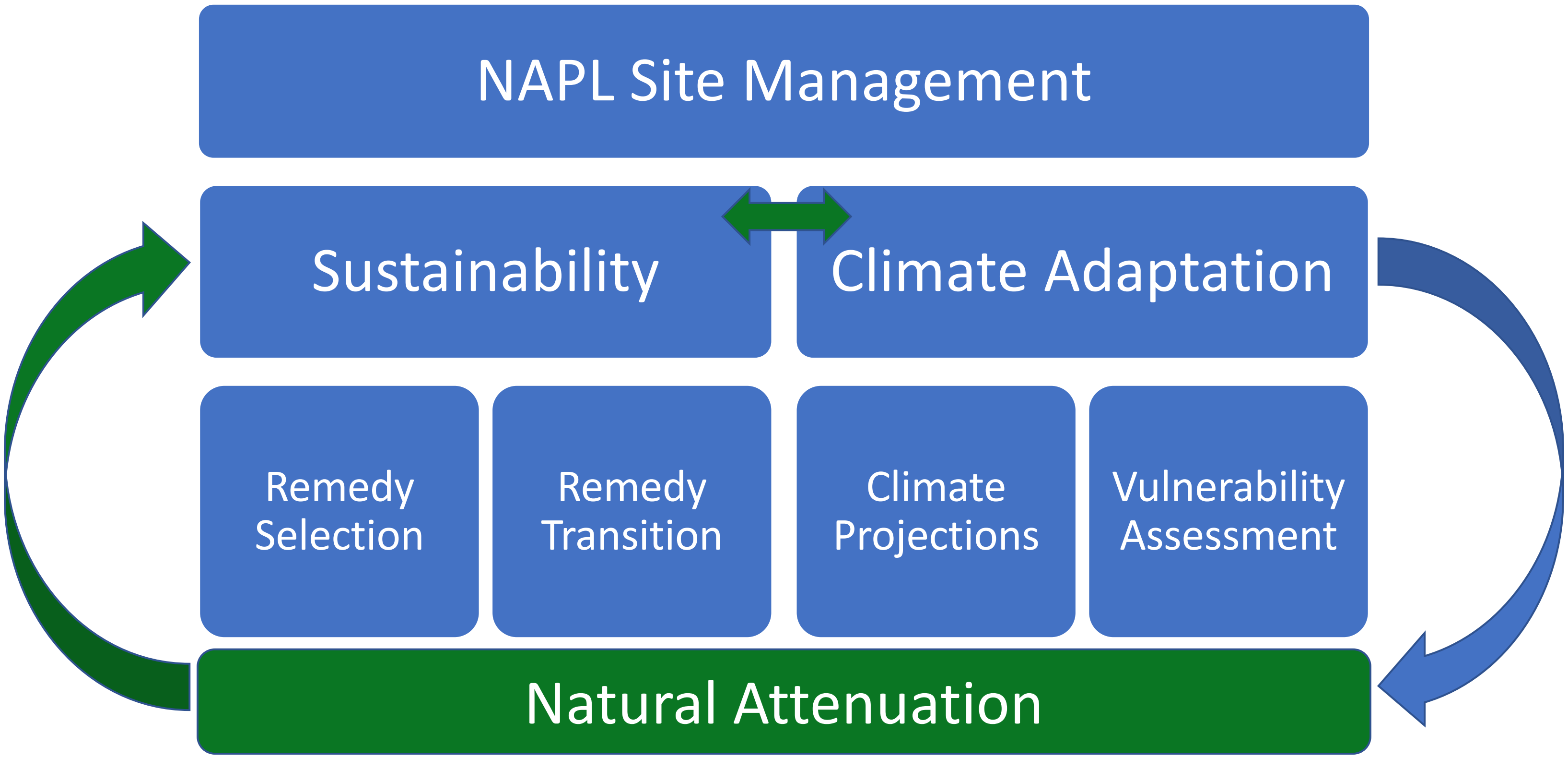
Step 1. Identify the relevant constituents
Step 2. Analyse data on mass fractions of NAPL constituents
Step 3. Identify potential markers
Step 4. Refinement on identifying potential markers
Step 5. Estimate the effective rates

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)

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



Site Management in a Changing Climate

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Thank You
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A New Framework for Efficient, Optimized and Sustainable Site Remediation Process (Toolkit 3)

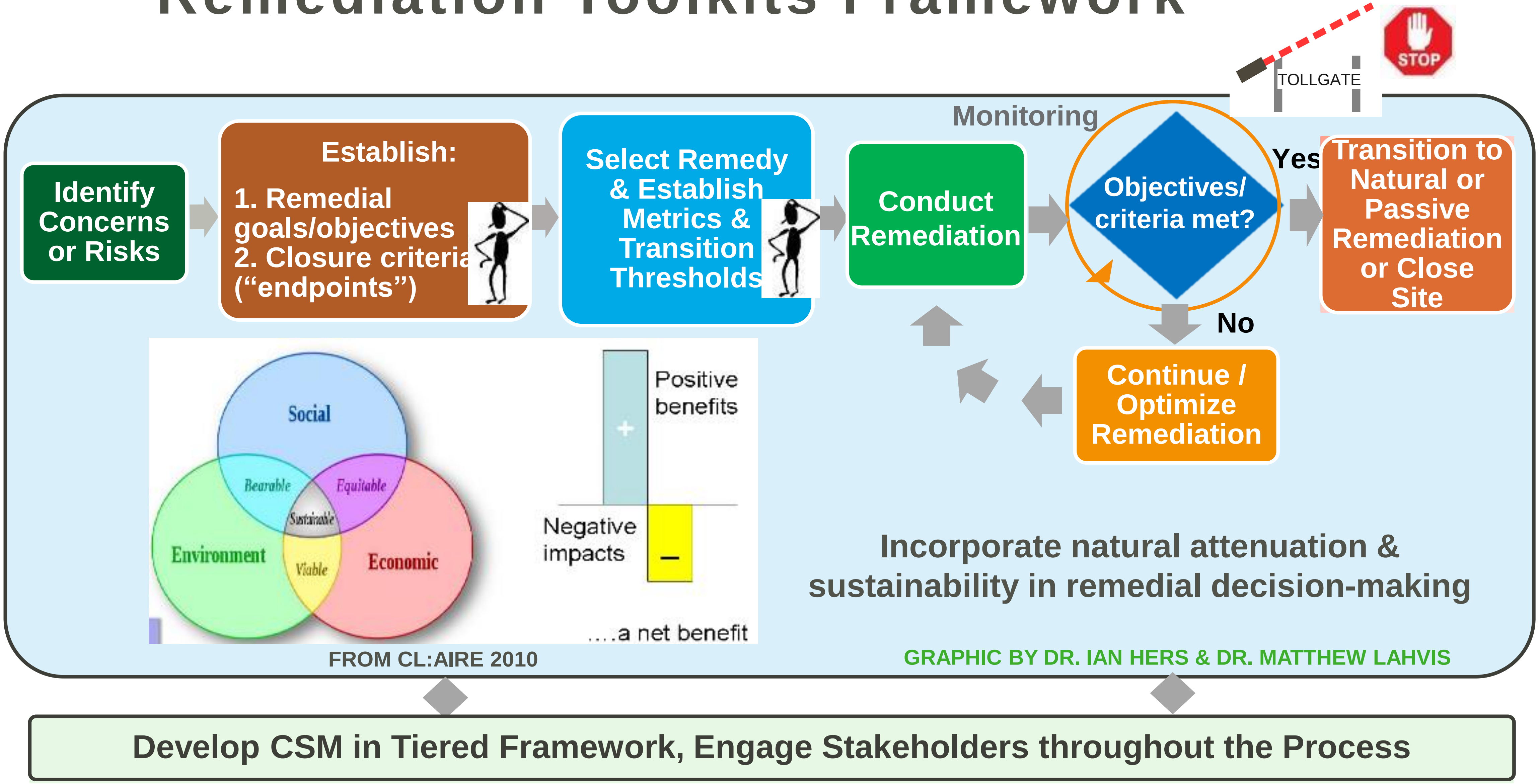
CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Dr. Ian Hers, HEC

Outline

1. Overall framework
2. Composition / concentration vs saturation concern
3. Four-step process
    i. Set remediation goals/objectives
    ii. Conduct baseline assessment of natural attenuation
    iii. Select remedy, define performance metrics, transition thresholds
    iv. Implement, optimize, transition and close

Remediation Toolkits Framework

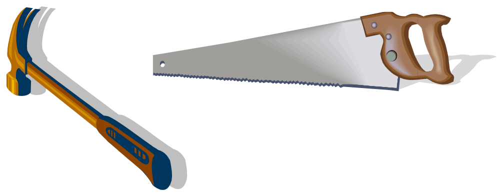


Let's Start with Concern, Goal and Mechanism

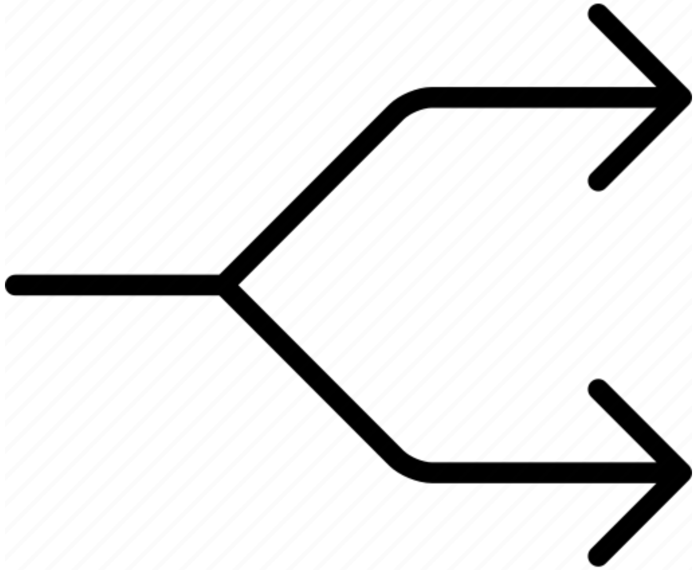
Concern or Risk
Migrating LNAPL
Presence of Mobile LNAPL above threshold, e.g., 2 mm
Dissolved Groundwater or Soil Vapour Plumes Exceed Standard – Potential Risk

Remedial Goal	Primary Mechanism
1. Reduce **Saturation**	Mass Recovery or Reduction
2. Change **Composition/** Reduce **Concentration**	Phase Change - change LNAPL characteristics and/or treat associated plumes
3. **Containment**	Control Measures - stop LNAPL and associated plumes
4. Reduce **Saturation** & Change **Composition**	Phase Change and Mass Recover – More Aggressive Technologies

Key point: Consider Saturation vs. Composition goal, & from there right tool for job



Concern, Goal and Mechanism

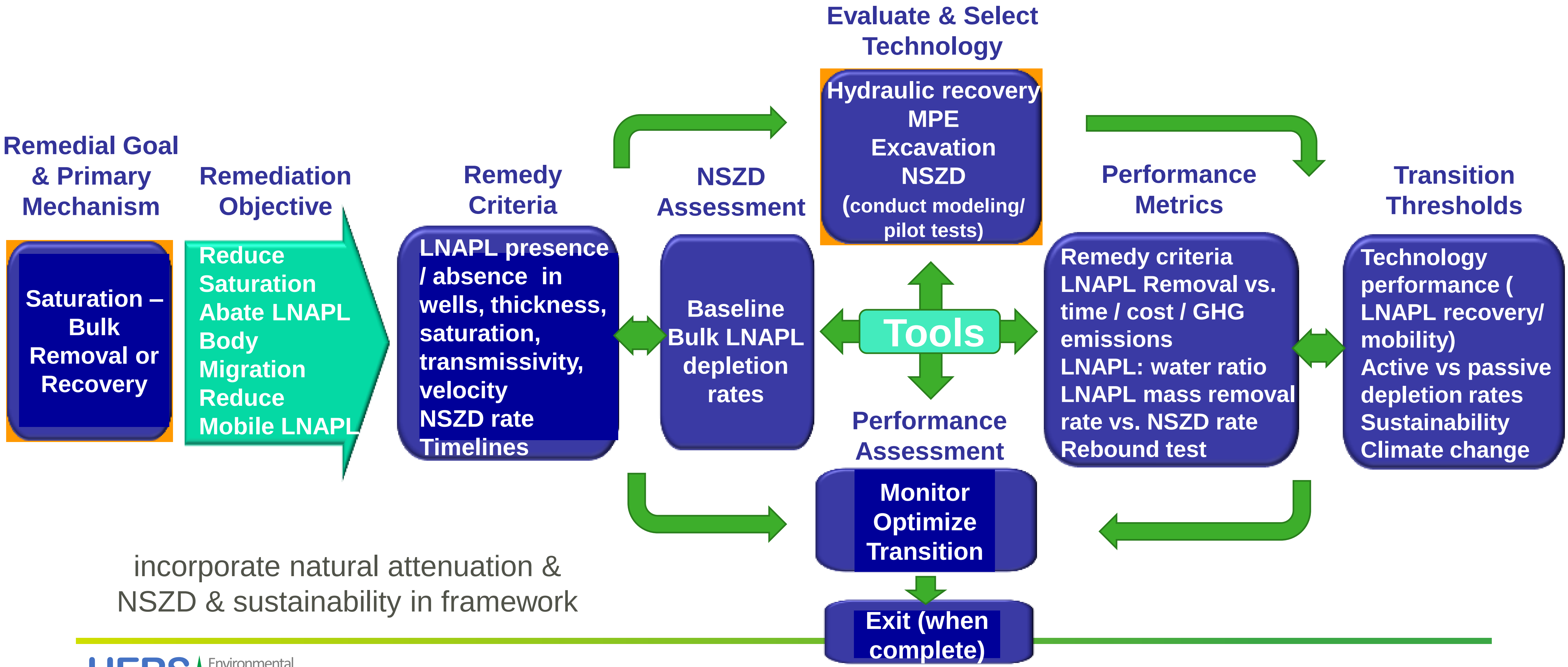


LNAPL Migration - Saturation

LNAPL-derived Plumes – Composition / Concentration

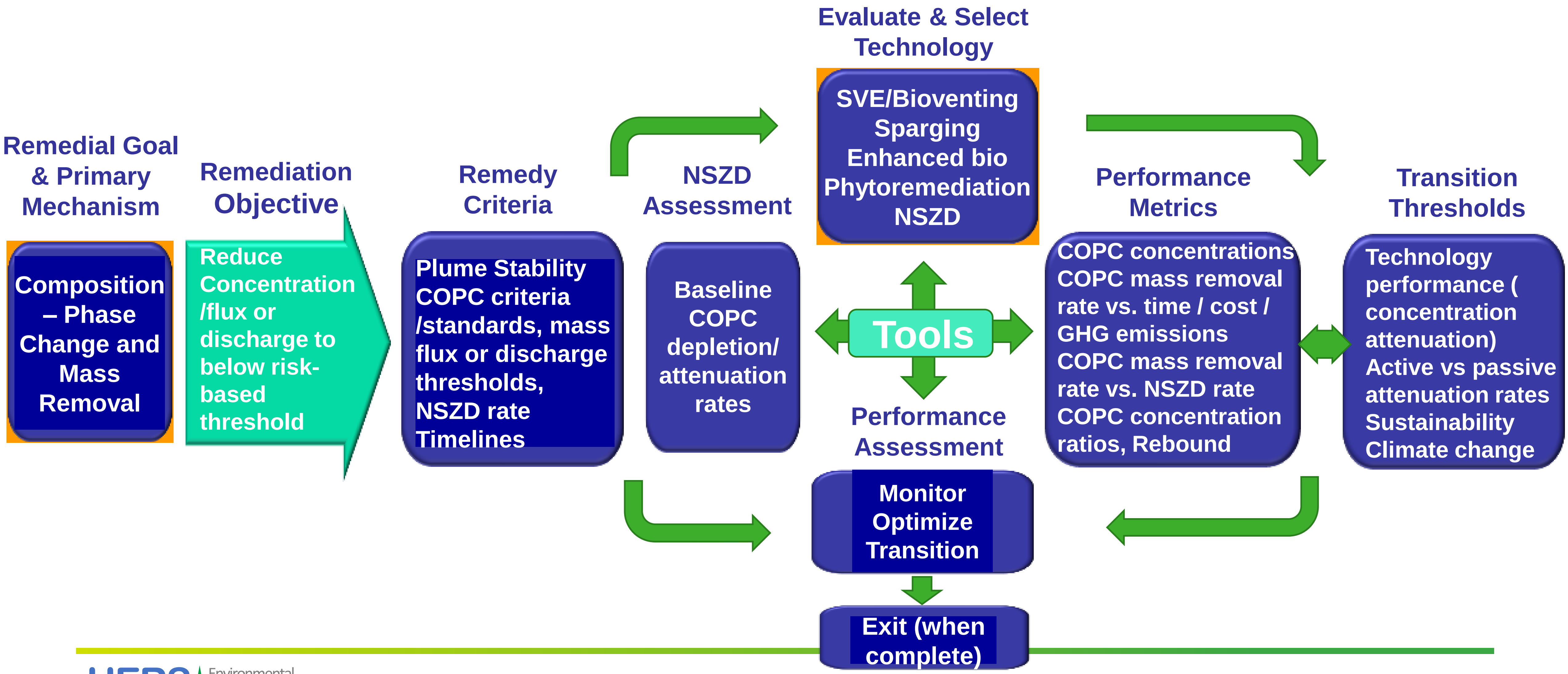
Detailed process framework developed and tools identified

Remediation Process for LNAPL Concern = Migration or Presence of Mobile LNAPL (Saturation)



incorporate natural attenuation & NSZD & sustainability in framework

Remediation Process for LNAPL Concern = Plumes & Health Risk (above standard) (Composition)



Remediation Process Outline

Simplified from Toolkits

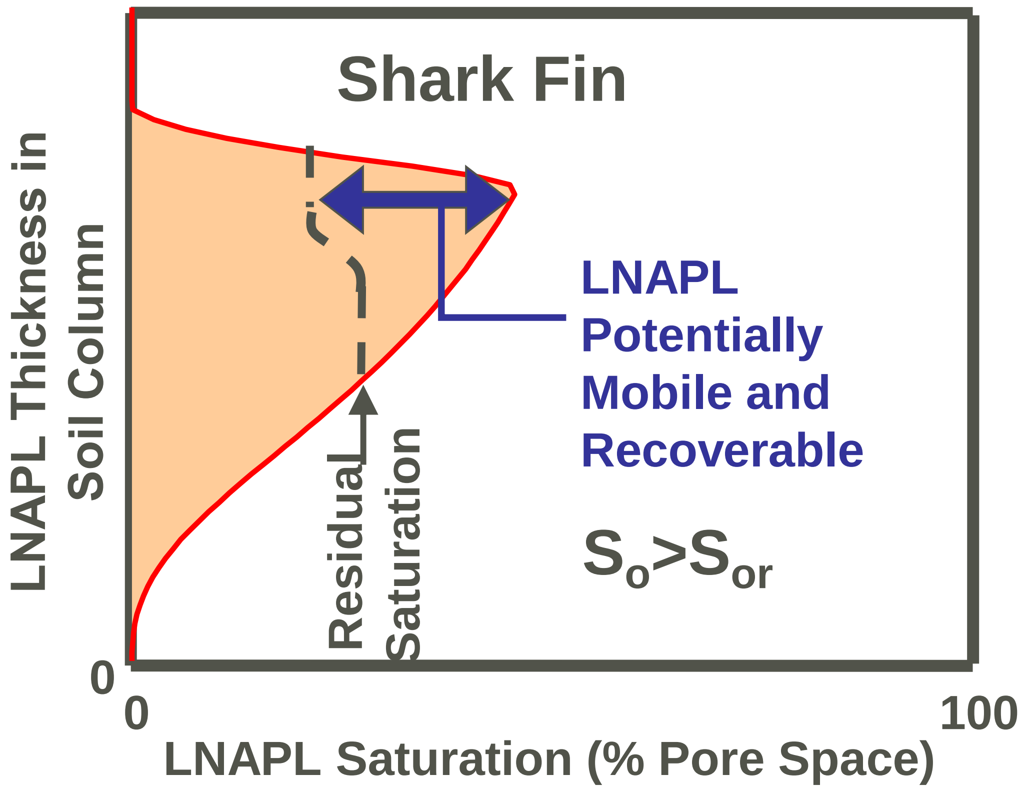
1. Set Goals/Objectives

2. Conduct baseline NSZD / NA Assessment

3. Select Remedy; Define Performance Metrics, Transition Thresholds

4. Optimize, Verify, Transition and Close

1. LNAPL Migration - Saturation Goal



Key Point: Importance of LNAPL CSM and Science (see Toolkit 3 for data needs)

1. Saturation goal only relevant when So > Sr and there is recoverable and migrating LNAPL
2. Use appropriate metrics / tools such as LNAPL transmissivity (Tn)
   - ITRC 2018 LNAPL Guidance:Tn threshold for hydraulic recovery = 0.1 to 0.8 m^2/day
3. Follow lines of evidence (LOE) evaluation for evaluating LNAPL mobility (science-based approach, allowed in BC ENV Protocol 16, see ITRC and ASTM guidance)
4. Incorporate NSZD in LOE evaluation

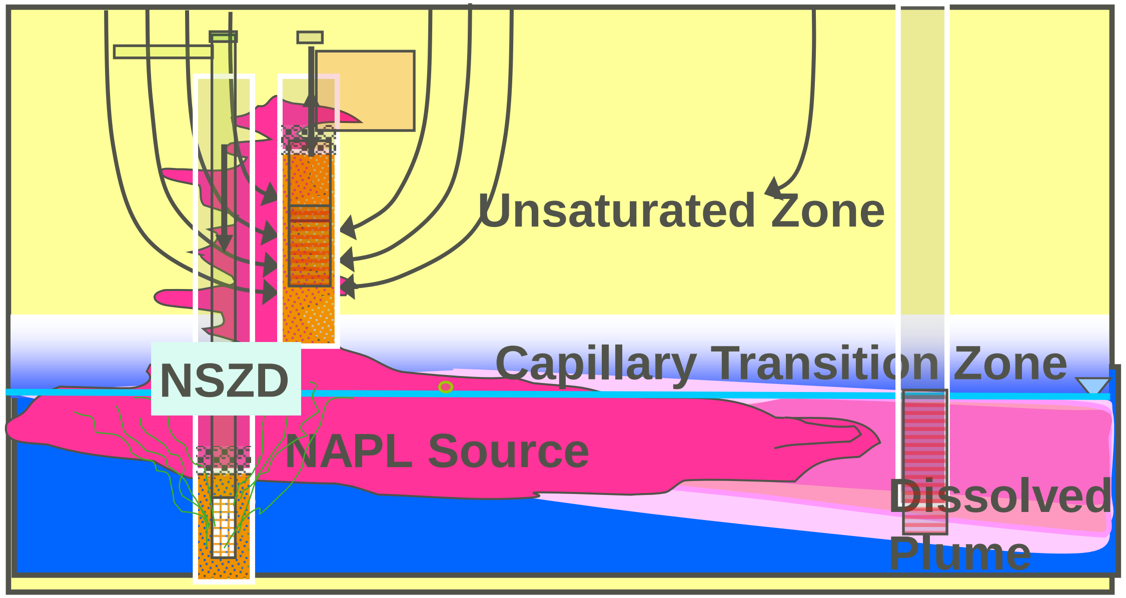
NSZD Assessment

To Evaluate LNAPL Stability

- NSZD rate can be used in evaluation of LNAPL body stability
- Compare mass flux from the LNAPL seepage rate to the NSZD rate
- LNAPL seepage rate can be obtained from LNAPL transmissivity and thickness
- CONCAWE 2022 LNAPL Toolbox provides equations for comparing NSZD rate to LNAPL mobility (https://lnapltoolbox.concawe.eu/lnapl_toolbox/)

Analogy between glacier, which moves slowly but looses mass because of melting and evaporation, and LNAPL body (adapted from ITRC IBT 2018)

1. Migration of Plumes – Composition / Concentration Goal

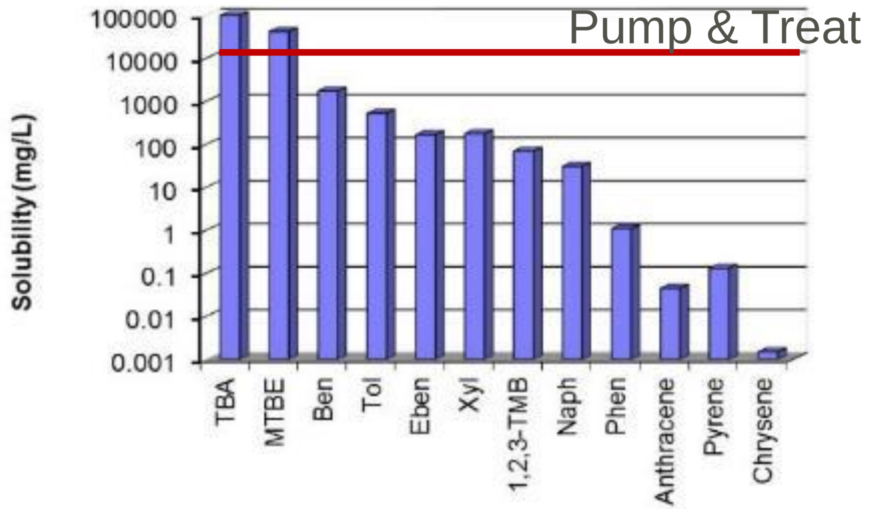


Air-phase technologies such as soil vapour extraction / air sparging can be effective

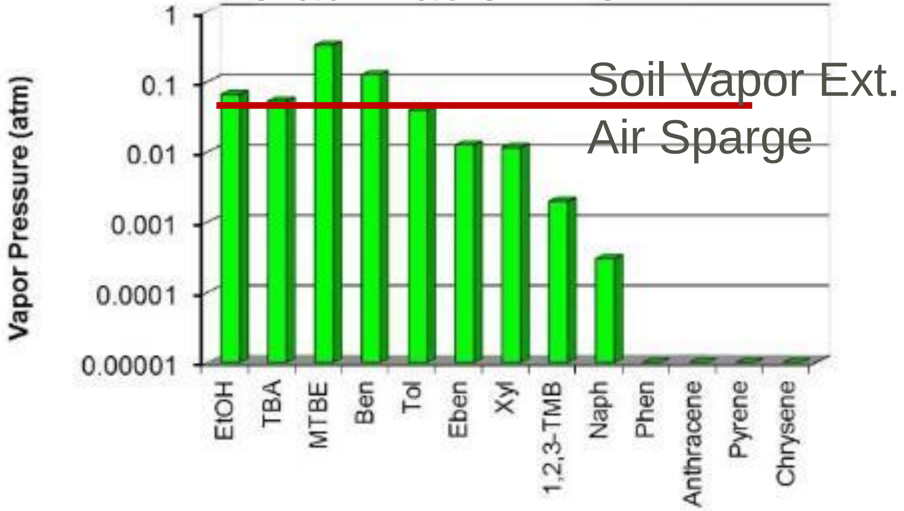
1. Entire NAPL body affects composition
2. Can target the source NAPL and/or treat plume
3. Use appropriate metrics / tools such as plume stability analysis
4. Recognize limits of remediation in reaching numeric standards
5. Consider whether NSZD (intrinsic bio) is an appropriate standalone remedy

How to Change LNAPL Composition (ITRC IBT)

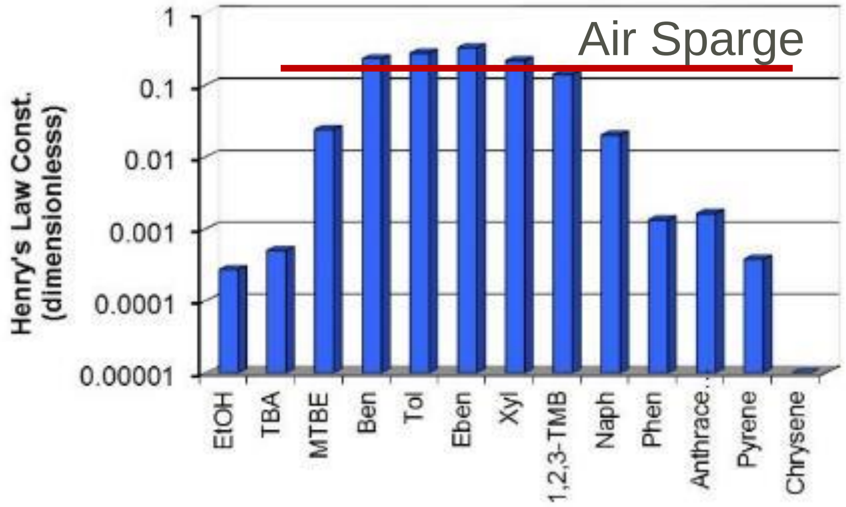
Dissolution



Volatilization from LNAPL



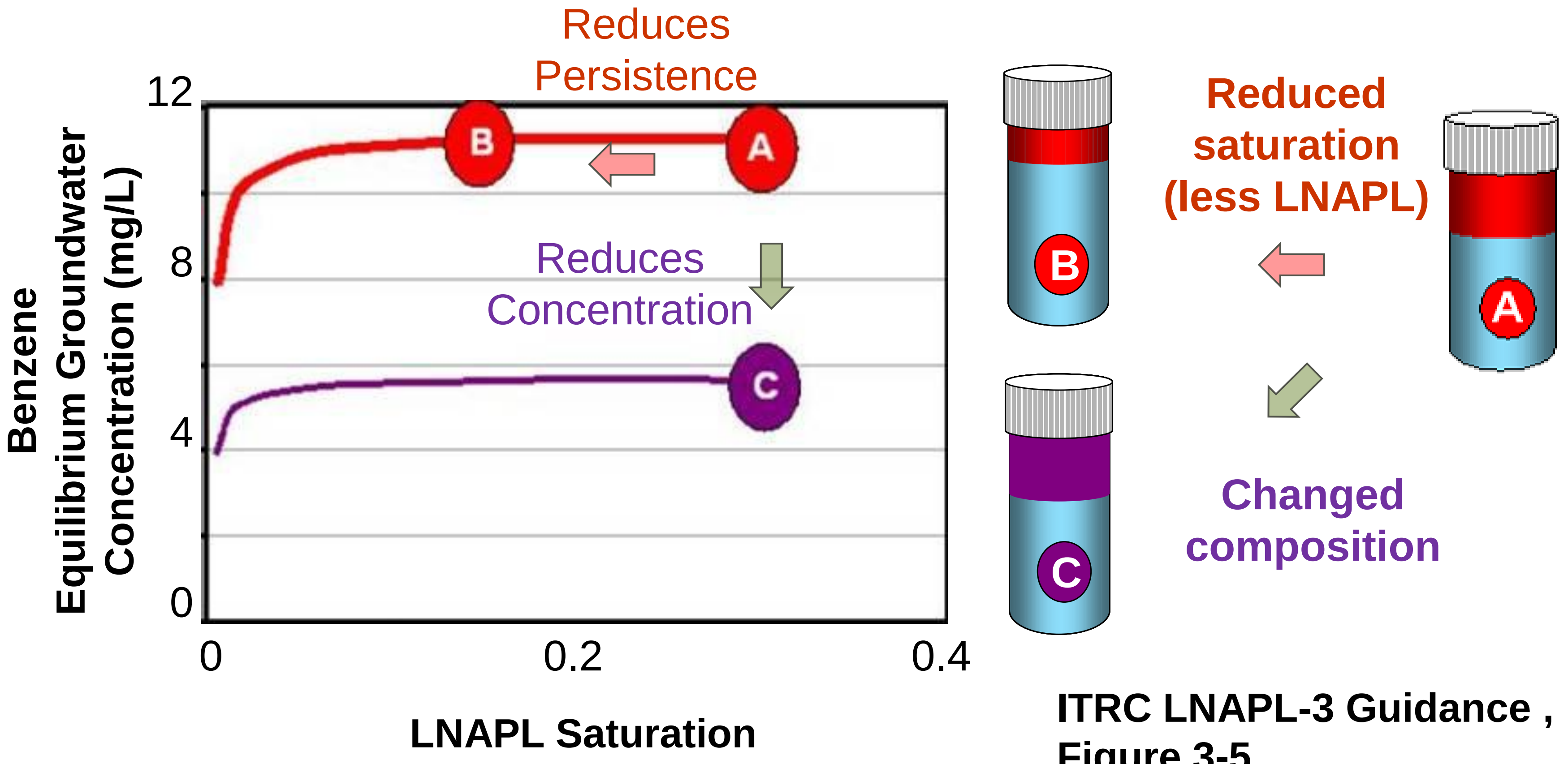
Volatilization from Water



Biodegradation

Compound	Aerobic conditions	Denitrifying conditions	Sulfate-reducing conditions	Iron-reducing conditions	Methano-genic conditions
Benzene	++	-	+	-	+
Toluene	++	++	+	+	+
m-Xylene	++	++	+	+	+
p-Xylene	++	+	+		+
o-Xylene	++	+/-[1)]	-	-	+/-
Ethylbenzene	++	+/-		-	+/-
1,2,4-trimethyl-benzene	++				+/-

Comparison between Composition and Saturation Goals (ITRC IBT)



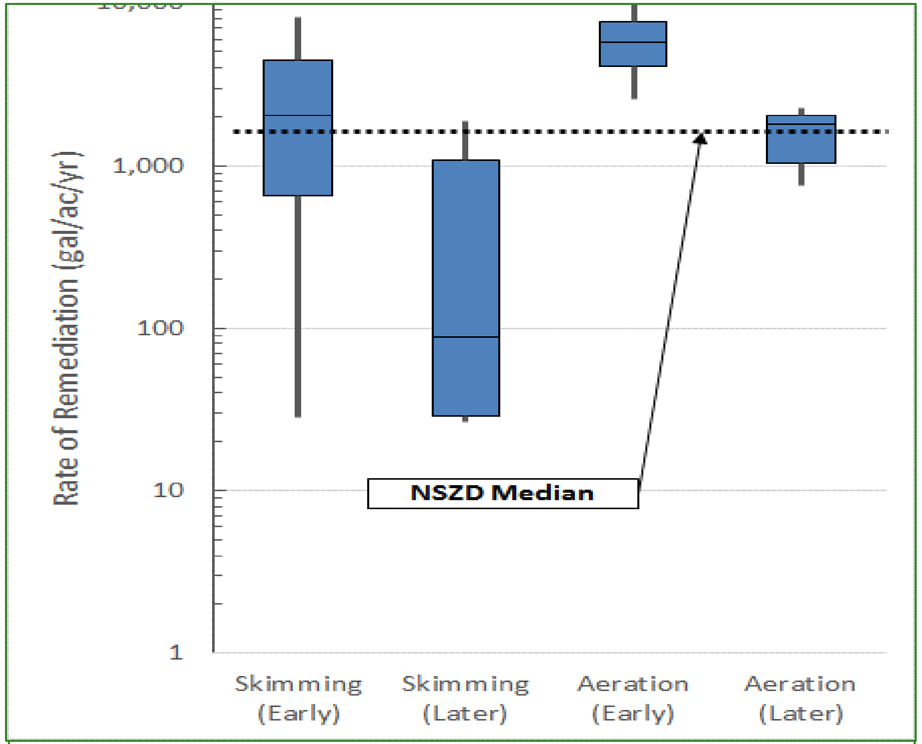
ITRC LNAPL-3 Guidance , Figure 3-5

Key Point: Abatement of dissolved or vapor concentration is dependent on change in composition (mole fraction) and not saturation (unless almost all LNAPL is removed)

2. Baseline NSZD Assessment

Support of Standalone Technology & Metric for Decision-making

- NSZD rates are often similar to or greater than later-stage active LNAPL removal rates for technologies such as LNAPL pumping, SVE, and MPE
- Consequently, NSZD rate comparisons can inform evaluation of practicality of remediation and decisions for technology transition as more sustainable approach
- NSZD rate can be benchmark to enhanced depletion technologies:
  - Soil vapour extraction/bioventing
  - Enhanced bioremediation
  - Thermal technologies



(Median NSZD rate from Garg et al., 2017. System data modified from Palaia, T. 2016. Natural source zone depletion rate assessment. Applied NAPL Science Review 6.)

