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DEPARTMENT OF THE NAVY GUIDANCE ON GREEN AND SUSTAINABLE REMEDIATION

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14. ABSTRACT

This document provides a general overview and explanation of key green and sustainable remediation (GSR) concepts as they pertain to the environmental restoration program. GSR metrics and issues related to the application of GSR components to general and specific optimization strategies are discussed. This document also presents a step-wise approach for application of GSR techniques at projects in all phases of the environmental restoration process, including site investigation, remedy selection, remedial design and construction, and operation and long-term monitoring. Methods for evaluating the remedy footprint during each of these phases is discussed in the guidance, along with strategies for footprint reduction.

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EXECUTIVE SUMMARY

The purpose of this guidance is to provide Navy remedial project managers (RPMs) and consultants with a clear approach to incorporating green and sustainable remediation (GSR) considerations into the current remediation process. The Navy's Environmental Restoration (ER) program involves both passive remedial approaches and active remedies, some of which require operation of remedial systems. The objective of these remedies is to eliminate unacceptable risk to human health and the environment by remediating or managing contamination in environmental media. The idea behind GSR is to improve the cleanup program by meeting the existing requirements, while minimizing potential negative environmental, societal and economic impacts that could occur during or as a result of remedial actions.

The growing emphasis to include GSR practices in the different phases of remedial action is being driven primarily by two Executive Orders (EOs), 13514 and 13423, which call for federal agencies to operate in a sustainable manner. In line with EO 13423, the office of the Under Secretary of Defense released a GSR memorandum [1] in August 2009 that states that the DoD is committed to conducting its environmental program in a sustainable manner.

The Department of the Navy (DON) is approaching implementation of GSR as part of the existing optimization program, and has included GSR in the Policy for Optimizing Remedial and Removal Actions at All DON Environmental Restoration Program Sites [2] that requires optimization and GSR evaluations at the remedy selection, design, and remedial action operation (RA-O) phases. This guidance document expands on the concepts and application of GSR within the framework of environmental remediation optimization principles.

This document will further define and elaborate on what *green* and *sustainable* mean within the context of environmental remediation, with respect to DON. A more thorough understanding of GSR metrics and application issues discussed in this guidance is intended to make it easier and more intuitive to apply GSR components to general and specific optimization strategies. This document includes a discussion of the following topics which provide relevant background information and a step-wise approach for Navy RPMs to understand and apply GSR techniques at projects in various phases of the ER process:

- **Introduction** (Section 1.0) – Includes an overview of GSR concepts, drivers, tracking requirements and resources.
- **GSR Metrics** (Section 2.0) – Includes a discussion of the sources for GSR metrics and how the Navy recommends incorporating metrics into the ER process for a given site. GSR metrics identified in the Navy fact sheet [3] include: (1) energy consumption, (2) green house gas (GHG) emissions, (3) criteria pollutant emissions, (4) water impacts, (5) ecological impacts, (6) resource consumption/waste generation, (7) worker safety/accident risk, and (8) community impacts. This list of metrics can be expanded or reduced based on site, technology, or stakeholder specific information. The selection and prioritization of GSR metrics for a project is discussed in this section.
- **Metric Calculation Methods and Tools** (Section 3.0) – Provides an introduction on how metrics are calculated and discusses various tools available to RPMs for assessing GSR

metrics. SiteWise™ and SRT™ are two publically available tools that were developed for quantifying GSR metrics for an entire remedial action. For some metrics, such as community impacts and ecological impacts, a qualitative or semi-quantitative assessment is appropriate. For ecological impacts, an alternative quantitative method such as Net Environmental Benefit Analysis (NEBA) can also be used. Use of these tools and various methods for evaluating GSR metrics is discussed in this section.

- **GSR Consideration during Site Characterization** (Section 4.0) – Similar to optimization, GSR should be considered throughout all project phases, including site characterization. Section 4 provides GSR considerations during site characterization activities. There are several proven methods and best management practices (BMPs) to optimize site characterization, which will in turn improve sustainability by minimizing environmental impacts. Typical methods for reducing the environmental impacts during site characterization include using efficient data collection and systematic planning, streamlining the characterization process (e.g., Triad), using efficient sample collection techniques, and minimizing and managing investigation derived waste.
- **GSR Considerations during Remedy Selection** (Section 5.0) – Remedy selection provides the greatest opportunity to lower the overall remedy footprint, during which selection of the most sustainable remedial option establishes a lower remedy footprint from the start. In general, remedies that tend to have a small footprint are those that make appropriate use of passive systems and those that enhance natural processes. However, when a technology is not effective in meeting the remedial goals and achieving the required level of protectiveness, the technology is simply not sustainable. Therefore, active and energy intensive remedial systems still play an important role in the ER program, as long as they are applied in suitable situations and appropriate exit strategies are developed. Section 5 includes a discussion of how to perform a GSR assessment during the remedy selection stage, which includes (1) identifying remedial alternatives that are protective and in compliance with all applicable or relevant and appropriate requirements (ARARs), (2) evaluating the remedial footprint of these alternatives using the GSR metrics described in Section 2, and (3) incorporating the GSR metrics into the evaluation of Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) criteria. GSR metrics fit well within the current regulatory frameworks.
- **GSR Considerations during the Remedial Design (RD) and Construction** (Section 6.0) – Once a sustainable remedial alternative is chosen, additional consideration should be given to further reducing the remedy footprint through the careful selection of footprint reduction methods during the RD and construction phase. Those activities with the greatest projected remedy footprint during implementation of the remedy should be targeted for further footprint reduction. Section 6 provides a discussion of footprint reduction methods to consider during the RD and construction phase, and the associated cost analysis that should be completed to support decisions regarding implementation of footprint reduction methods.
- **GSR Consideration during RA-O and Long-Term Monitoring (LTM)** (Section 7.0) – GSR should be included as part of optimization reviews which are performed periodically during RA-O/LTM phases. This expands the objective of optimization to include remedy footprint reduction through careful selection of footprint reduction methods as well as by

incorporating GSR metrics into the remedy exit strategy. A stepwise approach for implementing GSR during RA-O/LTM is presented in Section 7, along with a discussion of footprint reduction methods to consider during RA-O/LTM and how performance objectives and exit strategies are used to improve sustainability of a remedy.

- **General Footprint Reduction Methods** (Section 8.0) – A wide variety of footprint reduction technologies can be applied to a given project. The challenge to an RPM is to determine which technologies are appropriate for a given site. Section 8 provides information and guidance on how to make appropriate environmental cleanup choices that achieve the greatest reduction in the overall footprint while meeting the remedial goals and resulting in little or no additional costs. This is accomplished by providing a brief discussion of the more commonly used footprint reduction methods, along with guidance on what factors to take into consideration when determining whether a reduction method should be selected for a given site. General categories of footprint reduction methods which are discussed in this section include remedy optimization, alternative fuels, renewable energy, injection methods, alternative transportation, and energy efficiency.

This document can be used to obtain an overall familiarity with GSR concepts and/or as a resource on the application of these concepts at each phase of remediation. Regarding general concepts, the reader can obtain an overall familiarity with the primary GSR concepts, drivers, metrics and available resources through a review of Sections 1 and 2, whereas an understanding of tools and approaches available to conduct GSR evaluations can be obtained through a review of Section 3. When involved in a particular phase of a remediation project, the reader can refer to Sections 4 through 7 to obtain practical guidance on how to implement GSR in a given phase. The reader can continually refer to Section 8 for more detailed information regarding remedial footprint reduction methods that can be applied during any stage of the remedial process.

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ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Engineering and the Environment
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society for Testing and Material
BMP	best management practice
BRAC	Base Realignment and Closure
BTU	British Thermal Units
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CH_4	methane
CNG	compressed natural gas
CO_2	carbon dioxide
CSM	conceptual site model
DMF	diesel multistage filter
DOC	diesel oxidation catalyst
DoD	Department of Defense
DON	Department of the Navy
DPF	diesel particulate filter
dSAY	discounted service-acre-year
DTSC	Department of Toxic Substances Control
EERE	Energy Efficiency and Renewable Energy
EO	Executive Order
EPA	Environmental Protection Agency
ER	Environmental Restoration
FS	feasibility study
GHG	greenhouse gas
GSR	green and sustainable remediation
HEA	habitat equivalency analysis
HFC	hydrofluorocarbon
HVAC	heating, ventilation, and air-conditioning
IAS	in situ air sparging
IDW	investigative derived waste
IPCC	Intergovernmental Panel on Climate Change
IR	Installation Restoration
ISCO	in situ chemical oxidation
ITRC	Interstate Technology and Regulatory Council

LCA	life-cycle assessment
LCI	life-cycle inventory
LEED	Leadership in Energy and Environmental Design
LNG	liquefied natural gas
LTM	long-term monitoring
LUC	land use control
MEC	munitions and explosives of concern
MMR	Massachusetts Military Reservation
MNA	monitored natural attenuation
MPE	multiphase extraction
N_2O	nitrous oxide
NAVFAC	Naval Facilities Engineering Command
NAPL	non-aqueous phase liquid
NBB	National Biodiesel Board
NEBA	Net Environmental Benefit Analysis
NERP	Navy Environmental Restoration Program
NO_x	oxides of nitrogen
NPV	net present value
NREL	National Renewable Energy Laboratory
PFC	perfluorocarbon
PM	particulate matter
PQO	project quality objective
PRB	permeable reactive barrier
PV	photovoltaic
PVC	polyvinyl chloride
RAC	remedial action construction
RAO	remedial action objectives
RA-O	Remedial Action Operation
RCRA	Resource Conservation and Recovery Act
RD	remedial design
RI	remedial investigation
RPM	Remedial Project Manager
ROI	return on investment
SAP	Sampling and Analysis Plan
SCR	selective catalytic reduction
SF_6	sulfur hexafluoride
SO_x	sulfuric oxide
SRT™	Sustainable Remediation Tool
SURF	Sustainable Remediation Forum
SVE	soil vapor extraction
ULSD	ultra low sulfur diesel

USACE	United States Army Corps of Engineers
USGBC	Unites States Green Building Council
VFD	variable frequency device
VOC	volatile organic compound
WRI	World Resources Institute

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1.0 INTRODUCTION

The purpose of this guidance is to provide Navy remedial project managers (RPMs) and consultants with a clear approach to incorporating green and sustainable remediation (GSR) considerations into the current remediation process. The goal of the Navy's Environmental Restoration (ER) program is to select and implement remedies that are protective of human health and the environment and in compliance with applicable or relevant and appropriate requirements (ARARs). This guidance demonstrates how meeting this goal can be better accomplished by taking a more holistic view of the remedial action and considering other impacts that are the result of conducting the remedy. Social, economic, and environmental impacts not traditionally addressed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)/Resource Conservation Recovery Act (RCRA) can sometimes provide both negative and positive outcomes. Incorporating GSR into cleanups can be accomplished within the National Contingency Plan framework, while remaining focused on cleanup goals and mindful of meeting budgets and remedy in place/response complete dates.

The Department of the Navy (DON) is approaching implementation of GSR as part of the existing optimization program, and has included GSR in the Policy for Optimizing Remedial and Removal Actions at All DON Environmental Restoration Program Sites [2] that requires optimization and GSR evaluations at the remedy selection, design, and remedial action operation (RA-O) phases. This document expands on the concepts and application of GSR within the framework of environmental remediation optimization principles. When the DON released its Interim-Final document, *Guidance for Optimizing Remedial Action Operation* [5], followed by the issuance of the DON policy for optimizing remedial and removal actions under the Navy Environmental Restoration Program (NERP) [4], GSR had not been defined or specifically articulated in the initial production of these documents. Therefore, the DON Optimization Workgroup, which was established to promote the optimization of remedial actions by serving as an advisory body to Navy ER Managers, has worked to develop the strategy as presented in this guidance for applying GSR to the ER process. The Optimization Workgroup has also assisted in the development of other resources that will guide the implementation of GSR as a whole. For example, a GSR Web Portal was developed, and is available on the ER Technology Transfer Web site (www.ert2.org).

Sustainability has now been defined and specified as a goal-setting measure through the issuance of Federal Executive Orders (EOs) and policy statements by agencies such as the Department of Defense (DoD) and the Environmental Protection Agency (EPA). The DoD strategic sustainability plan [6] defines sustainability as:

> *"The Department's vision of sustainability is to* ***maintain the ability to operate into the future without decline – either in the mission or in the natural and manufactured systems that support it.*** *DoD embraces sustainability as a means of improving mission accomplishment. Sustainability is not an individual Departmental program; rather, it is an organizing paradigm that* ***applies to all DoD mission and program areas.*** *DoD personnel are learning to apply this mindset to their practices to* ***improve mission performance and reduce lifecycle costs."***

The conceptual development and understanding of the terms *green* and *sustainable* are reflected in current and future remediation optimization documents because it is now clear that GSR is an integral component of optimization within many phases of remediation. However, as new technologies and strategies are developed, or more rigorous sustainability mandates are issued, guidance offered in this document may need to be modified, supplemented, or replaced. As a result of GSR being a rapidly evolving tactic within the field of remediation, and the accelerated pace at which DoD is institutionalizing sustainability practices, it is recommended that information contained in this document be reevaluated as needed.

This document will further define and elaborate the DON perspective on what *green* and *sustainable* mean within the context of environmental remediation. It is hoped that a more thorough understanding of GSR metrics and application issues will provide information that will make it easier and more intuitive to apply GSR components to general and specific optimization strategies.

1.1 Overview of Green and Sustainable Remediation Concepts

The NERP involves both passive remedial approaches and active remedies, some of which require operation of remedial systems. The objective of these remedies is to eliminate unacceptable risk to human health and the environment by remediating or managing contamination in environmental media. The idea behind GSR is to improve the cleanup program by meeting the existing requirements, while minimizing potential negative environmental, societal and economic impacts that could occur during or as a result of remedial actions.

In most cases, more than one remedial alternative can satisfy the two threshold criteria for remedy selection (i.e., be protective of human health and the environment and satisfy regulatory requirements). Additional decision criteria for selecting the remedial alternative depend on the regulatory program. Many Navy sites are remediated following the requirements of CERCLA remedial actions, where there are five primary balancing criteria (long-term effectiveness and permanence; reduction in toxicity, mobility, or volume; short-term effectiveness; implementability, and cost) and two modifying criteria (state acceptance and community acceptance) in addition to the two threshold criteria. Although there is no one specific CERCLA criterion that uses sustainability as a metric, some of the existing criteria include elements of sustainability that should be considered when selecting the remedy. Once a remedy is selected, there are still many decisions to be made such as determining how each technology is to be implemented.

> Evaluate GSR throughout the remedial process: remedial selection, remedial design, and remedial operation.

The concept of GSR emphasizes and promotes consideration of sustainability throughout the entire remedial process. Figure 1-1 charts the ER process, and identifies steps during which elements of GSR can be applied: remedial investigation (RI), feasibility study (FS), remedial design (RD), RA-O and long-term monitoring (LTM) are steps of the remediation process that often present opportunities to apply some form of GSR.

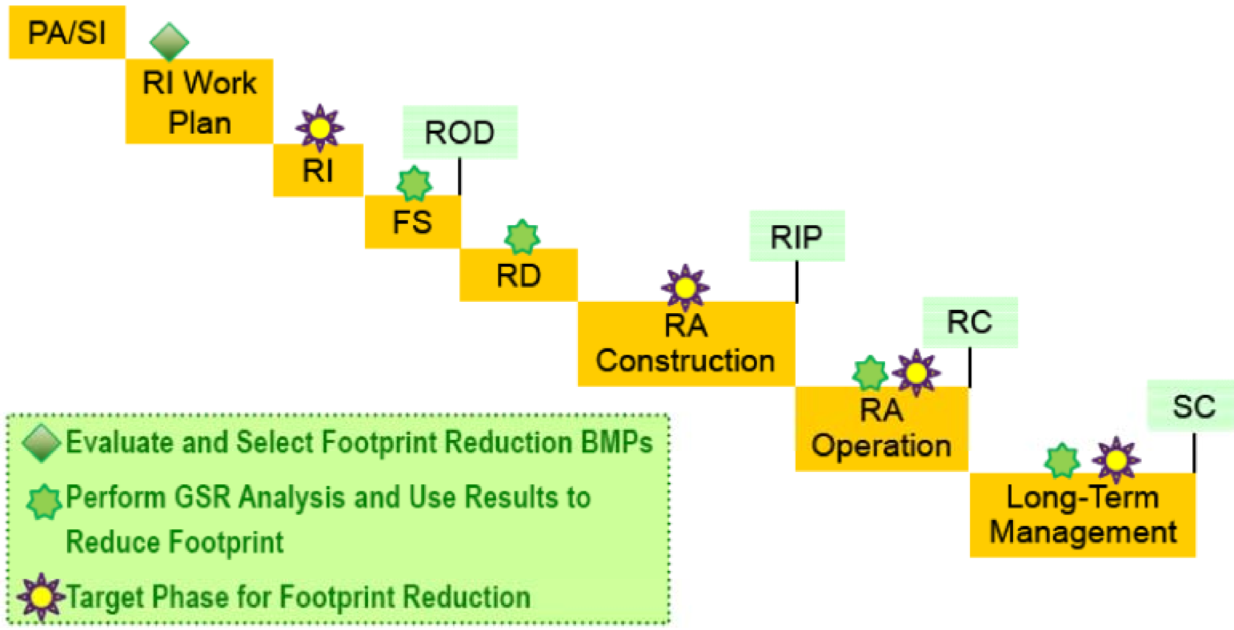

Figure 1-1. Applying GSR throughout the Environmental Restoration Process

Implementation of best management practices (BMPs) should be considered during the RI phase [7] to minimize the footprint during the investigation phase of work. During the FS, a full GSR evaluation should be completed and footprint reduction methods should be considered as part of the remedy selection. The GSR evaluation can be further refined during the RD to determine which footprint reduction methods should be implemented during construction and RA-O. The GSR evaluation can also be updated periodically during extended RA-O and LTM periods to identify any additional footprint reduction methods that may further improve sustainability of the remedy.

The idea behind GSR is to promote a more comprehensive way in which remediation practitioners approach remediation and consider the implication of their activities (such as heavy machinery and equipment use, energy consumption, chemical use, etc.) on the biophysical surroundings. A DoD memorandum [1] describes GSR as follows:

> *"Green and sustainable remediation expands upon the Department [of Defense]'s current environmental practices and employs strategies for cleanups that use natural resources and energy efficiently, reduce negative impacts on the environment, minimize or eliminate pollution at its source, protect and benefit the community at large, and reduce waste to the greatest extent possible. Green and sustainable remediation uses strategies that consider all environmental effects of remedy implementation and operation and incorporates options to maximize the overall environmental benefit of cleanup actions".*

It should be noted that within the remediation industry, some parties use the terms *green remediation* or *sustainable remediation* rather than GSR as described in the above referenced DoD memorandum. EPA's Green Primer [8] defines green remediation as the practice that reduces the environmental and energy footprint of a remediation activity by incorporating sustainable practices for conducting remediation. To guide the incorporation of green remediation into ER, EPA has developed five core elements (Figure 1-2). These elements are: energy requirements of the treatment system; air emissions; water requirements and impacts on water resources; land and ecosystem impacts; and material consumption and waste generation. By addressing these core elements during the cleanup process, the potential environmental and energy footprints of a remedial action affecting air, water, soil, ecosystems and the climate can be minimized. While EPA's green remediation focuses on the remedial action's impact on environmental media and resource consumption, the Navy also considers worker safety and other social impacts in the remedy footprint. Within the Navy ER Program, the term *remedy footprint* is meant to include adverse impacts on environmental media and society that are a direct or indirect consequence of performing the remedial action.

Within the Navy ER Program, the term *remedy footprint* is meant to include adverse impacts on environmental media and society that are a direct or indirect consequence of performing the remedial action.

Figure 1-2. EPA's Core Elements [8]

The DoD memorandum [1] includes a strong social element of protecting and benefiting the community at large as part of GSR. A total of eight metrics have been identified by the Navy for inclusion in GSR evaluations. Each of the following GSR metrics is discussed further in Section 2.0:

- Energy consumption,
- Greenhouse gas (GHG) emissions,
- Criteria pollutant emissions,
- Water impacts,
- Ecological impacts,
- Resource consumption,
- Worker safety, and
- Community impacts.

1.2 GSR Drivers

The growing emphasis from industry, regulatory, and federal agencies to include GSR practices in the different phases of remedial action is being driven by two EOs, policies issued by EPA and individual federal agencies, and also awareness among the remediation industry to curb the potential impact of remedial actions on the surrounding environment. EO 13514, released on October 8, 2009, calls for a reduction in GHGs, energy consumption, and potable and industrial water use by federal agencies. The EO also stresses that federal agencies consider green buildings, waste minimization, sustainable acquisitions, electronic stewardship, and local and regional planning to promote sustainable living and public transit systems on installations. The EO establishes that the federal agencies set an agency-wide reduction target for GHGs, and includes tracking and reporting requirements.[1] Since this EO calls for employing techniques that lead to a reduction in GHGs, energy consumption, and water usage in activities undertaken by federal agencies, remediation activities must also be conducted in a sustainable manner that help in achieving goals set by the EO. A similar EO, EO 13423, released in 2007 also calls for federal agencies to conduct their environmental, transportation, and energy-related activities under the law in support of their respective missions in an environmentally, economically and fiscally sound, integrated, continuously improving, efficient, and sustainable manner. Similar to EO 13514, EO 13423 also lays out definitive and specific goals for GHG reductions, reduction in energy use, pollution prevention, and reduced water consumption.

The office of the Under Secretary of Defense released a GSR memorandum [1] in August 2009 that states that the DoD is committed to conducting its environmental program in a sustainable manner, in line with EO 13423. The memorandum stresses the need to decrease energy demand for existing and future remedial systems and consider other available options to minimize the environmental impact of these systems. The practices laid out in this memorandum affect the NERP directly and provide certain guidelines and practices to incorporate GSR principles into remedial action decision making and implementation. The memorandum provides areas where opportunities to implement GSR practices exist such as:

- Sustainability analysis during remedy selection,
- Sustainability analysis on existing remedial systems,
- Reduction in energy, water, and emissions of GHGs (carbon dioxide [CO_2] in particular) and criteria air pollutants (e.g., oxides of nitrogen [NO_x], sulfur oxides [SO_x], and particulate matter [PM]),
- Waste minimization practices,
- Use of passive sampling techniques,
- Implementation of in situ remedial technologies such as enhanced bioremediation phytoremediation, and
- All other practices that can minimize the environmental impact of planned or existing remedial systems.

In 2008, EPA issued the Green Primer [8], which laid out the abovementioned five core elements of green remediation with different case studies. Since then, EPA has issued the superfund green remediation strategy [9] and many BMPs and guidance documents on this topic. Several EPA regions have already issued policy and guidelines on green remediation [10]. Therefore, there is growing awareness within the regulatory agencies of the value of including the principles of GSR into all phases of remediation. Many state regulatory agencies have also issued guidance documents or guidelines on how to incorporate GSR into the different phases of remedial

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[1] Tracking of optimization metrics is currently required by NORM, and a similar requirement for tracking of GSR metrics has also been mandated by the Navy's Optimization Policy (see Section 1.4).

activity. For example, the California Department of Toxic Substances (DTSC) released an interim advisory on green remediation [11] which discusses inclusion of GSR practices at any stage of cleanup activity and also life-cycle assessments as part of GSR assessments.

1.3 Optimization as a Framework for GSR Goals

The DON is approaching implementation of GSR as part of its existing optimization program. Optimization is an approach to environmental remediation that minimizes long-term project costs, streamlines remediation processes, and expedites the close-out phase. GSR strives for lower energy, water, fuel, chemical, and material use, local sourcing of material and manpower, recycling, cost efficiency, and safe work environments — most of which translates into cost avoidance, efficient remediation processes, and expedited project closeout through exit strategies and long-term planning. Therefore, GSR is not only compatible with optimization, but helps RPMs meet their optimization goals, while simultaneously fulfilling EO sustainability mandates.

GSR should be considered during (a) site characterization; (b) evaluation of remedies during the remedy selection process; (c) the RD phase; and (d) optimization of remedial actions during the RA-O phase. These optimization reviews are opportune times to evaluate incorporating green/sustainable methods into the cleanup strategies for Navy sites.

Before an RPM can implement GSR within an optimization project, it is important to understand the goals of the optimization effort. The following are general guidelines that an RPM should keep in mind when implementing GSR. More detail with respect to accomplishing the GSR objectives will be provided in subsequent sections of this document.

Select remedies/technologies that will work and are appropriate for the site. Technologies that fail to meet the established performance objectives and remedies that are not proving to be sufficiently protective of human health and the environment are wasteful of resources and needlessly add to the remedy footprint. On the other hand, remedies that are unnecessarily aggressive and energy intensive are both costly and have a high remedy footprint compared to less aggressive technologies that can meet the remedial action objective (RAO). While rapid cleanup to unrestricted use may be warranted in some cases, oftentimes sufficient protectiveness can be achieved through land use controls (LUCs), either permanently or temporarily while remedies such as enhanced bioremediation or monitored natural attenuation (MNA) can achieve cleanup goals and allow LUCs to be lifted.

Optimize the remedy. An ideal optimized remedy is a green and sustainable remedy. The Navy has been promoting remedy optimization for over a decade. Adhering to these optimization concepts ensures the effectiveness and efficiency of site cleanup activities and minimizes the amount of wasteful activities that would add to the remedy footprint with limited or no benefit. Navy remedy optimization policy and guidance documents are listed below:

- Policy for Optimizing Remedial and Removal Actions at All DON Environmental Restoration Program Sites [2]
- *Guide for Optimizing Remedial Action Operation* [5]; note that an update to this guidance will be available in 2012,

- *DON Guidance for Planning and Optimizing Monitoring Strategies* [12],
- *Guidance for Optimizing Remedy Evaluation, Selection and Design* [13].

Understand the footprint of the remedy. The footprint of a remedy must be understood before it can be efficiently reduced. The haphazard implementation of remedy footprint reduction methods or selection of "green technologies" will likely do more harm than good. For remedy footprint reduction to be efficient and truly beneficial, sufficient characterization of the metrics for each component of a remedy should be done so that the benefit/cost of each footprint reduction method can be evaluated and prioritized. This allows RPMs to properly consider sustainability metrics when selecting remedies and technologies and decide which remedy footprint reduction methods make the most sense for a specific site.

1.4 GSR Tracking

NORM is a Naval Facilities Engineering Command (NAVFAC) program management database system that includes environmental site registration, cradle-to-grave tracking, relative risk ranking, cost-estimating, budgeting and reporting functions for the ER Program. There is currently an optimization module within NORM that tracks optimization measures in all phases of a site cleanup, including remedial and removal action selection, design, construction, operation, monitoring, and long-term management. Reporting of optimization efforts in NORM is required. The NORM optimization module and the associated tutorial will include GSR metrics, and tracking of the GSR metrics throughout the stages of site cleanup will also be required.

Inclusion of the GSR metrics in NORM will allow tracking of progress toward the reduction of remedy footprints during site cleanup. The following GSR metrics will be included in the NORM optimization module: GHG emissions, energy usage, air pollutants, water impacts/use, ecological impacts, resource consumption, worker safety, and community impacts. The module will require that the RPM briefly describe actions taken to reduce the footprint of the remedy and provide an estimated percent reduction for the following metrics: GHG emissions, energy usage, air pollutants, waste generation, and water impacts/use.

1.5 GSR Resources

With the growing interest in GSR, many organizations have developed publications and maintain Web sites offering information related to GSR. RPMs should refer to the NAVFAC GSR portal at www.ert2.org/t2gsrportal for a current list of GSR guidance. This portal provides information pertaining to GSR, links to publications and other Web sites, and example GSR case study summaries (see also Appendices A and B). Other GSR-related Web sites for some key organizations are listed in Table 1-1.

The Navy issued a fact sheet [3] on GSR that provided an introduction to GSR to help RPMs determine which metrics to consider under GSR, when to consider GSR, and how to ensure that GSR is incorporated into each phase of the remedial process.

Table 1-1. GSR Web Sites for Key Organizations

ORGANIZATION	WEB SITE

NAVFAC GSR Portal	www.ert2.org/t2gsrportal
NAVFAC Environmental Restoration and Base Realignment and Closure (BRAC)	https://portal.navfac.navy.mil/go/erb
EPA	www.cluin.org/greenremediation
Interstate Technology and Regulatory Council (ITRC)	http://www.itrcweb.org/teampublic_GSR.asp
U.S. Army Corps of Engineers (USACE)	https://environment.usace.army.mil/what_we_do/superfund/green_remediation/
Sustainable Remediation Forum (SURF)	www.sustainableremediation.org
Air Force Center for Engineering and the Environment (AFCEE)	http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation/index.asp

Together with the U.S. Army Corps of Engineers (USACE) and Battelle, the Navy developed a tool called SiteWise™ which can assist in calculating certain GSR metrics such as GHG footprint, energy consumption, water impacts, criteria air pollutants, and worker safety for different remedial alternatives. Tools such as SiteWise™ or the Sustainable Remediation Tool (SRT™), developed by the Air Force, are helpful in determining more sustainable options among different feasible remedial alternatives that are protective of human health and the environment and in compliance with ARARs.

