REPORT

TOOLKIT#4 – METHODS FOR SUSTAINABLE REMEDIATION

Remediation Toolkits Project

Submitted to:

Contaminated Sites Approved Professional Society of British Columbia & Shell Global Solutions

Submitted by:

Golder Associates Ltd.

Suite 200 - 2920 Virtual Way, Vancouver, British Columbia, V5M 0C4, Canada

+1 604 296 4200

1417511-007-R-Rev1

6 April 2021

Acknowledgement

The funding for this project was provided by the Contaminated Sites Approved Professional Society of British Columbia and Shell Global Solutions US Inc.

The primary authors of Toolkit #4 were Dr. Ian Hers of Hers Environmental Consulting, Inc., Dr. Parisa Jourabchi of ARIS Environmental Ltd., and Mr. Francois Beaudoin of GHD Consultants Ltd. Ms. Linda Kemp and Mr. Sylvain Hains of Golder Associates Ltd. also contributed to the document.

The review and input provided by Dr. Matthew Lahvis, of Shell Global Solutions US Inc., and Mr. Guy Patrick, of Patrick Consulting, Inc. representing CSAP is gratefully acknowledged.

Disclaimer

This report provides a scientific review and guidance on sustainable remediation of petroleum hydrocarbon contaminated sites by Golder Associates Ltd. (Golder) for the Contaminated Sites Approved Professional (CSAP) Society of British Columbia in BC and Shell Global Solutions US Inc. Any use that a third party may make of this report, or any reliance on or decisions made based on it, are the sole responsibility of the third parties. Golder disclaim responsibility and consequential financial effects on site management, and/or requirements for follow-up actions and costs as a result of decisions or actions taken, based on this report. This report should not be construed to represent BC Ministry of Environment and Climate Change policy.

The services performed as described in this report were conducted in a manner consistent with the level of care and skill normally exercised by other members of the science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services. This report provides professional opinions and, therefore, no warranty is expressed, implied, or made as to the findings, conclusions, advice, and recommendations offered in this report. This report does not provide a legal opinion regarding compliance with applicable laws or regulations.

Executive Summary

Toolkit #4 - “Methods for Sustainable Remediation” comprises the fourth of a four-volume set of toolkits developed to provide guidance and improved decision-making for practitioners who are involved with the investigation and remediation of petroleum hydrocarbon contaminated sites. The framework and tools in the toolkits are intended to lead to better, more technically-defensible decisions for evaluation of remedial options and sustainable remediation.

The four toolkits in the series are as follows[1]:

- Toolkit #1: Conceptual Site Model (CSM) and Case Studies (Golder, 2016)
- Toolkit #2: Methods for Monitoring and Prediction of NSZD and MNA (Golder, 2016)
- Toolkit #3: Evaluation of Remediation Technologies for Petroleum Hydrocarbon Sites (Golder, 2021)
- Toolkit #4: Methods for Sustainable Remediation (this report)

Similar to other industry sectors, an important challenge facing the environmental remediation industry is how to integrate the principles of sustainable development into remedial decision-making. These principles are often summarized within the concept of the triple bottom line (or three pillars of sustainability), which encompass environmental, social and economic factors. An emerging consideration is incorporation of climate change and increased climate risk events in the remediation life cycle, which is leading to the integration of sustainability and resilience of remedies to climate change and the concept of sustainable resilient remediation. To focus the remedial options evaluation process, a framework is described in Toolkit #3 that enables selection of a short-list of technologies (e.g., typically up to four) based on site-specific considerations and remedial objectives for a site. Toolkit #4 addresses the added dimension of sustainability when assessing remedial options.

Practitioners are routinely challenged to decide on the “best” approach to achieve remedial objectives. Choosing among the feasible methods often involves the need to examine and incorporate trade-offs, which can be aided by a well-defined decision framework. Since the early 2000s, a new paradigm has appeared in the field of site clean-up, one which can both provide a comprehensive framework for addressing trade-offs, and a means to achieve maximum value, or net benefit, with regards to the triple bottom line: sustainable remediation (SR) (Figure ES-1). SR has historically been variably defined, but there is generally considered to be consensus about its broad purpose – to reduce impacts and maximize the long-term benefits of remediation projects and ensure an overall net benefit in relation to environmental, social and economic factors. ISO 18504 now provides a standardized definition of SR. The US EPA’s Green Remediation program seeks similar objectives but with a greater focus on environmental net benefit, and lesser focus on social and economic aspects. Greenhouse gas emissions and climate change are issues that are now recognized as fundamental to societal health and welfare and are integral to evaluations of SR. The recent guidance, standards, technical publications and other resources from government agencies, industry, societies, industry and forums summarized in the toolkit provide a useful and extensive knowledge base on guiding principles and sustainability frameworks on which to build from.

[1] Remediation Toolkits 1 and 2 are available at https://csapsociety.bc.ca/members/professional-development/technical-studies/

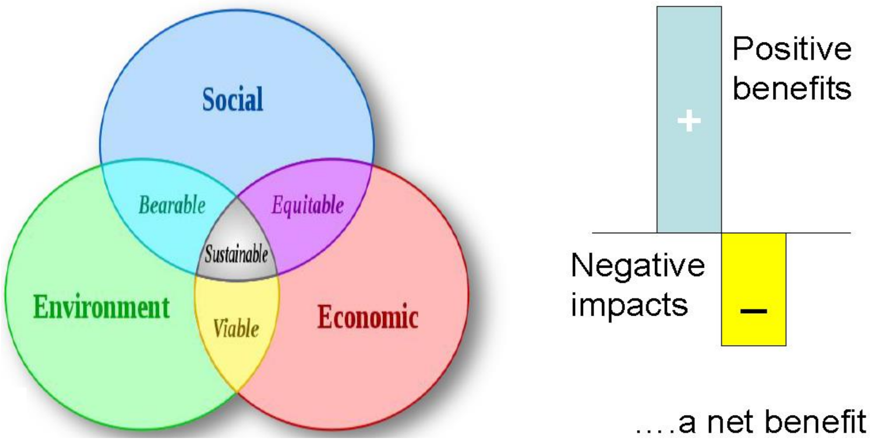


Figure ES-1: Illustrative Representation of SR, from the SuRF-UK Framework (CL:AIRE, 2010)

There is a range of methods and tools that are increasingly being incorporated in site remediation processes to achieve a more sustainable outcome or to increase the net environmental benefit of a project. The methods and tools discussed in this toolkit are best management practices (BMPs), also referred to as sustainable management practices (SMPs), footprint analysis, which incorporates life cycle analysis (LCA) and environmental footprint analysis (EFA) and multi-criteria analysis (MCA). Other tools, such as cost-benefit assessment (CBA), can be used to compare sustainability, but are not described in detail in this report.

Based on the frameworks presented, a Roadmap is described for implementing a successful SR project. Success is defined as the achievement of tangible and measurable benefits in all three spheres of sustainability and is captured in the following five steps:

I. Evaluate/update conceptual site model (CSM)

II. Establish goals

III. Stakeholder involvement

IV. Select indicators and SR evaluation method and tools

V. Record SR efforts

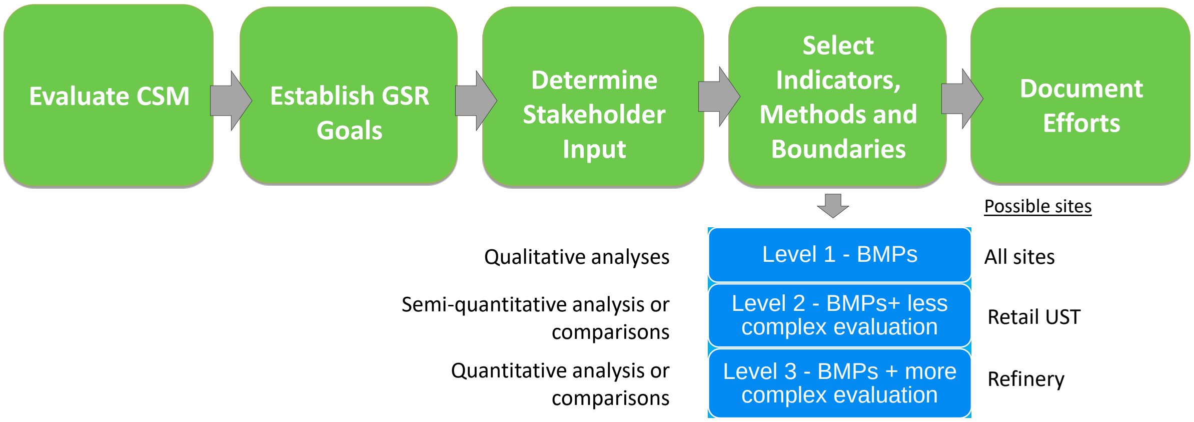


Figure ES-2: Toolkit Roadmap for Conducting Evaluation of SR

A key component of the Roadmap is to select indicators and the SR evaluation method and tools. Guidance on selection of indictors, methods and tools is provided within a tiered framework. Using the ITRC Green and Sustainable Remediation guidance as a model, a project should be evaluated from the lens of SMPs and process improvements to enable a more sustainable solution to be identified (Level 1). Select projects will warrant a Level 2 evaluation, which may consist of a relatively simple EFA and/or MCA where the three dimensions of sustainability are qualitatively evaluated, or a Level 3 evaluation where an in depth EFA and LCA is conducted and/or a quantitative MCA is performed. The toolkit illustrates how sustainability assessment tools, such as MCA, can be used to support practitioners in finding optimal solutions (those which achieve maximum net benefit with regards to project objectives) and provides guidance on how to assess the environmental footprint of remedial activities and measures that can be taken to reduce the footprint. Whether a Level 2 or 3 analysis is performed, it is important to select relevant and applicable indictors and conduct options comparisons that are bounded by similar constraints with respect to time (project phase), space (definition of site) and technology (best available or other criteria). Additionally, the Roadmap includes a framework for assessing climate change-induced impacts on remedy vulnerability and resilience.

Existing available tools and a new tool developed for this project, the SR Dashboard tool, are described. The SR Dashboard includes an Impact Summary Tool; an Environmental Footprinter Tool, which addresses energy use, GHG emissions and air pollutant emissions; and a MCA Tool, where different options may be evaluated based on select indicators and the multiple dimensions of sustainability. The tool is flexible, transparent, easy to use and provides a framework for comparing remedial options that includes BC-specific defaults where applicable. Case studies are presented illustrating the application of the Roadmap and comparison of options based on EFA and MCA concepts and tools.

By providing clarity on what is SR, how to implement it, and the benefits that can be gained by using such an approach, this toolkit aims to eliminate common barriers to adoption of SR practices. Practitioners will find methodologies and approaches they need in order to adapt the proposed Roadmap to their needs and objectives, and to reinforce the business case for integrating sustainability principles into their contaminated site management processes.

Glossary

ASTM	American Society for Testing and Materials
BMP	Best Management Practice
CBA	Cost Benefit Analysis
CEPA	Canadian Environmental Protection Act
CFA	Carbon Footprint Analysis
EFA	Environmental Footprint Analysis
FCSAP	Federal Contaminated Sites Action Plan
GHG	Greenhouse Gas
GSR	Green and Sustainable Remediation
HAZOP	Hazard and Operability Assessment
ISCO	In situ Chemical Oxidation
ISRA	International Sustainable Remediation Alliance
ITRC	Interstate Technology and Regulatory Council
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
MCA	Multi-criteria analysis
MNA	Monitored natural attenuation
NSZD	Natural source zone depletion
NEBA	Net Environmental Benefit Analysis
NICOLE	Network for Industrially Contaminated Land in Europe
SDAT	Sustainable Development Analysis Tool
SMP	Sustainable Management Practice
SWOT	Strength and Weakness, Opportunity and Threat
SuRF	Sustainable Remediation Forum
SDAT	Sustainable Development Analysis Tool
SR	Sustainable Remediation
SRR	Sustainable Resilient Remediation
VOC	volatile organic compound

Table of Contents

1.0 INTRODUCTION 1

2.0 CONCEPTS AND PRINCIPLES 4

3.0 REVIEW OF SELECT GUIDANCE 6

3.1 Sustainable Remediation Forum 6

3.2 SuRF-UK Sustainable Remediation Framework and Guidance 6

3.3 ITRC Green and Sustainable Remediation Guidance 9

3.4 US EPA Green Remediation Primer 11

3.5 Canadian Federal Government 12

3.6 ISO (2017) Standard 14

4.0 SR METHODS AND TOOLS 15

4.1 Best Management Practices 15

4.2 Footprint Analysis 17

4.2.1 Life Cycle Analysis 19

4.2.2 Carbon Footprint Analysis 20

4.3 Multi-Criteria Analysis 23

5.0 ROADMAP 27

I. Evaluate/Update Conceptual Site Model 28

II. Establish Goals 29

III. Stakeholder Involvement 29

IV. Select Indicators and SR Evaluation Method and Conduct Evaluation 30

V. Record SR Efforts – Monitoring and Evaluation of Key Sustainability Indicators 35

6.0 CASE STUDIES AND TOOLS 37

6.1 Case Study #1 - Train Derailment 37

6.2 Case Study #2 - Tank Farm Diesel Spill 41

6.3 SR Dashboard 46

6.3.1 Environmental Footprinter Tool 47

6.3.1.1 Description of the Tool 47
6.3.1.2 Example Calculations 48
6.3.2 Impact Tool 49
6.3.3 MCA Tool 50
6.3.4 Example use of SR Dashboard 50
6.3.5 Reduction of Carbon Footprint 53
7.0 SUMMARY 54
8.0 REFERENCES 55

TABLES

Table 1: Categories of Indicators for Sustainability Assessments Recommended by SuRF-UK (CL:AIRE 2011) 8
Table 2: Sustainable Remediation Practices and Objectives in ITRC Green and Sustainable Remediation Guidance (from ITRC 2011) 10
Table 3: Three-step Assessment Process for Incorporating Climate Change in Sustainable Resilient Remediation 35
Table 4: Indicator Selection for Case Study #1 38
Table 5: Indicator Selection for Case Study #2 42

FIGURES

Figure ES-1: Illustrative Representation of SR, from the SuRF-UK Framework (CL:AIRE, 2010) iii

Figure ES-2: Toolkit Roadmap for Conducting Evaluation of SR... iv

Figure 1: Illustrative Representations of Sustainable Remediation, from the SuRF-UK Framework (CL:AIRE, 2010) 7

Figure 2: Core Elements of Green Remediation from US EPA (2008) 11

Figure 3: Six Phases of Sustainability Evaluation using SDAT...13

Figure 4: Site Investigation and Remediation Phases where Best Management Practices (BMPs) can be Applied 16

Figure 5: BMP Implementation Steps from ASTM E2876 – 13...16

Figure 6: Project Lifecycle with Recommended Quantitative Evaluations (Modified from ASTM E2893-16)........21

Figure 7: Examples of On-site and Off-site Inputs 22

Figure 8: Example of Visual Representation of Detailed MCA Results..26

Figure 9: SR Roadmap Structure 27

Figure 10: Impact of Variable Based on Project Time (adapted from PMI 2017)..28

Figure 11: Example of Qualitative Options Analysis (total score % is total divided by sum of scores for options)...32

Figure 12: Example of Simplified MCA...33

Figure 13: Example Project Performance Dashboard..36

Figure 14: Example output from GoldSET-SR tool showing ternary diagrams indicating performance of each option for Case Study #1...39

Figure 15A: Example Output from GoldSET-SR tool Showing CO2 Emissions for Four Remedial Options for Case Study #1...43

Figure 15B: Example Output from GoldSET-SR Tool Showing Remediation Costs for Four Remedial Options for Case Study #1 44

Figure 15C: Example Output from GoldSET-SR Tool Showing Duration of Work and Employment Potential for Four Remedial Options for Case Study #1 44

Figure 16: Example Output from GoldSET-SR Tool Showing Ternary Diagrams Indicating Performance of Each Option for Case Study #1...45

Figure 17: Screen Shot of SR Dashboard Impact Tool...50

Figure 18A: Screen Shot of SR Dashboard Impact Tool Graphics 51

Figure 18B: Screen Shot of SR Dashboard MCA Tool 52

APPENDICES

APPENDIX A
Best Management Practices to Improve Sustainability of Remediation Technologies

APPENDIX B
SiteWise™, Goldset, DOD Green and Sustainable Remediation Tools

APPENDIX C
Accident Statistics

APPENDIX D
SR Dashboard Example

APPENDIX E
Measures to Reduce Carbon Footprint of Remediation

1.0 INTRODUCTION

"Toolkit #4 - Methods for Sustainable Remediation" comprises the fourth of a four-volume set of toolkits developed to provide guidance and improved decision-making for practitioners who are involved with the investigation and remediation of petroleum hydrocarbon contaminated sites (herein referred to as the "Remediation Toolkits"). The toolkits have been developed to provide both technical background and a science-based practical means to evaluate natural source zone depletion (NSZD), monitored natural attenuation (MNA) and remediation of light non-aqueous phase liquid (LNAPL) source zones and associated plumes. The four toolkits in the series are as follows:

- Toolkit #1: Conceptual Site Model (CSM) and Case Studies (Golder, 2016)
- Toolkit #2: Methods for Monitoring and Prediction of NSZD and MNA (Golder, 2016)
- Toolkit #3: Evaluation of Remediation Technologies for Petroleum Hydrocarbon Sites (Golder, 2021)
- Toolkit #4: Methods for Sustainable Remediation (this report)

The approaches and methods presented in these toolkits have been selected and configured to answer the following key questions that commonly present themselves at a petroleum hydrocarbon contaminated site:

1) Is the hydrocarbon groundwater plume expanding, stable or shrinking, and what attenuation processes are occurring?
2) Approximately how long will it take for the source zone to deplete with or without active intervention?
3) Approximately how far is the hydrocarbon groundwater plume expected to migrate?
4) What are the options for petroleum hydrocarbon remediation and, potentially, how effective and sustainable are these measures?
5) What are appropriate monitoring strategies to support the prediction and verification of natural and enhanced attenuation of the plume?

Similar to other industry sectors, an important challenge facing the environmental remediation industry is how to integrate the principles of sustainable development into remedial decision-making. These principles are often summarized within the concept of the triple bottom line, which encompass, social and economic factors. A practical, first step to make a project more sustainable is the adoption of best management practices for remediation. Project proponents can go a step further by integrating sustainability indicators into their planning and decision-making processes.

As described in Toolkit #3, there exists a wide range of remediation technologies and methods to address petroleum hydrocarbon contaminated sites. To focus the remedial options evaluation process, a framework is described in Toolkit #3 that enables selection of a short-list of technologies (e.g., typically up to four) based on site-specific considerations and remedial objectives for a site. Toolkit #4 addresses the added dimension of sustainability when assessing remedial options.

Practitioners are routinely challenged to decide on the "best" approach to achieve remedial objectives. Choosing among the feasible methods often involves the need to examine and incorporate trade-offs, which can be aided by a well-defined decision framework. Since the early 2000s, a new paradigm has appeared in the field of site clean-up, one which can both provide a comprehensive framework for addressing trade-offs, and a means to achieve maximum value, or net benefit, with regards to the triple bottom line: sustainable remediation (SR). The US EPA's Green Remediation program seeks similar objectives but with a greater focus on environmental net benefit, and lesser focus on social and economic aspects.

Conventional remediation has often focused on removal of contaminants to meet regulatory guidelines or to achieve conditions of current acceptable risk to human or ecological receptors. The paradigm shift with SR is the consideration of the impact of the remedial effort itself on human and ecological receptors, both negatively and positively (Harclerode et al. 2015). SR can add value through its proposition that remediation should not only aim to eliminate negative impacts, but also to generate positive impacts in a wider context of proactive land management and reuse. This is important because, in addition to clean air and water, clean land is the first building block of a strong community and vibrant ecosystem and, as such, any effort to reclaim contaminated lands should consider the interrelations between these elements. Likewise, greenhouse gas emissions and climate change are issues that are now recognized as fundamental to societal health and welfare and are integral to SR evaluations.

There is growing evidence that climate change and increasing extreme weather events will critically affect the performance of infrastructure, including contamination remediation and risk management measures intended to protect human and ecological health (US EPA 2015; Maco et al. 2018; BC ENV 2019; Jourabchi and Muppidi 2019; Kumar and Reddy 2020). To be effectively sustainable, a remedy must maintain its intended functionality throughout the duration of the design life, in essence, it must be resilient to extreme events and changing conditions. Consequently, there is increasing recognition of the interconnectedness between sustainability and remedy resilience. For this reason, guidance is being developed for "sustainable resilient remediation" that incorporates the concepts of the triple bottom line, considers positive and negative benefits of remediation, and the need for remedies that are resilient and adaptive in the face of increasing extreme weather events and wildfires (ITRC 2021).

This toolkit addresses the following:

- Presents an overview of SR concepts and principles that should be considered when developing a more sustainable approach to contaminated site remediation.
- Defines a practical approach to remedial technology selection within a sustainable framework (a "roadmap").
- Proposes SR tools and indicators, with supporting guidance on their selection and use.
- Illustrates how sustainability assessment tools, such as multi-criteria analysis (MCA), can be used to support practitioners in finding optimal solutions (those which achieve maximum net benefit with regards to project objectives).
- Provides guidance on how to assess the environmental footprint of remedial activities and measures that can be taken to reduce the footprint.
- Provides methods for project performance monitoring within the developed framework.

This toolkit also aims to address common obstacles to use and implementation of SR. These have been highlighted in different surveys conducted within the remediation community (Ellis and Hadley 2009; Hou et al. 2016) and include:

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

By providing clarity on what is SR, how to implement it, and the benefits that can be gained by using such an approach, this toolkit aims to eliminate common barriers to the adoption of SR practices. Practitioners will find methodologies and approaches they need in order to adapt the proposed roadmap to their needs and objectives, and to reinforce the business case for integrating sustainability principles into their contaminated site management processes.

The organization of this toolkit is summarized as follows:

Section 2.0 is designed to provide a clear understanding of the key concepts and principles necessary in order to adopt SR approaches.

Section 3.0 presents an overview of available guidance that is most frequently used around the globe. This section is important because Toolkit #4 does not aim to reinvent the wheel, but rather to build on recognized literature which has been tried and tested, and which has resulted from collaboration among regulators, academia and industry, all of whom provide important perspectives on sustainable remediation.

Section 4.0 describes the main methods and tools used to integrate sustainability principles into remediation projects. Remediation practitioners will need several, if not all, of these methods and tools to successfully “operationalize” sustainability, allowing them to move from principle to practice.

Section 5.0 presents the roadmap (the “Roadmap”) to the implementation of SR. This Roadmap contains all the key steps necessary to achieve tangible results from a SR approach, but remains flexible and adaptive to reflect the varying drivers and limitations of each project.

Section 6.0 presents two case studies on the implementation of SR for evaluation of remediation technologies for contaminated lands.

2.0 CONCEPTS AND PRINCIPLES

Sustainable remediation has been variably defined, but there is general consensus about its broad purpose – to reduce impacts and maximize the long-term benefits of remediation projects, and ensure an overall net benefit for biophysical, social and economic realms (Cundy et al. 2013).

The ISO 18504:2017 standard (ISO 2017) defines sustainable remediation as the elimination and/or control of unacceptable risks in a safe and timely manner while optimizing the environmental, social, and economic value of the work. We consider this definition as being useful as it combines concepts of risk, safety and the three pillars of sustainability. Sustainable remediation considers the environmental, social and economic impacts of a project to achieve an optimal outcome, while being protective of human and environmental health, both at a local level and for the larger community (SuRF Canada 2014). Smith (2019), following ISO (2017) and historical experience, addresses or debunks myths for sustainable remediation with the aim of improving future sustainable remediation. In the best examples, significant improvements in project sustainability have been delivered, including concurrent reduction of the environmental footprint of the remediation program, improved social performance, and cost savings and/or value creation.

US EPA (2008) largely focuses on the environmental component of sustainable remediation by defining green remediation, which is the practice of considering all environmental effects of remedy implementation and incorporating options to maximize the net environmental benefit of cleanup actions.

Literature on SR worldwide often illustrates the concept of SR by presenting its core elements, which are linked to overarching elements of sustainable development:

- 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

Corporate sustainability objectives are often centered on the above core elements. Other main SR themes found in guidance worldwide from various groups such as the Sustainable Remediation Forum (SuRF-UK, SuRF-US, SuRF-Italy, SuRF-NL), Interstate Technology and Regulatory Council (ITRC), American Society for Testing and Materials (ASTM), International Organization for Standardization (ISO), Network for Industrially Contaminated Land in Europe (NICOLE) include the following (Rizzo et al. 2016; Ridsdale and Noble 2016):

- Balanced decision-making process
- Optimizing benefits
- Three pillars of sustainability (environment, economy, society)

- Stakeholder involvement
- Sustainability assessment
- Long term vision
- Sound science
- Project life cycle and life cycle analysis
- Risk-based approach
- Sustainable decisions early in the process
- Future land use
- Tiered approach
- Best Management Practices (BMPs) or Sustainable Management Practices (SMPs)
- Total cost approach
- Non-technical risk management
- Intra- and inter-generational equity
- Participatory by design
- Record keeping and transparent reporting
- Safe working practices
- Social justice
- Net Environmental Benefit Analysis (NEBA)

The above themes are defined in the literature referenced in this toolkit. Practitioners are encouraged to read about those themes that are relevant to the context in which they are applied. The list is not meant as a check-list to verify the sustainability of a remediation approach, but rather should serve as a set of reference points to inform objectives to be achieved through SR. That being said there are a few key elements which are dissociable from a SR approach. Defining benefits based on relevant criteria and then maximizing benefits is necessary to achieve an optimal outcome. The common thread behind all SR approaches, regardless of the drivers and motivations of their proponents, or of the main principles chosen to guide their implementation, is the consideration of the overall impacts of the remediation effort. At a minimum one should examine the environmental footprint of the project; the socio-economic footprint should also be considered whenever possible.

For this document, the term SR is used consistent with the definition in ISO (2017). Historically, the term green and sustainable remediation has also been used, but since sustainable remediation incorporates all the elements considered in green remediation, SR is considered a more appropriate term to use.

3.0 REVIEW OF SELECT GUIDANCE

Key guidance from several jurisdictions is reviewed including: an overview of Sustainable Remediation Forum (SuRF) initiatives, the SuRF-UK SR Framework and guidance, ITRC Green and Sustainable Remediation Guidance, the US EPA Green Remediation Primer and Canadian Federal programs and ISO Standard.

3.1 Sustainable Remediation Forum

Sustainable Remediation Forum (SuRF) is a voluntary non-governmental organization comprising stakeholders with a common interest in SR. There are SuRF chapters in several countries including Canada. Although typically composed of representatives from private companies, environmental consultants and universities, most SuRF groups also include members of regulatory agencies and remediation contractors. The mission of SuRF groups centres around raising awareness, advancing the state-of-science and practice in SR, and providing guidance and tools to practitioners.

Groups such as SuRF-UK (United Kingdom) recommend combining compliance to regulatory mechanisms with a bottom-up approach where the individual stakeholders associated with a particular project have flexibility in identifying and agreeing to the SR criteria and assessment methodology they feel is the most relevant to their particular project's circumstances (CL:AIRE & NICOLE, 2015; Rizzo et al. 2016).

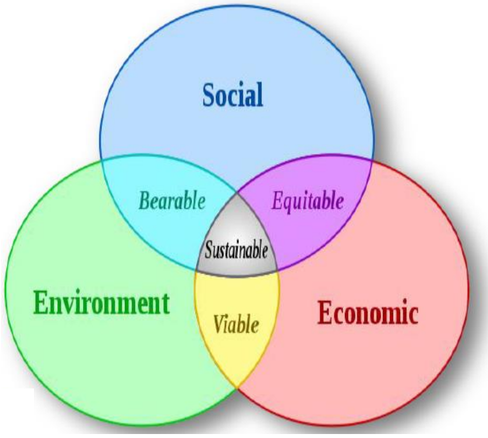
The SuRF-UK, in particular, has emerged as one of the most complete sustainability frameworks developed (Bardos et al. 2011; Bardos et al. 2020). It satisfies most sustainability principles as established by Ridsdale and Noble (2016). Other published frameworks and roadmaps usually referred to in literature include those by the SuRF-US, ASTM and ITRC.

There is increased effort in recent years by SR groups worldwide to share ideas and work collaboratively. The International Sustainable Remediation Alliance (ISRA - www.claire.co.uk/isra) brings together many of these groups and aims to bring more consistency and clarity in SR guidance. These efforts will make it easier for practitioners and managers to operationalize SR in their sphere of activities. One of the first initiatives of the ad-hoc alliance was to contribute towards drafting an ISO Standard on sustainable remediation (ISO Standard 18504).

SURF recently published a 10-year anniversary edition (Favara et al. 2019) of its 2009 white paper to highlight: 1) the early days of sustainable remediation, 2) current state of the practice, 3) new frontiers in sustainable remediation, and 4) sustainable remediation in the next 10 years. The new frontiers include climate change and resilience, weighting and valuation, programmatic implementation, and better integration of the societal impacts of sustainable remediation.

3.2 SuRF-UK Sustainable Remediation Framework and Guidance

The SuRF-UK Framework and supporting guidance (CL:AIRE 2010) describes how the principles of sustainable development can guide the selection of optimum and sustainable remediation strategies and treatments that are integrated with land use planning. SuRF-UK defines the assessment of sustainable remediation as "the practice of demonstrating, in terms of environmental, social and economic indicators, that the benefit of undertaking remediation is greater than its impact and that the optimum remediation solution is selected by a balanced decision-making process" (Figure 1).



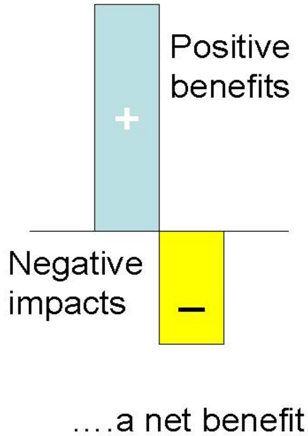


Figure 1: Illustrative Representations of Sustainable Remediation, from the SuRF-UK Framework (CL:AIRE, 2010)

Two main site management stages where sustainable remediation decision-making can be applied are identified:

1) Stage A: The project/plan design stage; this is an important step as often a sustainability strategy and principles can positively influence project design.

2) Stage B: At the remedial options evaluation through incorporation of SR principles.

As part of Stage A there is the opportunity to embed a sustainable remediation strategy into the wider project/plan design. Examples provided include: 1) site master planning to minimise the need for remediation, 2) construction and remediation processes that minimize waste generation; 3) integration of remediation to promote use of renewable energy, such as ground source heating and cooling, or biomass production; and 4) integrating remediation work with provision of sustainable drainage and flood protection measures.

SuRF-UK Six Guiding Principles:

1. *Protection of human health and the wider environment.*
2. *Safe working practices.*
3. *Consistent, clear and reproducible evidence-based decision making.*
4. *Record keeping and transparent reporting.*
5. *Good governance and stakeholder involvement.*
6. *Sound science.*

The process of sustainable remediation requires an assessment of environmental, social and economic aspects to demonstrate that net benefit exists, or more to the point, the benefits delivered by remediation exceed the costs of undertaking remediation. A number of steps are required in this process, including:

- What are the objectives and what management decision does the assessment support?
- Which stakeholders need to be consulted?
- What are the boundaries of the assessment (spatial scale of activities and remediation components selected)?
- What sustainability indicators should be used (several possible choices are in Table 1)?

- What assessment method should be used?
- How certain is the result of the assessment, and what parameters are most sensitive in defining the outcome?

A three-tiered assessment framework is recommended consisting of:

1) Qualitative (checklists and conversations with stakeholders)
2) Semi-quantitative multi-criteria analysis
3) Quantitative multi-criteria analysis, where costs and benefits may be monetized, and life cycle analysis is performed (complex sites).