CRC Care 47 2020: NSZD rates > active LNAPL recovery rates at 5 of 6 sites

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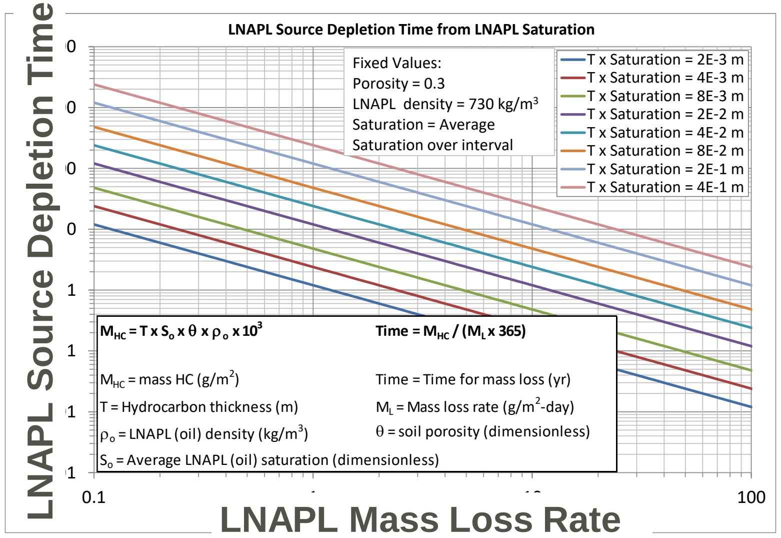
Baseline NSZD Assessment

Toolkit 2 and ASTM WK76688

Tier 1 – Literature/ Nomographs

- Qualitative
- Literature values
- Toolkit 2 nomographs



Tier 2 – Measurement & Models

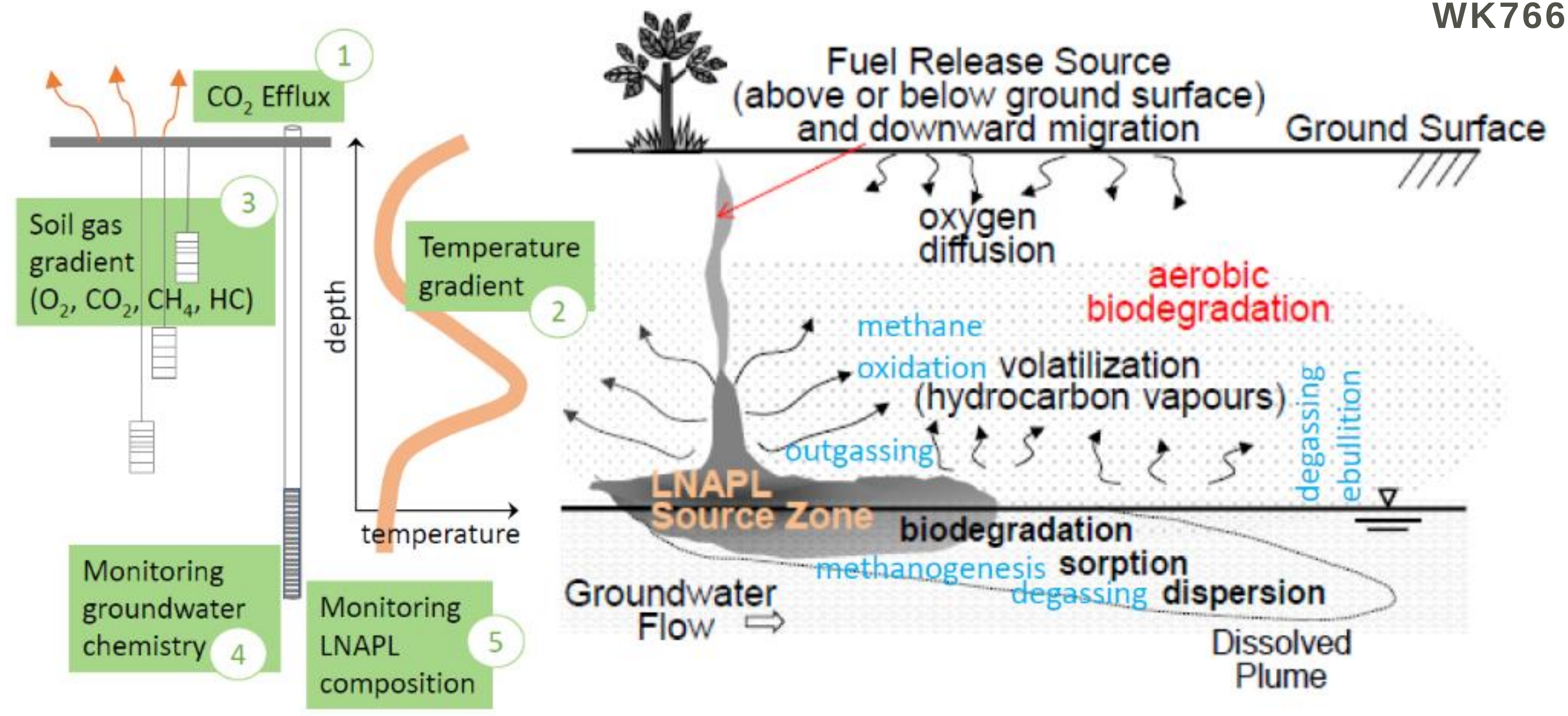
- CO_2 efflux method
- Gradient Method (soil gas)
- Thermal method

Tier 3 – Advanced Models

- Analytical: LNAST, RemFUEL
- Numerical MIN3P-DUSTY, COMPFLOW

Baseline Assessment – LNAPL Depletion Processes & "Bulk" NSZD Measurement Methods

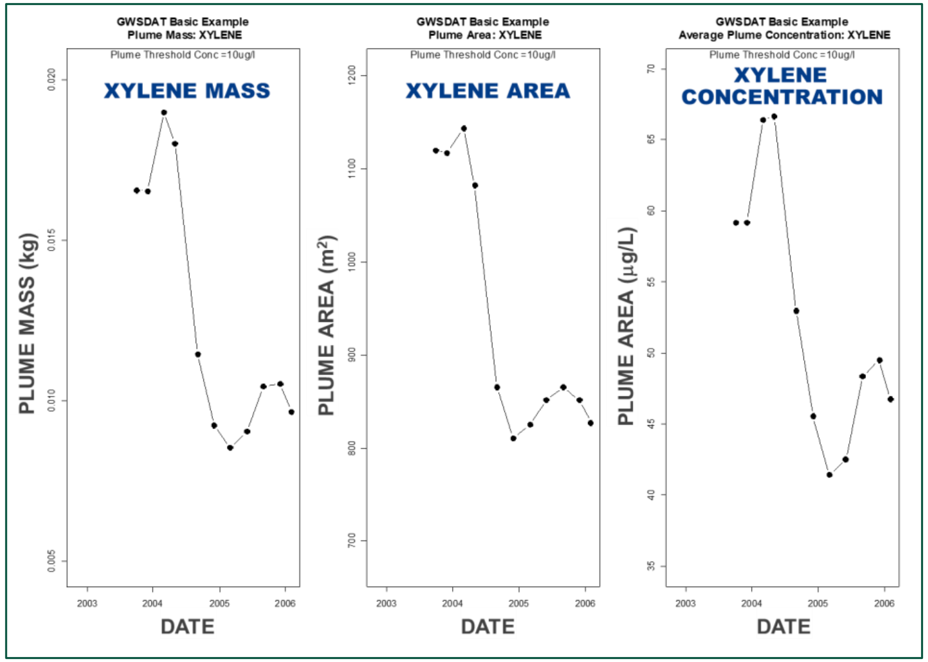
Jourabchi et al. 2019 ASTM WK76688



Select Method Comparisons Studies of "bulk" NSZD rates: Sweeney et al. 2018; Hers et al. 2019; Kulkarni et al. 2020; CRC Care 47 2020; Wozney et al. 2022

Baseline Assessment – Composition / Concentration Attenuation Methods

1. **Source compositional change**
2. **Plume stability** from **concentration**: (e.g.,Mann-Kendall, regression – Toolkit 2) or **mass** (e.g., Ricker method)
3. **Weathering assessments**: Compare current constituent ratios to those of fresh gasoline from full-scan GC/FID (e.g., (B+T)/(E+X))
4. **Mass discharge estimates**: transects, well pumping tests, passive meters or model (ITRC Mass Flux/Mass Discharge Guidance, GSI Mass Flux Toolkit)
5. **Attenuation rate/longevity modeling**: see next slide

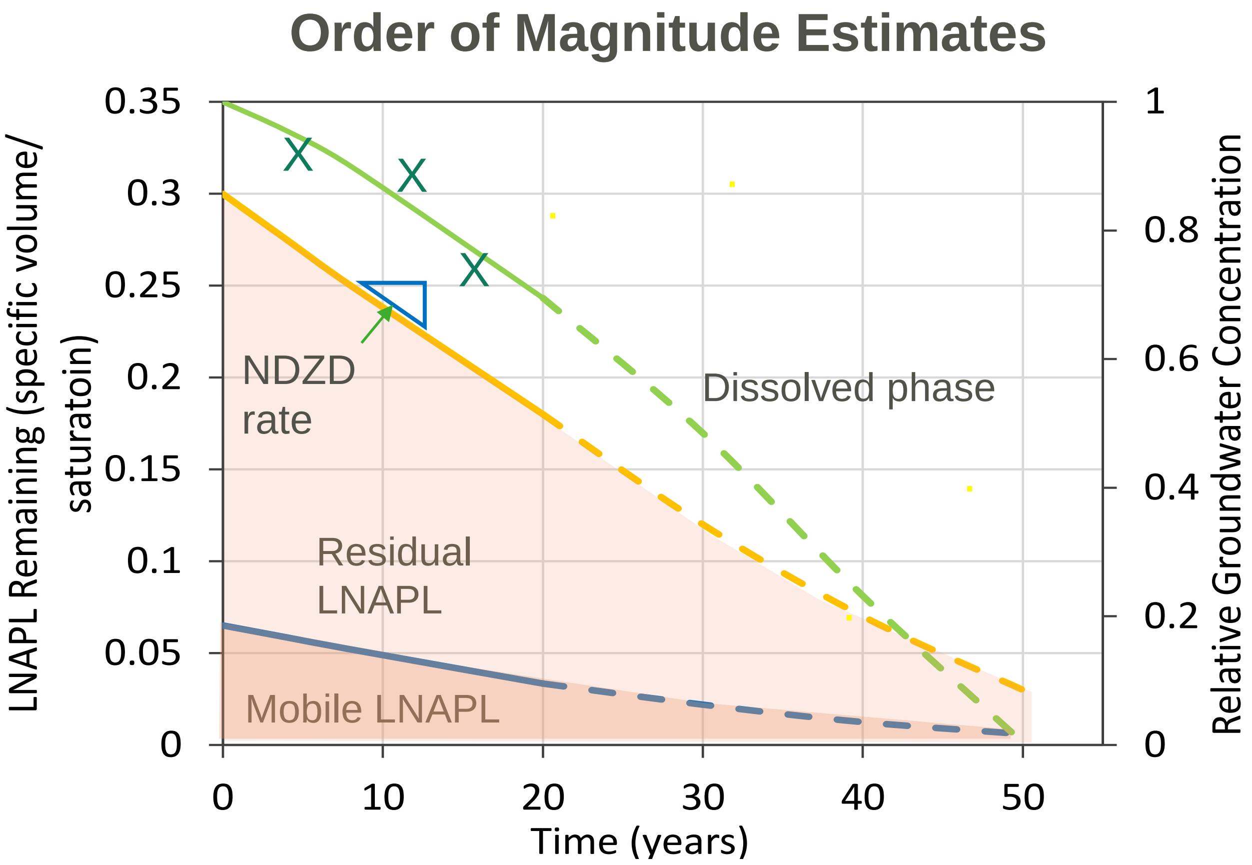


Ricker Method (in GWSdat)

Key Point: Use available data to evaluate trends and attenuation rate during and after (possible rebound) remediation

Timelines for Natural and Enhanced Attenuation

Toolkit 2 and CONCAWE 2022 Toolkit

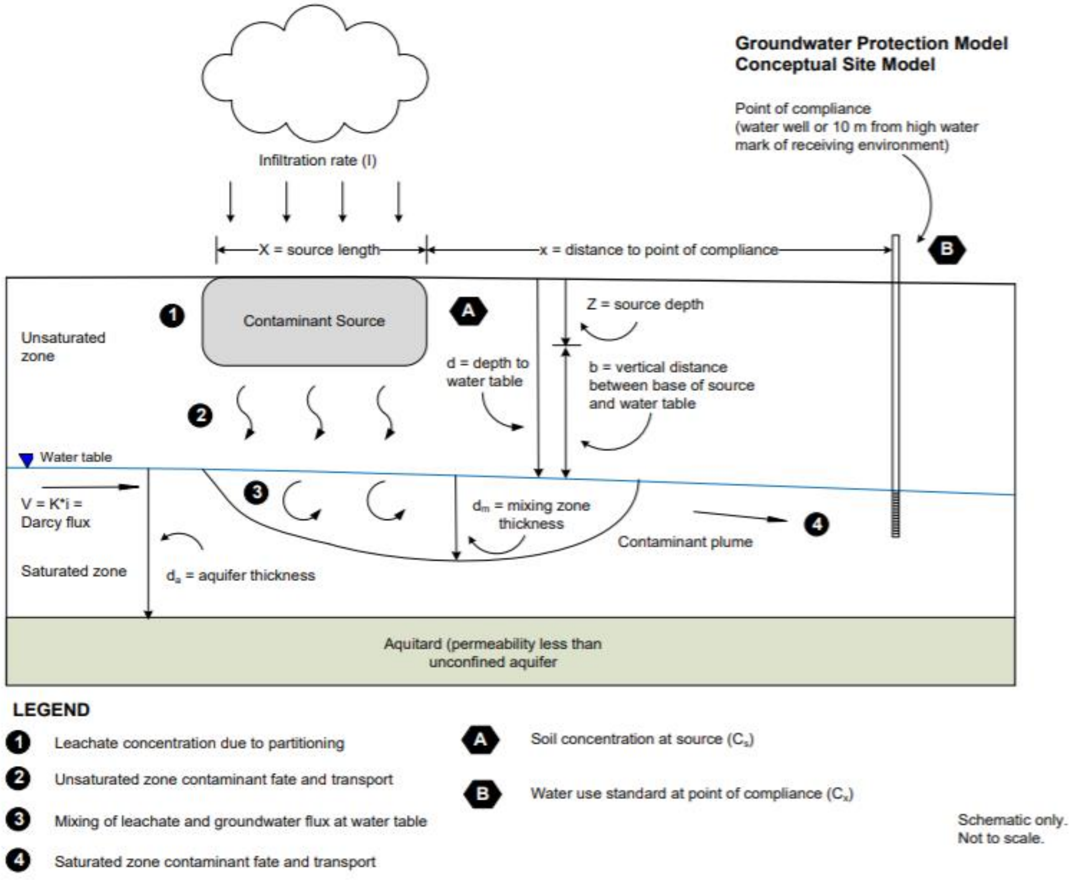


- Requires estimate of initial mass / concentration (API LDRM model)
- Can extrapolate measured NSZD rates or predict using a model – zero-order (constant) or first-order or combination (Concawe 2022 LNAPL Toolbox)
- Best current options for dissolved phase:
  - Source DK[1]
  - US EPA RemFUEL[2]
  - US EPA Bioscreen[3]
  - Uncertainty in source discharge model and source zone biodegradation

[1] https://www.gsi-net.com/en/software/free-software/sourcedk.html
[2] https://www.epa.gov/water-research/remediation-evaluation-model-fuel-hydrocarbons-remfue
[3] https://www.epa.gov/water-research/bioscreen-natural-attenuation-decision-support-systeml

Future of Risk-based Modeling

Millennium EMS PTAC Research Project



BC Groundwater Protection Model (GPM) and Screening Level Risk Assessment (P13)

- BC GPM and similar models provide general conceptual framework
- Add source (physical) depletion and source biodegradation (1st-order $C = C_o e^{-kt}$ or other models)
- Constrain inputs appropriately based on site data and natural attenuation rates
- Add concept of low probability receptor
- Institutional controls for offsite contamination
- Stay tuned!

3. Remedy Selection and Implementation

ARIS Environmental

Saturation and/or Composition Concern

Baseline Attenuation Rates and Remediation Timelines

Select Remedy

Tools: CRC Care #18, ITRC LNAPL Guidance, Remediation Toolkits, Remediation Technologies Screening Matrix[1]

[1] Federal Remediation Technologies Roundtable). https://frtr.gov/matrix2/top_page.html

Performance Metrics: 1) subsurface; 2) system; 3) sustainability

Transition Thresholds: Integrate remediation objectives & performance metrics

Key Point: Essential to define & agree to performance metrics & transition thresholds upfront with stakeholders prior to the implementation of active remediation

Performance Metrics & Transition Threshold Examples

ARIS Environmental

Performance Metric - Subsurface

- LNAPL presence/absence in wells (S)
- LNAPL transmissivity (S)
- LNAPL saturation (mobile fraction remaining)
- NSZD (bulk TPH or COC) rate (S&C)
- Concentration and mass discharge – absolute value or attenuation rate (C)
- Push-pull respiration test (bio) (C)

Performance Metric - System

- LNAPL recovery vs. time (S)
- LNAPL/vapour ratio or LNAPL/water ratio (S)
- TPH/COC mass recovery vs. time (C)
- COC ratios in water or vapour (C)
- CO_2 in system exhaust (bio) (S&C)

S = Saturation: C = Composition

Performance Metric - Sustainability/Cost (both subsurface & system)

- LNAPL recovery vs cost or GHG emissions or other metric (e.g., water use) (S)
- TPH/COC mass recovery vs. cost or GHG emissions of other metric (C)

Transition Threshold

- Recovery of 90-95% of mobile 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 (bulk) rates (S).
- Active attenuation rates similar to natural attenuation rates (C)

Remedial Technology Groups

1. Mass Recovery or Removal
(saturation)

2. Phase Change
(composition/concentration)

3. Containment
(composition/concentration or saturation)

4. Phase Change & Mass Recovery
(composition/concentration or saturation)

Key Point: Simplify the selection of technology

Remedial Technologies List

Primary Mechanism	Technologies Available
1. LNAPL Mass Recovery	• Excavation • Multi-phase extraction (MPE), dual-phase extraction (DPE), dual-phase liquid extraction (DPLE) • LNAPL skimming or vacuum-enhanced skimming • NSZD
3. Containment	• Permeable reactive barrier (PRB) • Drains • Impermeable/slurry walls • In-Situ Containment-Capping and Solidification-Stabilization (including vitrification) • Ankeny moat (hybrid mass containment method) • Groundwater pump & treat
4. Phase Change & Mass Recovery	• In-situ thermal (radio frequency heating, electrical resistance heating, thermal conductive heating) and enhanced recovery • Solvent or surfactant treatment for enhanced recovery • Steam treatment for enhanced recovery • Water flooding or hot water flooding for enhanced recovery

Remedial Technologies List

Primary Mechanism	Technologies Available
2. Phase Change	*In-situ (note some of these technologies can be used for plume treatment/containment)* • NSZD and MNA • Air Sparging • Soil vapour extraction (SVE) • Bioventing • Biosparging • In-situ chemical oxidation (ISCO) • In-situ bioremediation • Activated carbon injection • Phytoremediation • Chemically enhanced electrokinetics

Appendix A - Table A – Initial Screening

Technology	Technology Description	Feasibility Factors (e.g., hydrogeology, contaminant related…)	Feasibility Ranking	Constructability Factors (e.g., depth, access, cold climate…)	Constructability Ranking	Overall Ranking (retained?)
• Mechanism	• For 29 technologies	• Technology specific	• Low, Medium High	• Technology specific	• Low, Medium, High	• Yes or No

Key Point: Structured process to short-list technologies - extensive information included on technologies and factors

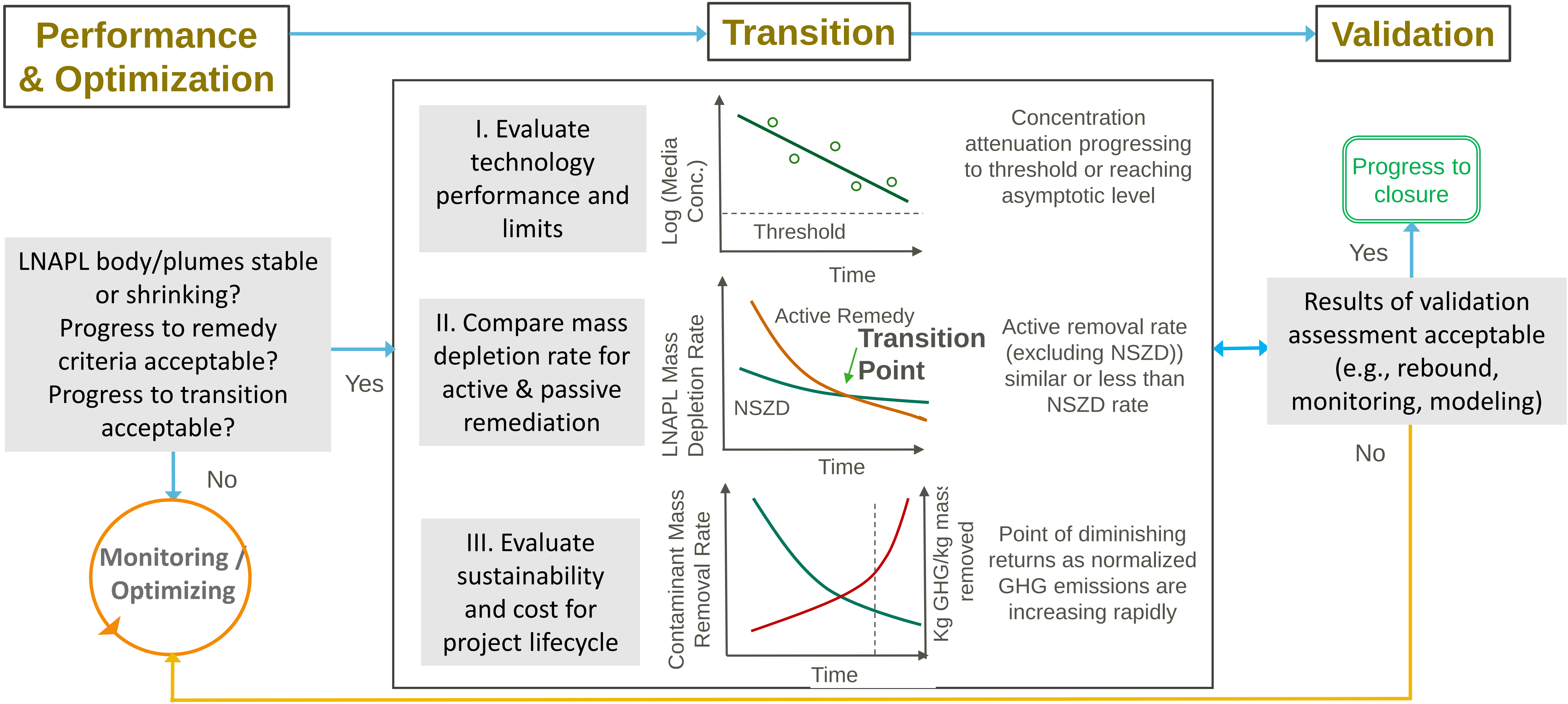
Appendix A – Table B – Generic Technology Info

Techno-logy	Waste Generation	Relative Remedial Timeframe	Data Requirements	Performance Metrics	Applicable Models	Relative General Safety Concerns	Relative Cost	BC Context
• 29 technlogies	• …	• …	• …	• …	• …	• …	• …	• …

Site or project-specific factors: GHG emissions, sustainability metrics, permanence, stakeholder input, First Nation input, permitting, safety, etc.

Key Point: Generic technology info plus site or project factors can be used in a remedial options evaluation for technology screening. More in-depth sustainability evaluations should follow Toolkit 4 process.

4. Performance Evaluation and Transition Assessment



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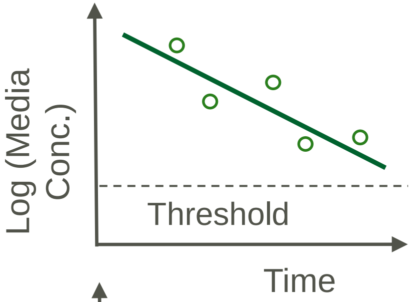
Select examples of transition metrics shown – consider others

Attenuating concentration below threshold?
Receptor > threshold distance?

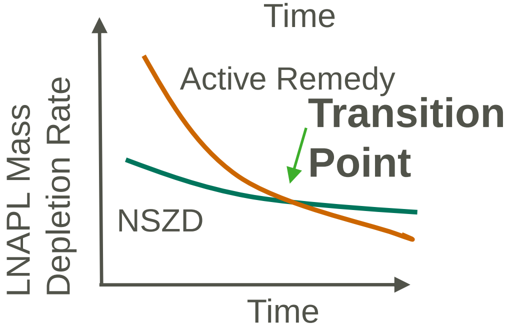
I. Evaluate technology performance and limits



Concentration attenuation progressing to threshold or reaching asymptotic level

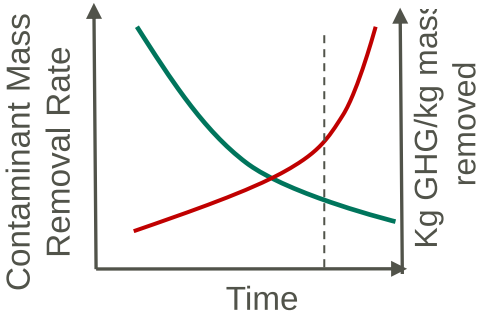
Consider comparisons for range of remediation including dig & dump

II. Compare mass depletion rate for active & passive remediation



Active removal rate (excluding NSZD)) similar or less than NSZD rate

III. Evaluate sustainability and cost for project lifecycle



Point of diminishing returns as normalized GHG emissions are increasing rapidly

What if no pathway or receptor? How do we balance possible future use, institutional controls and impacts (e.g., t-CO2-e, etc.)?

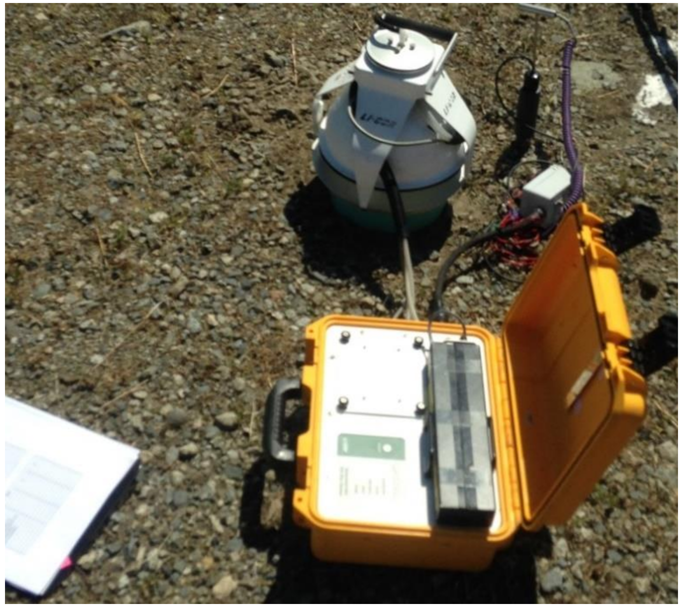
Case Study Former Refinery & Distribution Terminal

- Research study – lessons apply to non-research sites
- Petroleum hydrocarbon (PHC) consists of weathered middle distillate with lesser amounts of lube oil
- Silty sand and silt underlain by coarse sand
- Depth to corrected water table: 2.7 - 4.7 m
- Shallow PHC contamination from 0.5-5 m depth
- Apparent in-well LNAPL thickness 0.01 to 0.6 m
- Stable LNAPL body; LNAPL skimming conducted; stable dissolved plume

- Wozney, A., I. Hers, C. Campbell, C.Gosse, N. Nickerson. Multiple Lines of Evidence for Estimating NSZD Rates Overlying a Shallow LNAPL Source Zone. Accepted for publication. GWMR 2022.
- Wozney, A. and I. Hers 2021. Multiple Lines of Evidence for Estimating NSZD Rates. Presentation at RemTech 2021. https://esaa.org/wp-content/uploads/2021/10/RT21-Wozney.pdf
- Hers et al. 2019 (Battelle presentation); Jourabchi et al. 2018 (Battelle presentation)

CO_2 Efflux Measurement Methods

Dynamic Closed Chamber (DCC)



LI-COR Instrument: LI-8100A Short-term measurement (few minutes)

EoSense Forced Diffusion Sensors

EoSense Forced Diffusion Sensor continuous measurements; EoSense also has similar technology to LI-COR

E-Flux Low Profile Static Trap Units

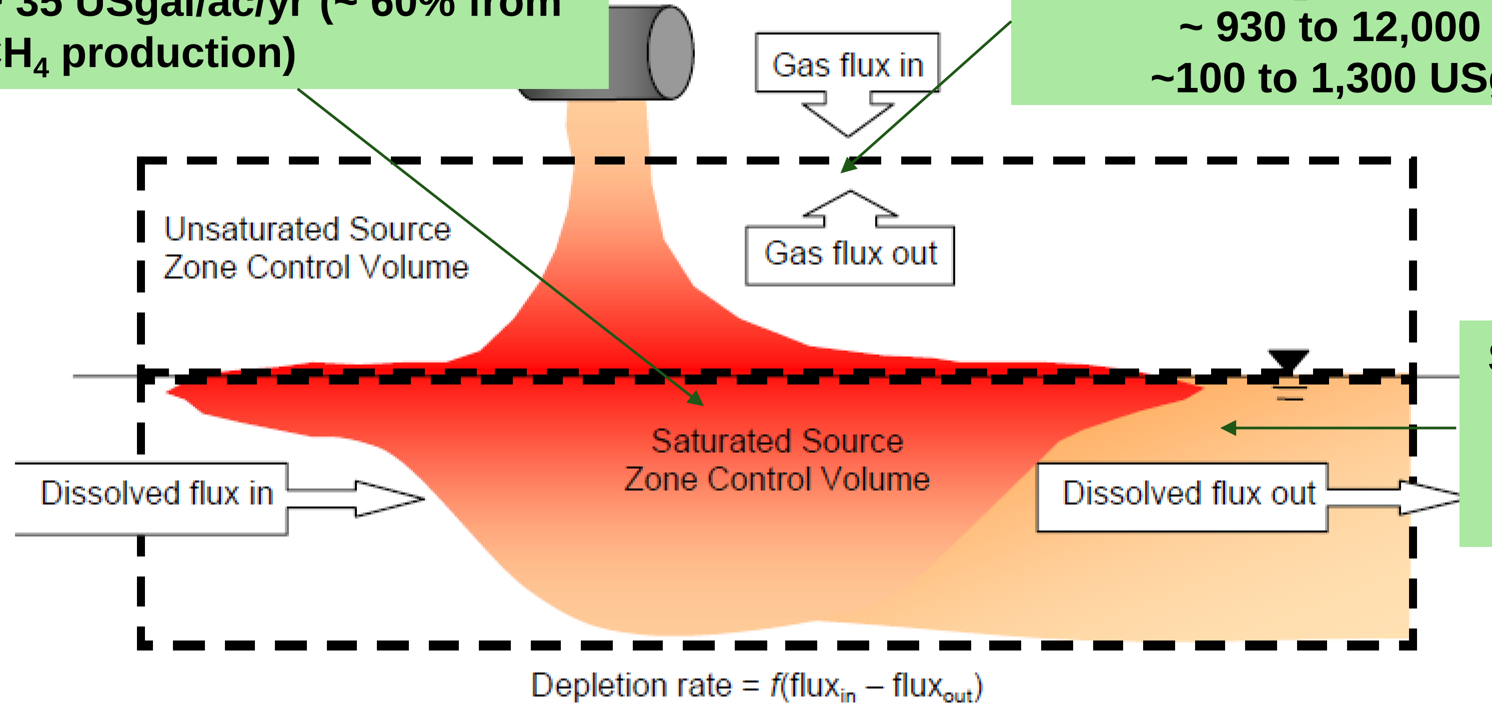
E-Flux Sorbent trap
Composite (1-2 week) measurement

For less complex, smaller projects, may be possible to use literature estimates or qualitative evaluations – a caution is NSZD rates may be relatively low when deeper contamination and/or confining surface layer

NSZD Rate Estimates

Saturated Zone Biodegradation –
Geochemical data (DO, NO3-, SO_4^{-2}, dissolved CH_4 from up and downgradient wells
~ 330 L/ha/yr ~ 35 USgal/ac/yr (~ 60% from CH_4 production)

Vadose Zone Biodegradation
Seasonal Range
CO_2 Efflux Method
~ 930 to 12,000 L/ha/yr
~100 to 1,300 USgal/ac/yr

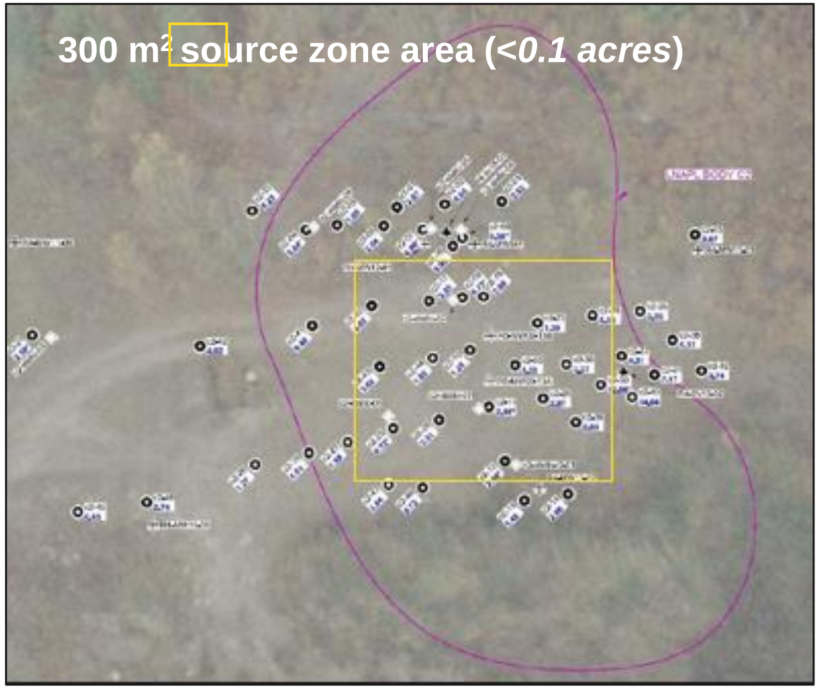


Saturated Zone Dissolution & Flow
From VPH/LEPH + hydro data
~ 670 L/hr/yr ~ 72 USgal/ac/yr

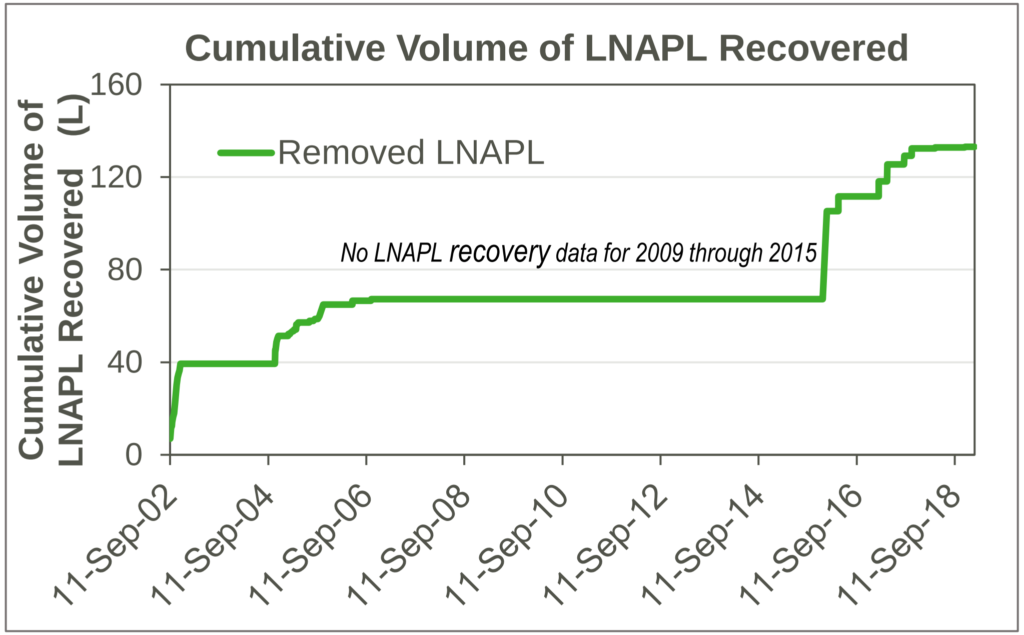
* For conversions, 2 sig figs used, generally 1 sig fig may be appropriate

Key Point: Vadose zone NSZD rate highly impacted by wet winter climate at site. While saturated zone rates were lower, somewhat important. Consider obtaining these data (low cost to add). See Toolkit 2 and ITRC Control Volume Method (ITRC 2009) for details.