The American Society for Testing and Materials (ASTM) is developing a standard guide for green and sustainable site assessment and cleanup. A consortium of industry leaders and experts called Sustainable Remediation Forum (SURF) meets periodically to discuss GSR practices and to advance the knowledge and science surrounding sustainable remediation. SURF is a member organization that includes GSR experts from industry, consulting firms, and technology vendors. To improve the understanding of GSR, SURF published a white paper [14] on GSR entitled "Sustainable Remediation White Paper - Integrating Sustainable Principles, Practices, and Metrics into Remediation Projects". In addition, the Interstate Technology and Regulatory Council (ITRC), led by state regulators, also formed a GSR team that has recently issued an overview document on GSR [15]. Therefore, emphasis on GSR metrics as an integral component of the remedial decision-making process is gaining ground and will soon become a standard practice. This GSR team is now developing a more detailed guidance document.

1.6 Document Organization

This document is organized as follows to provide relevant background information and a step-wise approach for Navy RPMs to understand and apply GSR techniques at projects in various phases of the ER process:

- **GSR Metrics** (Section 2.0) – Includes a discussion of the sources for GSR metrics and how the Navy recommends incorporating metrics into the ER process for a given site.
- **Metric Calculation Methods and Tools** (Section 3.0) – Provides an introduction on how metrics are calculated and discusses various tools available to RPMs for assessing GSR metrics.
- **GSR Consideration during Site Characterization** (Section 4.0) – Provides GSR considerations during site characterization activities.
- **GSR Considerations during Remedy Selection** (Section 5.0) – Provides GSR considerations during remedy selection.
- **GSR Considerations during the RD and Construction** (Section 6.0) – Provides GSR considerations during remedy design and construction.
- **GSR Consideration during Remedial Action Operation and Long-Term Monitoring** (Section 7.0) – Provides GSR considerations during operation of the remedy and LTM including optimization efforts.
- **General Footprint Reduction Methods** (Section 8.0) – Provides a general discussion of methods to reduce environmental and energy footprints such as remedy optimization, alternative fuels, renewable energy, injection methods, alternative transportation, and energy efficiency.

ADDITIONAL INFORMATION AND CASE EXAMPLES
Additional information and case examples are provided throughout the text and are contained in text boxes like this. They are intended to provide guidance on additional information/resources and to expand on key concepts presented in the text.

2.0 GSR METRICS

The first step in implementing GSR for a project is to determine what specific metrics are most important for that site and project. The metrics selected will then be assessed and used in making decisions throughout the remedial process. When selecting these metrics, note that the Navy considers GSR to include environmental, social, and economic impacts (commonly referred to as the triple bottom line), and thus the metrics selected should cover these impacts. Examples of environmental, social, and economic impacts of remedial actions adapted from the SURF white paper [14], on which metrics can be based, are:

- Environmental Impacts:
  - Energy use
  - Air emissions including GHGs and criteria air pollutants
  - Water use
  - Resource consumption
  - Ecological impacts
  - Waste generation

- Social Impacts:
  - Accident risk to site workers
  - Community impacts due to remediation
  - Restrictions on future land use
  - Cultural losses to the local community due to remediation activity
  - Environmental justice
  - Stakeholder engagement and acceptance
  - Public response to remedial activity

- Economic Impacts:
  - Life-cycle cost of remedy
  - Net economic result
  - Local job creation/job loss

The listed impacts can be adverse or positive to the environment, economy, and society. These impacts can be related to more than one aspect of the triple bottom line. For example, impacts on worker safety due to accident risk during remedial action deployment have a social and economic bearing. Specific metrics can be developed from the list of impacts and, in certain cases, more than one metric can be developed due to a single impact. For example, air emissions could include several metrics such as emissions of GHGs, emissions of criteria air pollutants, emissions of ozone depleting gases, and release of carcinogens such as volatile organic compounds (VOCs) into the atmosphere.

2.1 Navy GSR Metrics

The list of Navy GSR metrics in the fact sheet [3] are based on the core elements described in DoD's GSR memorandum [1], EOs, and by EPA in its Green Primer [8]. The Navy GSR fact sheet goes beyond the EPA's Green Primer elements in that it includes community impacts and worker safety. The inclusion of metrics such as community impacts provides a social aspect to the entire GSR assessment and, when considered with the cost of remedy, can render the GSR assessment a more holistic triple bottom line approach. The consideration of certain environmental, social, and economic aspects of remediation in the purview of the existing regulatory frameworks provides the Navy with the ability to choose more sustainable options and not just green options. The metrics developed by the Navy and outlined in the Navy's GSR fact sheet [3] can be mapped onto existing regulatory frameworks such as CERCLA and RCRA. These metrics can be expanded or reduced based on site, technology, or stakeholder specific information. The metrics outlined in the Navy's GSR fact sheet are:

- **Energy Consumption**: Consumption of energy is an important metric because of the need to conserve the U.S. energy supply and reduce dependence on foreign energy sources. Energy consumption also results in the generation of GHGs. Examples of activities resulting in energy consumption include: on-site electrical use, fuel consumed for on-site equipment and transportation, and energy used for the production of consumables associated with the remedy.

- **GHG Emissions**: Quantification of GHG emissions is also an important metric because of growing concern for climate change. The internationally accepted norm is to consider direct GHGs that include CO_2, nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) to develop GHG emission inventories. However, for remediation projects, GHG emissions would primarily include CO_2, N_2O, and CH_4; therefore, it is sufficient to consider only these factors. A standard DoD-wide approach for conducting GHG inventories is being developed. On April 17, 2009, EPA formally declared GHGs as major air pollutants with adverse human health and environmental effects. EPA is considering regulating these gases under the Clean Air Act. Activities that result in GHG emissions include: equipment and electrical use onsite; transportation of personnel, materials, and equipment; and production of consumables associated with the remedy.

- **Criteria Pollutant Emissions**: Air emission of criteria pollutants, regulated by the Clean Air Act of 1970, can cause smog and adverse health effects such as asthma, bronchitis, lung cancer, and eye irritation. Primary criteria air pollutants due to various activities such as transportation of personnel, materials, and equipment; electrical usage; and heavy machinery and equipment operation during remedy implementation include: SO_x, NO_x, PM, ozone, and ozone precursors (VOCs). However, for remediation projects, criteria pollutants would primarily include NO_X, SO_X, and PM; therefore, it is sufficient to consider only these factors. A summary of criteria pollutant sources and negative effects of the various pollutants can be found in the *Environmental Fact Sheet, EPA Criteria Air Pollutants* from the New Hampshire Department of Environmental Services at http://des.nh.gov/organization/commissioner/pip/factsheets/ard/documents/ard-41.pdf.

- **Water Impacts**: Water consumption can be evaluated both qualitatively and quantitatively. Water can be a lost resource if water from an aquifer is wasted during pump and treat operations and not returned to the aquifer, but rather discharged to surface water or a sewer treatment plant. Conversely, water can be a gained resource if contaminated water is treated and reinjected into the aquifer for beneficial use. In addition, water is consumed to produce electricity and manufacture consumables that can be used during remedial activities.

- **Ecological Impacts**: Ecological impacts include adverse effects such as: introduction of invasive species, changes in ecosystem structure or shifts in the geographic distribution and extent of major ecosystem types, disturbance to soil, sediment and surface water bodies, and destruction of habitats. These impacts should be evaluated along with the positive ecological effects of site remediation, such as wetland restoration.
- **Resource Consumption/Waste Generation**: Consumption of any resources that are not specifically identified in other metrics also can be an important consideration. Resource consumption metrics include, but are not limited to: land use restrictions, landfill space, and topsoil brought to the site.
- **Worker Safety/Accident Risk**: Worker safety/accident risk is the risk of fatality or injury of carrying out a specific task of a remedial activity. The guiding principle of any activity undertaken by DON is to operate safely. Therefore, worker safety is crucial and is also a part of NAVFAC's strategic plan. During remedial action operations, higher risk activities include working around heavy equipment and machinery, and operating remedial systems. In addition, there is increased risk of fatality or injury associated with personnel transportation. This risk applies to both site workers traveling to and from the site as well as non-workers traveling those same routes.
- **Community Impacts**: Community impacts are local disturbances, economic impacts of remediation to the local community (positive and negative), and health and safety issues caused by remedial activities, such as: noise; traffic issues; impacts to roadways due to truck traffic; odor; dust; and emissions of VOCs and other contaminants.

2.2 Metrics Selection and Prioritization

Metrics selection and prioritization is site specific and should incorporate stakeholder input.

Selection and prioritization of metrics to conduct a GSR assessment is site specific and should incorporate stakeholder input. Site-specific issues that influence metric selection and prioritization can include site location, site history and use, surrounding environment and communities, and site end use and development. For example, a site located in a residential area would result in a greater concern with community impacts (e.g., odor, noise, remediation traffic, etc.). Conversely, remediation of a site located near a forest that is home to endangered bird species would result in ecological impacts being of great importance. When evaluating metrics, it should also be noted that some are global in nature, such as energy use and GHG emissions, whereas others are important as local or regional impacts such as SO_x or NO_x emissions and for certain sites, depending upon the site location and stakeholders.

The selection of metrics for each site should begin with the list presented in the Navy's GSR fact sheet [3] and in Section 2.1. If one or more metrics are not applicable to the conditions at a given site, those metrics can be eliminated from the GSR evaluation. Conversely, additional metrics can be added as necessary based on site-specific circumstances. The reasoning for excluding a typical metric, or for including an additional metric, should be documented as part of the GSR evaluation.

There are various ways in which the GSR metrics can be prioritized and evaluated. One method is to prioritize metrics by assigning each a relative weight. The weight each metric might carry is based on Navy objectives and regulatory and stakeholder input, and dependent on site-specific issues as discussed above. Alternately, there are ways of conducting a comparative analysis of remedial alternatives without any weighting, such as denoting different metric outcomes as high, medium, and low among the different remedial alternatives. This is consistent with the way in which CERCLA balancing criteria are typically evaluated.

3.0 METRIC CALCULATION TOOLS AND METHODS

To most efficiently meet the objectives of GSR, the footprint of potential remedies should be assessed to determine which remedies, and which elements of a given remedy, have the greatest footprint. The GSR metrics identified for a particular project (see Section 2.0) are typically evaluated in both a quantitative and qualitative manner. Many of the Navy's metrics, such as air emissions and energy use, can be assessed quantitatively. This section focuses on methods and tools to assist in the quantification of these metrics. A qualitative or semi-quantitative assessment is appropriate for certain metrics such as community impacts or ecological impacts. Qualitative metrics can be assessed based on professional judgment, experience and stakeholder input and simply assigned high, medium or low values. For ecological impacts, an alternative quantitative method such as Net Environmental Benefit Analysis (NEBA) can be used as discussed in Section 3.3.

Several tools/models are available to help quantify GSR metrics. For example, tools can be found on Web sites to calculate GHG emissions due to transportation. Several tools are available in the public domain to calculate air emissions or water and electricity usage by remedial activities. However, most of the available tools are myopic in their view and concentrate on a single activity of the remedial action; most were not developed to conduct a GSR assessment for an entire remedial action. In the public domain, only SiteWise™ and SRT™ were developed for quantifying effects of an entire remedial action. These tools are both based on life-cycle assessment (LCA) concepts and employ certain aspects of the LCA approach to conduct GSR assessments. A brief discussion of LCA is provided in Section 3.1 followed by a discussion of both SiteWise™ and SRT™ in Section 3.2.

3.1 Life-Cycle Assessment

LCA has traditionally been used for quantifying the environmental impacts of product manufacturing. Recently, it has been proposed that the LCA process, using commercially available software and databases, be extended to quantify environmental impacts associated with remediation. However, LCA is an approach rather than a tool/model that can be used to quantify the effects of a remedial action.

LCA is a "cradle to grave" approach for assessing a system [16]. In the case of LCA of a product, cradle to grave begins with raw materials to produce the product and ends with final disposal. LCA is a consistent approach that evaluates the environmental impact of every stage of a product's lifecycle. Being a standardized methodology (ISO 14040:2006), LCA provides an internationally consistent approach in calculating the cumulative environmental, economical or social impact of a product. Figure 3-1 represents a system boundary being drawn on the lifecycle of a product and the inputs and outputs associated with the system. An LCA study consists of four steps:

- Defining the goal and scope of the study
- Making a model of the product lifecycle with all environmental inflows and outflows. This data collection effort is usually referred to as the life-cycle inventory (LCI) stage.
- Understanding the environmental relevance of all inflows and outflows
- Interpreting the study.

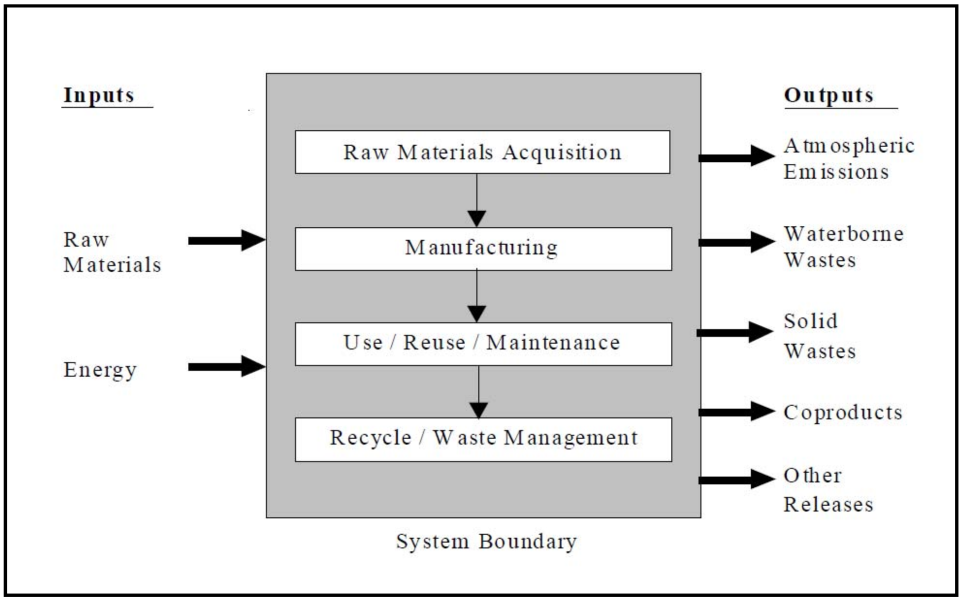

Figure 3-1. Life-Cycle Stages [16]

The output of an LCA study includes an impact assessment which converts the quantified environmental metrics into actual environmental impacts (e.g., the impact of atmospheric emissions resulting in climate change, acid rain and ozone layer impacts, or the impact of water emissions on ecological receptors).

The two primary LCA software packages or tools used historically in the manufacturing industry are SimaPro (developed and distributed by Pré Consultants) and GaBi (developed and distributed by PE International). Both tools provide the same function of providing a user interface to facilitate the use of life-cycle inventory databases in LCA studies. The European Reference Life Cycle Database and the Life-Cycle Inventory Database are two examples of publicly available life-cycle inventory databases. The Ecoinvent Data 2.1 database is one of the leading proprietary life-cycle inventory databases that has also been fully integrated into both SimaPro and GaBi. LCA using these tools has been applied to remediation sites; however, these tools are rigorous in nature and are not entirely geared towards remediation. Although they could be tailored for remediation, these tools and the databases used with them have restricted availability due to cost, and require considerable knowledge and expertise to use.

3.2 LCA-Based Tools Developed for ER Programs

The use of LCA tools specifically geared towards elements of remediation can be helpful in differentiating between multiple GSR strategies. These tools are designed to provide data relating to the sustainability of strategic and technological choices that an RPM may have to make. Some tools are in the public domain (e.g., SiteWise™ and SRT™) and some are proprietary. For DON sites, completion of a GSR evaluation using the SiteWise™ tool is now required for the remedy selection phase and may also be used during other phases of remediation. However, other GSR tools can also be used in conjunction with SiteWise™.

It is important to understand the difference between various LCA tools. All tools will not yield comparable results due to inconsistent system boundaries. Emission factors are dependent on the system boundary that was drawn to develop the emission factor and can vary between different sources based on the boundary conditions that were defined. The most important attribute of a good tool is the degree of comprehensiveness it brings to the accounting of air (including GHG emissions), water and land impacts of the various materials and energy sources used in a remedial action. This would include at the very least one step backwards (origins of the materials and energy sources) and one step forward (fate of end products), not just the current step (the use of a material or energy source during remediation). Databases such as Ecoinvent, Europa, the European Reference Life Cycle Database and the Life-Cycle Inventory Database provide life-cycle, or cradle to grave, emission factors (see Section 3.1.1 for more information on life-cycle analysis). For example, emission factors for a groundwater pump in Ecoinvent would include raw materials and manufacturing of the pump in addition to its use during the remediation project. However, EPA climate leaders provide only operational emissions factors, or that which would result from energy used during operation of the same pump. When performing a GSR assessment, it is important to ensure that consistent boundary conditions are used.

SiteWise™ (Figure 3-2) and SRT™ are two DoD tools developed specifically to assess the secondary environmental effects of site remediation. The advantages of SiteWise™ and SRT™ over other LCA software packages are their relative ease of use, availability (free), and foundation in Microsoft® Excel, which is approved for use on DoD computers. Another advantage of the tools is the transparency incorporated into the tools. All of the calculations and data such as emissions factors are available for user review and every data input in the tools is well referenced. The tools use emission factors provided by federal agencies such as EPA or non-governmental agencies such as the United Nations Intergovernmental Panel on Climate Change (IPCC) or World Resources Institute (WRI), and also national laboratories such as the National Renewable Energy Laboratory (NREL). Emission factors are usage rates that are used to quantify a metric. For example, air emission from equipment use undertaken during a remedial action can be calculated by multiplying emission factors for that equipment type by the hours of operation.

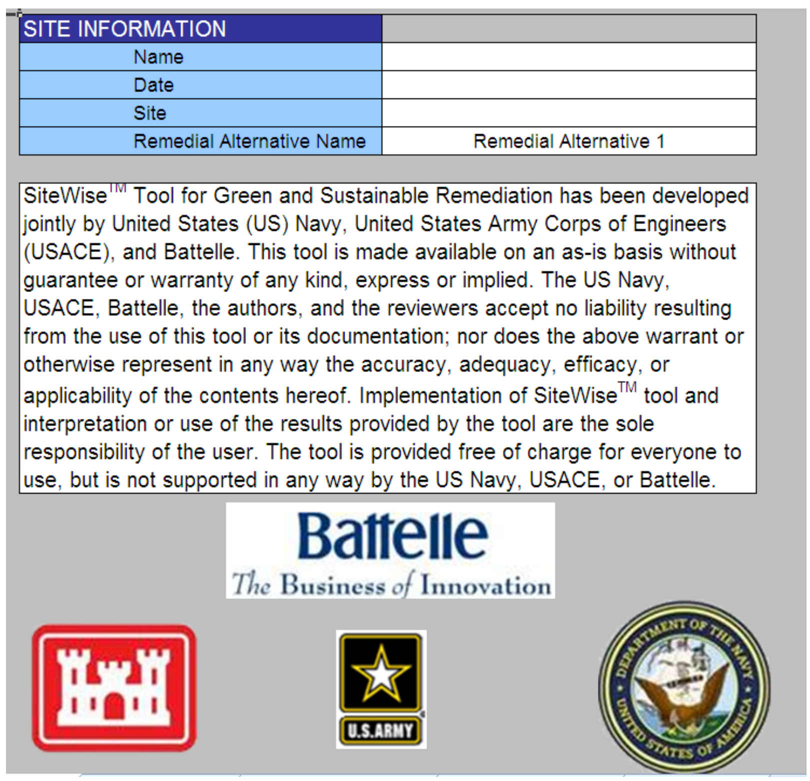

Figure 3-2. Screen Shot of SiteWise™ Start-up Screen

3.2.1 SiteWise™

SiteWise™ is a stand-alone tool developed jointly by the Navy, USACE, and Battelle that assesses the footprint of a remedial alternative/technology in terms of a consistent set of metrics, including: (1) GHG emissions; (2) energy use; (3) air emissions of criteria pollutants such as NO_x, SO_x, and PM, (4) water impacts; and (5) worker safety. Table 3-1 summarizes how metrics are reported in SiteWise™ and also lists ways to quantify metrics that are not included in the tool such as ecological impacts and community impacts.

The assessment is carried out using a building block approach where every remedial alternative is first broken down into modules that mimic the remedial phases in most remedial actions, including RIs, remedial action constructions (RACs), RA-Os, and LTM. Once broken down into various modules, the footprint of each module is calculated individually. The different footprints are then combined to estimate the overall footprint of the remedial alternative. This building block approach reduces redundancy in the sustainability evaluation and facilitates the identification of specific activities that have the greatest remedy footprint.

The inputs that need to be considered for SiteWise™ include (1) production of material required by the activity; (2) transportation of the required materials and equipment to the site; (3) any preparation carried out at the site for the activity to be performed; and (4) management of the waste produced by the activity. In the SiteWise™ model, LCA emission factors are used only for materials that are completely consumed and cannot be reused during the application of the alternative. For example, the footprint of polyvinyl chloride (PVC) for well casing or piping is considered because it is a consumable used for well installation or transfer pipe. However, the complete footprint for production of equipment used, or production of the vehicles used for transportation, is not considered. In cases such as this, the emissions factors are based on operation of the equipment.

SiteWise™ is a modular tool that helps in conducting a comparative analysis of up to six different remedial alternatives. The tool also helps in determining the phase of remedial action, such as remedial operation, LTM, RAC, or additional investigation, which contributes most to the overall remedy footprint. Once the phase that contributes most to the remedy footprint is determined, then applying footprint reduction measures during that phase would be most beneficial and cost effective. SiteWise™ also identifies impacts from individual activities (for example, the material production of consumables used during RAC and operation that contributes the most to the overall footprint). Once the activities and the phases that have the greatest contribution to the overall footprint of the remedy are known, then the efforts to reduce the remedy footprint can be focused towards that phase and activity.

SiteWise™ and the SiteWise™ User's Manual can be downloaded from the GSR portal at www.ert2.org. In addition, case studies where SiteWise™ was used are also available at this site. Examples of graphical outputs from SiteWise™ are presented in Figures 3-3 and 3-4.

Table 3-1. Summary of Navy GSR Metrics and Their Representation in SiteWise™

NAVY GSR METRIC	CALCULATED BY SITEWISE™	NOT CALCULATED BY SITEWISE™	METRIC REPRESENTATION
GHG Emissions	X		Emissions of CO_2, N_2O, CH_4 in metric tons of CO_2 equivalents are reported by the tool.
Energy Consumption	X		Energy consumption in million metric British Thermal Units (BTUs) are reported by the tool.
Criteria Pollutant Emissions	X		Metric tons of NO_x, SO_x, and PM_{10} are reported by the tool.
Water Impacts	X		Water consumption reported as gallons of water consumed is included in the tool, but the qualitative water impacts such as impacts on the aquifer hydrogeology due to remedial action are not included in SiteWise™.
Ecological Impacts		X	NEBA can provide some quantitative information regarding ecological impacts. This metric can be qualitatively reviewed also.
Resource Consumption/Waste Generation	X		Landfill space used in cubic yard is reported by the tool. Other resources consumed, such as top soil brought to the site, must be calculated outside of SiteWise™.
Worker Safety/Accident Risk	X		Risk of worker fatality and injury are reported by the tool.
Community Impacts		X	Number of trucks, congestion, and if other impacts such as job gains or loss due to remedial activities in a community can be reported as part of the community impacts. This metric can be qualitatively reviewed also.

3.2.2 SRT™

SRT™ is a stand-alone tool developed by AFCEE that calculates CO_2 emissions, emissions of criteria air pollutant emissions, total energy consumed, change in resource services, technology cost, and safety/accident risk for a remedial technology based on remedial parameters input by the user. The technologies currently enabled in the tool are excavation, soil vapor extraction (SVE), pump and treat, enhanced in situ biodegradation, thermal treatment, in situ chemical oxidation (ISCO), permeable reactive barrier (PRB), and LTM/MNA. The tool is structured into tiers that allow the user to choose the level of effort and detail appropriate for the study objectives. Tier 1 (simplest tier) calculations are based on inputs that are widely used in the environmental remediation industry. Tier 2 calculations are more detailed and incorporate site-specific factors. SRT™ also includes several features to help interpret the results. Users have the option to consider various scenarios for future costs of CO_2

DATA SOURCES FOR METRICS IN SITEWISE™

GHG Emission Footprint Calculation: The EPA Climate Leaders Program [17] provides a GHG Inventory Guidance that is used by industry to document emissions of GHGs including CO_2, CH_4, and N_2O. The EPA Climate Leaders GHG Inventory Guidance is a modification of the GHG protocol developed by the WRI and the World Business Council for Sustainable Development. SiteWise™ also uses emission factors developed by Argonne National Laboratory's GREET model, EPA's Mobile 6 model, and EPA's Non-road model.

Energy Usage Calculation Methodology: Electricity used onsite can be determined through meter readings for existing systems and/or by performing engineering calculations for each piece of equipment.

Air Emission Inventories Development: Mobile 6 and Non-road are two computer programs developed by the EPA's Office of Transportation and Air Quality that calculate NO_x, SO_x, carbon monoxide, VOCs, and PM_{10} emission factors for mobile and non-road equipment, respectively. Other inventories such as AP-42 [18] are available for obtaining emission factors for various activities.

Accident Risk Calculation Methodology: Several organizations (including Automobile Transport Statistics, Airplane Transport Statistics, Railroad Transport Statistics, and Labor Statistics) provide statistics of both fatalities and injuries that occur during various activities including transportation by automobile, airplane, rail and labor.

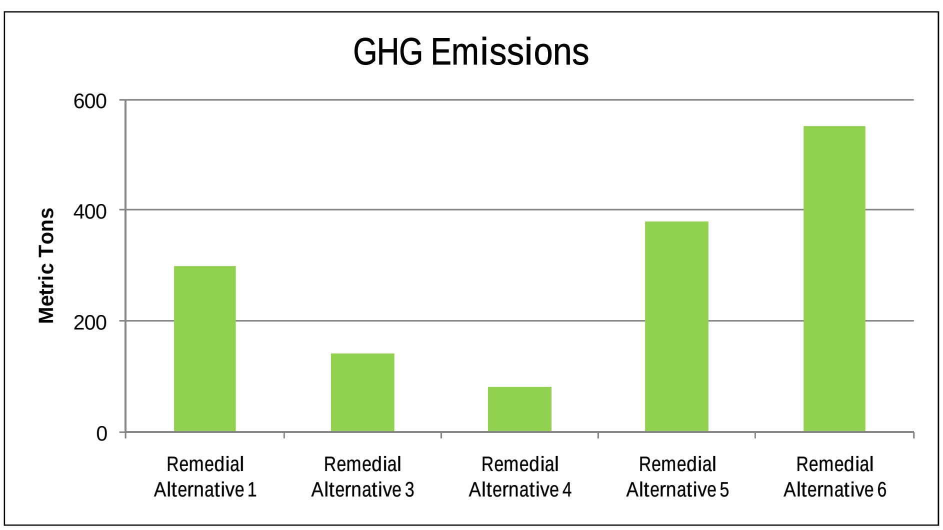

Figure 3-3. Example Output from SiteWise™: Comparative Analysis for Remedial Alternatives for GHG Emissions

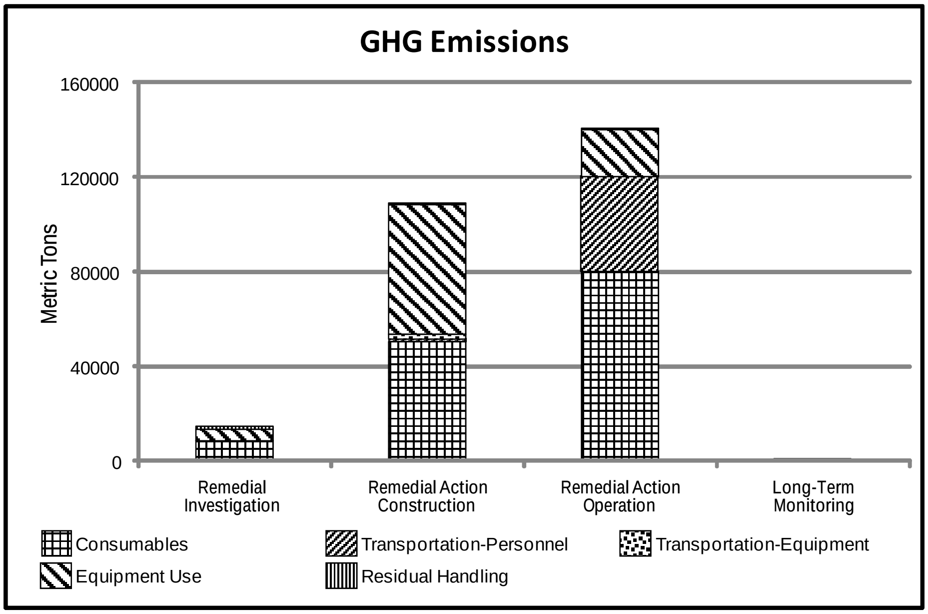

Figure 3-4. Example Output from SiteWise™: Detailed Analysis for One Remedial Alternative for GHG Emissions

offsets and for energy. These costs consider net present value (NPV) over the lifetime of the project. Also available to users is a Stakeholder Roundtable in which various parties involved can choose to weigh the importance of each metric. The group's weights are then compiled into a consensus set of metrics, which represents an equal compromise of metric weights for the group. These features allow users more flexibility and aid in the decision-making process. SRT™ is distributed through the AFCEE Web site (http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation/srt/index.asp).