Table 1: Categories of Indicators for Sustainability Assessments Recommended by SuRF-UK (CL:AIRE 2011)

Environmental	Social	Economic
ENV 1: Emissions to air	SOC 1: Human health and safety	ECON 1: Direct economic costs and benefit
ENV 2: Soil and ground conditions	SOC 2: Ethics and equity	ECON 2: Indirect economic costs and benefits
ENV 3: Groundwater and surface water	SOC 3: Neighbourhoods and locality	ECON 3: Employment and employment capital
ENV 4: Ecology	SOC 4: Communities and community involvement	ECON 4: Induced economic costs and benefits
ENV 5: Natural resources and waste	SOC 5: Uncertainty and evidence	ECON 5: Project lifespan and flexibility

Supplementary reports to the SURF-UK framework were published in 2020[2] presenting a general approach to sustainability assessment and selection of indicators/criteria for use in sustainability assessments for achieving sustainable remediation. Tools and guidance to support execution of sustainable remediation within a tiered implementation framework are also provided. Bardos et al. (2020) describe the rationale for the 15 overarching categories of indicators in Table 1 along with explanations of their application in sustainability assessment.

[2] https://www.claire.co.uk/projects-and-initiatives/surf-uk

3.3 ITRC Green and Sustainable Remediation Guidance

The goal of the ITRC Green and Sustainable Remediation (GSR) Guidance (ITRC 2011) is to assist decision makers in considering environmental, social, and economic factors throughout a site remediation. In doing so they can lessen the negative effects of the cleanup while still meeting regulatory objectives in terms of protecting human health and the environment. The document begins with concepts and definitions for green and sustainable remediation followed by review of other guidance and tools, with focus on programs in United States. A gap identified in the guidance is the lack of a commonly accepted set of metrics used by remediation practitioners to evaluate whether site cleanup activities are green and/or sustainable. Quantitative social indicators are also lacking, partly because of the challenge of quantifying this aspect of sustainability. Based on available publications, key indicators are summarized in Table 2.

ITRC Definition of Green and Sustainable Remediation: *A scalable method for evaluating and implementing green and sustainable elements beyond traditional decision-making factors. This scalable method can be applied at any or multiple point(s) in the cleanup process, thus allowing the user the ability to identify, evaluate, balance, and quantify environmental, economic, and social aspects. The GSR process should help users identify factors and elements they may want to consider and provide an approach for maximizing the short- and long-term social, economic, and environmental goals under various cleanup programs while continuing to protect human health and the environment.*

Table 2: Sustainable Remediation Practices and Objectives in ITRC Green and Sustainable Remediation Guidance (from ITRC 2011)

Sustainable remediation practices and objectives	Land	Water	Waste	Community	Economic	Metric units	Metric description
Fresh-water consumption						Gallons	Volume of fresh water used
Water reuse						Gallons, percentage	Volume of water used, percentage of water reused
Groundwater protection						Gallons, acre-feet	Volume of groundwater protected
Surface water protection						Gallons, acre-feet	Volume of surface water protected
Bioavailability of contaminants						Kg	Mass of bioavailable contaminants
Biodiversity						Specie count	Assessment of impacts on biodiversity
Habitat disturbance						Ecosystem services, area of land impacted	Measure of impact on area impacted or change in ecosystem services
Ecosystem protection						Ecosystem services, area of land impacted	Measure of impact on area impacted or change in ecosystem services
Natural resource protection						Acres, acre-feet, ecosystem services, human use value	Measure of impact on natural resources or natural resources quality
Nonrenewable energy use						Gallons, BTU, kWh	Measure of use of nonrenewable energy resources
Renewable energy use						Gallons, BTU, kWh	Measure of use of renewable energy
Net energy reduction						Percentage	Percent change from baseline
Greenhouse gas emissions						CO_2 equivalents emitted	Tons of GHGs emitted
Air pollution (non-GHGs)						Pounds emitted	Pounds of air pollutants emitted

The ITRC guidance includes a useful review of available approaches and tools, including best management practices, life cycle analysis and tools for assessing green remediation and the environmental footprint. Practical tips on how to indicate green and sustainable remediation (GSR) principles into different stage of site investigation and remediation are provided.

3.4 US EPA Green Remediation Primer

> ***US EPA Green Remediation Definition:***
> *The practice of considering all environmental effects of remedy implementation and incorporating options to maximize net environmental benefit of cleanup actions.*

The US EPA *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (US EPA 2008) is a primer for best management practices and green remediation. Green remediation is important because it reduces the demand placed on the environment during remedial actions, otherwise known as the environmental "footprint" and reduces the potential for negative environmental impacts that are associated with remediation. The core elements of green remediation addressed in the document are shown in Figure 2. While all elements are important, a focal point centres on the emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and other greenhouse gases that contribute to climate change.

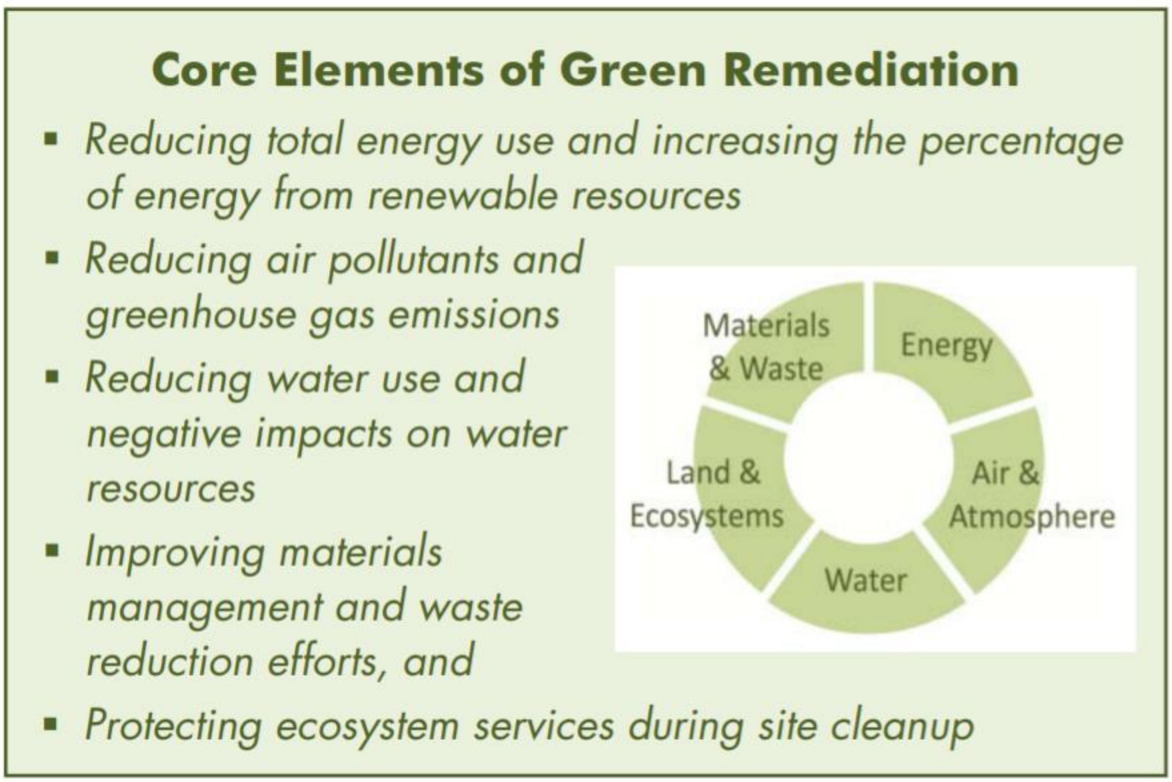


Figure 2: Core Elements of Green Remediation from US EPA (2008)

As stated in the primer, the US EPA strives for cleanup programs that use natural resources and energy efficiently, reduce negative impacts on the environment, minimize or eliminate pollution at its source, and reduce waste to the greatest extent possible. An important aspect of this strategy is reduction in GHG emissions and increased energy efficiency as required by US Federal mandates such as EO 13423 (*Strengthening Federal Environmental, Energy, and Transportation Management* 2007) and EO 13514 (*Federal Leadership in Environmental, Energy, and Economic Performance*). Low energy-intense remedial measures such as enhanced bioremediation, NSZD and MNA, and phytoremediation may have lower carbon footprints than other more energy intensive technologies.

US EPA Greenhouse Gas Equivalences Calculator: *Useful sources of data for CO_2 emissions are provided including reductions of kilowatt-hours into avoided units of carbon dioxide emissions, per gallon of gasoline combusted and natural gas burned.*

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

The strengths of this guidance include providing high-level objectives for five core elements of green remediation, followed by specific practical examples of how green remediation measures can be incorporated in the site investigation and remediation process. Practical tips for improving sustainability of remediation are included such as use of telemetry, passive sampling methods, low intensity remediation methods, minimizing the number of samples, minimizing investigation wastes, proper sizing of equipment, pulsed operation, and conversion of active to passive systems.

3.5 Canadian Federal Government

The foundation of federal environmental regulation in Canada is the Canadian Environmental Protection Act (CEPA; http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=26A03BFA-1), which has the following eight guiding principles:

1) Sustainable development
2) Pollution prevention
3) Virtual elimination (of persistent and bioaccumulative toxic substances)
4) Ecosystem approach
5) Precautionary principle
6) Intergovernmental cooperation
7) National standards
8) Science-based decision making

In line with these principles, the government of Canada has developed a tool called the Sustainable Development Analysis Tool (SDAT)[3] to embed sustainability principles in the Federal Contaminated Sites Action Plan (FCSAP). Its goal is to reduce environmental and human-health risks posed by the highest-priority federal contaminated sites, along with the associated federal financial liabilities. The tool is based on existing concepts and methods from several sources, including guidance described in this toolkit.

The SDAT is a multi-criteria analysis tool that integrates the three pillars of sustainability. It is simple and flexible, and designed to better understand and communicate SR issues. The main inputs for the tool are the conceptual site model as well as the results of the technology selection step.

For the identification of the optimal remedial technology for a site, the government of Canada has developed a tool called the “Guidance and Orientation for the Selection of Technologies” (GOST), which conducts a screening of suitable methods based on contaminants, type of soil, hydrogeological factors and other factors. The tool contains 65 different technologies. The tool generates a short-list of technologies, which is entered in the SDAT tool and evaluated through the six-stage process shown in Figure 3. Each option is compared within a framework of indicators chosen from a standard list, which includes 23 environmental indicators, 23 social indicators, and 19 economic indicators.

Other drivers for developing the SDAT specifically adapted to the Canadian context include the need to ensure technical quality and consistency, increase uniformity on FCSAP projects, and improve measures of success in meeting scope, schedule and budget. The tool addresses gaps that exist in other available tools as SDAT includes indicators that are relevant to the Canadian Federal context. The results are represented in triangular charts with each corner representing a pillar of sustainability. The largest most balanced triangle may be considered the preferable option if all three pillars of sustainability have similar importance. If select pillars have greater importance, then an option that most closely aligns with a skewed triangle that is consistent with the option’s relative importance while providing overall balance may be the preferable option.

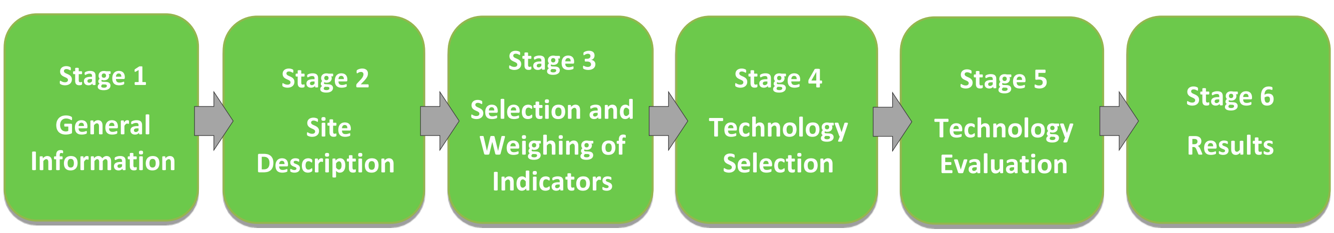


Figure 3: Six Phases of Sustainability Evaluation using SDAT

[3] Available at https://sdat.pwgsc.gc.ca/index.aspx?lang=eng

3.6 ISO (2017) Standard

The ISO 18504 standard (ISO 2017) describes important concepts for sustainability and definition that brings together risk considerations, time of remediation, and the three pillars of sustainability (see Section 2). Remediation technologies are considered in terms of pre-treatment, treatment, and post-treatment. Treatment is considered to break the source–pathway–receptor linkage and consequently the risk is eliminated or reduced.

A case for sustainability is made despite the challenges, which include the potentially subjective and relative nature of sustainability. Unnecessary remediation with trivial risk reduction is considered unsustainable. Sustainability is also not absolute but tends to be relative where alternatives may be evaluated using appropriate indicators and metrics. Best practices for selecting indicators and metrics and making comparisons between alternatives are provided. Indicators should be independent and non-overlapping. Strategies for defining metrics and comparisons using different weighting schemes are provided.

4.0 SR METHODS AND TOOLS

There is a range of methods and tools that are increasingly being incorporated in site remediation processes to achieve a more sustainable outcome or to increase the net environmental benefit of a project. The methods and tools discussed in this toolkit are:

- best management practices (BMPs), also referred to as sustainable management practices (SMPs)
- footprint analysis, which incorporates life cycle analysis (LCA) and environmental footprint analysis (EFA)
- multi-criteria analysis (MCA)

The complexity of methods and tools varies, and their selection should be based on project-specific requirements. In general, and in line with the principles of sustainability management, the simplest assessment approach that produces a reliable management decision should be used (ISO 2017). Smith & Kerrison (2013) showed how simple sustainability assessment methods can generate reliable decisions on relatively simple projects, and the rationale for adopting simple approaches for sustainability assessment is described further by Bardos et al. (2016). The Roadmap in Section 5.0 provides a suggested approach for tiered assessments that integrate these concepts in an effective and streamlined approach.

While we advocate sustainability assessments based on environmental, societal and economic factors, it is acknowledged that societal aspects have lagged behind other factors in importance and methodology (Favara et al. 2019). Harclerode et al. (2015) describe tools, methods and indicators to improve incorporation of societal considerations in sustainable remediation decision-making.

Other sustainability assessment techniques are available, such as Cost-Benefit Analysis (CBA), where indicators that can be assigned a monetary value are compared (Environment Agency 1999). One of the challenges associated with CBA is methodology for assigning a monetary value to certain environmental and social indicators. CRC Care (2018) presents a hybrid method of conducting a sustainability analysis that incorporates quantitative CBA for factors that can be monetized (e.g., remediation cost, land value, social-economic benefits with revitalization, GHG emissions) and qualitative MCA to derive impact scores for remediation alternatives. Hyusegoms et al. (2019) present methods for conducting CBA that include social factors. There are also tools for assessing the sustainability of an infrastructure project, such as Envision by the Institute for Sustainable Infrastructure[4], which includes an online scoresheet (a form of rating and scoring system).

4.1 Best Management Practices

Best management practices (BMPs) based on sustainability principles may be incorporated into all phases of the site investigation and remediation process, including site investigation, demolition, construction of remediation works, operation and monitoring of treatment systems, monitoring of remediation, and site close-out (Figure 4). BMPs are also, sometimes, referred to as Sustainable Management Practices (SMPs), for example in CL:AIRE (2014). Site-specific sustainable remediation measures can be promoted through incentives incorporated in service or vendor contracts or specified in site management plans.

[4] https://sustainableinfrastructure.org/

Figure 4: Site Investigation and Remediation Phases where Best Management Practices (BMPs) can be Applied

A framework for use of BMPs is provided in Figure 5 below.

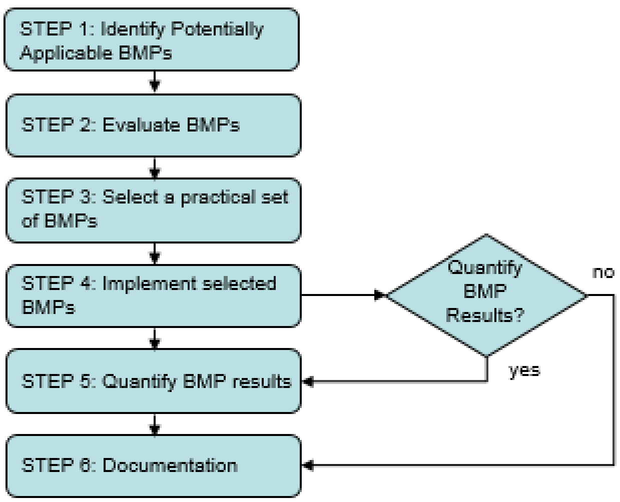


Figure 5: BMP Implementation Steps from ASTM E2876 – 13

There are many different ways remediation can be improved through best management practices that address remedial optimization, energy efficiency and use, and waste management (Appendix A). A subset of best practices includes consideration of the following measures, where appropriate and practical:

- Use of alternate or renewable energy sources (e.g., landfill gas, wind, power).
- Use of passive or low intensity investigation or remediation measures, such as passive sampling methods, smaller drill rigs or technologies such as bioventing or other low intensity enhanced bioremediation methods.

Best Management Practices: *Good sources of ideas and references for BMPs include:*

1. *ITRC GSR Guidance (ITRC 2011)*
2. *US EPA Green Remediation Primer (US EPA 2008).*
3. *SuRF-UK Sustainable Management Practices for Management of Land Contamination (CL:AIRE 2014)*
4. *ASTM E2876 – 13 Standard Guide for Integrating Sustainable Objectives into Cleanup.*
5. *ASTM E2893 – 16e1 Standard Guide for Greener Cleanups.*

- Appropriate sizing of equipment and operational efficiency through, for example, pulsed operation and energy efficient equipment.
- Reduction of investigation-derived wastes.
- Use of water efficient equipment and water re-cycling where feasible.
- Use of equipment that reduces GHG emissions and reduces energy use, such as electric or hybrid vehicles.
- Re-cycling or reclamation of materials, and use of products with re-cycled content.
- Sequencing of work to improve efficiency.
- Use of telemetry and advanced data collection and processing methods to improve monitoring and operational efficiency.
- Use of equipment and materials local to the site.
- Modifying cleanup approaches to address concerns about disruptions and disturbances to local residents and businesses; soliciting opinions from local residents and implementing suggested mitigation measures that are appropriate.
- Communicating site activities to stakeholders and the community in a non-technical fashion so that issues of public health risk are understood.

Best management practices to improve sustainable remediation based on key environmental and social indicators are provided in Appendix A.

Environmental Footprint Analysis (EFA) and Life Cycle Analysis (LCA) Tools:

Available tools for conducting EFA and LCA include:

- *SiteWise (Version 3.2, October 2018), developed by Battelle jointly with the Navy, U.S. Army Corps of Engineers, and Army, for evaluating site remediation options https://www.sustainableremediation.org/guidance-tools-and-other-resources*
- *US EPA Spreadsheets for Environmental Footprint Analysis (SEFA) (Version 3, 2019) addresses 21 metrics corresponding to elements of greener clean-up's. 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/*

The SiteWise and SEFA tools are two tools most applicable to EFA of site remediation. Jurisdiction specific defaults for emission factors should be used in these tools where warranted.

4.2 Footprint Analysis

An evaluation of the footprint of remediation is a component of many SR assessments. While often referred to as an environmental footprint analysis (EFA), the analysis does not need to be limited to environmental metrics. To be a true sustainability assessment, EFA should also consider relevant social and economic indicators, as recommended in the discussion on multi-criteria analysis (MCA) (Section 4.4) and the Roadmap (Section 4.5). Evaluation of a project with a wider lens tends to provide increased opportunity to improve sustainability.

Common metrics or indicators considered when conducting a footprint analysis include GHG emissions, energy consumption, material (natural resource) use, waste generation, air quality impacts, land ecosystem or resource impacts, community impacts and safety. Metrics should be identified that are aligned with the goals of the analysis and that are consistent with the remediation considered.

Guidance on selection of metrics and footprint analysis include the following:

- US EPA Green Remediation Primer (US EPA 2008), and additional guidance on specific remediation technologies, listed in Appendix A.
- US EPA Methodology for Understanding and Reducing a Project's Environmental Footprint (US EPA 2017).
- ITRC Green and Sustainable Remediation Guidance (ITRC 2011).
- SuRF-UK Sustainable Remediation Framework and guidance (UK-SuRF 2009, 2010, 2011, 2014)[5].

US EPA (2012) defines a comprehensive framework and twenty-two different environmental metrics. We consider a smaller number of key metrics will be sufficient for many projects. An important metric is the carbon footprint, described in detail in Section 4.2.2 below.

Conducting a footprint analysis typically involves quantitative analysis and consideration of the project lifecycle (e.g., investigation, construction, monitoring, decommissioning). While a complete life cycle analysis (LCA) is impractical, a simplified LCA can be used to guide a footprint analysis for quantifiable metrics such as GHG emissions, energy use, material use and waste generation.

There are only a few available tools for conducting a quantitative footprint analysis for environmental remediation. The SiteWise tool is one such commonly used tool that is relatively current. There is a range of tools available to assist with broader assessments of GHG emissions and sustainability, for example, the SMARTTool[6] developed by BC Ministry of Environment and Climate Change (MoECC) and SoFi TS Tool developed by Thinkstep; however, such tools are not designed to address SR metrics for environmental remediation. The SimaPro software and EcoInvent databases provide a comprehensive source of lifecycle assessment inventory (LCI) data. We note that the tool itself is not as important as understanding the inputs and using it to better understand how to improve sustainability. Current SR tools are not well suited for portfolio management and efficient assessment of remediation at multiple sites.

Example of Life Cycle Analysis Case Studies: *Higgins and Olson (2009) compared a permeable reactive barrier (PRB), a passive remediation technology, and conventional pump-and-treat system (PTS). A LCA included evaluation of construction and material production associated with the PRB, but found that because of energy demand, there was a greater environmental footprint associated with PTS. Lemming et al. (2012) conducted a LCA of remediation alternatives for a TCE-contaminated plume. All remediation options considered (in-situ chemical oxidation (ISCO), in-situ enhanced reductive dechlorination (ERD) and long-term monitoring) showed the secondary environmental impacts associated with remediation were greater than the reduction in primary impacts associated with contamination. The metrics for comparison were person equivalents (the impact normalized to the average impact a person has with respect to criteria evaluated). ERD and long term monitoring were the scenarios with the lowest secondary life cycle impacts and therefore were the preferred alternatives. This case study demonstrated the challenge in comparing different alternatives.*

[5] Referred to in references as Cl:AIRE.

[6] SMARTTool is currently only available to government agencies

4.2.1 Life Cycle Analysis

Life cycle analysis (LCA) is a standardized approach for evaluating the overall impacts of a product or activity throughout its life cycle. The International Organization for Standards (ISO) standard 14040:2006 *Environmental Management – Life Cycle Assessment – Principles and Framework* definition for LCA is the "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle." While not addressed in the ISO standard, the social and economic impacts of remediation should also be addressed.

Principles of LCA are often incorporated in a footprint analysis and used to measure the performance of green and sustainable remediation. A LCA may be comprehensive and attempt to include the breadth of environmental burdens (i.e., cradle to grave) and, through this broad approach, improve decision-making and lead to a better understanding of environmental trade-offs between remedial alternatives or activities. For evaluation of remedial technologies, a LCA can be designed to help minimize consumption of natural resources and generation of solid and liquid wastes and greenhouse gases, while maximizing use of renewable energy, land revitalization, and habitat and ecosystem restoration.

The US-SuRF proposed a nine-step process for conducting and documenting a footprint analysis and LCA for remediation projects (Favara et al. 2011). The US EPA California Department Toxic Interim Advisory for Green Remediation (CA DTSC 2011) provides a useful framework for quantifying inputs and outputs as part of a LCA approach. While not designed specifically to address environmental remediation, the SimaPro LCA software is a comprehensive process-based LCA tool.[7]

The US-SuRF nine step process is as follows (Favara et al. 2011; Morais et al. 2000):

1) Define the study goals and scope
2) Define the functional unit
3) Establish the system boundaries (the use of the term *system* here is broader than the remediation system and includes off-site and on-site considerations)
4) Establish the project metrics
5) Compile the project inventory (i.e., inputs and outputs)
6) Assess the impacts
7) Analyze the sensitivity and uncertainty of the impact-assessment results
8) Interpret the inventory analysis and impact-assessment results
9) Report the study results

[7] http://www.pre.nl/content/simapro-lca-software

The system boundaries should be described with respect to geography, time and technology, with consistent definitions needed when different options are compared. Geography includes consideration of on-site and off-site activities and transportation. Time includes consideration of project phases and can include investigation, construction, operation and decommissioning. The future use of a site (tertiary effects) can be considered but adds a dimension that can be challenging to quantify. Technology refers to the level or advancement of the technology considered, for example, best available technology or types of enhancements that may be incorporated in the technology. Challenges with LCA include setting consistent boundaries, the large and disparate range of possible impacts that can be considered including primary and secondary impacts (and concomitant challenges for standardized comparisons) and quantifying the impacts. When comparing alternatives, there are various approaches for quantifying impacts including those based on normalized parameters (e.g., impact per cubic metre, person equivalents) or schemes to enable absolute comparisons where impacts are monetized.

There continue to be advances in LCA including methods that incorporate societal and ecosystem impacts (Favara et al. 2019). However, conduct of a comprehensive LCA typically goes beyond the practical scope of a SR assessment but can be constrained by only evaluating impacts directly related to the project, incorporating reasonable boundaries, and limiting assessment to key indicators (e.g., GHG emissions, energy, material use, waste).

4.2.2 Carbon Footprint Analysis

A carbon footprint analysis is a sub-set of an environmental footprint analysis that addresses GHG emissions and uses LCA concepts to quantify impacts. A quantitative or semi-quantitative evaluation of GHG emissions or energy consumed associated with remediation projects is an essential component of many SR approaches. However, we caution against sole evaluation of GHG in isolation from other environmental burdens as the overall impact is important to assess, and measures to reduce GHG emissions may have negative consequences in other areas.

Greenhouse Gases (GHGs): *Common GHGs are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons. The 100-year Global Warming Potential (GWP) of N_20 and CH_4 are 298 and 25 CO_2-equivalent (e) (BC ENV 2018).*

At a minimum, a quantitative evaluation of GHG emissions or energy consumed should be performed during the remedy selection stage, remedy design stage, and operation and maintenance stage of a project life-cycle to support a MCA (ASTM E2893-16), as shown in Figure 6. Carbon footprint calculations can be performed to support MCA analyses, and can be used to quantify the effect (whether positive or negative) of a design upgrade or BMP implementation.

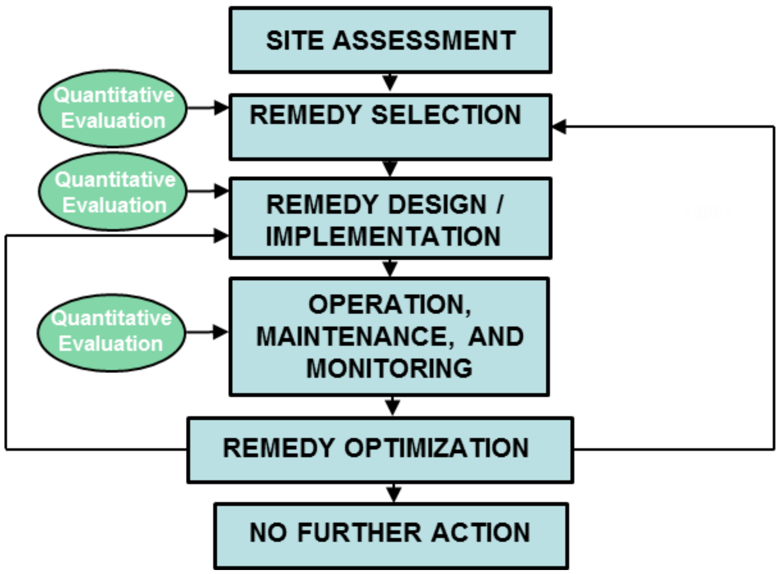


Figure 6: Project Lifecycle with Recommended Quantitative Evaluations (Modified from ASTM E2893-16)

A carbon footprint analysis should result in the identification and quantification of impacts from relevant on-site and off-site activities. The following steps should be implemented when performing a footprint analysis:

- Establish System Boundaries: The boundaries of a carbon footprint evaluation must be established for each project or activity being analyzed. System boundaries should be sufficiently large to include all relevant potential impacts to the system you are evaluating. All remediation projects have both on-site impacts (e.g., emissions from on-site drilling activities) and many have off-site impacts (e.g., emissions from transportation, energy consumed during treatment of extracted groundwater at a treatment plant). While off-site impacts should be identified and qualitatively considered on all projects, depending on the remedies being considered and the goals of the analysis, a quantitative evaluation of the off-site carbon footprint may not be necessary. However, off-site impacts should always be calculated under the following conditions:
  - **Expendable Materials** – If large quantities of expendable materials are to be used during the implementation or operation and maintenance of a remedy (e.g., granular activated carbon [GAC], sodium lactate, persulfate, etc.), off-site impacts should be calculated and should include those from the consumed materials. Off-site impacts from chemical reagents or GAC can be the largest component of the environmental footprint in some instances.
  - **Transportation Distances** – If large disparities exist in transportation distances or mobilization distances for subcontractors, the impacts should be calculated for the remedies being evaluated.
  - **Number of Samples** – If large disparities exist between remedies in the number of samples required for closure, then the impacts should be calculated. Sample shipment and analysis, when considering the wastes generated and solvents consumed, can represent a large fraction of an off-site environmental footprint under some conditions (EPA 542-R-12-002).

- **Generated Wastes** – If wastes are generated and transported to off-site facilities, the impacts should be calculated and compared among the remedies

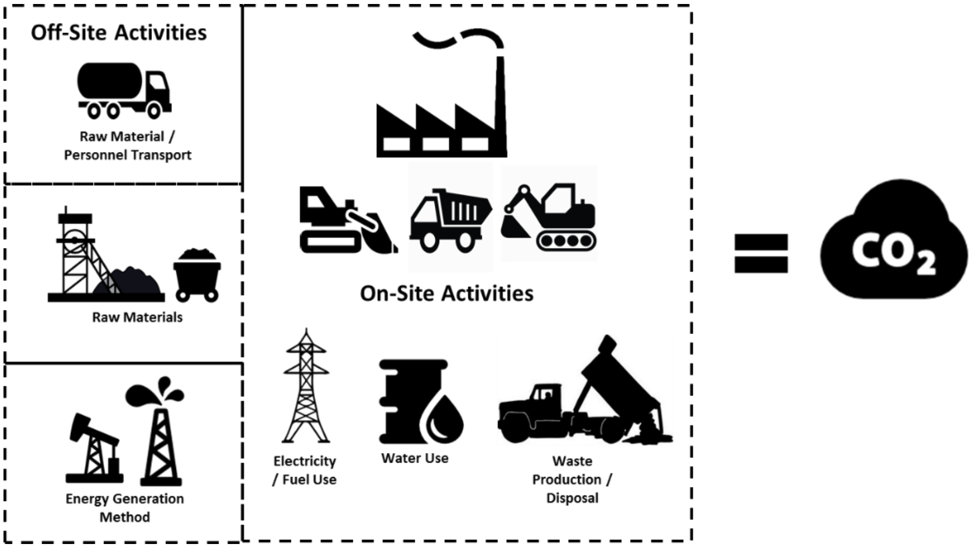


Figure 7: Examples of On-site and Off-site Inputs

- Environmental Inventory: Once the system boundaries are established, an inventory is created of all known activities on-site that contribute to energy use and carbon emissions, such as those associated with materials and wastes. Depending on the goal of the analysis and the boundaries of the system, this will include all components of the remediation system (PVC for wells, sand, injection materials, etc.) as well as the duration of on-site work (e.g., hours of drilling). If a high-level comparison is being performed, it is possible to only include major components of each remedial option.