Comparison of NSZD Rates to Active Recovery



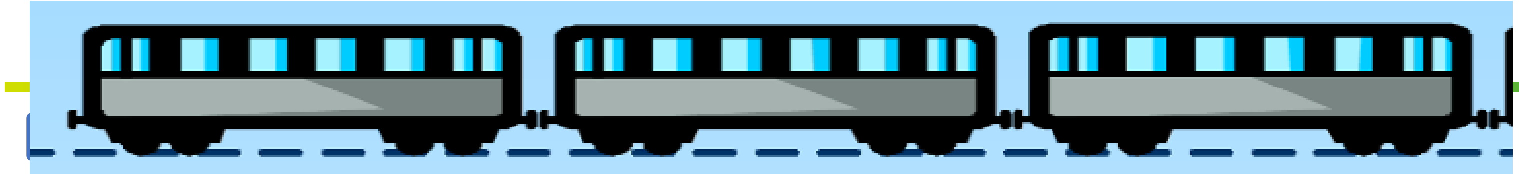
NSZD: ~ 80 Litres/yr



130 L recovered skimming 2002 – 2018
(no LNAPL recovery 2009 - 2015)

SKIMMING: ~ 13 L/yr

Key Point: NSZD rate > LNAPL recovery rate is line of evidence supporting risk management; simple example, but concepts can be applied / scaled for larger, more complex sites



Consider Treatment Train Approach

Summary

- Systematic approach to remediation is presented
- Numerous guidance and tools are available, and detailed information on technologies is provided
- Start with the end in mind, establish clear goals, performance metrics and transition thresholds
- Where appropriate (e.g., for petroleum hydrocarbons), incorporate natural attenuation and compare depletion rates for active and passive remedies
- Incorporate sustainability concepts when evaluating remedial performance and when necessary conducted detailed assessment of sustainability (Toolkit 4)
- Current project is Shell Compendium of Technologies, which will include roadmap and detailed information on technologies (e.g., hydraulic recovery, SVE, AS, bioventing)

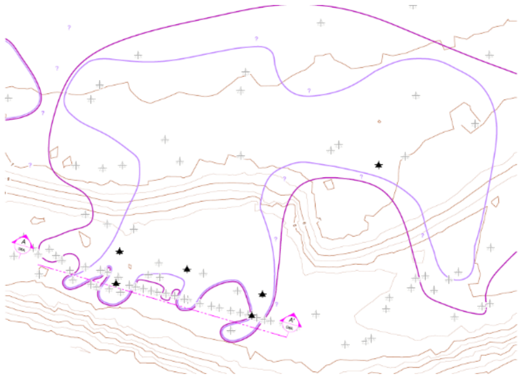
Acknowledgments

Dr. Parisa Jourabchi, ARIS
Dr. Matthew Lahvis, Shell
Linda Kemp, WSP Golder
Guy Patrick, Patrick Environmental
Beth Power, Azimuth

Questions?

Remedy Transition Case Studies

Former Refinery



Foreshore Area Release

- LNAPL skimming
- Performance (2015): LNAPL recovery asymptotic, Transmissivity (Tn) Foreshore: 0.001 ft^2/day, uplands 0.07 to 0.9 ft^2/day
- Comparison: Site complexity posed challenges but NSZD rate estimated to be similar to LNAPL flux (Hers et al. 2016 Battelle presentation)
- Transition to reduced monitoring/bailing

ITRC – IBT3 Case Study

Jet Fuel Pipeline Spill

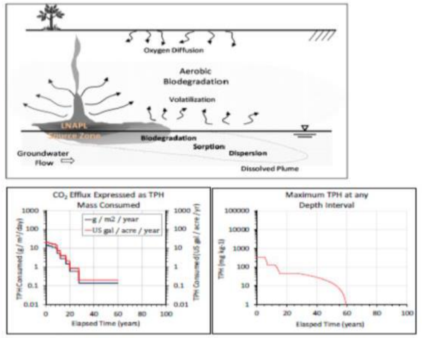
- Partial Excavation, skimming, SVE
- **Performance**: LNAPL recovery remediation approaching asymptotic limit, Tn < 0.05 ft^2/day
- **Comparison**: NSZD > active rates (1,000’s compared to 100’s gals/yr)
- **Sustainability**: Evaluation considered not needed
- Transition to passive remedy

Guidance & Research on Natural Attenuation

Remediation Toolkits (2016 & 2021)

8 July 2016

Toolkits for Evaluation of Monitored Natural Attenuation and Natural Source Zone Depletion



Submitted to:
Contaminated Sites Approved Professional Society
and Shell Global Solutions

Report Number: 1417511-001-R-Rev0

REPORT

API 2017

Quantification of Vapor Phase-related Natural Source Zone Depletion Processes

API PUBLICATION 4784
FIRST EDITION, MAY 2017

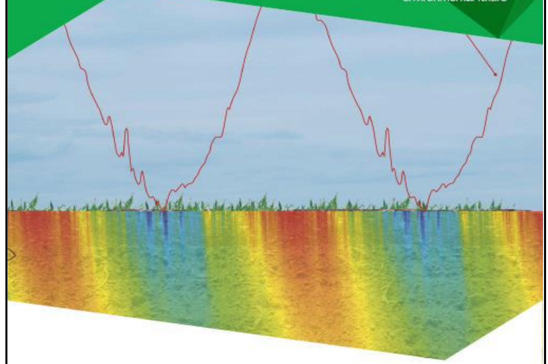
energy API
AMERICAN PETROLEUM INSTITUTE

CRC Care 44 2018

Cooperative Research Centre for Contamination Assessment and Remediation of the Environment

www.crccare.com

CRCCARE
A safer, cleaner environmental future



TECHNICAL REPORT NO. 44

Technical measurement guidance for LNAPL natural source zone depletion

CRC Care 47 2020

www.crccare.com

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TECHNICAL REPORT NO. 47

Australian case studies of light non-aqueous phase liquid (LNAPL) natural source zone depletion rates compared with conventional active recovery efforts

Garg et al 2017

Groundwater Monitoring&Remediation

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

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

ITRC 2018

LNAPL Update HOME

Welcome

Light Non-Aqueous Phase Liquid (LNAPL) Site Management: LCSM Evolution, Decision Process, and Remedial Technologies (LNAPL-3)

Welcome to ENVIRO Wiki

Developed and brought to you by

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REFERENCES ARE PROVIDED AT END OF PRESENTATION

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https://archive.org/details/CalculationAndUseOfFirst-orderRateConstantsForMonitoredNatural

Sustainable Remediation – A Framework, Roadmap and Tools (Toolkit 4)

CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Dr. Ian Hers, HEC

Question

Have you used sustainability principles in your projects?

If so what methods or tools have you used?

Use Chat to answer. We will compile the responses at the end of the presentation.

UN Sustainable Development Goals

Connection to Sustainable Projects

Is your company or organization part of the **UN Global Compact**?

Principle 9: **Development and diffusion of environmentally friendly technologies**

https://www.unglobalcompact.org/what-is-gc/mission/principles

Outline

- Sustainable Remediation (SR) definitions and principles
- Key guidance
- SR Roadmap and Tools
  - Best management practices (BMPs)
  - Environmental footprint analysis (EFA)
  - Multi-criteria analysis (MCA)
- SR Dashboard (developed for this project)
- Case Study
- Introduction to climate change considerations

Appendices to this presentation

- A: Sustainability Case Studies (12 studies)
- B: Library of Best Management Practices
- C: Life cycle analysis (LCA) information
- D: SR Dashboard information
- E: Sitewise Tool overview

Introduction & Definitions

ITRC (2011)

- Sustainable Remediation (SR) defined as integration of :
  - Sustainable Development: Triple bottom line (environmental, social and economic aspects)

    and
  - Green remediation: focus on environmental net benefit and ways to optimize remediation
- Overall impact of remedial activities on human and ecological receptors and society

Framework is described and tools are reviewed

ISO 18504 (2017) Definition: Sustainable remediation is the elimination and/or control of unacceptable risks in a safe and timely manner while optimizing the environmental, social, & economic value of the work ("a balance").

Common Obstacles to Implementation of Sustainable Remediation*

- Lack of regulatory driver
- Perceptions/lack of agreement on what is and what is not sustainable (“myths”)
- Lack of consistent standards
- Lack of training and/or resources
- Cost considerations

* highlighted in different surveys conducted within the remediation community (Ellis and Hadley, 2009, Hou, 2016)

SR Concepts & Principles

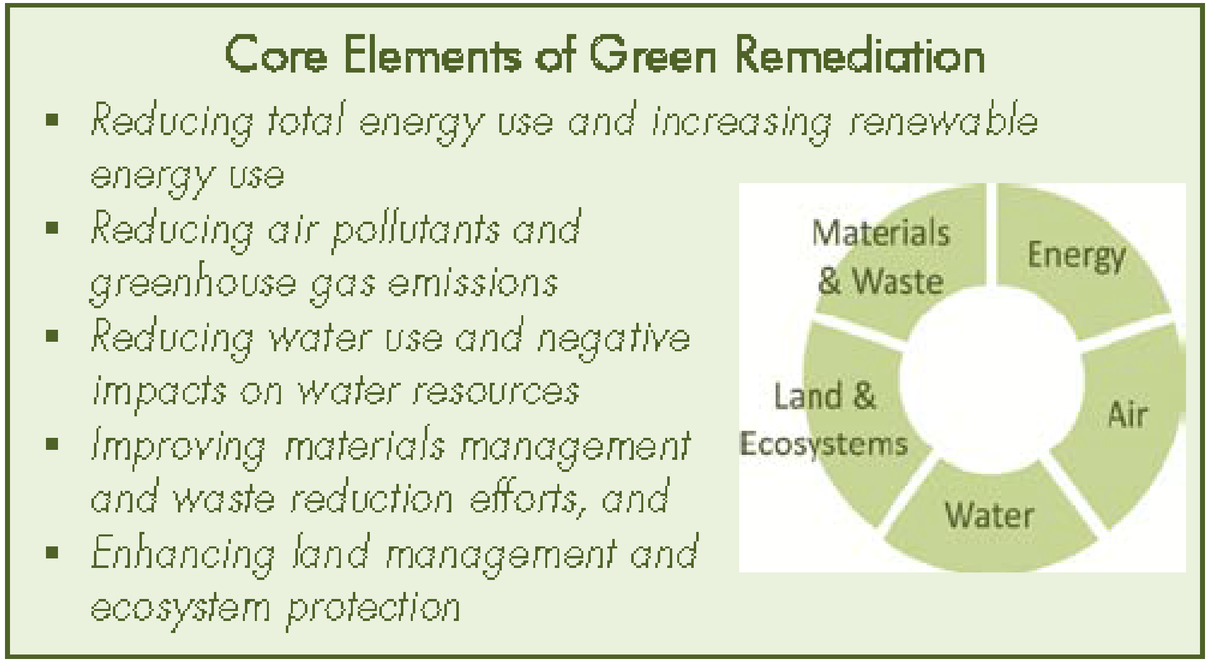
Core elements of SR (linked to sustainable development)	SR themes found in guidance worldwide (various guidance)
• Air pollution (e.g., particulates, volatile organic compounds (VOCs)) • Water use • Waste generation • Greenhouse gas (GHG) emissions • Surface soil degradation (e.g., erosion, nutrient depletion, geochemical change) • Ecological impacts • Energy use • Stewardship of resources • Local community vitality	• Balanced decision-making process ⋮ • Best Management Practices (BMPs) • Total cost approach • Non-technical risk management • Project life cycle & life cycle analysis • Record keeping and transparent reporting • Safe working practices • Social justice • Net Environmental Benefit Analysis (NEBA)

Common thread: overall impact of remediation effort & evaluation of the environmental footprint of the project (at minimum)

Key Guidance

- US EPA (2008) Green Remediation Primer
- ITRC (2011) Green & Sustainable Remediation Guidance
- Sustainable Remediation Forum (SuRF) Organizations
  - CL:AIRE (UK)
- Federal Contaminated Sites Action Plan (FCSAP) April 2018[1]
- ISO (2017) Sustainable Remediation Standard 18504
- ITRC 2021 Sustainable Resilient Remediation

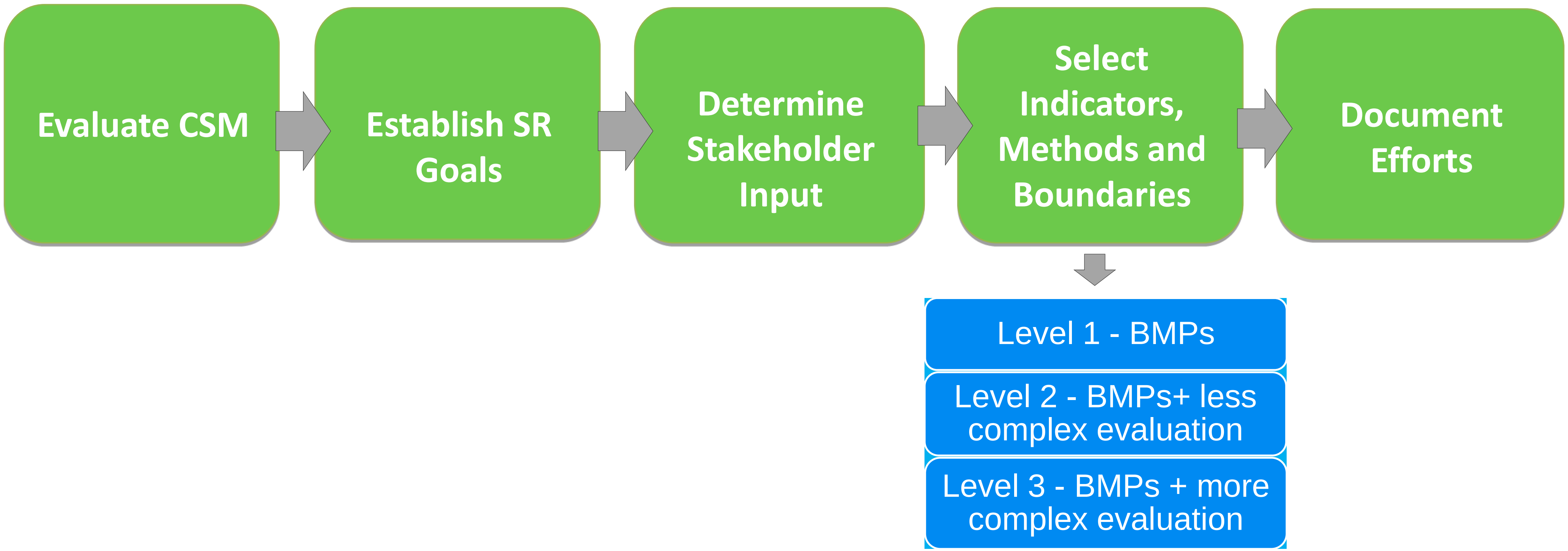
US EPA Green Remediation Primer



https://www.sustainableremediation.org/

https://publications.gc.ca/collections/collection_2018/eccc/En14-89-2018-eng.pdf

Toolkit Roadmap



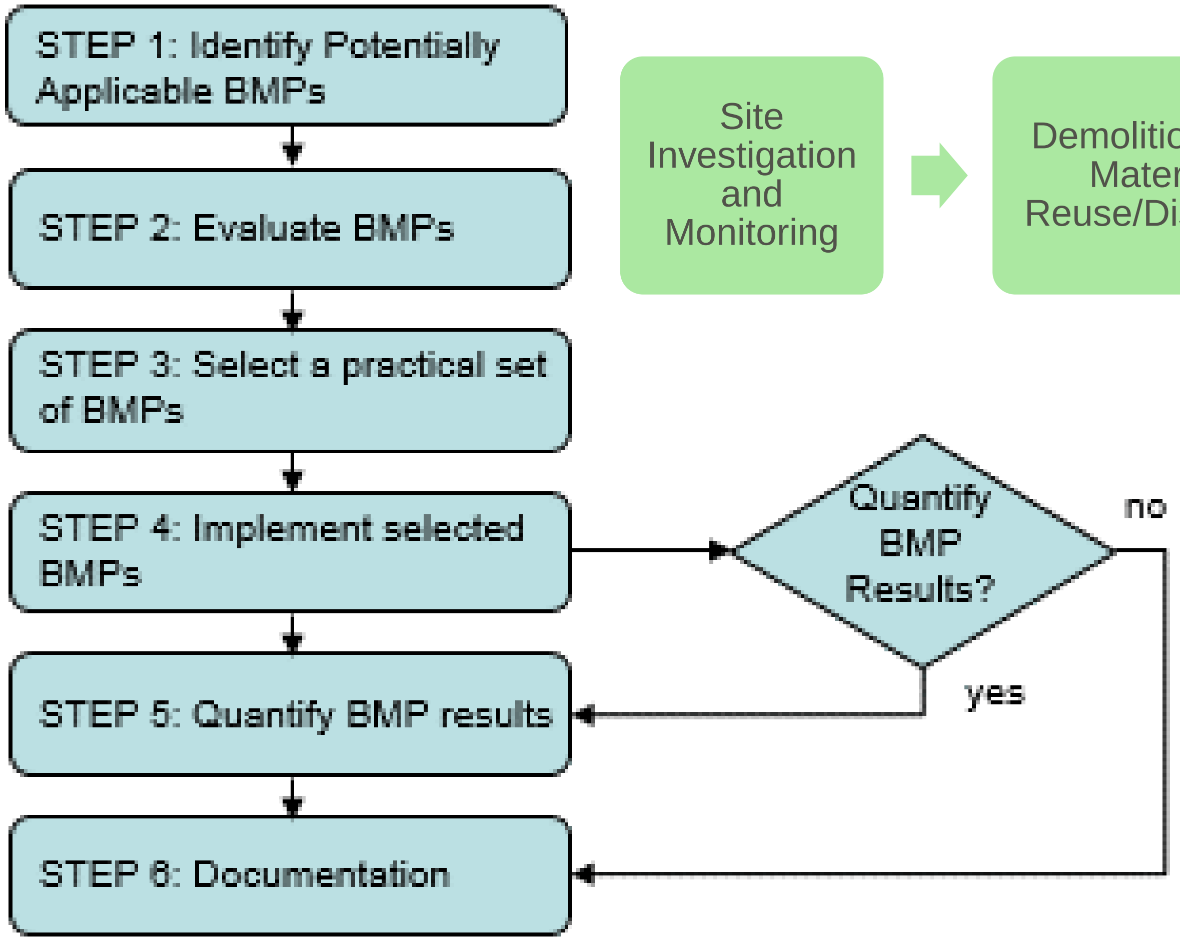
Acronyms defined on next slide

SR Methods and Tools

1. Level 1: Best (or sustainable) management practices (BMPs)
2. Level 2: Less complex qualitative ranking methods such as qualitative multi-criteria analysis (MCA), carbon footprint analysis (CFA) or simpler environmental footprint analysis (EFA)
3. Level 3: More complex evaluation consisting of life cycle analysis (LCA) and quantitative MCA of sustainability

Key Point: Consider Level 1 BMPs for all projects; Level 2 and 3 methods may be applicable for more complex projects.

Best Management Practices



- All phases of site investigation and remediation
- Site-specific GSR measures
  - GHG Emissions
  - Energy efficiency
  - Waste management

BMP implementation steps from ASTM E2876-13

Best Management Practices

Energy Efficiency & GHG Emissions

- Alternate or renewable energy sources (e.g., landfill gas, wind, solar power)
- Consideration of passive sampling methods, smaller drill rigs or technologies such as bioventing or other low intensity enhanced bioremediation methods
- Appropriate sizing of equipment and operational efficiency through for example pulsed operation and energy efficient equipment
- Sequencing of work to improve efficiency
- Telemetry and advanced data collection and processing methods to improve monitoring and operational efficiency
- Equipment and materials local to the site

Waste Reduction

- Reduction of investigation derived wastes
- Use of water efficient equipment and water re-cycling where feasible
- Re-cycling or reclamation of materials, and use of products with re-cycled content
- on-site reuse of excavated and treated materials (with due consideration for potential residual risk)

Socio-economic

- Modify approach to address concerns about disruptions & disturbances to local residents & businesses
- Communicate site activities to stakeholders & community in a manner that public health risk are understood

See Appendix A case studies and SURF website for ideas!

Environmental Footprint Analysis (EFA)

Purpose: Characterize and quantify impacts associated with remediation

Indicators

- Environmental (primary focus of US EPA tools)
  - GHG emissions
  - Energy use
  - Air emissions
  - Material use
  - Waste generation
  - others
- [Social, Economic?]

Boundaries

- Geography
- Time (think life cycle!)
- Technology (best available, optimized)

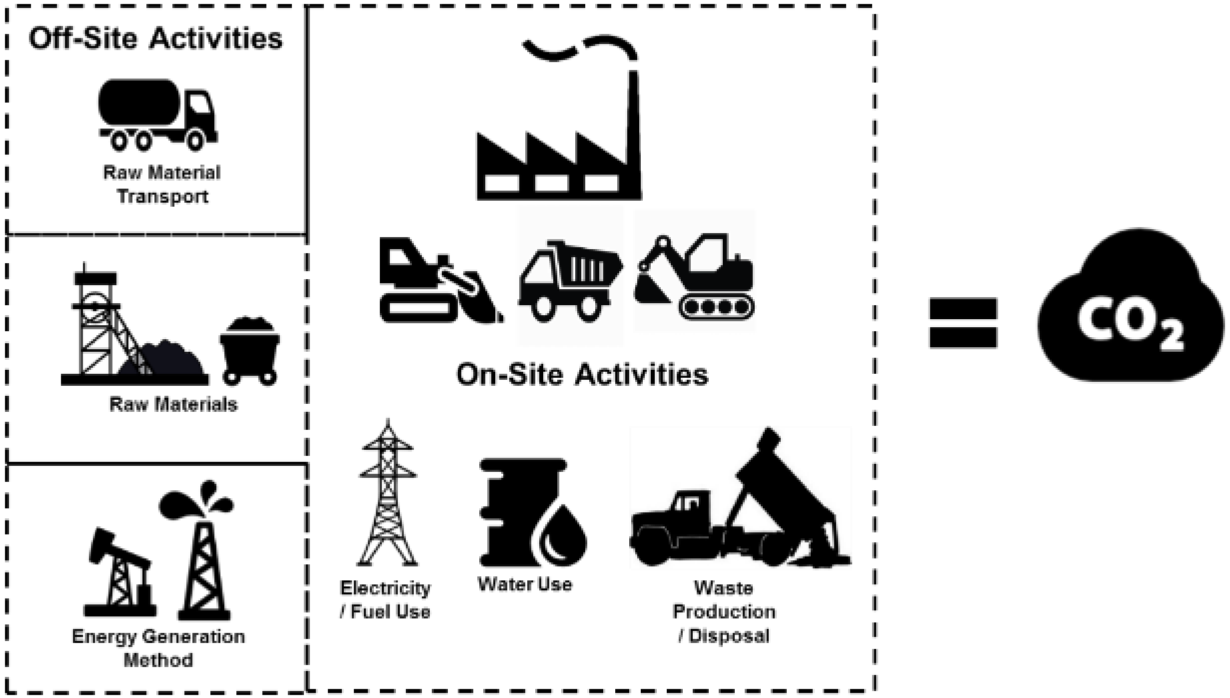
Inventory

- Inputs/outputs of remediation
- Materials
- Chemicals
- Wastes
- Transportation
- Construction
- Processes

Key Points: Follow life cycle analysis (LCA) concepts; EFAs can vary greatly in complexity; one challenge is how to include social and economic indicators (e.g., see Favara et al. 2011)

Environmental Footprint Analysis (EFA)

Examples of on-site and off-site inputs



Select Tools*:

Remediation:

SiteWise

US SEFA

GoldSET

SR Dashboard

Corporate:

SimaPro

SoFi TS Tool

BC SmartTool

Key Points: Important to define boundaries (time and space); evaluating GHG emissions is a great start but generally recommend an EFA so that impacts are not missed.

* Calculators also available[1] (cool!), but limited use for remediation

[1] https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

Greenhouse Gases

- Carbon dioxide (CO_2)
- Nitrous oxide (N_2O)
- Methane (CH_4)
- Sulphur hexafluoride (SF_6)
- Perfluorocarbons (PFCs), and
- Hydrofluorocarbons

Table 1a. Global warming potentials for GHG other than CO_2

100-Year Global Warming Potential (GWP)		
N_2O GWP	~~310~~ 273[1]	CO_2 e
CH_4 GWP	~~21~~ 27-30[1]	CO_2 e

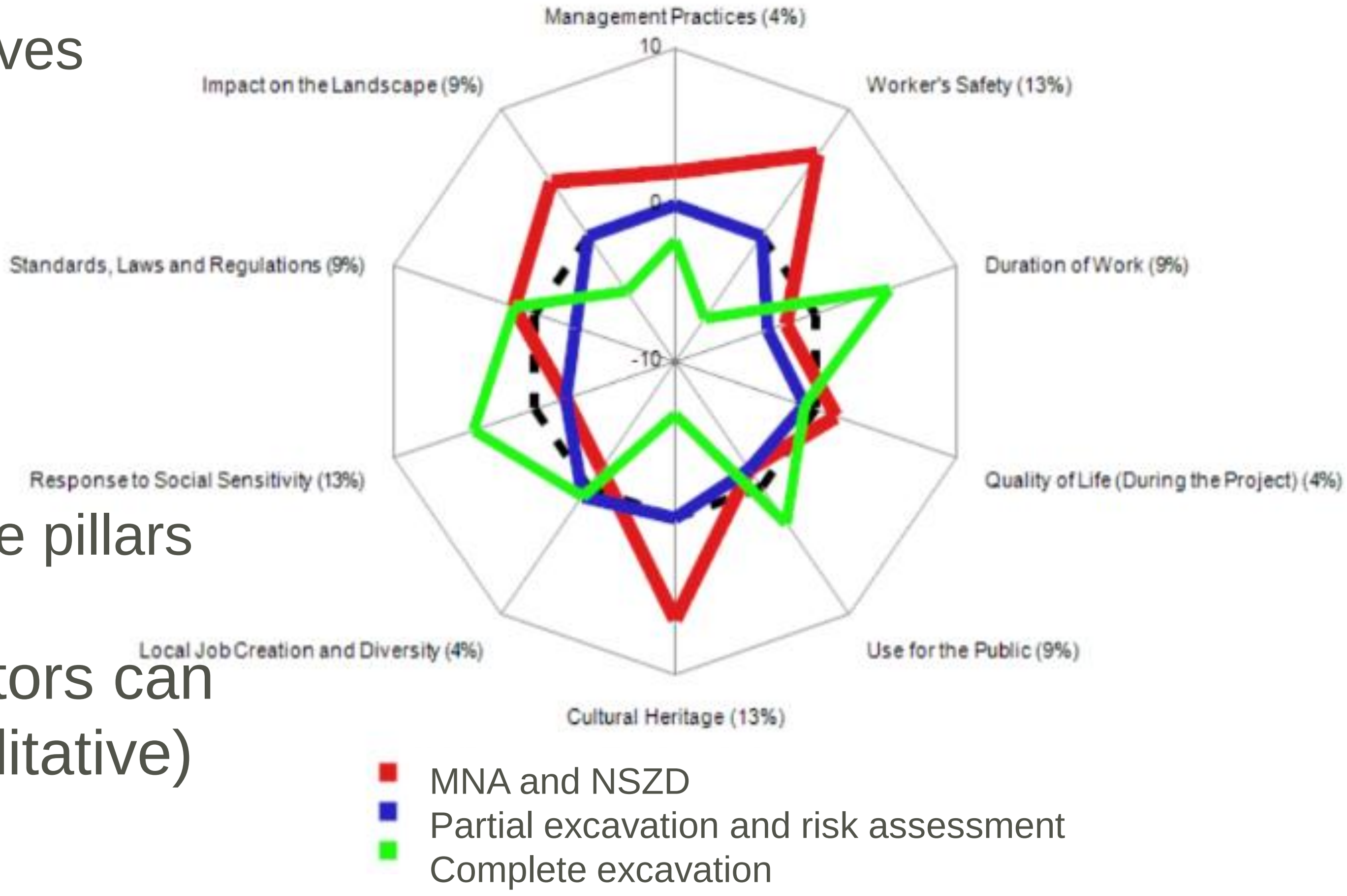
U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2008", EPA 430-R-10-006, page 1-7, Table 1-2 (April 15, 2010)

1 https://www.epa.gov/ghgemissions/understanding-global-warming-potentials#:~:text=Methane%20(CH4)%20is%20estimated,less%20time%20than%20CO2.

MCA Methods

- MCA is method for comparing alternatives
- Select indicators
  - Qualitative
  - Semi-quantitative
  - Quantitative
- Score indicators, select weighting
- Conduct sensitivity analysis
- Advantage is that can encompass three pillars of sustainability
  - Scoring & evaluation across indicators can be challenging (quantitative & qualitative)

$$\sum (\text{Score x Weight})_{\text{indicators}}$$



SuRF-UK's Sustainable Remediation Framework (and ISO 18504) Indicator Set

Environmental	Social	Economic
Emissions to air	Human health and safety	Direct economic costs and benefit
Soil and ground conditions	Ethics and equity	Indirect economic costs and benefits
Groundwater and surface water	Neighbourhoods and locality	Employment and employment capital
Ecology	Communities and community involvement	Induced economic costs and benefits
Natural resources and waste	Uncertainty and evidence	Project lifespan and flexibility

"What sustainable remediation constitutes is sustainable and risk-based management, which broadens the risk management outlook to ensure that reducing the potential for harm from land contamination avoids also unintentional consequences (e.g., emissions to air/water or excessive use of materials and energy), and is also broadly beneficial to society."

Bardos et al. 2018 The Development and Use of Sustainability Criteria in SuRF-UK's Sustainable Remediation Framework

SR Dashboard

See Toolkit 4 & Appendix D for Details

Impact Tool

- Compile and analyze impacts
- Can input data from Footprinter
- Holistic approach - **environmental, social and financial indicators**

MCA Tool

- Can input data from Impact Tool
- Compares technology options
- Assumes technology is **feasible**, **implementable** and meets **regulatory standards** (Toolkit 3)

Footprinter Tool

- GHG emissions, energy use and air pollutants
- Includes BC **regulatory defaults for some emission factors;** rest defaults mostly based on Sitewise
- Example worksheets for six technologies

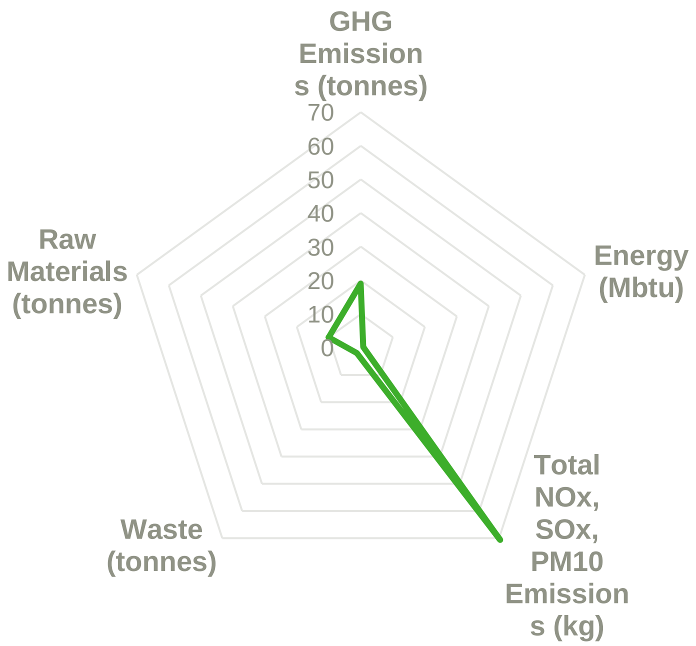
SR Dashboard is available (spreadsheet on CSAP website), transparent, simple to use, based on LCA principles, BC defaults. Limitations are pre-selected indicator set, not as comprehensive as Sitewise (also recommended). SR Dashboard is great learning tool.