3.2.3 Other Tools

Table 3-2 lists other tools that are available to gather and analyze data useful in evaluating sustainability alternatives. The tools can be applied in cases where equipment, materials or metrics are not included in SiteWise™ or other tools used in a GSR evaluation. The links to the tools listed in Table 3-2 are available at the Navy GSR portal (www.ert2.org/t2gsrportal).

Table 3-2. Tools Available in the Public Domain as Freeware to Conduct Sustainability Related Evaluations

TOOL	CAPABILITIES
Building for Environmental and Economic Sustainability	Evaluates part of remediation by considering green building products and impact on air, water, land, materials, and waste.
Beneficial Reuse Model (BenReMod)	Compares road construction materials using cancer risk, ecological toxicity potential, and materials.
Diesel Emissions Quantifier	Evaluates air emissions for highway and non-road vehicles with various control technologies.

Table 3-2. Tools Available in the Public Domain as Freeware to Conduct Sustainability Related Evaluations (Continued)

TOOL	CAPABILITIES
EIO-LCA	Estimates air, water, land, materials, and waste impacts of producing certain commodities or services in the U.S.
Energy & Materials Flow & Cost Tracker (EMFACTTM)	Tracks the air, water, and waste associated with material and energy usage by companies to identify improvement capabilities.
Green Remediation Evaluation Matrix	Qualitatively compares potential treatments using resource use, substance release, thermal release, and physical disturbance as metrics.
Greener Cleanups Matrix	Maximizes remediation benefit by evaluating different actions using air, water, land, materials, and waste as metrics.
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)	Evaluates vehicle and fuel combinations using energy, air emission, and material use metrics.
Greenscapes	Compares virgin materials to environmentally friendly products by evaluating water, land, materials, and waste.
Industrial Waste Management Evaluation Model (IWEM)	Evaluates waste management unit design based on potential impact to water and/or land resources.
RETScreen	Considers energy production and emission reductions for renewable energy and energy efficiency technologies.
Waste Reduction Model (WARM)	Compares waste management practices for air emissions, material usage, and waste production.

3.3 Net Environmental Benefit Analysis

NEBA is a time-based analysis that quantifies the net environmental loss or gain expected from remedial actions compared to baseline (i.e., no action). For each alternative, the analysis measures the benefits or gains in ecological services achieved due to the remedial action minus the environmental costs or loss due to the remedial action. The benefits to conducting a NEBA include the following:

- Provides stakeholders additional, quantitative information to support the remedy selection process;
- Identifies the remedy that protects human health and the environment while maximizing environmental benefits and minimizing negative environmental impacts;
- Enables an understanding of environmental costs and benefits in the context of dollar cost; and
- Can result in modification or addition of alternatives.

The comparative analysis among different remedial alternatives evaluated in a FS can be supplemented using NEBA to evaluate the change in ecological services provided by an area of land, wetland, or open water. It is an assessment of environmental cost/benefit that can help avoid remediation-related injury, reduce cost, and maximize environmental benefit. It is not employed to avoid remediation, but rather to identify the approaches (e.g., technology, spatial footprint, temporal) that provide for the protection of human health and the environment and, at the same time, optimize environmental tradeoffs in the context of cost. It is applicable to terrestrial and aquatic sites with chemical contamination or munitions and explosives of concern (MEC).

Habitat Equivalency Analysis (HEA) is the natural resource economic model most often used to calculate ecological services in a NEBA [19]. Within the HEA framework, benefits and losses associated with actions that affect the environment are quantified using a measure of the change in ecological service flows over time. Service flows are most often measured in units of ecological services provided per acre per year, also known as service-acre-years. Through discounting, which results in the metric discounted service-acre-years or dSAYs, services are expressed in net present value. Discounting is conducted because services provided in the future are not worth as much to the public today.

In addition to providing information to help in the decision-making process during the FS stage, NEBA can be a powerful complement to GSR analyses. While GSR metrics tend to focus on other environmental impacts from a remedy and the efficiency in addressing risk, NEBA quantifies net environmental benefit in the post-remedy landscape. Additionally, NEBA can address the EPA fifth green cleanup criterion; land management and ecosystem protection [9]. When using NEBA in a GSR analysis, remedial alternatives that have the greatest natural resource gain (or the lowest natural resource loss) would be considered to be the most sustainable with respect to ecological impact as a metric.

While NEBA can provide a GSR metric for environmental change in the post-remedy landscape, it is not always a required part of GSR evaluation. Cases where NEBA would be beneficial to a GSR evaluation include those where different remedial options may result in different ecological impacts. In these cases, a NEBA can be performed to help quantify the comparison of ecological impacts. NEBA can be particularly beneficial in situations where there are marginal ecological risks in low or high quality habitat. An example would be evaluating the net environmental benefit at a site where sediment risks are identified. The value of the habitat could be low and influenced by continuing anthropogenic contamination. In this situation, there could be concerns about the disproportionate cost to benefit of dredging or capping that NEBA can help address. In contrast, the value of the habitat could be high, resulting in concerns about dredging or capping causing more environmental impact than the risk driving it.

In some cases, a more aggressive remediation approach may cause a greater loss of ecological services. An example of this situation is illustrated in Figure 3-5. In this example, NEBA can be used to determine if there is an optimum point beyond which the additional remediation has only a marginal reduction in the risk caused by the contamination but causes greater harm in terms of ecological service loss. Here, the limited dredging option provides a small reduction in concentration/risk compared to the limited capping option, but results in a significantly greater ecological services loss. Being one of a host of factors considered during risk management, the analysis would not direct stakeholders what to do, but it would provide additional quantitative information to inform the decision-making process. While Figure 3-5 shows a net loss of ecological services for each alternative, a net gain is often identified through application of a NEBA.

For more information about NEBA, refer to the documents entitled:

- "A Framework for Net Environmental Benefit Analysis for Remediation or Restoration of Contaminated Sites", *Environmental Management*, 2004, Vol. 34, No. 3, 315-331.

- “A Framework for Net Environmental Benefit Analysis for Remediation or Restoration of Petroleum-Contaminated Sites,” Oak Ridge National Labs, January 2003. (http://www.esd.ornl.gov/programs/ecorisk/documents/NEBA-petrol-s-report-RE.pdf).
- “Habitat Equivalency Analysis: An Overview. Damage Assessment and Restoration Program, NOAA, March 1995.

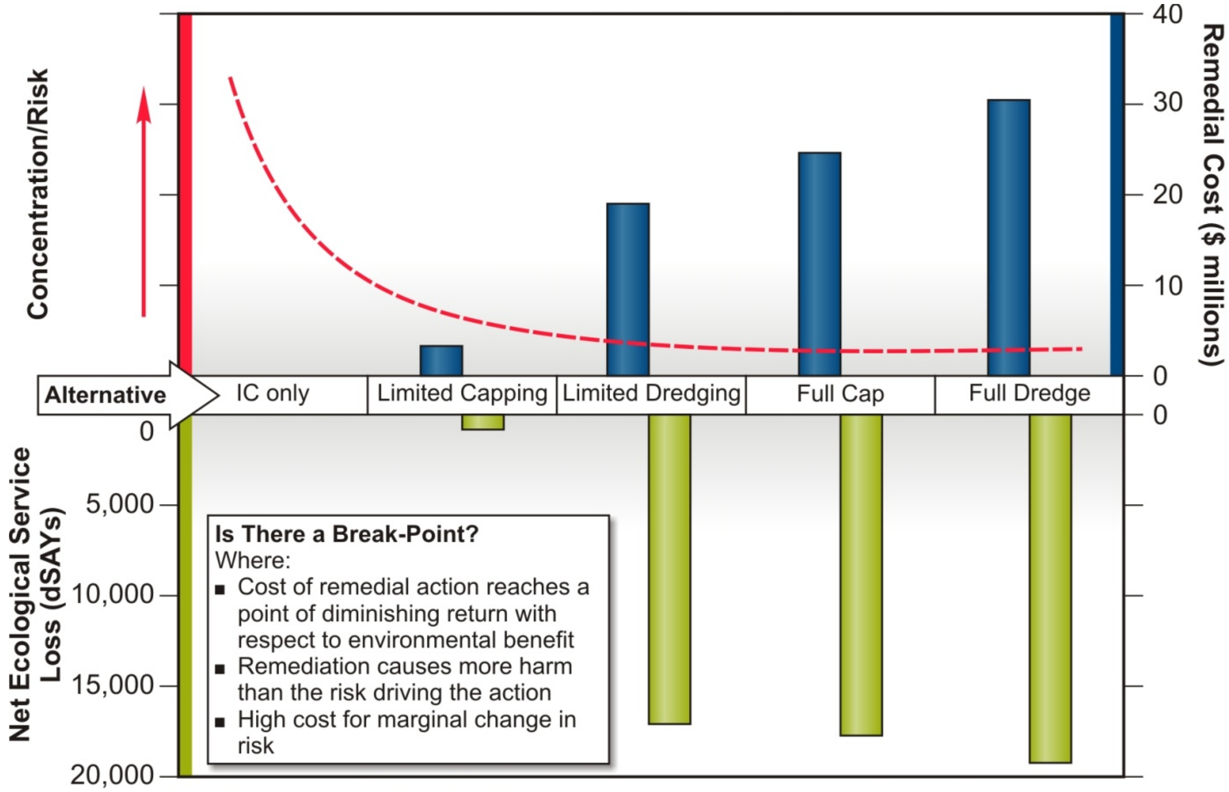

Figure 3-5. Example NEBA Results for Multiple Remedial Alternatives (Provided by CH2M Hill)

4.0 GSR CONSIDERATIONS DURING SITE CHARACTERIZATION

Similar to optimization, GSR should be considered throughout all project phases, including site characterization. Activities typically performed during site characterization that result in a significant footprint include well installation, soil borings and transportation of personnel, investigative derived waste (IDW) and samples. The primary impacts associated with these activities include increased GHG and criteria pollutant emissions, consumption of energy, and accident risk.

There are several proven methods to optimize site characterization. Application of site characterization BMPs promotes improved efficiency and quality, and also minimizes environmental impacts and overall site cleanup costs. An EPA fact sheet provides BMP guidance on how to include green remediation practices into site investigation activities [7]. Typical methods to reduce the footprint during site characterization include:

- **Efficient Data Collection:** Use systematic planning during development of the Uniform Federal Policy Quality Assurance Project Plan/NAVFAC Sampling and Analysis Plan (SAP) to ensure only the data necessary to meet the project quality objectives (PQOs) are collected;
- **Streamline Characterization Process:** Use the Triad approach to improve efficiency of the site characterization process;
- **Use Efficient Sampling Techniques:** Implement efficient sampling techniques such as passive sampling and proper equipment management; and
- **Minimize and Manage IDW:** Use the above described methods to minimize generation of IDW. For IDW generated, manage disposal efficiently.

A focus on sustainable and green approaches along with incentives for contractors to include green practices is helpful in reducing the footprint of site characterization. A cost analysis should be performed for each potentially applicable footprint reduction method to estimate the footprint reduction that would be achieved along with the cost or cost savings to implement.

4.1 Efficient Data Collection

Ensuring that only the data necessary to meet the PQOs are collected improves sustainability by minimizing the footprint associated with data collection, while still meeting the project goals. The environmental impacts of data collection can be significant, some of which include the GHG emissions of field activities, well drilling and sampling waste, and ecosystem disturbance. Systematic planning is a method that helps to focus data collection activities, thereby reducing the associated environmental impact.

Following this step-wise systematic planning process aids in identifying the PQOs and developing the SAP, which will govern the site investigation activities. PQOs define the type, quantity, and quality of data that are needed to answer specific environmental questions and support proper environmental decisions. During the initial scoping sessions, the project team should determine and agree on PQOs, and develop performance criteria specific to the type, quality, and quantity of the data needed using a systematic planning process.

However, implementing the systematic planning process should not adversely impact development of an adequate conceptual site model (CSM), as most remedial alternatives require robust CSMs for optimal implementation. Reducing the footprint during site characterization at the expense of not having an adequate CSM for efficient remediation will ultimately increase the overall footprint. Thus, it is essential that a suitable CSM be developed in the most efficient manner. For information regarding efficient site characterization, refer to Section 8.1.1 of the *NERP Manual* [21], ASTM E1689-95: Standard Guide for Developing Conceptual Site Models for Contaminated Sites [22], and the *DON Guidance for Planning and Optimizing Monitoring Strategies* [12].

4.2 Streamline Characterization Process

In general, methods that improve the efficiency of site characterization, such as the use of the Triad approach, will also reduce the overall footprint. The Triad approach leverages field screening techniques, such as field test kits and other real-time measurements where appropriate, along with systematic planning and dynamic work strategies to expedite characterization. This leads to a reduction in the number of samples that need to be collected (e.g., potential reduction in drilling activities), the transportation associated with laboratory shipments, and travel associated with a reduced number of field mobilizations.

Methods to minimize the amount of drilling without compromising the data quality include the reuse of wells and subsurface bore holes throughout investigations, and the use of screening methods that can allow the project team to more strategically select drilling locations for sampling and monitoring well installation. Such screening methods may include the use of a membrane interface probe tool, shallow soil vapor sampling (applicable for VOCs only), and geophysical techniques. In addition, geophysical methods are capable of determining the presence and distribution of MEC in the subsurface. Field screening tests for rapid sediment characterization can also be employed as part of the Triad approach. Appendix B.1 of the NERP manual provides a description of several screening technologies for groundwater, soil, sediment and MEC sites. These efficiencies can in turn minimize the amount of mobilizations required, further reducing the remedy footprint. In addition, practices such as planning multiple tasks for singular events to reduce transportation of personnel and equipment, and submittal of electronic documentation where appropriate can be considered during project implementation to reduce the overall footprint of the investigation activities.

4.3 Use Efficient Sampling Techniques

Site characterization often requires extensive use of drill rigs for sampling and monitoring well installation, and the operation of these rigs can result in a significant footprint, particularly for criteria pollutants and accidental injury risk. Three basic techniques should be used to reduce the footprint associated with drilling: (1) minimize drilling without compromising data quality, (2) selection of the optimum equipment for drilling, and (3) efficient management of equipment used. For sediment sampling, the timing of the sampling events can be evaluated to minimize the footprint. For example, perform sediment sampling at low tide in shallow/intertidal areas rather than needing a vessel to complete the sampling activities.

Methods for minimizing the amount of drilling required while achieving the project objectives was discussed in Sections 4.1 and 4.2. Selection of the optimum drilling equipment and efficient management of the equipment is discussed below.

4.3.1 Well Installation

When selecting the drilling method, consideration must be given to soil conditions and data needs to ensure that the equipment can effectively meet the objectives of the characterization program. Among the list of effective equipment types, consideration can then be given to other factors, including time, cost and the remedy footprint. Tools, such as SiteWise™, can be used to compare the operating footprint of one device to another as shown in Figure 4-1. The comparison shown here demonstrates that use of a direct push rig results in a significantly lower footprint over that from a traditional hollow stem auger rig. This example does not account for the fact that direct push coring typically requires less time in some soil conditions compared to drilling with hollow stem auger equipment. In addition, use of direct push equipment, where appropriate, rather than a rotary drill rig avoids the need for drilling fluids and eliminates the need for disposal of drill cuttings.

> Use of a direct push rig where appropriate can result in a significantly lower remedy footprint over that from a traditional hollow stem auger rig.

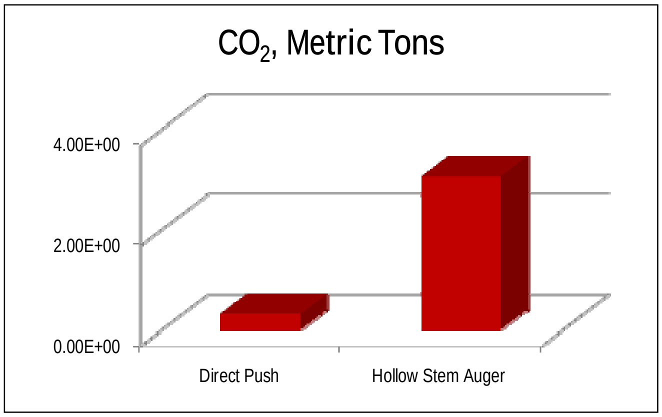

Figure 4-1. Comparison of Direct Push versus Hollow Stem Auger for 40 hours of Drilling (per SiteWise™ GSR Tool)

Effective management techniques associated with drill rig use include the following:

- Reduce mobilization requirements by procuring services from local drillers;
- Schedule field activities to allow a single mobilization to accomplish multiple tasks;
- Implement idle management/controls to prevent unnecessary idling of equipment; and
- Consider procuring drilling contractors that can offer footprint reduction alternatives such as zero carbon footprint mobilization and equipment that uses alternative fuels and/or after-treatment technologies.

4.3.2 Sampling

Another technique that can be evaluated to reduce the footprint is passive sampling of groundwater or sediment pore water. Passive sampling was specifically mentioned in the DoD GSR memorandum [1] as a technique to consider. Passive groundwater sampling techniques include four primary classifications:

- Grab sampler (e.g., HydraSleeve™ and Snap Sampler™);
- Samplers that rely on diffusion of analytes (e.g., low density polyethylene passive diffusion bag, regenerated cellulose dialysis membrane diffusion bag sampler, and rigid porous polyethene samplers);
- Samplers that rely on diffusion and sorption of analytes (GORE™ Module); and
- Surrogate samplers or membranes used to measure dissolved organic contaminants in the water column or at/near the sediment-water interface (semi-permeable membrane devices, solid-phase micro extraction, Tenax®, and thin films).

The primary advantages to each of these methods with respect to footprint reduction include:

- Elimination of pumping equipment needed;
- Elimination of purge water that requires treatment and/or off-site disposal; and
- Reduction of time needed to obtain samples, which may reduce the number of trips to the site.

For more information regarding advantages and limitations of passive sampling, refer to *DON Guidance for Planning and Optimizing Monitoring Strategies* [12] and the passive sampling tool at the NAVFAC technology transfer Web site: www.ert2.org/PDST/.

4.4 Minimize and Manage Investigative Derived Waste

Common IDW includes soil from drill cuttings and test pits, purged groundwater from sampling events and monitoring well development, and purged non-aqueous phase liquid (NAPL) during sampling events. At munitions sites, common IDW includes scrap metal recovered during the investigation. The footprint associated with management of these materials results from transportation to disposal sites and/or treatment of the material. Methods to reduce the footprint include the use of rail versus road transportation, the use of alternative fuels and/or after-treatment emission controls, the use of local disposal sites whenever possible, and optimization of treatment methods (e.g., consider on-site treatment). In addition, metal recycling should be considered at sites where a large amount of metal may be recovered during investigation activities. However, the best way to reduce the footprint is to minimize the amount generated without compromising the CSM. Methods to accomplish this include: efficient data collection, streamlined characterization process, optimal drilling techniques and equipment management, and passive sampling as discussed earlier within this section.

OVERALL FOOTPRINT REDUCTION METHODS CHECKLIST DURING SITE CHARACTERIZATION

- ❑ Systematic planning - identify the PQOs and data required to meet the project objectives
- ❑ Triad approach for site characterization
- ❑ Use efficient sampling techniques, where applicable, such as geoprobe and passive groundwater sampling.
- ❑ Minimize generation of IDW through use of efficient sampling techniques.
- ❑ Energy efficient lighting and heating, ventilating, and air-conditioning (HVAC) systems for all site trailers and buildings
- ❑ Energy conservation using premium efficiency motors and variable frequency drives (VFDs) for equipment
- ❑ Idle management control plan
- ❑ Alternative fuels use
- ❑ Alternative transportation such as rail and hybrid cars for personnel, equipment, and material transportation
- ❑ After treatment retrofits for diesel engine vehicles
- ❑ Considerations for contractor procurement to be local disadvantaged subcontractors
- ❑ Local material sourcing for all site activities
- ❑ Minimal ecological impact considerations to reduce destruction of site natural resources
- ❑ Site worker safety and health plans
- ❑ Proper protective equipment for all site work
- ❑ Daily log of any site accident to reach zero accident work
- ❑ Inventory of fuel, energy, water, material, and chemical
- ❑ Proper documentation and records to verify sustainability metrics later in the remedial action
- ❑ Efficient project management to bundle site activities and reduce personnel travel, where applicable
- ❑ Consider electronic submittals rather than hard copies where appropriate

5.0 GSR CONSIDERATIONS DURING REMEDY SELECTION

Remedy selection provides the greatest opportunity to lower the overall remedy footprint. Selecting the most sustainable remedial option among the alternatives identified in a CERCLA FS or RCRA corrective measure study establishes a lower remedy footprint from the start. Most importantly, a selected remedial alternative must meet all of the applicable CERCLA threshold criteria or RCRA performance standards, including overall protectiveness of human health and the environment. If more than one remedial alternative meets the threshold criteria, then GSR evaluation of alternatives should be included in the remedial alternative evaluation process to select the most feasible and sustainable process.

Remedy selection is the most critical phase in a project for footprint minimization. While it is possible to minimize the footprint during later stages of the project, the greatest benefit can be achieved by selecting the remedy that generates the smallest footprint at the start. In general, remedies that tend to have a small footprint are those that make appropriate use of passive systems and those that enhance natural processes. Examples of such technologies, as stated in the DoD GSR memorandum [1], include:

- Consider the use of less intrusive sampling methods such as direct push and passive sampling methods during LTM where appropriate.
- Consider the use of remedial technologies that rely on plants to achieve remediation goals and sequester CO_2, such as phytoremediation, evapotranspiration covers, and engineered wetlands.
- Consider the use of in situ remediation technologies such as enhanced bioremediation, biowalls, and composting.

It should be emphasized that when a technology is not effective in meeting the remedial goals and achieving the required level of protectiveness, the technology is simply not sustainable. Thus, active and energy intensive remedial systems still play an important role in the ER program as long as they are applied in suitable situations and appropriate exit strategies have been developed.

5.1 Optimization during Remedy Selection

The use of optimization techniques, such as optimizing remedial action objectives, treatment trains, target treatment zones, performance objectives, and exit strategies [4, 5, 12, 13, 21] can provide a great benefit in terms of footprint minimization. By making the overall process more efficient, the time and level of effort to reach the project milestones will decrease, thus increasing the sustainability of the remedy. Therefore, it is critical that optimization guidance be followed for any remedy. In fact, Navy optimization policy requires that it be incorporated into all phases of remediation, reflecting the importance of this approach.

To demonstrate the importance of optimization, consider a site requiring soil excavation or sediment dredging where steps should be taken to achieve the necessary level of protectiveness while minimizing the quantity of soil/sediment that is removed, particularly if transportation and off-site disposal are necessary. To accomplish this goal the following should be considered:

- Contaminant distribution both laterally and vertically.
- Cleanup goals should be risk-based and determined through a risk assessment (see Sections 8.2.3 and 8.3.1 of the NERP Manual [21]).
- Background concentrations (see Section 8.2.2 of the NERP Manual [21]).

In some cases, the area requiring excavation could be broken up into target treatment zones where different cleanup goals are developed for different depths. It may be appropriate to use less stringent cleanup levels for deeper soils. Also, statistical/geo-statistical approaches for achieving the remediation goals can be used to further minimize the amount of soil or sediment removed in comparison to achieving the remediation goals on a point by point basis.

5.2 Incorporating Metrics into Regulatory Framework

> GSR metrics fit well within the current regulatory frameworks, particularly short-term effectiveness, and do not need to be a stand-alone criterion.

Assessment of remedial alternatives with respect to sustainability should not be considered a unique criterion. The metrics included in a GSR assessment can be mapped into existing regulatory frameworks such as RCRA or CERCLA. Both RCRA and CERCLA programs have similar criterion for overall protection of human health and the environment. GSR fits well within the short-term effectiveness criterion, which calls for evaluating impacts of implementing the remedial alternative on the environment, community, and workers. Table 5-1 summarizes the CERCLA criteria and also describes what each criteria entails. The criteria where GSR assessment can fit are shaded in Table 5-1. Short- and long-term effectiveness within the primary balancing criteria category are the criteria under which most of the GSR metrics can be incorporated. Regulatory and community acceptance as modifying criteria also enable the societal aspect of sustainable remediation. The aspect of community acceptance and short- and long-term effectiveness are part of the RCRA program as well.

All of the metrics developed by the Navy such as energy consumption, criteria pollutant emissions, water impacts/use, ecological impacts, resource consumption, worker safety, and community impacts can be mapped onto the short-term effectiveness criteria of CERCLA and RCRA that call for addressing any adverse impacts on the workers, community, and the environment due to construction and operation of remedy. GHG emissions can also be mapped onto the long-term effectiveness because GHGs are residuals of remedial activity that do not attenuate for a long period of time. Some of the metrics such as energy consumption, water impacts/use, resource consumption, and worker safety have an economical aspect also and can increase or decrease the overall cost of the remedy, which is one of the balancing criteria. Similarly, community impacts can be related to the short-term effectiveness in the balancing criteria of CERCLA or RCRA but can also be a part of the community acceptance criterion of modifying criteria of CERCLA and balancing criteria of RCRA.

Table 5-2 lists the Navy metrics as mapped onto the existing regulatory frameworks and also demonstrates how each metric relates to the social, economic, and environmental triple bottom line of sustainable remediation. Most of the metrics are mapped according to their description to

Table 5-1. Summary of the CERCLA Nine Criteria

CATEGORY	CRITERIA	DESCRIPTIONS
Threshold Criteria	Overall protection of human health and the environment	Addresses whether or not a specific alternative will achieve adequate protection and describes how the contamination at the site will be eliminated, reduced, or controlled through treatment, engineering, and/or institutional controls.
	Compliance with ARARs	Addresses whether or not a remedial alternative meets all related federal and state environmental statutes and regulations. An alternative must comply with ARARs, or be covered by a waiver, to be acceptable.
Balancing Criteria	Long-term effectiveness and permanence	Addresses the ability of a remedial alternative to maintain reliable protection of human health and the environment over time. It also considers the risk posed by treatment residuals and untreated materials.
	Reduction in toxicity, mobility, or volume through treatment	Addresses the preference for remedial actions that use treatment technologies that permanently and significantly reduce toxicity, mobility, and/or volume of contaminants.
	Short-term effectiveness	Addresses the period of time needed to implement the remedy and any adverse impacts that workers, the community and the environment may be subjected to during construction and operation of the remedy.
	Implementability	Addresses the technical and administrative feasibility of implementing a remedial alternative from design through construction and operation. Factors such as availability of services, materials, and operational reliability are considered.
	Cost	Addresses the total cost of a remedial alternative, including consideration of the capital costs, annual operation and maintenance costs, and net present value of these costs.
Modifying Criteria	State acceptance	Addresses the acceptability of a remedial alternative to state regulatory agencies.
	Community acceptance	Addresses the acceptability of a remedial alternative to the public.

Shaded criteria are where the GSR assessment can fit into the nine CERCLA criteria.

social, economic, and environmental aspects of remediation except a few that are applicable to more than one aspect of remediation such as worker safety, which has economical and social impacts. If an impact of a metric is tracked for its lifecycle, then almost all the Navy metrics will eventually lead to a social, economical, and environmental impact. For example, emissions of criteria air pollutants is an environmental issue that eventually is a human health hazard that impacts the surrounding community, thus leading to social impacts and economical impacts should these hazards result in lost time worked or health care costs. However, in developing Table 5-2, only the more direct impacts were noted.

The Navy considers GSR as a part of the larger CERCLA program and plans to include GSR at all remedial phases and as part of the FS for remedy selection. EPA has not provided any guidance on how to include GSR into remedy selection. Most of EPA's guidance is on reducing the footprint of the remedy already in place.

Tools are available to help in selecting the most sustainable option on the basis of consistent GSR metrics. Table 3-2 lists some of the publically-available tools that can be used.