- Footprint Calculation: Footprint analysis typically involves simple calculations that could be performed using any spreadsheet software. For example, the total fuel consumed for the delivery of 1.5 tons of emulsified vegetable oil (a product used for in-situ bioremediation) is calculated[8] as follows:

Delivery trip for specialty freight:	500 miles at 6 miles per gallon	= 83 gallons
Delivery trip for specialty freight:	810 kilometres at 2.55 kilometres per litre	= 218 litres
Empty return trip (empty):	500 miles at 6 miles per gallon	= 83 gallons
Empty return trip (empty):	810 kilometres at 2.55 kilometres per litre	= 218 litres
Total Fuel Consumed:	**166 gallons or 544 litres**	**from EPA 542-R-12-002)**
Conversion to CO_2-e:	166 gallons x 22.5 lb CO_2-e/gallon diesel fuel	= 3735 lb CO_2-e
Conversion to CO_2-e:	544 L x 2.69 kg CO_2-e/L diesel fuel	= 1465 kg CO_2-e

[8] A combination of SI and Imperial units are used because the source of data is US guidance

Since most footprint analyses involve dozens of raw materials or on-site activities, footprint software tools (e.g., SiteWise, see Appendix B) are typically used as they include a database of impacts caused by a unit quantity of a given material (e.g., CO_2-e / kg PVC for well construction, CO_2-e / kg sand, CO_2-e / kg injection materials, etc.) and greatly add to the overall efficiency of the process. These impact databases are typically derived from peer-reviewed journals or from publicly available calculations. An evaluation of these references should be performed to ensure that the calculations are consistent with the project system boundaries and goals, and regulatory requirements. As the values employed by different software packages may vary, it is important to use the same software package, and reference impact values, across remedies being evaluated (from EPA 542-R-12-002). The SiteWise data set is a free publicly available reference that is commonly utilized by other software packages. The estimated carbon emissions can be monetized based on carbon off-sets to obtain the societal cost of carbon (Harclerode et al. 2016).

In some cases, it is necessary to use geographic information to differentiate between energy grid sources since GHG emissions vary between countries and within most countries. The US EPA has provided guidance on GHG emissions per unit of energy produced for different locations at the following website:

https://oaspub.epa.gov/powpro/ept_pack.charts

Assessments conducted in BC should follow the BC ENV (2020). Methodology Book for the British Columbia Provincial Inventory of Greenhouse Gas Emissions. August (the BC government website should be consulted for updates).

https://www2.gov.bc.ca/assets/gov/environment/climate-change/data/provincial-inventory/2018/bc_provincial_ghg_inventory_1990-2018_-_methodology_book.pdf

- Documentation: The resulting analysis should include the carbon footprint as well as the reference values and assumptions used to generate that result.

4.3 Multi-Criteria Analysis

Comprehensive sustainability evaluation frameworks are typically based on a set of indicators that are used to assess and compare options. Such frameworks typically incorporate a scoring system based on attributes or effects. Multi-criteria Analysis (MCA) is a tool that can be used to perform these evaluations. Conflicting criteria are to be expected; MCA is aimed at facilitating trade-offs to identify the optimal solution.

We intuitively make many MCA decisions in our everyday lives. For example, in buying a new car we may consider cost, comfort, safety and fuel economy as criteria for choosing a new car. However, it’s unlikely that the least expensive car will be the most comfortable and the safest. These problems are relatively straightforward, but for more complex problems it is important to build a structure for these MCA analyses.

A structured MCA approach explicitly defines:

- Indicators against which to measure options.
- Scoring schemes for qualitative indicators to provide a comparative basis for the evaluation.
- A mechanism to account for the relative importance of indicators.

And in doing so, a thorough MCA:

- Provides traceability and accountability.
- Allows one to explicitly identify priorities when making a decision.
- Removes subjectivity from the decision-making process.
- Enables an informed decision based upon the factors considered most important.
- Provides flexibility to consider all stakeholders concerns and objectives.

A MCA can be performed with varying levels of detail, using only qualitative or semi-quantitative indicators at first and gradually incorporating quantitative metrics. The step-by-step process to undertake a MCA in the context of site remediation is detailed below.

a) Indicator Selection

Indicator selection is a crucial step in implementing a SR approach. The indicators are the criteria used to decide on the best solution. When selected correctly, the indicator set for a given project will reflect the goals, the concerns, and the risk tolerance of the key project stakeholders. The likelihood that a sustainability framework will yield results that are representative of the project proponents' objectives and key stakeholder requirements will be influenced by the level of effort expended to identify and refine appropriate indicators.

The distinction between indicator and metric is important. An indicator is a single characteristic that represents a sustainability effect which can be compared across options to evaluate their relative performance (CL:AIRE 2011), while a metric is the measurement of an indicator. There can be multiple metrics for one indicator.

Most of the SR guidance documents referenced in Section 2.0 provide a list of key sustainability indicators. References for these guidance are included at the end of this document.

b) Indicator Weighting

The weights of the selected indicators reflect the relative importance of the evaluation criteria. These are typically determined using 1) the relevance of the indicators for the project proponent, and 2), whenever applicable, the level of concern to key stakeholders (those considered to have a high level of interest and influence). Indicator weighting is typically done using a 3-point or 5-point system.

c) Scoring and Evaluation

There are many different types of scoring schemes which allow differentiation of the options being compared. For the sake of simplicity and consistency, this toolkit proposes the use of two types of scoring, one for quantitative and one for qualitative indicators:

Choosing between a quantitative or qualitative indicator depends on:

- the existence of a physical or numerical unit to measure the impact
- the affordability and the availability of the resources to perform the measurement or calculation

In a MCA, quantitative indicators are typically normalized as numbers on a “local” scale. The highest score (100) is assigned to the best performing alternative and the lowest score (0), to the worst performing alternative. Other alternatives will receive scores interpolated between the best and worst. For qualitative indicators, as a good practice, a four-point scale should be used: this is a "forced choice" method since there is no middle option. Alternatively, a five-point scale has the advantage of providing a higher resolution. An “absolute” scoring system (e.g., 1 to 5) based on qualitative indicators may also be used. While these simpler methods are sufficient for evaluating options for most projects, there are ranking schemes based on positive and negative scores depending on impacts, for example, proposed for evaluating social aspects of sustainable remediation (Reddy et al. 2014) or Analytic Hierarchy Process (AHP) based on pair-wise comparisons (Trentin et al. 2019).

Similar to a hazard and operability (HAZOP) process, which is routinely used by engineers to ensure the robustness of systems, scoring should be conducted in a brainstorming session format by a group of specialists whose combined expertise encompasses the technical breadth of the project.

d) Analysis, Presentation and Documentation of Results

The results of MCA are often presented as numerical values for each option, which represent the sum of weighted indicator scores. The higher the number, the better the option. Although this statement is true in a general sense, it is important that decision makers understand the underlying reasons behind these numbers; as this will go a long way in making sure that the actual performance of the selected solution meets the needs and expectations of the key stakeholders. The detailed analysis is the most important step of the process in several ways.

- During the detailed analysis, all the knowledge concerning the site and the remedial options is synthesized to present a structured, transparent and objective representation of possible approaches, and their anticipated performance.
- The detailed analysis provides a coherent business case for the selected approach
- By challenging the results of the detailed analysis and assessing the changes resulting from modifications to the input parameters of the MCA, practitioners can test the sensitivity of the analysis.
- A greater understanding of performance of each option relative to selected metrics allows for the optimization of the preferred option.
- By identifying those metrics that provide the greatest differentiation between options, the detailed analysis will reveal potential data gaps or additional analysis to be conducted before validating the preferred option (because of the sensitivity and hence importance of these metrics).

The benefits of the detailed analysis can be more easily achieved with the use of visualisation tools such as charts, graphics and figures on which the detailed results of the MCA can be plotted (Figure 8). One of the ways that a detailed assessment of relative option performance can be made is by conducting a Strength Weakness Opportunity and Threat (SWOT) analysis.

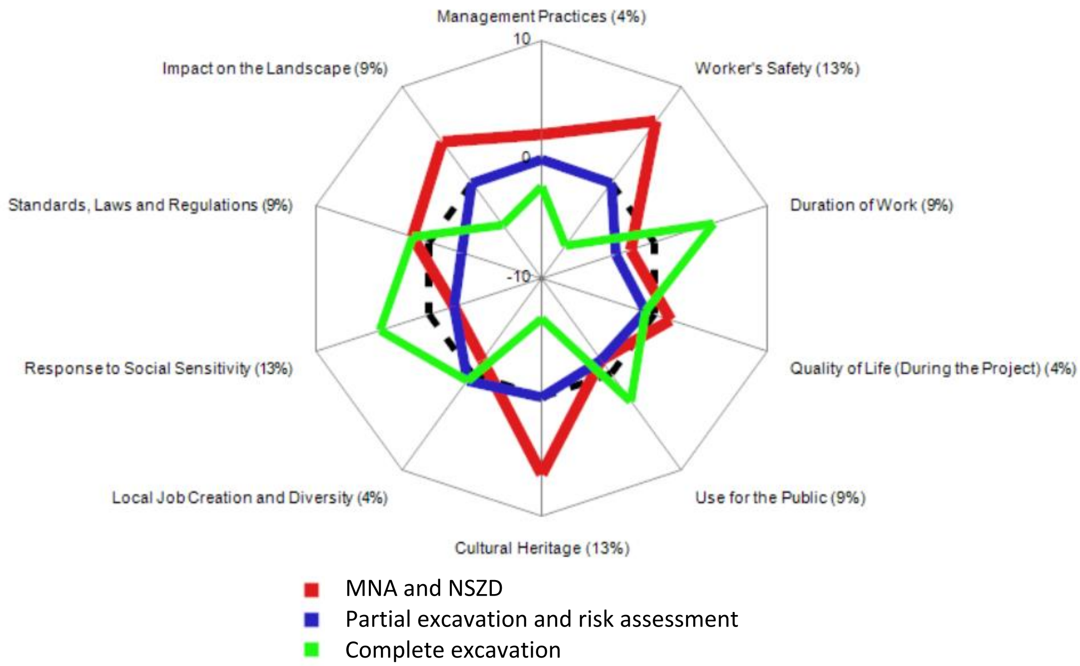


Figure 8: Example of Visual Representation of Detailed MCA Results

We caution against over reliance on the outcome of MCA scoring to make decisions; the value in the process is to help understand, demonstrate and document why a certain decision is being made, and what the impacts of that decision are, in view of the triple bottom line. In addition, the MCA results analysis can help identify weaknesses associated with an option and propose best management practices to improve performance of the option. Finally, documentation of the MCA process should be complete and accurate. Comments and justification relative to indicator selection, weighting and scoring should be recorded for future reference.

5.0 ROADMAP

The following Roadmap proposes a step-by-step process for implementing a SR project. The process is similar to the steps defined in ITRC (2011), which are described as "the starting point for integrating SR principles and practices into a project". For each step, the authors of this toolkit provide their own experience-based interpretation of the key elements that should be considered to achieve a successful SR implementation. Success is defined as the achievement of tangible and measurable benefits in all three spheres of sustainability and is captured in the following five steps (Figure 9).

I. Evaluate/update conceptual site model (CSM)

II. Establish goals

III. Stakeholder involvement

IV. Select indicators and SR evaluation method

V. Record SR efforts

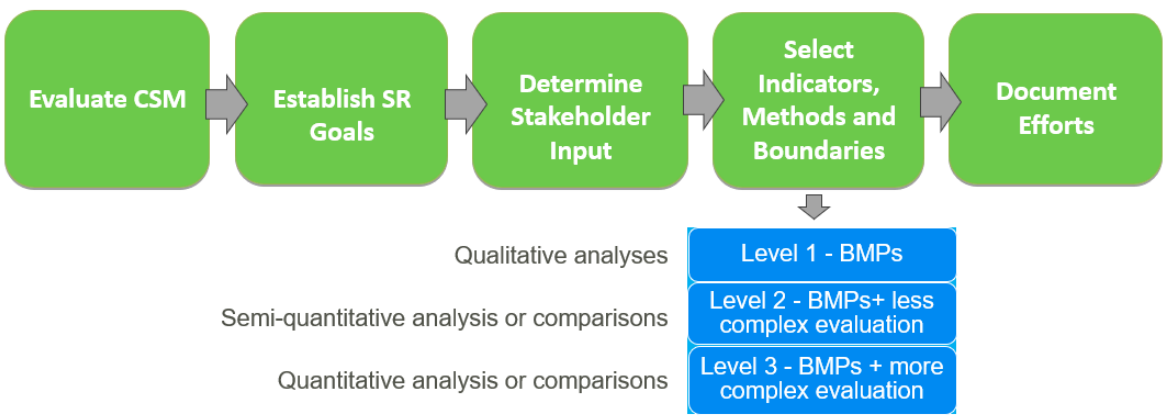


Figure 9: SR Roadmap Structure

The CSM, objectives, stakeholder list, indicators, and SR evaluation method make up the SR framework for a specific project or program. It is important to consider that, as with any aspect of project management, the influence of decisions made early in the planning phase of a project is much greater than those made later in the process. As such, it may be more effective to use a simple approach early in the project life-cycle than a more complex method later on. As a project moves closer to the execution stage and resources are assigned to tasks, it may become increasingly difficult to conduct the internal and external consultation processes that are the cornerstone of a SR approach, as highlighted in the SuRF-UK guidance (Section 3.2 of this guidance). This guidance as well as other SR frameworks (e.g., NICOLE, ITRC, SuRF and ASTM) highlight the importance of early assessment of sustainable aspects of remediation to deliver projects that are better by design. Figure 10 below illustrates that the cost of changes increase substantially as the project moves forward, while the level of influence over the project direction gradually diminishes.

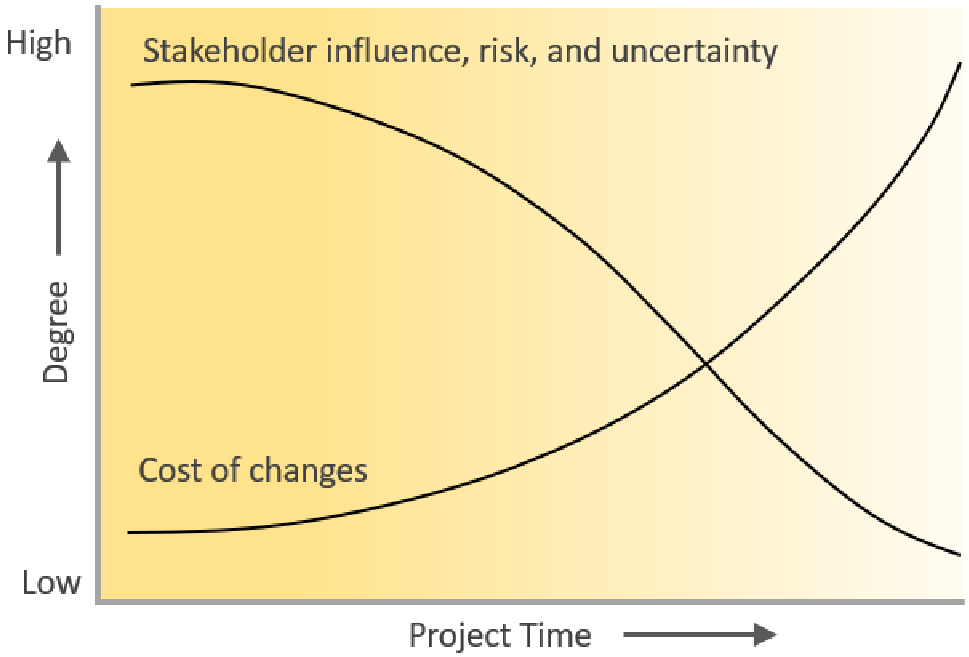


Figure 10: Impact of Variable Based on Project Time (adapted from PMI 2017)

I. Evaluate/Update Conceptual Site Model

IMPORTANCE: Decisions concerning site remediation should not be taken unless the CSM is adequately understood.

Before beginning the assessment of the different ways that the overall sustainability of a remediation project can be increased, the following information must be known:

- Extent of source zone and dissolved and vapour plume zones.
- Potential receptors that may be affected by contaminants.
- Migration and exposure pathways.
- Understanding of natural source zone depletion (NSZD) and natural attenuation (NA) processes occurring in the different areas of the site.
- Anticipated effect of each feasible remediation method or NSZD/NA enhancement method being considered for the site, on contaminant concentrations and longevity.
- Technology capabilities and limits.

The accuracy and validity of the results of the sustainable decision-support and optimization processes will be directly influenced by the quality of the input data above.

II. Establish Goals

IMPORTANCE: in order to be successful, the SR process must be guided by a clear understanding of what the project proponent is trying to achieve by integrating sustainability principles within the clean-up effort. Goals will typically include one or several SR core elements listed in Section 2.0.

For example, these goals may be:

- Create project description and decision framework that could be shared with stakeholders (enhanced transparency, early stakeholder engagement).
- Use a process to better define alternatives with the regulator.
- Adopt a sustainable and balanced approach in the evaluation of options.
- Adopt a risk management solution that is sustainable.
- Use the SR evaluation to advocate for alternative options.
- Use the process as a new approach in remediation decision making.
- Achieve remedial objectives while using less energy and generating less waste than other similar projects (with quantitative metrics provided for energy and waste).
- Integrate solutions for addressing non-technical risks into the project schedules and design.
- Not rely solely on government approval (permits) but address and include the local community from the project inception, to gain agreement and buy-in.
- Obtain data for corporate sustainability reporting purposes, such as the Global Reporting Initiative (globalreporting.org).

The identification of clear sustainability goals for the project will also inform the notion of the ideal or optimal outcome for the site. The starting point for this optimal outcome is the initial project purpose, or charter. For example, the initial project purpose could be to reduce contaminant levels to acceptable levels or meet risk-based criteria for eventual sale of a property. If one of the sustainability goals is local community vitality, the goal may then be modified in the following manner: to reduce contaminant levels to acceptable levels for the site reuse scenario desired by the community or municipal planners.

III. Stakeholder Involvement

IMPORTANCE: the importance of involving stakeholders is threefold: 1) their involvement can draw out crucial information about particular aspects of sustainability, 2) consultative processes improve transparency and robustness of decisions and 3) engaging stakeholders is part of good governance (CL:AIRE, 2010).

Certain stakeholders such as longstanding community members or First Nation elders, may possess unique information about the social and physical environment which may be impacted by the project (this impact can be negative or positive). This information can be crucial to the CSM and may help to avoid unnecessary or misaligned efforts. In the context of sustainability assessment, input from various stakeholders is needed for the selection and weighting of indicators for MCA.

The typical level of stakeholder involvement in remediation projects varies widely by jurisdiction and is dependent on the nature and scope of the work. Stakeholder identification and stakeholder expectation management is not a new process and is often performed at some level in remediation projects. However, this may be conducted in a reactionary way, and will be much less likely to enhance the social sustainability of a project than would a proactive, structured and transparent process performed across the entire project life-cycle. Smaller remediation projects conducted outside of high density residential and public sectors, and those with few or no impacts beyond the site boundary, may have little or no stakeholder involvement.

In order to gain a better understanding of the social impacts of a remediation project, whether these are negative or positive, obtaining information about relevant stakeholders, through survey or consultation for example, can be useful. In addition, as noted by ITRC, "communication with stakeholders regarding GHG emissions, water use, waste generation, truck traffic, noise, etc., may identify alternatives that address stakeholder concerns" and may speed up the process of regulatory approval for a remedial action. Social science specialists should be involved whenever there are sensitive or complex issues, or if there is information of significant importance to gather.

At minimum, the stakeholder engagement strategy should focus on identifying who are the main stakeholders along with a description of their role, needs and level of influence and interest. Typically, stakeholders will fall into five categories:

a) Site owners/site developers

b) Regulatory entities

c) Public

d) First Nations

e) Industry service providers (e.g., consulting firms, developers).

IV. Select Indicators and SR Evaluation Method and Conduct Evaluation

IMPORTANCE: the selection and weighting of indicators, which are the decision criteria of the SR framework, and the method by which they will be measured and used, will ultimately form the basis of decision-making in the project, and as such should be done carefully and linked to the objectives set in step II.

a) Indicator and Metric Selection

When choosing a set of indicators for a particular project or project portfolio, there are some key items that should be considered (Mining, Minerals and Sustainable Development, March 2002). The indicator set should:

- Reflect the drivers for the use of a SR approach.
- Be manageable and fairly easy to measure.
- Generally provide a balance between economic, environmental and social indicators.
- Be tailored to the project characteristics and not generic, and generally be a mix of qualitative and quantitative measures.
- Represent the needs and requirements of the various stakeholders involved in the project.

- Cover the issues that can be controlled and/or influenced by the project proponent.
- Capture risk, opportunities and ancillary impacts associated with the project.
- Be capable of showing a meaningful pattern in the evolution of progress over time, and of predicting progress.

b) SR Evaluation Method Selection

Many guidance and tools include flexibility in the effort required to implement SR, for example, by presenting a tiered approach with increasing level of complexity and detail. This is important because, when implementing a SR approach, it can be difficult to justify additional planning effort without being able to predict benefits in a clear and measurable way. Using a tiered approach can also be useful for eliminating flawed or lower performing alternatives with relatively little effort. This will allow one to focus on differentiating between the front-runners, gradually reducing the level of uncertainty in incremental assessments. Tiered evaluation and ranking tools are summarized in ITRC (2021).

For the purposes of this toolkit, standard approaches have been divided into three levels based on their complexity and level of effort, as follows:

- Level 1: Qualitative analysis consisting of best management practices (BMPs), sustainable management practices (SMPs) and/or simple multi-criteria analysis (MCA).
- Level 2: Semi-quantitative evaluation consisting of environmental footprint analysis (EFA) or carbon footprint analysis (CFA) and/or MCA.
- Level 3: Quantitative and more complex evaluation consisting of life cycle analysis (LCA) and/or MCA.

BMPs, footprint analysis, and MCA may or may not be used at each of these levels, although all three should be used at some level in order to maximize the sustainability gains of the approach. MCA may only be used if there is a need to compare options, technologies or strategies. If the objective of the project proponent is simply to enhance or optimize a remedial strategy, the integration of BMPs and limited scope EFA with focus on GHG emissions may be sufficient.

- Level 1: Qualitative evaluation. At this level no complex calculations are performed, so a footprint analysis is excluded and only simple BMPs and MCA are applied. If used, this level of MCA consists of performing a simple comparison of options, or design improvements, based on comparing relative performance against set indicators. This is similar to a pros and cons evaluation. Although this is a subjective evaluation method, it can still provide an overview of strength and weaknesses of different approaches and reveal potential data gaps. The net impacts or benefits of the remedial alternatives are not evaluated with this approach.

  An example of a Level 1 evaluation is provided in Figure 11. The example criteria represent a subset of environmental indicators, but don’t include several common indicators that are often also evaluated (e.g., GHG emissions, waste generation). Options 2 and 3 are equally good for this example.

Criteria	Remediation Options: Option 1	Option 2	Option 3
Off-site Migration	3	3	3
Contaminant Volume Reduction	1	5	3
Community Health and Safety	2	4	3
Worker's Health & Safety	1	4	3
Duration of Work	5	1	3
Net Present Value of Options Costs	4	1	1
Potential Litigation	3	2	4
Environmental Reserve	5	3	4
Standards, Laws and Regulations	5	5	3
Service Reliability and Performance	1	4	3
Reliability (maintenance & repair)	4	4	4
Technological Uncertainty	4	3	5
Corporate Image	2	4	4
Total	**40**	**43**	**43**
Total Score	**62%**	**66%**	**66%**

Figure 11: Example of Qualitative Options Analysis (total score % is total divided by sum of scores for options).

- Level 2: Semi-quantitative evaluation. At this level, SR processes may increase in complexity and include additional metrics. BMPs which involve planning and design can be used. A footprint analysis may be performed that includes a limited CFA for comparative purposes but will not be detailed enough to provide a precise quantification of GHG and energy use associated with the remedial option or options. Metrics can be weighted based on their relative importance to key stakeholders, which makes this type of analysis better suited to address trade-offs. In the MCA performed at this level, normalized scoring schemes are introduced that make semi-quantitative evaluations less subjective, and more rigorous and consistent, than a qualitative evaluation. The scores are multiplied by the weight to come up with a score for each category and remedial option. An example of a simplified MCA is provided in Figure 12.
  - Examples of available semi-quantitative tools include simple GHG estimators developed by US EPA (see Section 3.4).

Criteria	*Option 1* Dig & Dump	*Option 2* Bioventing	*Option 3* ISCO	Weight	Scoring
Reduction of Contaminant Volume	90	90	100	1	**Reduction of Contaminants:** Efficacy of option in reducing the volume of contaminated soils **Scoring scheme:** 0 - < 33% of soil volume estimated to be remediated to below criteria 45 - 33 to 66% of soil volume estimated to be remediated to below criteria 90 - 66 to 100% of soil volume estimated to be remediated to below criteria 100 - all soil volume estimated to be remediated to below criteria
Contaminant Migration	90	100	100	3	**Contaminant Migrations** Efficacy of option in reducing migration risk and potential impacts to non-biological receptors (sewers, buildings, etc.) 0 - Does not prevent risk of offsite migration 50 - Partially prevents risk of offsite migration 90 - Prevents migration risk through containment 100 - Contaminant source is removed; migration risk eliminated
Community Health & Safety	33	100	66	2	**Community Health and Safety** Potential adverse impacts on health & safety arising from the option (excluding drinking water) **Scoring Scheme:** 0 - Significant potential impact on the community 33 - Moderate potential impact on the community 66 - Low potential impact on the community 100 - No anticipated potential impact on the community
Total Score (%)	47	66	59		

Figure 12: Example of Simplified MCA

- Level 3: Quantitative evaluation. This type of evaluation is similar to the Level 2 evaluation but often incorporates a greater number of quantitative indicators and more complex metrics. A more advanced level of design is performed in order to integrate detailed EFA and/or more BMPs into a MCA for comparison of multiple options. The level of effort required to conduct the measurement or calculation depends on the affordability and availability of the required data or resources. The evaluation often relies on a detailed EFA where absolute values are compared directly, or normalized to facilitate detailed comparative analysis and trade-offs. Evaluation of safety including transportation risk may be part of a Level 3 evaluation (see information on vehicle accident statistics in Appendix C).
  - Examples of available quantitative tools include the SiteWise tool or SR Dashboard developed for this project (Section 6.3)

SR Dashboard: *The SR Dashboard tool (Section 6.3) provides a structured approach and tool for conducting sustainability evaluations based on environmental, social and economic indicators. There are three parts to the Dashboard: 1) Impact tool; 2) Footprinter tool; and 3) MCA based on desired indicator weighting/scoring scheme. While example indicators are provided, a flexible approach is recommended where relevant project-specific indicators are selected. The Footprinter tool enables GHG emissions, energy use and air emissions to be quantified based on select indicators, and a limited scope LCA (for in-depth analysis SiteWise is recommended). The Sustainability evaluation is implemented in a workbook format that is practical, transparent, simple to use and focuses on key metrics. The level of analysis is considered appropriate for simpler assessments and as a heuristic learning tool (for more in-depth analysis SiteWise or other tools are recommended).*

Regardless of the implementation level, the SR evaluation process provides an important opportunity to optimize the remedial design based on an assessment of risks and benefits associated with different alternatives.

c) Incorporation of Climate Change-induced Impacts in SR Evaluation

An emerging consideration is incorporation of climate change and increased climate risk events in the evaluation of sustainable remediation (US EPA 2015, Washington Department of Ecology 2017, Maco et al. 2018; Jourabchi and Muppidi 2019; Kumar and Reddy 2020; BC ENV 2019; ITRC 2021). As climate-change-induced impacts are becoming increasingly apparent, there is a concomitant need to assess the vulnerability and resilience of longer-term remediation and in particular risk managed contamination. The “Preliminary Strategic Climate Risk Assessment for BC” (BC ENV 2019) describes a risk assessment framework and 15 “provincially significant” risk events in terms of likelihood and consequences of risks (loss of life, loss of natural resources, economic impact). The greatest climate risks to BC were deemed to be drought and water scarcity, wildfire, extreme heat, ocean acidification and glacier mass loss with the highest consequence risks being severe riverine flooding and severe coastal storm surge. Jourabchi and Muppidi (2019) highlight the key factors of the climate risk events identified by BC ENV (2019) with potential impact on remediation, particularly those that impact the hydrogeologic cycle.

Examples of weather events with potential implications for site remediation in Canada include increased temperature, which could affect ecosystems, and in northern areas permafrost; increased precipitation and/or drought (depending on region), which could affect groundwater systems and water table elevations; declining snowpack, which may affect surface water and groundwater systems; sea level rise, which could affect remediation in low-lying areas and/or cause increased salt-water intrusion; and increased flooding, which could affect remediation in flood-prone areas. The extreme events that impact remediation can result in unanticipated costs or spreading or mobilization of contamination causing increased risk to human and ecological health. Where vulnerabilities are identified, resiliency and adaptation measures can be developed and incorporated in the remedial design to maintain the long-term integrity of the remedy.

A framework is presented with the goal of increasing resilience defined as the capacity to withstand and recover from threats to remediation measures. A three-step assessment process for incorporating climate change in sustainable and resilient remediation is:

1) climate exposure assessment
2) vulnerability assessment
3) adaptation assessment, implementation and monitoring

The framework and information sources are described in Table 3. The level of detail and methods used in the assessment will vary depending on the site and remediation implemented. For some sites, a qualitative assessment of potential climate change related impacts and vulnerabilities will be sufficient, while at other sites, a more in-depth, quantitative evaluation may be warranted including climate modeling.

It is recognized that climate change resilience and adaptation is an emerging field of practice and that assessment methods are continuing to evolve. There remain significant questions on how to practically incorporate climate change into a sustainability assessment, which itself is a newer area that continues to advance.

Table 3: Three-step Assessment Process for Incorporating Climate Change in Sustainable Resilient Remediation

Step	Description	Information Sources
1	**Climate exposure assessment**: Determines how climate change is affecting climate risk factors (e.g., weather, flooding, sea level, wildfires) at a local site level, and what are the effects on intensity, frequency and duration of extreme weather events. From this information, the CSM is updated to include climate-related factors.	Pacific Climate Impacts Consortium website[9] Fraser Basin Council Retooling for Climate Change website[10] Environment Canada Climate Trends and Variations Bulletins[11]
2	**Vulnerability assessment**: Considers the adaptive capacity and sensitivity in a remediation system from exposure to potential hazards or threats. Loss or reduced function may adversely impact the environment, affect social well-being and have economic implications.	BC ENV 2019 Preliminary Strategic Climate Risk Assessment for British Columbia.[12] Addressing the New Normal: 21st Century Disaster Management in British Columbia[13] US EPA Superfund Climate Resilience website[14] Maco et al. 2018 ITRC 2021
3	**Adaptation assessment, implementation and monitoring:** Consists of measures that increase resilience and enable remedies to adjust to new or changing environments. Periodic monitoring of implemented measures should be conducted, and resiliency should be reassessed.	Washington State Washington Department of Ecology 2017. Adaptation Strategies for Resilient Cleanup Remedies. November. Publication 17-09-052. US EPA Superfund Climate Resilience website[15] ITRC 2021

V. Record SR Efforts – Monitoring and Evaluation of Key Sustainability Indicators

IMPORTANCE: What doesn't get measured doesn't get done. Documenting SR efforts is an important part of determining whether SR goals are being achieved at a site and communicating benefits and accomplishments to stakeholders.

Tracking of key performance indicators will allow the practitioners to:

- Measure and report GHG, energy costs, and sustainable initiatives associated with remediation projects.
- Illustrate the benefits achieved through the consideration of sustainability principles when managing contaminated sites.
- Improve and optimize the environmental, social and economic performance of their projects.

