5-2016

Evaluating Sustainable Aspects of Hazardous Waste Remediation

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EVALUATING SUSTAINABLE ASPECTS OF HAZARDOUS WASTE REMEDIATION

A DISSERTATION

Submitted by the Faculty of

Montclair State University in partial fulfillment

of the requirements

for the degree of Doctor of Philosophy

by

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2016

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MONTCLAIR STATE UNIVERSITY

THE GRADUATE SCHOOL

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ABSTRACT

EVALUATING SUSTAINABLE ASPECTS OF HAZARDOUS WASTE REMEDIATION

by Melissa A. Koberle-Harclerode

The main objective of the research presented herein is to be a major contributor to the current international initiative to advance sustainability assessments for remediation projects by integrating methodologies from the environmental economics and social science disciplines. More specifically, the study aims to address some of the knowledge gaps related to conducting a comprehensive sustainability assessment for a remediation project. These knowledge gaps include: (1) there are few studies that include sustainability assessments of the variety of techniques and technologies implemented during site characterization; (2) the majority of sustainable remediation publications and assessment tools focus on evaluating the environmental impact of a contaminated site's life cycle and minimally, if at all, on related socio-economic impacts; and (3) the role of risk perception in stakeholder engagement has not been explored in existing sustainable remediation frameworks. Chapters 2 through 4 presents a societal cost analysis methodology to quantify global socio-economic impacts arising from cleanup activity by monetizing the emissions and energy consumption through the integration of the social cost of environmental metrics. The results of environmental footprint and life cycle assessment evaluations conducted at various stages throughout the project life cycle were used as the basis for the societal cost analysis. Chapter 5 presents a survey developed and implemented to identify risk perception factors that influenced residents' level of

participation in risk management activities conducted by the local health department. Based on the case study evaluations presented herein, it can be concluded that the integration of methodologies from the environmental economics and social science disciplines into existing sustainable remediation frameworks results in a more comprehensive evaluation of triple bottom line impacts, a reduction in emissions and resources consumed during site activities, efficient use of financial resources, and a maximization of benefits to stakeholders, in particular the community.

ACKNOWLEGEMENTS

This research was made possible by the financial and facility support from Montclair State University, CDM Smith, and the Sustainable Remediation Forum (SURF). Thanks go to Bernabase Wolde and Prahlad Burli (Montclair State University) for their help in data analysis and review; Jason Darley (Montclair State University) for his assistance developing figures; Laura Leon and Katherine Chuya (Union City High School interns), and Thomas Wright and Rutvij Antala (New Jersey City University) for their assistance in conducting the surveys; Michaela Bogosh (CDM Smith) for LCA support; Joanna Samson (CDM Smith) for editorial review; and to Anna Adams (CDM Smith) for assistance with developing figures.

A wholehearted thank you to the co-authors of the publications presented herein and my advisement committee for pushing me out of my comfort zone and enabled me to become the scientist I am today. More specifically, gratitude to Dr. Pankaj Lal (Montclair State University advisement chair), Dr. Michael E. Miller (CDM Smith), Dr. Neeraj Vedwan (Montclair State University), and Dr. Yang Deng (Montclair State University).

Special thank you to my international colleagues who participated in this adventure with me the past five years to advance the remediation community’s understanding of sustainability. Your collaborative feedback, constructive criticism, advice, support, and willingness to share ideas created an environment of innovation that I am forever thankful for. I look forward to our future collaborations.

Lastly, thank you to my family and friends for your continuous support and love throughout this journey, especially my dearest husband. With one last shout out to Dr. Jason Kelsey of Muhlenberg College, thank you for introducing me to the world of sustainable remediation and taking me on as an undergraduate research assistant. That experience forged the path to an exciting career in environmental management and research.

DEDICATION

"We are very proud of you and know that great thighs are still yet to come!"

Wonderful encouragement from my loving mother and a typo of a lifetime,
Rutherford High School Yearbook (2001)

TABLE OF CONTENTS

<u>**LIST OF TABLES**</u>

TABLE **PAGE**

LIST OF FIGURES

FIGURES **PAGE**

LIST OF ACRONYMS

%	percent
AOC	Area of Concern
APEEP	Air Pollution Emission Experiments and Policy
bgs	below ground surface
BMP	best management practices
CBS	Costs Borne By Society
CF	Common Forum
CH_4	methane
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalents
DICE	Dynamic Integrated Climate and Economy
DNAPL	dense non-aqueous phase liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DR	discount rate
ELCD	European Reference Life Cycle Database
EO	Executive Order
EU	European Union
FCSAP	Federal Contaminated Sites Action Plan
FUND	Climate Framework for Uncertainty, Negotiation and Distribution
GAC	granular activated carbon
GHG	greenhouse gas
ICCL	Contaminated Land in Europe, International Committee on Contaminated Land