Table 5-2. Sustainability GSR Metrics for CERCLA and RCRA in Relation to Balancing Criteria and the Sustainable Remediation Triple Bottom Line

SUSTAINABILITY METRICS	BALANCING CRITERIA					MODIFYING CRITERIA	
	LONG-TERM EFFECTIVENESS	REDUCTION IN TOXICITY, MOBILITY, OR VOLUME	SHORT-TERM EFFECTIVENESS	IMPLEMENTABILITY	COST	STATE ACCEPTANCE	COMMUNITY ACCEPTANCE
Energy Consumption			X		X	X	X
GHG Emissions	X		X			X	X
Criteria Pollutant Emissions	X		X			X	X
Water Impacts/Use	X		X		X	X	X
Ecological Impacts	X		X			X	X
Resource Consumption	X		X		X	X	X
Worker Safety			X		X	X	X
Community Impacts			X			X	X
Cost of Remedy					X		

5.3 Performing a GSR Assessment

When approaching a GSR analysis, the first step is to follow Navy optimization guidance [13] to identify remedial alternatives that satisfy the threshold criteria of overall protectiveness of the human health and the environment and compliance with ARARs. Next, evaluate the remedy footprint of these alternatives using the GSR metrics described in Section 2. Then incorporate the GSR metrics into the evaluation of the CERCLA criteria as described in Table 5-2.

The GSR metrics selected for a comparative analysis during the remedy selection phases should be site specific and prioritized based on the site-specific considerations as well (see Section 2.2). Once the metrics are selected and prioritized, Navy policy should be followed regarding the use of tools to quantify the GSR metrics and help in the comparative analysis and interpretation of results. At the FS stage, most GSR data and assumptions can be obtained from the cost estimate information; however, additional assumptions may still be needed (see Section 3). Metrics that are not quantified by these tools can be evaluated qualitatively. Engineering judgments and BMPs can aid in conducting qualitative evaluation of certain metrics such as community impacts. Certain assessment principles such as NEBA can be employed for evaluating ecological impacts. Figure 5-1 is a flowchart that summarizes the steps taken for conducting a GSR assessment during the remedy selection phase. Two example case studies showing the results of a GSR assessment implemented during the remedy selection phase are provided in Appendices A and B.

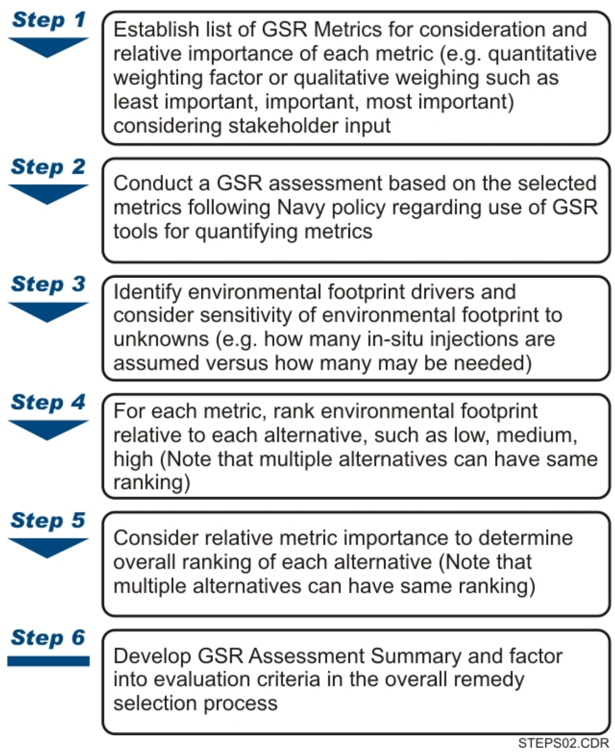

Figure 5-1. GSR Assessment Steps Undertaken during the Remedy Selection Stage

The results obtained from tools such as SiteWise™ are generally reported in GHG and criteria air pollutants emitted, water or energy consumed, and risk of injury. These results do not present an endpoint such as the metric tons of carbon emissions related to the sea level rise or criteria air pollutant emissions related to an increase in bronchitis levels. Such direct measurement studies are difficult to conduct. There are some equivalency calculators available for carbon emissions that can be used to better understand the emission levels. For example, 1000 metric tons of CO_2 is equivalent to annual GHG emissions of 173 passenger vehicles, or electricity use by 110 homes for one year, or carbon sequestered by 193 acres of pine or fir forests in one year. One such GHG equivalency calculator is available on the EPA Web site (http://www.epa.gov/cleanenergy/energy-resources/calculator.html). During the remedy selection phase, a relativistic comparison between the remedial alternatives using a weighted average or a comparison based on equivalent weights helps in determining the most sustainable option among the selected alternatives.

When performing a comparative analysis, caution should be exercised to ensure that assumptions are realistic and that an appropriate consistent functional unit is being used for each alternative evaluated. The term functional unit refers to the end result that is achieved. For Navy sites, this is typically either response complete or site closeout. In some cases, there is a trade-off between alternatives that can reach site closeout with no restrictions compared to alternatives that are less aggressive and may require long-term management. In these cases, the functional unit may not be exactly the same for all alternatives but for where long-term management is needed, the GSR analysis should account for the footprint of performing this management (e.g., LTM) into the future. If the end result is site closeout, then all activities taking place to achieve site closeout should be included in the analysis. For an excavation alternative, that may only require construction and post construction sampling, while for a passive alternative that may require 30 years of monitoring. For cases where there is a high degree of uncertainty (e.g., the number of chemical injections that is needed to reach the performance objective), a sensitivity analysis could be performed to determine a range for the remedy footprint.

Certain active remedial approaches that require heavy machinery and equipment use, long and frequent monitoring events, or displacement and use of large site resources, tend to have a larger remedy footprint. In situ technologies such as bioremediation and ISCO, as well as passive technologies such as phytoremediation and MNA, are generally more sustainable than other more active approaches such as excavation and pump and treat. However, conventional results related to remedial technologies can change based on site-specific issues and inputs, so a GSR assessment should still be conducted. For example, a site can have lower remedy footprint for excavation than bioremediation depending on the size of the excavation and soil disposal options, and the bioremediation technology assumptions used in the model. In addition, if a passive approach requires a long period of extensive monitoring and/or maintenance of reactive barriers, a more aggressive approach with a high initial footprint (e.g., electrical resistance heating) may prove to have a lower life-cycle footprint. Therefore, making general assumptions should be avoided in favor of performing the comparative analysis using one of the available tools.

The results of a GSR assessment can be presented separately within an FS as an appendix and the results can be discussed within the main text in which the appropriate balancing criteria are referenced. An example template for reporting results of a GSR assessment is provided below.

GSR ASSESSMENT REPORT TEMPLATE

A. Introduction

- Objectives of Analysis
- Summary of Alternatives

B. Green and Sustainable Remediation Metrics

- Standard Navy Metrics
- Site Specific Metric Selection and Prioritization Rationale

C. GSR Assessment Methodology

- General Methods and Tools used for Analysis
- Summary of Inputs and Assumptions

D. Results

Comparative Analysis of Alternatives

Identification of Footprint Drivers for each Alternative

Identification of Potential Footprint Reduction Methods for each Alternative

E. Summary and Conclusions

Case Study: GSR Analysis using SiteWise™ at Marine Corps Recruit Depot, Parris Island, South Carolina

Project Summary: Tetrachloroethene was released from an aboveground storage tank overflow in 1994 at a former dry cleaning facility at Marine Corps Recruit Depot, Parris Island, South Carolina, causing soil and groundwater contamination. During the remedy selection process, an analysis was performed as part of a feasibility study to allow for consideration of remedy footprint in terms of green and sustainable remediation metrics.

Analysis Summary: The GSR analysis was performed using SiteWise™ during the remedy selection. Five remedial alternatives (enhanced bioremediation, ISCO, in situ chemical reduction, electrical resistive heating, and excavation) were evaluated with GSR metrics such as GHG emissions, energy usage, emissions of criteria air pollutants, and accident risk. Table 1 shows the relative impact of each alternative for the metrics evaluated in the GSR analysis. Only the remedial activities that produce significant emissions were considered: personnel and equipment transportation, operation of equipment onsite, manufacturing of materials consumed, and management of residual waste. The tabular and graphical outputs of the SiteWise™ tool allow project personnel to quickly compare remedial alternatives for the given metrics and to see what elements of each remedy are causing the greatest remedy footprint. A comparative analysis of the GSR evaluation for the Parris Island remedial alternatives showed that the enhanced bioremediation alternative coupled with shallow excavation had the lowest environmental impact overall, which is also the relatively most cost-efficient and the preferred remedy in the FS. As an example, the result for the GHG emissions metric is shown in Figure 1, which breaks down the specific activities causing those emissions for each of the alternatives.

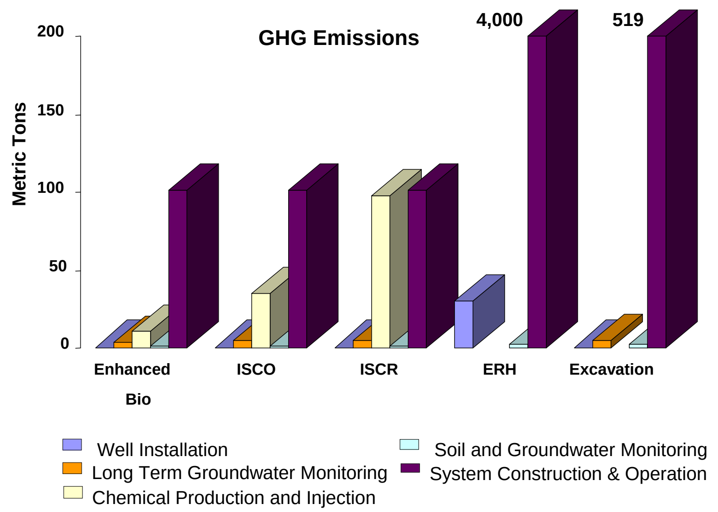

Figure 1. Comparative Analysis of GHG Emissions

Table 1. Relative Impact Assessment based on Sustainability Metrics

Alternative	GHG Emissions	Energy Usage	Air Emissions	Accident Risk	Community Impacts	Resources Lost	Water Usage
Enhanced Bioremediation	Low	Low	Low	Low	Medium	Medium	Medium
ISCO	Low to Medium	Low to Medium	Low	Low	Medium	Medium	Medium
ISCR	Low to Medium	Low to Medium	Low	Low	Medium	Medium	Medium
ERH	High	High	High	Medium	Low	Low	High
Excavation	Medium	Medium	Medium	High	High	High	Low

6.0 GSR CONSIDERATIONS DURING REMEDIAL DESIGN AND CONSTRUCTION

Once a sustainable remedial alternative is chosen, there are still opportunities to reduce the remedy footprint through the careful selection of footprint reduction methods that make sense for the project. The key here is to perform the analysis required to determine which footprint reduction methods are cost-effective means of reducing the overall footprint. Activities undertaken during construction, such as transportation of material and personnel, residual handling, and material consumption all lead to adverse environmental impacts. During the design phase, the contribution of remedial activities during construction, RA-O and LTM phases to the overall remedy footprint must be understood. This allows footprint reduction methods to be targeted at those activities that contribute the most to the overall remedy footprint. During the design phase, it is also necessary to evaluate the cost and benefit of implementing each potential footprint reduction technique so they can be prioritized and selected for implementation. Some potential footprint reduction methods that could be evaluated during the RD phase are (see also Section 8):

- Retrofits to existing equipment to reduce emissions,
- Material and waste minimization,
- Energy conservation and efficiency,
- Local material procurement,
- Local contractor procurement to spur local jobs and reduce transportation needs,
- Enhanced site worker safety measures, and
- Increased stakeholder engagement.

A cost analysis can be performed to determine which methods will be most cost effective in reducing the overall remedy footprint. It is important to consider the life-cycle cost impacts because many footprint reduction methods result in increased initial cost but have a reduction in operating cost, usually as a result of savings in the use of energy, water, emissions, resources, and materials. Depending on economic conditions, some of these methods will have a short payback period and high return on investment (ROI). In other cases, the payback period may be longer, requiring a judgment to be made as to whether the approach will be cost effective in the long term. Therefore, the approach to include footprint reduction methods into the RD phase would be:

- Perform or update the baseline sustainability assessment.
- Identify high footprint elements in a remedial action.
- Develop a list of potential footprint reduction methods.
- Perform cost and footprint sensitivity analysis.
- Prioritize footprint reduction methods for implementation (Appendix C).
- Include the selected footprint reduction methods in the remedial action design.

This approach is also represented as a flowchart in Figure 6-1. In cases where a formal RD is not completed, this approach for identifying footprint reduction methods can be completed during the procurement process.

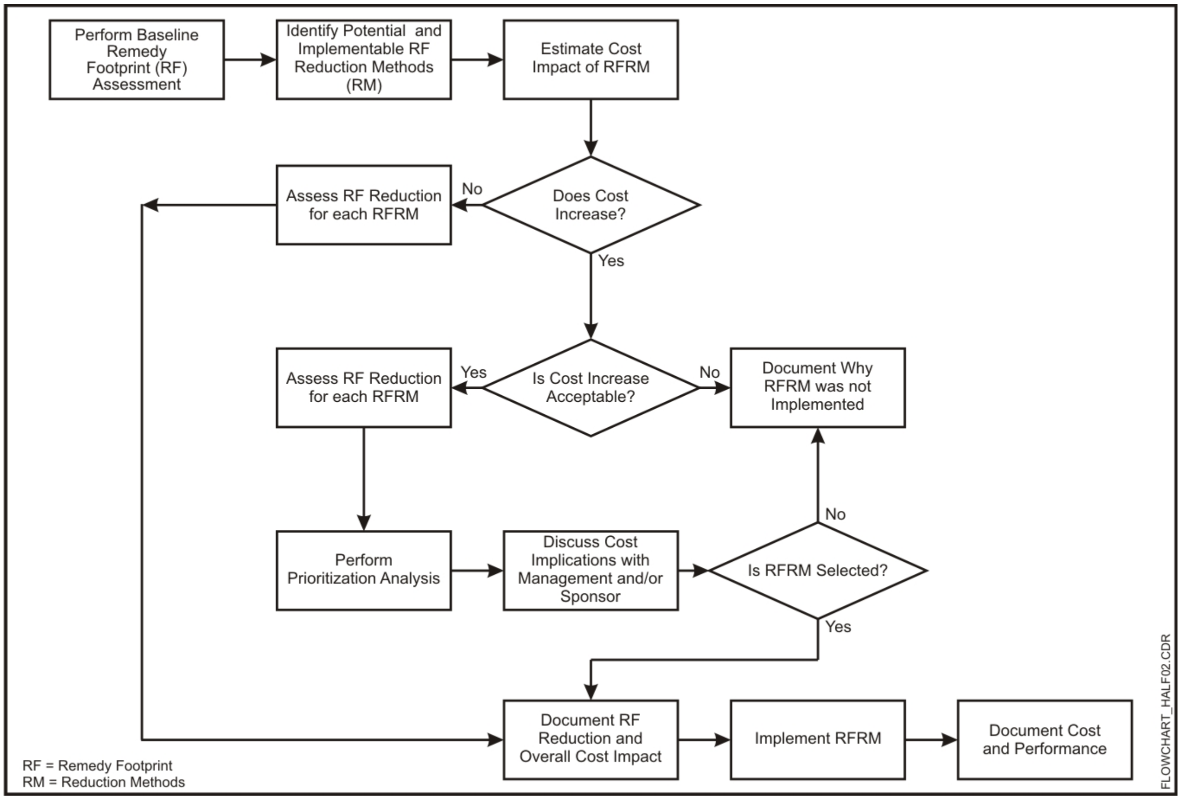

Figure 6-1. Flowchart Representing the General Methodology That Can be Adopted to Reduce the Remedy Footprint During the Design Phase

6.1 Project Design

Many design optimization techniques also apply to GSR because an efficient design tends to be a sustainable design. EPA (www.cluin.org/greenremediation) provides BMPs on how to include green remediation design, construction, and operation principles into RD for the following remediation technologies: excavation and surface restoration, pump and treat, bioremediation, SVE and air sparging, and clean fuel and emission. Many of the design inefficiencies are a result of designing for the initial site conditions only and not accounting for the likely changes that will occur during the lifecycle of the project as contaminant levels decrease over time. Other inefficiencies are caused by over-designing equipment rather than taking the time to more carefully size equipment and, in some cases, inefficiencies are caused by a short-term goal of reducing the initial installation cost by using low-cost but less energy-efficient devices. These factors can manifest into the following conditions:

- Equipment that is larger than required and cannot achieve efficient power turndown,
- Continuously running equipment,
- Unit operations that are not necessary or are only useful for a short period of time with no transition strategy,
- Excess volume of chemical injection,
- Inefficient injection strategy, and
- Too many monitoring locations.

Such conditions, although designed for meeting the RAOs, are deterrent to the overall sustainability of the project and should be optimized for the efficient use of energy, chemical, fuel, water, and material while still meeting all RAOs. Examples of footprint reduction methods that can be included in the RD are (additional information regarding footprint reduction methods is included in Section 8):

- Optimized injection strategies based on treatability studies to reduce chemical and material use for injection technologies,
- Pulsing of equipment to reduce energy use,
- Retrofitting equipment with VFDs and premium efficiency motors to reduce energy use,
- Use of optimally designed equipment that can meet the performance objectives without using extra energy,
- Operate, monitor, and manage the system through remote sensing or telemetry to reduce transportation to the site,
- Use of alternative fuel and mode of transportation,
- After treatment technologies for diesel engines,
- Reduction in transportation activities by use of locally sourced material, equipment, and workers,
- Reducing and recycling waste (e.g., recycling of metal fragments recovered at a munitions site), and
- Incorporating green building design principles for systems that include building construction, such as high efficiency lighting (see also the NAVFAC Sustainable Development Program within the Whole Building Design Guide, http://www.wbdg.org/references/pa_dod_sust.php).

Tools such as SiteWise™ can help in conducting an assessment easily by comparing the different activities in the RAC phase of the tool with and without footprint reduction technologies. The same can be accomplished for the RA-O and LTM phases by using those respective input sheets within the SiteWise™ tool. SiteWise™ has some built-in after-treatment technologies and alternative fuel options that can be used to observe the change in the remedy footprint due to such variables. The tool also helps in comparing different options such as rail vs. road transportation, different drilling technologies, or conventional vs. VFD pump motors. The amount of material injected, different equipment sizes, and duration of equipment run time are all inputs in SiteWise™ that can be changed to observe the sensitivity of the GSR metrics and the overall remedy footprint to these parameters. During the design phase, comparing such variables can shed light on different options available that might be relatively more sustainable than the conventional way of designing and implementing the remedy. For example, using rail transport for personnel travel not only reduces the carbon footprint but also reduces criteria air pollutant emissions, energy use, and accident risk (Figure 6-2). Therefore, different options can be chosen in the tool to conduct a comparative analysis between the available remedy implementation alternatives.

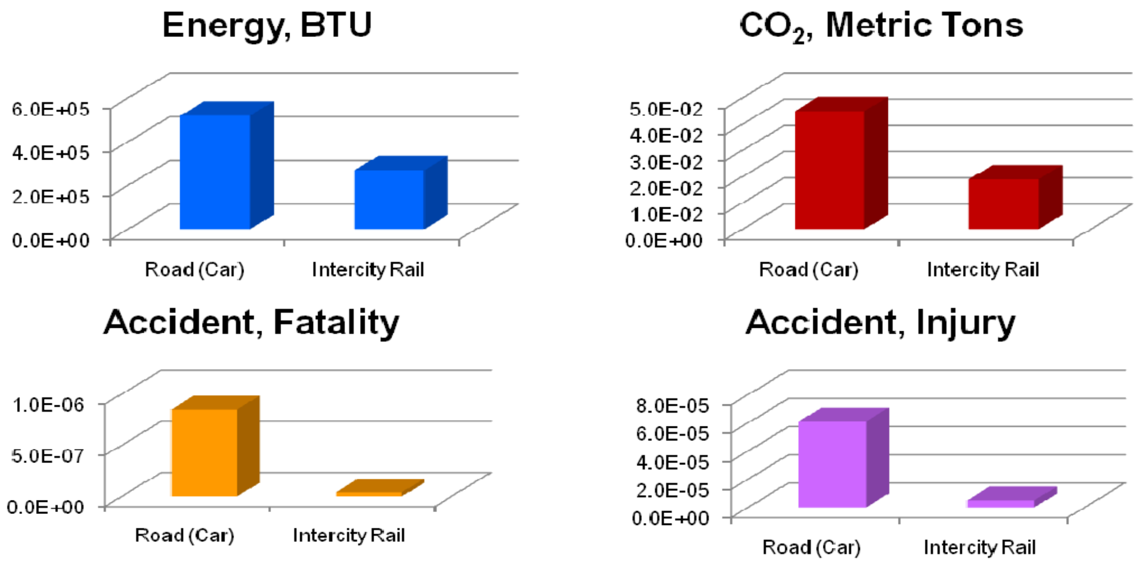

Figure 6-2. Advantages in Terms of GSR Metrics of Rail Travel for 100 Miles by Site Personnel in Comparison to Travel by Car for the Same Distance

Footprint reduction technologies will lead to the maximum benefit if they are applied to the activities that are contributing the largest to the overall remedy footprint of the remedial action. Just applying BMPs and creative ideas to a RD may not lead to an appreciable decrease in the overall footprint if the highest footprint activities are not targeted. Therefore, determining the highest footprint elements of the overall remedial action is essential for developing the optimal sustainable RD.

6.2 Cost Analysis

Prior to implementing any footprint reduction technology, a cost analysis should always be performed. A determination of the ROI and payback period for using different footprint reduction technologies provides an understanding of the cost effectiveness of each available option. A sensitivity analysis based on the overall reduction of the remedy footprint should be conducted in conjunction with the cost analysis to determine the technology that leads to an overall reduction in the remedy footprint in the most cost-effective manner. Bundling of more than one footprint reduction technology can also lower the overall impact to project costs. For example, during in situ injection remediation, an increase in cost to use alternative flex fuel vehicles or hybrid vehicles can be mitigated by the reduction in cost from optimizing the injection and using less injection chemical. There are certain aspects of the technologies other than cost that can be a reason for a particular footprint reduction technology not to be considered. Certain examples of such cases are:

- Caution should be exercised in using technologies that reduce a certain metric but do not reduce the overall footprint of the remedy. For example, alternative fuels reduce the carbon footprint of transportation-related activities but increase the emissions of NO_x, which can have higher regional impacts than carbon emissions. The overall benefit to the use of alternative fuels is site specific.

- After-treatment technologies for diesel engines such as diesel oxidation catalyst (DOC) and diesel particulate filter (DPF) require a certain temperature to be attained to be functional. This increases the idle time for heavy equipment with such retrofits and can cause more GHGs to be released. Therefore, such retrofits require proper investigation before use.
- At certain sites, a drilling option such as direct push technology that has a lower footprint than other drilling options might not be feasible due to site lithology and not cost.
- Certain footprint reduction technologies might not receive concurrence from regulatory agencies. The logic behind reduced chemical injection or pulsing of equipment has to be presented to regulatory agencies and backed up with data that reduced performance will still meet the RAOs.

6.3 Project Management

The footprint reduction technologies selected based on the cost analysis may require data gathering and oversight during the construction and operational phase of the remedy. Therefore, all the material and energy use during construction and later operation of the remedy should be properly documented. If available or planned, all emission data of the remedial system should always be well documented for future use. Any sustainability plan for the remedial action, if developed, should include plans for idle management control, minimal waste generation, energy savings, reduction in water consumption, reduction in material use, and reduction in accident risk for site workers. All of these activities can lower the overall footprint of the remedial action. The checklist at the end of this section provides a list of items that can be considered for reducing the footprint of remedial technologies. BMPs are available for several technologies at the EPA Web site (www.cluin.org/greenremediation). Forms for gathering data relating to energy, material, fuel, water, and chemical use should be a part of site work plans so that site personnel can fill the data forms as and when such data are made available. Such data will help in verifying the decisions made during the RD and selection phase using assumptive data.

Overall Footprint Reduction Methods Checklist during Remedial Design and Construction

Potential Remedy Footprint Reduction Areas

- ❑ Energy star products use (Section 8.6)
- ❑ Energy efficient lighting and HVAC systems for all site trailers and buildings (Section 8.6)
- ❑ Energy conservation using premium efficiency motors and VFDs for equipment (Sections 6.2 and 8.6.3)
- ❑ Leadership in Energy and Environmental Design (LEED) principles consideration for all landscaping and construction (Whole Building Design Guide, NAVFAC Sustainable Development Program. http://www.wbdg.org/references/pa_dod_sust.php)
- ❑ Idle management control plan (Section 4.3.1)
- ❑ Alternative fuels use (Section 8.2)
- ❑ Alternative transportation such as rail and hybrid cars for personnel, equipment, and material transportation (Section 8.4)
- ❑ After treatment retrofits for diesel engine vehicles (Section 8.2)
- ❑ Considerations for contractor procurement to be local disadvantaged subcontractors (Section 6.0)
- ❑ Local material sourcing for all site activities (Section 6.0)
- ❑ Minimal to zero waste generation by reduction, reuse, recycling of all construction and demolition debris (Section 8.7)
- ❑ Sourcing waste to waste-to-energy plants (Section 8.7)
- ❑ Considering minimal invasive and least energy intensive site activities (Section 5.0)
- ❑ Considering use of products that have EPA Water Sense certification (http://www.epa.gov/WaterSense/)
- ❑ Passive sampling technologies (Sections 4.3.2 and 7.2)
- ❑ Consider remote data procurement or telemetry for monitoring to reduce travel (Sections 6.2 and 7.1)
- ❑ Minimal ecological impact considerations to reduce destruction of site natural resources (Section 3.3)
- ❑ Consider low impact drilling options such as direct push technology if feasible (Section 4.3.1)
- ❑ Comply with all applicable health and safety requirements, including site worker safety and health plans, proper protective equipment for all site work, daily log of any site accident to reach zero accident work (Section 8.10)

- Stakeholder communication and engagement on all issues (Section 8.10)
- Land use controls and restrictions always in sight (Section 1.3)
- Minimize community impact of remedial activities (Section 8.10)
- Inventory of fuel, energy, water, material, and chemical (Sections 1.4, 7.1, 7.2 and 8.9)
- Proper documentation and records to verify sustainability metrics later in the remedial action (Sections 1.4, 7.1, 7.2, and 8.9)
- Consider site restoration using native plants (Section 8.7)

7.0 GSR CONSIDERATIONS DURING RA-O AND LTM

Implementation of GSR during the RA-O and LTM phases is very similar to what is done during the design and construction phases with two important differences. The first difference is that optimization reviews must be performed periodically and during each of these reviews, GSR should be included in the analysis. Undertaking GSR practices during remedial operation and optimization will often lower energy and material use, ultimately leading to cost avoidance. The second difference is that exit strategies should be continually evaluated and GSR should be part of that exit strategy. To achieve this objective, it is essential to track performance data as well as GSR metrics, documenting all system inputs and outputs.

The following stepwise approach should be used to implement GSR practices during RA-O and optimization:

- Perform optimization review, including evaluation of RAOs, CSM, remedy performance, operating cost, and evaluation of alternative remedial options (see [5]; note that this guidance is being updated in 2011) and as part of this review, conduct a baseline sustainability assessment of the RA-Os and monitoring.
- Perform sustainability assessment of any recommended alternative remedial options.
- Compare remedy performance and sustainability metrics for the existing remedial system and any recommended alternative remedial options.
- Evaluate potential footprint reduction techniques for the recommended remedial approach (i.e., the existing remedial system or recommended alternative remedial option) in a similar manner as discussed in Section 7.0.
- Implement any footprint reduction techniques as appropriate based on the evaluation of the impact on overall remedy footprint and costs.
- Oversee proper implementation of selected footprint reduction methods and document activities to verify sustainability metrics.
- Track contaminant removal with GSR metrics to implement exit strategies and support system shut-down recommendations.

7.1 Performance Objectives and Exit Strategies

For sites that require ongoing operation of remedial systems, it is important to use performance objectives with the treatment train approach to prevent a system from operating beyond its point of diminishing returns. The point of diminishing returns is shown on Figure 7-1 as the point when adverse impacts resulting from implementation of the remedy are significantly higher than the benefit gained by further treatment (e.g., high GHG emissions per mass of contaminant removed). Sustainability metrics should be considered in developing the remedial performance objectives and exit strategies to ensure that the remedy is performed in a sustainable manner. As shown in Figure 7-1, the use of performance objectives and exit strategies not only reduces the cost of implementation but also the duration of activities that result in sustainability impacts, thereby minimizing the overall impact. Performance objectives and exit strategies are discussed further in the Navy's *Optimization Guidance for Optimizing Remedy Evaluation, Selection and Design* [13], Section 8.3.3 of the NERP Manual [21] and the NAVFAC Remedial Action Performance Objective Tool [23].