[9] https://pacificclimate.org/data
[10] https://www.retooling.ca/
[11] https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/climate-trends-variability/trends-variations/summer-2020-bulletin.html

[12] https://www2.gov.bc.ca/gov/content/environment/climate-change/adaptation/risk- assessment

[13] https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/embc/bc-flood-and-wildfire-review-addressing-the-new-normal-21st-century-disaster-management-in-bc-web.pdf

[14] https://www.epa.gov/superfund/superfund-climate-resilience

[15] https://www.epa.gov/superfund/superfund-climate-resilience

One recommended method for achieving a higher level of optimization and control of project performance involves using standardized metrics, which are ratios of key performance metrics. Examples include cost per contaminant mass reduction unit, energy use per liter of LNAPL recovered or GHG emission per cost unit. These can be compared to internal or industry benchmarks, allow for a more robust assessment of performance, and can have a significant impact on project optimization. An example of a project performance dashboard is presented in Figure 13.

PERFORMANCE ANALYSIS - GREENHOUSE GAS EMISSION / LNAPL RECOVERY									
Projects	Region	Technology	Status	Greenhouse Gas Emissions	KPI Unit	Free product recovered	KPI Unit	Performance Ratio	Unit
Project #1	Saskatchewan	*VER*	Completed	97.05	T CO2 eq	10 835.0	L	9.0	kg CO2 eq / L
Project #2	Alberta	*Dual phase extraction*	Ongoing	220.57	T CO2 eq	14 971.0	L	14.7	kg CO2 eq / L
Project #3	British Columbia	*VER*	Ongoing	4.03	T CO2 eq	17 810.0	L	0.2	kg CO2 eq / L
TOTAL	**-**	**-**	**-**	**321.7**	**T CO2 eq**	**43 616.0**	**L**	**7.37**	**kg CO2 eq / L**

Figure 13: Example Project Performance Dashboard

Roadmap Summary

The roadmap detailed in this section is meant to serve as a guideline to apply the SR process to many different types of projects. It is up to the project team to decide which aspects of the Roadmap are useful for their needs and the needs of the project. Having a structured approach to the implementation of SR provides credibility to the process. This is important because the perception of greenwashing has been a significant obstacle to adoption of SR in the past. Other aspects that can be considered to enhance the credibility and robustness of the chosen approach include:

- Proactive stakeholder engagement and consultative processes.
- Thorough and transparent documentation and reporting.
- Consistency of the approach, in terms of methods and indicators, both within the project life-cycle and across multiple projects (programmatic approach).

6.0 CASE STUDIES AND TOOLS

6.1 Case Study #1 - Train Derailment

The first case study described in this section involves a large petroleum hydrocarbon spill caused by a train derailment. The derailment occurred in a peat bog, and the applicable regulation stated that contamination must be remediated promptly. The different aspects of this project are presented in the same order as the Roadmap in this guidance.

I. Evaluate/Update Conceptual Site Model

The main elements of the Conceptual Site Model are as follows:

- Approximately 280,000 litres 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 over a 1.21 hectare area.
- Contamination reached a depth of 2.44 metres; most of the petroleum hydrocarbons have been adsorbed into the peat due to high organic content; in some areas where the organic layer is thinner hydrocarbons have reached underlying mineral soils.
- The derailment occurred in a sensitive natural environment at the junction of multiple ecological units: a bog, a lagg, a fen and a forest. Special-status plants are present about 300 m from the spill site. Ditches are present in the spill area and these eventually discharge into a river. Surface flow patterns are complex in wet seasons when the water table level is near the ground surface.
- Stakeholders include the rail company, regulators, land owners and an environment protection group.
- Private supply wells are present 1.3 km downstream of the site; dissolved-phase impacts are shown to be limited in extent.
- The initial assessment is that natural attenuation processes will be slow due to the acidic environment.
- Matrix interference (high organic content) creates high uncertainty in analytical results.
- Due to the sensitive nature of the site, only a limited number of remediation technologies were initially considered feasible to undergo further assessment:
  - Complete excavation of soils impacted above applicable criteria.
  - Partial excavation of soils impacted above applicable criteria, and risk analysis.
  - Remediation by monitored natural attenuation.

II. Establish Goals

Considering the sensitive natural habitat and the risk that excavation could create long-term damage, a SR approach was adopted to compare less potentially damaging remedial options and to provide a sound scientific basis for communicating these options with stakeholders. The ultimate goal was to identify a remedial method that would reduce risk to acceptable levels, preserve the integrity of the ecosystem, and satisfy stakeholder expectations.

III. Stakeholder Involvement

From early on after the spill, stakeholders included the provincial regulator and land owners. These two stakeholders had a high level of interest and influence and, as such, frequent communication and engagement was a necessity.

Later in the project an environmental protection group (conservation society) became involved. This group had, in past years, been working with Ducks Unlimited Canada to obtain ecological reserve status for the peat bog where the spill occurred. In addition, a university research unit, which had been conducting research on peat bog ecosystems in the area, also became involved. The unique knowledge of the ecosystem provided by landowners, environmental protection groups and university research staff was useful to refine the CSM. University staff were engaged in the project early on. Some of the staff were hired to support the site characterization effort. One community member started a blog on the project that was updated regularly to inform residents and other interested members of the public. This initiative was encouraged.

The transparent and consistent approach that was adopted, including consultation and collaboration with stakeholders, was paramount in reaching consensus on the SR approach to implement at this site. These efforts culminated during a technical review panel held between project proponent, consultants, regulators and university research staff, in which final outstanding concerns were addressed and a path forward was agreed upon.

IV. Select Indicators, Metrics, and SR Evaluation Method

a) Indicator Selection

Several iterations of MCA were performed using the GoldSET-SR tool (discussed in Appendix B). A set of indicators reflective of corporate objectives based on site-specific conditions was developed (Table 4). The following table list those indicators for each dimension. The indicators formed a balanced mix and included:

- qualitative and quantitative indicators
- indicators indicative of risks and benefits
- corporate objectives and site-specific indicators

Table 4: Indicator Selection for Case Study #1

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	

b) Indicator Weighting

Indicator weighting was completed on a 3-point scale based on project objectives and stakeholder concerns. Indicators that were the most important were those pertaining to the risk of off-site migration, ecological integrity, health and safety, social sensitivity, and corporate image, cost, and potential litigation.

c) Scoring and Evaluation

For qualitative indicators, a four-point scale was used: Scores were assigned to each option for each metric by the project team. The scoring was reviewed by the project proponent to ensure alignment with the remedial strategy and corporate objectives.

The carbon footprint of each option was assessed using the GoldSET footprinter tool. In this case, the most significant emissions elements were machinery and transport for soil excavation scenarios. For the MNA option, drilling equipment and field personnel mobilization were the most significant sources of emissions. The footprint calculated for each option was as follows:

- Complete excavation: 321 tons CO_2-e.
- Partial excavation and risk analysis: 255 tons CO_2-e.
- MNA: 17 tons CO_2-e.

d) Analysis, Presentation and Documentation of Results

Results were presented on ternary diagrams where each axis represents the performance of the option with respect to environmental, social and economic dimensions (Figure 14). The performance for each dimension of sustainability is represented by a percentage score calculated based on individual scores and weights for each factor considered. Typically, the largest and most balanced triangle is considered the most sustainable.

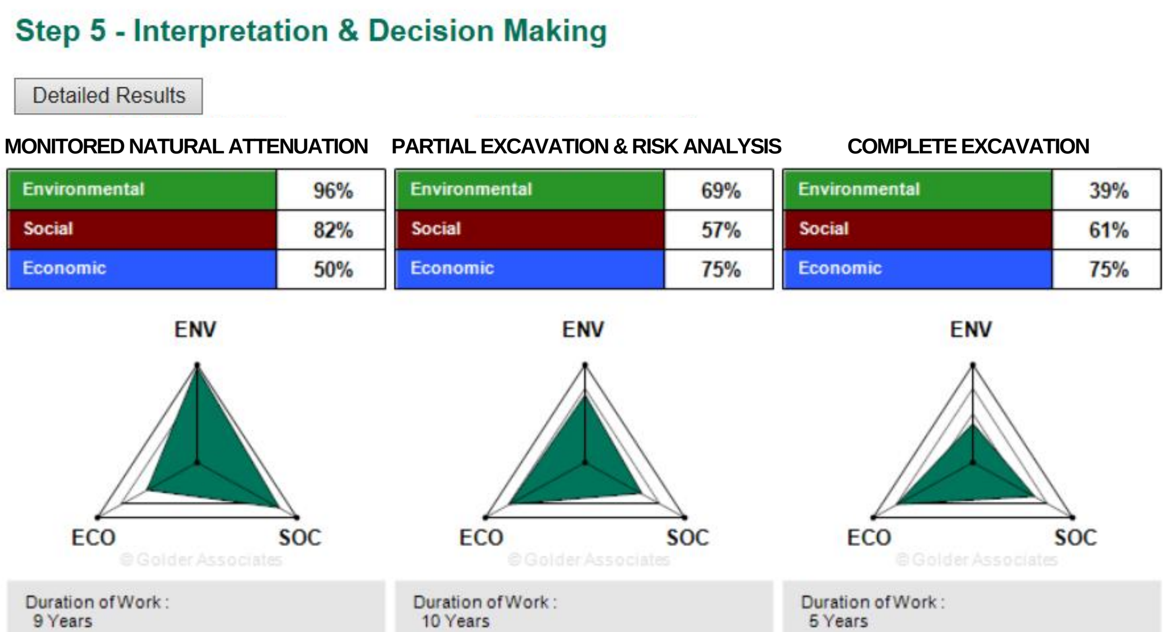


Figure 14: Example output from GoldSET-SR tool showing ternary diagrams indicating performance of each option for Case Study #1

According to the initial scoring, the most sustainable option was MNA. However, after presenting the rationale to the regulator, the technical uncertainty was considered too great to accept as-is. Using the results of the SWOT analysis, a new option was designed that incorporated parts of Options #1 and #2. This alternative would include some excavation of the most contaminated areas and enhanced bioremediation for the remainder of the impacted area. A review panel was organized with several of the key stakeholders in order to streamline the selected alternative and obtain consensus on the path forward. The final refined option was approved and is currently being implemented.

The following benefits were identified as resulting from the adoption of a sustainable approach for this site:

- Using solar panels to operate blowers will avoid one tonne CO_2-e over 20 years (BMP).
- Special walkways built by the owner to facilitate site monitoring and O&M activities encourage the local economy and minimize impacts to vegetation (BMP).
- Collaboration with academic research staff from project inception up to execution improved the robustness of the technical approach (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 land owners for remedial action plan approval, providing site access to public, and supporting a blog to inform concerned citizens about the remediation project, all contributed to social participation and acceptance.
- Tripod-mounted drilling equipment and manual augers were used instead of track-mounted equipment for soil sampling to avoid damage to vegetation (BMP).
- Training and use of resources from the local university peat bog research department reduced the number of personnel that mobilized to the site (GHG) and provided additional expertise on the science of peat bog restoration (BMP).

Some of the above benefits stemmed from the use of a sustainable decision framework (in the form of MCA). Other benefits such as the use of solar panels and low-impact drilling equipment are BMPs. These benefits were realized due to early integration of sustainability as a project objective, and the systematic consideration of key SR indicators across the entire project life cycle.

6.2 Case Study #2 - Tank Farm Diesel Spill

The second case study described in this section involves a diesel spill in a former liquid-fuels tank farm in Victoriaville, Québec. The presence of a total petroleum hydrocarbon (TPH) plume migrating off the property made it necessary to consider technologies to either treat the source or provide hydraulic control (by installing a barrier). The different aspects of this project are presented in the same order as the Roadmap presented in this guidance.

I. Evaluate/Update Conceptual Site Model

The main elements of the Site Conceptual Model are as follows:

- Location: Québec, residential area
- Former tank farm
- Closed at the end of 1980s (after 40 years operation)
- Site area: 1,600 m^2
- Gasoline and diesel above-ground storage tanks (ASTs) and fueling station
- Petroleum equipment dismantled, building remained
- Monitoring network: 30 monitoring wells on site
- Fine sandy soils
- Hydraulic conductivity ranged between approximately 2.9 to 3.8 x 10^{-3} cm/sec
- Contaminants of Concern: BTEX + Petroleum Hydrocarbons C_{10}-C_{50}
- Estimated subsurface mass of TPH: 7,000 kg
- Groundwater BTEX plume migrated off-site
- Plume impacted municipal sewer below street

The five options considered to address the environmental issues were:

- Monitored natural attenuation (MNA)
- Hydraulic barrier
- Complete excavation of the contaminated soil
- Excavation of shallow contaminated soil and bioremediation
- In-situ chemical oxidation (ISCO)

II. Establish Goals

Following an initial screening of potential solutions for this Site, which generated several promising yet very different approaches, the site owner decided to use this site as a pilot project to integrate sustainability objectives into the remedial decision-making process. One of the key success factors was to minimize and mitigate environmental and social impacts of the remediation work. Golder recommended a SR approach and use of a MCA tool as a balanced, impartial and informed way to operationalize sustainable development principles.

III. Stakeholder Involvement

The stakeholders identified in this project included the neighbouring property owners and the regulator. The municipality additionally was a key stakeholder since the contaminant plume extended below a roadway where underground utilities were present. While the level of stakeholder involvement was relatively low, both the regulator and municipality had a high level of authority over the project due to the remedial approval process, which required both parties' review and sign off. The stakeholder engagement strategy consisted of keeping all parties informed of the progress of the project and ensuring timely submission of deliverables and communications.

IV. Select Indicators, Metrics, and SR Evaluation Method

a) Indicator selection

The MCA analysis was performed using the GoldSET-SR tool. A set of indicators that reflected corporate objectives based on site-specific conditions was developed for each dimension (Table 5). The indicators were selected mainly from the Global Reporting Initiative (GRI, 2006) and the International Federation of Consulting Engineers (FIDIC) "Project Sustainability Management" guide (PSM 2004).

Table 5: Indicator Selection for Case Study #2

Environment	Society	Economy
Soil quality improvement	Local resident safety	Initial capital cost
Groundwater quality improvement	Corporate image	Maintenance cost
Water supply usage	Duration of work	Local suppliers
Material use	Work pollution (noise, dust, visual, traffic)	Research and development tax credits
Transportation impacts	Local job creation	Technological uncertainty
Hazardous waste generation		
GHG emissions		
Energy consumption		

b) Indicator Weighting

Indicator weighting was completed on a 3-point scale based on project objectives and stakeholder concerns. Indicators that were the most important were those pertaining to cost, technological uncertainty, and soil and groundwater quality improvement.

c) Scoring and Evaluation

For qualitative indicators, a five-point scale was used: very negative, negative, neutral, positive and very positive. As part of the initial scoring and evaluation process the ISCO option was found to be fatally flawed due to the presence of underground utilities that could be damaged by the presence of oxidants. Furthermore, the bioremediation option was modified to include excavation of surficial soils, which could not be treated using the chosen technology. While monitored natural attenuation was retained as an option, as indicated environmental performance was low because of off-site plume migration.

The carbon footprint of each option was assessed using the GoldSET footprinter tool. In this case, the most significant emissions elements were machinery and transport for soil excavation scenarios. Some of the quantitative indicators assessed as part of the evaluation are represented in the following charts (Figures 15a, b, c).

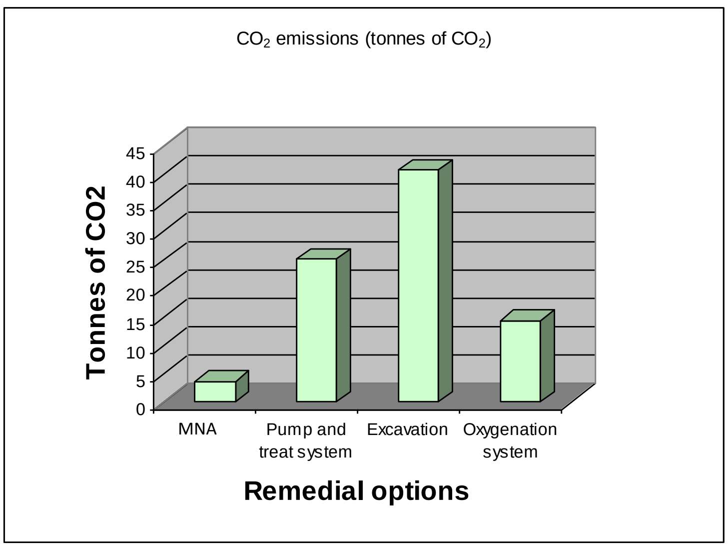


Figure 15A: Example Output from GoldSET-SR tool Showing CO2 Emissions for Four Remedial Options for Case Study #1

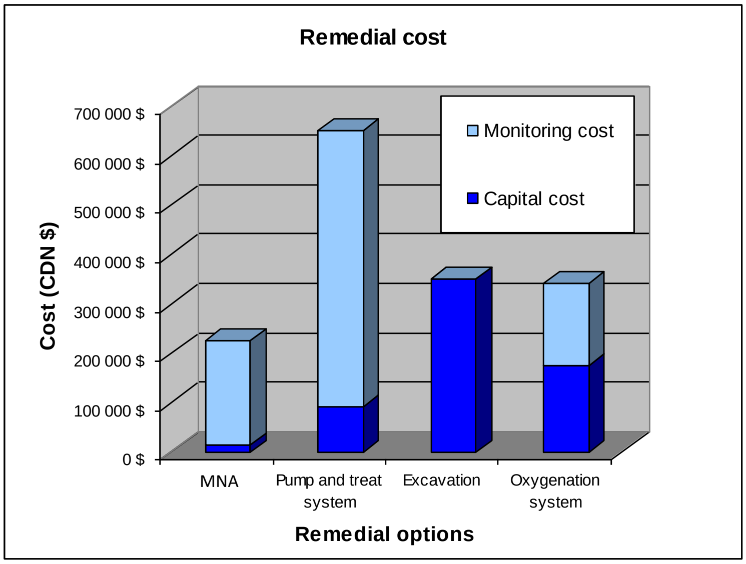


Figure 15B: Example Output from GoldSET-SR Tool Showing Remediation Costs for Four Remedial Options for Case Study #1

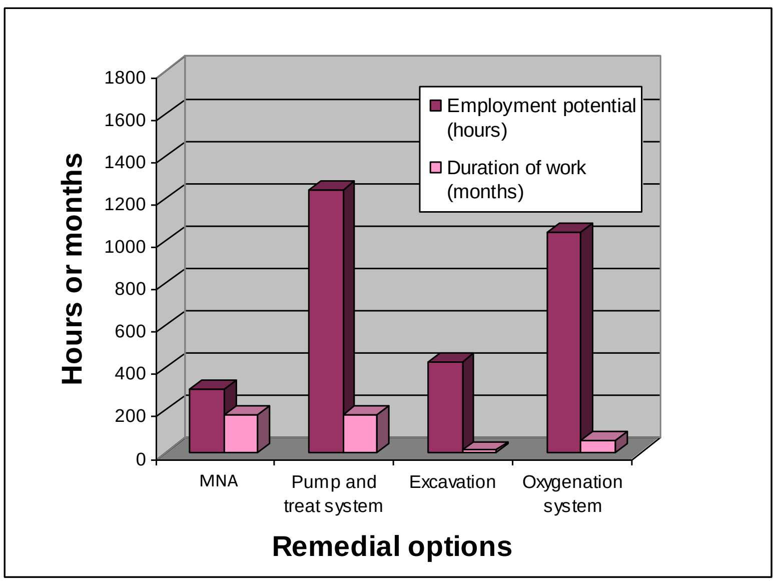


Figure 15C: Example Output from GoldSET-SR Tool Showing Duration of Work and Employment Potential for Four Remedial Options for Case Study #1

d) Analysis, Presentation and Documentation of Results

The results were presented on ternary diagrams where each axis represents the performance of the option with respect to environmental, social and economic dimensions (Figure 16). The performance for each dimension of sustainability was represented by a percentage score calculated based on individual scores and weights for each factor considered. Typically, the option with the largest, most balanced triangle is considered the most sustainable.

GRID INPUT DATA - SITE REMEDIATION

TYPE OF REMEDIATION

OPTION 1 :
NATURAL ATTENUATION with monitoring of the groundwater quality

OPTION 2 :
PUMP AND TREAT to prevent offsite migration of groundwater

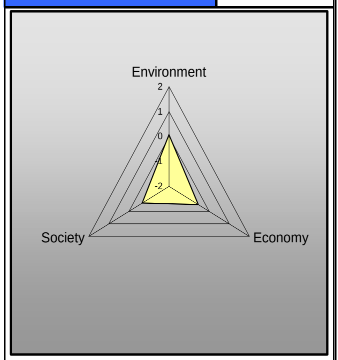
OPTION 3 :
EXCAVATION AND OFFSITE DISPOSAL to respect the applicable criteria

OPTION 4 :
EXCAVATION of the superficial soils (non saturated) and **BIOREMEDIATION** of the saturated soils by injection of oxygenated water

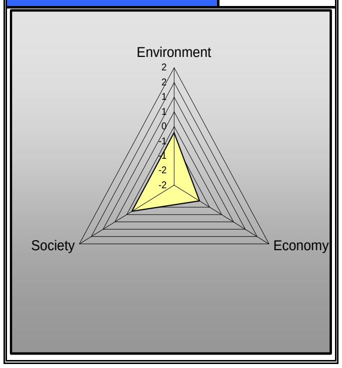
OPTION 5 :

REMARKS :
Working Document

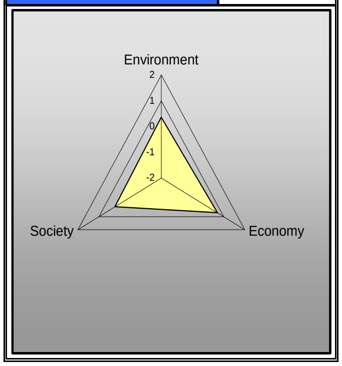
RESULTS - OPTION 1	
ENVIRONMENT	0,07
SOCIETY	-0,67
ECONOMY	-0,54



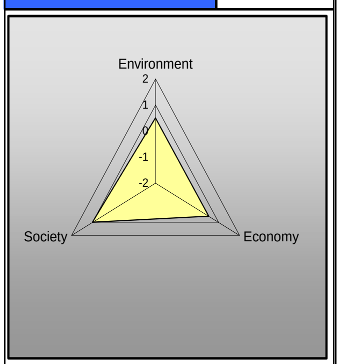
RESULTS - OPTION 2	
ENVIRONMENT	-0,21
SOCIETY	-0,22
ECONOMY	-0,92



RESULTS - OPTION 3	
ENVIRONMENT	0,36
SOCIETY	0,22
ECONOMY	0,69



RESULTS - OPTION 4	
ENVIRONMENT	0,50
SOCIETY	1,00
ECONOMY	0,54



RESULTS - OPTION 5	
ENVIRONMENT	#VALEUR!
SOCIETY	#VALEUR!
ECONOMY	#VALEUR!

REMARKS :

N/A : Non Applicable Indicator

Notation Attribution :

Effects	Note
Very Negative	-2
Negative	-1
Neutral	0
Positive	+1
Very Positive	+2

Figure 16: Example Output from GoldSET-SR Tool Showing Ternary Diagrams Indicating Performance of Each Option for Case Study #1

Based on the scoring, the most sustainable option was determined to be partial excavation of shallow contaminated soil and aerobic bioremediation through injection of water that was super-saturated with oxygen. The selected option was successful in meeting project objectives and had minimal negative impacts on the local neighborhood. The containment of the contaminant plume was quickly achieved and impacts to the City sewer were eliminated. The lessons learned from this project include:

- The water oxygenation system was the most sustainable of the options evaluated under the site conditions and an efficient technology to remediate saturated soil and groundwater impacted with hydrocarbons.
- The use of a comprehensive MCA tool is an efficient and robust way to manage trade-offs and decide on the best remedial approach for a site; it adds structure to the process and provides a high level of confidence on the overall outcome of the project.
- Bioremediation was implemented through extraction and treatment of groundwater, water oxygenation and reinjection. Treatment through a recirculation loop was effective.
- Iron clogging was a technical challenge. Conductivity probes used as sensors to control equipment operation were clogged after a few weeks of operation. These probes were replaced by hydrostatic pressure sensors. Bag filters were added to the recirculation process.

6.3 SR Dashboard

The Sustainable Remediation (SR) Dashboard is a new tool developed for this project to conduct sustainability evaluations and is available on the CSAP website[16]. The SR Dashboard consists of three tools:

1) **Environmental Footprinter Tool** is a spreadsheet tool for conducting a lifecycle analysis (LCA) of the environmental footprint for key indicators using BC reference values (BC ENV 2018).
2) **Impact Tool** is a spreadsheet tool for summarizing environmental, social and economic dimensions. The tool incorporates key indicators from US EPA (2018) and includes additional social and economic indicators. Summary data from the Footprinter Tool can be added to the Impact Tool worksheet.
3) **Multi-criteria Analysis (MCA) Tool** is a spreadsheet tool to enable structured comparison of remediation options. The MCA Tool incorporates information from the Impact Tool.

The three tools are described below.

[16] Available at https://csapsociety.bc.ca/members/professional-development/technical-studies/

6.3.1 Environmental Footprinter Tool

The Environmental Footprinter Tool is described and example calculations are provided in this section.

6.3.1.1 Description of the Tool

The Footprinter Tool enables a focused LCA to be conducted for the following impacts:

- GHG emissions
- Energy use
- Air pollutants (NO_X; SO_X; PM_{10} emissions)

The rationale for the environmental Footprinter Tool is to provide a simple-to-use screening tool for assessing environmental impacts associated with site remediation that incorporates BC defaults for energy use and greenhouse gas emissions associated with vehicle and equipment use. The tool quantifies impacts in eleven categories for the lifecycle of environmental site investigation, remediation or construction, operation and monitoring and decommissioning. The Footprinter does not include certain impacts such as equipment and vehicle manufacture and shipping of equipment to a site, and only addresses air treatment using granular activated carbon, given the complexity in estimating emissions for other air treatment technologies. The SiteWise model is recommended for more in-depth evaluations.

Where BC defaults are available, the inputs may be accessed through drop-down menus. For other defaults, the data must be input in the calculation sheet. To aid in this process, references are provided, which are primarily defaults provided in the SiteWise model, as this model includes a comprehensive database oriented on remediation. As warranted, the user should access other sources of data, for example, the US EPA SEFA model, and the Ecoinvent and SimaPro databases. The input of data in this way promotes a heuristic or learning approach to conducting a footprint analysis.

The users of the Footprinter Tool should be reasonably knowledgeable on LCA methods and available tools. The context of Footprinter Tool within broader LCA should be understood. A LCA may consider not only impacts associated with remediation (often termed secondary impacts), but primary impacts associated with contamination at the site, and tertiary impacts associated with future redevelopment and site use. In some cases, human health and ecological risks or eco-system impacts have been assessed in LCA or have included social indicators, for example, Reddy et al. (2014) describe an MCA and scoring system for social indicators.

A step-by-step process for conducting a LCA is described by Favara et al. (2011) and guidance for conducting LCA is available, e.g., ISO 14040. Essential steps include defining the functional unit, the impact categories and boundaries of the LCA. Examples of detailed LCA that includes a monetized LCA and cost benefit analysis (CBA) are described by Cappuyn (2013) and Huysegoms et al. (2019). Another approach is to conduct a cost-benefit and MCA analysis where factors that can be monetized such as remediation costs, land value and greenhouse gas emissions are combined in a cost-benefit analysis, and then input into a qualitative multi-criteria analysis.

6.3.1.2 Example Calculations

An example energy calculation[17] is provided below for truck travelling 100 miles (161 kilometres).

EC = AD x G x E x EFF

EC = Energy Consumption (e.g., MJ)
AD = Activity Data (e.g., miles) = 100 mi
G = Energy Efficiency (e.g., US gal/mile) = 0.0394 US Gal/mi (BC MOECC 2018)
E = Energy Coefficient (e.g., Btu/US gal) = 10.633 Btu/US Gal
EFF = Energy Efficiency or Load Factor = 1 (typical value)

EC = 100 mi x 0.0394 US Gal/mi x 10.633 Btu/US Gal x 1 = 42 Btu

EC = 161 km x 0.0926 L/km x 0.00296 MJ/L x 1 = 0.044 MJ

Energy efficiency decreases with increasing load. The SiteWise equation for a truck is:

G = -0.102 x Load (tons) + 7.4 (in mpg)

An example calculation is provided below for truck traveling 100 miles with emission factor default from BC government guidance (BC MOECC 2018).

GHG Emissions = AD x G x EF

AD = Activity Data (e.g., miles) = 100 mi
G = Energy Efficiency (e.g., US gal/mile) = 0.0394 US Gal/mi
EF = Emission factor (e.g., kg CO_2/US gallon) = 8.8 kg CO_2-e/US Gal

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

GHG Emissions = 161 km x 0.0926 L/km x 2.32 kg CO_2-e/L = 0.035 tonnes CO_2-e

The Dashboard Footprinter does not currently include the CO_2 emissions from natural biodegradation of hydrocarbons through NSZD (SiteWise does not include this emission source either).

The GHG emissions from NSZD can be estimated using the following equation:

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

GHG = 0.0025 t-CO_2/L x NSZD Rate (L/m^2/yr)

Assuming a NSZD rate of 700 US-gal/acre/yr, the equivalent CO_2 emission rate would be 6.6 tonne CO_2-e/acre/year. NSZD has lower total emissions compared to active technologies that oxidize petroleum hydrocarbons (e.g., bioventing, soil vapour extraction with oxidation of air emissions, in situ chemical oxidation).

[17] Both SI and Imperial units are shown as source of some equation and input parameters is US guidance and because NSZD rates are often expressed in Gal/acre/yr.