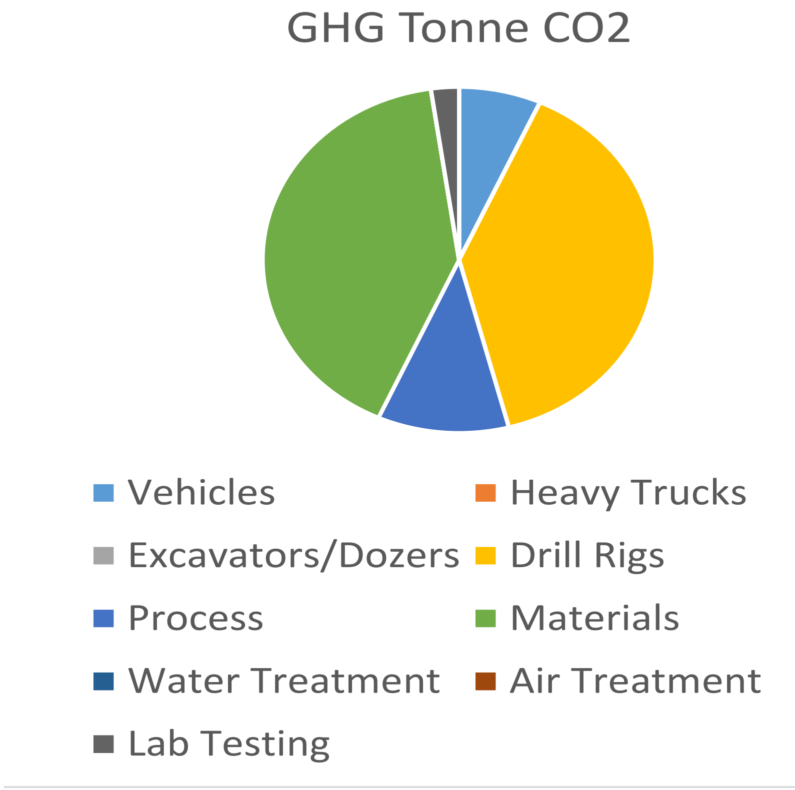
SR Dashboard – Optimize / Reduce Footprint

Indicator Set

Environmental	GHG
	Energy
	Air Pollutants
	Waste
	Materials
	Land, Water & Ecosystem
	Permance /Long-term Effectiveness
	Technology Reliability
Social	Community
	Safety
	Time
Cost	Cost

ISCO - Quantitative Impact

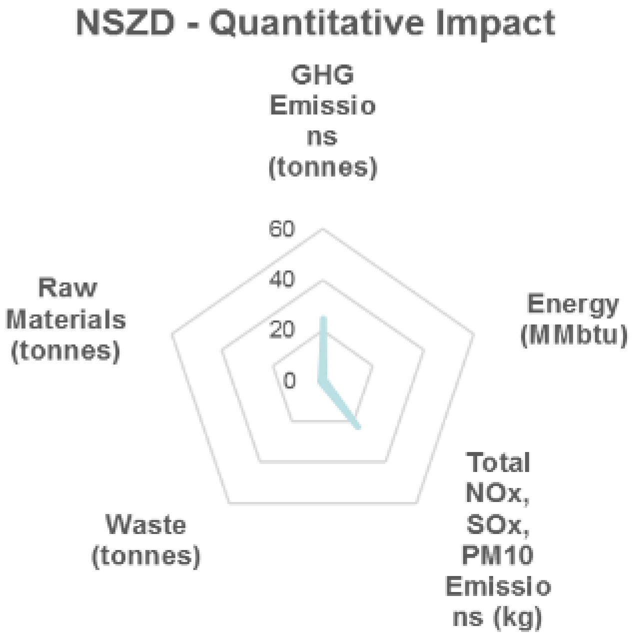


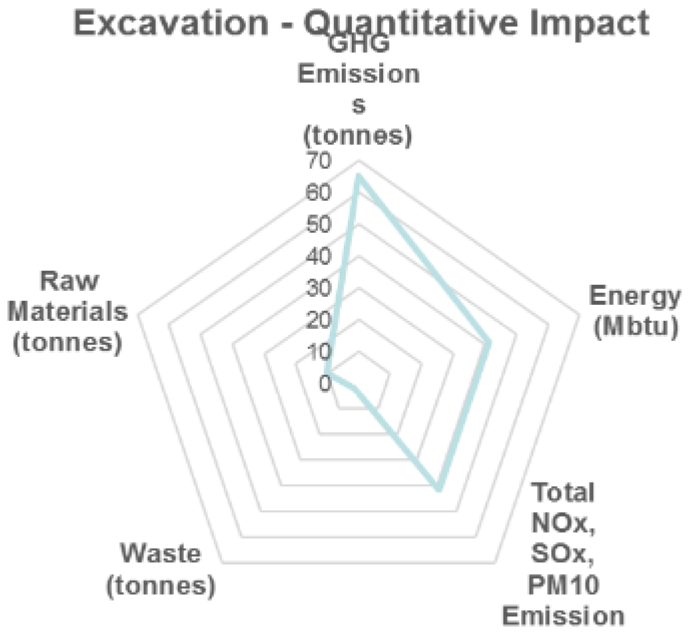


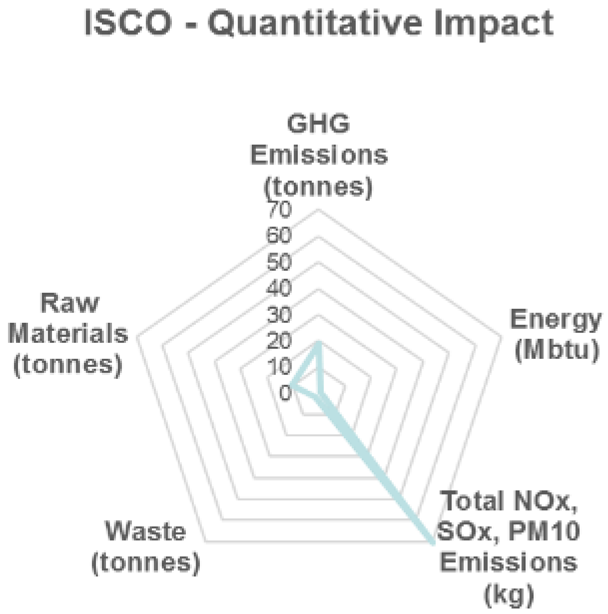
Optimize technology to reduce footprint and impacts by applying BMPs

SR Dashboard – Compare Impacts

Indicator
GHG
Energy
Waste
Air Pollutant
Materials



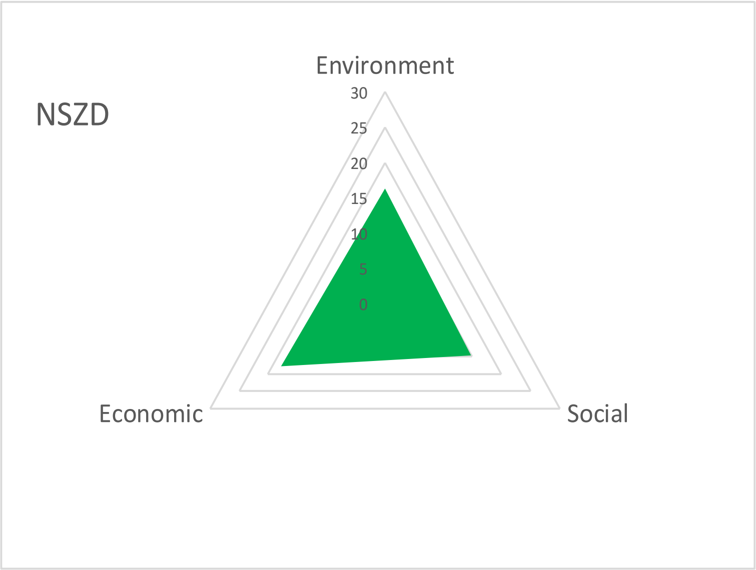


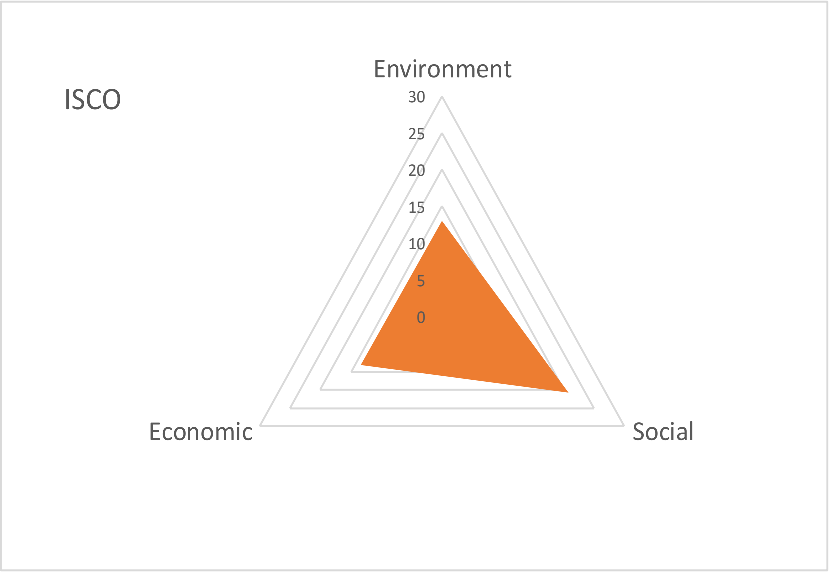


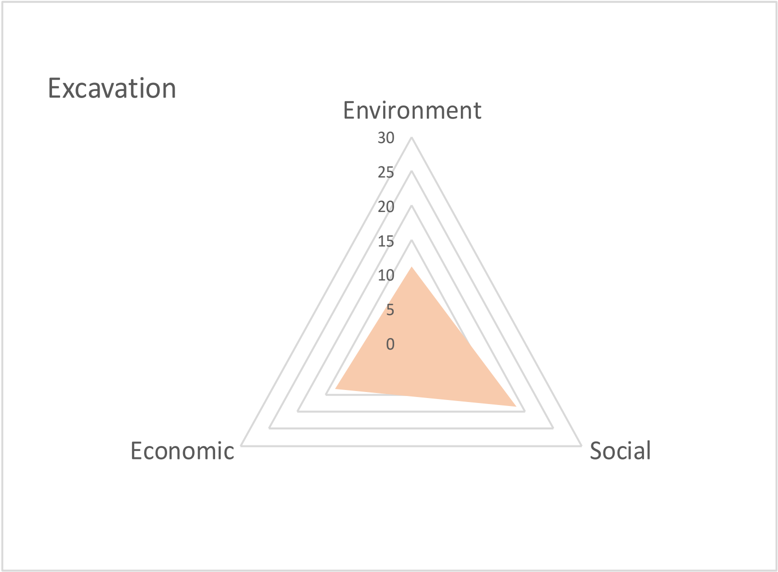
All options assume baseline LNAPL recovery option (skimming)

New metrics could be considered such as CO_2-e/kg-LNAPL treated i.e. integration with Toolkits 1-3 and value of baseline measurements

SR Dashboard – Compare Options using MCA







Often the option with the largest triangle in relation to environmental, social and economic factors is taken as the most sustainable

Toolkit 4 Case Study #1

Release and Site Setting

- Approximately 280,000 L of petroleum product, consisting of mostly diesel and some gasoline, were released.
- An estimated volume of 12,700 cubic metres of peat and mineral soils were affected.
- Contamination reached a depth of 2.44 metres; most of the petroleum hydrocarbons have been adsorbed into the peat due to high organic content.
- The derailment occurred in a sensitive natural environment at the junction of multiple ecological units: a bog, a lagg, a fen and a forest.

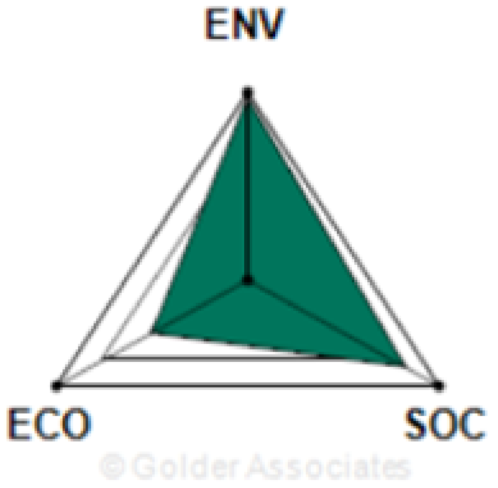
Indicators used to Evaluate Sustainable Approaches

ENVIRONMENT	SOCIETY	ECONOMY
Soil quality	Public safety	Net Present Value of Options' Costs
Groundwater quality	Worker safety	Potential Litigation
Surface water quality	Duration of work	Financial Recoveries
Off-site migration	Quality of life during work	Environmental Reserve
Short-term and long term impacts on biodiversity and species status	Use for the public	Economic Advantages for the Local Community
Short-term and long term impacts on habitat	Cultural heritage	Technological uncertainty
GHG emissions	Local job creation and diversity	Logistics
Energy consumption	Response to social sensitivity	
Waste generation	Standards, laws and regulation	
Hazardous waste generation	Impact on the landscape	
	Management practices	

Results of MCA

MONITORED NATURAL ATTENUATION

Environmental	96%
Social	82%
Economic	50%

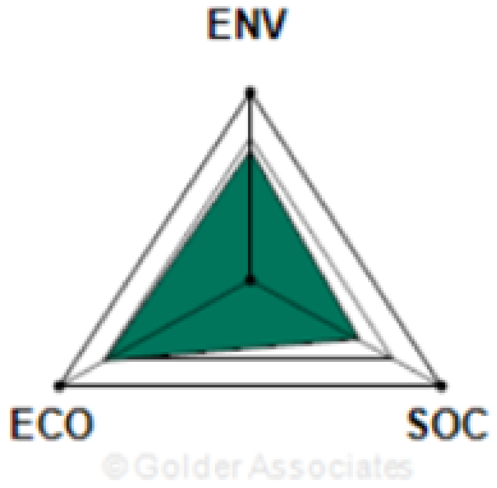


Duration of Work :
9 Years

17 tons CO_2-e.

PARTIAL EXCAVATION & RISK ANALYSIS

Environmental	69%
Social	57%
Economic	75%

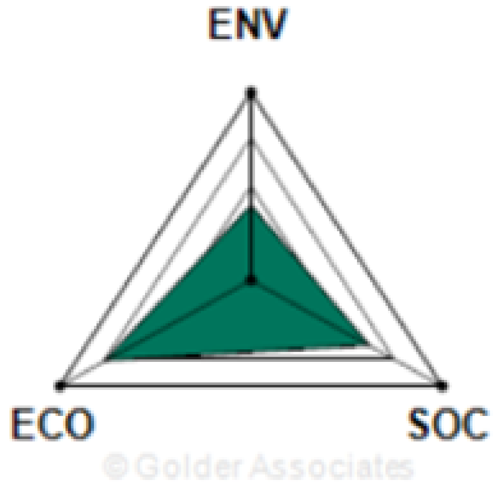


Duration of Work :
10 Years

255 tons CO_2-e.

COMPLETE EXCAVATION

Environmental	39%
Social	61%
Economic	75%



Duration of Work :
5 Years

321 tons CO_2-e.

Results of MCA

MONITORED NATURAL ATTENUATION

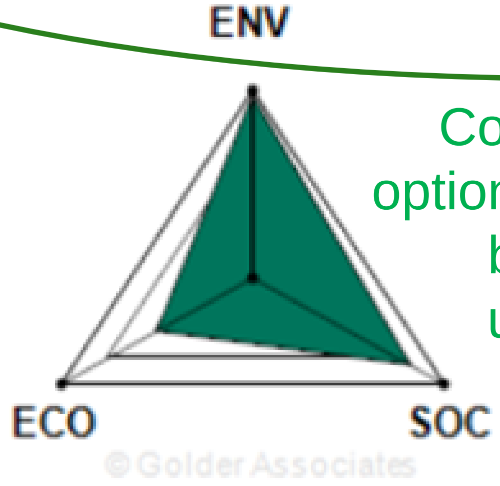
Environmental	96%
Social	82%
Economic	50%

PARTIAL EXCAVATION & RISK ANALYSIS

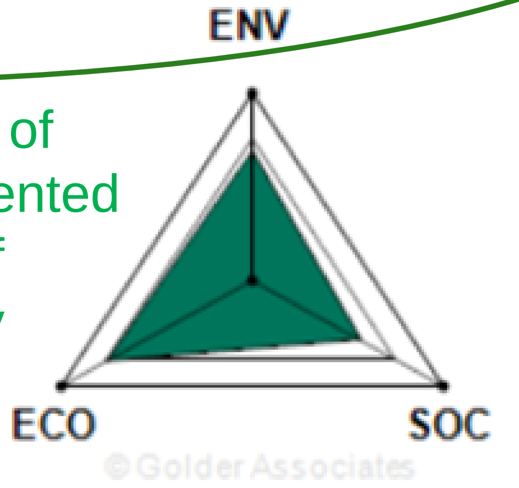
Environmental	69%
Social	57%
Economic	75%

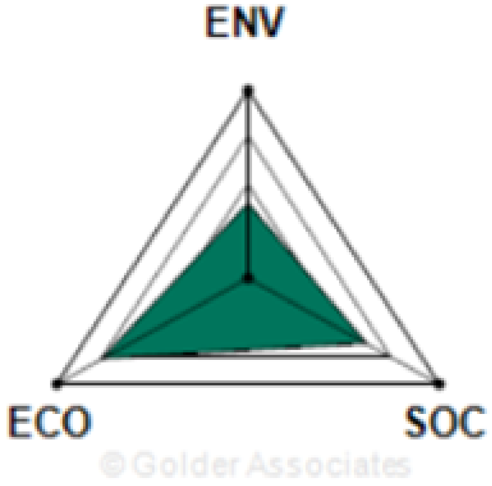
COMPLETE EXCAVATION

Environmental	39%
Social	61%
Economic	75%



Combination of options implemented because of uncertainty





Duration of Work : 9 Years

Duration of Work : 10 Years

Duration of Work : 5 Years

17 tons CO_2-e.

255 tons CO_2-e.

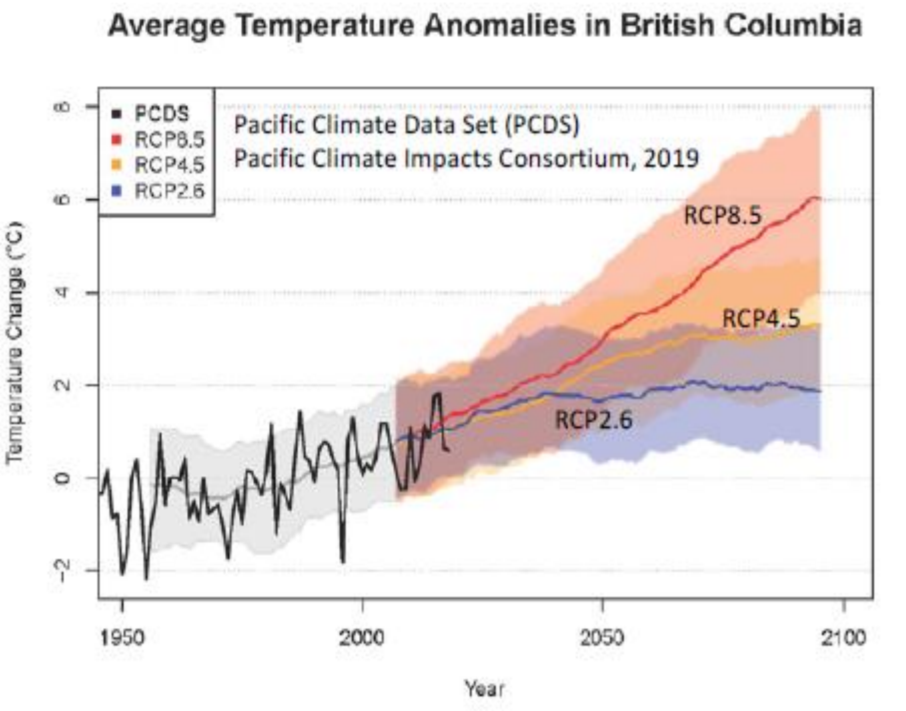
321 tons CO_2-e.

Benefits of Sustainable Approach

- Using solar panels to operate blowers will avoid one tonne CO_2-e over 20 years (BMP).
- Special walkways built by the owner to minimize impacts to vegetation (BMP).
- Collaboration with academic research staff (BMP).
- High health and safety risk tasks associated with excavation and trucking were minimized, to the benefit of both workers and the community (Level 3 MCA).
- Using a sustainable framework to build a case for enhanced natural attenuation resulted in avoiding 250 tonne CO_2-e. from the excavation and transport of roughly 7,000 m^3 of impacted peat and mineral soil. This also avoided generation of hazardous waste from carbon media (GAC) to treat water from an excavation (Level 3 MCA).
- Consultation with local stakeholders and concerned citizens (BMP).
- Tripod-mounted drilling equipment and manual augers to avoid damage to vegetation (BMP)

Climate Change Risks Considerations

Toolkit includes overview of issue – additional guidance needed



Source: Preliminary Strategic Climate Risk Assessment For British Columbia (July, 2019)

Climate Predictions

↓

Vulnerabi-lities

↓

Adaptive Management

↓

Increased Sustainability

- Tools for climate predictions, assessment of vulnerabilities and adaptative strategies are available (e.g., Pacific Climate Impacts Consortium, Environment Canada, US EPA Climate Resilience website, ITRC Sustainable Resilient Remediation, Washington State guidance)
- No prescribed or legislated requirements in BC but good practice to consider

Question: How do climate change risks affect site management?

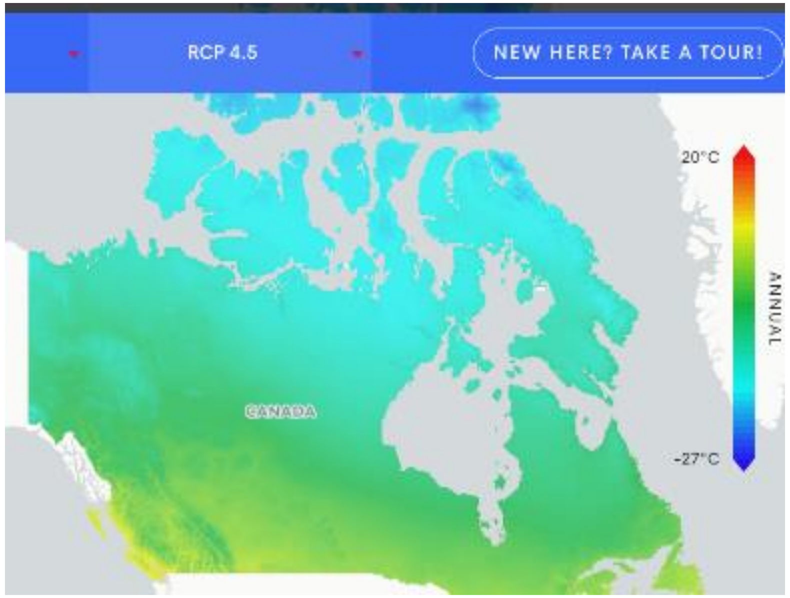
Climate Change Risks Tools

ARIS Environmental

Adaptation Case Studies

https://changingclimate.ca

Climate Projections



https://climatedata.ca

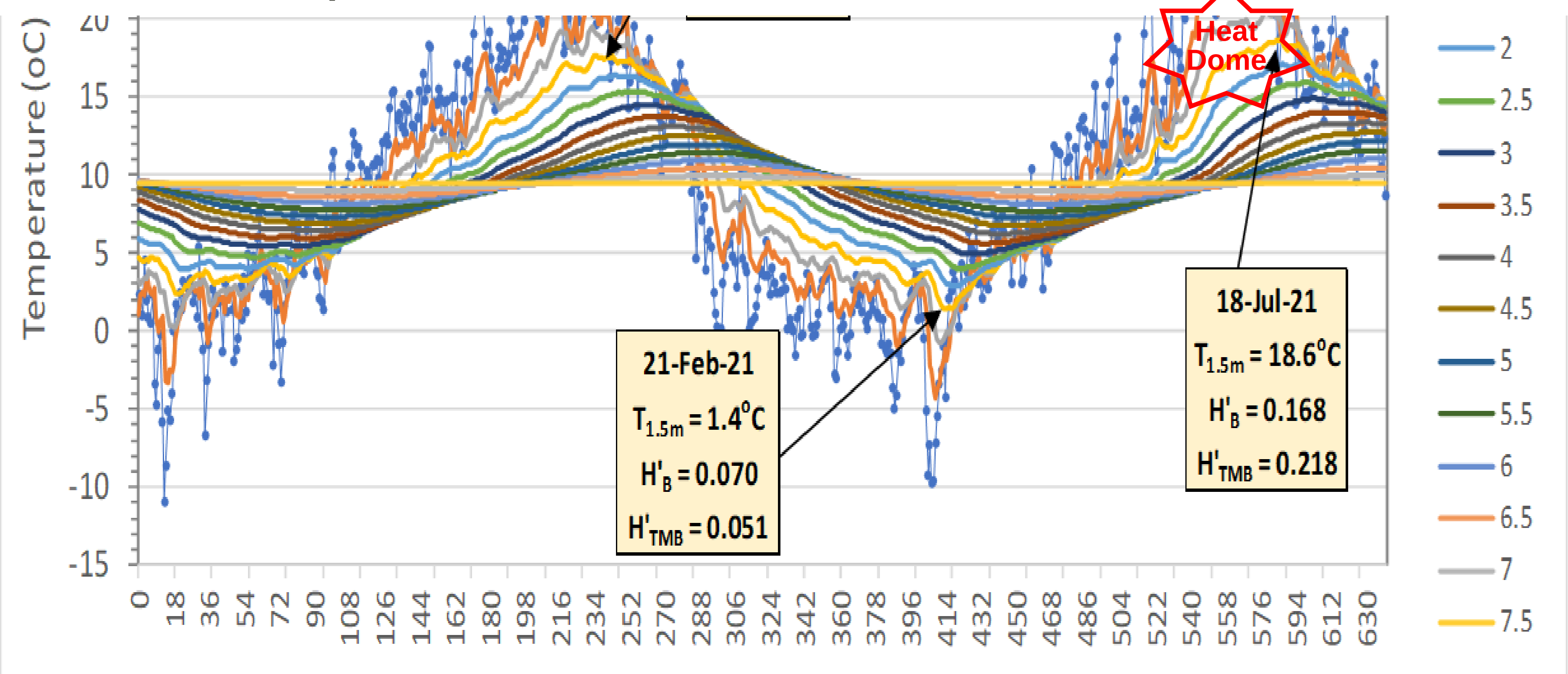
Climate Resilience Evaluation and Awareness Tool (CREAT)

https://www.epa.gov/crwu/climate-resilience-evaluation-and-awareness-tool-creat-risk-assessment-application-water

Climate Change - Local and Community Implications

Numerical Modeling Predictions of Soil Temperature

Numerical model predictions of Average Daily Soil Temperature 0-7.5 m - Surface temperature for site in BC interior – Jan 1, 2020 – Oct. 1, 2021



Question: Modeling indicates temperature effect attenuated with depth. Long-term average soil temperature expected to increase in relation to average air temperature. Seasonal differences in temperature could be important for shallow soil. Implications for natural attenuation and soil vapour sampling?

Nature-based Solutions

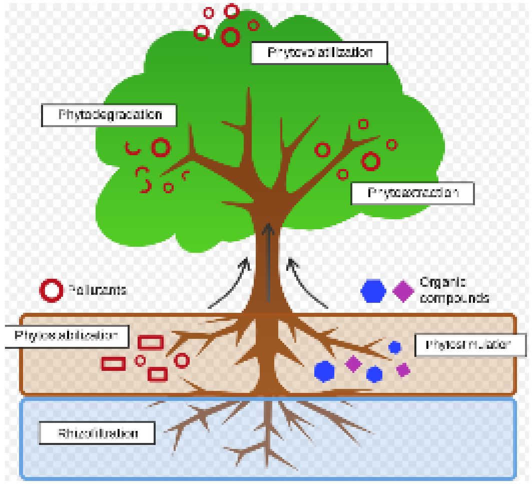
Where Passive Remediation is Primary Attenuation Mechanism

Bioventing

Low impact technology for enhanced NA
Consider whether solar-or wind-powered implementation could be effective
Can outperform hydraulic recovery (Koons et al. 2017)[1]
US EPA Guidance - Excellent resource
https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=124631

Solarization

May be effective for shallow contamination biodegradation rates increase with temperature
Case studies needed



Phytoremediation

Low impact
Can be effective for PHCs
Sequesters carbon
Habitat, human benefit
ITRC Guidance
http://sabcs.ca/11th-annual-sabcs-conference/
https://esaa.org/remtech/agenda/proceedings/2017-2/

[1] https://www.battelle.org/docs/default-source/conferences/bioremediation-symposium/proceedings/biosymposium/managing-petroleum-hydrocarbon-sites/b5_1030_-511_koonsaurev.pdf?sfvrsn=15bfac88_0

Off-sets for CO_2 Emissions

Vancouver-Toronto Flight (3364 km roundtrip)

	Emission Factor	CO_2-e tonnes
BC Government	0.1048 t-CO_2/psn-km	0.71
SiteWise	0.21 t-CO_2/psn-mile	0.89
Offsetters	Not provided	1.25
CarbonZero	Not provided	1.64

Distance Vanc-Toronto 3364 km www.distancefromto.net

Assume 1 tonne, off-set cost ~ $20 (Offsetters), or about 5 trees

Could off-set principle be applied to environmental remediation?

For Natural Source Zone Depletion: assume depletion rate = 1,000 gal/acre/yr and 1 acre site; **GHG emissions ~ 9 CO_2-t/yr**

Crush calcium-rich concrete and place on ground to sequester CO_2

Plant trees or use phytoremediation to enhance bioremediation and remove CO_2

Re-purpose site for solar energy

Soil Re-use

- BC ENV Final Policy Direction - Regulating Soil Relocation (January 2022)
- Sustainability is not mentioned but there are intrinsic sustainable aspects to greater flexibility in soil reuse
- Broader question of sustainable remediation options not addressed

Summary

- Sustainability can mean many different things – for remediation recommend principles of net environmental benefit
- Toolkit roadmap provides structured process for assessing sustainability
- Many examples and sources of best management practices – let's learn from them
- SR Dashboard tool enables assessment of impacts, footprint and multi-criteria analysis comparisons
- Interestingly, while there are footprint tools (e.g., Sitewise) I could find no other readily available tools for MCA (although there are interesting papers on fuzzy logic MCA and some companies have their own internal tools)
- Important to monitor and document sustainability efforts to provide a baseline for improvement
- Climate change risk is an added important dimension affecting sustainability

Acknowledgments

Francois Beaudoin, GHD
Dr. Parisa Jourabchi, ARIS
Dr. Matthew Lahvis, Shell
Linda Kemp, WSP Golder
Guy Patrick, Patrick Environmental
Beth Power, Azimuth


Illustrates
indicators
technology
optimal
practitioners
approach
following
developing
contaminated
analysis
monitoring
environmental
Proposes
remediation
concepts
petroleum
dashboard
developed
finding
performance
considered
GSR
Provides
objectives
mca
overview
benefit
solutions
addresses
framework
guidance
footprint
support
used
site
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assess
tools
remedial
can
maximum
hydrocarbons
achieve
sustainable
methods
green
use
impact
selection
within
toolkit
practical
project
regards
carbon
sustainability
activities
Defines
Presents
principles
multi-criteria
supporting

Appendix A – Sustainability Case Studies

1. Wind-Powered Groundwater Pump and Treat
2. Wind-assisted Passive Bioventing – A
3. Wind-assisted Passive Bioventing - B
4. Wind-assisted Passive Bioventing – C
5. Phytoremediation – Oahu Del Monte Corporation Superfund Site
6. Subgrade Biogeochemical Reactor
7. Permeable Reactive BioWall – Altus AFB
8. Excavation - Whitney Young Project
9. Co-Composting
10. Brownfields Carbon Sequestration - Phytoremediation, Carbon Gardens and Demolition Material Reuse
11. Solar Powered Groundwater Pumping – Small System
12. Solar Powered Groundwater Pumping – Large System

Several case studies are award-winning projects for sustainability. This information is not in toolkits (only on slides)

Wind-Powered Groundwater Pump and Treat

Case Study #1

Site Description and Background information

- Groundwater is contaminated with chlorinated solvents at the Massachusetts Military Reservation (MMR)
- Nine groundwater pump and treat systems

SR Approach and Methods

- Groundwater pump and treat systems at MMR used over $2 M in electricity costs and indirectly produced tons of GHGs and other air emissions associated with fossil fuel-based power.
- Two 1.5 MW wind turbine installed by AFCEE
- Costs were approximately 10.4 M

SR Outcome

- Wind turbines will offset the AFCEE cleanup program's electricity costs and air emissions by 100% for next 25 years. The cleanup program's cost savings are estimated at $26M (over this time period); an additional $42M of renewable electricity are estimated for other DOD uses.

References

- https://www.massnationalguard.org/JBCC/afcee-documents/fact-sheet-wind-2-oct-2011.pdf

Wind-assisted Passive Bioventing - A

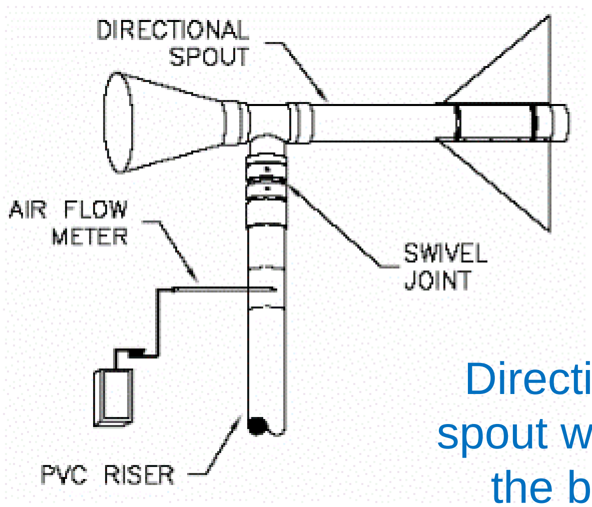
Case Study #2

Site Description and Background Information

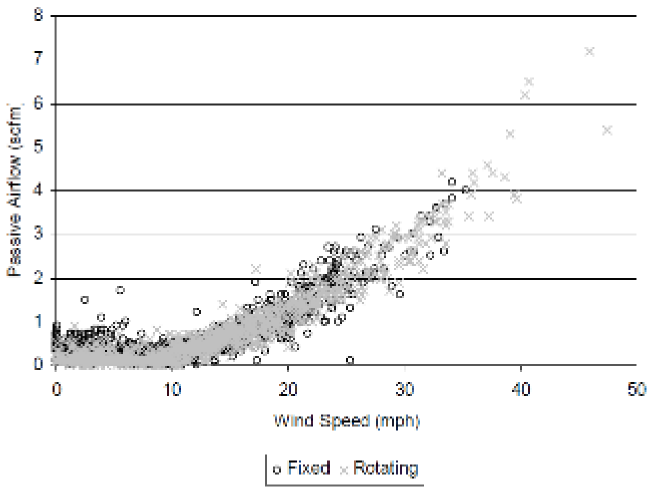
- Petroleum refinery site

SR Approach and Methods

- Four different passive bioventing techniques were evaluated
  1) barometric pumping
  2) barometric pumping with a check valve (baro-valve)
  3) wind assisted air injection, and
  4) wind assisted air extraction.