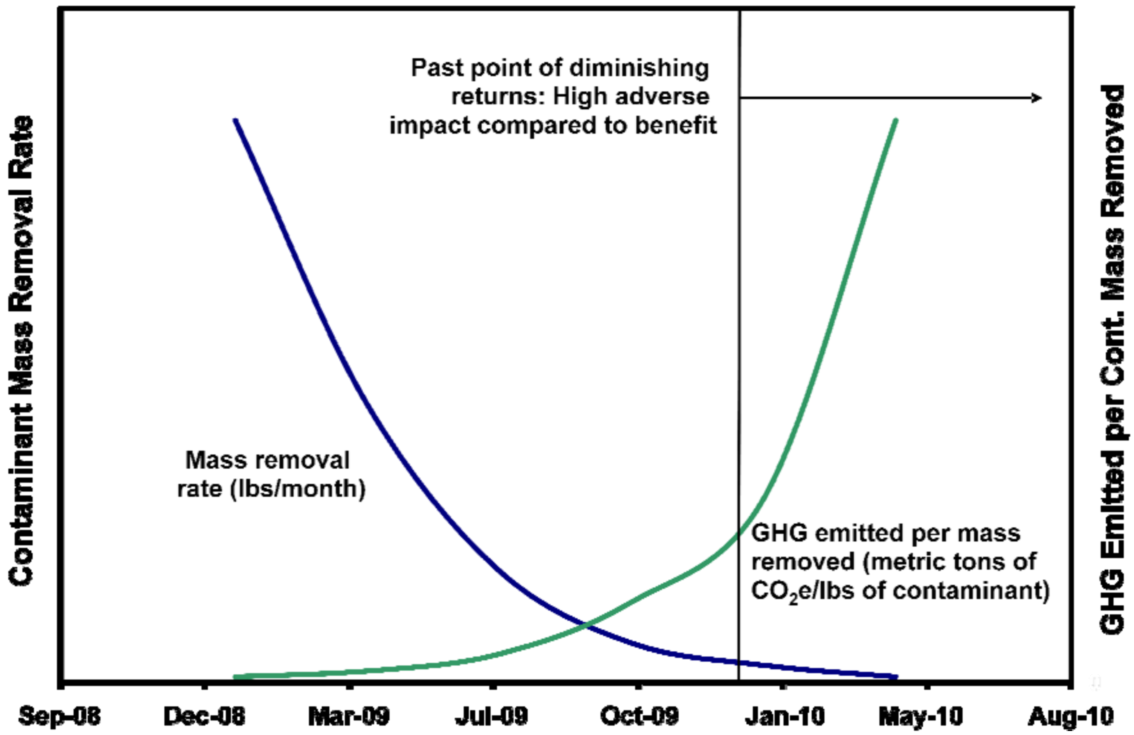

Figure 7-1. Exit Strategies Minimize the Remedy Footprint

Similarly, for long-term management, optimization of the monitoring plan should be done on an on-going basis following the Navy's *Guidance for Planning and Optimizing Monitoring Strategies* [12]. Optimization of the monitoring program helps to minimize the resources used and the sustainability impacts. Following the optimization guidance and performing optimization reviews typically results in cost reduction as well as improving the effectiveness of the remedy and minimizing the remedy footprint.

7.2 Operation

Several footprint reduction approaches can be implemented during the RA-O phase of the remedial action, many of which are similar to the ones discussed in earlier sections. A few GSR considerations that relate primarily to this phase of the remedial action include the following:

- Consider renewable energy for system operation.
- Implement exit strategies.
- Plan for operation, monitoring, and management of the system through remote sensing or telemetry to reduce transportation to the site.
- Improve energy efficiency of operating components.
- Optimize operating conditions to reduce waste generation.
- Reuse/recycle (e.g., recovered free product).
- Optimize chemical injection strategies.

CASE STUDY: SOLAR-POWERED FREE PRODUCT RECOVERY AT SITE 44 NAVAL AIR WEAPONS STATION CHINA LAKE, CA

Project Background

From 1945 to 1988, fire fighting training was performed at a fire fighting training area (FFTA) located in the southwest portion of Site 44 at the point of interest (POI) 197 Fuel Dump. The FFTA consisted of one pad, where techniques for fighting petroleum fires were practiced. Unburned gasoline, JP-5 fuel, and water would evaporate or flow off the pad and percolate into the surrounding soil. Site 44 also encompasses POI 197, called the "Water Road Fuel Dump," located 750 ft east of the old FFTA. Based on site records and aerial photographs, fuels may have been released at POI 197 in the 1960s and 1970s. Free product is present in monitoring and extraction wells at Site 44. A mobile product recovery system (MPRS) has been utilized for free product recovery at Site 44 since 2000. The Navy performed a pilot test in 2008 to evaluate vacuum-enhanced skimming (VES) and other skimming approaches. Based on the results of the testing, passive skimming was identified as the appropriate technology to address the free product at Site 44. An RD prepared for the Navy recommended installation of a solar-powered passive skimming system to take advantage of the readily available solar energy.

GSR Evaluation

Several skimmer designs were evaluated prior to selecting two designs for installation: the Abanaki PetroXtractor and the Geotech Solar Sipper. Five extraction wells have been fitted with Abanaki PetroXtractor units, a solar-powered oleophilic belt skimmer, while five other wells have been fitted with Geotech Solar Sipper skimmer systems. Vendor estimates indicate that each solar-powered unit saves approximately 0.15 pounds of CO_2 per hour of continuous operation compared to traditional electrical powered units. Additionally, the passive skimming system will result in reduced operation and maintenance activities compared to the MPRS, resulting in further reduction in the remedy footprint associated with personnel travel and site visits.

Figure 1. Solar-Powered Product Recovery, NAWS China Lake, CA

During RA-O, documenting the energy, fuel, water, materials, and chemical use is essential in order to document the remedy footprint of the system and compare the performance objectives with the GSR metrics. Many remedial systems achieve asymptotic levels of contaminant recovery, reduction of contaminant concentration or other measurement of the benefit of remediation. A typical example of this asymptotic behavior is illustrated in Figure 7-2. Once the system has reached this point of diminishing returns, the cost of running the system per mass of contaminant recovery (or other measurement of environmental benefit) is prohibitive, thus requiring a change in the system or evaluation of a polishing step to optimize the remedial system. GSR metrics such as air emissions (i.e., criteria pollutants and GHG) due to the operating system also follow the same trajectory as the cost; therefore, running the system beyond the point of diminishing returns is not sustainable or cost-effective. Tracking data pertaining to sustainability metrics is an essential consideration for GSR practices during the RA-O phase of the remedial action as this allows GSR to be considered as part of the exit strategy.

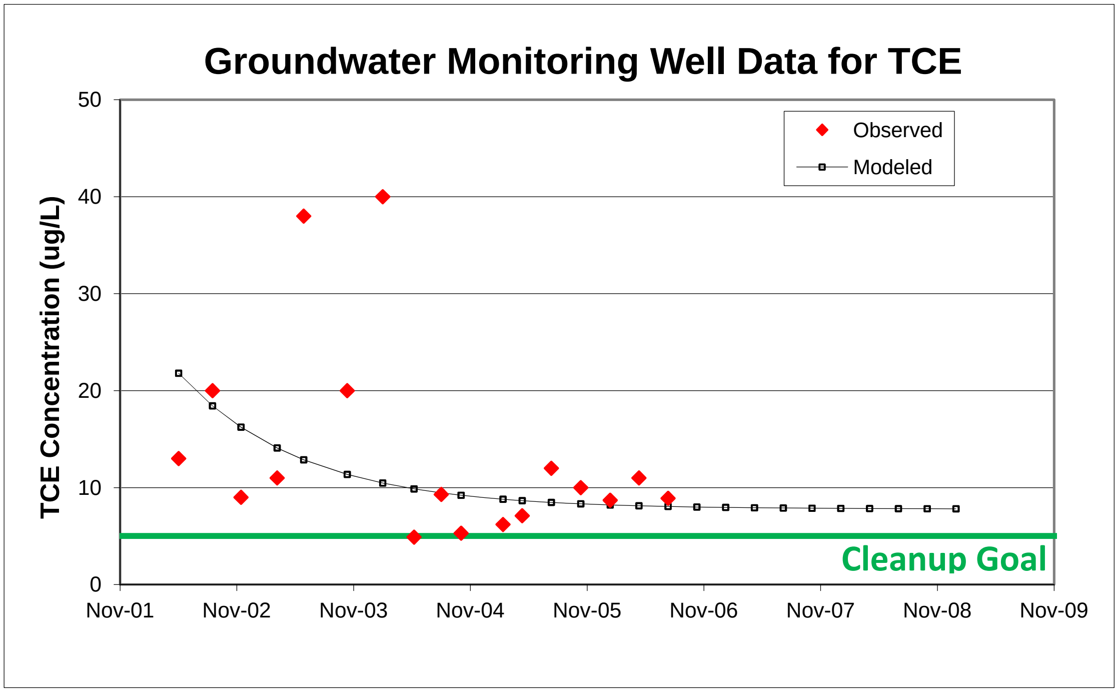

Figure 7-2. Groundwater Monitoring Well Data for TCE

7.3 Long-Term Monitoring

Similar to construction and operation phases, tracking and documenting all inputs related to energy, water, fuel, materials, and chemicals is essential during LTM and the long-term management phase. During LTM, transportation-related activities should be the biggest driver for the remedy footprint. Therefore, any activities such as passive sampling, telemetry, or optimizing the monitoring events will reduce the overall remedy footprint of this phase. Similar to monitoring during site characterization, including more passive sampling techniques such as grab samplers can reduce the pumping requirements and also number of monitoring events.

Potential ecological impacts should also be considered when evaluating the sustainability of LTM. For example, LTM that includes frequent tissue monitoring will have a greater ecological impact compared to implementing alternative sampling techniques. An alternate approach may be to sample tissue and the related media of concern to establish a statistical relationship, and then monitor only the media of concern in the long term. The *DON Guidance for Planning and Optimizing Monitoring Strategies* [12] can help in optimizing monitoring events, methods, analytes, and locations.

Inclusion of any GSR practice requires oversight of data tracking, operations, and monitoring events to ensure that sustainable practices that were determined to be included into the remedial action are being implemented. GSR practices should be identified and included in all project reports. Similar to the construction phase, a sustainability plan for the operations of the remedial system should also be developed. Data forms relating to energy, material, fuel, water, and chemical use should be a part of site operational work plans so that the site personnel can fill the data forms as and when such data are made available.

CASE STUDY: USING WIND TURBINES TO POWER FREE PRODUCT RECOVERY FORMER ADAK NAVAL COMPLEX, AK

Project Summary

A total of three petroleum areas requiring free product recovery were identified at the former Adak Naval Complex, AK. Rather than constructing several systems in remote locations, mobile systems were constructed and moved from site to site. Obtaining a power source also presented a challenge for some of the remote site locations. Equipment included in the free product recovery system was recovery pumps and product recovery and storage tanks. The remote location and severe climate of Adak did not only present challenges, but also opportunities for innovation to design and implement energy efficient and sustainable remedial systems. To address the challenges presented in this case, mobile wind-powered turbines (Figure 1) were designed to power the free product recovery systems. The wind turbines initially designed were damaged when gale force winds hit the site, highlighting the importance of planning to meet energy needs based on site conditions. The wind turbines were subsequently redesigned with a shorter fan blade length to hold up to an environment where sustained wind speeds of 50 miles per hour are common.

Figure 1. Mobile Wind Turbine at Former Adak Naval Complex, AK

GSR Strategy Employed

Construction of a renewable energy system for operation of a remediation system is often not cost-effective. However, at a remote site such as this where a power source is not always available, the cost of bringing in power lines can offset the cost of a renewable energy system. At the former Adak Naval Complex, mobile wind turbines were designed and constructed to generate power for the free product recovery systems. The mobile wind turbines power a 1,000-watt generator that can produce 12 volts of electricity, enough to power the free product recovery pumps. In addition to eliminating electrical infrastructure costs, wind power is a clean source of energy.

8.0 GENERAL FOOTPRINT REDUCTION METHODS

The goal of Navy's GSR initiative is to reduce the remedy footprint associated with the ER program by selecting appropriate remedies and implementing footprint reduction techniques where and when they make sense. A wide variety of footprint reduction technologies can be applied to a given project. The challenge to an RPM is to determine which technologies are appropriate for a given site. Applying footprint reduction methods without an understanding of the real benefits and costs associated with these technologies could potentially do more harm than good. Therefore, the purpose of this section is to provide information and guidance on how to make appropriate environmental cleanup choices that achieve the greatest reduction in the overall footprint while meeting the remedial goals and resulting in little or no additional costs. This is accomplished by providing a brief discussion of the more commonly used footprint reduction methods along with guidance on what factors to take into consideration when determining whether a reduction method should be selected for a given site.

Each activity performed in support of the remediation process contributes to the overall remedy footprint, and footprint reduction methods can be applied during any phase of the process. There are three basic methods of reducing the footprint of a site cleanup: (1) select technologies and approaches that have a low footprint relative to the other alternatives (primarily applied during the remedy selection phase but should be revisited as part of optimization during the RA-O phase); (2) apply general BMPs that should be implemented on a routine basis (applied during site characterization, construction, RA-O and LTM); and (3) implement footprint reduction methods to enhance the sustainability of selected or existing remedies (developed during remedy design and applied during construction and RA-O). Each of these techniques is discussed in this section.

8.1 General Guidance when Choosing Footprint Reduction Methods for Selected Remedies

Before considering any footprint reduction method, it is important to perform a baseline GSR assessment using methods outlined in Section 3 to determine which elements or activities of the remedy have the most significant footprint. In some cases, the baseline assessment may consist of updating the GSR evaluation completed during the FS phase; in other cases, a new baseline assessment may be needed depending on the alternative and technologies implemented. A baseline GSR assessment helps to quantify the level of sustainability as it applies to the selected remedy. Understanding the baseline remedy footprint allows the RPM to better focus resources to address those activities for which footprint reduction will have the greatest benefit. The baseline assessment also allows the RPM to determine the reduction in sustainability metrics that can be reported in NORM (see Section 1.4). The footprint of each remedy will vary based on site-specific factors but some of the activities that generally tend to have a high footprint are summarized in Table 8-1, along with possible footprint reduction methods. For each site, a table such as this should be developed.

A cost analysis should be performed for each possible footprint reduction method to estimate the footprint reduction that would be achieved along with the cost to implement. It may be possible to bundle certain footprint reduction methods together where some would be implemented contingent on another being implemented. Bundling can allow a cost increase from one method to be offset by a cost reduction from another, thus achieving an overall decrease in footprint with

Table 8-1. Examples of Footprint Reduction Techniques for Selected Activities

ACTIVITY	IMPACT(S)	FOOTPRINT REDUCTION TECHNIQUE(S)
Excavation and backfilling	Soil erosion, consumption of energy, transport of air-borne contaminants, ecosystem disturbance	• Optimized planning to determine best options for excavated material (e.g., treat material and keep on site or remove and use local material for back-fill, find nearby facility to accept waste or one allowing for rail transport) • Establish decision points that could lead to in situ treatment instead of excavation for part or all the material.
Sediment dredging, dewatering, and disposal	Emissions of GHGs, criteria pollutants, consumption of energy, ecosystem disturbance	• Consider passive dewatering instead of physical/mechanical methods • If available, consider hydraulic dredging directly to disposal facility instead of mechanical dredging, dewatering, and traditional transportation disposal.
Transportation of materials and waste	Emissions of GHGs, criteria pollutants, consumption of energy, accident risk, traffic	• Improved CSM and/or risk analysis to optimize excavation volume • Rail versus road • Locate closer disposal facility • In situ or on-site treatment • Greener fuels • After-treatment emission controls.
Transportation of personnel during RA-O and long-term management	Worker safety, traffic, emissions of criteria pollutants and GHGs, consumption of energy	• Increase automation in operating systems to reduce operator trips • Optimize LTM plans to reduce frequency of trips • Take holistic approach to base long-term management activities to reduce number of trips to base • Establish performance objectives linked with exit strategies to prevent systems from operating beyond point of diminishing returns.
Operate mechanical equipment with motors, such as pumps, blowers and compressors	Emissions of GHGs, criteria pollutants, consumption of energy	• Use high or premium efficiency motors and VFDs where appropriate • Ensure equipment is optimally sized considering life-cycle characteristics of the cleanup • Apply system pulsing where appropriate (e.g., for air sparge systems) • Consider renewable energy • Establish performance objectives linked with exit strategies for each system component as well as the overall system to prevent equipment and system from operating beyond point of diminishing returns.
Drilling/well installation	Emissions of GHGs, criteria pollutants, consumption of energy, accident risk	• Optimize selection of well casing material and diameter to minimize material use and well installation time • Consider direct push to decrease drilling time and reduce waste from drill cuttings.
Consumption of chemicals or other materials for treatment	Emissions of GHGs, criteria pollutants, consumption of energy	• Improve CSM to minimize treatment area • Perform additional design work or treatability testing to optimize injection strategy and make more efficient use of treatment materials.

no additional cost to the program. For example, if passive sampling can be used for monitoring, then alternative fuels will be used for drill rigs during monitoring well installation and/or chemical injections. In this example, passive sampling typically results in a cost reduction, which can be used to offset the cost of using alternative fuels.

General steps for implementing footprint reduction methods for selected remedies are summarized as follows:

- Baseline GSR Assessment: Perform baseline GSR assessment to determine which elements of the remedy have the most significant footprint using methods and tools discussed in Section 3.
- Brainstorming: Develop a list of potential footprint reduction methods that are applicable to the elements that have the most significant impact.
- Cost Analysis: Estimate the footprint reduction that would be achieved for each potential method along with an estimate of the cost increase or reduction.
- Prioritization: Prioritize footprint reduction methods for implementation.
- Planning: Develop a plan (that will be incorporated into other required planning documents) for implementing the footprint reduction methods, including an estimate of the overall footprint reduction and the cost increase or reduction.

8.2 Alternative Fuels

The two fossil fuels that are most widely used for remediation site vehicles and mechanical equipment (e.g., generators) are diesel and standard unleaded gasoline. These traditional fuel sources can result in large emissions of GHGs and criteria pollutants. There are alternatives that can be used, although some have limited use in field applications due to the specific type of vehicle or equipment needed. However, where an alternative fuel may not be available for use in field based operations, it is becoming increasingly practical to utilize alternative fuel vehicles for worker transportation to and from the site itself.

Alternative fuels, and their most likely application include:

- Electric – transportation
- Hybrid electric – transportation
- Hydrogen fuel cell – transportation, non-road vehicles (future use)
- Biodiesel – transportation, non-road vehicles
- Ultra low sulfur diesel (ULSD) – non-road vehicles
- Natural gas: compressed natural gas (CNG) and liquefied natural gas (LNG) - transportation
- Emulsified diesel fuel – non-road vehicles

Biodiesel and ULSD are the most widely available alternate fuels and can be used in most on- and off-road diesel engines. Beginning on December 1, 2010, ULSD became the only fuel available for highway use. ULSD will also soon be required for all non-road vehicles and equipment. ULSD fuel enables the use of cleaner technology diesel engines and vehicles, resulting in significant emission reductions of criteria air pollutants. Table 8-2 provides a summary of each of these fuel types along with benefits and concerns. Additional information, including approximate cost, emission reduction, and other considerations is provided in Table 8 of the EPA *Smart Energy Resources Guide* [24]. Other sources of information regarding alternative fuels are listed below:

- EPA. 2010. *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup*. EPA 542-F-10-008. August.
- EPA. 2010. *Biodiesel*. EPA-420-F-10-009. February.
- EPA. 2007. *Cleaner Diesels: Low Cost Ways to Reduce Emissions from Construction Equipment*. March.
- EPA Web site http://www.epa.gov/otaq/fuels.htm
- West Coast Collaborative Web site http://www.westcoastcollaborative.org/fuel-use.htm

Currently, biodiesel is the most practical choice of renewable energy sources. Although biofuels are a renewable energy source and reduce GHG emissions and priority pollutants, there are concerns about impacts associated with the production of biodiesel, including the use of land that would otherwise be used to grow food products. However, EO 13423 calls for a 10% annual increase in the use of non-petroleum fuel in motor vehicles and EO 13514 calls for guidance to be developed regarding the use of biodiesel blends in diesel vehicles. It is recommended that information from the manufacturer be checked to ensure that warranties will not be voided by the use of biofuel blend. In most cases, B5 and B20 will not void warranties but this should be confirmed. Formal statements from manufacturers have been compiled and are available on the National Biodiesel Board (NBB) Web site at www.biodiesel.org/resources. Locations of where biofuels can be purchased are available at http://www.biodiesel.org/. This site is sponsored by the NBB and provides other information regarding biofuels.

At the current time, biodiesel is more expensive than conventional diesel. This fluctuates and an RPM should be aware of current fuel prices. In some cases, the cost differential may be low enough to justify the use of biodiesel and/or there may be opportunities to bundle footprint reduction methods to allow the purchase of biodiesel.

8.3 Renewable Energy

The use of renewable energy not only reduces the consumption of fossil fuels but also reduces GHG emissions. The Defense Authorization Act (2007) indicates that the DoD renewable energy goal is to have not less than 25% of the total quantity of electric energy within DoD facilities and activities during FY 2025 and thereafter from renewable energy sources (as defined in Section 203(b) of the Energy Policy Act of 2005). Many techniques for generating renewable energy are only economical for large-scale applications and are not practical for use in the relatively small-scale applications that are typical of site remediation systems. However, in

Table 8-2. Summary of Alternative Fuels

ALTERNATIVE FUEL TYPE	DESCRIPTION OF ALTERNATIVE FUEL	BENEFITS	CONCERNS/ LIMITATIONS	USE IN DIESEL ENGINES
Biodiesel	Produced from new or used vegetable and animal oils and fats. Available in different blends, including B2 (2% biodiesel), B5 (5% biodiesel), B20 (20% biodiesel) and B100 (100% biodiesel also referred to as neat biodiesel).	Renewable fuel. Reduces air pollutants such as GHGs, PM, CO, HC and air toxics. Approximate reductions include: B20 reduces lifecycle GHG by 10%,[2] PM by 10%.[1] B100 reduces lifecycle greenhouse gas emissions by more than 50%.[2]	Found to increase NO_x by approximately 2% in B20 and 10% in B100.[2] Adverse impacts associated with the production of biodiesel, such as loss of land for food production, are currently under investigation.	Blends, such as B5 (5% biodiesel) and B20 (20% biodiesel) can be used in any diesel engine but pure biodiesel (B100) requires a retrofit and is not suitable in cold climates
ULSD and Lower Sulfur Fuel	ULSF (15 ppm) is required for on-road vehicles and will be required for off-road by 2010.[3]	Reduces SOx and enables additional after treatment technologies to be used.[3]	Slightly higher price than regular non-road diesel.	Does not require engine retrofit.
Natural Gas: Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG)	Natural gas consists of a mixture of hydrocarbons, mostly methane	Significant reduction of PM. A portion of NG could come from collection of landfill gas and thus be considered renewable.[3]	Not used in diesel engines. Needs more frequent fueling. Natural gas vehicles cost about \$3,500 to \$6,000 more than gasoline equivalents.[6]	Not used in diesel engines.
Emulsified Diesel Fuel	Blended mixture of diesel fuel, water, and other additives	May be able to reduce emissions of PM by 10 to 20% and NO_x by 50 to 60%[4]	Reduction in power. Not widely available.	Retrofit not required.
Ethanol or E85	Produced by fermenting plant sugars. E85 is 85% ethanol and 15% gasoline	Renewable fuel. Reduces emissions of CO, hydrocarbons, and air toxics. Life-cycle reduction of GHG emissions is 15 to 20% when E85 is made from corn and approximately 70% when made from cellulose.[5]	Reduced fuel economy by 20 to 30%.[5] Adverse impacts associated with the production of biodiesel, such as loss of land for food production, are currently under investigation.	Requires flex vehicles.

(1) EPA. 2007. Cleaner Diesels: Low Cost Ways to Reduce Emissions from Construction Equipment, National Center for Environmental Innovation, March.
(2) http://www.epa.gov/smartway/growandgo/documents/factsheet-biodiesel.htm
(3) http://www.westcoastcollaborative.org/fuel-use.htm
(4) http://www.epa.gov/cleanschoolbus/retrofit.htm
(5) http://www.epa.gov/smartway/growandgo/documents/factsheet-e85.ht
(6) EPA. 2008. Smart Energy Resources Guide, Superfund Division Region 9, EPA/600/R-08/049, March.

cases where operation of a remedial system will continue for a long duration and regional electricity costs are high, renewable energy options may be more economically viable. The use of alternative energy may also be cost effective for remote sites where the cost of bringing in electric power lines is expensive. For example, range sites are often located in remote locations where the use of alternative energy may be cost effective for implementing a remedial action. Additionally, the economics for generating renewable energy may be improved if future reuse or recycling of the system components is considered.

The benefits in terms of preserving fossil fuels and reducing GHG emissions can also be taken into consideration when evaluating the benefits of using alternative energy. If the unrecovered cost of the alternative energy system is not an excessive addition to the remediation project, the benefits in terms of supporting EO 13423 and EO 13514 and community relations may warrant the additional expense.

Another option to consider is purchasing green power from an energy provider. Renewable energy is often more expensive than non-renewable energy, and therefore, using renewable energy can be at odds with DoD guidance that calls for DoD to invest in energy projects when cost effective. In response, DoD plans to obtain additional funds by joining with private industry, such as local electric utilities, to develop renewable energy projects [25]. If a remedy requiring energy is located near a renewable energy project, then this presents an opportunity for using renewable over non-renewable energy to power the remediation system.

The following subsections focus on commonly available on-site methods of supplying renewable energy to generate electricity to power remediation equipment. This primarily includes photovoltaics, wind power and micro-turbines. Also discussed are the benefits of peak shaving and peak shifting.

8.3.1 Photovoltaics

Photovoltaics (PVs) are well suited for smaller scale remediation systems. Equipment and qualified contractors for installing the equipment are readily available. They can be installed with battery systems to store energy during sunny periods and use this stored energy during dark or cloudy periods. They can also be tied into the power grid such that during periods where site demand exceeds what the PV system can provide, power is delivered from the grid to the site. Conversely, when the PV system output exceeds the site demand, energy is transmitted from the PV system to the grid and the utility company gives credit to the PV system owner for this energy. Section 3 and Appendix III of the *Smart Energy Resources Guide* [24] provide information regarding PV, including practical considerations, such as determining the location-specific solar radiation potential (also see the DOE NREL Web site at http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/ for maps of solar radiation), estimating the capital cost and energy output of a PV system, finding installers of PV systems, warranties, permits and other environmental issues (e.g., disposal of spent PV cells). Numerous success stories can be found where PV systems have been used to supply power for remediation projects, including:

- Aberdeen Proving Ground O-Field, Englewood, MD; Solar-powered data collection system.

- Altus AFB, Altus, OK; Solar-powered pump for groundwater circulation.
- Apache Powder, St. David, AZ; Solar-powered pumps for recirculation in wetlands.
- BP Paulsboro, Paulsboro, NJ; Solar panel system providing electricity for remediation pumps.
- Crozet Township Arsenic Site, Charlottesville, VA; Solar and gravity-powered irrigation system.
- Lawrence Livermore National Lab (Site 300), Livermore, CA; Solar-powered pumps for GAC systems.
- Pemaco, Maywood, CA; PV system for emergency backup battery power.
- Raytheon Beech Aircraft Site, Boulder, CO; Solar-powered monitoring stations with wireless data-transmission well loggers.
- Savannah River Site, Aiken, SC; 10 solar-powered MicroBlower systems.

Other examples of PV powered remediation projects are documented in various publications, including (not a complete listing):

- *Smart Energy Resources Guide* [24]
- *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* [8]
- *Incorporating Sustainable Practices into Site Remediation* [26]
- *Green Remediation and the Use of Renewable Energy Sources for Remediation Projects* [27]

> PV powered remediation systems tend to be more cost effective in remote locations that are unconnected to the electrical grid. The cost of the PV system is likely to be less than the installation costs of new electrical infrastructure.

Due to the generally high capital costs of most PV systems, they are most cost effective where operation of a remedial system will continue for a long duration and regional electricity costs are high, assuming the cleanup site is accessible from existing electrical grid infrastructure. PV systems can also be a cost-effective option in remote locations which are unconnected to the electrical grid. However, non-economic factors are also important in determining the value of a PV system. These include reducing demand on fossil fuel, adherence to EOs 13423 and 12514, and supporting alternative energy technologies and associated suppliers.

8.3.2 Wind Power

The power generation capacity of a wind turbine ranges from less than 1 kW to greater than 1 MW and the smaller units can be applicable for use with remediation systems. Similar to PV systems, wind turbine systems can be installed with batteries and/or tied in with the electrical grid. Various sources of information can be used to determine wind data for a particular area, including the following Web sites:

- Energy Efficiency and Renewable Energy (EERE): Provides annual average wind speed maps for individual states. www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp
- NREL: Provides annual average and seasonal wind speed maps for individual states and U.S. territories. http://rredc.nrel.gov/wind/pubs/atlas/maps.html
- Bergey Windpower: Provides wind maps for individual states and U.S. territories. www.bergey.com/wind_maps.htm

Depending on location, wind power can be an attractive option for energy production. Favorable site conditions include high and consistent wind speeds, large area for installation of a wind turbine and allowance for construction of tall structures. Under the right conditions, the use of wind energy is more cost effective than the use of PV systems.