6.3.2 Impact Tool

The Impact Tool incorporates the following indicators (sub-indicators are in parentheses):

- **Environmental**
  - GHG emissions
  - Energy use (total energy use; energy from renewables)
  - Air pollutants (NO_X; SO_X; PM_{10} emissions)
  - Waste (hazardous waste disposed off-site; non-hazardous waste disposed off-site)
  - Materials (water use, other raw materials, e.g., cement; steel; minerals)
  - Land, Water and Ecosystem (environmental quality; biota (animals and plants) and habitat effects; soil fertility and functionality effects; water quality effects)
  - Permanence and long-term effectiveness
  - Technology reliability and resiliency
- **Social**
  - Community revitalization (economic, social)
  - Noise, dust, traffic, visual impacts
  - Land use access (improved, restricted)
  - Safety (worker safety on-site; public safety near-site, vehicle accident risk (non-fatal))
  - Time (time of remediation)
- **Economic**
  - Cost (capital and operation and maintenance)

The above indicator set focuses on primarily the impacts of the environmental remediation conducted at a site, which are considered secondary impacts in a LCA of site remediation. The set also includes benefits of remediation associated with social-economic factors (community revitalization), which are secondary impacts when associated with the remediation phase, or tertiary impacts when associated with future conditions or land use. The impacts of site contamination itself, which are considered the primary impacts in a LCA, while not included as default impacts may also be considered. Possible indicators in this category include reduction in human and/or ecological health risk or toxicity. Because typically all remediation should achieve an acceptable threshold of risk or compliance with environmental quality standards or guidelines, a comparative evaluation of remedial options may not require consideration of these indicators unless there is uncertainty in achieving standards or guidelines. Practitioners are encouraged to add, subtract or modify indicators based on project requirements. There are several sources of example indicators including UK CL:AIRE Sustainability Guidance.[18]

[18] https://www.claire.co.uk/component/phocadownload/category/16-surf-uk-bulletins%3Fdownload%3D365%3Asurf-case-study-1 (updated in 2020)

DRAFT BETA SR DASHBOARD (*V1.1 - Golder Associates*)

IMPACT OF TECHNOLOGY - ____________________

	Indicator (add/subtract as warrented)	Metric	Typical Measurement Unit[12]	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 effects 3. Soil fertility or functionality effects 4. Water quality effects (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 and climate change	Qualitative	Site-specific assessment		
Social	Community	1. Economic and/or social revitalization 2. Noise, dust, traffic, visual impacts 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		

Figure 17: Screen Shot of SR Dashboard Impact Tool

6.3.3 MCA Tool

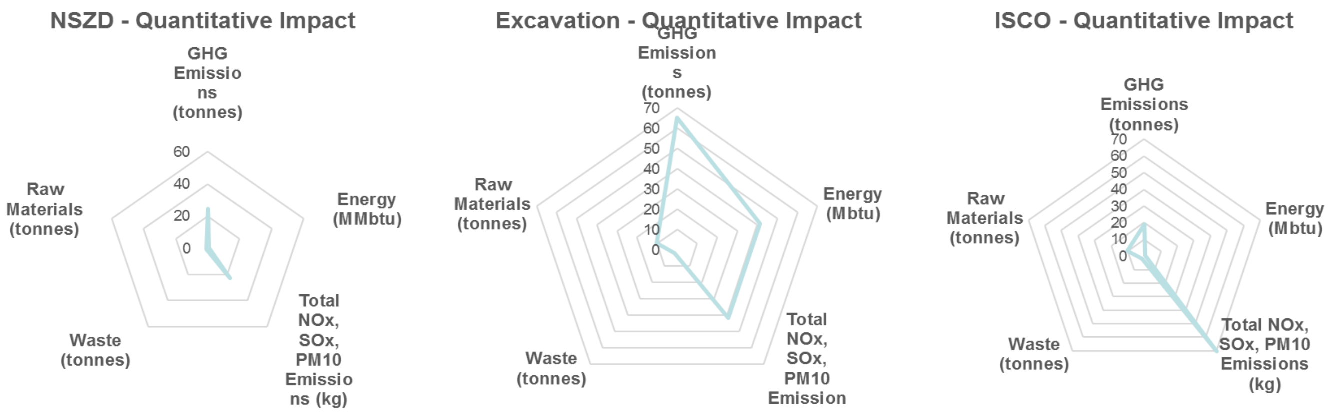
The MCA Tool enables comparison of three technologies based on the three dimensions of sustainability, environmental, social and economic. A five-point scoring system is used with 5 being the highest score, and 1 the lowest score. For indicators that can be positive or negative depending on remediation (e.g., social aspects), 5 indicates a highly positive impact, while 1 is a highly negative impact, with 3 being neutral. With indicators that are always associated with negative impacts (e.g., GHG gas emissions), 5 is a minimal negative impact, while 1 is a significant negative impact. Each indicator is weighted according to a three-point scale. As discussed in Section 4.3 of this guidance alternative scoring systems are available.

6.3.4 Example use of SR Dashboard

A hypothetical example of the use of the SR Dashboard is provided where three technologies are evaluated: 1) NSZD, 2) excavation and offsite disposal of soil and 3) ISCO (using persulfate). All three scenarios assume an initial soil and groundwater investigation and recovery of mobile LNAPL to the extent practicable using skimming technology. The site has sandy soils and contamination is present to a depth of 4 m below ground surface.

The estimated volume of contaminated soil is 5,000 m^3. For all three technologies, the distance from the impacted site to the consultant's office, laboratory, drilling company yard, or landfill (for excavation scenario) is 50 km. The output sheets for the hypothetical comparison are provided below with results of the Footprinter provided in Appendix D. Quantitative impacts are compiled in the Dashboard Impact Tool sheet and compared using radar plots.

Based on the quantitative impacts and qualitative evaluation for non-quantitative impacts, comparisons are given scores in the multi-criteria assessment. The overall scores of three technologies were similar, with NSZD receiving the highest score. The overall scores are influenced by scoring of individual indicators and weighting chosen. A sensitivity analysis should be performed by varying the scores.



All options assume baseline LNAPL recovery option (skimming)

Figure 18A: Screen Shot of SR Dashboard Impact Tool Graphics

COMPARISON OF IMPACT & MCA FOR MULTIPLE TECHNOLOGIES										MCA				
Indicator (add/subtract as warrented)		Metric	Typical Measurement Unit[12]	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. Environmental quality 2. Biota (animals and plants) and habitat effects 3. Soil fertility or functionality effects 4. Water quality effects (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 and resiliency of technology with respect to performance/risk particularly in relation to extreme events and climate change	Qualitative	Site-specific assessment	Site-specific assessment	Site-specific assessment	2	3	4		3	6	9	12
Social	Community	1. Revitalization (economic, social) 2. Disturbance through 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
												84	81	78

Figure 18B: Screen Shot of SR Dashboard MCA Tool

6.3.5 Reduction of Carbon Footprint

Many companies and organizations are considering measures to reduce their carbon footprint and GHG emissions. While the goal should be emission reduction, an additional way to reduce an organizations carbon footprint is through purchase of offsets. For example, these may be used to offset carbon emissions from electricity use, fuel use and travel. An emerging concept is where specific measures incorporated in the environmental remediation or post-remediation site development phase are used to reduce the carbon footprint. Measures that have been proposed are phytoremediation where trees reduce carbon emissions in addition to remediating soil or groundwater (where the trees are a permanent feature of site development), planting trees on a site for the sole purpose of reducing carbon emissions or use of surface amendments such as concrete wastes to sequester carbon dioxide from bioremediation migrating toward the ground surface. Through such measures it may be possible to reduce carbon emissions and potentially achieve carbon neutrality of remediation. The practical application of measures to reduce carbon emissions requires further evaluation and demonstration. Measures to reduce the carbon footprint of remediation are further discussed in Appendix E.

7.0 SUMMARY

Sustainable remediation incorporates the triple bottom line, which encompass environmental (or referred to as biophysical factors), social and economic factors, to improve remedial decision-making. This new paradigm in the field of site clean-up provides a comprehensive framework for addressing trade-offs, and a means to achieve maximum value, or net benefit, with regards to the triple bottom line: sustainable remediation. Green remediation seeks similar objectives but with a greater focus on environmental net benefit, and lesser focus on social and economic aspects.

This toolkit provides a comprehensive review of SR concepts and guidance. Standard approaches and methods for SR evaluations have been divided into three levels based on their complexity and level of effort, as follows:

- Level 1: Qualitative analysis consisting of best management practices (BMPs), sustainable management practices (SMPs) and/or simple multi-criteria analysis (MCA).
- Level 2: Semi-quantitative evaluation consisting of environmental footprint analysis (EFA) or carbon footprint analysis (CFA) and/or MCA.
- Level 3: Quantitative and more complex evaluation consisting of life cycle analysis (LCA) and/or MCA.

A Roadmap that provides a step-by-step process for implementing a SR project is presented. For each step, the authors of this toolkit provide their own experience-based interpretation of the key elements that should be considered to achieve a successful SR implementation. Success is defined as the achievement of tangible and measurable benefits in all three spheres of sustainability and is captured in the following five steps.

I. Evaluate/update conceptual site model (CSM)

II. Establish goals

III. Stakeholder involvement

IV. Select indicators and SR evaluation method

V. Record SR efforts

There are tools available for evaluations of sustainable remediation that should be used in improving greening of technologies and for selection of options based on sustainability indicators including a new SR Dashboard tool that combines a footprint analysis with MCA tool developed for this project. The use of these approaches and tools for evaluation of remedial options for management of contaminated sites is encouraged.

8.0 REFERENCES

ASTM E2876-13, Standard Guide for Integrating Sustainable Objectives into Cleanup, ASTM International, West Conshohocken, PA, 2013. https://www.astm.org/Standards/E2876.htm

ASTM E2893-16e1, Standard Guide for Greener Cleanups, ASTM International, West Conshohocken, PA, 2016. https://www.astm.org/Standards/E2893.htm

Bardos RP, Bone BD, Boyle R, Ellis D, Evans F, Harries N, & Smith JWN, 2011. Applying sustainable development principles to contaminated land management using the SuRF-UK framework. *Remediation*, *22*, 77-100

Bardos RP, Bone BD, Boyle R, Evans F, Harries N, Howard, T & Smith JWN. 2016. The rationale for simple approaches for sustainability assessment and management in contaminated land practice. *Science of the Total Environment*. 563-564, 755-768. http://dx.doi.org/10.1016/j.scitotenv.2015.12.001

Bardos, R.P., H.F. Thomas, J. W. N. Smith, N.D. Harries, F. Evans, R. Boyle, T. Howard, R. Lewis, A. O. Thomas, V.L. Dent and A. Haslam. Sustainability assessment framework and indicators developed by SuRF-UK for land remediation option appraisal. Remediation, V. 31, Issue 1, Winter, pp. 5-27. https://doi.org/10.1002/rem.21668

BC Ministry of Environment and Climate Change (BC ENV) 2018. 2018 B.C. Methodological Guidance for Quantifying Greenhouse Gas Emissions. January 2019, draft https://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2018-pso-methodology.pdf

BC Ministry of Environment and Climate Change (BC ENV) 2019. Preliminary Strategic Climate Risk Assessment for British Columbia. July. https://www2.gov.bc.ca/gov/content/environment/climate-change/adaptation/risk-assessment

CL:AIRE, 2009. A Review of Published Sustainability Indicator Sets: How applicable are they to contaminated land remediation indicator-set development? SuRF-UK Report, CL:AIRE, London. https://www.claire.co.uk/projects-and-initiatives/surf-uk

CL:AIRE, 2010. A framework for assessing the sustainability of soil and groundwater remediation. SuRF-UK Report, CL:AIRE, London. https://www.claire.co.uk/projects-and-initiatives/surf-uk

CL:AIRE, 2011. A framework for assessing the sustainability of soil and groundwater remediation. Annex 1 – SuRF-UK indicator set for sustainable remediation. SuRF-UK Report, CL:AIRE, London. https://www.claire.co.uk/projects-and-initiatives/surf-uk

CL:AIRE, 2014. Sustainable Management Practices for Management of Land Contamination. SuRF-UK Report, CL:AIRE, London. https://www.claire.co.uk/projects-and-initiatives/surf-uk/21-executing-sustainable-remediation/84-sustainable-management-practices includes supporting spreadsheet SURF-UK SMPs: https://www.claire.co.uk/component/phocadownload/file/403-surf-uk-smps

CL:AIRE & NICOLE, 2015. *A review of the legal and regulatory basis for sustainable remediation in the European Union and the United Kingdom*. Joint SuRF-UK/NICOLE report. CL:AIRE, London. Download at http://www.claire.co.uk/surfuk

CRC for Contamination Assessment and Remediation of the Environment (CARE). 2018. Guidance on performing cost-benefit and sustainability analysis of remediation options. V. 0.1. August.

Cundy, A.B., R. P. Bardos, A. Church, M. Puschenreiter, W. Freisl-Hanl, I. Muller, S. Neu, M. Mench, N. Witters and J. Vangronsveld. 2013. Developing principles of sustainability and stakeholder engagement for “gentle” remediation approaches: the European context. J. of Environ Manage. Nov. 129: 283-291.

Environment Agency,1999. Costs and Benefits Associated with Remediation of Contaminated Groundwater: A Review of the Issues. Environment Agency R&D Technical Report P278. Bristol, UK. Available at: http://webarchive.nationalarchives.gov.uk/20140329112119/http://cdn.environment-agency.gov.uk/str-p278-e-e.pdf

Ellis, D.E. and P. Hadley, 2009. Sustainable Remediation White Paper—Integrating Sustainable Principles, Practices, and Metrics Into Remediation. REMEDIATION Summer 2009.

Favara, P.J., T.M. Krieger, B. Bougton, A.S. Fisher, M. Bhargava. 2011. Guidance for performing footprinting analysis and life-cycle assessments for the remediation industry. Remediation Journal, Vol. 21, Issue 3. https://doi.org/10.1002/rem.20289

Favara, P., D. Raymond, M. Ambrusch, A. Libera, G. Wolf, J.A. Simon, B. Maco, E.R. Collins, M.A. Harclerode, A. D. McNally, R. Ridsdale, M. Smith and L. Howard. 2019. Ten years later: The progress and future of integrating sustainable principles, practices, and metrics into remediation projects. Remediation. 2019;29:5–30.

Harclerode, M., D. Risdale, D. Darmendrail, P. Bardos, F. Alexandrescu, P. Nathanail, L. Pissol and E. Rizzo. 2015. Integrating the Social Dimension in Remediation Decision-Making: State of the Practice and Way Forward. Remediation. 17 December. https://doi.org/10.1002/rem.21447.

Harclerode, M. A., Pankaj, L., & Miller, M. E. (2016). Quantifying global impacts to society from the consumption of natural resources during environmental remediation activities. Journal of Industrial Ecology, 20(3), 1088–1980. https://doi.org/10.1111/jiec.12380

Higgins, M.R. and T. M. Olson. 2009. Life-Cycle Case Study Comparison of Permeable Reactive Barrier versus Pump-and-Treat Remediation. Environ. Sci. Technol., 43 (24), pp 9432–9438. DOI: 10.1021/es9015537.

Hou, D., P. Guthrie and M.Rigby. 2016. Assessing the trend in sustainable remediation: a questionnaire survey of remediation professionals in various countries https://www.repository.cam.ac.uk/bitstream/handle/1810/264031/GSR%20Trend%202016-08-12a%20-%20complete.pdf?sequence=1&isAllowed=n

Huysegoms, L., S. Rousseau and V. Cappuyns. 2019. Chemical or Natural? Including LCA in Social CBA to Compare Remediation Alternatives for a Dry-Cleaning Facility. Sustainability 2019, 11, 1975; doi:10.3390/su11071975

ISO 18504:2017 Soil quality -- Sustainable remediation.

ITRC, 2011. ITRC Green Sustainable Remediation Guidance. May 2011. http://www.itrcweb.org/Team/Public?teamID=7

Interstate Technology & Regulatory Council (ITRC). 2021. Sustainable Resilient Remediation, Washington, D.C.: Interstate Technology & Regulatory Council, Sustainable Resilient Remediation Technical Team (In progress). http://www.itrcweb.org/.

Jourabchi, P., P. Muppidi 2019. Climate Change and Management of Petroleum Hydrocarbon Sites: Tools for Informed Decision Making. Presented at Science Advisory Board for Contaminated Sites (SABCS) in British Columbia Workshop, 25 September 2019.

Kaliyavaradhan, S.K., T.C. Ling. 2017. Potential of CO_2 Sequestration Through Construction and Demolition (C&D) Waste – An Overview. J. of CO_2 Utilization, 20: 234-242.

Kumar, G. and K. R. Reddy. 2020. Addressing Climate Change Impacts and Resiliency in Contaminated Site Remediation. J. of Hazardous, Toxic and Radioactive Waste. Volume 24, Issue 4, October. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000515

Lemming, G., M.Z. Hauschild, J. Chambon, P.J. Binning, C. Bulle, M. Margni and P.L. Bjerg. 2012. Environmental Impacts of Remediation of a Trichloroethene-Contaminated Site: Life Cycle Assessment of Remediation Alternatives. Journal of Environmental Management 112 392-403.

Maco, B., Bardos, P., Coulon, F., Erickson-Mulanax, E., Hansen, L., Harclerode, M., … Wick, W. (2018). Resilient remediation: Addressing extreme weather and climate change, creating community value. Remediation, 18(29), 7–18. https://doi.org/10.1002/rem.21585.

Morais, S.A. and C.Delerue-Matos. 2010. A perspective on LCA application in site remediation services: Critical review of challenges. J. of Hazardous Materials. 175, 12-22.

Project Management Institute (PMI). 2017. A guide to the Project Management Body of Knowledge (6th ed.). Project Management Institute.

Ridsdale, D.R. and B.F. Noble. 2016. Assessing Sustainable Remediation Frameworks Using Sustainability Principles. J. Environ. Manage. Dec 15. 184 (Pt 1): 36-44.

Rizzo, E., P. Bardos, L. Pizzol, A. Critto, E. Giubilate, A. Marcomini, C. Albano, D. Darmendrail, G. Doberl, M. Harclerode, N. Harris, P. Nathanail, C. Pachon, A. Rodriguez, H. Slender, and G. Smith. 2016. Comparison of International Approachs to Sustainable Remediaion. J. Environ. Manage. 15 Environ Manage, 184(Pt 1):4-17. doi: 10.1016/j.jenvman.2016.07.062.

Smith JWN & Kerrison G. 2013. Benchmarking of decision-support tools used for tiered sustainable remediation appraisal. *Water, Air & Soil Pollution*, *224(12)*. http://dx.doi.org/10.1007/s11270-013-1706-y

Smith, J.W.N. 2019. Debunking myths about sustainable remediation. Remediation. Volume 29, Issue 2 Spring Pages 7-15 28 February https://doi.org/10.1002/rem.21587Ci

US EPA 2008. US EPA Green Remediation Primer. Report 542-R-08-002. April 2008. https://www.epa.gov/sites/production/files/2015-04/documents/green-remediation-primer.pdf

US EPA 2010. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008. EPA Report 430-R-10-006. April 15.

U.S. Environmental Protection Agency (U.S. EPA). 2015. Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies. https://semspub.epa.gov/work/11/177110.pdf

US EPA 2017. Overview of EPA's Methodology to Address the Environmental Footprint of Site Cleanup. September 14. https://www.epa.gov/remedytech/green-remediation-best-management-practices-overview-epas-methodology-address

Washington Department of Ecology 2017. Adaptation Strategies for Resilient Cleanup Remedies. November. Publication 17-09-052.

APPENDIX A

Best Management Practices to Improve Sustainability of Remediation Technologies

BEST MANAGEMENT PRACTICES TO IMPROVE SUSTAINABILITY OF REMEDIATION PROJECTS

Sustainable remediation practices are aimed at optimizing the elimination or mitigation of contamination (technical performance) and social, environmental, and economic impacts of the remediation activities in short and long terms. The approach to sustainable land remediation thus begins with the decision on the intended land use following remediation, and follows through all the stages: design, management, construction, and monitoring.

Regulatory agencies are increasingly encouraging a more sustainable approach to land remediation and are developing guidance and policies on sustainable remediation (SR) practices (ITRC 2011; SuRF-UK 2011; US EPA 2008; US Corps of Engineers 2012). An important aspect of SR are best management practices (BMPs) or measures to reduce the environmental footprint and improve sustainable best management practices of remedial measures (ASTM 2876-13). Case studies describing implementation of BMPs are provided at the SuRF website[1].

This appendix addresses BMPs to improve primarily the environmental sustainability of remediation projects although some social indicators are also addressed. The following information is provided:

1) General principles
2) BMPs for key indicators of SR that address environmental and social impacts of remediation.
3) BMPs for twelve remediation technologies

1.0 GENERAL PRINCIPLES

As a general principle, appropriate selection of technologies including risk-based measures, efficient implementation of technologies and system optimization will improve remediation sustainability. The following are important general principles:

1) Consider risk-based remediation approaches where feasible, as opposed to remediation to generic criteria. This is particularly important for larger and more difficult to remediate sites.
2) Adopt the right remediation technology or combination of technologies. If an inappropriate treatment technology is selected, the system will run an indefinite time without achieving the treatment goals. It is important to match the technology with the problem.
3) Set achievable remediation objectives and metrics and define an exit strategy. Often as the remediation goes on the mass removed or concentration reduction achieved is reduced. Correspondingly, the energy and cost per unit of contaminant treatment often increases and may become unsustainable.
4) Select the right combination of technologies and where appropriate phase technology implementation following a treatment train approach. Move from initial more aggressive technologies to polishing technologies, for example, a remediation train could consist of hydraulic removal of product followed by natural source zone depletion (NSZD) or monitored natural attenuation (MNA).
5) Select equipment that is energy efficient or uses renewable energy and optimizes processes to reduce energy use, reduce the use of natural resources and minimize greenhouse gas emissions.
6) Conduct upfront planning and establish reasonable timeframes for implementation of remediation.

[1] http://www.sustainableremediation.org/library/case-studies/case-study-initiative-database/

2.0 BEST MANAGEMENT PRACTICES

The following sections identify BMPs for the following core indicators (US EPA 2008):

- Energy consumption
- Greenhouse gas emissions
- Air Quality
- Ecosystem
- Waste generation
- Material (Natural Resource) Use
- Water Quality
- Soil and Sediment Quality
- Community
- Worker Safety/Accident Risk

Each section below identifies and best practices for reducing environmental footprint (for environmental indicators) and improving sustainability (for social indicators).

2.1 Energy Consumption

Issues

- amount and type of energy consumed by technology including transportation
- use of non-renewable energy

More sustainable measures

- use of renewable energy (wind, solar, geothermal) for operation of equipment or heating
- use of wind turbines for aeration (to promote natural biodegradation)
- passive or low intensity technologies (e.g., skimming, bioventing)
- options that reduce transportation distances (for material, equipment, products, and wastes)
- energy efficient equipment and low power requirement when in stand-by
- proper maintenance of equipment according to manufacturer’s recommendations
- use of power derived on site without external utility demand
- pump size optimization (all equipment) and periodic re-evaluation

- remote data collection to reduce site visits (less fuel consumption and vehicle emissions)
- solar powered telemetry systems
- meteorological stations
- air emission sensors, mobile laboratory equipment
- quick data access for faster response (real-time measurement system)
- use of heat pump or exchanger (e.g., when pumping heated groundwater)
- process that requires low-energy production for amendments/reactants
- minimize equipment idling
- use of smaller drilling rigs including direct push rigs when appropriate

2.2 Greenhouse Gas Emissions

Issues

- greenhouse gas emissions (carbon dioxide, CO_2, methane, CH_4, nitrous oxide, N_2O, chlorofluorocarbons, CFCs and sulphur hexafluoride, SF_6)
- potential for climate change

More sustainable measures

- many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered)
- caution should be taken in evaluating measures in isolation, a simple example is just quantifying GHG emissions from transportation may miss significant emissions from other sources such as on-site equipment operation and materials use (carbon miles can be is a useful metric for comparison to other factors)
- use of renewable energy (wind, solar, geothermal) for operation of equipment or heating
- options that reduce transportation distances (for material, equipment, products, and wastes)
- options that substitute cleaner fuels with respect to GHG emissions (e.g., biodiesel) or use of renewable-generated electricity in place of fossil fuel use
- options that reduce the use of fossil fuels (e.g., optimum pump size, efficient equipment)
- options that reduce material use particularly those materials associated with high carbon footprints

2.3 Air Quality

Issues

- pollutants (e.g., oxides of nitrogen, NOx, oxides of sulphur, SOx)
- particulates
- odour

More sustainable measures

- reducing dust by wet-spray techniques
- equipment and vehicles with alternative fuel (or hybrid vehicles)
  - cleaner fuels such as ultra low sulfur diesel, or biodiesel for heavy equipment (e.g., drill rigs)
  - use of particulate filters and oxidation catalysts (diesel retrofits) for exhaust treatment
  - electric vehicles with zero tailpipe emissions.
- use of smaller equipment (e.g., smaller drill rigs) or vehicles, when practical
- use of technologies that minimize generation of volatile non-desirable or toxic by-products
- minimize equipment idling
- Using vapor treatment methods appropriate for the influent vapor concentrations and maintaining treatment works such that efficiency is maintained (e.g., carbon change-out).

2.4 Ecosystem

Issues

- impacts with respect to ecological integrity indicators (quantity, quality, type) and biodiversity
- potential for risk to species with special status (rare, endangered, vulnerable, etc.)
- impact to protected or conservation areas
- habitat alteration or destruction
- disturbances (e.g., noise, light and vibrations, forest clearings, introduction of exotic or invasive species)

More sustainable measures

- use passive energy technologies such as bioremediation and phytoremediation as primary remedies or “finishing steps,” where possible and effective
- minimize soil and habitat disturbance
- minimize intrusive activities in sensitive areas or use alternate techniques (e.g., risk management, mitigation)
- conduct work during times when disturbance will be less (during dry periods, when ground is frozen, low flow)

- reduce noise from power generators and lighting
- relocate species and/or provide for habitat compensation
- adopt specific discharge criteria
- reduce noise and lighting disturbance

2.5 Waste Generation

Issues

- amount and type of wastes generated (hazardous waste, industrial waste, solid waste)
- handling, transportation and disposal of wastes

More sustainable measures

- reduce contaminated soil excavation volumes through excavation method (shoring, trench-box)
- on-site reuse of excavated and treated materials (with due consideration for potential residual risk)
- reduction of secondary wastes (soil cores, drill cuttings, drilling fluids, wastewater, reagents, chemicals, etc.) through changed or optimized practices
  - passive sampling techniques or techniques that reduce purge volumes when appropriate
  - on site sample analysis to reduce number of soil cores obtained and samples sent to laboratory
  - field screening to reduce number of samples
  - smaller boreholes for investigation programs
  - optimized pumping strategies for pump and treat systems
- use of recycled material for wastewater or air treatment (e.g., compost biofilter, regenerated activated carbon, etc.)
- adopt appropriate e-waste separation techniques
- consider sustainable or “green” purchasing, which considers product materials and life cycles and gives preference to:
  - products that are re-cycled and bio-based (as opposed to petroleum products)
  - products and packing materials that used re-cycled material and/or minimize disposables
  - product contents and manufacturing processes involving nontoxic chemical alternatives
- set up re-cycling program on-site
- use of smaller drilling rigs including direct push rigs when appropriate to reduce drill cuttings

2.6 Material (Natural Resource) Use

Issues

- amount and type of materials used
- water, aggregate, construction materials, etc.

More sustainable measures

- use water conserving fixtures, valves and piping
- re-cycle or re-use materials
- re-use of construction debris (e.g., demolition concrete as on-site fill or road-base)
- re-cycling of non-contaminated, pest-free organic matter as compost or mulch
- use of local by-products as part of remediation (e.g., bio-solids as part of soil cover)
- total or partial use of non-potable (stormwater/greywater) instead of potable water for aspects of remediation, if feasible
- use of treated water or excess of pumped water for irrigation, vegetation, etc.
- use of native vegetation for reclamation to reduce irrigation

2.7 Water Quality

Issues

- Chemical: release of contaminants, nutrients, dissolved organic carbon, changes in salinity and mobility of contaminants
- Physical: release of particulates, changes in river levels, water tables, flooding
- Biological: aquatic ecosystems
- Current and future water use

More sustainable measures

- limit discharges to water bodies through re-cycling or re-use of water on-site in process, for irrigation, or for other use
- cleaning equipment
  - use of steam and non-phosphate detergent for cleaning equipment
  - avoiding the use of organic solvents and acid solutions unless necessary given contaminant type
- managing or reducing the load of suspended solids from remediation activities
- scheduling of work to reduce potential for sediment impacts, limiting traffic in sensitive areas

- use of enclosed water wash systems for cleaning of vehicles
- adherence to relevant best management practices for control of sediment through control of runoff, silt fences, basins, etc. and control of discharges to water bodies to prevent impacts from nutrients, temperature, or other aspects

2.8 Soil and Sediment Quality

Issues

- chemical: residual contamination, contaminant by-products, potential for release of contaminants
- physical: erosion, stability, drainage, compaction
- biological: ecosystem function
- soil sealing (permanent covering with impermeable layer) and loss of ecological function and impacts to runoff

More sustainable measures

- measures to control traffic, excavation, etc. to prevent erosion, soil sealing, increased runoff
- specialized techniques to minimize soil compaction such as mulch layers and geosynthetic mats
- quick-growth seeding and geotextiles to promote vegetative growth and minimize erosion and sediment runoff
- limiting footprint of remediation to limit impacts to ecosystem
- scheduling work to reduce potential impacts to terrestrial receptors (e.g., migrating species)
- methods that minimize sediment impacts, run-on and runoff
- environmental dredging methods that minimize turbidity

2.9 Impacts to Community

Issues

- revitalization of brownfields
- economic benefits to community
- noise
- dust
- traffic
- visual effects

- time duration of remediation
- impact on local and traditional land uses
- impact on recreational uses

More sustainable measures

- integrate remediation with land use planning to maximize benefit to community
- involve stakeholders in the process
- measures or modifications that reduce time of remediation if there are negative impacts
- minimizing road closures or reduced access
- adjusting working hours
- measures to reduce noise (e.g., mufflers), dust (e.g., watering) and visual impacts (e.g., barriers)
- dust suppressants and substitution of less hazardous investigation or remediation methods

2.10 Health and Safety/Accident Risk

Issues

- safety of workers
- safety of public
- equipment risk
- vehicle risk
- direct contact with contaminated media
- exposure to volatile chemicals in air
- toxicity of contaminant
- toxicity of chemicals that are used in treatment process

More sustainable measures

- development of risk matrix for severity and probability of risk
- identification of measures to reduce probability of risk
- job safety assessments
- exposure assessment and control plan
- monitoring programs
- substitution of less hazardous investigation or remediation methods
- change in work practices

3.0 BMPS FOR SELECT REMEDIATION TECHNOLOGIES

BMPs for reducing the impact of remediation and improving environmental sustainability of different technologies are provided for select remedial technologies in the sections below.

3.1 Excavation and off-site disposal

a. Planning and Design

   i. More intensive investigation to refine and potentially reduce excavation footprint

   ii. Risk-based approaches to reduce excavation footprint

   iii. Combining excavation with targeted in situ treatment in subareas to reduce excavation footprint

   iv. Scheduling optimization for resource sharing and fewer days of mobilization

   v. Sustainable or “green” requirements for product and service procurement, for example, preference for products with recycled and bio-based contents

b. Energy Consumption

   i. Selecting waste receivers that are closer to site and options that reduce transportation distances (for material, equipment, products, and wastes)

   ii. Investigating alternate shipping methods such as rail lines, if more energy efficient

   iii. Investigating opportunities for resource sharing with other waste haulers

   iv. Selecting suitably sized equipment for the task

   v. Measures to avoid engine idle and using machinery with automatic idle-shutdown devices

   vi. Use of more energy efficient equipment or motors

   vii. Consideration of onsite treatment of soil when feasible and acceptable

c. Greenhouse Gas Emissions

   i. Many of the measures that reduce energy consumption will also reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered); caution should be taken in evaluating measures in isolation

   ii. Installation of modular renewable energy system for field equipment (e.g., solar panels for small equipment)

   iii. Use of cleaner fuels such as biodiesel especially when made from recycled products

d. Air Quality

   i. Cleaner fuel such as ultra-low sulfur diesel, wherever available (and as required by engines with particulate matter traps)

    ii. Appropriately maintained equipment such as regular replacement of filters
    iii. Dust suppression measures such as appropriately applied water
    iv. Revegetation of areas as soon as practical
    v. Use of biodegradable fabrics or mats that reduce erosion and dust generation while also promoting regrowth
    vi. Use of truck wheel wash to minimize tracking of soil across the site and offsite
    vii. Limiting speed of vehicles onsite

e. Ecosystem, Human Health, Impacts to Water, Soil and Sediment

    i. Minimize soil erosion through appropriate temporary road construction methods, silt fences and retention basins
    ii. Minimize soil compaction through for example use of mulch layer and well-defined vehicle routes
    iii. Mitigate uncontrolled stormwater run-off
    iv. Use of biodegradable fabrics and mats to promote regrowth and enhancing soil fertility
    v. Revegetation of areas as soon as practical and use of native plants for revegetation if applicable to reduce irrigation
    vi. Consider whether operational graywater can be re-infiltrated (if non-contaminated) as opposed to disposing of it in public sewer system
    vii. Use of phosphate-free detergents
    viii. 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 sediment and soil across non-work areas or offsite
    i. Avoiding tree removal in staging areas or intermittent uncontaminated zones, and retrieving and transplanting native, non-invasive plants

f. Material (Natural Resource) Use

    i. Measures to reduce excavation footprint to reduce backfill needed

g. Waste

    i. Recycling of asphalt and concrete; there are several companies in BC that provide this service; City of Richmond (2017) presents a methodology for estimating GHG emission reduction through re-cycling as recycled aggregates generally produce less emissions than an equivalent quarry product
    ii. Reuse of treated material as backfill or cover material, with careful consideration of potential liability and issues with reuse

iii. Conversion of excavated waste to fuel (e.g., coal tar-derived waste materials with high BTU have been mixed with coal to produce synthetic fuels, although overall this technology has high GHG emissions associated with it)[2]

h. References (additional general references at end of document)

i. City of Richmond, 2017. Concrete and Asphalt Recycling for Road Base Material Production, City of Richmond Option 2 Project Plan. Svend Andersen, GHG Accounting Services, February.

ii. US EPA 2008. Green Remediation: Best Management Practices for Excavation and Surface Restoration. EPA 542-F-08-012. December.