Directional spout worked the best

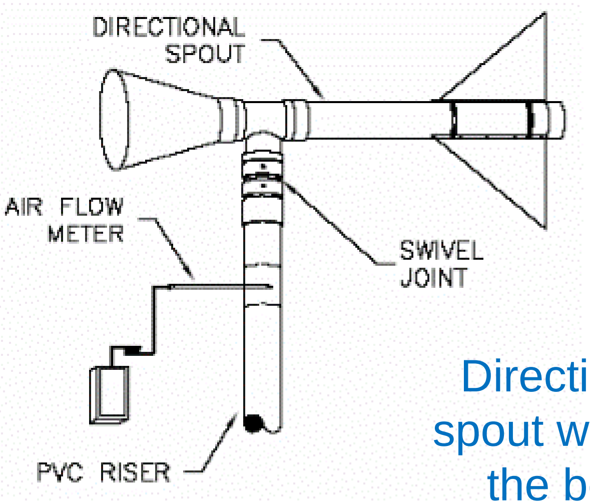


Wind-assisted Passive Bioventing - A

Case Study #2

SR Outcome

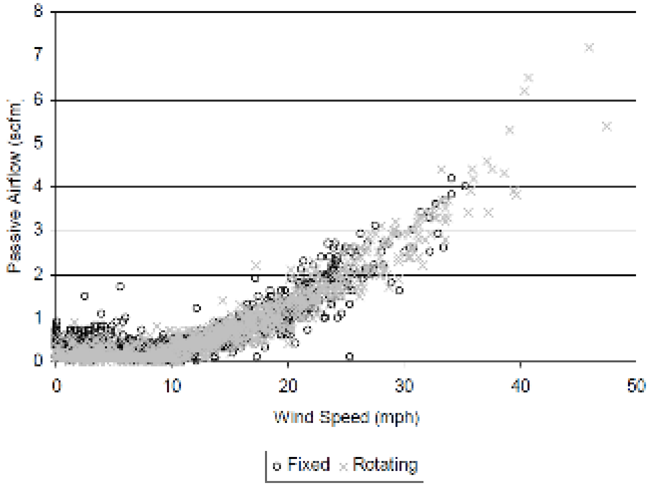
- Wind assisted injection techniques created significant aeration of vadose zone with O_2 concentrations > 5% at all soil gas probes.
- Average air injection rate ~ 0.77 scfm with maximum rate of 7 scfm
- Barometric methods Inadequate as O_2 was not measured at any probes.
- Considered ideal for remote sites with average wind speeds > 15 mph



Directional spout worked the best

References

- Zenker et al. Passive Bioventing Pilot Study at a Former Petroleum Refinery
- https://www.researchgate.net/publication/228458033_Passive_Bioventing_Pilot_Study_at_a_Former_Petroleum_Refinery



Wind-assisted Passive Bioventing - B

Case Study #3

Site Description and Background Information

- BTEX contaminated site

SR Approach and Methods

- 30 cm diameter funnel/vane 360-degree wind collectors connected to existing monitoring wells
- On-site weather station

Wind-assisted Passive Bioventing - B

Case Study #3

SR Outcome

- Measured air velocity ranged from 20-110 feet per minute
- Wind-assisted bioventing was able to reduce VOC concentrations by greater than approximately 90 percent
- O_2 increased from approximately 2.5% to 20%
- No fugitive emissions were measured using PID
- Energy savings relative to similar electrical-powered system was approximately 20,000 kWh/yr.
- Reduced CO_2 emissions by approximately 12 tonnes CO_2/yr.
- More work needed to assess radius of influence

References

- Dominguez et al. 2012. Sustainable Wind-Driven Bioventing at a Petroleum Hydrocarbon–Impacted Site. Remediation. Summer.

Wind-assisted Passive Bioventing - C

Case Study #4

Site Description and Background Information

- Site impacted with condensate
- Sandy clay
- Primary zone of impact 7-14 m
- Depth to water table > 20 m
- Remote area

SR Approach and Methods

- Windmills used to provide energy for remediation of diesel contaminated soil
- 60 wells at 5 m spacing
- Windy area

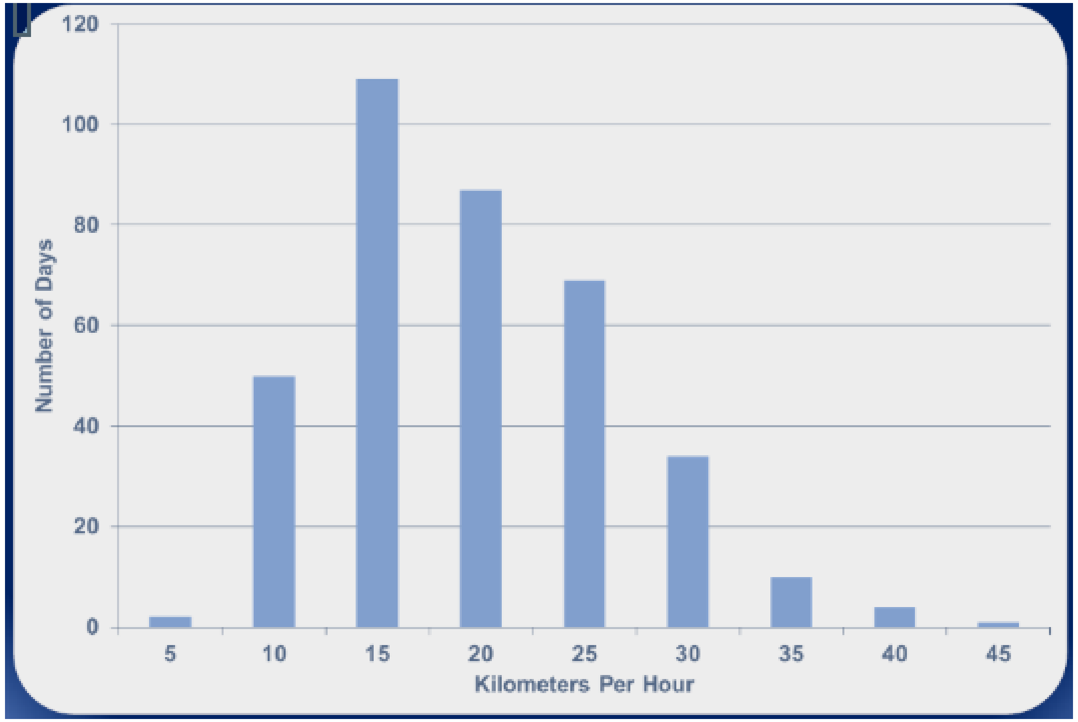
Koender Windmills

Wind-assisted Passive Bioventing - C

Case Study #4

SR Outcome

- 5 windmills were able to provide average of 2.9 cfm per well
- The equivalent electrical pump would draw 3.4A (i.e., relative to 5 windmills)
- Compared to energy provided by a diesel powered generator, wind power results in reduction between 3.5 and 8.4 tonnes CO_2 per year



Average daily wind speed

References

- Knafla, A. and McIvor, I. 2016. Harnessing Wind Power for Remediation via Soil Vapour Extraction in Remote Areas. Presentation at Remtech Conference, Banff, AB, Canada.

Phytoremediation – Oahu Del Monte Corporation Superfund Site

Case Study #5

Site Description and Background Information

- Superfund site with > 1,000 m3 of soil impacted with soil fumigants ethylene dibromide (EDB) and 1,2-dibromo-3-chloropropane (DBCP), used to combat destructive microscopic worm-like nematodes that attack crops such as pineapples, bananas and potatoes.
- Conventional remedial option was excavation of soil, shipment and disposal in mainland US, which was expensive and non-sustainable
- Phytoremediation proposed but outcome uncertain because phytoremediation not previously attempted for EDB and DBCP

SR Approach and Methods

- Proposed solution was to use a tropical leguminous tree, Koa Haole, as a phytoremediation agent. The year-round growing conditions, and the availability of this tree on Oahu, made it an attractive option.
- Bench-scale testing determined that Koa Haole could fully degrade EDB to bromide ion

Koa Haole Tree Pilot Test plots

Phytoremediation – Oahu Del Monte Site

Case Study #5

SR Approach and Methods

- A pilot-scale test site was conducting where impacted soil amended with yard waste and cow manure was placed in a lined cell. Koa Haole trees were planted in the cells, 53 cm (21 inches) apart. Drip irrigation lines were installed to feed the trees with collected contaminated groundwater and recirculated leachate sump water. The two-year pilot test proved to be successful in that soil and groundwater concentrations were treatment to below standards.
- Based on the success of the pilot test, a full-scale system was constructed using the 1000 m^3 of contaminated soil and Koa Haole trees. The phytoremediation cells were connected to the perched aquifer pump-and-treatment system, which included 35 groundwater extraction wells, equipped with pneumatic pumps to continuously pump water from the impacted parts of the aquifer. The impacted water is distributed to the phytoremediation treatment cells, containing the Koa Haole trees.

Phytoremediation – Oahu Del Monte Site

Case Study #5

SR Outcome

- As of September 2017, the phytoremediation system has successfully treated over 18 million litres (4.7 million gallons) of groundwater to concentrations below drinking water standards.
- Given that these fumigants have been widely used, this project is important in that it demonstrates soil and water impacted by EDB and DBCP can be treated efficiently and cost-effectively using phytoremediation which supports a sustainable remediation approach.
- Golder and Del Monte Fresh Produce received the American Council of Engineering Companies (ACEC) of Washington's Best in State Gold Award for Uniqueness and/or Innovative Application of New or Existing Techniques for this project.

Subgrade Biogeochemical Reactor

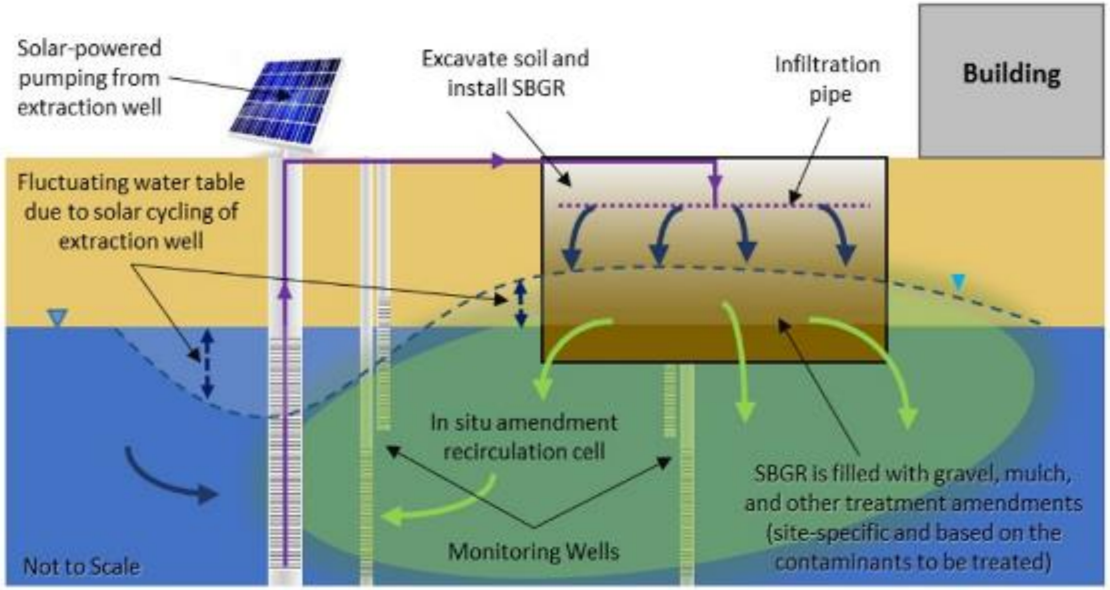
Case Study #6

Site and Background Information

- Improved methods needed for chlorinated solvent site remediation; conventional methods such as groundwater pump & treat are often ineffective and water treatment is costly

SR Approach and Methods

- SBGR involves partial excavation of contaminant source area and backfill with a mixture of composted mulch, gravel, and other sources of organic carbon
- Iron amendments (such as iron pyrite) are added to promote abiotic dechlorination of chlorinated compounds
- Contaminated groundwater is recirculated through the bioreactor using solar/wind power
- Contaminant removal occurs through: Physical removal during excavation, biotic and abiotic dechlorination of impacted water within the bioreactor and dissolved organics stimulate reductive dechlorination in the subsurface outside the bioreactor



Solar powered bioreactor
https://cluin.org/products/newsltrs/tnandt/view.cfm?issue=0507.cfm#1

Subgrade Biogeochemical Reactor

Case Study #6

SR Outcome (for multiple sites)

- At two sites where implemented, TCE concentrations reduced 97-99% inside 47-99% outside SBGR depending on distance
- At multiple sites, annual electricity reduction of ~790,000 KWH/yr and GHG reduction of ~930 tons/yr
- Use of non-refined, recycled or waste materials (used fast food fryer oil, recycled drywall, back mulch, straw, repurposed pump and treat system components)
- Won 2013 Environmental Business Journal Technology Merit Award and 2015 NICOLE Technology Innovation award

References

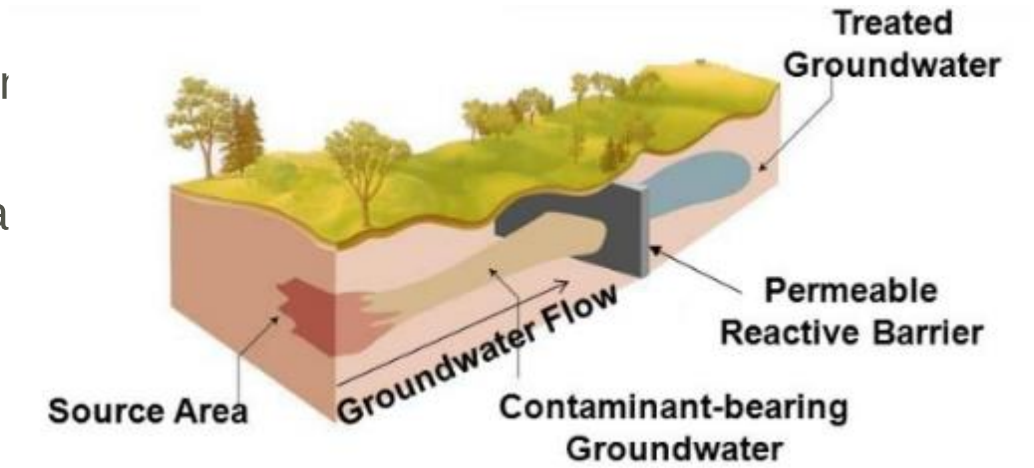
- “Design and Performance of Subgrade Biogeochemical Reactors” in *Journal of Environmental Management*
- Gamlin, J., Downey, D., Shearer, B., and Favara, P., 2017. Design and performance of subgrade biogeochemical reactors. J Environ Manage. 15;204(Pt 2):804-812. doi: 10.1016/j.jenvman.2017.02.036.
- https://www.enviro.wiki/index.php?title=Subgrade_Biogeochemical_Reactor_(SBGR)

Permeable Reactive BioWall – Altus AFB

Case Study #7

Site and Background Information

- 1,520 m-long chlorinated solvent plume with TCE concentratior reaching 78 mg/L in source area
- Sandy clay to ~ 4.6 m depth, underlain by fractured clayey sha with occasional gypsum layers.
- Most contaminant transport in groundwater appears to occur through weathered shale fractures
- Soil and groundwater contain high levels of ferrous iron and sulfate.



From ITRC 2011 Permeable Reactive Wall Guidance

SR Approach and Methods

- 455 ft long, 24 ft deep biowall constructed of mulch, compost & sand
- Objective to promote Biogeochemical Reductive Dechorination(BiRD) through abiotic reactions of chlorinated solvents with FeS produced through biotic reactions
- Promote use of on-site materials, take advantage of naturally elevated iron and sulphate

Permeable Reactive Biowall – Altus AFB

Case Study #7

SR Outcome

- Initial 99% reduction in TCE downgradient of wall reducing to 93% in 7 years
- After ~ 3 yrs, DCE and VC started to appear in downgradient wells, complete degradation no longer occuring
- As a consequence of less than desired performance, on-going research is being conducted where the PRB is being amended with hematite (supplemental iron source) to enhance abiotic reactions through BIRD technology and emulsified oil injection; initial monitoring of degradation promising
- Demonstrates caution needed for long-term effectiveness of solutions

References

- ITRC 2011 Permeable Reactive Barrier Guidance
- Obiri-Nyarko, F., J. Grajales-Mesa and G. Malina 2014. An overview of permeable reactive barriers for in situ sustainable. Chemosphere 111 (2014) 243–259.
- Pilots to Enhance Trichloroethene Reductive Dechlorination & Ferrous Sulfide Abiotic Transformation

Organic waste used for Biowall (ITRC)

Excavation - Whitney Young Project

Case Study #8

Site Description and Background Information

- 0.34-acre urban site impacted with tetrachloroethylene and associated degradation products
- Over 1,000 m^3 impacted soil

SR Strategy

- ASTM Standard Guide for Greener Cleanups (E2893-13) used to identify best management practices(BMPs) for reducing he remediation project's environmental footprint. The primary BMPs were:

  1. Establish a clearly defined target treatment zone (TTZ) and associated performance standards to help avoid unnecessary excavation and resource consumption,
  2. Link remediation activities to site development to enhance material reuse and to reduce transportation distances and
  3. Use local resources, when possible to minimize transportation-related resource consumption.

Excavation - Whitney Young Project

Case Study #8

GSR Outcome

- Numerous green remediation improvements were achieved including approximately 56 and 55 % reduction in energy and greenhouse gas emissions compared to non-optimized baseline assumptions.

- CO_2-e reduction of 387 tonnes

References

- https://clu-in.org/greenremediation/profiles/whitneyyoung

Co-Composting

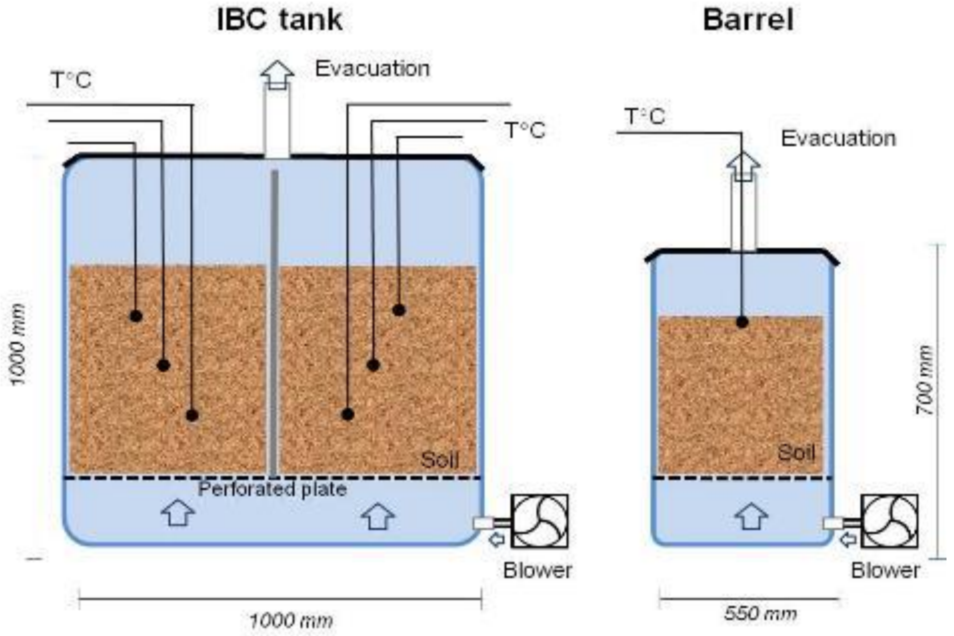
Case Study #9

Site Description and Background Information

- Treatment of 150,000 m^3 of soil impacted by chlorinated compounds (EDC and BCEE), high molecular weight polycyclic aromatic hydrocarbons (PAHs) and heavy fraction petroleum hydrocarbons (PHC C10-C50)

SR Strategy

- Co-composting: soil + amendments + water + air
  Typical goal increase temperature 55-70ºC to optimize treatment
- Tested different amendments: manure types/loadings
- Biopiles used to treat soil in batches
- Leachate recirculation
- Data collection with tablets – automatic report generation
- Monitoring by telemetry with data visualization
- Extracted air treatment performed using activated carbon filters & biofilters.



Several mixes (horse, laying hens, roasters manure and wood shaving) and organic loading (25-75%) were tested

Co-Composting

Case Study #9

SR Outcome

- 48 Biopiles of 1,000 m^3 connected to 8 air/leachate extraction units
- Lab and pilot scale testing of amendments to optimize treatment
- Contaminant biodegradation took < 24-months.
- Target temperature = 55 ^{0}C was achieved for > 1 month.
- Co-composting mixture also breaks down clay cohesion which increases biodegradation rates.
- Reduced GHGs through reduced travel to site
- Reduced cost

Co-Composting

Case Study #9

- Client and Golder won award from Consulting Engineers of Quebec

References

- E.Bergeron, C.Gosselin, J. Côté, 2016. SustRem, RPIC FCS National Workshop, Co-Composting of TPH and PAH impacted soil.
- Bergeron, E., C. Gosselin and J. Côté, Co-Composting of Soil Impacted by Hydrocarbons, Third International Symposium on Bioremediation and Sustainable Environmental Technologies, Battelle, Miami, May 2015.

Brownfields Carbon Sequestration - Phytoremediation, Carbon Gardens and Demolition Material Reuse

Case Study #10

Site Description and Background Information

- Brownfields are often re-developed for mixed use purposes that includes green space and gardens.
- With increased urbanization, sustainable land uses are of increased importance

SR Approach and Methods

- Carbon sequestration through both inorganic and organic carbon has been identified a potential means to reduce GHG emissions
- Soil organic carbon is formed by plants used for phytoremediation of gardens or landscaped areas.
- Phytoremediation may be an appropriate interim or long-terms solution for some Brownfields where there are relatively lower levels of contamination
- Soil inorganic carbon is formed through combination of CO_2 with soil minerals (typically magnesium and calcium) to form carbonates in a process known as mineral carbonation.
- Often deconstruction and redevelopment will result in generation of concrete construction wastes, which is source of calcium

Brownfields Carbon Sequestration - Phytoremediation, Carbon Gardens and Demolition Material Reuse

Case Study #10

SR Outcome

- A research project called SUCCESS led by Newcastle University is evaluating carbon sequestration through demolition material reuse and carbon gardens.
- They found that calcium availability is the key limiting factor, and this is provided abundantly in brownfield soils that contain demolition wastes such as concrete dust and lime and that a hectare of urban soil can sequester up to 85 tonnes of atmospheric CO_2 per year.
- A possible negative outcome is reduced permeability and infiltration of water into soils and greater potential for flooding

SUCCESS
Sustainable Urban Carbon Capture: Engineering Soils for Climate Change

Newcastle University

References

- https://www.sciencedaily.com/releases/2016/12/161213074347.htm
- https://eandt.theiet.org/content/articles/2016/12/brownfield-sites-incredibly-efficient-in-capturing-atmospheric-co2/

Solar Powered Groundwater Pumping – Small System

Case Study #11

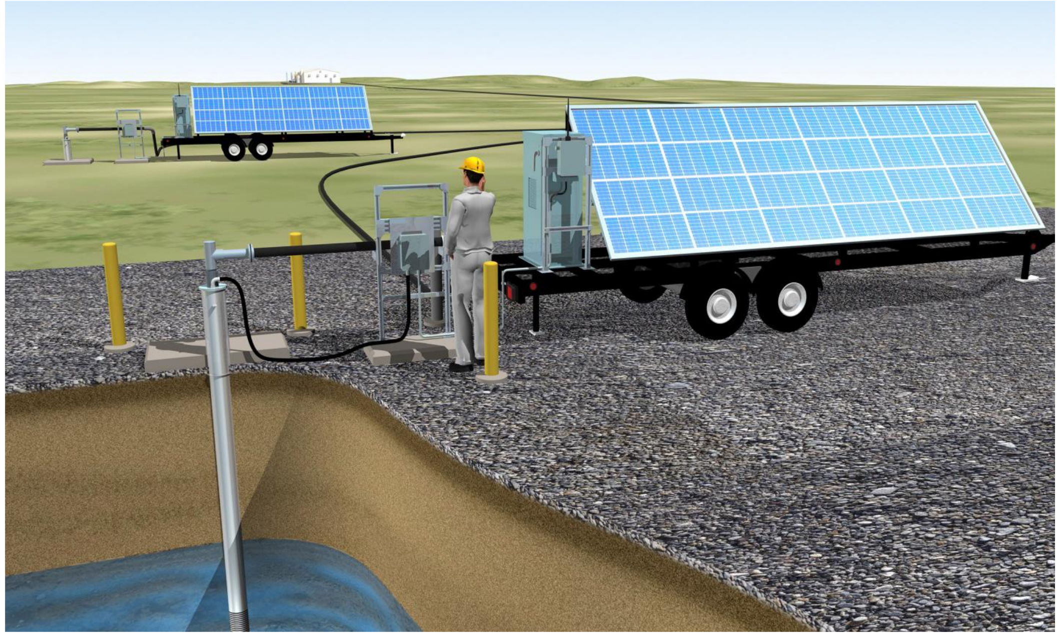
- This case study describes the design of solar-powered groundwater pumping system based on pumping from a single well at 3.5 GPM for approximately 20% of the day.
- A 200W photovoltaic (PV) array optimized with PV solar tilt controller was chosen. An optional item for greater reliability are deep cycle batteries.
- The estimated cost for the system not including batteries was approximately 11,000 USD.
- A detailed review of solar pump suppliers is provided. Performance specifications for pumps are typically provided based on 6kWh/m2/day of solar irradiance

http://extension.colostate.edu/docs/pubs/natres/06705.pdf

Solar Powered Groundwater Pumping – Large System

Case Study #12

- Photovoltaic (PV)-powered groundwater extraction alternatives for the Hanford Site were assessed for technical and economic feasibility.
- Solar PV alternatives ranging in size from 1.2 to 22.1 kWp DC were evaluated and compared to traditional grid-powered systems based on their pumping performance, operational constraints, and economic indicators



Pacific Northwest National Laboratory 2015. Technical and Economic Assessment of Solar Photovoltaic for Groundwater Extraction on the Hanford Site. September.

https://availabletechnologies.pnnl.gov/technology.asp?id=395

https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24741.pdf

Appendix B - Best Management Practices (BMPs) Library

Appendix B - Best Management Practices (BMPs) Library

Focus of case studies are examples of low intensity active or passive and potentially more sustainable technologies

	Impacts Considered for BMPs
PD	Planning and Design
E	Energy
G	Greenhouse Gas Emissions
A	Air Quality
EH	Ecosystem, Human Health, Impacts to Water, Soil and Sediment
M	Materials
W	Waste

Excavation – BMPs

PD1	More intensive investigation to refine and potentially reduce excavation footprint
PD2	Risk-based approaches to reduce excavation footprint
PD3	Combining excavation with targeted in situ treatment in subareas to reduce excavation footprint
PD4	Scheduling optimization for resource sharing and fewer days of mobilization
PD5	Green requirements for product and service procurement (for example preference for products with recycled and bio-based contents)

E1	Selecting waste receivers that are closer to site and options that reduce transportation distances (for material, equipment, products, and wastes)
E2	Investigating alternate shipping methods such as rail lines, if more energy efficient
E3	Investigating opportunities for resource sharing with other waste haulers
E4	Selecting suitably sized equipment for the task
E6	Measures to avoid engine idle and using machinery with automatic idle-shutdown devices
E7	Use of more energy efficient equipment

Excavation – BMPs (cont.)

PD1	Consideration of onsite treatment of soil when feasible and actually
G1	Many of the measures that reduce energy consumption will also reduce GHG emissions although lifecycle of relevant inputs and outputs should be considered
G2	Installation of modular renewable energy system for field equipment (e.g., solar panels for small equipment)
G3	Use of cleaner fuels such as biodiesel especially when made from recycled products
A1	Cleaner fuel such as ultra-low sulfur diesel, wherever available (and as required by engines with particulate matter traps)

A2	Appropriately maintained equipment such as regular replacement of filters
A3	Dust suppression measures such as appropriately applied water
A4	Revegetation of areas as soon as practical
A5	Use of biodegradable fabrics or mats that reduce erosion and dust generation while also promoting regrowth
A6	Use of truck wheel wash to minimize tracking of soil across the site and offsite
A7	Limiting speed of vehicles onsite
EH1	Minimize soil erosion through appropriate temporary road construction methods, silt fences and retention basins

Excavation - BMPs (cont.)

EH2	Minimize soil compaction through for example use of mulch layer and well-defined vehicle routes
EH3	Mitigate uncontrolled stormwater run-off
EH4	Use of biodegradable fabrics and mats to promote regrowth and enhancing soil fertility
EH5	Revegetation of areas as soon as practical and use of native plants for revegetation if applicable to reduce irrigation
EH6	Consider whether operational graywater can be re-infiltrated (if non-contaminated) as opposed to disposing of it in public sewer system
EH7	Use of phosphate-free detergents

EH8	Truck wheel wash where use of water and disposal requirements are minimized (advanced system with grates and closed system for water) to minimize vehicle tracking of material across non-work areas or offsite
EH9	Avoiding tree removal in staging areas or intermittent uncontaminated zones, and retrieving and transplanting native, noninvasive plants
M1	Measures to reduce excavation footprint to reduce backfill needed
W1	Recycling of asphalt and concrete
W2	Reuse of treated material as backfill or cover material, with careful consideration of potential liability and issues with reuse

Excavation - BMPs (cont.)

W3	Conversion of excavated waste to fuel (e.g. coal tar-derived waste materials with high BTU)

Phytoremediation - BMPs

PD1	Scheduling optimization for resource sharing and fewer days of mobilization
PD2	Green requirements for product and service procurement (for example preference for products with recycled and bio-based contents)
E1	Consider means to optimize maintenance and monitoring programs such as automated irrigation systems combined with telemetry (e.g., soil moisture).
E2	Minimizing site visits by the use of telemetry for remote monitoring of site conditions.
E3	Use of energy efficient machinery in planting and harvesting

G1	Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered)
EH1	Minimize soil erosion through appropriate temporary road construction methods, straw-bale barrier installation, silt fences and retention basins
EH2	Consider biosafety concerns and take appropriate safeguards and follow all regulations when using genetically modified (trans genetic) plants (e.g., consider cultivation methods, rooting, flowering, etc).

Phytoremediation – BMPs (cont.)

EH3	Implement measures to control exposures to wildlife to avoid food chain impacts when plants uptake contaminants
M1	Optimize fertilizer and water addition through plant specific considerations, soil nutrient studies and drip irrigation systems.
W1	Consider use harvested plants for energy while addressing potential adverse effects from contaminant uptake in hyperaccumulating plants.
W2	Consider methods for metal recovery from biomass (phytomining)

SVE, Bioventing, Air Sparging - BMPs

PD1	Scheduling optimization for resource sharing and fewer days of mobilization.
PD2	Conduct additional design and pilot testing to optimize full scale design with respect to operational requirements and air treatment.
PD3	Consideration of horizontal extraction wells when potentially more efficient.
PD4	Transition to monitored natural attenuation (MNA) as soon as conditions are favorable to effectively remediate residual contaminants
PD5	Potentially adding nutrients and water to optimize bioventing rates, e.g., Shewfelt et al (2005) report optimal conditions for bioventing at 18 wt.% soil water content and C:N = 10:1, using NH_4^+-N.

PD6	Consideration of complementary technologies to increase the rate of biodegradation through bioventing through soil heating. Leeson et al. (1993) report hot-water injection and solar-heating resulted in consistently significantly higher temperatures than control plot for northern climate site.
E1	Optimization of pump size and use of variable speed motors to match system demand.
E2	Pulsed operation of pumps for soil vapour extraction and air sparging when continuous operation is not warranted (e.g., when contaminants are slowly being released from soil)

SVE, Bioventing, Air Sparging (cont.) - BMPs

E2	For bioventing, air injection mode as oppose to air extraction mode to avoid air treatment, lower energy and eliminate wastes.
E3	Use of passive bioventing that exploits changes in barometric pumping through one-way check valve, when there is sufficient different in atmospheric and subsurface pressures and adequate response time lag (ESTCP, 2004).
E4	Use of solar powered pumps for bioventing, with pumps appropriate to solar energy available. For low energy application, small microblowers (e.g., AMETEK “Microjammer”) can be considered.
E5	Taking well off-line if a well in a manifold system is not contributing to treatment
E6	Constructing a cap to minimize air intrusion and extending radius of influence, the impacts of, and cost of constructing a cap need to be taken into consideration
E7	Using piping of sufficient diameter to minimize pressure drops and resulting need for additional energy to operate blowers
E8	Use of automation such as electronic pressure transducers and soil gas quality monitoring and data loggers and telemetry to minimize site visits and transportation to site.

SVE, Bioventing and Air Sparging (cont.) - BMPs

E9	Establishing decision points triggering a change in the vapor treatment approach, such as switching from thermal oxidation to granular activated carbon (GAC) media; effective evaluation of alternate methods will consider tradeoffs such as potential increases in material consumption or waste generation.
E10	Use of direct push or smaller drill rigs when appropriate
G1	Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered) although caution should be taken in evaluating measures in isolation

G2	Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for extraction).
A1	Ensuring that the zone of influence for soil gas flow to vapor extraction wells completely covers the treatment area
A2	Installing and maintaining surface seals around wells and monitoring points
A3	Using vapor treatment methods appropriate for the influent vapor concentrations and maintaining treatment works such that efficiency is maintained (e.g., carbon change-out).
A4	Use of biofilter for air treatment.