Section 4 and Appendix IV of the *Smart Energy Resources Guide* [24] provide information regarding wind energy, including practical considerations, such as determining the location-specific wind speed, estimating the capital cost and energy output, finding installers of wind turbine systems, warranties, permits and other environmental issues (e.g., evaluating impacts on bird and bats).

There have been numerous success stories where wind systems have been used at site remediation systems. One example is the 1.5 MW wind turbine installed by AFCEE at the Massachusetts Military Reservation (MMR). In 2008, the eight groundwater pump and treat systems at MMR used over two million dollars in electricity costs and indirectly produced tons of GHGs and other air emissions associated with fossil fuel-based power. The wind turbine is anticipated to reduce the program's electricity costs and offset air emissions, generated indirectly through the use of electricity from fossil fuel-based power plants, by approximately 25 to 30 percent. Based on a range of utility cost projections and an estimate of the turbine's energy production, the $4.6 million project is anticipated to have a payback period between six and eight years [28].

8.3.3 Other Renewable Energy Technique/Technologies

Other techniques or technologies to use energy from renewable sources include: recovery of landfill gas, micro-turbines, and peak shaving and/or shifting. These are discussed in various publications, including: *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Site* [8] and the *Smart Energy Resources Guide* [24]. Peak shaving and/or shifting is an applicable method of increasing the percent of energy that comes from renewable sources provided by the utility company.

The basis for peak shaving/shifting in increasing the use of renewable energy is that in some cases utility companies may need to supplement the power generation capacity with more expensive and less green power sources to accommodate peak power consumption periods.

CASE STUDY: GREEN AND SUSTAINABLE REMEDIATION AT MARINE CORPS BASE CAMP PENDLETON

Project Summary
Marine Corps Base Camp Pendleton was the location of a few distinct GSR strategies and technologies. The Box Canyon (Site 7) Landfill was used for placement of PV and methane micro-turbine projects. Five other installation restoration (IR) sites were used to test the effectiveness of various emission control options for heavy-duty, off-road diesel equipment.

GSR Strategies Employed at Site 7

Figure 1. PV system incorporated into IR Site 7 landfill cap, Marine Corp Base Camp Pendleton

In 1996, IR Site 7 Landfill was designated a corrective action management unit (CAMU) for purposes of consolidating remediation wastes from various Marine Corps Base Camp Pendleton IR sites. The site began closure construction in July 2001. Actions included installation of an evapotranspiration cover to close the CAMU and the landfill, installation of lined drainage structures and erosion control devices, groundwater and landfill gas monitoring, and post-closure site maintenance. The incorporation of PV and micro-turbine technologies hinged on whether or not the equipment could be installed and operated without compromising the integrity of the existing evapotranspiration landfill cap. Issues included: bearing capacity of soil, stability, erosion, drainage control, infiltration, site access, and the landfill gas control system. Resolving these issues provided the basis for a customized approach to the PV design specifications, i.e., units built on self-ballasted, non-penetrating foundation, gravel interface between ballasts and landfill cover, adequate spacing between modules (maintenance), and no excavation of the existing evapotranspiration cover. The completed project consisted of 220, 28-module 6.6 kW building blocks, producing 1.48 MW (DC) of electricity. In addition, the utilization of existing landfill space as the location for the PV system maximized the usefulness of the property. The installation of a state-of-the-art micro-turbine, capable of running efficiently at low methane concentrations, leveraged the existing methane gas collection wells, and provided an additional 30 kW of energy, fed into the PV panel system.

Thus, by shifting the time in which peak power is being used for the remediation system, a greater percentage of power can come from greener sources. This can reduce electricity cost (cost per kW-hr is often less during non-peak periods) as well as reduce emissions of GHGs and other pollutants. If it is acceptable to operate the remedial system (or high power portions of the system) during non-peak periods only, this is an attractive way to reduce cost as well as reduce the footprint of the remedial system. To quantify the benefit, it is necessary to investigate how scheduling impacts power production sources. Peak shaving/shifting can decrease cost because utilities often offer lower rates during non-demand periods and the price structure allows lower rates to be applied if the peak energy consumption is lower.

8.4 Alternative Transportation

Selection of the optimum mode of transportation is a low-cost method for reducing the footprint. The best example is the use of rail to transport personnel or materials rather than road vehicles. Tools such as SiteWise™ can be used to quantify the differences. Figure 8-1 demonstrates the difference in the GHG emissions between rail and truck transport of materials. As shown on the figure, the GHG footprint for rail transport is only about 10% that of truck transport. The cost difference would be site specific and rail transport may not be practical in all cases.

> Marine Corps Base Camp Pendleton has nine areas of soil and groundwater contamination due to past disposal practices. Rail transport of the 120,000 yd^3 of soil that were excavated helped reduce the total PM_{10}, NO_X and SO_X emissions associated with implementation of this remedy.

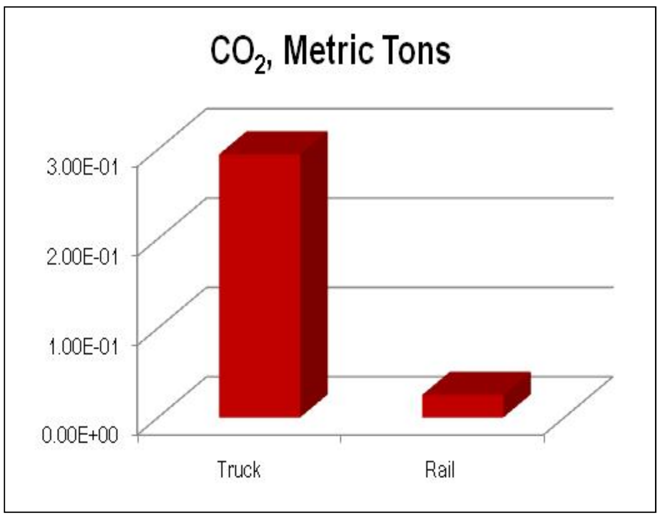

Figure 8-1. Comparison of Truck versus Rail for Transportation of 10 Tons for 100 Miles (per SiteWise™ GSR Tool)

This could be extended to include personnel transportation to project sites as well as for meetings where alternative transportation could be encouraged and the project managed to minimize the number of trips needed (e.g., time trips to serve a dual purpose, use teleconferencing or video conferencing as appropriate, etc.). Ideally, the most effective method of reducing transportation impacts is to reduce the amount of miles travelled. This can be accomplished by a variety of methods such as: using support staff located near the remediation site or operations headquarters, effective project management to accomplish multiple tasks during each trip, use of the Triad approach to reduce mobilization requirements during site characterization, and optimization techniques to minimize trips needed during RA-O and LTM phases.

8.5 After-Treatment Technologies for Diesel Engines

Diesel engines retrofitted with after-treatment technologies can reduce the emissions of some pollutants. Several options of after-treatment technologies are available to reduce emissions of PM, hydrocarbons, NO_x, and carbon monoxide, as well as odor reduction. These devices can be added onto existing trucks and heavy equipment as a retrofit and thus reduce the footprint of the remedial efforts. Devices that can reduce emissions from diesel engines include:

- Diesel oxidation catalysts (DOCs);
- Diesel particulate filters (DPFs);
- Selective catalytic reductions (SCRs); and
- Diesel multistage filters (DMFs).

A description of these devices (except DMF) is provided in Table 8 of the *Smart Energy Resources Guide* [24]. As shown in this table, the use of ULSD is either required or recommended when using these devices. DMFs are designed to be maintenance free and can reduce emissions of PM, hydrocarbons, NO_X, and carbon monoxide [29].

The RPM should be aware of some issues associated with the use of after-treatment technologies. The use of after-treatment technologies will result in a cost increase. An RPM must determine if the benefits warrant the additional cost or if there are ways to bundle this with other footprint reduction methods to offset the cost. More importantly, the manufacturer of the equipment should be consulted to determine if a retrofit would impact the warranty. Damaged equipment could have a significant cost implication if the Navy directed the use of after-treatment technologies. Also, some devices cause a decrease in fuel efficiency and require a warm-up period before use. If not planned for, this could impact the on-site work. It also increases the idle time, total fuel consumed and GHG emissions. Thus, it may be more appropriate to consider these devices in locations where emissions of criteria pollutants and odors are of particular concern, such as highly populated areas.

8.6 Energy Conservation

Energy conservation typically results in a cost savings as long as the operating period is sufficient to recover up-front costs. A payback analysis is recommended to determine the operating time needed to recover the up-front costs and compare this to the expected operating time. Electricity consumption can cause significant impacts with respect to energy use and generation of GHGs. This is particularly important for cases where electric motors are part of an active remediation system and are required to operate continuously as part of routine operations. Systems of this type include pump and treat, SVE, in situ air sparging (IAS) and multiphase extraction (MPE). These are commonly used technologies and in the case of pump and treat, the system may be in operation for an extended period of time unless an exit strategy has been developed. In some cases, even SVE, IAS and MPE can operate for a long period of time (e.g., 10 years), although operation is often in the two- to five-year range. Even with a reasonable operating duration, the impact for a moderately-sized system can be significant.

Several general techniques can be used to minimize the impact of equipment operation, including: selecting energy efficient equipment (e.g., high efficiency motors), proper sizing of equipment, and the use of variable frequency drives. Technology-specific methods for improving the efficiency of operation and thereby reducing energy consumption can be found in several references including the NAVFAC document *Guidance for Optimizing Remedial Action Operation* [5], and *Introduction to Energy Conservation and Production at Waste Cleanup Sites* [30].

Significant energy reduction can also be made by adopting the conservation strategies included in certification programs that include energy conservation components such as United States Green Building Council (USGBC) LEED, or EPA's Energy Star program. The use of other strategies such as noise reduction technologies and "dark sky" lighting (i.e., lights designed to light only the intended area with minimal excess lighting of the dark sky) can also be considered to minimize ecological and community impacts. Noise reduction strategies may include acoustical enclosures for equipment, or restrictions on drilling times to mitigate adverse noise impacts. The remainder of this section is focused on general strategies applicable to a wide variety of site types.

8.6.1 High Efficiency or Premium Efficiency Motors

Improvements in motor technology have resulted in increased motor efficiencies with the highest ratings being referred to as premium efficiency motors. The energy savings for using premium efficiency motors can exceed 5% and thus reduces not only energy but emissions of GHGs and other pollutants. Although premium efficiency motors cost more than standard or high efficiency motors, the payback in electric cost is typically about one year if the motor runs for 7,500 or more hours per year. Examples of equipment that would demand this level of motor run-time include: a stripping tower blower, SVE system, or groundwater treatment system pumps. As the operating hours fall to 4,000 per year, the payback increases to 2 to 5 years (Premium Efficiency Motors Fact Sheet, Nevada Sure Bet Program). Thus, for remedial systems that operate continuously (not including routine system downtime), premium efficiency motors should be used where feasible for new systems or where motors are being replaced. Since the installation cost of replacing a working motor is high relative to the cost differential between a premium motor and a standard efficiency motor, it may not be economical to replace existing motors that are operating properly.

Other sources of information to assist in motor selection are available at the following Web sites:

- http://www.esource.com/BEA/hosted/PNM/PA_35.html
- http://www1.eere.energy.gov/industry/bestpractices/software.html#mm
- http://www.neep.org/html/NEEP_Comm.final.pdf

8.6.2 Proper Sizing of Equipment

In many cases, equipment that has been purchased and is in operation has a capacity much greater than what is found to be necessary. If this is the case, the equipment may be highly inefficient. If oversized equipment is being used, it may be necessary to throttle down flow control valves, which reduces volumetric flow rate to the proper level. However, this is accomplished by increasing the pressure (or vacuum) that the device must overcome. This may actually increase the energy consumed. In some cases, a properly sized device could reduce energy consumption by 50% or more. Thus, an analysis should periodically be conducted to determine if the equipment is properly sized and if not, an analysis should be conducted to determine if equipment replacement is warranted.

8.6.3 Variable Frequency Drives

A VFD is a device used with electric motors that allows the speed of the motor to be reduced through electronic controls. This reduction in speed reduces the speed of the pump or blower, thereby reducing the flow rate without throttling a flow control valve. The use of VFDs is a much more energy efficient method of controlling flow rate compared to flow control valves because throttling a flow control valve reduces flow by increasing pressure loss across the valve and forcing the mechanical device (pump or blower) to work harder. When VFDs are used, the flow rate is decreased by allowing the motor and pump to turn at a reduced speed, thereby drawing less energy as flow rate decreases.

Similar to premium efficiency motors, cost is added for using VFDs and should be evaluated. For applications where it is anticipated that flow rate will need to vary significantly, VFDs should be considered for all new applications. For existing applications, an economic analysis is needed to determine the cost-effectiveness of replacing an existing unit.

Information regarding VFDs is available at several Web sites, including:

- http://www.energy.ca.gov/process/pubs/vfds.pdf for general information;
- http://www.variablefrequencydrives.net/variablefrequencydrivebasics.htm
- http://www.alliantenergy.com/docs/groups/public/documents/pub/p010794.hcsp (includes a calculator tool to estimate the cost savings compared to a flow control valve)

8.6.4 Pulsed Operation of IAS/SVE

Pulsed operation refers to the ability for systems to cycle through on/off phases. For IAS systems, it has been found that pulsing not only reduces energy requirements but also increases remedial effectiveness by allowing additional flow pathways to be established for air flow. For SVE systems that are in diffusion limiting conditions (most often is the case), periods of downtime allow the vapors to re-equilibrate, resulting in higher concentrations of vapors once the system is turned back on. By pulsing these systems, less energy is used to operate the mechanical equipment and the overall remedial effectiveness can be increased. Smaller, mobile systems can also be used to treat portions of a site on a rotating schedule, thereby pulsing the wells. This would allow smaller sized equipment to be used, in turn reducing the capital and operation and maintenance costs as well as the GHG footprint. In addition, if an oxidizer or internal combustion engine is used for emission controls, the amount of supplemental fuel can be significantly reduced by pulsing. In some instances, it may be possible to synchronize pulsed operation with peak shifting, such that the "on" phase of the mechanical equipment occurs during periods of lower electrical usage and costs.

8.7 Resource Conservation and Green Materials

During construction activities and associated landscape alteration activities, green building strategies such as those outlined in the USGBC LEED should be considered. LEED includes guidelines and recommendations for new construction, and existing building operations and management that fall under six categories important for reducing the environmental impact of facilities of all types:

- Sustainable sites
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation in operations

The DoD has issued a Sustainable Buildings Policy that supplements the existing requirements of DoDI 4170.11 and Unified Facilities Criteria 4-030-01. The policy requires adherence to the Guiding Principles of the High Performance and Sustainable Buildings Memorandum of Understanding, which establishes green building standards for the new construction of Federal buildings. Following the example of LEED, the Guiding Principles institute a framework for advancing principles of sustainability within the construction industry.

As noted across the LEED categories, resources other than energy that can be conserved include water, raw materials for materials consumed, topsoil, paper for reports and landfill space. Conserving one resource typically conserves other resources and has other sustainability benefits. For example, recycling of construction and demolition debris or metal recovered at a munitions site will reduce consumption of landfill space and may also save energy and reduce air emissions by having less material transportation. At the Former Live Impact Area Vieques, Puerto Rico, 15.2 million lb of metals were accumulated during the remedial action and 11.5 million lb were recycled, saving significant landfill resources. Another example is the use of waste-to-energy plants for waste disposal rather than landfills in states where these plants are currently operating. This too reduces the consumption of landfill space and also results in energy production from the waste processing. Other examples of resource conservation include: treated water reinjection, the reuse of treated soil onsite, and the beneficial use of sediments.

The use of "green" construction and project management products and materials such as eco-friendly concrete or the use of native plants for site restoration also advances the sustainability objectives of the project. It is important to understand that GSR implies minimizing the entire footprint of the remediation project, which includes the environmental impacts of products and materials associated with the project. For example, eco-friendly concrete generally refers to concrete that is produced with a certain percentage of fly-ash (a waste product from the coal-firing process). This type of "green" concrete takes a problematic substance out of the waste stream and reduces the cumulative amount of energy associated with the production of concrete. The use of native plants for site restoration helps to conserve water and eliminate the need for potentially harmful fertilizers and pesticides.

8.8 Improved Injection Methods for In Situ Remedies

It has been found that for in situ remediation technologies, a large component of the remedy footprint is related to the manufacturing of the material consumed during injection (e.g., oxidant, zero valent iron and biostimulants). In addition, the operation of drill rigs during the injection process also adds a significant contribution to the total footprint. Therefore, it is important to optimize the injection strategy to efficiently distribute the chemicals to where they need to be at the necessary concentration. This will result in less time in the field and less consumption of injected materials. It can also reduce/eliminate the need for additional mobilizations for reinjections. It is recommended that an evaluation be done prior to performing injections to ensure that an adequate CSM is available to allow the injection program to be optimized. In addition, pilot testing should be considered, particularly for medium to large sites. Direct-push technology (where appropriate) instead of rotary drill rigs can reduce drilling duration, avoid drilling fluids, and eliminate drill cuttings.

8.9 Procurement

Early integration of green objectives and criteria into contracts and administrative documents increases the likelihood that BMPs of green remediation will be used throughout a project life. Useful resources for identifying methods that can be used to integrate sustainability into bid documents can be found at EPA's Clu-in Web site (www.cluin.org). The following general approaches for integrating green specification into contracts were taken from the *Green Response and Remedial Action Contracting and Administrative Toolkit* [31].

- **Green Remediation:** To the extent practicable, the contractor shall evaluate and implement green remediation strategies and applications in the performance of the requirements of this work assignment to maximize sustainability, reduce energy and water usage, promote carbon neutrality, promote industrial materials reuse and recycling, and protect and preserve land resources.
- **Environmentally Preferable Practices:** The contractor shall, to the greatest extent practical, utilize environmentally preferable practices in their course of business. "Environmentally preferable" is defined as products or services that have a lesser or reduced effect on human health and the environment when compared with competing products or services that serve the same purpose. Consideration of environmentally preferable practices must be consistent with price, performance, availability, and safety conditions.

As part of contractor procurement, bid documents can also be developed to incorporate incentives for contractors to be sustainable. This can include monetary incentives for demonstrated footprint reduction and/or a requirement that the contract include a description of footprint reduction methods that can be evaluated as part of the selection criteria. This can be incorporated into performance-based contracts as well as fixed-price contracts. For cost plus fee and time and material type contracts, GSR requirements can be included in the scope of work. Contracts designed to require GSR elements within the scope of work should also include the use of tracking mechanisms for verification that targets have been met. SiteWise™ and GSR analysis reports can provide metrics supporting contract requirements and specific GSR deliverables. Selection criteria can also include past performance in sustainable business practices. An example of language regarding a request for quotation evaluation criterion for sustainable business practices is provided below.

EXAMPLE REQUESTS FOR QUOTATION LANGUAGE FOR SUSTAINABLE PRACTICES EVALUATION CRITERION

Example 1:

In furtherance of the Green Port Policy [the policy of the entity issuing the solicitation], consultants will be given the opportunity to demonstrate their firm's commitment to sustainable business practices. Sustainable business practices can include: resource conservation; environmentally-preferable purchasing; community outreach; recycling; hazardous waste reduction; fair recruitment, hiring, and benefit policies for employees; technology advancement and/or investment; and GHG reduction or compensation.

Demonstration of sustainable business practices can include submission of an annual report of sustainable practices or related policies, procedures, or implementation plan. Companies with documented goals and reported progress toward sustainable business practices will be given a higher score than those companies that have not documented goals and implementation progress. Electronic copies (PDF format on CD-ROM attached to statement of qualifications submittal) or Web site addresses (referenced in the statement of qualifications submittal) for this information are preferred.

Example 2:

The Contractor shall consider and implement green response/remediation strategies and applications to maximize sustainability, reduce energy and water usage, promote carbon neutrality, promote industrial materials reuse and recycling, and protect and preserve land resources, consistent with DoD's Policy on Consideration of Green and Sustainable Remediation Practices in the Defense ER Program. The contractor shall present green remediation options and approaches in its work plans, maintain records of "green-related" activities, and report this information to the Contracting Officer's Representative in its project status reports.

Sub-Factor I.4 Sustainable Practices

Offerors should demonstrate consideration of GSR practices in all aspects of the technical approach and project execution, and provide logic for acceptance or rejection of implementing such.

8.10 Project Management Considerations

Practices such as planning multiple tasks for singular events to reduce transportation of personnel and equipment, hosting virtual meetings to eliminate unnecessary travel, electronic submittals, employing telemetry if possible for reporting, and use of “greener” equipment are examples of effective project management approaches to GSR. These practices can have a positive impact on many of the GSR metrics, from reduced emissions due to less travel, to improved worker safety by eliminating unnecessary travel. All applicable health and safety requirements and use of proper personal protective equipment should also be enforced during remedial activities. A focus on sustainable and green approaches along with incentives for contractors to include green practices is helpful in reducing the footprint of remediation activities.

It is also important to keep in mind the social/community and local economic components of GSR. The social element of GSR can be addressed by perceiving the surrounding community as stakeholders, communicating openly and transparently, and inclusion in appropriate phases of planning. A GSR approach to clean up can have a stimulative effect on the local economy if local contractors and subcontractors are favored when possible.

9.0 CONCLUSIONS

The primary benefit of GSR is maximizing the overall net environmental benefit of a remedial action by minimizing the remedy footprint resulting from the remedial action activities. Implementing GSR can help to identify methods for using natural resources and energy efficiently, reducing negative impacts on the environment, minimizing or eliminating pollution at its source, and reducing waste to the greatest extent possible. GSR improves the remedial action by maximizing the overall environmental benefit while still meeting the existing requirements for site cleanup.

Implementation of GSR also helps to achieve goals set forth by EOs 13514 and 13423, which require a reduction in GHGs, energy consumption, and potable and industrial water use by federal agencies. Using GSR to identify methods to minimize the footprint of a remedial action supports the mission for effective site remediation in an environmentally, economically sound, and sustainable manner. GSR also supports the DoD's goal to decrease energy demand for existing and future remedial systems and consider other available options to minimize the environmental impact of the systems.

GSR considerations should be made at every phase of the remedial action. Agencies and stakeholders should be engaged early in the process to assist with reviewing GSR assessments and footprint reduction methods throughout the remedial action. The general approach to include GSR metrics during any remedial phase is to determine and prioritize metrics for the site, establish a methodology to quantify or characterize each metric, obtain consensus on metric weighing against each other and traditional criteria, identify footprint reduction methods, and prioritize, select, and document the footprint reduction methods implemented within the stipulated budget. This approach can easily be tailored for remedy selection, design, construction, operation, and long-term management.

During the remedy selection phase, selecting a relatively more sustainable option by conducting a baseline assessment of the footprint of the feasible remedial alternatives using SiteWise™ provides the greatest benefit to reduce the overall footprint of the NERP. After selecting a sustainable option, further footprint reduction technologies can be evaluated based on a sensitivity analysis. During RD, selecting a footprint reducing technology for the activities that contribute the most to the overall footprint of the remedial action leads to a more sustainable remedial alternative than initially selected. It is important that all aspects of footprint reduction technologies be evaluated. For example, the use of alternative fuels is site specific because the increased NO_x emissions may have a greater impact than the carbon emissions of that from conventional fuel.

Some footprint reduction technologies that are cost effective in the long term can be capital intensive requiring budget appropriation accordingly. A proper cost analysis and GSR sensitivity analysis should be performed to ensure that the most cost-effective GSR practices are implemented, considering the lifecycle of the project. Considering sustainability during development of exit strategies will also help to further reduce the overall remedy footprint. Tracking GSR metrics during RA-O and LTM is also important to verify the success of any footprint reduction technologies implemented.

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APPENDIX A

Paris Island Sustainable Remediation Case Study

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Parris Island Sustainable Remediation Case Study
NAVFAC ENGINEERING SERVICE CENTER

Facility: Site 45 Marine Corps Recruit Depot, Parris Island, SC

EFD: NAVFAC Engineering Service Center/NAVFAC Southeast

Site Description: Former dry cleaning facility with contamination in soil and groundwater caused by PCE release from an aboveground storage tank.

Technology or Method: Sustainability analysis using SiteWise^{TM} during remedy selection phase

Contaminant: PCE

Action Levels: Not Applicable

Legal Driver: CERCLA

Decision Document: Not Applicable

Project Summary

This case study presents the approach taken and results obtained from a sustainability analysis performed by Naval Facilities Engineering Command (NAVFAC) for Site 45, former Morale, Welfare and Recreation (MWR) dry cleaning facility at Marine Corps Recruit Depot (MCRD), Parris Island, South Carolina (now referred to as Parris Island). This analysis was performed as part of a feasibility study (FS) to allow the environmental footprint, in terms of specific sustainability metrics, to be considered during the remedy selection process. The results of the analysis can be used to implement green and sustainable remediation (GSR) practices, which require site cleanups to not only meet the traditional requirements of remediation (i.e., protection of human health and the environment and compliance with applicable or relevant and appropriate requirements [ARARs]), but also strive to minimize the environmental footprint of the remedy itself.

The Parris Island dry cleaning facility (Building 193) was located in the Main Post area of MCRD Parris Island. Environmental investigation at Parris Island began in 1994 when an aboveground storage tank overflowed while being filled with tetrachloroethene (PCE). In 2008, a draft FS was developed by TetraTech, which outlined the soil and groundwater remedial alternatives. The remedial alternatives evaluated within the FS are: no action, enhanced bioremediation, in situ chemical oxidation (ISCO), in situ chemical reduction (ISCR), electrical resistive heating (ERH) and excavation. A treatment train approach was used allowing multiple remedial technologies to be applied to one remedial alternative (Table 1). Shallow excavation to 4 ft was included in the treatment train with enhanced bioremediation, ISCO and ISCR. The excavation alternative involved a deep excavation to 20 ft. For the GSR analysis, the no action alternative assumed to have no or negligible environmental footprint and thus was not evaluated. This GSR analysis was performed by Battelle using SiteWise,^{TM} a tool developed jointly by Battelle, the U.S. Navy and U.S. Army Corps of Engineers (USACE).

Table 1. Remedial Alternatives Evaluated and the Technologies Included in Each Treatment Train

Remedial Alternatives	Bio-remediation	ISCO	ISCR (ZVI)	ERH	Shallow Excavation (4 ft)	Deep Excavation (20 ft)	MNA	Monitoring	LUCs
Enhanced Bio remediation	✓				✓		✓	✓	✓
ISCO		✓			✓		✓	✓	✓
ISCR			✓		✓		✓	✓	✓
ERH				✓				✓	✓
Excavation						✓	✓	✓	✓

Assessment Methodology

The SiteWise^{TM} GSR tool is an Excel-based tool comprised of spreadsheets used to conduct a baseline assessment of GSR metrics. The quantitative metrics calculated by the tool include: (1) greenhouse gases (GHGs) reported as carbon dioxide equivalents (CO_2e) and includes carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); (2) energy usage (expressed as BTU and MWH); (3) air emissions of criteria pollutants including oxides of nitrogen (NOx), sulfur oxides (SOx), and particulate matter (PM); and (4) accident risk (risk of injury and risk of fatality). For Parris Island, the remedies being evaluated would have similar impacts for many other metrics, such as ecological impacts, and thus these metrics were not included in the analysis. However, the amount of water and landfill space consumed and impacts to the community would vary depending on what remedy was selected so these metrics were included in the analysis; this was done outside of the SiteWise™ tool.

The environmental footprint of each remedial alternative is assessed by SiteWise™ to determine which potential remedies and which elements of the remedy have the greatest environmental footprint. This allows the Remedial Project Manager (RPM) to better focus on footprint reduction methods. The remediation industry has not yet developed standard methods of performing these assessments; however, information that can be used to perform an analysis is available from several recognizable sources. SiteWise™ uses footprint factors taken out of various government sources to determine the environmental footprint of each activity. These footprint factors are all referenced within the tool.

To estimate the environmental footprint for each remedial alternative, only the remedial activities that produce significant emissions were considered. These include the following:

- Well installation: manufacturing of well materials; transportation of personnel; transportation of equipment; operation of equipment onsite (e.g., drill rigs); and management of residual waste.

- System construction and operation: manufacturing of materials consumed (e.g., chemical oxidants, organic substrates, zero valent iron media, and carbon media, noting that in some cases surrogate materials are used where data could not be found for the actual material that would be consumed); transportation of personnel; transportation of equipment and waste; and operation of equipment onsite (e.g., excavation equipment, drill rigs, pumps for injection, and in situ air sparging/soil vapor extraction [IAS/SVE] equipment).

- Monitoring: transportation of personnel and equipment; operation of equipment onsite; and management of residual waste.

Results of Analyzing the Remedial Alternatives on GSR Metrics

A comparative analysis of the GSR evaluation for the Parris Island remedial alternatives is summarized in Figure 1. Among the five alternatives, enhanced bioremediation coupled with shallow excavation had the lowest environmental footprint overall. ERH on the other hand had the highest footprint. In general, the environmental footprint of the alternatives followed this order: enhanced bioremediation < ISCO < ISCR < excavation < ERH. Table 2 shows the quantitative environmental footprint metrics evaluated for each remedial alternative during the GSR review. Figure 2 is a graphical representation of the environmental footprint for the enhanced bioremediation alternative broken down by specific activities that make up the remedy. This figure allows project personnel to quickly see what elements of the remedy are causing the greatest environmental footprint. This type of figure was generated for each of the remedies evaluated. Table 3 is an overall summary and describes which metric has the greatest footprint for each alternative and also highlights which specific activities contribute to the footprint of the metric. The environmental footprint for each alternative is discussed below.