IDW	investigation derived waste
IPCC	Intergovernmental Panel on Climate Change
IRO	interim remedial option
ISO	International Standards Organization
ITRC	Interstate Technology and & Regulatory Council
kWh	kilowatt hour
LCA	life cycle assessment
LCI	life cycle inventory
LNAPL	light non-aqueous phase liquid
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MCDA	multi-criteria decision analysis
mg/kg	milligrams per kilogram
MMBTUs	millions of British thermal units
MOU	Memoranda of Understanding
N_2O	nitrous oxide
NAVFAC	Navy Facilities Engineering Command
NICOLE	Network for Industrially Contaminated Land in Europe
NJDEP	New Jersey Department of Environmental Protection
NO_x	nitrogen oxides
O&M	operation and maintenance
PAGE	Policy Analysis of the Greenhouse Effect
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
$PM_{2.5}$	fine particulate matter

PM_{10}	coarse particulate matter
polyDADMAC	polydiallyldimethylammonium chloride
P&T	pump-and-treat
RGGI	Regional Greenhouse Gas Initiative
RSM	regional sediment management
SCBA	social cost benefit analysis
SDST	Sustainable Decision Support Tool
SedNet	European Sediment Research Network
SEFA	Spreadsheets for Environmental Footprint Analysis
SI	Supplemental Information
SO_2	sulfur dioxide
SO_x	sulfur oxides ()
SR	Sustainable remediation
SSDS	sub-slab depressurization system
SURF	sustainable Remediation Forum
SVE	soil vapor extraction
Synapse	Synapse Energy Economics, Inc.
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
TSCA	Toxic Substances Control Act
UK	United Kingdom
USACE	U.S. Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USG	United States Government
USLCI	United States Life Cycle Inventory

UVOST	ultraviolet optical screening tool
VBN	values-beliefs-norms
VC	vinyl chloride
VOC	volatile organic compound

Chapter 1

INTRODUCTION TO RESEARCH AND ORGANIZATION OF THE DISSERTATION

(A portion of this chapter has been published in the journal, Remediation)

1. Introduction

Since 2008, the environmental remediation community has discussed the importance of performing contaminated site remediation in a manner that maximizes benefits and reduces detrimental impacts towards stakeholders and global society. This concept, known as sustainable remediation, seeks to manage unacceptable risks in a safe and timely manner, whilst optimizing the overall environmental, social, and economic benefits (International Standards Organisation [ISO], 2015; Interstate Technology and & Regulatory Council [ITRC], 2011a; Network for Industrially Contaminated Land in

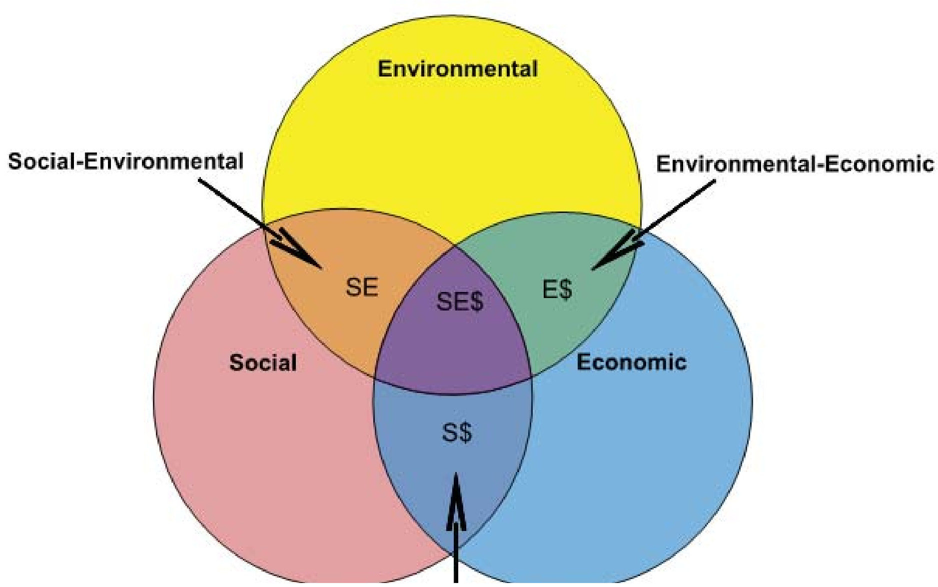

Figure 1-1: Three Interrelated Dimensions of Sustainability *(USEPA, 2012a* adapted from Beach 2010 and Sikdar 2003*).*

Europe [NICOLE], 2010; Sustainable Remediation Forum [SURF], 2009; SuRF-Italy, 2014; and SuRF-UK, 2010). The three main dimensions of sustainability, often referred to as the triple bottom line, are the environment, society and economy (Pope et al., 2004), as presented on **Figure 1-1**.