SVE, Bioventing and Air Sparging (cont.) - BMPs

EH1	Minimizing footprint of remediation works.
EH2	Minimizing noise.
M1	Optimization of well networks to reduce materials needed for well construction
W1	Regeneration of granular activated carbon

Groundwater Pump and Treat - BMPs

PD1	Scheduling optimization for resource sharing and fewer days of mobilization
PD2	Conduct additional design and pilot testing to optimize full scale design with respect to operational requirements and air treatment.
PD3	Consideration of horizontal extraction wells when potentially more efficient.
PD4	modify a system to suit changes in a contaminant plume over time;
PD5	Transition to natural source zone depletion (NSZD) and monitored natural attenuation (MNA) as soon as conditions are favorable to effectively remediate residual contaminants

PD6	Consider reinjecting treated water down-gradient of the extraction system to flatten the hydraulic gradient and increase the capture zone width near the extraction wells, and potentially reduce the overall extraction rate; conduct hydrogeologic evaluation to determine whether reinjection could adversely affect extraction efficiency
PD7	Consider diverting upgradient, uncontaminated groundwater around the contaminant plume to reduce the amount of water to be extracted; feasibility of groundwater diversion would likely involve evaluation of environmental tradeoffs such as disturbance to land, ecosystems, and subsurface hydraulic conditions

Groundwater Pump and Treat (cont.) - BMPs

PD8	Green requirements for product and service procurement for example preference for products with recycled and bio-based contents)
E1	Optimization of pump, motor and fan size to reduce energy demand and use of variable speed motors to match system demand instead of throttling flow with valves.
E2	Use of gravity flow where feasible to reduce the number of pumps for water transfer after groundwater extraction
E3	Use of geothermal energy for extraction and treatment plant
E4	Use of geothermal energy for extraction and treatment plant

E5	Use of solar or wind powered groundwater pumps
E6	Selecting suitably sized water treatment equipment
E7	Use of solar or wind powered groundwater pumps
E8	Selecting suitably sized water treatment equipment
E9	Consider whether pulsed groundwater pumping and/or batch treatment of water is a protective remedy; additional gains in energy savings may be possible by pumping during off-peak utility periods

Groundwater Pump and Treat (cont.) - BMPs

E10	Use of automation such as electronic pressure transducers and soil gas quality monitoring and data loggers and telemetry to minimize site visits and transportation to site.
E11	Heat exchangers enable reuse of heat rather than discharging it as part of the effluent
E12	Evaluate the footprint advantages and disadvantages of preheating the vapour influent prior to treatment with vapor-phase GAC; for example, preheating can significantly reduce relative humidity (an efficiency deterrent) but increases the system's energy demand.

G1	Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered) although caution should be taken in evaluating measures in isolation
G2	Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for extraction).
A1	Use appropriate treatment technologies including possibly pre-treatment or pre-filtering prior to use of adsorption media such as GAC to increase treatment efficiency (i.e., so that solids to not cause fouling) and to reduce emissions.

Groundwater Pump and Treat (cont.) - BMPs

EH1	Minimizing footprint of remediation works.
EH2	Avoiding dewatering of wetlands and disrupting wetland ecosystems located near extraction wells
EH3	Minimizing noise.
M1	Water is a lost resource if removed from an aquifer and discharged elsewhere. Consider re-injected treated water into the aquifer for beneficial use where feasible and permitted.

W1	Use of sequestering agents to increase the amount of iron and manganese in solution, to minimize equipment fouling, rather than removing them and generating additional process waste.
W2	Evaluate options for and impacts associated with discharge of treated water including surface water, reinjection to the subsurface, and discharge to a publicly owned treatment works (POTW). All will have varying regulatory requirements and potential impacts.
W3	Consider the source materials used for treatment media; for example, GAC media used in adsorption units can consist of virgin or reactivated coal-based GAC or virgin coconut-based GAC, each with differing impacts

In Situ Chemical Oxidation - BMPs

PD1	Scheduling optimization for resource sharing and fewer days of mobilization
PD2	Conduct high resolution investigation to identify contamination zones to target and bench scale and pilot testing to optimize full scale design with respect to oxidant requirements. Carefully evaluate natural oxidant demand
PD3	Transition to natural source zone depletion (NSZD) and monitored natural attenuation (MNA) as soon as conditions are favorable to effectively remediate residual contaminants
PD4	Consideration of complementary technologies or combined remedies to transition from.

PD5	Green requirements for product and service procurement for example preference for products with recycled and bio-based contents).
E1	Use of direct push technologies when feasible to reduce energy associated with drilling
E2	Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for reagent delivery)
E3	Use of telemetry for remote monitoring of site conditions to minimize site visits and transportation to site.
E4	Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for reagent delivery)

In Situ Chemical Oxidation (cont.)

E5	Evaluate source of oxidant (i.e. supply chain consideration in manufacturing)
E6	Use of groundwater for on-site chemical solution preparation
E7	Evaluate delivery options by rail (for large volume of oxidant) rather than trucks
E8	Use of recyclable bulk solution containers
G1	Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered) although caution should be taken in evaluating measures in isolation

G2	Consider the carbon footprint of oxidants during the selection process. Footprints of the most commonly used oxidants include: hydrogen peroxide, 1.2 tons carbon dioxide (CO_2) per ton; sodium persulfate, 1.25 tons CO_2 per ton; potassium permanganate, 4 tons CO_2 per ton (Siegrest et al. 2011)
A1	Selection of appropriate oxidant and caution in design and implementation to avoid excessive gas generation and migration to ground surface
EH1	Minimizing footprint of remediation works
EH2	.Minimizing noise

In Situ Chemical Oxidation (cont.)

G2	Evaluation of potential impacts to and compatibility with subsurface infrastructure such as utilities from oxidant injection and reactions.
M1	Optimization of well networks to reduce materials needed for well construction

In Situ Bioremediation (cont.)

PD1	Scheduling optimization for resource sharing and fewer days of mobilization
PD2	Optimizing treatment through innovative technology adoption such as use of waste substrates (e.g., sugar-based or other organic compounds) that reduce waste while enhancing biodegradation
PD3	Green requirements for product and service procurement, for example, preference for products with recycled and bio-based contents
E1	Enhancing bioremediation through solar powered methods (e.g., hot-water injection)
E2	Use of geothermal source for soil heating to enhanced bioremediation

E3	Use of direct push technologies when feasible to reduce energy associated with drilling
E4	Use of telemetry for remote monitoring of site conditions to minimize site visits and transportation to site
E5	Reduce the number of environmental samples that are collected for analysis and consider local laboratory to reduce energy for shipping
E6	Use of renewable energy for vehicle transportation

In Situ Bioremediation (cont.)

GHG1	Scheduling optimization for resource sharing and fewer days of mobilization.Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered) although caution should be taken in evaluating measures in isolation
GHG2	Avoidance of excavation and offsite disposal reduces GHGs
M1	Optimization of well networks to reduce materials needed for well construction

In Situ Bioremediation (cont.)

E5	Scheduling optimization for resource sharing and fewer days of mobilization
E6	Optimizing treatment through innovative technology adoption such as use of waste substrates (e.g., sugar-based or other organic compounds) that reduce waste while enhancing biodegradation
E7	Green requirements for product and service procurement, for example, preference for products with recycled and bio-based contents
	Enhancing bioremediation through solar powered methods (e.g., hot-water injection)
	Use of geothermal source for soil heating to enhanced bioremediation

G2	Use of direct push technologies when feasible to reduce energy associated with drilling
A1	Use of telemetry for remote monitoring of site conditions to minimize site visits and transportation to site
EH1	Reduce the number of environmental samples that are collected for analysis and consider local laboratory to reduce energy for shipping
EH2	Use of renewable energy for vehicle transportation

Appendix C – Life Cycle Analysis (LCA) Information

Challenges of LCA

Many potential rabbit holes, some useful, others not

- Various levels of complexity
- Boundaries challenging to define
- Secondary impacts vary widely
- Large number of potential impacts that can be considered
- Some impacts challenging to quantify (e.g., social)
- Comparisons between quantitative and qualitative impacts is challenging (e.g., GHG emissions vs community revitalization)
- Relative comparisons between impacts possible by normalizing and scoring schemes

https://lca-net.com/services-and-solutions/impact-assessment-option-full-monetarisation/

Challenges of LCA – One Literature Example

Lemming et al. 2012

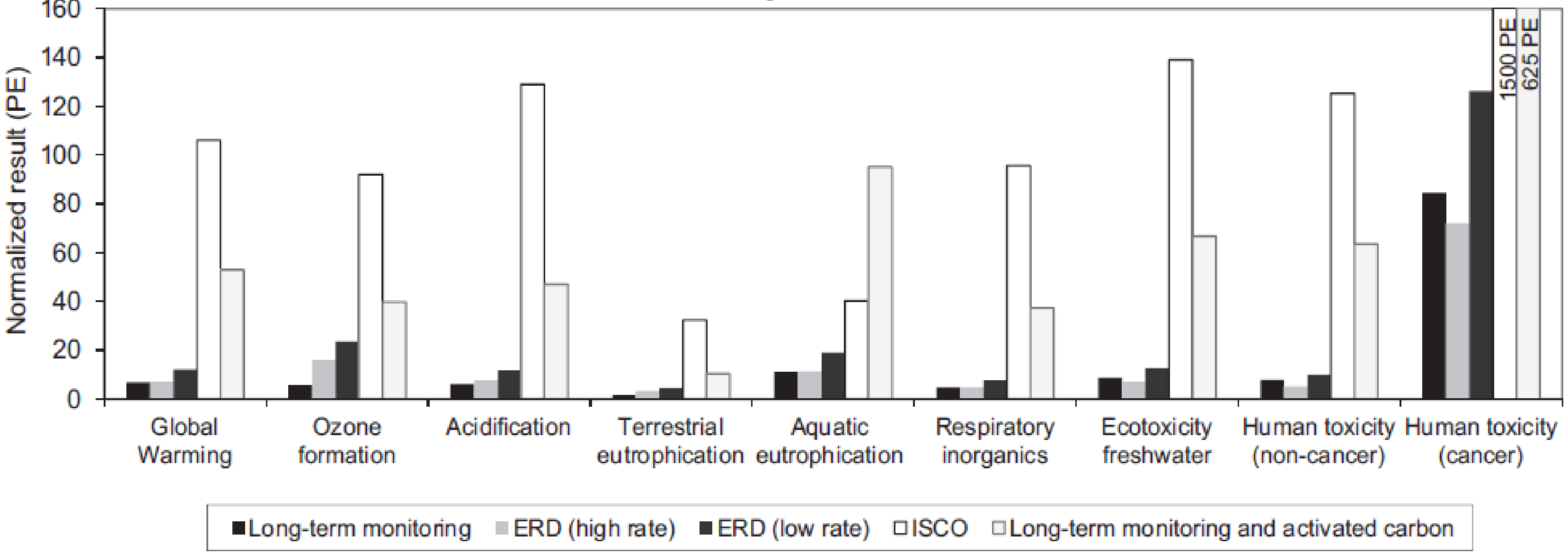


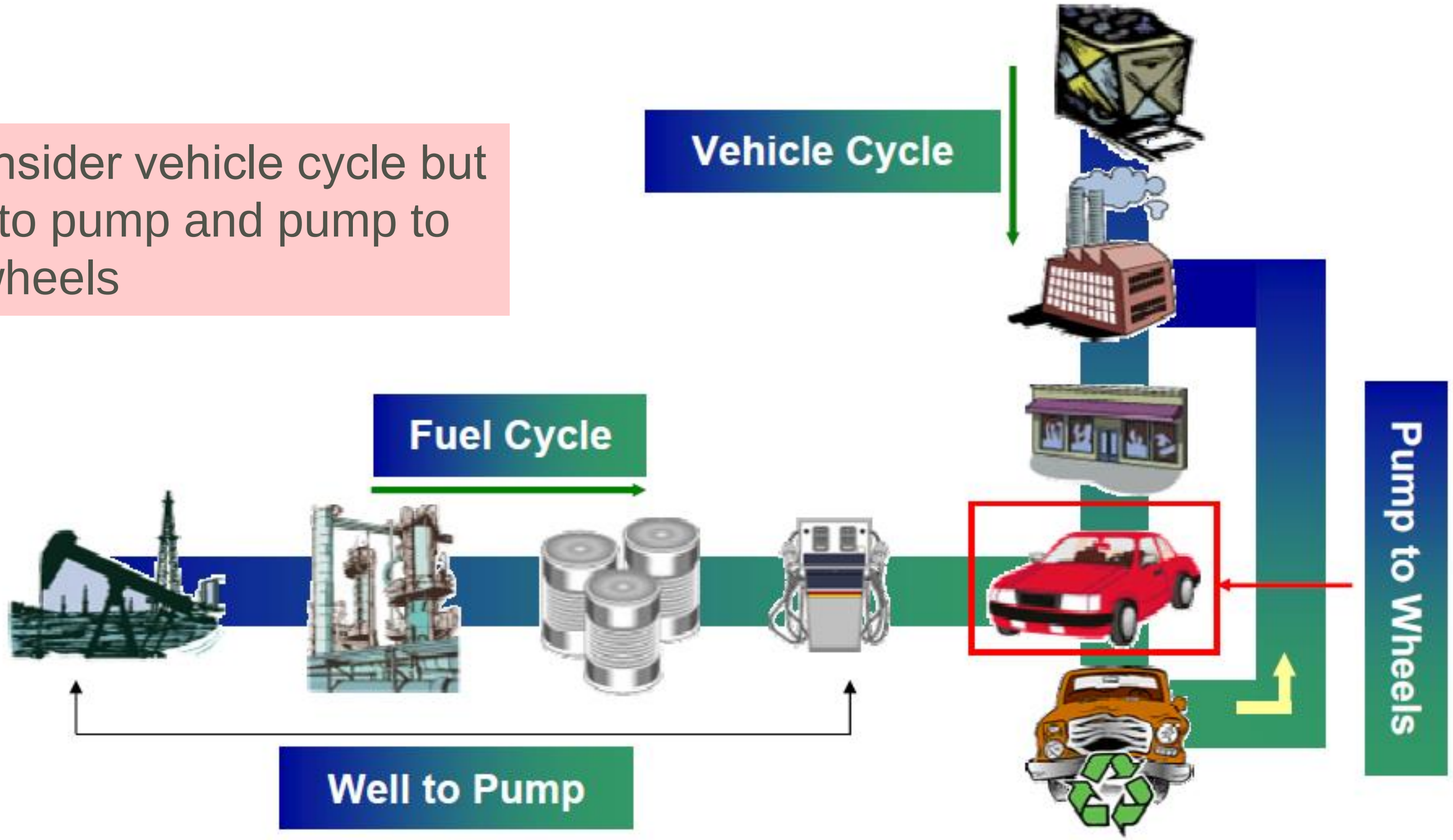
Fig. 6. Life cycle assessment results for the secondary impacts in PE (person equivalents) for the five compared management options.

Results are normalized to person equivalents (PE) by dividing by the average impact from a European citizen in 2004

- Evaluated 1) long-term monitoring, enhanced insitu dechlorination (high and low rate), in situ chemical oxidation (ISCO) and long-term monitoring with activated carbon
- Impacts considered are environmental, ecotoxicity and human health risk
- Challenging to compare across all indicators
- Quantified through normalized person equivalents
- Other examples in literature monitize impacts (i.e., put $ value to impact)

LCA for Vehicles- Example of Boundaries and Complexity

Generally don't consider vehicle cycle but do consider well to pump and pump to wheels



CO_2 Emission Calculations Comparison for Well to Pump and Pump to Wheels (Combustion)

Compare CO_2 Emission for Well to Pump and Pump to Wheel for Heavy Truck

Well to Pump = 15.8 kg/mmBTU x 139000 BTW/gal = 2.2 kg CO_2-e/gal

Well to Pump + Pump to Wheel = 1.37 kg/mile x 8 miles/gal = 11.1 CO_2-e/gal

Well to pump ~ 20% of total for truck so this factor is important, but not always included in LCA (is included in SiteWise), illustrates trade-offs that occur

All factors from SiteWise (uses GREET model)

Conclusions

- Sustainability concepts should be incorporated in site investigation and remediation practice
- Current reality is that sustainability is infrequently considered and incorporated in remediation practice in BC
- Holistic approaches that optimize the environmental, social and economic value of the project are recommended
- Recommend following the **Toolkit Roadmap** and project- and site-specific approach
- Best management practices and optimization should be considered on all projects
- Assessment of the footprint or impacts or comparisons between alternatives can be performed using LCA tools or multi-criteria analysis and is appropriate for some projects

Conclusions (continued)

- LCA can quickly become overly complex, practical approaches are needed, but minimum level of knowledge by practitioners is needed
- Tools available for conducting more in-depth evaluations include SiteWise and GSR Dashboard; the Dashboard can be used as learning tool to ask questions on sustainability
- New metrics could be considered such as CO_2-e/kg-LNAPL treated i.e. integration with Toolkits 2 and 3, which highlight the potential value of baseline measurements
- Possibility of emerging approaches, such as achieving net-zero or positive impacts; is there a role for offsets or similar innovative approaches?

EFA or LCA Tools - References

- SiteWise, developed by Battelle jointly with the Navy, U.S. Army Corps of Engineers, and Army, for evaluating site remediation options https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/erb/gsr.html
- US EPA Spreadsheets for Environmental Footprint Analysis (SEFA) addresses 21 metrics corresponding to elements of greener clean-ups.
- https://clu-in.org/greenremediation/methodology/
- BC Government SmartTool is used for carbon emissions inventory and reporting but is not focused on site remediation https://www.toolkit.bc.ca/Program/SMARTTool-Carbon-Emissions-Inventory-and-Reporting
- SoFi TS Tool by Thinkstep is a corporate sustainability tool but is not focused on site remediation https://www.thinkstep.com/software/corporate-sustainability/sofi-ts
- SimaPro, developed by Pre Sustainability, is comprehensive software for conducting LCA but is not focused on site remediation, includes the EcoInvent database. https://simapro.com/
- WRATE, developed by Golder, for LCA of waste projects http://www.wrate.co.uk/

Appendix D – SR Dashboard Tool Information

SR Dashboard - Impact Tool

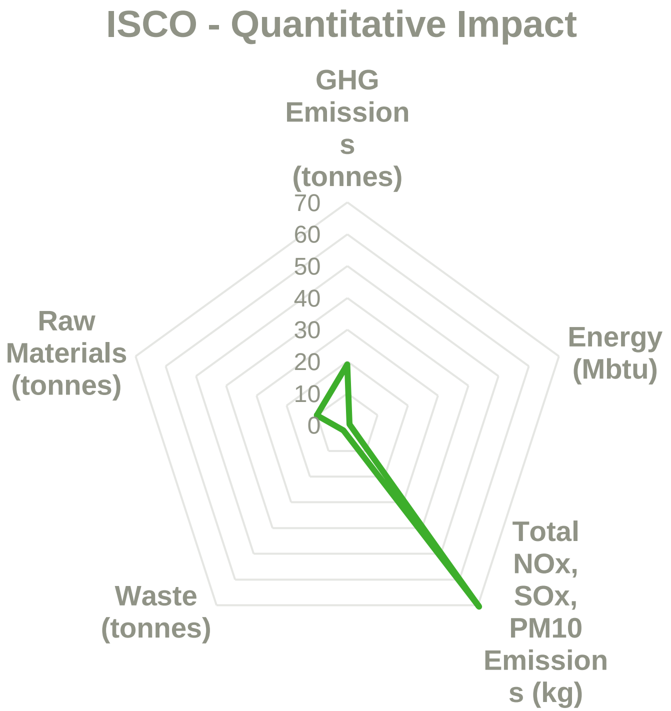
DRAFT BETA GSR DASHBOARD (*V1.1 - Golder Associates*) - Not for Distribution						
IMPACT OF TECHNOLOGY - ____________________						
	Indicator (add/subtract as warrented)	**Metric**	**Measurement Unit**	**Data Sources and Calculators**	**Impact Result**	**Possible Greening or Improvements**
Environmental	GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	Tonne CO_2e	US EPA Calculators[1,3] US EPA SEFA[2] SiteWise: Table A-3, App B BC MoE[9]		
	Energy	1. Total energy use 2. Energy from renewable resources	MMBtu	SiteWise: Table A-2, App B; EPA[8], BC MoE[9]		
	Air Pollutants	1. NOx emissions 2. SOx emissions 3. PM10 emissions	Kilograms	SiteWise: Table A-2, App B		
	Waste	1. Hazardous waste disposed of offsite 2. Non-hazardous waste disposed of offsite	Tonnes or Litres	Site-specific estimate		
	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Tonnes or Litres	Site-specific estimate		
	Land, Water and Ecosystem	1. Environmental quality 2. Biota (animals and plants) and habitat 3. Soil fertility effects 4. Water quality (e.g., Eutrophication)	Qualitative Qualitative Qualitative Qualitative	Site-specific assessment		
	Permance /Long-term Effectiveness	1. What is permance and long-term effectiveness of technology in meeting remedial goals	Qualitative	Site-specific assessment		
	Technology Reliability	1. What is reliability in technology with respect to risk and uncertainty particularly in relation to extreme events	Qualitative	Site-specific assessment		
Social	Community	1. Revitalization (economic, social) 2. Noise, dust, traffic, visual 3. Land use access (improved, restricted)	Qualitative Qualitative Qualitative	Site-specific assessment		
	Safety	1. Worker Safety On-site 2. Public Safety Near-site 3. Vehicle Accident Risk (non-fatal)	Qualitative Qualitative Accidents per km	Site-specific assessment 4,5,6		
	Time	1. Time of remediation	Years	Site-specific estimate		
Cost	Cost	1. Capital 2. Operation & maintenance	$ $ (NPV)	7		

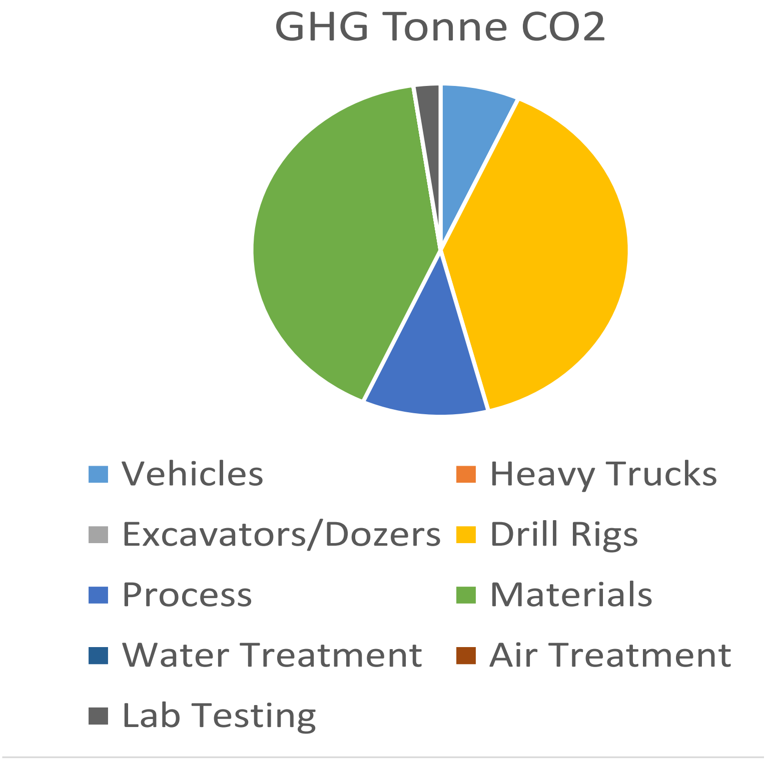
Relatively Simple Framework that addresses Key Indicators and provides guidance on Metrics

- GHG
- Energy
- Air Pollutants
- Waste
- Materials
- Land, Water & Ecosystem
- Permance /Long-term Effectiveness
- Technology Reliability
- Community
- Safety
- Time
- Cost

SR Dashboard Tool – Example #1

Indicator
GHG
Energy
Waste
Air Pollutant
Materials

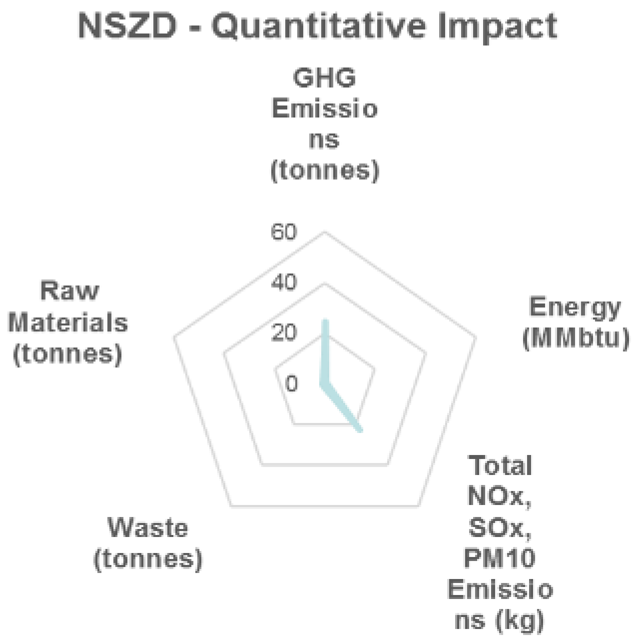


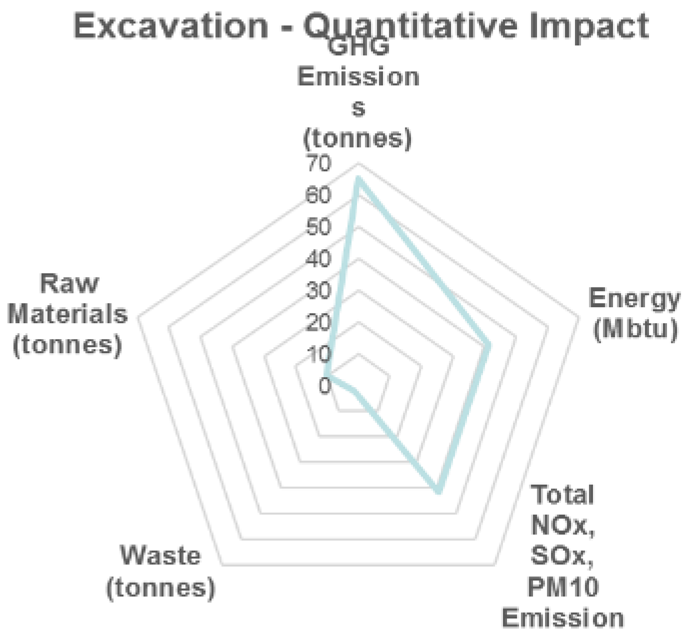


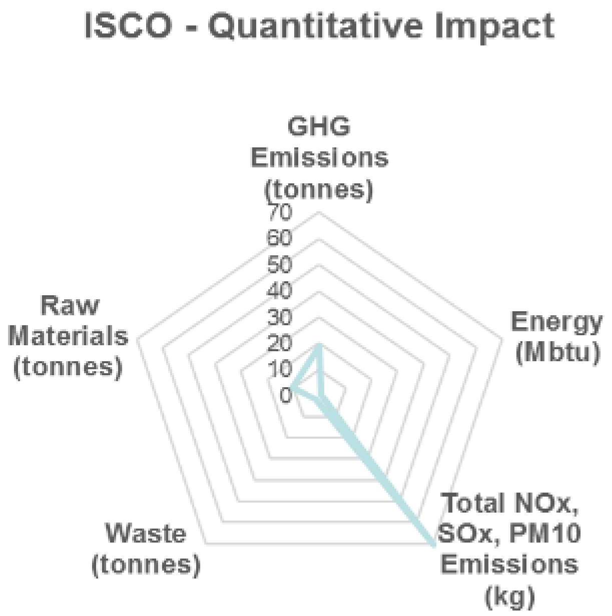
Using ideas in the Golder Remediation Technology BMPs and Case Studies can optimize remediation and assess reduction in footprint for a specific technology

SR Dashboard Tool Example #2

Indicator
GHG
Energy
Waste
Air Pollutant
Materials







All options assume baseline LNAPL recovery option (skimming)

New metrics could be considered such as CO_2-e/kg-LNAPL treated i.e. integration with Toolkits 1-3 and value of baseline measurements

SR Dashboard - MCA Tool

DRAFT BETA SR DASHBOARD (*V1.1 Golder Associates*)														
COMPARISON OF IMPACT & MCA FOR MULTIPLE TECHNOLOGIES							**MCA**							
Indicator (add/subtract as warrented)		**Metric**	**Measurement Unit**	**Impact Result**			**Raw Score**			**Scoring Rationale**	**Weight (3 high, 1 low)**	**Weighted Score = Raw**		
				NSZD	**ISCO**	**Excavation**	**NSZD**	**ISCO**	**Excavation**			**NSZD**	**ISCO**	**Excavation**
Environmental	GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	Tonne CO_2e	10	30	100	4	2	1	Describe rationale & uncertainty	3	12	6	3
	Energy	1. Total energy use 2. Energy from renewable resources	MBtu	20 -	40 -	60 -	4	3	2		2	8	6	4
	Air Pollutants	1. NOx emissions 2. SOx emissions 3. PM10 emissions	Kilograms	20 20 20	30 30 30	30 30 30	3	2	2		2	6	4	4
	Waste	1. Hazardous waste disposed of offsite 2. Non-hazardous waste disposed of offsite	Tonnes or Litres	- 20	- 30	- 30	3	2	2		2	6	4	4
	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Tonnes or Litres	- 1	- 1	- 1	3	3	2		2	6	6	4
	Land, Water and Ecosystem	1. Aquatic Receptors and Habitat 2. Terrestrial Receptors and Habitat 3. Soil fertility effects 4. Water quality (e.g., Eutrophication)	Qualitative Qualitative Qualitative Qualitative	Site-specific assessment	Site-specific assessment	Site-specific assessment	2	3	3		3	6	9	9
	Permance /Long-term Effectiveness	1. What is permance and long-term effectiveness of technology in meeting remedial goals	Qualitative	Site-specific assessment	Site-specific assessment	Site-specific assessment	2	2	4		3	6	6	12
	Technology Reliability	1. What is reliability in technology with respect to risk and uncertainty particularly in relation to extreme events	Qualitative	Site-specific assessment	Site-specific assessment	Site-specific assessment	2	3	4		3	6	9	12
Social	Community	1. Revitalization (economic, social) 2. Noise, dust, traffic, visual 3. Land use access (improved, restricted)	Qualitative Qualitative Qualitative	Description Description Description	Description Description Description	Description Description Description	3	4	3		2	6	8	6
	Safety	1. Worker Safety On-site 2. Public Safety Near-site 3. Vehicle Accident Risk (non-fatal)	Qualitative Qualitative Accidents per km	Description Description Description	Description Description Description	Description Description Description	4	3	2		3	12	9	6
	Time	1. Time of remediation	Years	30	2	1	1	4	5		2	2	8	10
Cost	Economic	1. Capital 2. Operation & maintenance	$k $ (NPV)	100	150	170	4	3	2		2	8	6	4

SR Dashboard - MCA Tool

Example indicator

GSR IMPACT					
Indicator	Metric	Measurement Unit	Result		
			NSZD	Bioventing	Excavation
GHG	1. GHG Emissions	Ton CO_2e	10	30	100

GSR MCA							
Raw Score			Scoring Rationale	Weighting (3 high, 1 low)	Weighted Score		
NSZD	Bioventing	Excavation			NSZD	Bioventing	Excavation
4	2	1		3	120	60	30

Scoring System

Qualitative Indicators: 5 = very positive impact, 4 = positive impact, 3 = neutral, 2 = negative impact, 1 = very negative impact

Quantitative Scale: 5 = low negative impacts, 3 = moderate negative impact, 1 = high negative impact

SR Dashboard - MCA Tool

Absolute Scoring System

For Qualitative indicators, under Raw Score use following scoring: 5 = very positive beneficial impact, 4 = positive impact, 3 = neutral, 2 = negative impact, 1 = very negative impact

For Quantitative Indicators, under Raw Score use following scoring: 5 = low negative impacts, time or cost, 3 = moderate impacts, 1 = high negative impacts, time or cost

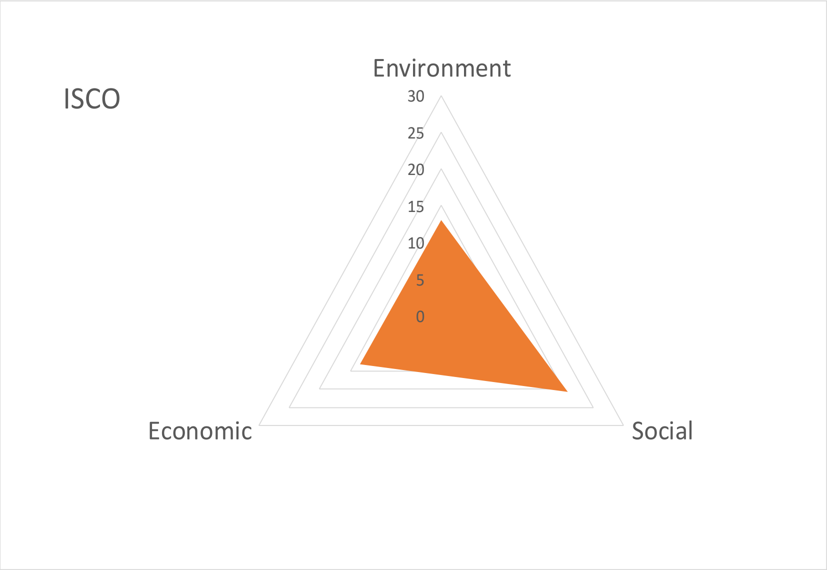
Local Scoring System

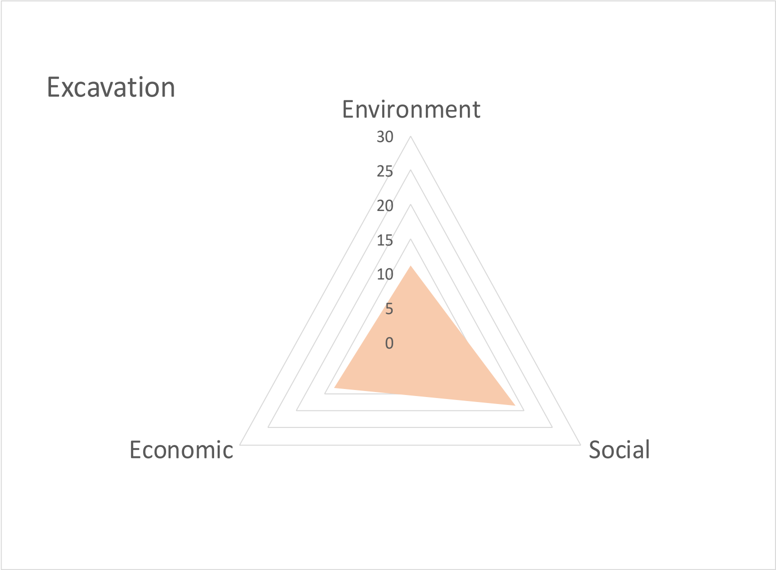
Rank options from best to worst. Best options in terms of positive impact or low negative impacts receive score of 100. Worst option receives score of 0. In-between options are scoring accordingly.

For example, if four options are evaluated, the top ranked option receives 100, the 2nd receives 66, the 3rd receives 33 and 4th receives 0.