Table 2. Sustainability Metric Quantified for Each Alternative

Remedial Alternative	CO_2e Emissions	NOx Emissions	SOx Emissions	PM10 Emissions	Total Energy Usage	Electrical Energy Usage	Water Usage	Accident Risk	Accident Risk
	metric ton	metric ton	metric ton	metric ton	MMBTU	MWH	gallons	Fatality	Injury
Enhanced Bioremediation	117	4.80E-01	2.90E-02	1.40E-02	1.50E+03	1.30E-01	7.60E+03	1.10E-04	6.50E-02
ISCO	143	5.20E-01	4.70E-02	1.50E-02	2.50E+03	1.60E-01	1.10E+05	1.20E-04	7.10E-02
ISCR	205	5.10E-01	8.20E-02	1.30E-02	2.90E+03	1.60E-01	5.60E+04	1.00E-04	6.50E-02
ERH	4036	5.70E+00	2.10E+01	4.20E-03	6.60E+04	7.70E+03	3.90E+06	4.90E-04	7.10E-02
Excavation	526	2.20E+00	1.00E-01	5.60E-02	7.30E+03	1.70E+01	9.00E+03	7.80E-04	2.40E-01

***Enhanced Bioremediation* –** Enhanced bioremediation had the lowest footprint among all of the alternatives considered except for PM10 emissions and accident risk (Table 2). Activities with the greatest environmental footprint include: production of the biostimulant, personnel and equipment transportation, and equipment use during shallow excavation. Accident risk leading to fatality for this alternative was due mostly to personnel transportation during long-term groundwater monitoring. Accident risk leading to an injury was driven by both transportation and the heavy machinery use during the shallow excavation portion of this alternative (Table 3).

ISCO – The footprint from ISCO was also low, having only a slightly higher footprint than enhanced bioremediation except for PM10 and accident risk where the footprint was the third highest (Table 2). Production of the oxidant, personnel and equipment transportation, and equipment use during shallow excavation were the footprint drivers. Personnel travel was the most significant driver for accident risk that results in a fatality and transportation and equipment use during shallow excavation was the driver for accident risk leading to injury.

ISCR – The footprint from ISCR was slightly higher than the footprint from ISCO. For most metrics, including GHG and energy usage, the footprint driver was the production of zero valent iron (ZVI) and transportation and equipment use during shallow excavation. Personnel travel was the most significant driver for accident risk that results in a fatality and transportation and equipment use during shallow excavation was the driver for accident risk leading to injury.

ERH – This alternative had the highest environmental footprint, an order of magnitude higher than the other remedial alternatives. Energy usage is very high during ERH, leading to high emissions of GHGs. However, ERH had the lowest PM10 footprint and second highest accident risk. The accident risk leading to fatality and injury was due to the transportation activities undertaken to transport used granular activated carbon (GAC) for groundwater treatment and personnel for monitoring.

Excavation – Excavation produced the second highest emissions after ERH except for PM10 of which it had the highest emission (Table 2). For all metrics except water usage, the impact was primarily driven by the transportation and disposal activities due to excavation up to 20 feet below ground surface (bgs). The footprints for excavation are almost exclusively due to transportation of equipment and materials (Table 3). This is due to the large volume of soil that would be disposed of and transported to landfills (much of it to a hazardous waste landfill located 350 miles [assumed value] from the site) and the subsequent import of clean fill.

Additional Metrics Evaluated Outside the Tool

Water consumption, resource consumption and community impacts are three metrics not calculated by SiteWise™; however, during the Parris Island GSR review, these metrics were evaluated outside of the tool (water consumption has since been added to SiteWise™). The results of these three additional metrics for Parris Island are discussed below.

Water Consumption – ERH had the greatest potential for lost groundwater due to vaporization. High temperatures almost near the boiling point of water were applied to the subsurface, causing the groundwater to evaporate. If the vaporized groundwater was not condensed, treated and re-injected into the aquifer or otherwise beneficially used, then this would be considered a lost resource. Dewatering during excavation would also result in high volumes of lost groundwater unless treated and re-injected or beneficially used. Enhanced bioremediation, ISCO and ISCR had the lowest water loss compared to ERH and excavation.

Resource Consumption – The main resource consumed at Parris Island was landfill space. Excavation of contaminated soil led to the highest use of landfill space; therefore, the excavation alternative that excavated down to 20 ft had the highest footprint. On the other hand, ISCO, ISCR and ERH all had similar footprints in terms of landfill space, which was much less than the excavation alternative.

Community Impacts – Community impacts due to increased traffic volume associated with each remedial action were qualitatively evaluated. An increase in traffic and noise for the work undertaken in this alternative created a footprint on routine activities due to excavation of shallow and deep soil (Table 3). However, this footprint was similar for all of the groundwater remedial alternatives. Community impact due to full excavation of the site was large in comparison to all other remedial alternatives

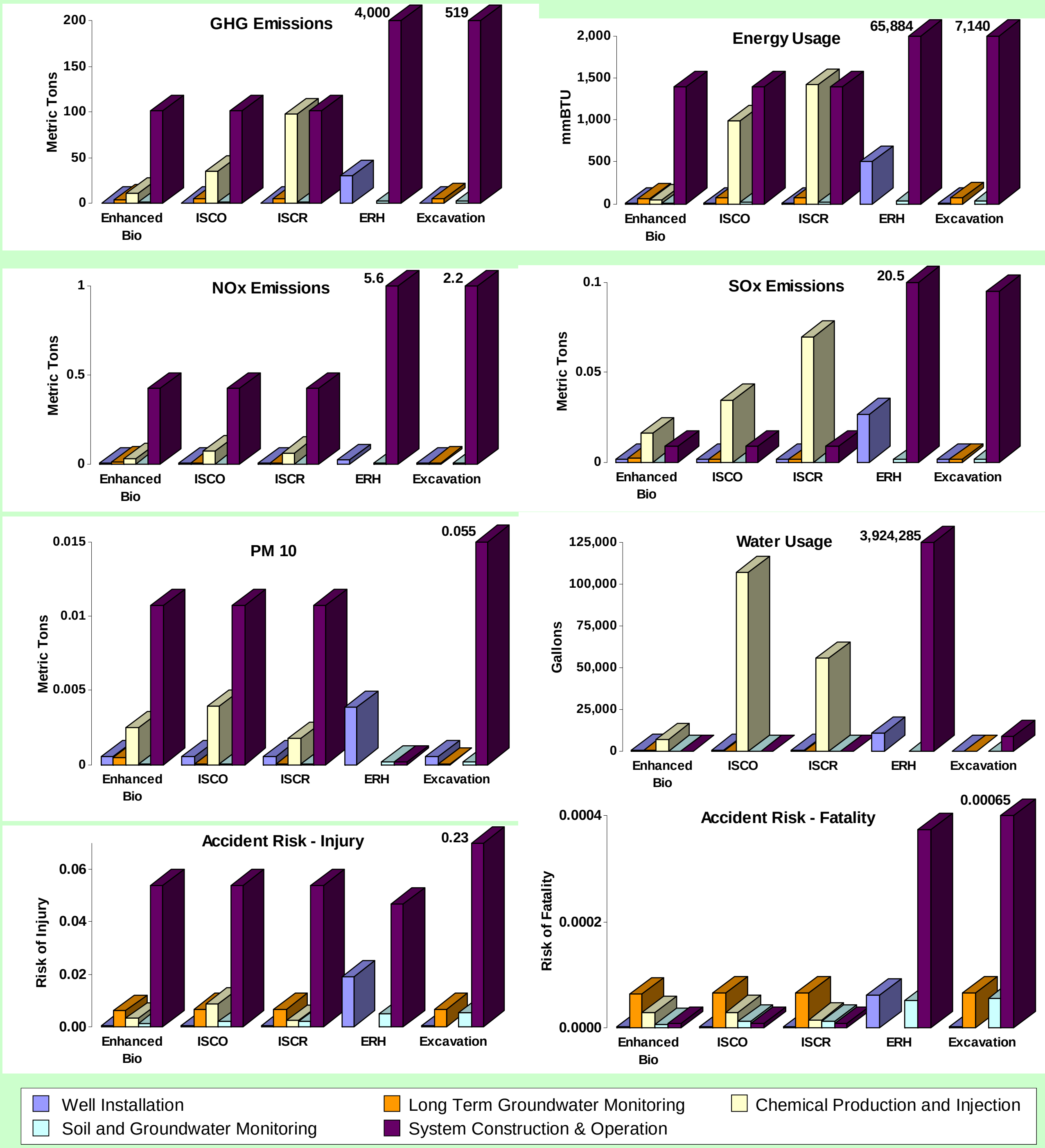

Figure 1. Comparative Analysis of GSR Metrics

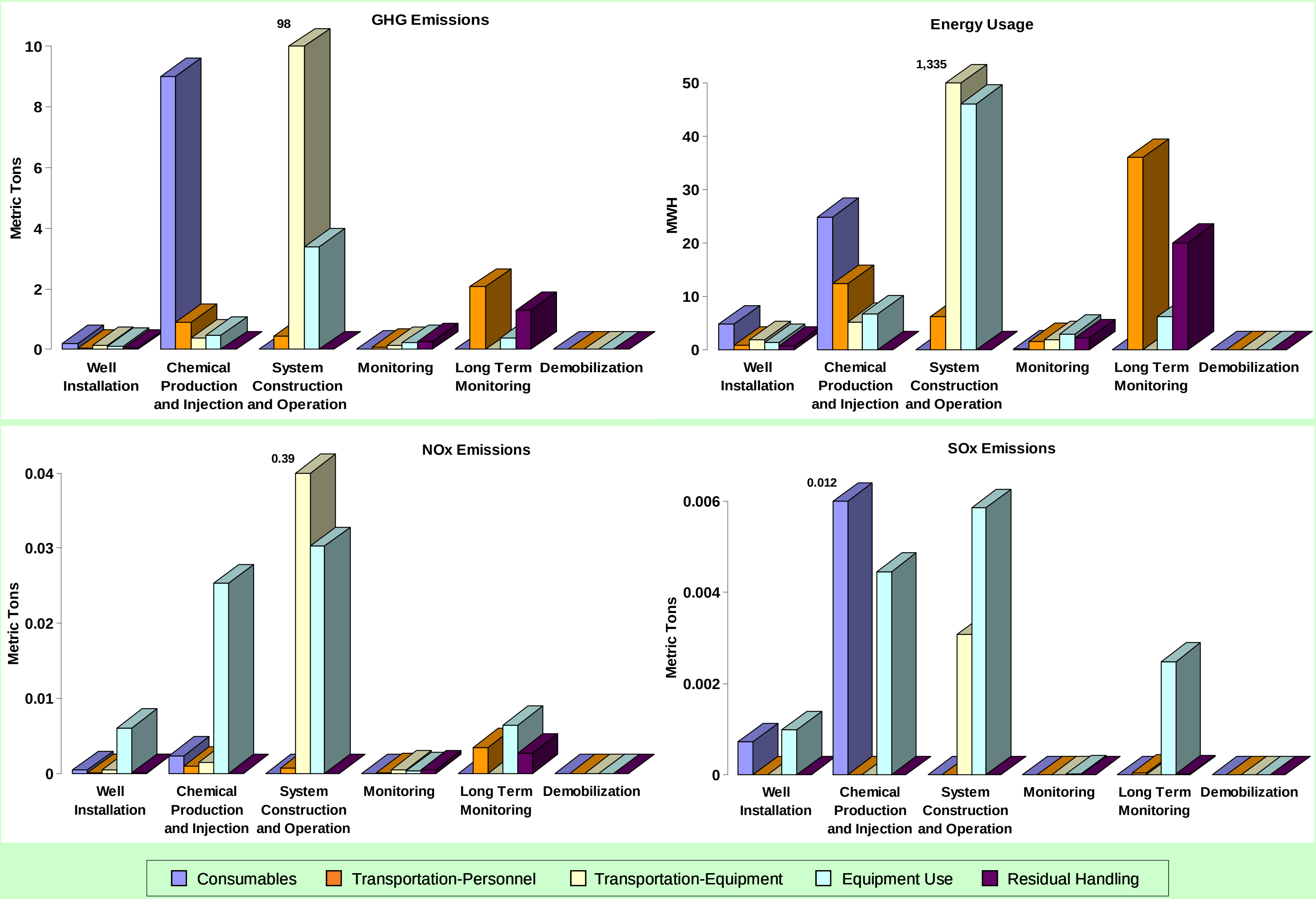

Figure 2. Breakdown of Sustainability Metric Footprint for Remedial Alternative Enhanced Bioremediation

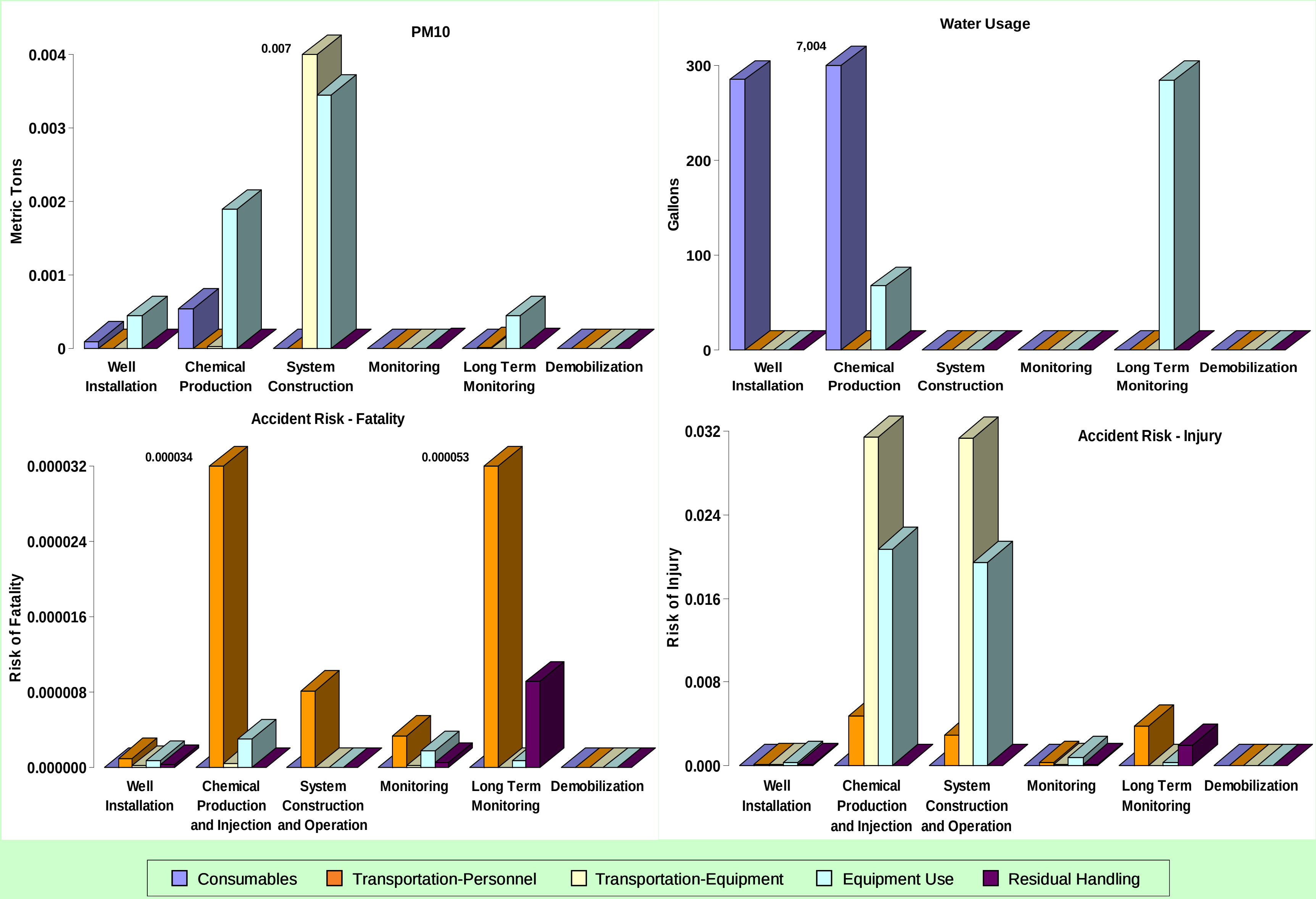

Figure 2. Breakdown of Sustainability Metric Footprint for Remedial Alternative Enhanced Bioremediation (Continued)

Table 3. Footprint Analysis Based on Sustainability Metrics

Alternative	Impact Assessment	GHG Emissions	Energy Usage	Air Emissions	Accident Risk	Community Impacts	Resources Lost	Water Usage
Enhanced Bioremediation	Relative Impact	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**
	Impact Drivers	Biostiumulant Production and transportation & equip during shallow GW excavation	Biostiumulant Production and transportation and equip during shallow GW excavation	Biostiumulant Production and transportation and equip during shallow GW excavation	Transportation related to long term groundwater monitoring and transportation and equip during shallow GW excavation	Disturbance due to increased traffic during shallow excavation	Landfill space for shallow excavation	Biostiumulant Production
ISCO	Relative Impact	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**
	Impact Drivers	Oxidant Prod,, transportation & equip during shallow GW excavation	Oxidant Prod., transportation & equip during shallow GW excavation	Oxidant Prod., transportation & equip during shallow GW excavation	Transportation & equip during shallow GW excavation	Disturbance due to increased traffic during shallow excavation	Landfill space for shallow excavation	Chemical Oxidant Production
ISCR	Relative Impact	**Low to Medium**	**Low to Medium**	**Low**	**Low**	**Medium**	**Low**	**Medium**
	Impact Drivers	ZVI production, transportation & equip during shallow GW excavation	ZVI Production, transportation & equip during shallow GW excavation	ZVI Production, transportation & equip during shallow GW excavation	Transportation & equip during shallow GW excavation	Disturbance due to increased traffic during shallow excavation	Landfill space for shallow excavation	ZVI Production
ERH	Relative Impact	**High**	**High**	**High**	**Medium**	**Low**	**Low**	**High**
	Impact Drivers	Electrical Usage	Electrical Usage	Electrical Usage	System Construction and Operation	Land Use Controls during the period of application	Lost groundwater	Electrical Production
Excavation	Relative Impact	**Medium**	**Low to Medium**	**Medium**	**High**	**High**	**High**	**Low**
	Impact Drivers	Transportation & Disposal	Transportation & Disposal	Transportation & Disposal	Excavation to 20 ft	Disturbance due to increased traffic	Landfill Space and lost groundwater	Production of PVC for wells and GAC for water treatment

Footprint Reduction Methods
Minimize the volume of soil that is excavated and shipped offsite, while still being protective of human health.
Investigate the possibility of rail shipments for soil disposal.
Use green fuels and/or after-treatment technologies to reduce emissions from excavation equipment, drill rigs and trucks. Examples of after-treatment technologies include: diesel oxidation catalyst (DOC), diesel particulate filter (DPF), selective catalytic reduction (SCR), and/or diesel multistage filter (DMFs).
Implement an idle control plan and other operating strategies to improve efficiency of site activities.
Additional characterization to minimize the area in which treatment is to be applied.
Additional design and perhaps pilot testing to optimize the manner in which injections are performed to reduce the mass of materials injected while still meeting treatment requirements.
Optimization of the monitoring plans to reduce trips to the site while still meeting the objectives of the program.

Benefits of Footprint Reduction Measures

The sustainability analysis provides a comparison of the environmental footprint for each remedy and also which specific activities contribute the most to the footprint for each remedy. This allows the RPM to consider GSR metrics during remedy selection and, if possible, choose the alternative with the lowest footprint out of those alternatives that meet cleanup goals in an acceptable timeframe. This would have a significant benefit in footprint reduction during remedial activities. Once the remedy is selected, the GSR analysis then indicates which specific elements of the remedy have the greatest footprint, allowing the project team to focus on footprint reduction methods for those elements that have the greatest footprint giving a greater benefit for the efforts.

Lessons Learned

This sustainability analysis of the remedial alternatives selected for cleanup of Site 45, Parris Island, South Carolina provided information about the activities in each remedial alternative that contribute most to their environmental footprint. In general, the more aggressive and energy intensive technologies and activities have the greatest footprint. For example, ERH, which requires high electrical consumption, not only uses a large amount of energy but leads to high emissions of GHGs and criteria pollutants. Transportation of personnel and equipment also contributes significantly to emissions of GHGs and criteria pollutants, although not as high as energy intensive technologies, and also has the greatest risk of accidental fatalities. In general, the greatest risk of accidental injury tends to be from operation of large equipment, such as drill rigs. Remedies involving chemical injection into the sub-surface, such as ISCR, ISCO and enhanced bioremediation, tend to have a lower overall environmental footprint than the more aggressive remedies but even for these remedies, the footprint can be significant, most of which is due to production of the material injected into the subsurface for remediation and transportation of personnel and equipment.

The results of the sustainability analysis demonstrated that an understanding of what causes the greatest environmental footprint is critical in determining the best methods of footprint reduction, by both selecting remedies with a lower footprint and implementing footprint reduction methods on those specific activities that are causing the greatest footprint.

APPENDIX B

Former Naval Air Station Alameda, Operable Unit 2C, Green and Sustainable Remediation Case Study

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Naval Air Station Alameda, Operable Unit 2C
Green and Sustainable Remediation Case Study
NAVFAC ENGINEERING SERVICE CENTER

Facility:	Site OU-2C Former Naval Air Station Alameda
EFD:	BRAC PMO West
Site Description:	53-acre site covered mostly by a large building formerly used as a base of operations for naval surface craft
Technology or Method:	Sustainability Analysis using SiteWise™ during remedy selection phase
Contaminant:	Heavy metals, volatile organic compounds (VOCs), and a radioactive contaminant (radium-226)
Action Levels:	Not Applicable
Legal Driver:	CERCLA
Decision Document:	Not Applicable

Project Summary

The green and sustainable remediation (GSR) analysis summarized in this case study was conducted for Operable Unit (OU)-2C (hereafter referred to as the site) at the former Naval Air Station (NAS) Alameda in Alameda, California (hereafter referred to as Alameda Point). This analysis was performed as part of a feasibility study (FS) to allow sustainability metrics to be considered during the remedy selection process. The goal of the analysis was to provide information regarding the environmental footprint of the alternatives. The results of the analysis can be used to implement GSR practices, requiring site cleanups to not only meet the traditional requirements of remediation (i.e., protection of human health and the environment and compliance with applicable or relevant and appropriate requirements [ARARs]), but also strive to minimize the environmental footprint of the remedy itself. This case study presents the approach taken and results of a sustainability analysis performed by Battelle for Base Realignment and Closure (BRAC) Program Management Office (PMO) West for Site OU-2C at Alameda Point.

OU-2C (Figure 1), a 53 acre parcel of land, is located on the eastern side of San Francisco Bay. It has been used as a base of operations for naval surface craft from before 1940 until its closure in 1993. Contaminants of concern (COCs) at the site include heavy metals, volatile organic compounds (VOCs), and a radioactive contaminant (radium-226). Site investigation determined that the soil, shallow first water bearing zone groundwater (referred to here as shallow groundwater), and deep first and second water bearing zones groundwater (referred to here as deep groundwater) were contaminated with VOCs. Several remedial alternatives were investigated in the FS to meet the remedial action objectives (RAOs) of protecting future receptors, preventing exposure to radionuclides and providing source control.

Remedial alternatives were proposed for the soil, shallow groundwater and the deep groundwater matrices. The soil remedial alternatives included in the GSR analysis were excavation and engineered cap (Eng Cap), excavation only, and excavation and soil vapor extraction (SVE). The remedial alternatives considered for the shallow groundwater were in situ chemical oxidation (ISCO), in situ chemical reduction (ISCR) and in situ air sparging (IAS)/SVE (Table 1). Each alternative also included a component of enhanced bioremediation; electrical resistive heating (ERH) was evaluated separately as an optional technology that could be added to each groundwater treatment train. For this case study the GSR analysis for the shallow groundwater alternatives will be discussed in more detail than those for the deep groundwater and soil, but a similar analysis was also performed for those media.

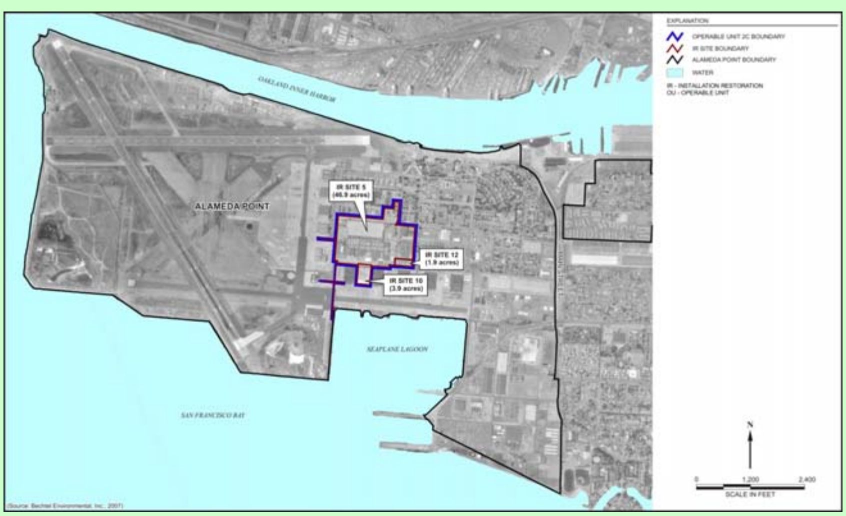

Figure 1. Alameda Site Map

Table .1 Remedial Alternatives Evaluated and the Technologies Included in Each Treatment Train

Soil Treatment Train							
Remedial Alternatives	**Excavation**	**Eng Cap**	**SVE**	**Off-Site Disposal**	**ICs**	**LTM**	
Excavation and Eng Cap	✓	✓		✓	✓	✓	
Excavation	✓			✓	✓	✓	
Excavation /SVE	✓		✓	✓	✓	✓	
Shallow Groundwater Treatment Train							
Remedial Alternatives	**ISCO**	**ISCR**	**IAS/ SVE**	**Enhanced Bio**	**ICs**	**LTM**	**ERH**
ISCO	✓			✓	✓	✓	Optional
ISCR		✓		✓	✓	✓	Optional
IAS/SVE			✓	✓	✓	✓	Optional
Deep Groundwater Treatment Train							
Remedial Alternatives	**ISCO**	**ISCR**	**ERH**	**ICs**		**LTM**	
ISCO	✓			✓		✓	
ISCR		✓		✓		✓	
ERH			✓			✓	

Assessment Methodology

The SiteWise™ GSR tool is an Excel based tool comprised of spreadsheets used to conduct a baseline assessment of GSR metrics. The quantitative metrics calculated by the tool include: 1) greenhouse gases (GHGs) reported as carbon dioxide equivalents (CO_2e) and includes carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); 2) energy usage (expressed as BTU and MWH); 3) air emissions of criteria pollutants including oxides of nitrogen (NOx), sulfur oxides (SOx), and particulate matter (PM); and 4) accident risk (risk of injury and risk of fatality). For Alameda, the remedies being evaluated would have similar impacts for many other metrics, such as ecological impacts; thus, these metrics were not included in the analysis. The amount of landfill space consumed would vary depending on what remedy was selected, so landfill space was included in the analysis of the soil alternatives. However, this was done outside of the SiteWise™ tool.

The environmental footprint of each remedial alternative is assessed by SiteWise™ to determine which potential remedies and which elements of the remedy have the greatest environmental footprint. This allows the Remedial Project Manager (RPM) to better focus on footprint reduction methods. The remediation industry has not yet developed standard methods of performing these assessments; however, information that can be used to perform an analysis is available from several recognizable sources. SiteWise™ uses footprint factors taken out of various government sources to determine the environmental footprint of each activity. These footprint factors are all referenced within the tool.

To estimate the environmental footprint for each remedial alternative, only the remedial activities that produce significant emissions were considered. These include the following:

- Well installation: manufacturing of well materials; transportation of personnel; transportation of equipment; operation of equipment onsite (e.g., drill rigs); and management of residual waste.

- System construction and operation: manufacturing of materials consumed (e.g., chemical oxidants, organic substrates, zero valent iron (ZVI) media, and carbon media, noting that in some cases surrogate materials are used where data could not be found for the actual material that would be consumed); transportation of personnel; transportation of equipment and waste; and operation of equipment onsite (e.g., excavation equipment, drill rigs, pumps for injection, and IAS-SVE equipment).

- Monitoring: transportation of personnel and equipment; operation of equipment onsite; and management of residual waste.