3.2 Groundwater Pump and Treat

a. Planning and Design

i. Scheduling optimization for resource sharing and fewer days of mobilization

ii. Conduct additional design and pilot testing to optimize full scale design with respect to operational requirements and air treatment

iii. Consideration of horizontal extraction wells when potentially more efficient

iv. Modify a system to suit changes in a contaminant plume over time

v. Transition to natural source zone depletion (NSZD) and monitored natural attenuation (MNA) as soon as conditions are favorable to effectively remediate residual contaminants

vi. Consider reinjecting treated water downgradient of the extraction system to flatten the hydraulic gradient and increase the capture zone near the extraction wells, and potentially reduce the overall extraction rate; conduct hydrogeologic evaluation to determine whether reinjection could adversely affect extraction efficiency[3]

vii. Consider diverting upgradient, uncontaminated groundwater around the contaminant plume to reduce the amount of water to be extracted; feasibility of groundwater diversion involves evaluation of environmental trade-offs such as disturbance to land, ecosystems, and subsurface hydraulic conditions

viii. Sustainable or “green” requirements for product and service procurement, for example, preference for products with recycled and bio-based contents

---

[2] https://clu-in.org/products/newsltrs/tnandt/view.cfm?issue=1111.cfm

[3] Under the BC provincial regulatory framework re-injection of treated groundwater requires an authorization under the Waste Discharge Regulation and should meet applicable requirements of BC Groundwater Protection Regulation. As treated water re-injection is a non-standard practice, specific regulatory requirements should be confirmed.

b. Energy Consumption

   i. 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

   ii. Use of gravity flow where feasible to reduce the number of pumps for water transfer after groundwater extraction

   iii. Use of renewable or geothermal energy for extraction and treatment plant

   iv. Use of solar or wind powered groundwater pumps

   v. Selecting suitably sized water treatment equipment

   vi. 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

   vii. 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

   viii. Heat exchangers to enable reuse of heat rather than discharging it as part of the effluent

   ix. 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

c. Greenhouse Gas Emissions

   i. Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered); caution should be taken in evaluating measures in isolation

   ii. Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for extraction)

d. Air Quality

   i. 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 do not cause fouling) and to reduce emissions

e. Ecosystem, Human Health, Impacts on Water, Soil and Sediment

   i. Minimizing footprint of remediation works

   ii. Avoiding dewatering of wetlands and disrupting wetland ecosystems located near extraction wells

   iii. Minimizing noise

f. Material (Natural Resource) Use

   i. 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[4]

g. Waste

   i. Use of sequestering agents to keep a maximum amount of iron and manganese in solution, to prevent equipment fouling, rather than removing them and generating additional process waste

   ii. 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

   iii. 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

h. References

   i. US EPA 2005. Cost-Effective Design of Pump and Treat Systems. OSWER 9283.1-20FS EPA 542-R-05-008. April.

   ii. US EPA 2007. Technology News Trends. Issue 30. May.

   iii. US EPA 2009. Green Remediation Best Management Practices: Pump and Treat Technologies. EPA Report 542-F-09-005. December.

3.3 Excavation and Off-site Bioremediation (Including Land Farming)

a. Planning

   i. More intensive investigation to refine and potentially reduce excavation footprint

   ii. Risk-based approaches to reduce excavation footprint

   iii. Combining excavation with targeted in situ treatment in subareas to reduce excavation footprint

   iv. Scheduling optimization for resource sharing and fewer days of mobilization

   v. Optimizing treatment through innovative technology adoption such co-composting or using amendments that increase biodegradation rates (Bergeron et al. 2015)

[4] Under BC provincial regulatory framework re-injection of treated groundwater requires an authorization under the Waste Discharge Regulation and should meet applicable requirements of BC Groundwater Protection Regulation. As treated water re-injection is a non-standard practice, specific regulatory requirements should be confirmed.

vi. Sustainable or "green" requirements for product and service procurement, for example, preference for products with recycled and bio-based contents

b. Energy Consumption

i. Selecting suitably sized equipment for the task

ii. Measures to avoid engine idling and using machinery with automatic idle-shutdown devices

iii. Use of more energy efficient equipment or motors

iv. Use of passive or low powered active venting of biopiles using solar or wind power

v. Use of insulating material such as hay or straw-bale insulation

c. Greenhouse Gas Emissions

i. Many of the measures that reduce energy consumption will also reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered); caution should be taken in evaluating measures in isolation.

ii. Installation of modular renewable energy system for field equipment (e.g., solar panels for small equipment)

iii. Use of cleaner fuels such as biodiesel especially when made from recycled products

d. Air Quality

i. Cleaner fuel such as ultra-low sulfur diesel, wherever available (and as required by engines with particulate matter traps)

ii. Appropriately maintained equipment such as regular replacement of filters

iii. Dust suppression measures such as appropriately applied water

iv. Revegetation of areas as soon as practical

v. Use of biodegradable fabrics or mats that reduce erosion and dust generation while also promoting regrowth

vi. Limiting speed of vehicles onsite

e. Ecosystem, Human Health, Impacts to Water, Soil and Sediment

i. Minimize soil erosion through appropriate temporary road construction methods, silt fences and retention basins

ii. Minimize soil compaction through for example use of mulch layer and well-defined vehicle routes

iii. Mitigate uncontrolled stormwater run-off

iv. Use of biodegradable fabrics and mats to promote regrowth and enhancing soil fertility

v. Revegetation of areas as soon as practical and use of native plants for revegetation if applicable to reduce irrigation

vi. Consider whether operational graywater can be re-infiltrated (if non-contaminated) as opposed to disposing of it in public sewer system

vii. Use of phosphate-free detergents

viii. 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 sediment and soil across non-work areas or offsite

ix. Avoiding tree removal in staging areas or intermittent uncontaminated zones, and retrieving and transplanting native, non-invasive plants

f. Material (Natural Resource) Use

i. Measures to reduce excavation footprint to reduce backfill needed

ii. Measurement of soil moisture and analysis to optimize addition of water to avoid over irrigation during treatment

g. Waste

i. Recycling of asphalt and concrete; there are several companies in BC that provide this service; City of Richmond (2017) presents a methodology for estimating GHG emission reduction through re-cycling as recycled aggregates generally produce less emissions than an equivalent quarry product

ii. Reuse of treated material as backfill or cover material, with careful consideration of potential liability and issues with reuse

h. References

i. Bergeron, E., C. Gosselin, S. Hains and J. Cote. 2015. Co-composting of contaminated soil, Battelle, Third (3rd) International Symposium on Bioremediation and Sustainable Environmental Technologies, May 18-21, Miami, FL.

ii. City of Richmond, 2017. Concrete and Asphalt Recycling for Road Base Material Production, City of Richmond Option 2 Project Plan. Svend Andersen, GHG Accounting Services, February.

3.3 Dual or Multi-phase Extraction

a. Planning and Design

i. Scheduling optimization for resource sharing and fewer days of mobilization

ii. Conduct additional design and pilot testing to optimize full scale design with respect to operational requirements and air treatment

iii. Consideration of horizontal extraction wells when potentially more efficient

iv. Define optimal recovery end-points based on LNAPL mobility concepts to avoid unnecessary operation

v. Transition to natural source zone depletion (NSZD) and monitored natural attenuation (MNA) as soon as conditions are favorable to effectively remediate residual contaminants

vi. Sustainable or “green” requirements for product and service procurement, for example, preference for products with recycled and bio-based contents)

b. Energy Consumption

i. 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

ii. Potentially cycling operation to reduce energy demand

iii. Selecting suitably sized air and water treatment equipment

iv. 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

v. Heat exchangers enable reuse of heat rather than discharging it as part of the effluent

vi. 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

c. Greenhouse Gas Emissions

i. Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered); caution should be taken in evaluating measures in isolation

ii. Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for extraction)

d. Air Quality

i. Use of biofilters for air and water treatment

e. Ecosystem, Human Health, Impacts on Water, Soil and Sediment

i. Minimizing footprint of remediation works

ii. Avoiding dewatering of wetlands and disrupting wetland ecosystems located near extraction wells

iii. Minimizing noise

f. Waste

   i. Re-cycling of recovered free product (fuels)

   ii. Use of sequestering agents to keep a maximum amount of iron and manganese in solution, to prevent equipment fouling, rather than removing them and generating additional process waste

   iii. 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

   iv. 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

g. References

   i. US Army Corps of Engineers EM 1110-1-4010 “Engineering and Design: Multi-Phase Extraction”.

3.4 Soil Vapour Extraction, Bioventing and Air Sparging

a. Planning and Design

   i. Scheduling optimization for resource sharing and fewer days of mobilization

   ii. Conduct additional design and pilot testing to optimize full scale design with respect to operational requirements and air treatment

   iii. Consideration of horizontal extraction wells when potentially more efficient

   iv. Transition to NSZD and MNA as soon as conditions are favorable to effectively remediate residual contaminants

   v. 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; also see US EPA (1995)

   vi. 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

b. Energy Consumption

   i. Optimization of pump size and use of variable speed motors to match system demand

   ii. 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)

iii. For bioventing, air injection mode as oppose to air extraction mode to avoid air treatment, lower energy and eliminate wastes

iv. Use of passive bioventing that exploits changes in barometric pumping through one-way check valve, when there is sufficient difference in atmospheric and subsurface pressures and adequate response time lag (ESTCP, 2004)

v. Use of solar- or wind-powered pumps or fans for bioventing and SVE (Knafla; for low energy application, small microblowers (e.g., AMETEK “Microjammer”) can be considered

vi. Taking well off-line if a well in a manifold system is not contributing to treatment

vii. 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

viii. Using piping of sufficient diameter to minimize pressure drops and resulting need for additional energy to operate blowers

ix. 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

x. 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 trade-offs such as potential increases in material consumption or waste generation

xi. Use of direct push or smaller drill rigs when appropriate

c. Greenhouse Gas Emissions

i. Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered); caution should be taken in evaluating measures in isolation

ii. Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for extraction)

d. Air Quality

i. Ensuring that the zone of influence for soil gas flow to vapor extraction wells completely covers the treatment area

ii. Installing and maintaining surface seals around wells and monitoring points

iii. Using vapor treatment methods appropriate for the influent vapor concentrations and maintaining treatment works such that efficiency is maintained (e.g., carbon change-out)

iv. Use of biofilter for air treatment

e. Ecosystem, Human Health, Impacts on Water, Soil and Sediment

   i. Minimizing footprint of remediation works

   ii. Minimizing noise

f. Material (Natural Resource) Use

   i. Optimization of well networks to reduce materials needed for well construction

g. Waste

   i. Regeneration of granular activated carbon

h. References

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

   ii. Environmental Security Technology Certification Program (ESTCP) 2004. Cost and Performance Report. Natural Pressure-Driven Passive Bioventing. U.S. Department of Defense (CU-9715) January. *http://www.dtic.mil/dtic/tr/fulltext/u2/a604106.pdf*

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

   iv. Leeson, A., R.E.Hinchee, J. Kittel, G. Sayles, C.M. Vogel and R.N. Miller. 1993. Optimizing Bioventing in Shallow Vadose Zones and Cold Climates. Z.W. Dundzewisc, D. Koutsoyiannis (ed.), Hydrological Sciences Journal, IAHS Press, Wallingford, UK, 38(4): 283-295. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=96120

   v. Leeuven, J. 2013. Green Remediation – Zero Emission in situ soil Remediation. www.hazmatmag.com Spring. *https://rwsenvironment.eu/publish/pages/126601/green_remediation_1.pdf*

   vi. Shewfelt, K., H. Lee and R.G. Zytner. 2005. Optimization of nitrogen for bioventing of gasoline contaminated soil. J. of Environmental Engineering and Science, Vol. 4, No. 1, pp. 29-42.

   vii. US EPA 1995. Principles and Practices of Bioventing Volume I: Bioventing Principles. EPA/540/R-95/534a September.

   viii. US EPA 2010. Green Remediation Best Management Practices: Soil Vapour Extraction and Air Sparging. EPA 542-F-10-007. March.

   ix. Zenker, M., G. *R.* Brubaker, D. Shaw and S. R. Knight. Passive Bioventing Pilot Study at a Former Petroleum Refinery. https://www.researchgate.net/publication/228458033_Passive_Bioventing_Pilot_Study_at_a_Former_Petroleum_Refinery

3.5 Permeable/Passive Reactive Barriers

a. Planning and Design

   i. Conduct more intensive investigation to refine and potentially reduce footprint of wall.

   ii. Optimization of wall configuration (funnel and gate, etc.) to reduce volume of reactive material

   iii. Scheduling optimization for resource sharing and fewer days of mobilization

   iv. Sustainable or "green" requirements for product and service procurement (for example preference for products with recycled and bio-based contents)

b. Energy Consumption

   i. Use of biowall if applicable using solid carbon sources, such as mulch, compost, sawdust, wheat straw

   ii. Use of materials specifically processed for environmental purposes such as dissolved and suspended carbon sources, such as cheese whey, sodium lactate, molasses, emulsified vegetable oils (EVOs), and various other carbohydrates and alcohols

   iii. Use of sustainable or "green" nanoscale Zero-Valent Iron (GnZVI), which uses natural plant extracts (Cassidy et al. 2011)

   iv. Selecting suitably sized equipment for construction of the wall

   v. Measures to avoid engine idle and using machinery with automatic idle-shutdown devices

   vi. Use of more energy efficient equipment or motors

   vii. Minimizing site visits by the use of telemetry for remote monitoring of site conditions.

c. Greenhouse Gas Emissions

   i. Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered)

   ii. Use of cleaner fuels such as biodiesel especially when made from recycled products

d. Air Quality

   i. Most potential air emissions are associated with manufacture of wall materials; minor impacts may occur during construction.

e. Ecosystem, Human Health, Impacts on Water, Soil and Sediment

   i. Use of sustainable or "green" nano-scale ZVI or biowall material that avoids use of less environmentally friendly chemicals

f. Material (Natural Resource) Use

   i. Measures to reduce PRB footprint to reduce backfill needed

g. References

i. Cassidy, D., G. Hoag, J. Collins, B. McAvoy; R. Varma. 2011. Green Nano Zero-Valent Iron (GNZVI) as a Novel Reductant and Catalyst for the Remediation of Environmental Contaminants. IPEC 2011: Proceedings of the 18th International Petroleum & BioFuels Environmental Conference, 7-10 November 2011, Houston, Texas.

ii. ITRC 2011 Permeable Reactive Barrier Guidance

iii. 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.

3.6 In situ (active/enhanced) Bioremediation

a. Planning

i. Scheduling optimization for resource sharing and fewer days of mobilization

ii. Optimizing treatment through innovative technology adoption such as use of waste substrates (e.g., sugar-based or other compounds) that reduce waste while enhancing biodegradation

iii. Sustainable or “green” requirements for product and service procurement, for example, preference for products with recycled and bio-based contents

b. Energy Consumption

i. Enhancing bioremediation through low or solar powered methods for injections

ii. Use of geothermal energy source

iii. Use of direct push technologies when feasible to reduce energy associated with drilling

iv. Use of telemetry for remote monitoring of site conditions to minimize site visits and transportation to site

v. Reduce the number of environmental samples that are collected for analysis and consider local laboratory to reduce energy for shipping

vi. Use of renewable energy for vehicle transportation

c. Greenhouse Gas Emissions

i. 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

d. Material (Natural Resource) Use

i. Optimization of well networks to reduce materials needed for well construction.

3.7 Monitored Natural Attenuation and/or Institutional Controls

a. Planning and Design

   i. Scheduling optimization for resource sharing and fewer days of mobilization

   ii. Sustainable or "green" requirements for product and service procurement for example preference for products with recycled and bio-based contents)

   iii. Long period and extensive characterization can lead to high energy use

b. Energy Consumption

   i. Use of direct push technologies when feasible to reduce energy associated with drilling

   ii. Use of telemetry for remote monitoring of site conditions to minimize site visits and transportation to site

   iii. Reduce the number of environmental samples that are collected for analysis and consider local laboratory to reduce energy for shipping

   iv. Use of renewable energy for vehicle transportation

c. Greenhouse Gas Emissions

   i. 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

d. Material (Natural Resource) Use

   i. Optimization of well networks to reduce materials needed for well construction.

3.8 In situ Chemical Oxidation

a. Planning and Design

   i. Scheduling optimization for resource sharing and fewer days of mobilization

   ii. 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

   iii. Transition to natural source zone depletion (NSZD) and monitored natural attenuation (MNA) as soon as conditions are favorable to effectively remediate residual contaminants

   iv. Consideration of complementary technologies or combined remedies to transition from.

   v. Sustainable or "green" requirements for product and service procurement for example preference for products with recycled and bio-based contents).

b. Energy Consumption

   i. Use of direct push technologies when feasible to reduce energy associated with drilling

   ii. Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for reagent delivery)

   iii. Use of telemetry for remote monitoring of site conditions to minimize site visits and transportation to site.

   iv. Use of renewable energy and energy efficient machinery (e.g., geothermal or solar energy for reagent delivery)

   v. Evaluate source of oxidant (i.e. supply chain consideration in manufacturing)

   vi. Use of groundwater for on-site chemical solution preparation

   vii. Evaluate delivery options by rail (for large volume of oxidant) rather than trucks

   viii. Use of recyclable bulk solution containers

c. Greenhouse Gas Emissions

   i. 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

   ii. 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)

d. Air Quality

   i. Selection of appropriate oxidant and caution in design and implementation to avoid excessive gas generation and migration to ground surface

e. Ecosystem, Human Health, Impacts to Water, Soil and Sediment

   i. Minimizing footprint of remediation works.

   ii. Minimizing noise.

   iii. Evaluation of potential impacts to and compatibility with subsurface infrastructure such as utilities from oxidant injection and reactions.

f. Material (Natural Resource) Use

   i. Optimization of well networks to reduce materials needed for well construction

g. References

   i. NAVFAC, 2015. TM-NAVFAC-EXWC-EV-1502. Design Considerations for In Situ Chemical Oxidation. March.

ii. Siegrist, R.L., M. Crimi, and T.J. Simpkin. 2011. In Situ Chemical Oxidation for Groundwater Remediation Series: SERDP ESTCP Environmental Remediation Technology, Vol. 3, first edition, 678 p.

iii. City Chlor, 2013. Code of Good Practice - In-situ chemical oxidation, April 5 2013.

3.9 Phytoremediation

a. Planning and Design

   i. Scheduling optimization for resource sharing and fewer days of mobilization.

   ii. Sustainable or “green” requirements for product and service procurement (for example preference for products with recycled and bio-based contents)

   iii. Phytoremediation can be used to remediate soil and groundwater impacts through several mechanisms including phytoextraction (uptake of pollutants into plant tissue), phytodegradation (contaminants are taken up into plant tissues where they are metabolized), phytostimulation (simulation of enzymes in the rhizosphere that result in biodegradation), phytovolatilization (uptake of pollutants and volatilization from surface of leaves), phytofiltration or rhizofiltration (use of plants to remove contaminants from water) and phytostabilization (adsorption by roots or facilitated by biochemicals produced by roots)

   iv. The potential environmental benefits of phytoremediation in addition to remediation include:

      1. Carbon capture and possible offsets
      2. Increased local biodiversity
      3. Increased local cooling
      4. Increased erosion control and protection of watershed quality

   v. The potential social benefits of phytoremediation include:

      1. Local neighbourhood aesthetics
      2. Increased property values
      3. Increased community pride
      4. Passive recreational opportunities.

b. Energy Use

   i. Consider means to optimize maintenance and monitoring programs such as automated irrigation systems combined with telemetry (e.g., soil moisture)

   ii. Minimizing site visits by the use of telemetry for remote monitoring of site conditions

   iii. Use of energy efficient machinery in planting and harvesting

   iv. A possible option may be to use not only use plants for phytoremediation, but to use plants for energy and carbon dioxide abatement (Witters et al. 2012)

c. Greenhouse Gas Emissions

   i. Many of the measures that reduce energy consumption will all reduce greenhouse gas emissions (although lifecycle of relevant inputs and outputs should be considered)

d. Ecosystem, Human Health and Impacts to Soil, Sediment and Water

   i. Consideration phytoremediation approaches to increase biodiversity.

   ii. During planting minimize soil erosion through appropriate temporary road construction methods, straw-bale barrier installation, silt fences and retention basins as warranted (note phytoremediation will reduce soil erosion)

   iii. 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.)

   iv. Implement measures to control exposures to wildlife to avoid food chain impacts when plants uptake contaminants

e. Material (Natural Resource Use)

   i. Optimize fertilizer and water addition through plant specific considerations, soil nutrient studies and drip irrigation systems

f. Waste

   i. Consider use harvested plants for energy while addressing potential adverse effects from contaminant uptake in hyperaccumulating plants.
   ii. Consider methods for metal recovery from biomass (phytomining)

g. References

   i. ITRC 2009. Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised.
   ii. Witters, N., R. O. Mendelsohn, S. Van Slychen, N. Weyens, E. Schreurs, E.Meers, F. Tack, R. Carleer and J. Vangronsveld (2012). Phytoremediation, a sustainable remediation technology? Conclusions from a case study. I: Energy production and carbon dioxide abatement.

4.0 GENERAL REFERENCES

ASTM E2876-13, Standard Guide for Integrating Sustainable Objectives into Cleanup, ASTM International, West Conshohocken, PA, 2013. *https://www.astm.org/Standards/E2876.htm*

ASTM E2893-16e1, Standard Guide for Greener Cleanups, ASTM International, West Conshohocken, PA, 2016. *https://www.astm.org/Standards/E2893.htm*

ITRC, 2011. ITRC Green Sustainable Remediation Guidance. May 2011. *http://www.itrcweb.org/Team/Public?teamID=7*

SURF – UK Sustainable Management Practices Spreadsheet *https://www.claire.co.uk/projects-and-initiatives/surf-uk/21-executing-sustainable-remediation/84-sustainable-management-practices*

US Corps of Engineers. 2012. Evaluation and Consideration and Incorporation of Green and Sustainable Remediation Practices in Army Environmental Remediation. August 27.

US EPA 2008. US EPA Green Remediation Primer. Report 542-R-08-002. April 2008. *https://www.epa.gov/sites/production/files/2015-04/documents/green-remediation-primer.pdf*

US EPA 2008. Green Remediation: Best Management Practices for Excavation and Surface Restoration. Report No. 542-F-08-012, December. *https://www.epa.gov/remedytech/green-remediation-best-management-practices-excavation-and-surface-restoration*

US EPA 2009. Green Remediation Best Management Practices: Site Investigation *https://www.epa.gov/remedytech/green-remediation-best-management-practices-site-investigation*

US EPA 2010. Green Remediation Best Management Practices: Bioremediation. Report 542-F-10-006. March. https://www.epa.gov/remedytech/green-remediation-best-management-practices-bioremediation

US EPA 2012. Green Remediation Best Management Practices: Implementing In Situ Thermal Technologies. Report 542-F-12-029. October https://www.epa.gov/sites/production/files/2015-04/documents/gr_factsheet_ist.pdf

US EPA 2017. Overview of EPA's Methodology to Address the Environmental Footprint of Site Cleanup https://www.epa.gov/remedytech/green-remediation-best-management-practices-overview-epas-methodology-address

APPENDIX B

SiteWise™, Goldset, DOD Green and Sustainable Remediation Tools

1.0 SITEWISE™ TOOL

SiteWise™ is an Excel-based tool for evaluating sustainability in the context of the environmental footprint, in sustainability in addition to effectiveness, cost, and ease of implementation.

The SiteWise™ tool was developed jointly by the Navy, Army Corps of Engineers, and Battelle.

With this tool, the following factors can be evaluated:

1) greenhouse gas emissions
2) energy use (total energy use and electricity from renewable and non-renewable sources)
3) air emissions of criteria pollutants including nitrogen oxide (NOx), sulfur oxide (SOx), and particulate matter (PM)
4) water consumption
5) resource consumption (landfill space and top soil consumption
6) worker safety (risk of fatality, injury and lost hours)

SiteWise™ incorporates a "building block" approach to conduct sustainability assessments and multiple remedial options can be compared with respect to environment footprint. Each technology is broken down into 4 modules: well installation; soil/groundwater monitoring; system monitoring; system start up, operations and maintenance; and decommissioning. In SiteWise™, emissions factors for GHGs and energy used for consumables such as materials, fuel, and electricity are based on life-cycle analysis.

The strength of the tool is that is comprehensive and enables a detailed assessment of environmental footprint. A potential limitation is complexity and requirement for relatively extensive data, some of which may be difficult to obtain or estimate. The tool is a valuable resource for structured footprint assessments including data sources for metrics (Table 4.1 User's Guide) including GHG emission footprint calculation, water usage, Energy Usage Calculation Methodology, Air Emission Inventories Development, and accident risk calculation Methodology are provided.

SiteWise™ Ver. 3.1 (October 2018) is free software that can be downloaded from the SURF Library or from NAVFAC
https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/erb/gsr.html

An introductory, on-demand webinar is also available from Battelle.

https://www.navfac.navy.mil/content/dam/navfac/Specialty%20Centers/Engineering%20and%20Expeditionary%20Warfare%20Center/Environmental/Restoration/er_pdfs/s/SiteWise3.1/sitewisetm_user_guide_Version%203%201_20150924.pdf

2.0 GOLDSET TOOL

GoldSET was developed in 2007 to bring Sustainable Development at the operational level, by creating a qualitative evaluation tool. It is a web-based tool built by Golder to compare options, with the following objectives in mind:

- measuring sustainability of a project
- balanced, impartial and comprehensive, yet simple to use
- maximizing efficiency
- convincing demonstration to stakeholders & regulators
- transparency of the decision process

GoldSET offers a structured MCA approach which explicitly defines:

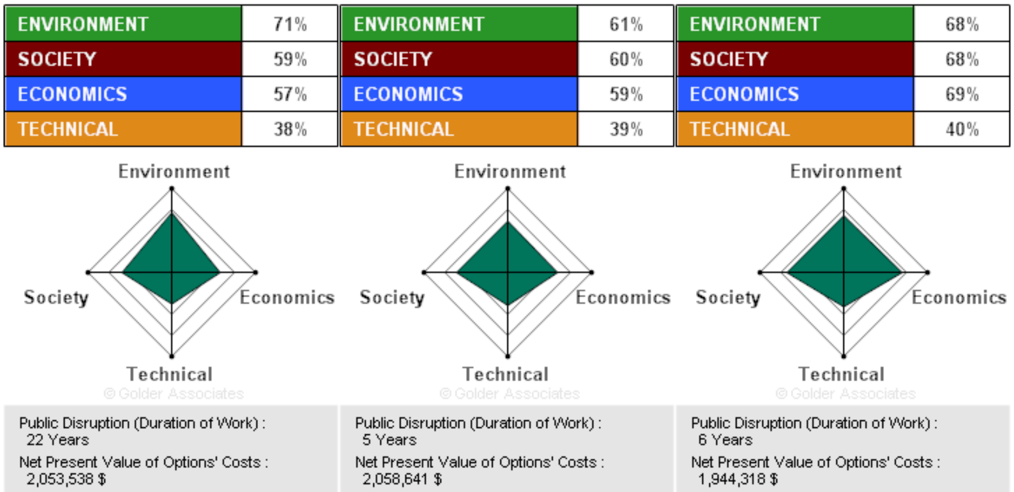
- indicators against which to measure options
- scoring schemes for the indicators to use for measuring
- a mechanism to account for the relative importance of indicators

GoldSET includes integrated calculators to asses Net Present Value (NPV), as well as carbon footprint. The *GoldSET Footprinter* has been embedded within GoldSET to allow the estimation of energy consumption and greenhouse gas (GHG) emissions associated with a project, which are two indicators often considered as part of an option analysis within GoldSET.

The objective of the *Footprinter* is to provide a relative profile of energy consumption and GHG emissions among various options being considered for a project, while incorporating the life-cycle perspective. As such, the *Footprinter* is intented to provide a simple and consistent way of performing first-order estimates of life-cycle energy consumption and GHG emissions. It is *not* intended to be a tool for precise calculation. Rather, the *Footprinter* is designed to inform the user on the options that are most likely to consume less (or more) energy or emit less (or more) GHG emissions. The estimation of these two metrics can also provide preliminary indications as to where the options under consideration could potentially be optimized in terms of energy consumption and GHG emissions.

The energy and GHG estimates can then be normalized to be included within the multicriteria analysis framework of GoldSET to support the comparison of the options. The results can provide a basis to further refine the evaluation and reducing the uncertainties when additional information (based on a detailed design) is made available.

GoldSET provides an intuitive visual representation of results. Impacts are scored and rolled-up typically into the four dimensions of sustainability: **environmental, social, economic and the technical performance**. For each dimension, the rolled-up score ranges from 0% to 100% — the higher the score, the better. The four axes of the diamond illustrate the performance of an option with respect to the three dimensions of sustainable development and the technical development. Under normal circumstances, the optimal option is illustrated by the largest, most balanced diamond.



3.0 US EPA SPREADSHEETS FOR ENVIRONMENTAL FOOTPRINT ANALYSIS (SEFA)

SEFA (Version 3, 2019) is a collection of Microsoft Excel spreadsheets designed to apply the US EPA's "Methodology for Understanding and Reducing a Project's Environmental Footprint". The Methodology presents green remediation metrics associated with contaminated site cleanup and a process to quantify those metrics. US EPA's green remediation metrics correspond with the five core elements of a greener cleanup. The Methodology includes 21 metrics corresponding to core elements of a greener cleanup, and a seven-step quantification process.

SEFA enables input information to be organized in up to six different component areas including materials use, water use, waste disposal, transportation and equipment use. Based on these inputs, output is provided for the metrics defined in the Methodology. In SEFA, the conversion factors for energy and emission metrics are life-cycle based. The boundaries that are established for calculating the energy and emission factors considers the entire life cycle or 'cradle-to-grave' of the material used or fuel or electricity consumed. In contrast, the water and waste footprints consider only the water used on site or the waste generated on site. Consistent with the methodology, SEFA does not conduct an impact assessment, which may be a component of the LCA process, to convert the sustainability metrics into environmental impacts.

SEFA generally requires less than a full day of training or independent use to learn how to apply the tool to a variety of remediation projects. SEFA is free software that can be downloaded from the following website:

http://www.cluin.org/greenremediation/methodology

4.0 DOD GREEN AND SUSTAINABLE REMEDIATION TOOL

The US Department of Defense (DoD) has developed a tool for evaluation of green and sustainable remediation. The Web-based tool provides an overview of GSR concepts including policy drivers, GSR metrics, methods for quantifying GSR metrics, available tools and inventories, how to incorporate GSR practices into the environmental remediation process, and examples of footprint reduction methods

Sustainability metrics are defined as primarily core environmental metrics defined by US EPA, but also include additional metrics such as worker safety and community impacts. The GSR metrics that are currently part of the DOD tool are as follows:

- Energy Consumption
- GHG Emissions
- Water Usage
- Resource Consumption
- Ecological Impacts
- Air Emissions
- Community Impacts
- Worker Safety / Accident Risk

Information on the DOD Green and Sustainable Remediation Tool is available here:

http://t2.serdp-estcp.org/t2template.html#tool=GSR&page=Intro

This tool is no longer supported.