Score = Sum (Weighted Scores) / Sum (Maximum Possible Weighted Scores)
Maximum Possible Weighted Score = Maximum Score x Maximum Weight

SR Dashboard - Example MCA Tool Output





Toolkit 4: SR Dashboard – Footprinter Tool

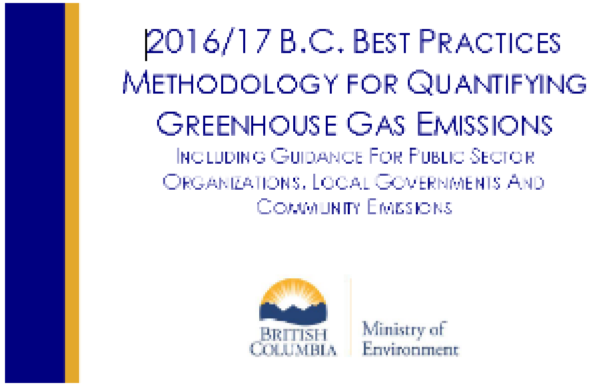
DRAFT BETA GSR DASHBOARD (*V1.1 - Golder Associates*) - Not for Distribution																		
GSR IMPACT TOOL - CONSIDER LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - OPERATION / MONITORING - DECOMMISSIONING) TECHNOLOGY: ____________________________																		
CATEGORIES		INFORMATION				ENERGY CONSUMPTION			GHG EMISSIONS				AIR EMISSIONS					
		Activity Data (AD)	Fuel Type (FT)	Energy Efficiency (G) (can be site specific)	Energy Efficiency Source	Energy Coefficient (E)	Efficiency Factor (EFF)	Energy Consumption (EC) EC = ADxGxExEFF	Emission Factor (EF)	Emission Factor Source	GHG Emissions (GHG) GHG = ADxGxExEF	e-equivalent i.e., includes CH_4,N_2O?	NOx Emission Factor	NOx Emission	SOx Emission Factor	SOx Emission	PM10 Emission Factor	PM10 Emission Factor
1. Light On Road Mobile Sources (vehicles, light trucks)		mile		US gallon-fuel/mile		Btu/US gallon	unitless	MJ	kg CO_2/US gallon		tonne-CO_2		g-NOx/mile	kg-NOx	g-SOx/mile	kg-SOx	g-PM10/mile	kg-PM10
Investigation	*Describe*	*100*	*Site specific*	*0.0394*	*BC Car - gasoline*	*SW T2a*	1	#VALUE!	8.880	*BC Light-duty*	0.034964784		*SW T2b*	#VALUE!	*SW T2b*	#VALUE!	*SW T2b*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*0.0394*	*BC Car - gasoline*	*SW T2a*	1	#VALUE!	10.026	*BC Light-duty*	#VALUE!		*SW T2b*	#VALUE!	*SW T2b*	#VALUE!	*SW T2b*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*0.0394*	*BC Car - gasoline*	*SW T2a*	1	#VALUE!	8.880	*BC Light-duty*	#VALUE!		*SW T2b*	#VALUE!	*SW T2b*	#VALUE!	*SW T2b*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*Site specific*	*0.0394*	*BC Car - gasoline*	*SW T2a*	1	#VALUE!	8.880	*BC Light-duty*	#VALUE!		*SW T2b*	#VALUE!	*SW T2b*	#VALUE!	*SW T2b*	#VALUE!
2. Heavy On Road Mobile Sources (heavy trucks)		mile		US gallon-fuel/mile		Btu/US gallon	unitless	MJ	g CO_2/mile		tonne-CO_2		g-NOx/mile	kg-NOx	g-SOx/mile	kg-SOx	g-PM10/mile	kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*	1	#VALUE!	*SW T6b*		#VALUE!		*SW T6b*	#VALUE!	*SW T6b*	#VALUE!	*SW T6b*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*	1	#VALUE!	*SW T6b*		#VALUE!		*SW T6b*	#VALUE!	*SW T6b*	#VALUE!	*SW T6b*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*	1	#VALUE!	*SW T6b*		#VALUE!		*SW T6b*	#VALUE!	*SW T6b*	#VALUE!	*SW T6b*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*	1	#VALUE!	*SW T6b*		#VALUE!		*SW T6b*	#VALUE!	*SW T6b*	#VALUE!	*SW T6b*	#VALUE!
3. Heavy Off Road Mobile Sources (excavators, dozers, etc)		hrs		US gallon-fuel/hrs		Btu/US gallon	unitless	MJ	g CO_2/hour		tonne-CO_2		g-NOx/hr	kg-NOx	g-SOx/hr	kg-SOx	g-PM10/hr	kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*	*SW T3a*	#VALUE!	*SW T3b*		#VALUE!		*SW T3b*	#VALUE!	*SW T3b*	#VALUE!	*SW T3b*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*	*SW T3a*	#VALUE!	*SW T3b*		#VALUE!		*SW T3b*	#VALUE!	*SW T3b*	#VALUE!	*SW T3b*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*	*SW T3a*	#VALUE!	*SW T3b*		#VALUE!		*SW T3b*	#VALUE!	*SW T3b*	#VALUE!	*SW T3b*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*	*SW T3a*	#VALUE!	*SW T3b*		#VALUE!		*SW T3b*	#VALUE!	*SW T3b*	#VALUE!	*SW T3b*	#VALUE!
4. Drill Rigs Fuel Combustion Stationary Sources (drill rigs)		hrs		US gallon-fuel/hrs		Btu/US gallon	unitless	MJ	kg CO_2/US gallon		tonne-CO_2		g-NOx/gal	kg-NOx	g-SOx/hr	kg-SOx	g-PM10/hr	kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T3c*		*SW T2a*	1	#VALUE!	*SW T2a*		#VALUE!		*SW T3d*	#VALUE!	*SW T3d*	#VALUE!	*SW T3d*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3c*		*SW T2a*	1	#VALUE!	*SW T2a*		#VALUE!		*SW T3d*	#VALUE!	*SW T3d*	#VALUE!	*SW T3d*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3c*		*SW T2a*	1	#VALUE!	*SW T2a*		#VALUE!		*SW T3d*	#VALUE!	*SW T3d*	#VALUE!	*SW T3d*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3c*		*SW T2a*	1	#VALUE!	*SW T2a*		#VALUE!		*SW T3d*	#VALUE!	*SW T3d*	#VALUE!	*SW T3d*	#VALUE!
5. Process Fuel Combustion Stationary Sources (generators, other)		hrs		US gallon-fuel/hrs		Btu/US gallon	unitless	MJ	g CO_2/hr		tonne-CO_2		g-NOx/hr	kg-NOx	g-SOx/hr	kg-SOx	g-PM10/hr	kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*	1	#VALUE!	*SW T4b, T5, T6*		#VALUE!		*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*	1	#VALUE!	*SW T4b, T5, T6*		#VALUE!		*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*	1	#VALUE!	*SW T4b, T5, T6*		#VALUE!		*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*	1	#VALUE!	*SW T4b, T5, T6*		#VALUE!		*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!	*SW T4b, T5, T6*	#VALUE!
6. Process Electricity Stationary Sources Use		hrs		KW		unitless	unitless	MJ	tonne-CO_2/GW-hr		tonne-CO_2		kg-NOx/KWh	kg-NOx	kg-SOx/KWh	kg-SOx	kg-PM10/KWh	kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	*Site specific*		1	1	#VALUE!	10.670	BC Hydro	#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*N/A*	*Site specific*		1	1	#VALUE!	10.670	BC Hydro	#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	*Site specific*		1	1	#VALUE!	10.670	BC Hydro	#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*N/A*	*Site specific*		1	1	#VALUE!	10.670	BC Hydro	#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
7. Materials (well pipe, bentonite, sand, fill, cement, amendments)		kg		unitless		MJ/kg	unitless	MJ	kg-CO_2/kg		tonne-CO_2		g-NOx/kg	kg-NOx	g-SOx/kg	kg-SOx	g-PM10/kg	kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1		*SW T1c*	1	#VALUE!	*SW T1c*		#VALUE!		*SW T1c*	#VALUE!	*SW T1c*	#VALUE!	*SW T1c*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*N/A*	1		*SW T1c*	1	#VALUE!	*SW T1c*		#VALUE!		*SW T1c*	#VALUE!	*SW T1c*	#VALUE!	*SW T1c*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1		*SW T1c*	1	#VALUE!	*SW T1c*		#VALUE!		*SW T1c*	#VALUE!	*SW T1c*	#VALUE!	*SW T1c*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*N/A*	1		*SW T1c*	1	#VALUE!	*SW T1c*		#VALUE!		*SW T1c*	#VALUE!	*SW T1c*	#VALUE!	*SW T1c*	#VALUE!
8. Waste Water Treatment		US gallons		unitless		Btu/US gallon	unitless	MJ	kg CO_2/US gallon		tonne-CO_2		g-NOx/USGal	kg-NOx	g-SOx/USGal	kg-SOx	g-PM10/USGal	kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1		*SW T7d*	1	#VALUE!	*SW T7d*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*N/A*	1		*SW T7d*	1	#VALUE!	*SW T7d*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1		*SW T7d*	1	#VALUE!	*SW T7d*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*N/A*	1		*SW T7d*	1	#VALUE!	*SW T7d*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
9. Soil Disposal		Ton (2000 lb)		unitless		MMBtu/ton	unitless	MJ	lb CO_2/ton soil		tonne-CO_2		lb-NOx/ton	kg-NOx	lb-SOx/ton	kg-SOx	lb-PM10/ton	kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1		*SW T7a*	1	#VALUE!	*SW T7a*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*N/A*	1		*SW T7a*	1	#VALUE!	*SW T7a*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1		*SW T7a*	1	#VALUE!	*SW T7a*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*N/A*	1		*SW T7a*	1	#VALUE!	*SW T7a*		#VALUE!		*SW T7d*	#VALUE!	*SW T7d*	#VALUE!	*SW T1c*	#VALUE!
10. Laboratory Analyses		$		unitless		N/A	unitless	MJ	kg-CO_2/$		tonne-CO_2		g-NOx/$	kg-NOx	g-SOx/$	kg-SOx	g-PM10/$	kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1		*N/A*	1	#VALUE!	*0.021*		#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Construction (remediation)	*Describe*	*Site specific*	*N/A*	1		*N/A*	1	#VALUE!	*0.021*		#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1		*N/A*	1	#VALUE!	*0.021*		#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Decommissioning	*Describe*	*Site specific*	*N/A*	1		*N/A*	1	#VALUE!	*0.021*		#VALUE!		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
11. Travel		km		unitless		N/A	unitless	MJ	kg-CO_2/km-psn		tonne-CO_2		g-NOx/$	kg-NOx	g-SOx/$	kg-SOx	g-PM10/$	kg-PM10
Investigation	*Describe*	*1*	*N/A*	1		*Site specific*	1	#VALUE!	0.094	Bus-City	0.0000943		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Construction (remediation)	*Describe*	*1*	*N/A*	1		*Site specific*	1	#VALUE!	0.094	Bus-City	0.0000943		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Operation/Monitoring	*Describe*	*1*	*N/A*	1		*Site specific*	1	#VALUE!	0.094	Bus-City	0.0000943		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
Decommissioning	*Describe*	*1*	*N/A*	1		*Site specific*	1	#VALUE!	0.094	Bus-City	0.0000943		*Site specific*	#VALUE!	*Site specific*	#VALUE!	*Site specific*	#VALUE!
							Total	**#VALUE!**	**Total**		**#VALUE!**		**Total**	**#VALUE!**	**Total**	**#VALUE!**	**Total**	**#VALUE!**
							Total (MMJ)	**#VALUE!**	**Total (tonnes)**		**#VALUE!**		**Total NOx, SOx, PM10 (tonnes)**					**#VALUE!**

SR Dashboard – Footprinter Factors

DRAFT SR DASHBOARD (*V1.1 - Golder Associates*)			
SR IMPACT TOOL - LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - OPERATION MONITORING - DECOMMISSIONING)			
TECHNOLOGY: LNAPL Recovery (skimming) followed by NSZD			
CATEGORIES	ENERGY CONSUMPTION	GHG EMISSIONS	AIR EMISSIONS
1. Light On Road Mobile - Vehicles, Trucks			
2. Heavy On Road Mobile - Trucks			
3. Heavy Off Road Mobile - Excavators, Dozers			
4. Drill Rigs Stationary			
5. Process Equipment Stationary Sources - Fuel Combustion	Joules	CO2e (kg)	NOx (kg) SOx (kg) PM10 (kg)
6. Process Equipment Stationary Sources - Electricity Use			
7. Materials - Well Pipe, Bentonite, Sand, Fill, Cement, Chemicals			
8. Waste Water Treatment			
9. Air Treatment			
10. Laboratory Analyses			
11. Travel			

GHG EMISSIONS			
Emission Factor (EF)	Emission Factor Source	GHG Emissions (GHG) GHG = ADxGxL	e i
kg CO_2/US gallon		tonne-CO_2	
8.880	BC Light-duty	#VALUE!	
10.026	BC Light-duty vehicl	#VALUE!	
8.880	BC Light-duty vehicl	#VALUE!	
8.880	BC Light-duty vehicl BC Light-duty vehicl	#VALUE!	
g CO_2/mile	BC Light-duty truck BC Light-duty truck	tonne-CO_2	
SW T6b	BC Light-duty truck	#VALUE!	
SW T6b	BC Light-duty truck	#VALUE!	

Drop down menu to BC defaults

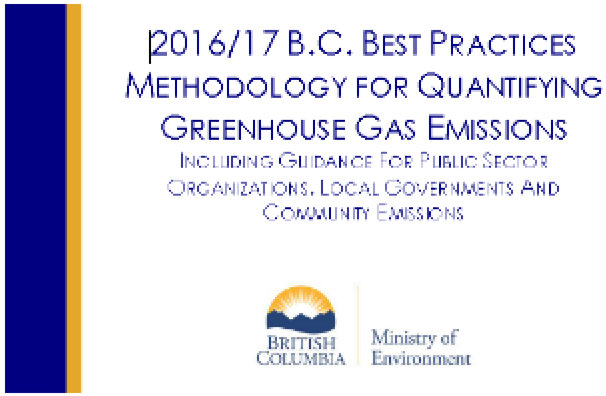


SR Dashboard – Footprinter Data Sources

DRAFT SR DASHBOARD (*V1.1 - Golder Associates*)			
SR IMPACT TOOL - LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - TECHNOLOGY: LNAPL Recovery (skimming) followed by NSZD			
CATEGORIES	ENERGY	GHG	AIR
	DATA SOURCE FOR FACTORS		
1. Light On Road Mobile - Vehicles, Trucks	BC	BC	SW
2. Heavy On Road Mobile - Trucks	SW	SW	SW
3. Heavy Off Road Mobile - Excavators, Dozers	SW	SW	SW
4. Drill Rigs Stationary	SW	SW	SW
5. Process Equipment Stationary Sources - Fuel Combustion	SW	SW	SW
6. Process Equipment Stationary Sources - Electricity Use	ACTUAL	BC	SW
7. Materials - Well Pipe, Bentonite, Sand, Fill, Cement, Chemicals	SW	SW	SW
8. Waste Water Treatment	SW	SW	SW
9. Air Treatment	SW	SW	SW
10. Laboratory Analyses	N/A	ALS	SW
10. Travel	N/A	BC	N/A
Data sources: BC = British Columbia, SW = SiteWise, ALS = ALS Laboratories, Burnaby, BC			

GHG EMISSIONS		
Emission Factor (EF)	Emission Factor Source	GHG Emissions (GHG) GHG = ADxGxL
kg CO_2/US gallon		tonne-CO_2
8.880	BC Light-duty	#VALUE!
10.026	BC Light-duty vehicl	#VALUE!
8.880	BC Light-duty vehicl	#VALUE!
8.880	BC Light-duty vehicl	#VALUE!
g CO_2/mile	BC Light-duty truck	tonne-CO_2
SW T6b	BC Light-duty truck	#VALUE!
SW T6b	BC Light-duty truck	#VALUE!

rop down menu to BC defaults


2016/17 B.C. BEST PRACTICES METHODOLOGY FOR QUANTIFYING GREENHOUSE GAS EMISSIONS

INCLUDING GUIDANCE FOR PUBLIC SECTOR ORGANIZATIONS, LOCAL GOVERNMENTS AND COMMUNITY EMISSIONS

BRITISH COLUMBIA

Ministry of Environment

Energy Calculation

EC = AD x G x E x EFF

- EC = Energy Consumption (e.g., MJ)
- AD = Activity Data (e.g., miles)
- G = Energy Efficiency (e.g., US gal/mile)
- E = Energy Coefficient (e.g., Btu/US gal)
- EFF = Energy Efficiency or Load Factor generally =1 , except see SiteWise Table 3a, 3e, SW) (unitless),

Energy efficiency decreases with increasing load, SiteWise equation for truck:

G = -0.102 x Load (tons) + 7.4

(in mpg)

Example calculation

EC = 100 mi x 0.0394 US Gal/mi x 10.633 Btu/US Gal x 1 = 0.044 MJ

Important to use internally consistent units

Greenhouse Gas Emission Calculation

GHG Emissions = AD x G x EF

- AD = Activity Data (e.g., miles)
- G = Energy Efficiency (e.g., US gal/mile)
- EF = Efficiency factor (e.g., kg CO_2/US gallon)

Example calculation

GHG Emissions = 100 mi x 0.0394 US Gal/mi x 8.8 kg CO_2-e/US Gal = 0.035 tonnes CO_2-e

Factors are from BC gov't

SR Dashboard Footprinter Tool

Not included in Impact tool are

- Impacts associated with equipment manufacture
- Particulate emission factors do not factor in technologies to reduce particulate emissions; SiteWise indicates they may reduce emissions by ~ 70%
- Impacts from air treatment technologies beyond granular activated carbon
- Impacts from equipment transport to the site
- Impacts from some consumables
- GHGs associated with bioremediation (including NSZD)

GHG = 0.0094 t-CO_2/US Gal x NSZD Rate (US Gal/Acre/yr)

Assuming a NSZD rate of 700 US-gal/acre/yr, the equivalent CO_2 emission rate would be 6.6 tonne/acre/year

NSZD still "cleanest" technology of those that oxidize fuels

NSZD CO_2 emissions to be added to Dashboard (not part of SiteWise)

Safety Statistics

A comprehensive compilation of vehicle accident statistics is provided in Canadian Motor Vehicle Traffic Collision Statistics compiled by Transport Canada. For BC, there were 7.7 fatalities per billion vehicle-kilometres and 584 injuries per billion vehicle-kilometres.
https://www.tc.gc.ca/media/documents/roadsafety/Canadian_Motor_Vehicle_Traffic_Collision_Statistics_2015-EN.pdf

Table 1: Vehicle Accident Statistics for British Columbia and Canada for 2015 (Transport Canada)

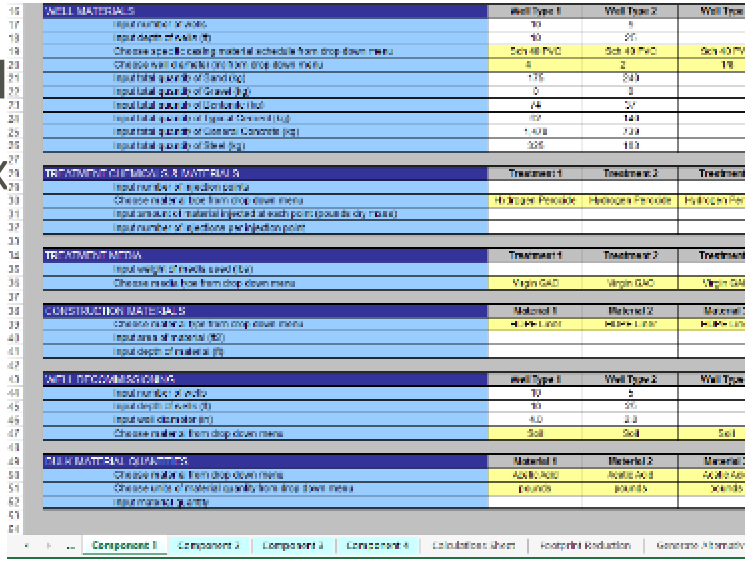
	Per Billion Vehicle-Kilometres	
	Fatalities	**Injuries**
BC	7.7	583.7
Canada	5.1	442.5

Statistics for United States include those provided by the Insurance Institute for Highway Safety, which reports 6.98 fatalities per billion kilometres driven in US for 2015.
http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/state-by-state-overview

Appendix E – Sitewise Tool Information

SiteWise

- Excel-based tool for evaluating sustainability with regards to environmental footprint, and includes elements of effectiveness, cost, and ease of implementation.
- Developed jointly by the Navy, Army Corps of Engineers, and Battelle.
- With this tool, you can estimate:
  - greenhouse gas emissions
  - energy use (total energy use and electricity from renewable and
  - air emissions of criteria pollutants including nitrogen oxide (NOx particulate matter (PM)
  - water consumption
  - resource consumption (landfill space and top soil consumption
  - worker safety (risk of fatality, injury and lost hours).



Toolkit 4: SiteWise – Input Sheet

SITE INFORMATION	
User Name and Date	
Site Name	
Remedial Alternative Name	
Alternative File Name	
Choose electricity profile	AK

Component	Component Alias
Component 1	Component 1
Component 2	Component 2
Component 3	Component 3
Component 4	Component 4

Do you want to reload a previously saved remedial alternative in the SiteWise input sheet?

Yes

Refresh List

Reset all input values on all worksheets to default

Reset All Values on All Sheets

-= Status =-

Reset complete.

Battelle

The Business of Innovation

U.S. ARMY

DEPARTMENT OF THE NAVY · UNITED STATES OF AMERICA

SiteWise – File Structure

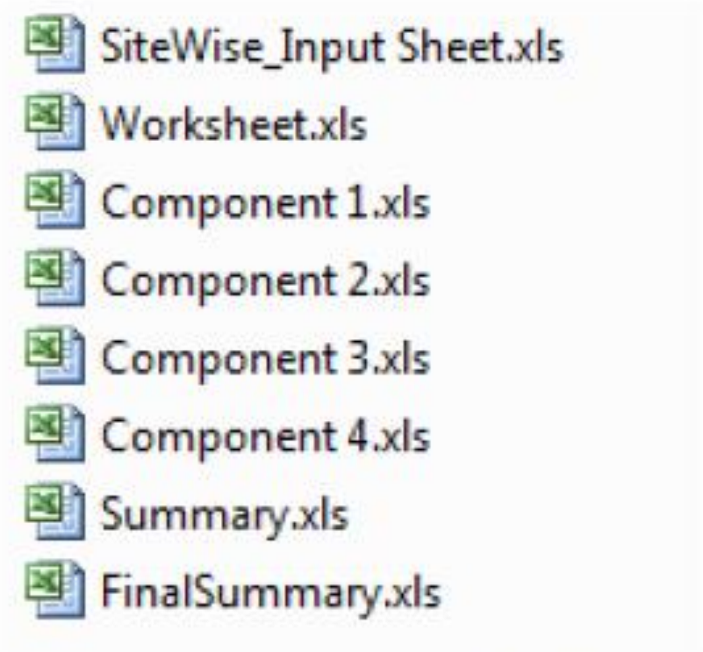


Figure 1-1. SiteWise™ Files

- SiteWise_Input – input data
- Components are options
- Enable macros
- Close all spreadsheets except SiteWise_Input when running software
- Summary has output

SiteWise – Inputs and Impacts Considered

BASELINE INFORMATION

COMPONENT 1 DURATION AND COST	Entire Site
Input duration of the component (unit time)	1
Input component cost per unit time ($)	

MATERIAL PRODUCTION

WELL MATERIALS	Well Type 1
Input number of wells	1
Input depth of wells (ft)	300
Choose specific casing material schedule from drop down menu	Sch 40 PVC
Choose well diameter (in) from drop down menu	2
Input total quantity of Sand (kg)	750
Input total quantity of Gravel (kg)	
Input total quantity of Bentonite (kg)	750
Input total quantity of Typical Cement (kg)	
Input total quantity of General Concrete (kg)	
Input total quantity of Steel (kg)	

TREATMENT CHEMICALS & MATERIALS	Treatment 1
Input number of injection points	
Choose material type from drop down menu	Hydrogen Peroxide
Input amount of material injected at each point (pounds dry mass)	
Input number of injections per injection point	

TREATMENT MEDIA	Treatment 1
Input weight of media used (lbs)	
Choose media type from drop down menu	Virgin GAC

CONSTRUCTION MATERIALS	Material 1
Choose material type from drop down menu	General Concrete
Input area of material (ft2)	
Input depth of material (ft)	

WELL DECOMMISSIONING	Well Type 1
Input number of wells	
Input depth of wells (ft)	
Input well diameter (in)	
Choose material from drop down menu	Sand

SILT CURTAIN MATERIALS	Curtain 1
Input length or perimeter of silt curtain (ft)	
Input depth of silt curtain (ft)	

BULK MATERIAL QUANTITIES	Material 1
Choose material from drop down menu	Acetic Acid
Choose units of material quantity from drop down menu	pounds
Input material quantity	

TRANSPORTATION

PERSONNEL TRANSPORTATION - ROAD	Trip 1
Will DIESEL-run vehicles be retrofitted with a particulate reduction technology?	No
Choose vehicle type from drop down menu*	Cars
Choose fuel used from drop down menu	Gasoline
Input distance traveled per trip (miles)	3000
Input number of trips taken	1
Input number of travelers	1

SiteWise - Inputs

Input number of travelers	1
Input estimated vehicular fuel economy (mi/gal) (Input only if known for the vehicle selected, otherwise a default will be used by the tool)	
*For vehicle type 'Other' please enter values in Table 2b in the Look Up Table tab.	

PERSONNEL TRANSPORTATION - AIR	Trip 1
Input distance traveled (miles)	
Input number of travelers	
Input number of flights taken	

PERSONNEL TRANSPORTATION - RAIL	Trip 1
Choose vehicle type from drop down menu	Intercity rail
Input distance traveled (miles)	
Input number of trips taken	
Input number of travelers	

EQUIPMENT TRANSPORTATION - DEDICATED LOAD ROAD	Trip 1
Will DIESEL-run vehicles be retrofitted with a particulate reduction technology?	No
Choose fuel used from drop down menu	Gasoline
Account for an empty return trip?	No
Input one-way distance traveled (miles) with a given load. If applicable, impact for an empty return trip will be accounted for (no additional input is needed).	
Input weight of equipment transported per truck load (tons)	

EQUIPMENT TRANSPORTATION - SHARED LOAD ROAD	Trip 1
Input distance traveled (miles)	
Input weight of equipment transported (tons)	

EQUIPMENT TRANSPORTATION - AIR	Trip 1
Input distance traveled (miles)	
Input weight of equipment transported (tons)	

EQUIPMENT TRANSPORTATION - RAIL	Trip 1
Input distance traveled (miles)	
Input weight of load (tons)	

EQUIPMENT TRANSPORTATION - WATER	Trip 1
Input distance traveled (mile)	
Input weight of load (tons)	

EQUIPMENT USE

EARTHWORK	Equipment 1
Choose earthwork equipment type from drop down menu	Dozer
Choose fuel type from drop down menu	Diesel
Input volume of material to be removed (yd3)	
Will DIESEL-run equipment be retrofitted with a particulate reduction technology?	No

DRILLING	Event 1
Input number of drilling locations	25
Choose drilling method from drop down menu	Hollow Stem Auger
Input time spent drilling at each location (hr)	2.00
Choose fuel type from drop down menu	Diesel

TRENCHING	Trencher 1
Choose fuel type from drop down menu	Gasoline
Choose horsepower range from drop down menu	1 to 3
Input operating hours (hr)	

SEDIMENT DREDGING	Equipment 1
Choose dredge equipment type from drop down menu	Mechanical

SiteWise- Inputs

Choose dredge fuel type from drop down menu	Diesel
Input volume of material to be dredged (yd3)	
Choose dredge equipment size	Crawler Crane, 25 ton, 1 CY
Suggested dredge equipment size	awler Crane, 25 ton, 1
Input number of dredge tenders (default already present, user override possible)	1
Choose dredge tender fuel type from drop down menu	Diesel
Input operating time for dredge tenders (hr) (default calculated value, user override possible)	0
Input number of scow tenders (default already present, user override possible)	2
Choose scow tender fuel type from drop down menu	Diesel
Input operating time for scow tenders (hr) (default calculated value, user override possible)	0
Choose size of research vessel from drop down menu	Research Vessel (large)
Choose research vessel fuel type from drop down menu	Diesel
Input number of research vessels (default already present, user override possible)	1
Input operating time for research vessels (hr) (default calculated value, user override possible)	0
Will DIESEL-run equipment be retrofitted with a particulate reduction technology?	No
SEDIMENT MANAGEMENT (STAGING AND DRYING)	**Equipment 1**
Choose earthwork equipment type from drop down menu	Crawler Crane
Choose fuel type from drop down menu	Diesel
Input volume of material to be removed (yd3)	
Is volume input that of saturated sediment?	Yes
Will the sediment be dry when this work is performed?	No
Will DIESEL-run equipment be retrofitted with a particulate reduction technology?	No
SEDIMENT CAPPING	**Equipment 1**
Choose capping method from drop down menu	Surface Release
Choose capping equipment fuel type from drop down menu	Diesel
Input volume of capping material to be placed (yd3)	
Choose capping equipment size/type	Hopper Barge
Suggested capping equipment size/type	Hopper Barge
Input number of dredge tenders (hr) (default already present, user override possible)	1

Choose tender fuel type from drop down menu	Diesel
Input operating time for dredge tenders (hr) (default calculated value, user override possible)	0
Input number of scow tenders (default already present, user override possible)	0
Choose scow tender fuel type from drop down menu	Diesel
Input operating time for scow tenders (hr) (default calculated value, user override possible)	0
Choose size of research vessel from drop down menu	Research Vessel (large)
Choose research vessel fuel type from drop down menu	Diesel
Input number of research vessels (default already present, user override possible)	1
Input operating time for research vessels (hr) (default calculated value, user override possible)	0
Will DIESEL-run equipment be retrofitted with a particulate reduction technology?	No
WATERCRAFT OPERATION	**Equipment 1**
Choose size of research vessel from drop down menu	Research Vessel (large)
Choose research vessel fuel type from drop down menu	Diesel
Input number of vessels	
Input operating time (hours)	
Will DIESEL-run equipment be retrofitted with a particulate reduction technology?	No
For each pump, select only one of the three methods to calculate energy and GHG emissions Enter "0" for all user input values for unused pump columns or unused methods	
PUMP OPERATION	**Pump 1**
Choose method from drop down	Method 1
Method 1 - ELECTRICAL USAGE IS KNOWN	
Input pump electrical usage (KWh)	0
Method 2 - PUMP HEAD IS KNOWN	
Input flow rate (gpm)	0
Input total head (ft)	0
Input number of pumps operating	0
Input operating time for each pump (hrs)	0
Pump efficiency (default already present, user override possible)	0.6

SiteWise - Inputs

MIXING EQUIPMENT	Mixer 1
Choose fuel type from drop down menu	Gasoline
Choose horsepower range from drop down menu	1 to 3
Input volume (yd3)	
Input production rate (yd3/hr)	
Input estimated fuel consumption rate (gal/hr) (Input only if known for the mixer selected, otherwise a default will be used by the tool)	

INTERNAL COMBUSTION ENGINES	Engine 1
Choose fuel type from drop down menu	Diesel
Input fuel consumption rate (gal/hr or scf/hr)	
Input operating hours (hr)	

OTHER FUELED EQUIPMENT	Fuel 1
Choose fuel type from drop down menu	Natural gas
Input volume (scf for Natural gas, gallons for all others)	

DIESEL EQUIPMENT OPERATION (PER HOUR BASIS)	Equipment 1
Choose equipment type from drop down menu	Dozer
Choose equipment size for Dozer (HP)	65
Choose equipment size for Loader (HP)	65
Choose equipment size for Excavator (HP)	150
Choose equipment size for Scraper (HP)	330
Choose equipment size for Crawler Crane	Crawler Crane, 25 ton, 1 CY
Choose equipment size for Tillage Tractor (HP)	16
Choose equipment size for Paver (HP)	25
Choose equipment size for Roller (HP)	6
Choose equipment size for Trencher (HP range)	6 to 11
Choose fuel type from drop down menu	Diesel
Input operating hours (hr)	

Pump motor efficiency (default already present, user override possible)	0.85
Input specific gravity (default already present, user override possible)	1
Method 3 - NAME PLATE SPECIFICATIONS ARE KNOWN	
Input pump horsepower (hp)	0
Input number of pumps operating	0
Input operating time for each pump (hrs)	0
Percent of max speed for pump motor (Optional input for variable speed motor)	100%
Pump load if max motor speed draws full nameplate horsepower	1
Input pump load (default already present, user override possible, consider above value)	0.85
Pump motor efficiency (default already present, user override possible)	0.85
Region	
Electricity Region	VT

DIESEL AND GASOLINE PUMPS	Pump 1
Choose fuel type from drop down menu	Gasoline
Choose horsepower range from drop down menu	2-Stroke: 0 to 1
Equipment operating hours (hrs)	
Input estimated fuel consumption rate (gal/hr) (Input only if known for the pump selected, otherwise a default will be used by the tool)	

For each type of equipment, select only one of the methods to calculate energy and GHG emissions
Enter "0" for all user input values for unused equipment columns or unused methods

BLOWER, COMPRESSOR, MIXER, AND OTHER EQUIPMENT	Equipment 1
Choose type of equipment from drop down	Compressor
Choose method from drop down	Method 1
Method 1 - NAME PLATE SPECIFICATIONS ARE KNOWN	
Input equipment horsepower (hp)	5
Input number of equipments operating	1
Input operating time for each equipment (hrs)	17520