Results of Sustainability Analysis

A comparative analysis of the results of the GSR analysis for the soil, shallow and deep groundwater remedial alternatives was conducted. When compared to the shallow and deep groundwater alternatives, the soil alternatives had the highest environmental footprint overall. The shallow and deep groundwater alternatives had similar environmental footprints. Table 2 shows the quantitative metrics evaluated for each remedial alternative for the soil, shallow and deep ground water. The environmental footprint for the remedial alternatives for soil, shallow and deep groundwater is discussed below. Figure 2 depicts a comparison of the environmental footprint for the shallow groundwater alternatives and Figure 3 shows a breakdown of the specific activities that contributed to the footprint for the ISCO remedial alternative. As part of the GSR, analysis figures similar to Figure 2 were developed for deep groundwater and soil, and figures similar to Figure 3 were developed for each remedial alternative.

Table 2. Sustainability Metric Quantified for each ALTERNATIVE

Remedial Alternative	CO_2 Emissions metric ton	NOx Emissions metric ton	SOx Emissions metric ton	PM10 Emissions metric ton	Energy Usage MWH	Accident Risk Fatality	Accident Risk Injury
Soil Alternatives							
Excavation and Eng Cap	2.94E+02	1.19E+00	1.13E-02	2.17E-01	1.18E+03	2.26E-04	5.30E-02
Excavation	1.70E+03	6.85E+00	5.52E-02	1.25E+00	6.82E+03	1.15E-03	2.59E-01
Excavation /SVE	1.43E+03	5.65E+00	5.58E-02	1.03E+00	5.70E+03	9.46E-04	2.08E-01
Shallow Ground Water Alternatives							
ISCO	1.20E+02	5.10E-01	2.10E-01	8.40E-02	2.50E+02	1.40E-04	2.40E-02
ISCR	2.80E+02	8.80E-01	4.80E-01	1.90E-01	4.70E+02	1.40E-04	2.40E-02
IAS/SVE	1.40E+02	1.70E-01	5.80E-02	2.00E-02	3.70E+02	1.20E-04	1.20E-02
ERH	**3.00E+02**	**1.50E-01**	**5.20E-02**	**1.40E-03**	**6.00E+02**	**8.30E-04**	**6.30E-06**
Deep Ground Water Alternatives							
ISCO	3.34E+01	1.51E-01	4.41E-02	1.72E-02	1.04E+02	4.29E-05	8.44E-03
ISCR	1.72E+02	4.06E-01	2.74E-01	1.05E-01	3.00E+02	3.96E-05	6.40E-03
ERH	7.2E+02	4.2E-01	9.6E-02	6.1E-03	1.8E+03	2.5E-05	5.6E-03

Soil Alternatives – Excavation combined with an engineered cap appeared to have the lowest environmental footprint of the three soil alternatives evaluated. Excavation alone had the highest environmental footprint but was only slightly higher than the excavation combined with SVE option. The footprint associated with excavation was mainly due to system construction and operation, specifically transportation of equipment and materials. The activity contributing most to the environmental footprint of excavation was the large volume of soil that would be disposed of and transported to landfills (much of it to a hazardous waste landfill located 200 miles from the site) and the subsequent import of clean fill. Excavation alone required more than 10 times the amount of soil to be excavated than excavation combined with engineering cap. Landfill space, a resource that is consumed from remediation activities, was also evaluated outside of the tool. The excavation only alternative used the highest amount of landfill space due to the contaminated soil excavated from the site and disposed of in a landfill.

Shallow Groundwater Alternatives **–** For the metrics considered, the implementation of ISCR resulted in the greatest environmental footprint for the shallow groundwater alternatives, except for accident risk where ISCR had the second highest footprint. IAS/SVE on the other had had the lowest air emissions footprint and only a slightly smaller energy usage footprint than ISCR. The high environmental footprint of ISCR was caused mainly by the volume of the reductant consumed during ISCR due to the high environmental footprint of manufacturing the reductant. The environmental footprint of ISCO originated in the volume of the oxidant used mainly due to the environmental footprint of manufacturing the oxidant (Figure 4). For IAS/SVE the environmental footprint is mainly due to the electricity used to run pumps to force air through the soil and water. The risk of an accident causing a fatality was similar for all three alternatives because the risk was driven by transportation of personnel during the remediation activities. Similar numbers of trips are required for monitoring and transporting material for the three alternatives.

ERH was evaluated as a stand-alone alternative to investigate the additional environmental footprint that would be caused by the activities associated with shallow groundwater remediation by ERH. The environmental footprint for ERH was greater than that of ISCR, ISCO and IAS/SVE for GHG and energy usage. This high footprint resulting from energy usage is a result of intensive use of electricity when implementing ERH. GHG emissions were mainly driven by equipment usage during

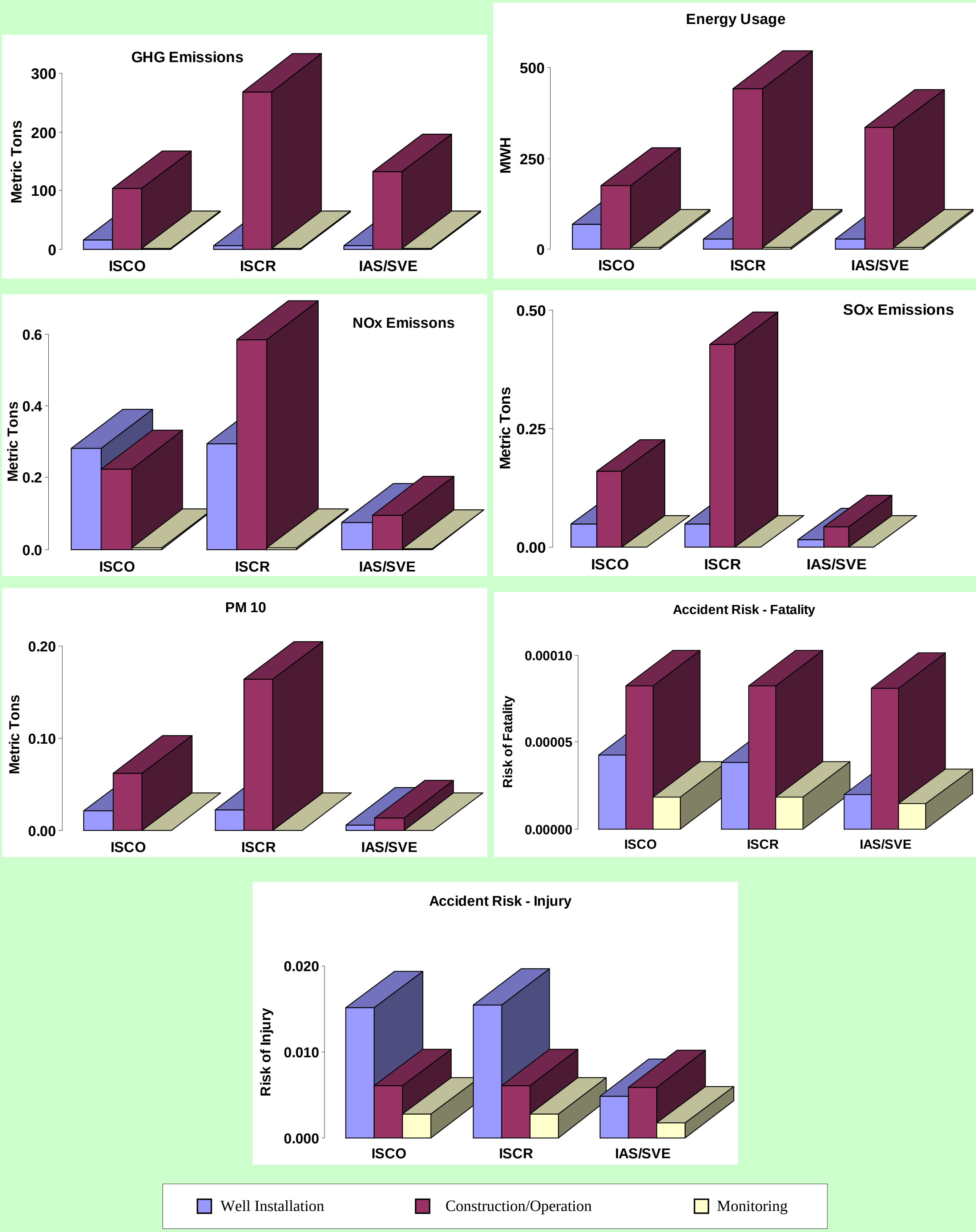

Figure 2. Comparative Analysis of the Shallow Groundwater Remedial Alternatives

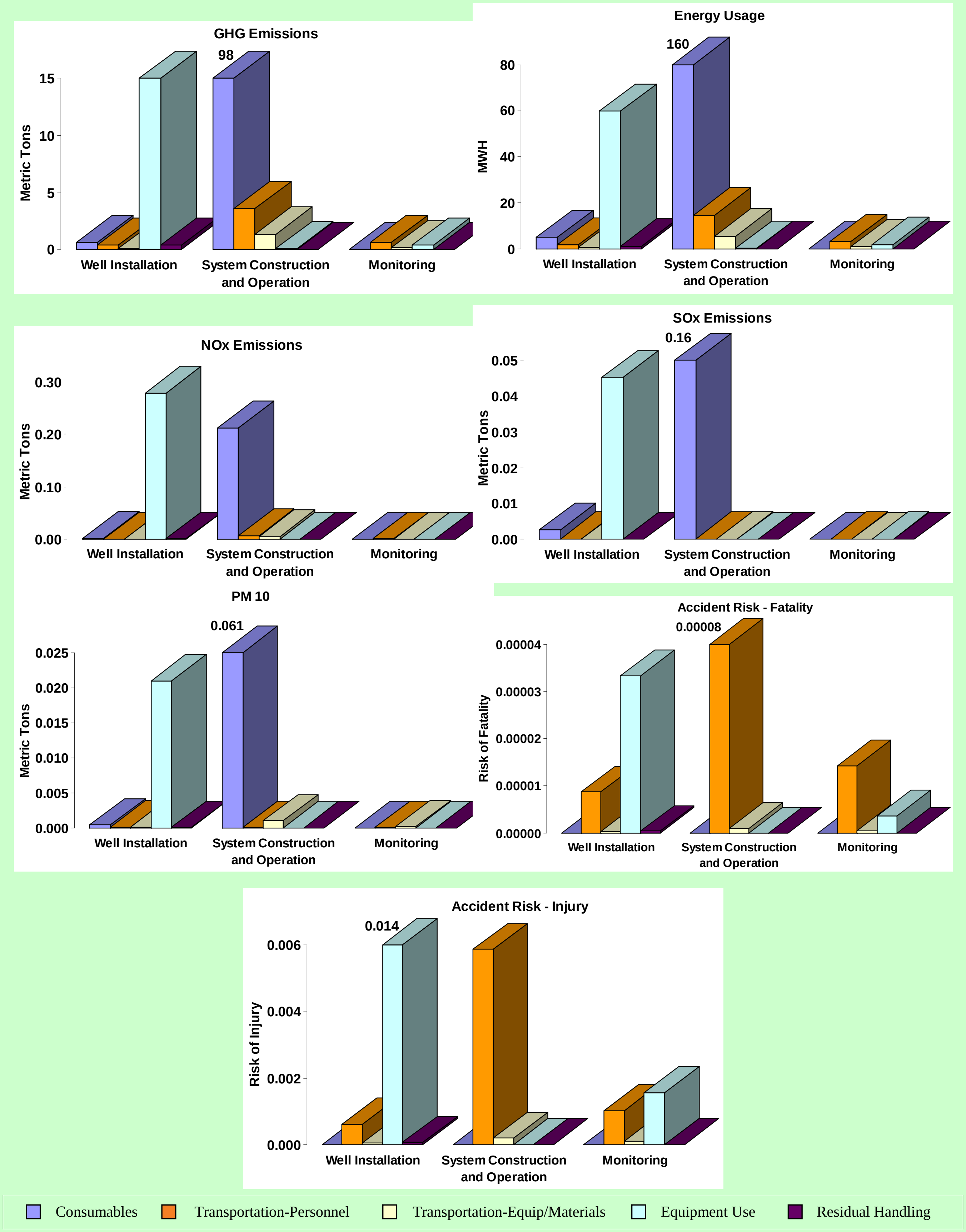

Figure 3. Breakdown of Sustainability Metric Footprint for Shallow Groundwater Alternative ISCO

Table 3. Footprint Analysis Based on Sustainability Metrics

Soil					
Alternative	**Sustainability Metric**	**GHG Emissions**	**Energy Usage**	**Air Emissions**	**Collateral Risk**
Excavation & Engineered Cap	Relative Impact	Low	Low	Low	Low
	Impact Drivers	Transportation of Equipment	Transportation of Equipment	Transportation of Equipment	Transportation of Equipment
Excavation Only	Relative Impact	High	High	High	High
	Impact Drivers	Transportation of Equipment	Transportation of Equipment	Transportation of Equipment	Transportation of Equipment
Excavation and SVE	Relative Impact	Medium	Medium	Medium	Medium
	Impact Drivers	Transportation of Equipment	Transportation of Equipment	Transportation of Equipment	Transportation of Equipment
Shallow Groundwater					
Alternative	**Sustainability Metric**	**GHG Emissions**	**Energy Usage**	**Air Emissions**	**Collateral Risk**
ISCO	Relative Impact	Low	Low	Medium	High
	Impact Drivers	Consumption of oxidant and biostimulant	Consumption of oxidant and biostimulant	Consumption of oxidant and biostimulant, and well installation	Personnel Travel
ISCR	Relative Impact	High	High	High	High
	Impact Drivers	Consumption of ZVI Media	Consumption of ZVI Media	Consumption of ZVI Media	Personnel Travel
IAS/SVE	Relative Impact	Medium	Medium	Low	Low
	Impact Drivers	Operation of SVE Equipment	Operation of SVE Equipment	Operation of SVE Equipment and consumption of biostimulant and GAC	Personnel Travel
Deep Groundwater					
Alternative	**Sustainability Metric**	**GHG Emissions**	**Energy Usage**	**Air Emissions**	**Collateral Risk**
ISCO	Relative Impact	Low	Low	Low	High
	Impact Drivers	Consumption of oxidant and operation of drilling equipment	Consumption of oxidant and operation of drilling equipment	Consumption of oxidant and operation of drilling equipment	Operation of drilling equipment
ISCR	Relative Impact	Medium	Medium	High	Medium
	Impact Drivers	Consumption of ZVI Media	Consumption of ZVI Media	Operation of drilling equipment	Personnel Travel
ERH	Relative Impact	High	High	Medium	Low
	Impact Drivers	Operation of ERH	Operation of ERH	Operation of ERH	Personnel Travel

system construction and operations. Adding ERH to any of the shallow groundwater remedial alternatives would greatly increase the environmental footprint. It was later learned that Alameda Power, the supplier of electricity for the site, has a greater percentage of power from renewable sources than the regional average used in the analysis. An adjustment will be made in the future to account for this, but it is still expected that ERH will have a high footprint for energy and GHG emissions.

Deep Groundwater Alternatives – Overall, the ISCO alternative for remediating the deep groundwater had the lowest environmental footprint. GHG, air emissions and energy usage were much lower than the ISCR and ERH alternatives. ISCR had the highest air emissions, greater than ISCO and ERH combined. However, ERH had the highest GHG and energy footprint. Accident risk resulting in fatality or injury was similar for all three alternatives. The GHG and energy footprint of ERH was mainly due to implementation of the technology which is energy intensive. For ISCR the footprint was mainly due to the amount of material injected during remediation. The footprint originates in the manufacture of the material. ISCO also involves injection of material into the subsurface but a greater footprint is produced from manufacture of a reductant like ZVI than from an oxidant.

Benefits of Footprint Reduction Measures

The sustainability analysis provides a comparison of the environmental footprint for each remedy and also which specific activities contribute the most to the footprint for each remedy. This allows the RPM to consider GSR metrics during remedy selection and choose the alternative with the lowest footprint (if possible). This would have a significant benefit in footprint reduction during remedial activities. Once the remedy is selected, the GSR analysis then indicates which specific elements of the remedy have the greatest footprint, allowing the project team to focus on footprint reduction methods and providing a greater benefit for the efforts. For the Alameda analysis, the suggested footprint reduction methods for consideration and their benefits are listed below.

Footprint Reduction Methods
Soil
Implement emission control measures for drilling equipment, such as greener fuels, after-treatment technologies and idle control.
Select high or premium efficiency motors for the equipment used.
Use variable frequency drives for the equipment used.
Apply pulsing for IAS system.
Ensure proper conditioning of air into the granular activated carbon (GAC) units to optimize adsorption efficiency of the GAC.
Develop performance objectives and an exit strategy to ensure that the system or components of the system (including individual wells) are taken off-line at the appropriate time.
Shallow and Deep Ground Water
Minimize the volume of soil that is excavated and shipped offsite, while still being protective of human health.
Investigate the possibility of rail shipments for soil disposal.
Use after-treatment technologies such as: diesel oxidation catalyst (DOC), diesel particulate filter (DPF), selective catalytic reduction (SCR), and/or diesel multistage filter (DMFs) for excavation equipment and trucks for emission reduction.
Implement an idle control plan and other operating strategies to improve efficiency of site activities.
Conduct additional characterization to minimize the area in which treatment is to be applied.
Conduct additional design and perhaps pilot testing to optimize the manner in which injections are performed to reduce the mass of materials injected while still meeting treatment requirements.
Implement emission control measures for drilling equipment, such as greener fuels, after treatment technologies and idle control.
Optimize the monitoring plans to reduce trips to the site while still meeting the objectives of the program.

Lessons Learned

This sustainability analysis of the remedial alternatives selected for cleanup of Site OU-2C, Alameda, California provides information about the activities in each remedial alternative that contribute most to their environmental footprint. For the soil alternatives, excavation contributed a high environmental footprint due to transport of soil to a landfill and trucking in clean fill to the site. For the shallow groundwater alternatives, the highest footprint originated from technologies where materials were injected into the subsurface; this was due to the footprint from manufacture of chemicals like ZVI and oxidants. On the other hand, ERH (the more aggressive and energy intensive technology) had the greatest footprint, but this will need to be revisited considering the emission factors provided by the local power supply company. Transportation of personnel and equipment also contributed to emissions of GHGs and criteria pollutants, although not as high as energy intensive technologies. These technologies have the greatest risk of accidental fatalities. The results of the sustainability analysis demonstrate that an understanding of what causes the greatest environmental footprint is critical in determining the best methods of reducing the footprint, by both selecting remedies with a lower footprint and implementing footprint reduction methods on those specific activities causing the greatest footprint.

APPENDIX C

PRIORITIZATION ANALYSIS

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Prioritization Analysis for Remedy Footprint Reduction

A remedy footprint reduction prioritization analysis starts with two primary considerations:

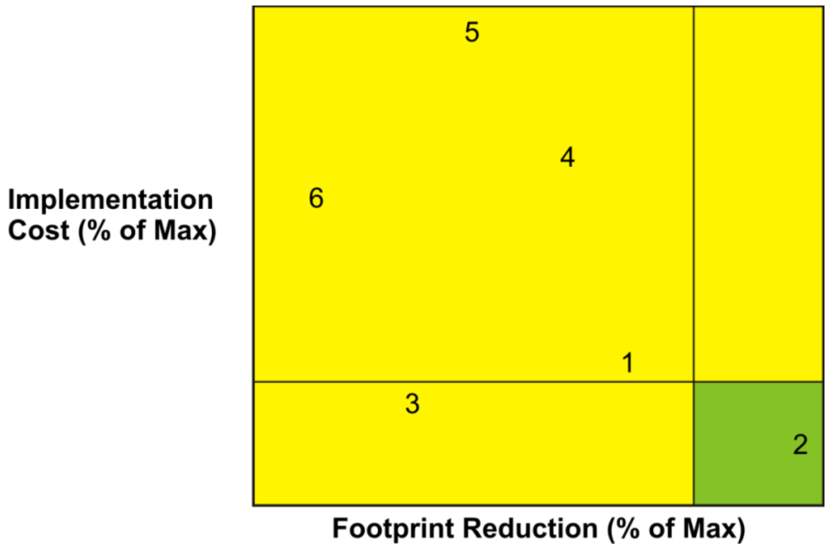
- Implementation Cost
- Footprint Reduction

The prioritization analysis graphs shown below provide a visual representation of how to compare different footprint reduction methods based on implementation cost and footprint reduction. For many smaller projects with less opportunity for remedy footprint reduction, the detailed prioritization analysis for remedy footprint reduction may not be necessary. However, if several footprint reduction options are identified, a prioritization analysis, such as that described below, may be advantageous to select those methods which will have the greatest impact and be most cost-effective.

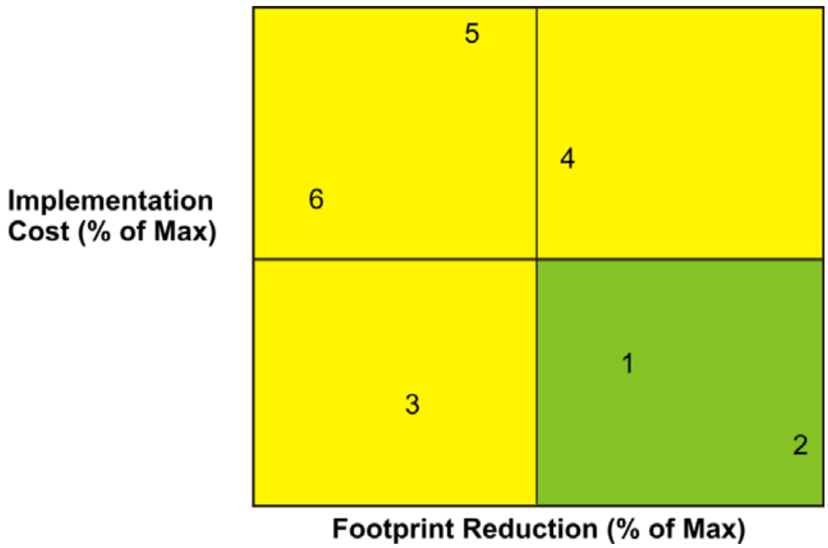
The relative implementation cost of each method is plotted along the vertical axis and the relative footprint reduction is plotted along the horizontal axis. The units could be either in dollars and metrics or in percent of the maximum alternative. Thus the most costly method would be placed along the top of the plot and the method with the greatest footprint reduction would be placed along the right side. The optimum method ideally would be in the lower right quadrant of the box as it would have low cost and high benefit.

Once the footprint reduction methods have been plotted, the next step is to determine the level of selectivity. Figure B-1 represents a project with relatively high selectivity. A project that has a high level of selectivity may be one in which there are severe budgetary constraints. In Figure B-1, the constraints allow the application of a single footprint reduction method. The green shaded area indicates that footprint reduction method "2," offers the highest possible footprint reduction, at the lowest possible implementation cost. The yellow shaded area represents the footprint reduction methods that are too costly, or do not offer enough return on investment given the high degree of project constraint.

Figure B-2 shows a project with greater flexibility. Footprint reduction methods with a slightly higher cost can be considered, while the footprint reduction success can be moderate, yet still acceptable. Given this level of screening, the acceptable range (green) is expanded, and now includes two footprint reduction methods. The yellow shaded area still contains four footprint reduction methods that do not offer enough value, given their cost to benefit ratio.

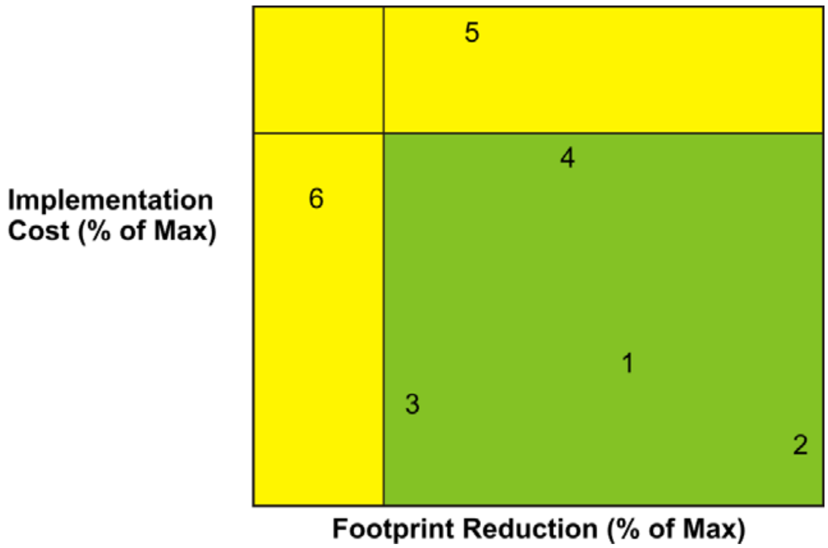


Result: Footprint Reduction Method Selected = Method 2 only
Figure B-1. Most Selective Screening of Footprint Reduction Methods



Result: Footprint Reduction Method Selected = Methods 1 and 2
Figure B-2. Moderately Selective Screening of Footprint Reduction Methods

Figure B-3 indicates the least selective screening process, and results in the greatest number of footprint reduction methods fit to be incorporated into the project. Only the extreme cost of footprint reduction method 5 and the minimal footprint reduction percentage of Method 6 prevent their inclusion into the project.



Result: Footprint Reduction Method Selected = Methods 1, 2, 3, 4
Figure B-3. Less Selective Screening of Footprint Reduction Methods

Figure B-4 depicts different prioritization zones. Each zone represents a different level of selectivity. It is easy to see the order in which each footprint reduction method should be implemented based on the implementation cost and footprint reduction.

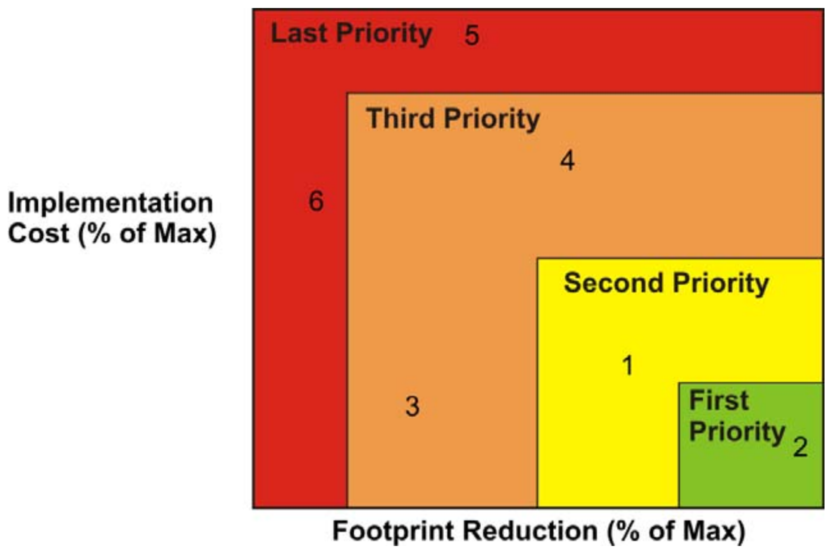


Figure B-4. Prioritization Zones

Figure B-5 represents a prioritization analysis that narrows the footprint reduction goal. *Footprint Reduction* along the X axis has been replaced with the specific sustainability goal of "*Energy Load Reduction*." The analysis now focuses on the relationship between implementation cost versus the energy load reduction success of the given footprint reduction methods. A different sustainability goal is likely to change the prioritization order of the footprint reduction methods. Notice that the footprint prioritization methods in Figure B-5 have ended up in different prioritization zones because they result in different degrees of success, given the purpose of accomplishing the specific sustainability goal of reducing the energy load of the remediation project.

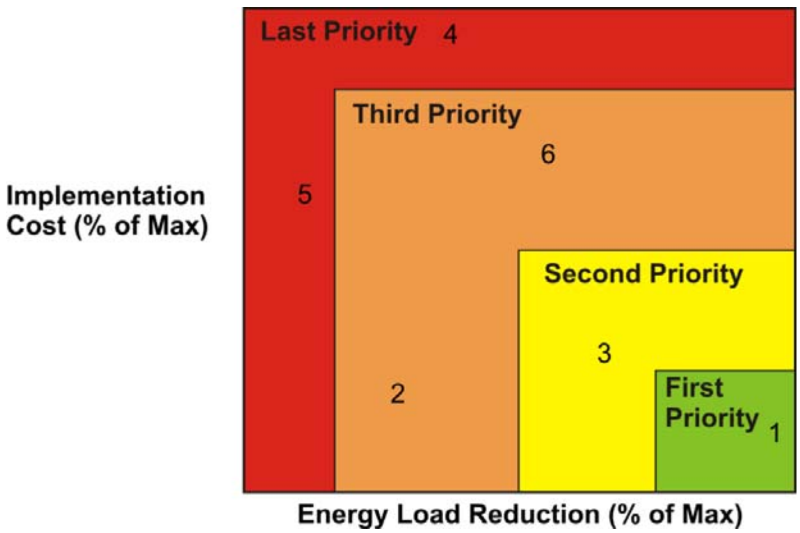


Figure B-5. Narrowing the Footprint Reduction Goal