Over the last decade, the international remediation community has made substantial progress in developing guidance and tools to evaluate impacts to the triple bottom line from remediation activities. Although there are commonalities among guidance and tools, how the social dimension of the triple bottom line is defined and measured varies significantly within individual countries and organizations (Hadley and Harclerode, 2015; Harclerode et al., 2015a; Frantál et al., 2015; and Nathanail, 2011).

The social aspect of sustainable remediation is one of the three integrated dimensions of the triple bottom line (Pope et al., 2004). As such, a sustainable remediation evaluation includes assessing the potential impacts to all three of these sustainability dimensions. Unfortunately, a single tool does not currently exist that considers both quantitative and qualitative data among all three dimensions of the triple bottom line (Harclerode et al., 2015a). Therefore, remediation practitioners often use multiple tools to comprehensively evaluate sustainable aspects of cleanup activities. Pope et al. (2004) suggests that the sum of separate environmental, social, and economic assessments does not equal the whole (i.e., sustainability). Rather they argued that the sum of an integrated impact assessment incorporating the inter-linkages among the three dimensions of the triple bottom line would be greater than the whole. As the remediation community advances its understanding of sustainability, it is important to acknowledge the interconnections of these dimensions and consider a flexible, integrated, and objective-led impact assessment approach when defining sustainability indicators and metrics of remediation (Harclerode et al., 2015a; Ridsdale, 2015).

In addition to impacts, another facet comprising the social dimension of remediation activities are the drivers and barriers for achieving sustainable practices (Alexandrescu et al., 2013; CLARINET, 2002; CABERNET, 2006; Dixon, 2007; HOMBRE, 2014; RESCUE, 2005; and REVIT, 2007). Drivers are those characteristics of a given country, region or project, which can be of regulatory, economic or institutional/cultural in nature, that foster the regeneration of contaminated properties (Ridsdale, 2015). Barriers, in contrast, are characteristics that have the opposite effect, such as outspoken aversion to the process, opposition to cleanup, avoidance of the redevelopment (Alexandrescu et al., 2013) and risk perception (Harclerode et al., 2015a). Recent research on sustainable remediation has indicated that the sustainable management of contaminated sites is driven, in part, by stakeholder demands from site owners, regulators, or consultants and also by institutional processes, including social norms and public policy (CABERNET, 2006; Cundy et al., 2013; HOMBRE, 2014; Hou and Tabbaa, 2014; RESCUE, 2005; and REVIT, 2007).

Therefore, social drivers and barriers should be identified during project planning and integrated into sustainability objectives for the site (Harclerode et al., 2015a).

The objective of the research presented herein is to be a major contributor to the current international initiative to advance sustainability assessments for remediation projects by integrating methodologies from the environmental economics and social science disciplines.

1.1. Literature Review

The following sub-sections present a literature review of sustainable remediation guidance, with a focus on how the social dimension of sustainable remediation is assessed among various countries and organizations.

United States (U.S.)

Several tools, guidance and policy documents on incorporating and addressing sustainable aspects of remediation activities have been issued by federal, state, private, and professional organizations (e.g., Interstate Technology and Regulatory Council [ITRC], Sustainable Remediation Forum [SURF], and ASTM International). The guidance document used for a specific site is usually dictated by the regulatory framework and responsible party. Guidance among the different institutions have commonalities among evaluating environmental impacts from remedial activities, however, are not in alignment for assessing social and economic impacts (Hadley and Harclerode, 2015).

Federal and State Agencies

Presently, state and federal regulatory sustainability guidance places more weight on quantifying and addressing environmental impacts of remedial activities. Executive Orders (EOs) 13514 and 13423 are the basis for incorporation of sustainable practices into regulatory cleanup programs. The goal of EO 13514 (2009) is "to establish an integrated strategy towards sustainability in the Federal Government and to make reduction of [greenhouse gas] GHG [emissions] a priority for Federal agencies." EO13423 (2007), which consolidates and strengthens five previous EOs and two Memoranda of Understanding (MOU), requires federal agencies to lead by example in advancing the country's energy security and environmental performance. It compels federal agencies to achieve goals across a variety of environmental and energy-related programs, including practices listed under EO13514, as well as pollution prevention, alternative fuels, building performance, petroleum conservation, vehicles, and energy efficiency. EO 13514 (2009) guides federal agencies to support renewable energy generation, water and energy conservation, green buildings, waste minimization, green procurement, electronic stewardship, and local and regional planning to promote sustainable living and public transit systems near existing town centers. The United States Environmental Protection Agency (USEPA) responded to EOs 13514 and 13423 by issuing the Superfund Green Remediation Strategy (2010a) and developing the Spreadsheets for Environmental Footprint Analysis (SEFA) tool (USEPA, 2016a). Green remediation is the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup actions (USEPA, 2010a). In 2013, a Memorandum was issued by USEPA’s Assistant Administrator that encouraged the use of the ASTM International *Standard*