SiteWise - Output

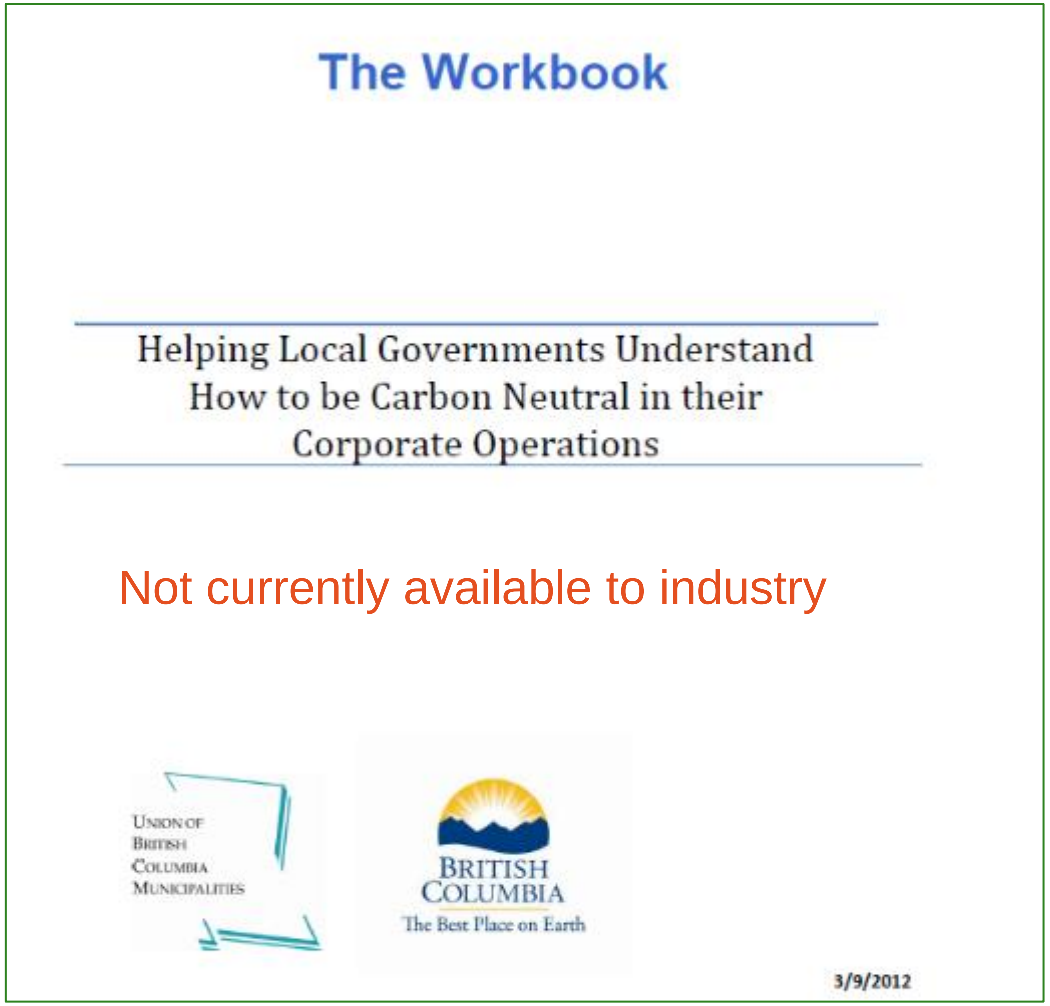
Sustainable Remediation - Environmental Footprint Summary

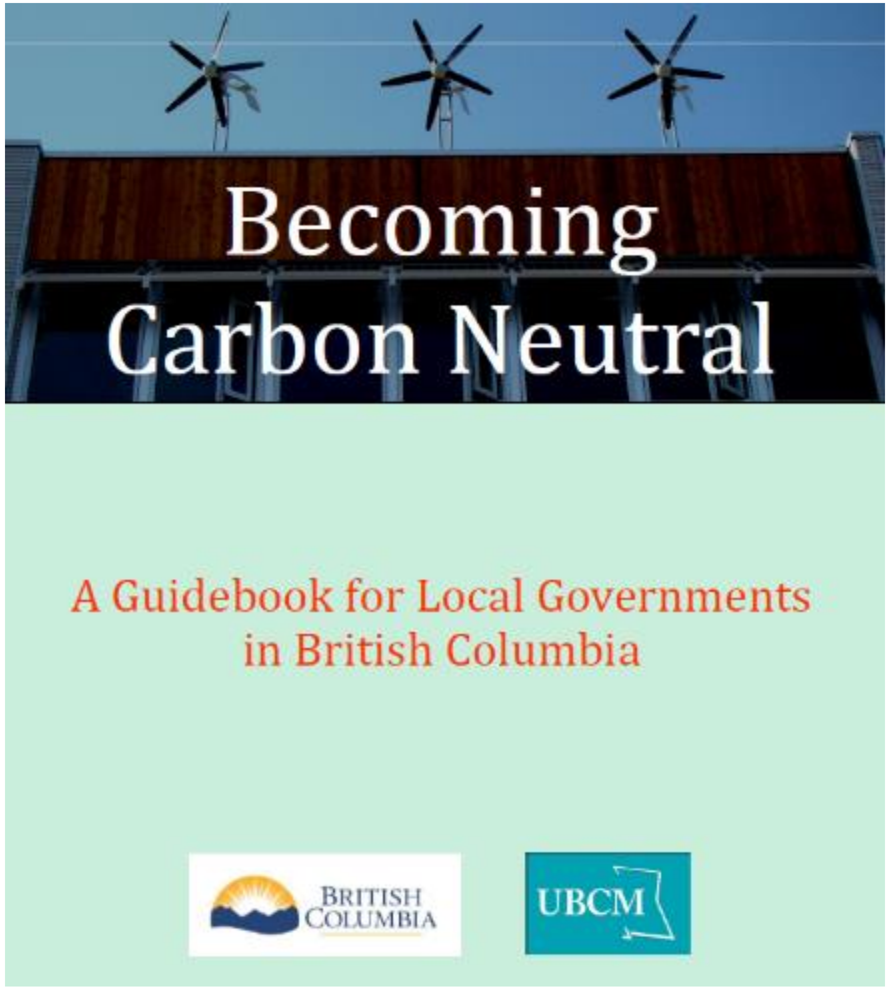
Phase	Activities	GHG Emissions	Total Energy Used	Water Consumption	Electricity Usage	Onsite NOx Emissions	Onsite SOx Emissions	Onsite PM10 Emissions	Total NOx Emissions	Total SOx Emissions
		metric ton	MMBTU	gallons	MWH	metric ton	metric ton	metric ton	metric ton	metric ton
Component 1	Consumables	6.42	5.7E+03	NA	NA	NA	NA	NA	1.3E-02	1.7E-02
	Transportation-Personnel	1.14	1.4E+01	NA	NA	NA	NA	NA	4.2E-04	1.5E-05
	Transportation-Equipment	0.00	0.0E+00	NA	NA	NA	NA	NA	0.0E+00	0.0E+00
	Equipment Use and Misc	18.26	5.5E+02	3.3E+04	6.5E+01	4.3E-03	4.4E-04	3.9E-04	9.3E-02	6.3E-02
	Residual Handling	0.00	0.0E+00	NA	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	25.82	6.29E+03	3.33E+04	6.53E+01	4.30E-03	4.40E-04	3.87E-04	1.06E-01	8.03E-02

For this example large portion of GHG emissions from laboratory analysis – this appears unrealistically high, in GSR Dashboard, values replaced with factors from local laboratory (ALS)

Appendix F – BC Smart Tool

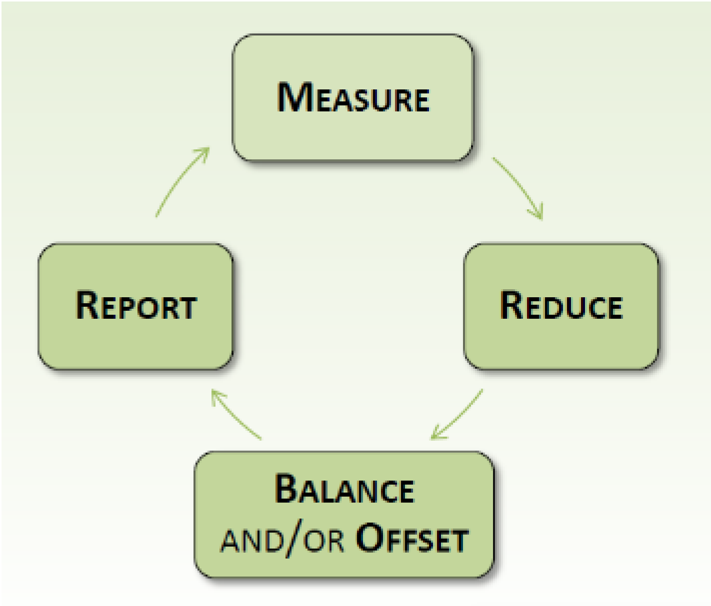
BC SMART Tool





BC SMART Tool

Web based GHG emissions inventory and reporting tool which provides a standardized approach to calculating and reporting an organization's corporate GHG emissions.



1. **Measure** your total corporate GHG emissions,

2. **Reduce** them where possible,

3. **Balance** the remaining emissions through the purchase of carbon offsets and / or through investments in local GHG reduction projects; and

4. **Report** to your public on the actions you have

Considerations for Application of Toolkits within BC Regulatory Framework

CSAP Workshop on Toolkits for Sustainable Remediation of Petroleum Hydrocarbons
May 12, 2022

Linda Kemp
WSP Golder

Outline

APPLICATION OF TOOLKITS WITHIN BC REGULATORY FRAMEWORK

- Provincial targets and legislation status
- Which parts of the BC regulatory framework currently discourages us from selecting more sustainable remedial options?
- Which parts of the BC regulatory framework currently support the selection of more sustainable remedial options?
- Which sections of the Toolkits can help us implement more sustainable remediation options, while meeting regulatory requirements?

Provincial Climate Change Targets

Using 2007 as the baseline, B.C. is committed to greenhouse gas (GHG) reductions of:

- 16% by 2025
- 40% by 2030
- 60% by 2040
- 80% by 2050

Source:
https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action

BRITISH COLUMBIA

BC Ministry of Environment and Climate Change Strategy

"The Land Remediation Section has prepared a discussion paper outlining possible ideas for "Making Contaminated Sites Climate Ready".

The discussion paper will be posted for public comment in Summer/Fall 2022."

Source: CSAP Spring update
https://csapsociety.bc.ca/members/members-updates/

BRITISH COLUMBIA

EGBG Professional Practice Guidelines: Sustainability

"We have a responsibility to the public, consistent with the APEGBC Code of Ethics, to provide sustainable solutions that adhere to the basic pillars of sustainability (environmental, social and economic). This requires that we consider the long-term consequences that flow directly and indirectly from our actions."

Source: https://www.egbc.ca/getmedia/3686f97d-f6cf-41a1-9ca2-b99f298f15cf/APEGBC-Sustainability-Guidelines.pdf.aspx

ENGINEERS & GEOSCIENTISTS BRITISH COLUMBIA

BC Contaminated Sites Framework

SECTIONS THAT CAN DISCOURAGE SUSTAINABLE REMEDIATION

Environmental Management Act (EMA) (Part 4: Line 56):

*"A person conducting or otherwise providing for remediation of a site **must give preference to remediation alternatives that provide permanent solutions to the maximum extent practicable**, taking into account the following factors: …"*

BC Contaminated Sites Framework

PARTS THAT CAN DISCOURAGE SUSTAINABLE REMEDIATION

Protocol 1 of Contaminated Sites Regulation (CSR) – Detailed Risk Assessment

"*Risk assessment is generally intended to address residual contamination on a contaminated site.* ***Risk based remediation that does not provide a permanent solution to contamination should only be use where alternatives that provide permanent solutions are not practicable***"

BC Contaminated Sites Framework

PARTS THAT ENCOURAGE SUSTAINABLE REMEDIATION

Acts and Sections in Progress:

ENVIRONMENTAL MANAGEMENT ACT

[SBC 2003] CHAPTER 53

Part 6.1 — Greenhouse Gas Reduction

Division 1

(Current status: Not in force - Repealed)

CLIMATE CHANGE ACCOUNTABILITY ACT

[SBC 2007] CHAPTER 42

(Current status: Many sections repealed)

BC Contaminated Sites Framework

PARTS THAT ENCOURAGE SUSTAINABLE REMEDIATION

EMA (Part: Line 53):

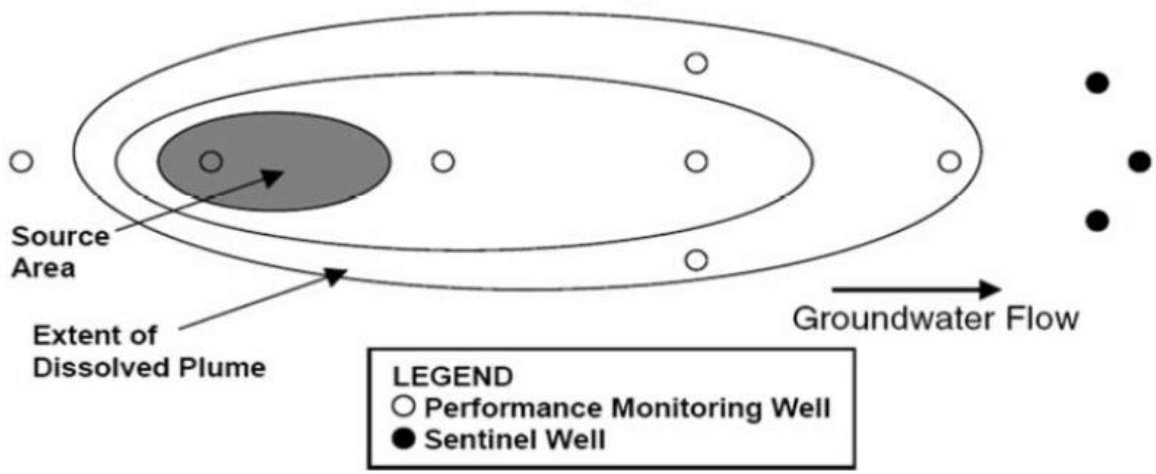
*"A director, in accordance with the regulations, **may issue a certificate of compliance with respect to remediation of a contaminated site** if (a) the contaminated site has been remediated in accordance with (i) the numerical **or risk based standards** prescribed for the purposes of the definition of "contaminated site",*

BC Contaminated Sites Framework

PARTS THAT ENCOURAGE SUSTAINABLE REMEDIATION

Key Requirements for Risk Based Certificates of Compliance:

- “*The DSI must assert… …that the contamination that is present at a site is **stable** or decreasing in concentration and extent*.” (CSR Protocol 1 – Detailed Risk Assessments)
- Certificate to be supported by a Performance Verification Plan (PVP) (Administrative Guidance 14)



BC Contaminated Sites Framework

PARTS THAT ENCOURAGE SUSTAINABLE REMEDIATION

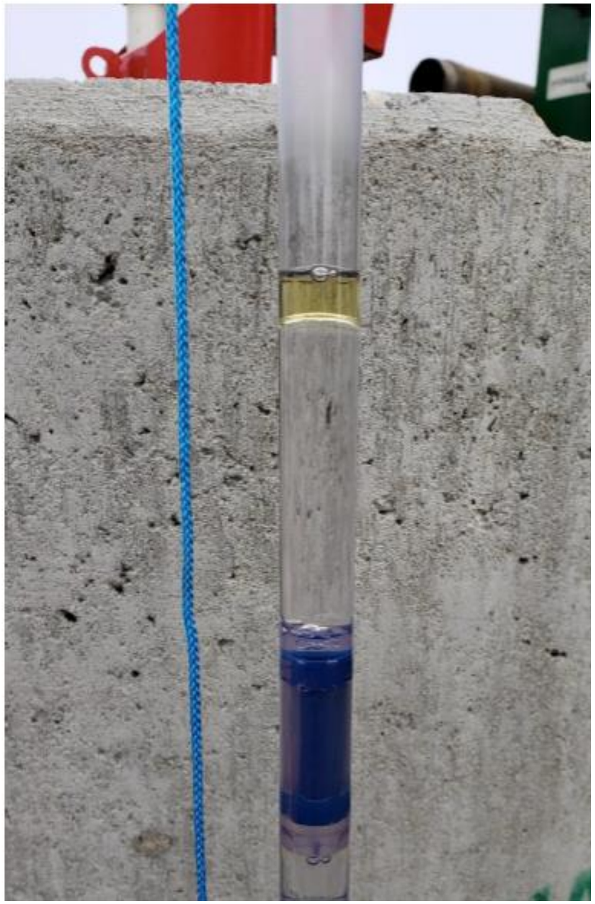
CSR Protocol 16 (NAPL Mobility):

"Mobile NAPL sources have the potential to migrate… until any of the following conditions is met:

a) …

b) …

c) <u>Multiple lines of evidence evaluation showing reduced potential for NAPL migration following current science-based approaches</u>"



BC Contaminated Sites Framework

PARTS THAT ENCOURAGE SUSTAINABLE REMEDIATION

Biodegradation under the CSR:

- (DRAFT) Technical Guidance 22 – Using MNA and Enhanced Attenuation
- Protocol 22 – Soil Vapour Attenuation Factors (biodegradation attenuation adjustment divisor (BAAD) - 10x reduction)
- Protocol 13 and Technical Guidance 13 – Screening Level Risk Assessment and Groundwater Protection Model (biodegradation rates)
- Protocol 15 and Technical Guidance 14 – Soil Treatment Facilities using biodegradation

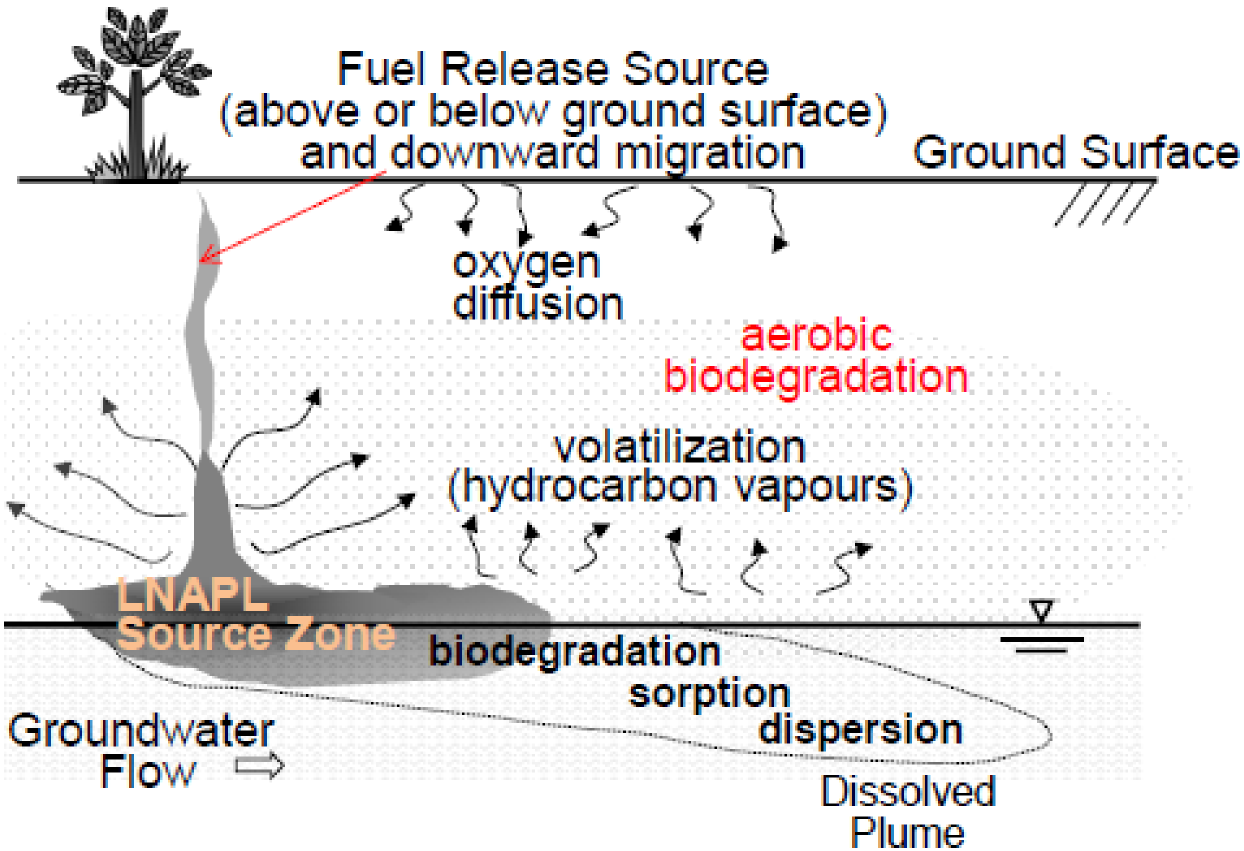
BC Contaminated Sites Framework

USE OF TOOLKITS FOR FINDING A BALANCE

Key concepts in BC CSR:

- **Stable Plume / Stable LNAPL**
- **Permanence of Remediation**
- **Remediation to the extent practicable**

Can be risk-based



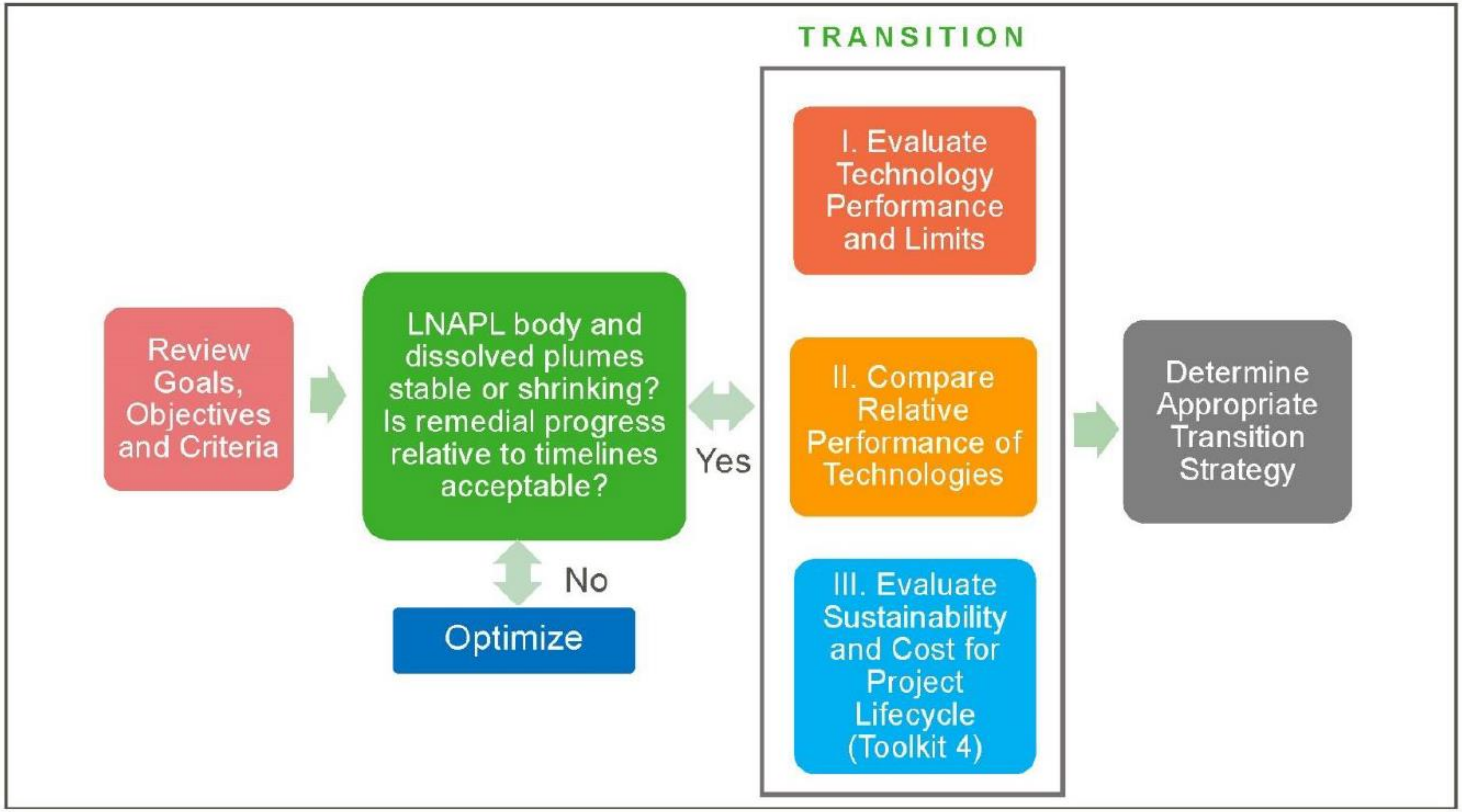
BC Contaminated Sites Framework

USE OF TOOLKITS FOR FINDING A BALANCE

- **Plume stability and discussion on statistical methods (Toolkit #2)**
- **Measurements for Estimates of NSZD (Toolkit #2)**
- **Science based approach to LNAPL Mobility (Toolkit #3)**
- **LNAPL specific remedial options analysis guidance (Toolkits #3)**

BC Contaminated Sites Framework

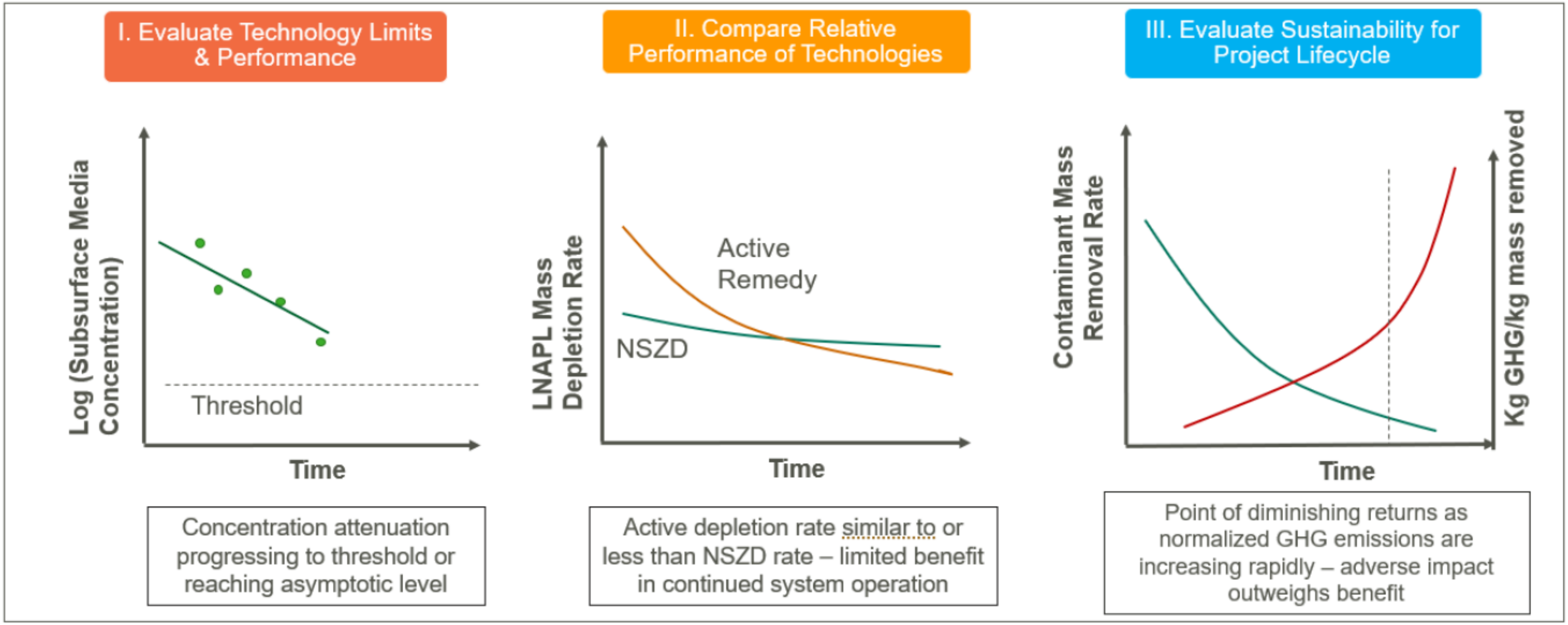
USE OF TOOLKITS FOR FINDING A BALANCE



TRANSITION FRAMEWORK (Toolkit 3)

BC Contaminated Sites Framework

USE OF TOOLKITS FOR FINDING A BALANCE



EXAMPLE TRANSITION THRESHOLDS (Toolkit 3)

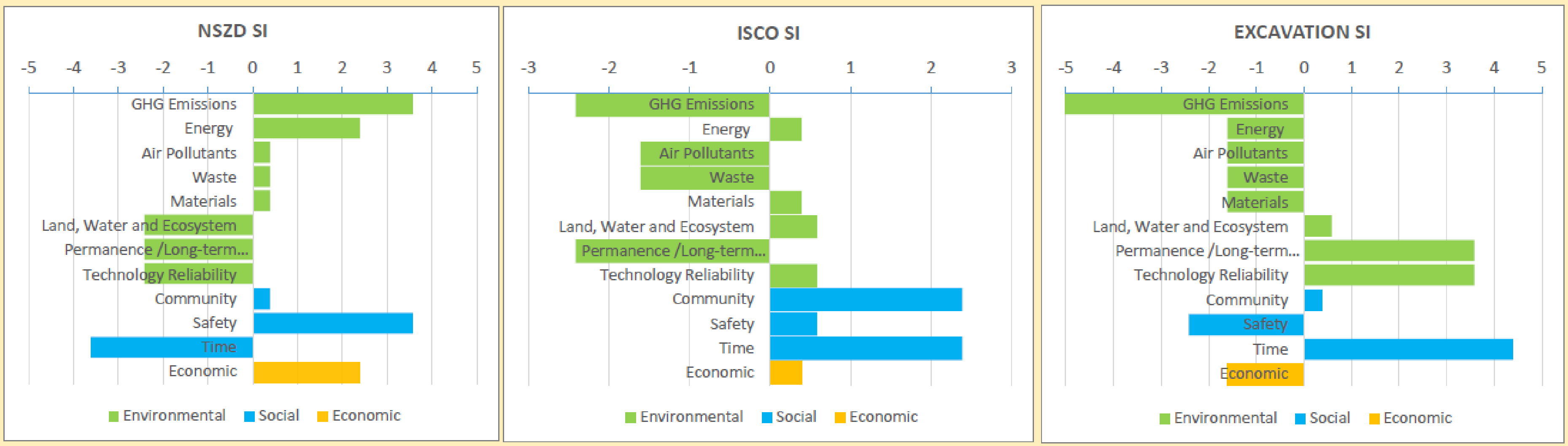
WSP GOLDER

BC Contaminated Sites Framework

USE OF TOOLKITS FOR FINDING A BALANCE

DRAFT SR DASHBOARD (*V1.1*)

SENSITIVITY INDEX (NORMALIZED TO MEAN SCORE ALL OPTIONS)

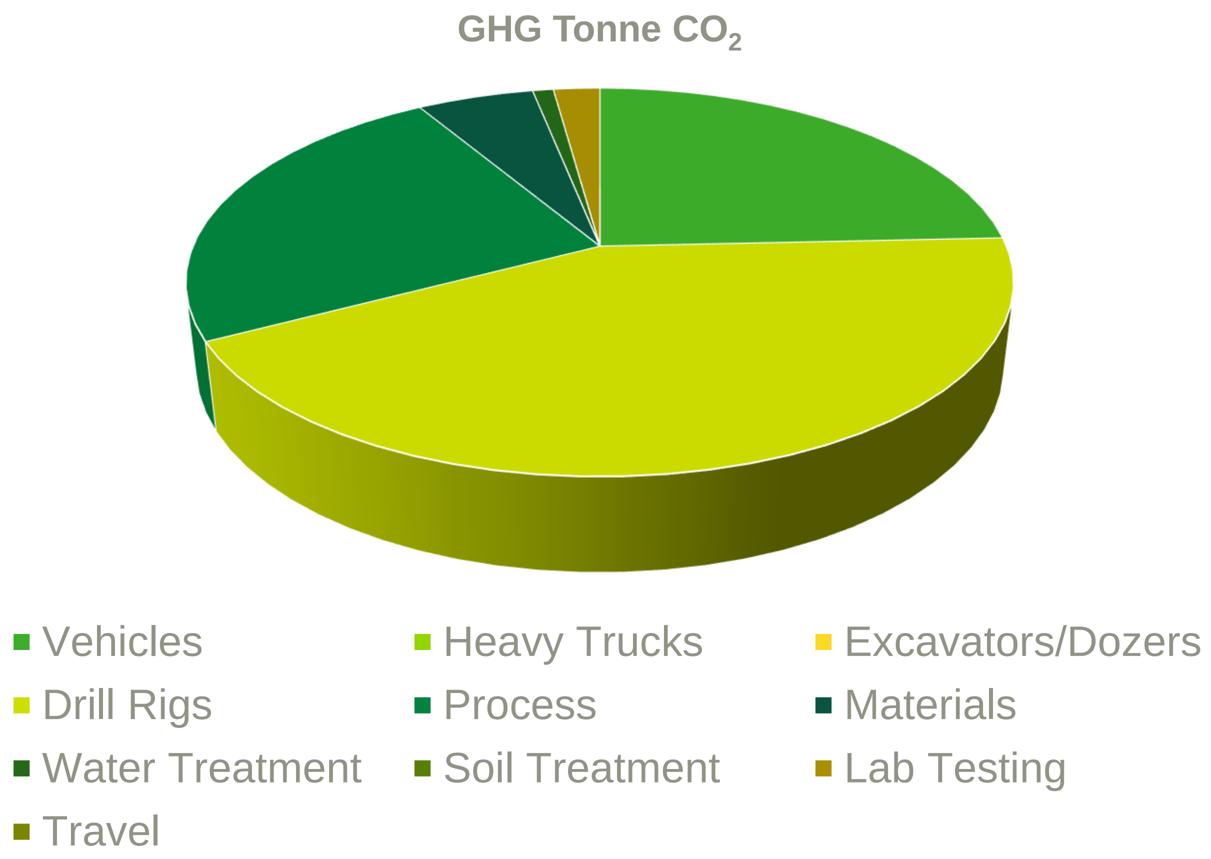


SI = Sensitivity Index	SI = Sensitivity Index	SI = Sensitivity Index
SI = (Score - Average Score) x Weight	SI = (Score - Average Score) x Weight	SI = (Score - Average Score) x Weight
Average Score of all indicators	Average Score of all indicators	Average Score of all indicators

SUSTAINABLE REMEDIATION DASHBOARD AND USE OF OTHER MULTI-CRITERIA ANALYSIS TOOLS (Toolkit 4)

BC Contaminated Sites Framework

USE OF TOOLKITS FOR FINDING A BALANCE



SUSTAINABLE REMEDIATION DASHBOARD (Toolkit 4)

Toolkit #	Key Info in Relation to BC Regulatory Framework	Related Regulations / Guidance
Toolkit 1	Conceptual site models and case studies on the use on MNA and NSZD	(DRAFT) TG-22: Monitored Natural Attenuation TG-11: DSI checklist
Toolkit 2	Technical support for conceptual site models, plume stability and MNA/NSZD demonstration and modelling	(DRAFT) TG-22: Monitored Natural Attenuation TG-8: Plume stability Protocol 1: Detailed Risk Assessment Protocol 13 and TG 13: Screening Level Risk Assessment and Groundwater Protection Model
Toolkit 3	LNAPL conceptual site models and mobility evaluations; technical remedial options selection for LNAPL sites with focus on treatment train strategy (transition from active to passive remediation); performance metrics.	EMA (Section 56): Remedial Options AG-14: Performance Verification Plans Protocol 16: NAPL Mobility CSR (Part 6): Remediation Standards (Numeric or Risk Based)
Toolkit 4	Incorporation of sustainability into projects and into remedial options analysis. Use of multi-criteria analysis (MCA) tools and carbon footprint analysis to document and provide rationale for selection of more sustainable remedial options.	CSR (Part 6): Remedial Options EMA (Section 56): Remedial Options EMA (Part 6.1): Greenhouse Gas Reduction (not currently in force) EGBC Sustainability Guidelines

THANK YOU FOR ATTENDING