5.0 SIMAPRO

SimaPro® may be used for many types of LCA evaluations, but it is not specifically intended for assessment of soil and groundwater remediation. The SimaProTM LCA software was developed by PRé (www.pre-sustainability.com) and is a tool that accesses life-cycle inventory (LCI) databases consistent with ISO Standards 14040:2006 and 14044:2006. SimaProTM comes fully integrated with several LCI databases including the extensive proprietary Ecoinvent database.

Using project-specific information, using SimaPro involves compiling materials, processes, and disposal practices from the LCI databases into project lists (assemblies) and life-cycles that describe the overall project. Footprint information or environmental impacts can then be obtained from the assemblies and life-cycles. Input is project specific and there are hundreds of output parameters, including total energy use, greenhouse gas emissions, NOx emissions, SOx emissions, PM emissions, releases of toxic chemicals to various environmental media (soil, water, and air) and the environmental impacts associated with these various emissions and releases.

The SimaPro® is for-purchase software. Using SimaPro effectively takes several days of training. Further information is available at the following link

https://simapro.com/business/?gclid=EAIaIQobChMIzaLJkP3A2wIVi7bACh0SKQkEEAAYASAAEgJDzfD_BwE

6.0 GREM

The GREM is a publicly available, free tool that was introduced in the California Department of Toxic Substances Control *Interim Advisory for Green Remediation* (http://www.dtsc.ca.gov/OMF/upload/GRT_Draft_-Advisory_-

20091217_ac1.pdf). The GREM enables remediation researchers and practitioners to perform comparisons of remediation alternatives based on a comprehensive list of environmental indicators. The Interim Advisory references other tools that can be used for calculating sustainability impacts. The GREM can be downloaded at http://www.dtsc.ca.gov/omf/grn_remediation.cfm.

APPENDIX C

Accident Statistics

A comprehensive compilation of vehicle accident statistics is provided in Canadian Motor Vehicle Traffic Collision Statistics compiled by Transport Canada. The latest statistics based on a search conducted on 17 November 2020 are for 2018. In 2018, there were 4.9 fatalities per billion vehicle-kilometres and 391 injuries per billion vehicle-kilometres. For BC, there were 6.9 fatalities per billion vehicle-kilometres and 477.5 injuries per billion vehicle-kilometres.

https://tc.canada.ca/en/road-transportation/motor-vehicle-safety/canadian-motor-vehicle-traffic-collision-statistics-2018

Table 1: Vehicle Accident Statistics for British Columbia and Canada for 2018 (Transport Canada)

	Per Billion Vehicle-Kilometres	
	Fatalities	Injuries
BC	6.9	477.5
Canada	5.9	391

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

More recent statistics are provided in the SiteWise software.

There is additional US data compiled by the AAA Foundation for Traffic Safety (Tefft, 2012). Based on 2008-2009 data, the fatalities and injuries per billion kilometres driven were 8.94 and 611, respectively.

Motor Vehicle Crashes, Injuries, and Deaths in Relation to Driver Age: United States, 1995–2010 *(November 2012)* Brian C. Tefft Senior Research Associate AAA Foundation for Traffic Safety.

https://www.aaafoundation.org/sites/default/files/2012OlderDriverRisk.pdf

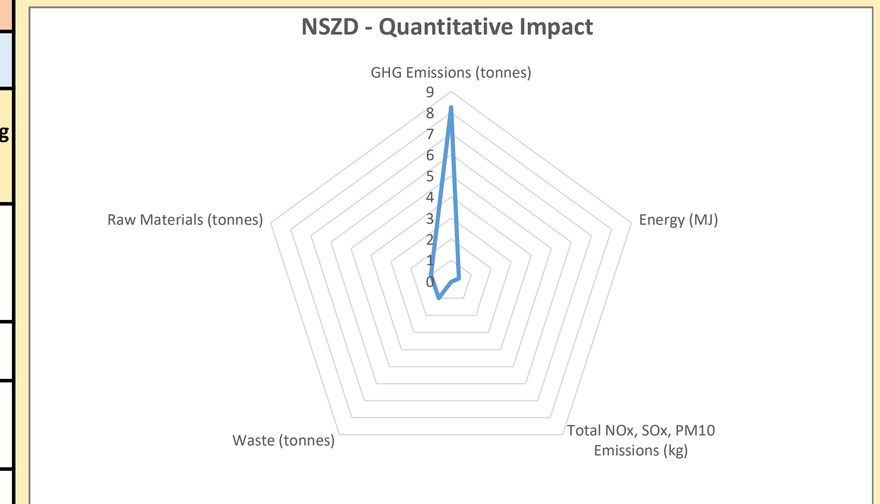
APPENDIX D

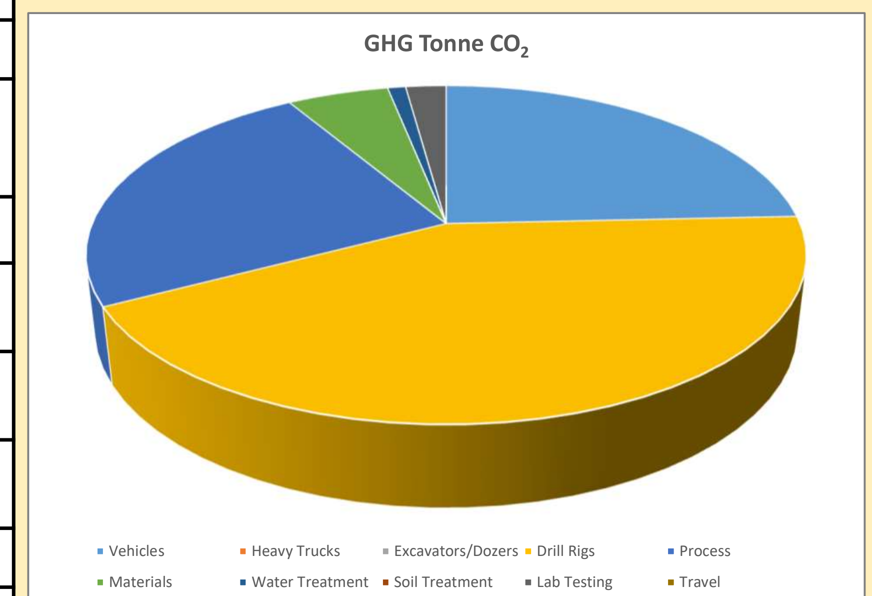
SR Dashboard Example

SR DASHBOARD (*V1.1*)

IMPACT OF INDIVIDUAL TECHNOLOGY - LNAPL SKIMMING and NSZD

	Indicator (add/subtract as warranted)	Metric	Data Sources and Calculators	Typical Measurement Unit[12]	Impact Result	Comments, Possible Greening or Improvements
Environmental	GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	US EPA Calculators[1,3] US EPA SEFA[2] SiteWise: Table A-3, App B BC MoE[9]	Tonne CO_2e	25	
	Energy	1. Total energy use 2. Energy from renewable resources	SiteWise: Table A-2, App B; EPA[8], BC MoE[9]	MMBtu	0.80	
	Air Pollutants	1. NOx emissions 2. SOx emissions 3. PM10 emissions	SiteWise: Table A-2, App B	Kilograms	23	
	Waste	1. Hazardous waste disposed of offsite 2. Non-hazardous waste disposed of offsite	Site-specific estimate	Tonnes or Litres	1	LNAPL, drilling waste
	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Site-specific estimate	Tonnes or Litres	1	Well materials
	Land, Water and Ecosystem	1. Environmental quality 2. Biota (animals and plants) and habitat effects 3. Soil fertility or functionality effects 4. Water quality effects (e.g., Eutrophication)	Site-specific assessment	Qualitative Qualitative Qualitative Qualitative		
	Permanence /Long-term Effectiveness	1. What is permanence and long-term effectiveness of technology in meeting remedial goals	Site-specific assessment	Qualitative		
	Technology Reliability	1. What is reliability and resiliency of technology with respect to performance/risk including in relation to extreme events and climate change	Site-specific assessment	Qualitative		
Social	Community	1. Economic and/or social revitalization 2. Noise, dust, traffic, visual impacts 3. Land use access (improved, restricted)	Site-specific assessment	Qualitative Qualitative Qualitative		
	Safety	1. Worker Safety On-site 2. Public Safety Near-site 3. Vehicle Accident Risk (non-fatal)	Site-specific assessment 4,5,6	Qualitative Qualitative Accidents per km		
	Time	1. Time of remediation	Site-specific estimate	Years		
Cost	Cost	1. Capital 2. Operation & maintenance	7	\$ \$ (NPV)	100000	





Notes

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

2 USEPA Spreadsheets for I USEPA Spreadsheets for Environmental Footprint Analysis
https://clu-in.org/greenremediation/methodology/index.cfm

3 https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

4 https://www.tc.gc.ca/media/documents/roadsafety/Canadian_Motor_Vehicle_Traffic_Collision_Statistics_2015-EN.pdf

5 http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/state-by-state-overview

6 https://www.aaafoundation.org/sites/default/files/2012OlderDriverRisk.pdf

7 Federal Remediation Technologies Roundtable https://frtr.gov/
https://frtr.gov/

8 US EPA https://oaspub.epa.gov/powpro/ept_pack.charts

9 BC ENV 2018 Methodology Gguidance for Quantifying Greenhouse Gas Emissions
https://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2018-pso-methodology.pdf

General reference: http://www.sustainableremediation.org/tools/

10 Include ozone depleting substances and volatile organic compounds or hazardous air pollutants where warranted.

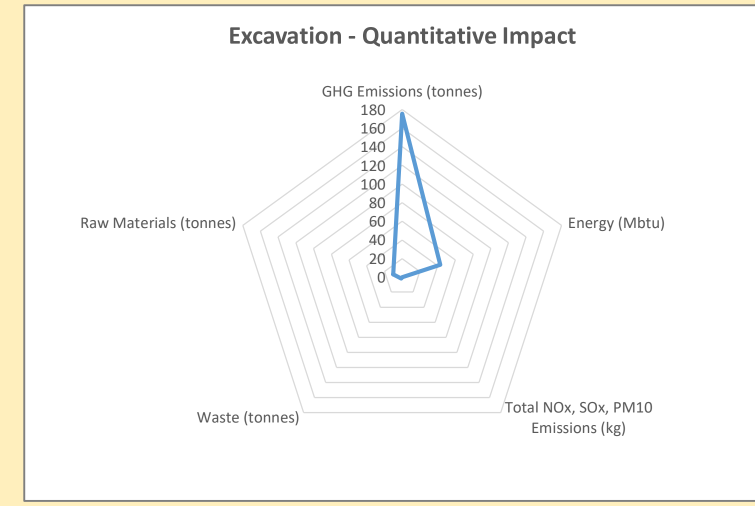
11 Wastes should include soil, wastewater, refuse, etc.
General reference: http://www.sustainableremediation.org/tools/

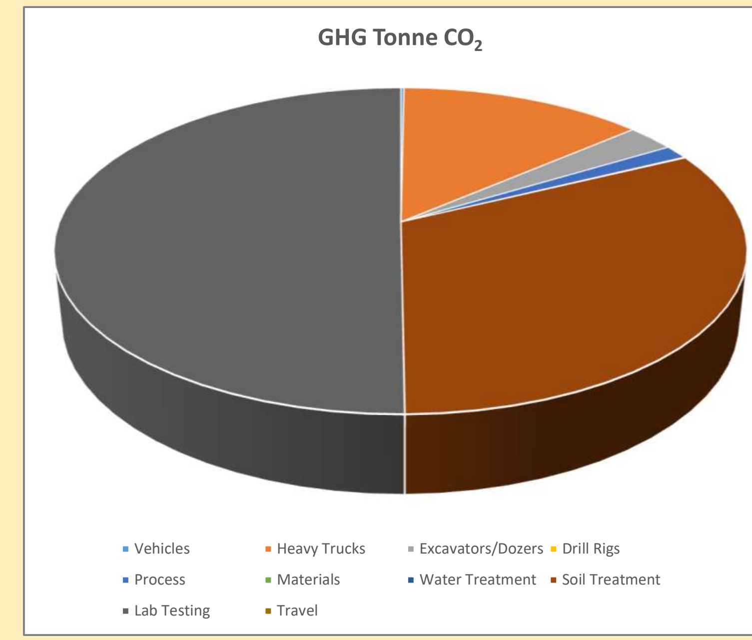
12 Following LCA methods some qualitative indicators may be quantified

DRAFT BETA SR DASHBOARD (*V1.1- Golder Associates*)

IMPACT OF INDIVIDUAL TECHNOLOGY - LNAPL SKIMMING and EXCAVATION

	Indicator (add/subtract as warranted)	Metric	Data Sources and Calculators	Typical Measurement Unit[12]	Impact Result	Possible Greening or Improvements
Environmental	GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	US EPA Calculators[1,3] US EPA SEFA[2] SiteWise: Table A-3, App B BC MoE[9]	Tonne CO_2e	65	
	Energy	1. Total energy use 2. Energy from renewable resources	SiteWise: Table A-2, App B; EPA[8], BC MoE[9]	MMBtu	41	
	Air Pollutants	1. NOx emissions 2. SOx emissions 3. PM10 emissions	SiteWise: Table A-2, App B	Kilograms	41	
	Waste	1. Hazardous waste disposed of offsite 2. Non-hazardous waste disposed of offsite	Site-specific estimate	Tonnes or Litres	2 (LNAPL, drilling/excavation)	
	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Site-specific estimate	Tonnes or Litres	10 (backfill, drilling)	
	Land, Water and Ecosystem	1. Environmental quality 2. Biota (animals and plants) and habitat effects 3. Soil fertility or functionality effects 4. Water quality effects (e.g., Eutrophication)	Site-specific assessment	Qualitative Qualitative Qualitative Qualitative		
	Permanence /Long-term Effectiveness	1. What is permanence and long-term effectiveness of technology in meeting remedial goals	Site-specific assessment	Qualitative		
	Technology Reliability	1. What is reliability and resiliency of technology with respect to performance/risk including in relation to extreme events and climate change	Site-specific assessment	Qualitative		
Social	Community	1. Economic and/or social revitalization 2. Noise, dust, traffic, visual impacts 3. Land use access (improved, restricted)	Site-specific assessment	Qualitative Qualitative Qualitative		
	Safety	1. Worker Safety On-site 2. Public Safety Near-site 3. Vehicle Accident Risk (non-fatal)	Site-specific assessment 4,5,6	Qualitative Qualitative Accidents per km		
	Time	1. Time of remediation	Site-specific estimate	Years		
Cost	Economic	1. Capital 2. Operation & maintenance	7	$ $ (NPV)	200000	

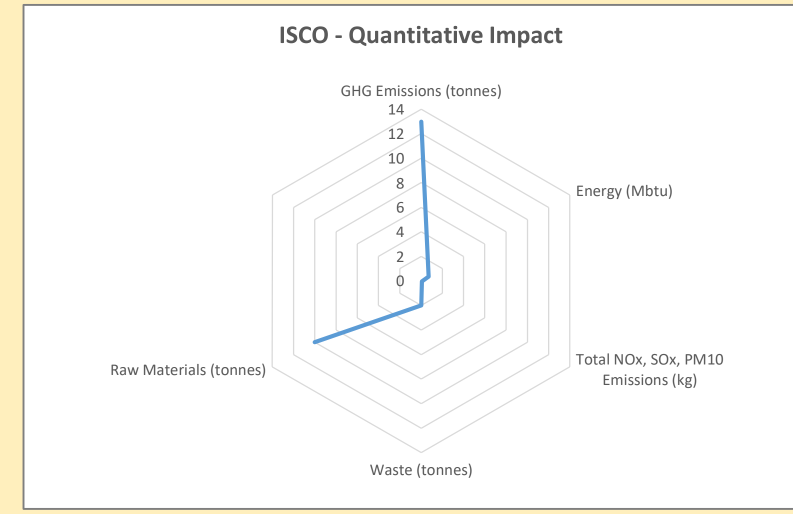


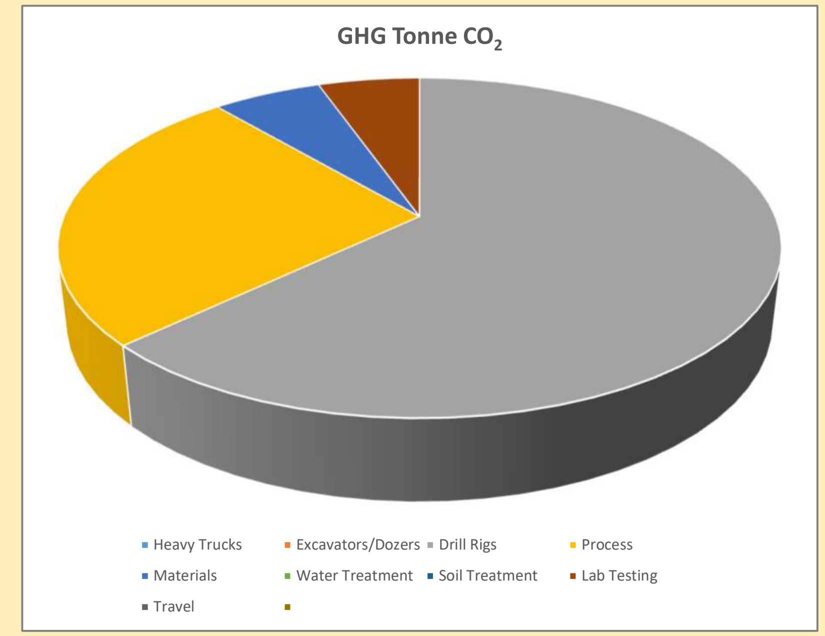


DRAFT SR DASHBOARD (*V1.1*)

FOOTPRINT IMPACT OF INDIVIDUAL TECHNOLOGY - LNAPL SKIMMING and ISCO

Indicator (add/subtract as warranted)		Metric	Data Sources and Calculators	Typical Measurement Unit[12]	Impact Result	Possible Greening or Improvements
Environmental	GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	US EPA Calculators[1,3] US EPA SEFA[2] SiteWise: Table A-3, App B BC MoE[9]	Tonne CO_2e	19	
Environmental	Energy	1. Total energy use 2. Energy from renewable resources	SiteWise: Table A-2, App B; EPA[8], BC MoE[9]	MBtu	0.79	
Environmental	Air Pollutants	1. NOx emissions 2. SOx emissions 3. PM10 emissions	SiteWise: Table A-2, App B	Kilograms	71	
Environmental	Waste	1. Hazardous waste disposed of offsite 2. Non-hazardous waste disposed of offsite	Site-specific estimate	Tonnes or Litres	2 (LNAPL, drilling)	
Environmental	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Site-specific estimate	Tonnes or Litres	10 (well materials, oxidant)	
Environmental	Land, Water and Ecosystem	1. Environmental quality 2. Biota (animals and plants) and habitat effects 3. Soil fertility or functionality effects 4. Water quality effects (e.g., Eutrophication)	Site-specific assessment	Qualitative Qualitative Qualitative Qualitative		
Environmental	Permanence /Long-term Effectiveness	1. What is permanence and long-term effectiveness of technology in meeting remedial goals	Site-specific assessment	Qualitative		
Environmental	Technology Reliability	1. What is reliability and resiliency of technology with respect to performance/risk including in relation to extreme events and climate change	Site-specific assessment	Qualitative		
Social	Community	1. Revitalization (economic, social) 2. Disturbance through noise, dust, traffic, visual 3. Land use access (improved, restricted)	Site-specific assessment	Qualitative Qualitative Qualitative		
Social	Safety	1. Worker Safety On-site 2. Public Safety Near-site 3. Vehicle Accident Risk (non-fatal)	Site-specific assessment 4,5,6	Qualitative Qualitative Accidents per km		
Social	Time	1. Time of remediation	Site-specific estimate	Years		
Cost	Economic	1. Capital 2. Operation & maintenance	7	$ $ (NPV)	150000	





DRAFT BETA SR DASHBOARD (*V1.1)*)

COMPARISON OF IMPACT & MCA FOR MULTIPLE TECHNOLOGIES							MCA							
	Indicator (add/subtract as warranted)	**Metric**	**Typical Measurement Unit[12]**	**Impact Result**			**Raw Score**			**Scoring Rationale**	**Weight (3 high, 1 low)**	**Weighted Score = Raw Score**		
				NSZD	**ISCO**	**Excavation**	**NSZD**	**ISCO**	**Excavation**			**NSZD**	**ISCO**	**Excavation**
Environmental	GHG Emissions	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
Environmental	Energy	1. Total energy use 2. Energy from renewable resources	MBtu	20 -	40 -	60 -	4	3	2		2	8	6	4
Environmental	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
Environmental	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
Environmental	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Tonnes or Litres	- 1	- 1	- 1	3	3	2		2	6	6	4
Environmental	Land, Water and Ecosystem	1. Environmental quality 2. Biota (animals and plants) and habitat effects 3. Soil fertility or functionality effects 4. Water quality effects (e.g., Eutrophication)	Qualitative Qualitative Qualitative Qualitative	Site-specific assessment	Site-specific assessment	Site-specific assessment	2	3	3		3	6	9	9
Environmental	Permanence /Long-term Effectiveness	1. What is permanence 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
Environmental	Technology Reliability	1. What is reliability and resiliency of technology with respect to performance/risk including in relation to extreme events and climate change	Qualitative	Site-specific assessment	Site-specific assessment	Site-specific assessment	2	3	4		3	6	9	12
Social	Community	1. Revitalization (economic, social) 2. Disturbance through 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
Social	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
Social	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
						Mean Enviro	2.63					**84**	**81**	**78**
						Mean Social	3.22							
						Mean Cost	3.00							
						Mean All	2.81							

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 received 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.

DRAFT BETA SR DASHBOARD (V1.1)

AGGREGATE MCA SCORES

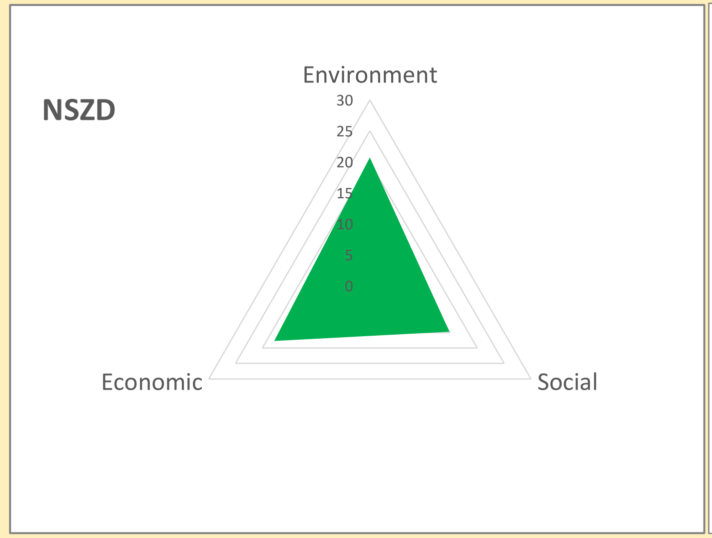
	Option #1	Option #2	Option #3
Environment	56	50	52
Social	20	25	22
Economic	8	6	4
Max Value			
Environment	90	90	90
Social	45	45	45
Economic	15	15	15
Normalized	**NSZD**	**ISCO**	**Excavation**
Environment	20.74074074	18.51851852	19.25925926
Social	14.81481481	18.51851852	16.2962963
Economic	17.77777778	13.33333333	8.888888889

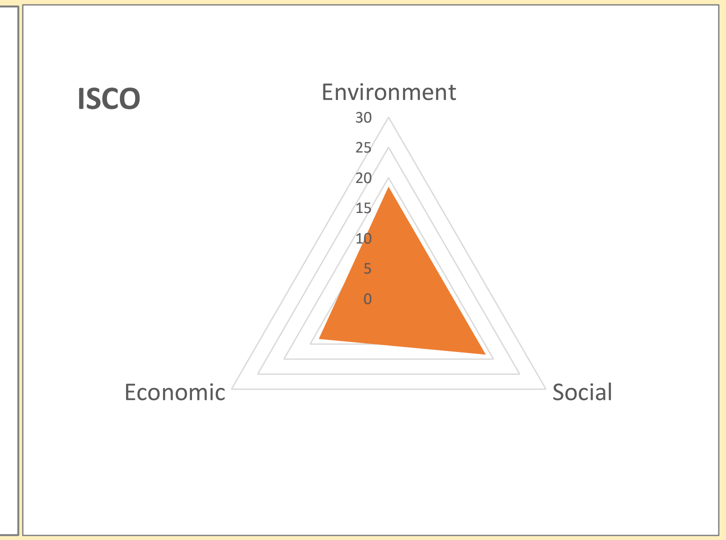
Enter Maximum Score	**5**
Enter Maximum Weight	**3**

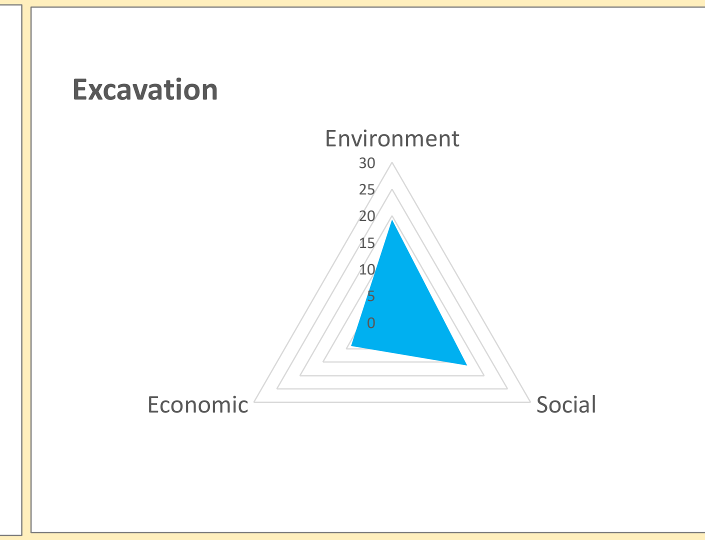
Score = Sum Weighted Score / (Sum (Maximum Possible Weighted Score))
Maximum Possible Weighted Score = Maximum Score x Maximum Weight

DRAFT SR DASHBOARD (*V1.1*)

RADAR PLOTS

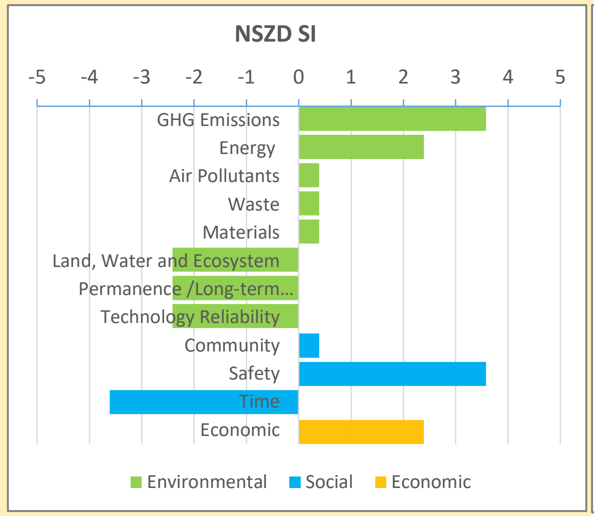




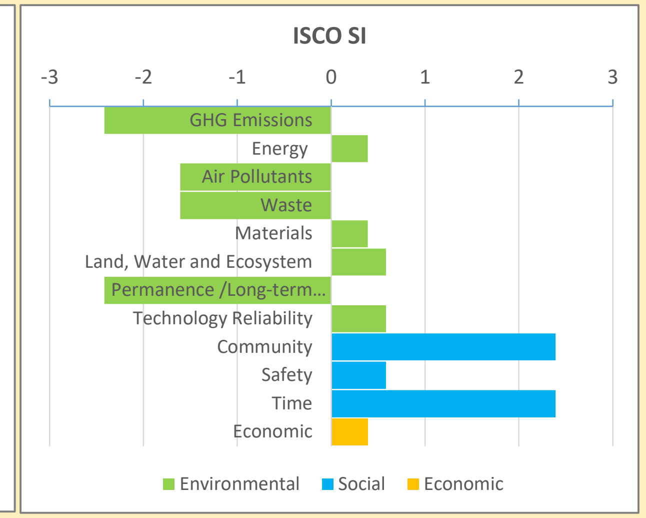


DRAFT SR DASHBOARD (*V1.1*)

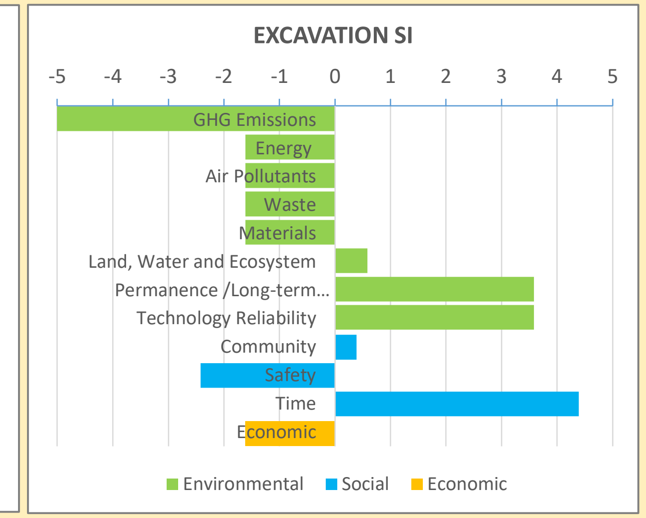
SENSITIVITY INDEX (NORMALIZED TO MEAN SCORE ALL OPTIONS)



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



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



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

How to Use:
1. Conduct Footprinter Analysis and create copy for each technology.
2. Define boundaries of the LCA.
3. Inputs with drop-down menus are BC defaults, remaining inputs are user defined (SiteWise generally recommended)
4. GHG estimates are copied to Impact Tool.

DRAFT BETA SR DASHBOARD (*V1.1*)

SR IMPACT TOOL - CONSIDER LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - OPERATION / MONITORING - DECOMMISSIONING)

TECHNOLOGY: LNAPL Recovery (skimming) followed by Natural Source Zone Depletion   DEFINE BOUNDARIES OF LCA: All on-site activities associated with investigation/remediation plus travel to site

Site: moderate sized source (50x100 m), 5000 m3 contaminated soil; LNAPL saturation = 0.1, Porosity = 0.3, LNAPL massInvestigation: 10 wells; Construction (remediation): 10 passive skimmers, 5 NSZD wells; Operation/Monitoring: Skimmers 2 yrs, NSZD 30 yrs total, 1st yr quarterly, annual monitoring for 5 yrs, every 5 yrs thereafter; Decommissioning: Abandon wells. 50 miles roundtrip to site from consultant/vendors/contractors

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)	Energy Coefficient Source	Efficiency Factor (EFF)		Energy Consumption (EC) EC = ADxGxExEFF	Emission Factor (EF)	Emission Factor Source	GHG Emissions (GHG) GHG = ADxGxEF	e-equivalent i.e., includes CH_4,N_2O?[4]	NOx Emission Factor	NOx Emission Factor Source	NOx Emission	SOx Emission Factor	SOx Emission Factor Source	SOx Emission	PM10 Emission Factor	PM10 Emission Factor Source	PM10 Emission Factor
1. Light On Road Mobile Sources (vehicles, light trucks)		mile		US gal-fuel/mile		Btu/US gal		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	*Install 10 wells, 2 days, light truck*	*100*	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.059	8.880	*BC Light-duty vehicle - ga*	0.0467	e	0.141	*SW T2b*	0.0141	0.005	*SW T2b*	0.00050	0.029	*SW T2b*	0.00290
Investigation	*Soil & gw sampling, 3 days, light truck*	*150*	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.088	10.026	*BC Light-duty vehicle - die*	0.0792	e	0.141	*SW T2b*	0.0212	0.005	*SW T2b*	0.00075	0.029	*SW T2b*	0.00435
Construction (remediation)	*Install 5 NSZD wells/gas probes 1 day, light truck, r*	*1250*	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.735	8.880	*BC Light-duty vehicle - ga*	0.5843	e	0.141	*SW T2b*	0.1763	0.005	*SW T2b*	0.00625	0.029	*SW T2b*	0.03625
Operation/Monitoring	*Quarterly 1st yr, annual for 5 yr, every 5 yr, 2 day e*	*1400*	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.823	8.880	*BC Light-duty vehicle - ga*	0.6544	e	0.141	*SW T2b*	0.1974	0.005	*SW T2b*	0.00700	0.029	*SW T2b*	0.04060
Decommissioning	*Decommission 15 wells, 2 days, light truck*	*100*	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.059	8.880	*BC Light-duty vehicle - ga*	0.0467	e	0.141	*SW T2b*	0.0141	0.005	*SW T2b*	0.00050	0.029	*SW T2b*	0.00290
2. Heavy On Road Mobile Sources (heavy trucks)		mile		US gal-fuel/mile		Btu/US gal		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 T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
3. Heavy Off Road Mobile Sources (excavators, dozers, etc)		hrs		US gal-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 T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
4. Drill Rigs Fuel Combustion Stationary Sources (drill rigs)		hrs		US gal-fuel/hrs		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/gal		kg-NOx	g-SOx/hr		kg-SOx	g-PM10/hr		kg-PM10
Investigation	*Install 10 wells, 2 days, auger rig*	20	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	21681.181	10.955	*SW T2a*	1.6652	not e	46.6	*SW T3d*	7.0832	2.1	*SW T3d*	0.31920	1.4	*SW T3d*	0.21280
Construction (remediation)	*Install 5 wells, 1 day, auger rig*	10	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	10840.591	10.955	*SW T2a*	0.8326	not e	46.6	*SW T3d*	3.5416	2.1	*SW T3d*	0.15960	1.4	*SW T3d*	0.10640
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW T2a*	1	*Typically 1*		10.955	*SW T2a*		not e	46.6	*SW T3d*		2.1	*SW T3d*		1.4	*SW T3d*	
Decommissioning	*Remove 15 wells, 2 days*	20	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	21681.181	10.955	*SW T2a*	1.6652	not e	46.6	*SW T3d*	7.0832	2.1	*SW T3d*	0.31920	1.4	*SW T3d*	0.21280
5. Process Fuel Combustion Stationary Sources (generators, other)		hrs		US gal-fuel/hrs		Btu/US gal		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 T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	SW T4b, T5, T6			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*	*SW T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	SW T4b, T5, T6			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*	*SW T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	SW T4b, T5, T6			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*	*SW T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	SW T4b, T5, T6			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
6. Process Electricity Stationary Sources Use		hrs		unitless		KW		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*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Construction (remediation)	*LNAPL skimming, 10 wells, 2-5 HP compressors, 2 y*	17520	*N/A*	1	*Typically 1*	7.5	*Site specific*	1	*Typically 1*	63072.000	10.670	BC Hydro	1.4020	e	*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
7. Materials (well pipe, bentonite, sand, fill, cement, amendments, water treatment		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	*Well pipe , 2 inc dia, 200 ft*	65.5	*N/A*	*1*	*Typically 1*	67.5	*SW T1c*	1	*Typically 1*	4418.182	3.11	*SW T1c*	0.2036	e	6	*SW T1c*	0.392727	9.7	*SW T1c*	0.63491	1.4	*SW T1c*	0.09164
Investigation	*Bentonite*	500	*N/A*	*1*	*Typically 1*	3	*SW T1c*	1	*Typically 1*	1500.000	0.22	*SW T1c*	0.1100	e	0.44	*SW T1c*	0.22	0.88	*SW T1c*	0.44000	0.176	*SW T1c*	0.08800
Investigation	*Sand*	500	*N/A*	*1*	*Typically 1*	0.1	*SW T1c*	1	*Typically 1*	50.000	0.005	*SW T1c*	0.0025	e	0.02	*SW T1c*	0.01	0.025	*SW T1c*	0.01250	0.01	*SW T1c*	0.00500
Construction (remediation)	*Well pipe , 2 inc dia, 100 ft*	32.72727273	*N/A*	*1*	*Typically 1*	67.5	*SW T1c*	1	*Typically 1*	2209.091	3.11	*SW T1c*	0.1018	e	6	*SW T1c*	0.196364	9.7	*SW T1c*	0.31745	1.4	*SW T1c*	0.04582
Construction (remediation)	*Bentonite*	250	*N/A*	*1*	*Typically 1*	3	*SW T1c*	1	*Typically 1*	750.000	0.22	*SW T1c*	0.0550	e	0.44	*SW T1c*	0.11	0.88	*SW T1c*	0.22000	0.176	*SW T1c*	0.04400
Construction (remediation)	*Sand*	250	*N/A*	*1*	*Typically 1*	0.1	*SW T1c*	1	*Typically 1*	25.000	0.005	*SW T1c*	0.0013	e	0.02	*SW T1c*	0.005	0.025	*SW T1c*	0.00625	0.01	*SW T1c*	0.00250
8. Waste Water and Air Treatment		Tech specific		unitless		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/USGal		kg-NOx	g-SOx/USGal		kg-SOx	g-PM10/USGal		kg-PM10
Water - AD = gal water treated	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7d*	*SW T7d*	1	*Typically 1*		*SW T7d*	SW T7d			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*	
Air thermal oxidizer - AD = gal fu	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7c*	*SW T7c*	1	*Typically 1*		*SW T7c*	SW T7c			*SW T7c*	*SW T7c*		*SW T7c*	*SW T7c*		*SW T7c*	*SW T7c*	
Other - all phases	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7d*	*SW T7d*	1	*Typically 1*		*SW T7d*	SW T7d			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Other - all phases	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		*Site specific*	*Site specific*			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
9. Soil Disposal /Treatment		Ton (2000 lb)[5]		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	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	SW T7a			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Construction (remediation)	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	SW T7a			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	SW T7a			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	SW T7a			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
10. Laboratory Analyses		$		unitless		MJ/$		unitless		MJ	kg-CO_2/$		tonne-CO_2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Soil and groundwater investigation*	6000	*N/A*	1	*Typically 1*	6490	*SW T7e*	1	*Typically 1*	40887.000	*0.021*	*ALS*	0.1260	e	*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*	
Construction (remediation)	*Additional NSZD testing*	4000	*N/A*	1	*Typically 1*	6490	*SW T7e*	1	*Typically 1*	27258.000	*0.021*	*ALS*	0.0840	e	*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*	
Operation/Monitoring	*14 events x $2,000/event*	28000	*N/A*	1	*Typically 1*	6490	*SW T7e*	1	*Typically 1*	190806.000	*0.021*	*ALS*	0.5880	e	*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		*SW T7e*	*ALS*			*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*	
11. Travel		km		unitless		MJ/km		unitless		MJ	kg-CO_2/km-psn		tonne-CO_2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Addressed under #1*	0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.155	Sea Bus	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Construction (remediation)		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Operation/Monitoring		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Decommissioning		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
								Total		**385180**	**Total**		**8.2**		**Total**		**19.1**	**Total**		**2.44**	**Total**		**0.90**
								Total (MMJ)		**0.39**	**Total (tonnes)**		**8.2**					**Total NOx, SOx, PM10 (tonnes)**					**0.022**

General Notes
1. SW = SiteWise
2. BC Ministry of Environment Best Practices Methodology for Quantifying Greenhouse Gas Emissions 2018 Data
3. ALS = ALS Laboratory, Burnaby, BC, Canada
4. If CO2-e values are not available should sum the emissions are follows based on US EPA 100-yr global warming potential equivalents: 1x(mass-CO_2) + 25x(mass-CH_4) + 298x(mass-$N_2$0)
5. ton = 2000 lbs, tonne = 1000 kg

How to Use:

1. Conduct Footprinter Analysis and create copy for each technology.
2. Define boundaries of the LCA.
3. Inputs with drop-down menus are BC defaults, remaining inputs are user defined (SiteWise generally recommended)
4. GHG estimates are copied to Impact Tool.

DRAFT BETA SR DASHBOARD (*V1.1*)

SR IMPACT TOOL - CONSIDER LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - OPERATION / MONITORING - DECOMMISSIONING)

TECHNOLOGY: LNAPL Recovery (skimming) followed by Excavation and Offsite Landfill Disposal DEFINE BOUNDARIES OF LCA: All on-site activities associated with investigation/remediation plus off-site disposal plus travel to site

Site: moderate sized source (50x100 m), 5000 m^3 contaminated soil; **Investigation:** 10 wells; **Construction (remediation)**: LNAPL skimming, excavation 10000 m3 offsite disposal 5000 m3 (9000 tonnes, 9E6 kg) contaminated soil; **Operation/Monitoring**: Skimmers 2 yrs, excavation construction 3 weeks, two monitoring events to confirm removal; **Decommissioning**: Abandon wells. 50 miles roundtrip to site from consultant/vendors/contractors

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)	Energy Coefficient Source	Efficiency Factor (EFF)	Efficiency Factor Source	Energy Consumption (EC) EC = ADxGxExEFF	Emission Factor (EF)	Emission Factor Source	GHG Emissions (GHG) GHG = ADxGxEF	e-equivalent i.e., includes CH_4,N_2O?[4]	NOx Emission Factor	NOx Emission Factor Source	NOx Emission	SOx Emission Factor	NOx Emission Factor Source	SOx Emission	PM10 Emission Factor	PM10 Emission Factor Source	PM10 Emission Factor
1. Light On Road Mobile Sources (vehicles, light trucks)		mile		US gal-fuel/mile		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/mile		kg-NOx	g-SOx/mile		kg-SOx	;-PM10/mile		kg-PM10
Investigation	*Install 10 wells, 2 days, light truck*	100.0	*Gasoline*	*0.0526*	*BC Light truc*	10.633	*SW T2a*	1	*Typically 1*	0.059	8.880	*BC Light-duty*	0.0467	e	0.141	*SW T2b*	0.0141	0.005	*SW T2b*	0.00050	0.029	*SW T2b*	0.00290
Investigation	*Soil & gw sampling, 3 days, light truck*	150.0	*Gasoline*	*0.0526*	*BC Light truc*	10.633	*SW T2a*	1	*Typically 1*	0.088	10.026	*BC Light-duty*	0.0792	e	0.141	*SW T2b*	0.0212	0.005	*SW T2b*	0.00075	0.029	*SW T2b*	0.00435
Construction + monitor	*Excavation monitoring 3 weeks + 3 events*	900.0	*Gasoline*	*0.0526*	*BC Light truc*	10.633	*SW T2a*	1	*Typically 1*	0.529	8.880	*BC Light-duty*	0.4207	e	0.141	*SW T2b*	0.1269	0.005	*SW T2b*	0.00450	0.029	*SW T2b*	0.02610
Decommissioning	*Decommission 15 wells, 2 days, light truck*	100.0	*Gasoline*	*0.0526*	*BC Light truc*	10.633	*SW T2a*	1	*Typically 1*	0.059	8.880	*BC Light-duty*	0.0467	e	0.141	*SW T2b*	0.0141	0.005	*SW T2b*	0.00050	0.029	*SW T2b*	0.00290
2. Heavy On Road Mobile Sources (heavy trucks)		mile		US gal-fuel/mile		Btu/US gal		unitless		MJ	g-CO_2/mile		tonne-CO_2		g-NOx/mile		kg-NOx	g-SOx/mile		kg-SOx	;-PM10/mile		kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Construction (remediation)	*10,000 t contaminated soil, 714 truck trips, 2 hr*	35700.0	*Diesel*	8	*SW T6b*	135847	*SW T2a*	1	*Typically 1*	40737798.4	1329	*SW T6b*	47.4453	not e	*0.028*	*SW T6b*	0.9996	*0.018*	*SW T6b*	0.6426	*0.036*	*SW T6b*	1.2852
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
3. Heavy Off Road Mobile Sources (excavators, dozers, etc)		hrs		US gal-fuel/hrs		Btu/US gal		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 T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Construction (remediation)	*2 CY Exc, 100 HP, 239 CY/hr, 184 m^3/hr, adjust 1*	100.0	*Diesel*	10.8	*SW T3b*	135847	*SW T2a*	1	*SW T3a*	154050.498	93350	*SW T3b*	9.3350	not e	546	*SW T3b*	54.6	149	*SW T3b*	14.9	34	*SW T3b*	5.1
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
4. Drill Rigs Fuel Combustion Stationary Sources (drill rigs)		hrs		US gal-fuel/hrs		Btu/US gal		unitless		MJ	kg-CO_2/US gal		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 T3c*	*SW T2a*	*SW 2a Gasoline*	1	*Typically 1*		*SW T2a*	*SW T2a*			*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW 2a Gasoline*	1	*Typically 1*		*SW T2a*	*SW T2a*			*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW 2a Gasoline*	1	*Typically 1*		*SW T2a*	*SW T2a*			*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW 2a Gasoline*	1	*Typically 1*		*SW T2a*	*SW T2a*			*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*		*SW T3d*	*SW T3d*	
5. Process Fuel Combustion Stationary Sources (generators, other)		hrs		US gal-fuel/hrs		Btu/US gal		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	*Install 10 wells, 2 days, auger rig*	20.0	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	21681.18	10.955	*SW T4b, T5, T6*	1.6652	not e	46.6	*;W T4b, T5, T*	7.0832	2.1	*;W T4b, T5, T*	0.3192	1.4	*W T4b, T5, T*	0.2128
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW T2a*	1	*Typically 1*		10.955	*SW T4b, T5, T6*			46.6	*;W T4b, T5, T6*		2.1	*;W T4b, T5, T6*		1.4	*W T4b, T5, T6*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW T2a*	1	*Typically 1*		10.955	*SW T4b, T5, T6*			46.6	*;W T4b, T5, T6*		2.1	*;W T4b, T5, T6*		1.4	*W T4b, T5, T6*	
Decommissioning	*Remove 10 wells, 2 days*	20.0	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	*1*	*Typically 1*	21681.18	10.955	*SW T4b, T5, T6*	1.6652	not e	46.6	*;W T4b, T5, T*	7.0832	2.1	*;W T4b, T5, T*	0.3192	1.4	*W T4b, T5, T*	0.2128
6. Process Electricity Stationary Sources Use		hrs		unitless		KW		unitless		MJ	tonne-CO_2/GW-hr		tonne-CO_2		kg-NOx/KWh		kg-NOx	kg-SOx/KWh		kg-SOx	;-PM10/KWh		kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Construction (remediation)	*LNAPL skimming, 10 wells, 2-5 HP compressors,*	17520.0	*N/A*	1	*Typically 1*	7.5	*Site specific*	1	*Typically 1*	473040.000	10.670	BC Hydro	1.4020	e	*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
7. Materials (well pipe, bentonite, sand, fill, cement, amendments, water treatmen		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	*Well pipe , 2 inc dia, 200 ft*	65.5	*N/A*	*1*	*Typically 1*	67.5	*SW T1c*	1	*Typically 1*	4418.18	3.11	*SW T1c*	0.2036	e	6	*SW T1c*	0.392727273	9.7	*SW T1c*	0.634909091	1.4	*SW T1c*	0.091636364
Investigation	*Bentonite*	500.0	*N/A*	*1*	*Typically 1*	3	*SW T1c*	1	*Typically 1*	1500.000	0.22	*SW T1c*	0.1100	e	0.44	*SW T1c*	0.22	0.88	*SW T1c*	0.44	0.176	*SW T1c*	0.088
Investigation	*Sand*	500.0	*N/A*	*1*	*Typically 1*	0.1	*SW T1c*	1	*Typically 1*	50.000	0.005	*SW T1c*	0.0025	e	0.02	*SW T1c*	0.01	0.025	*SW T1c*	0.0125	0.01	*SW T1c*	0.005
8. Waste Water and Air Treatment		Tech specific		unitless		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/USGal		kg-NOx	g-SOx/USGal		kg-SOx	PM10/USGal		kg-PM10
Water - AD = gal water treated	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7d*	*SW T7d*	1	*Typically 1*		*SW T7d*	*SW T7d*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*	
Air thermal oxidizer - AD = gal fu	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7c*	*SW T7c*	1	*Typically 1*		*SW T7c*	*SW T7c*			*SW T7c*	*SW T7c*		*SW T7c*	*SW T7c*		*SW T7c*	*SW T7c*	
Other - all phases	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7d*	*SW T7d*	1	*Typically 1*		*SW T7d*	*SW T7d*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T7d*	
Other - all phases	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		*Site specific*	*Site specific*			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
9. Soil Disposal		Ton (2000 lb)[5]		unitless		MMBtu/ton		unitless		MJ	lb-CO_2/ton soil		tonne-CO_2		lb-NOx/ton		kg-NOx	lb-SOx/ton		kg-SOx	b-PM10/ton		kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T7d*	
Construction (remediation)	*Disposal contaminated soil offsite landfill*	9900	*N/A*	1	*Typically 1*	0.16	*SW T7a*	1	*Typically 1*	1671120	25	*SW T7a*	112.5		*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T7d*	
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T7d*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T7d*	
10. Laboratory Analyses		$		unitless		MMBtu/$		unitless		MJ	kg-CO_2/$		tonne-CO_2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Soil and groundwater investigation*	6000.0	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	*ALS*	0.1260	e	0.0048	*SW T7e*	0.0288	0.0036	*SW T7e*	0.0216	0.0004	*SW T7e*	0.0024
Construction (remediation)	*100 soil samples*	20000.0	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	*ALS*	0.4200	e	0.0048	*SW T7e*	0.096	0.0036	*SW T7e*	0.072	0.0004	*SW T7e*	0.008
Operation/Monitoring	*1 events x $2,000/event*	2000.0	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	*ALS*	0.0420	e	0.0048	*SW T7e*	0.0096	0.0036	*SW T7e*	0.0072	0.0004	*SW T7e*	0.0008
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		ALS	*ALS*			*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*	
11. Travel		km		unitless		MJ/km		unitless		MJ	kg-CO_2/km-psn		tonne-CO_2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Addressed under 1)*	0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Construction (remediation)		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Operation/Monitoring		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Decommissioning		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
								Total		**43085340**	**Total**		**176**		**Total**		**70.7**	**Total**		**17.4**	**Total**		**7.04**
								Total (MMJ)		**43.09**	**Total (tonnes)**		**176**		**Total NOx, SOx, PM10 (tonnes)**								**0.095**

General Notes

1. SW = SiteWise
2. BC Ministry of Environment Best Practices Methodology for Quantifying Greenhouse Gas Emissions 2018 Data
3. ALS = ALS Laboratory, Burnaby, BC, Canada
4. If CO2-e values are not available should sum the emissions are follows based on US EPA 100-yr global warming potential equivalents: 1x(mass-CO_2) + 25x(mass-CH_4) + 298x(mass-N_2O)
5. ton = 2000 lbs, tonne = 1000 kg

How to Use:
1. Conduct Footprinter Analysis and create copy for each technology.
2. Define boundaries of the LCA.
3. Inputs with drop-down menus are BC defaults, remaining inputs are user defined (SiteWise generally recommended)
4. GHG estimates are copied to Impact Tool.

DRAFT BETA SR DASHBOARD (V1.1)

SR IMPACT TOOL - CONSIDER LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - OPERATION / MONITORING - DECOMMISSIONING

TECHNOLOGY: LNAPL Recovery (skimming) followed by ISCO DEFINE BOUNDARIES OF LCA: All on-site activities associated with investigation/remediation plus travel to site

Site: moderate sized source (50x100 m), 5000 m^3 contaminated soil; **Investigation:** 10 wells; **Construction (remediation):** 50 injection wells, inject 5000 kg of persulfate. **Operation/Monitoring:** Monitoring 1st yr quarterly, annual monitoring for 2 yrs. **Decommissioning:** Abandon wells. 50 miles roundtrip to site from consultant/vendors/contractors

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)	Energy Coefficient Source	Efficiency Factor (EFF)	Efficiency Factor Source	Energy Consumption (EC) EC = ADxGxExEFF	Emission Factor (EF)	Emission Factor Source	GHG Emissions (GHG) GHG = ADxGxEF	e-equivalent i.e., includes CH_4,N_2O?[4]	NOx Emission Factor	NOx Emission Factor Source	NOx Emission	SOx Emission Factor	SOx Emission Factor Source	SOx Emission	PM10 Emission Factor	PM10 Emission Factor Source	PM10 Emission Factor
1. Light On Road Mobile Sources (vehicles, light trucks)		mile		US gal-fuel/mile		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/mile		kg-NOx	g-SOx/mile			g-PM10/mile		kg-PM10
Investigation	*Install 10 wells, 2 days, light truck*	100	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.059	8.880	*BC Light-duty vehicle*	0.0467	e	0.141	*SW T2b*	0.0141	0.005	*SW T2b*	0.00050	0.029	*SW T2b*	0.00290
Investigation	*Soil & gw sampling, 3 days, light truck*	150	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.088	10.026	*BC Light-duty vehicle*	0.0792	e	0.141	*SW T2b*	0.0212	0.005	*SW T2b*	0.00075	0.029	*SW T2b*	0.00435
Construction (remediation)	*Install 50 injection points 5 days light truck, 4 i*	1000	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.588	8.880	*BC Light-duty vehicle*	0.4675	e	0.141	*SW T2b*	0.1410	0.005	*SW T2b*	0.00500	0.029	*SW T2b*	0.02900
Operation/Monitoring	*Quarterly 1st yr, annual for 1 yr, 2 day event*	500	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.294	8.880	*BC Light-duty vehicle*	0.2337	e	0.141	*SW T2b*	0.0705	0.005	*SW T2b*	0.00250	0.029	*SW T2b*	0.01450
Decommissioning	*Decommission 10 wells, 2 days, light truck*	100	*Gasoline*	*0.0526*	*BC Light truck -*	10.633	*SW T2a*	1	*Typically 1*	0.059	8.880	*BC Light-duty vehicle*	0.0467	e	0.141	*SW T2b*	0.0141	0.005	*SW T2b*	0.00050	0.029	*SW T2b*	0.00290
2. Heavy On Road Mobile Sources (heavy trucks)		mile		US gal-fuel/mile		Btu/US gal		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 T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T6b*	*SW T6b*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T6b*	*SW T6b*			*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*		*SW T6b*	*SW T6b*	
3. Heavy Off Road Mobile Sources (excavators, dozers, etc)		hrs		US gal-fuel/hrs		Btu/US gal		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 T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3b*	*SW T3b*	*SW T2a*	*SW T2a*	*SW T3a*	*SW T3a*		*SW T3b*	*SW T3b*			*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*		*SW T3b*	*SW T3b*	
4. Drill Rigs Fuel Combustion Stationary Sources (drill rigs)		hrs		US gal-fuel/hrs		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/gal		kg-NOx	g-SOx/hr		kg-SOx	g-PM10/hr		kg-PM10
Investigation	*Install 10 wells, 2 days, auger rig*	20	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	21681.181	10.955	*SW T2a*	1.6652	not e	46.6	*SW T3d*	7.0832	2.1	*SW T3d*	0.31920	1.4	*SW T3d*	0.21280
Construction (remediation)	*Direct push 50 injection points, 4 events*	200	*Site specific*	0.8	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	22822.296	10.955	*SW T2a*	1.7528	not e	46.6	*SW T3d*	7.4560	2.1	*SW T3d*	0.33600	1.4	*SW T3d*	0.22400
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3c*	*SW T3c*	*SW T2a*	*SW T2a*	1	*Typically 1*		10.955	*SW T2a*		not e	46.6	*SW T3d*		2.1	*SW T3d*		1.4	*SW T3d*	
Decommissioning	*Remove 10 wells, 2 days*	20	*Diesel*	7.6	*SW T3c*	135847	*SW T2a*	1	*Typically 1*	21681.181	10.955	*SW T2a*	1.6652	not e	46.6	*SW T3d*	7.0832	2.1	*SW T3d*	0.31920	1.4	*SW T3d*	0.21280
5. Process Fuel Combustion Stationary Sources (generators, other)		hrs		US gal-fuel/hrs		Btu/US gal		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 T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	*SW T4b, T5, T6*			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*	*SW T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	*SW T4b, T5, T6*			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*	*SW T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	*SW T4b, T5, T6*			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*	*SW T4b, T5, T6*	*SW T2a*	*SW T2a*	1	*Typically 1*		*SW T4b, T5, T6*	*SW T4b, T5, T6*			*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*		*SW T4b, T5, T6*	*SW T4b, T5, T6*	
6. Process Electricity Stationary Sources Use		hrs		unitless		KW		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*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Construction (remediation)	*LNAPL skimming, 10 wells, 2-5 HP compressors*	17520	*N/A*	1	*Typically 1*	7.5	*Site specific*	1	*Typically 1*	473040.000	10.670	BC Hydro	1.4020	e	*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		10.670	BC Hydro			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
7. Materials (well pipe, bentonite, sand, fill, cement, amendments, water treatme		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	*Well pipe , 2 inc dia, 200 ft*	65.5	*N/A*	1	*Typically 1*	67.5	*SW T1c*	1	*Typically 1*	4418.182	3.11	*SW T1c*	0.2036	e	6	*SW T1c*	0.3927273	9.7	*SW T1c*	0.63491	1.4	*SW T1c*	0.09164
Investigation	*Bentonite*	500	*N/A*	1	*Typically 1*	3	*SW T1c*	1	*Typically 1*	1500.000	0.22	*SW T1c*	0.1100	e	0.44	*SW T1c*	0.22	0.88	*SW T1c*	0.44000	0.176	*SW T1c*	0.08800
Investigation	*Sand*	500	*N/A*	1	*Typically 1*	0.1	*SW T1c*	1	*Typically 1*	50.000	0.005	*SW T1c*	0.0025	e	0.02	*SW T1c*	0.01	0.025	*SW T1c*	0.01250	0.01	*SW T1c*	0.00500
Construction (remediation)	*Persulfate*	5000	*N/A*	1	*Typically 1*	30	*SW T1c*	1	*Typically 1*	150000.000	1	*SW T1c*	5.0000	e	3	*SW T1c*	15	5	*SW T1c*	25.00000	1	*SW T1c*	5.00000
8. Waste Water and Air Treatment		Tech specific		unitless		Btu/US gal		unitless		MJ	kg-CO_2/US gal		tonne-CO_2		g-NOx/USGal		kg-NOx	g-SOx/USGal		kg-SOx	g-PM10/USGal		kg-PM10
Water - AD = gal water treated	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7d*	*SW T7d*	1	*Typically 1*		*SW T7d*	SW T7d			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*	
Air thermal oxidizer - AD = gal fue	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7c*	*SW T7c*	1	*Typically 1*		*SW T7c*	SW T7c			*SW T7c*	*SW T7c*		*SW T7c*	*SW T7c*		*SW T7c*	*SW T7c*	
Other - all phases	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7d*	*SW T7d*	1	*Typically 1*		*SW T7d*	SW T7d			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Other - all phases	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		*Site specific*	*Site specific*			*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
9. Soil Disposal		Ton (2000 lb)[5]		unitless		MMBtu/ton		unitless		MJ	lb-CO_2/ton soil		tonne-CO2		lb-NOx/ton		kg-NOx	lb-SOx/ton		kg-SOx	lb-PM10/ton		kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Construction (remediation)	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7a*	*SW T7a*	1	*Typically 1*		*SW T7a*	*SW T7a*			*SW T7d*	*SW T7d*		*SW T7d*	*SW T7d*		*SW T1c*	*SW T1c*	
10. Laboratory Analyses		$		unitless		MMBtu/$		unitless		MJ	kg-CO_2/$		tonne-CO2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Soil and groundwater investigation*	6000	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	ALS	0.126		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T1c*	*SW T7e*	
Construction (remediation)	*Additional lab testing*	4000	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	ALS	0.084		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T1c*	*SW T7e*	
Operation/Monitoring	*2 events x $2,000/event*	4000	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	ALS	0.084		*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T1c*	*SW T7e*	
Decommissioning	*Describe*	*Site specific*	*N/A*	1	*Typically 1*	*SW T7e*	*SW T7e*	1	*Typically 1*		0.021	ALS			*SW T7e*	*SW T7e*		*SW T7e*	*SW T7e*		*SW T1c*	*SW T7e*	
11. Travel		km		unitless		MJ/km		unitless		MJ	kg-CO_2/km-psn		tonne-CO_2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Addressed under #1*	0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Construction (remediation)		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Operation/Monitoring		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
Decommissioning		0	*N/A*	1	*Typically 1*	*Site specific*	*Site specific*	1	*Typically 1*		0.101	Bus-City	0		*Site specific*	*Site specific*		*Site specific*	*Site specific*		*Site specific*	*Site specific*	
								Total		**695194**	**Total**		**13.0**		**Total**		**37.5**	**Total**		**27.1**	**Total**		**5.89**
								Total (MMJ)		**0.70**	**Total (tonnes)**		**13.0**		**Total NOx, SOx, PM10 (tonnes)**								**0.070**

General Notes
1. SW = SiteWise
2. BC Ministry of Environment Best Practices Methodology for Quantifying Greenhouse Gas Emissions 2018 Data
3. ALS = ALS Laboratory, Burnaby, BC, Canada
4. If CO2-e values are not available should sum the emissions are follows based on US EPA 100-yr global warming potential equivalents: 1x(mass-CO_2) + 25x(mass-CH_4) + 298x(mass-N_20)
5. ton = 2000 lbs, tonne = 1000 kg

APPENDIX E

Measures to Reduce Carbon Footprint of Remediation

Many companies and organizations are considering measures to reduce their carbon footprint and GHG emissions. While the goal should be emission reduction, an additional way to reduce an organizations carbon footprint is through purchase of offsets. For example, these may be used to offset carbon emissions from electricity use, fuel use and travel. For example, assuming a round trip of 3,364 km between Vancouver and Toronto, using the emission factor published by BC Government (0.1048 t-CO_2/passenger-km), a GHG emission rate of 0.71 CO_2-e tonnes is calculated. This GHG emission can be off-set through purchase of an off-set from organizations such as Off-Setters or CarbonNeutral (approximately $20, which is used to plant approximately five trees).

An emerging concept is where specific measures incorporated in the environmental remediation or post-remediation site development phase are used to reduce the carbon footprint thereby qualifying as an offset. Through such measures it may be possible to reduce carbon emissions or potentially achieve carbon neutrality of remediation. This may be desirable for addressing carbon emissions associated with natural attenuation. If the boundary for evaluating carbon neutrality were to include future development, the calculation of offsets could include specific measures in the future development for reducing carbon emissions (e.g., use of clean energy).

Examples of how GHG emissions could potentially be reduced through integration with site remediation and development include:

1) Use of green gardens or landscaping where practices promote plant growth and formation of stable soil organic carbon (e.g., in humus). A similar option could be to implement phytoremediation when there is relatively shallow soil contamination and conditions amenable to this technology. Properly engineered, this technology could not only be beneficial in reducing contamination levels, but also result in carbon capture if trees are a permanent feature of the site development.
2) Use of solar- or wind-power for equipment used during remediation or installed on a permanent basis and integrated in the power grid as part of the future development. For example, contaminated sites in remote areas associated with oil and gas exploration may already have infrastructure in-place that would promote conversion to a clean energy project.
3) Use of crushed concrete wastes to sequester carbon dioxide as soil inorganic carbon through the process of carbonation. While there is limited research on this option one study suggested that 11 kg of CO_2 could be sequestered for each ton of crushed concrete (Kaliyavaradhan and Ling 2017). The re-use of crushed concrete on development sites would require consideration of other factors such as secondary effects on water quality due to change in pH, geotechnical strength, and water drainage and infiltration.

> ***Carbon Sequestration:*** *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 that this is provided abundantly in brownfield soils that contain demolition wastes such as concrete dust and lime. One 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.*

References

Kaliyavaradhan, S.K., T.C. Ling. 2017. Potential of CO_2 Sequestration Through Construction and Demolition (C&D) Waste – An Overview. J. of CO_2 Utilization, 20: 234-242.

GOLDER

golder.com