Guide for Greener Cleanups on remediation sites. State regulatory agencies also responded similarly by issuing green and sustainable remediation policies and guidance (*see Exhibit 1 of Hadley and Harclerode, 2015 for a complete list*).

In the **U.S., federal and state regulatory** “sustainable” remediation guidance emphasizes the quantification of environmental impacts (e.g., emissions and resources consumed) of remediation activities more than social and economic impacts (Hadley and Harclerode, 2015; USEPA 2010a). Federal regulators identify and address social impacts from remediation activities primarily in the form of community outreach. According to the *Superfund Community Involvement Handbook*, the primary objective of community outreach is to identify and communicate community concerns and interests to remediation decision makers (USEPA, 2005). Local community needs are then considered for integration into remediation and redevelopment activities. Economic impacts are primarily focused on project implementation cost (i.e., comparing the cost of each proposed remediation strategy) (Hadley and Harclerode, 2015; Harclerode et al., 2015a).

On the other hand, **U.S. federal agencies**, including the U.S. Navy, U.S. Army Corps of Engineers (USACE), and U.S. Air Force have incorporated remediation worker safety and accident risk into their established sustainability evaluation frameworks (NAVFAC, 2012; USACE, 2010; and US DOD, 2009) and tools (i.e., SiteWise™ and Sustainable Remediation Tool). These agencies also include social responsibility metrics to evaluate potential beneficial and detrimental impacts to the local community from remedial activities (e.g., noise, odor, traffic) (US DOE, 2011; NAVFAC, 2012). The U.S. Department of Energy (DOE) *2011 Strategic Sustainability Performance Plan* recommends utilizing a cost benefit analysis that incorporates the social cost of carbon to aid in the policy decision making process (e.g., remedy evaluation). The incorporation of the social cost of carbon supports EO 12866, in which agencies are "required, to the extent permitted by law to assess both the costs and the benefits of the intended regulation" and encourages using the social cost of carbon to consider the social benefits of reducing carbon emissions from sustainable practices.

Private Entities and Professional Organizations

Other organizations, such as the SURF, ITRC, and ASTM International have developed sustainable remediation frameworks. Summaries of each guidance and the organization's contributions to the social dimension of sustainable remediation are presented in the following paragraphs.

Sustainable Remediation Forum (SURF) was initiated in late 2006 to promote the use of sustainable practices during remedial action activities with the objective of balancing economic viability, conservations of natural resources and biodiversity, and the enhancement of the quality of life in surrounding communities. SURF defines sustainable remediation as site assessment and remediation that protects human health and the environment while maximizing the environmental, social, and economic benefits throughout the project life cycle (SURF, 2009).

In 2011, SURF published three documents to guide remediation professionals while conducting a sustainability assessment, including *Framework for Integrating Sustainability into Remediation Projects* (Holland et al., 2011); *Metrics for Integrating Sustainability Evaluations into Remediation Projects* (Butler et al., 2011); and *Guidance for Performing Footprint Analyses and Life-Cycle Assessments for the Remediation Industry* (Favara et al. 2011). These documents illustrate the importance of going beyond evaluating environmental and human health impacts by considering potential impacts on worker and community safety, stakeholder involvement, and stimulating the local economy throughout the entire life cycle of a remediation project. SURF also identified the importance and potentiality of linking local emissions to regional and global health impacts. SURF's *Sustainable Remediation White Paper* referenced tools that evaluated social outputs pertaining to community acceptability, risk reduction, socioeconomic cost of secondary emissions, human health, and barriers. The tools referenced are among international and private organizations that may not be publicly accessible (SURF, 2009).

In the Spring of 2013, SURF published *Integrating Remediation and Reuse to Achieve Whole-System Sustainability Benefits*. This document presents the concept of sustainable reuse, which is the "regeneration of abandoned, derelict, underused, and potentially contaminated sites in a way that increases the environmental, economic, and social benefits of a site." Sustainable reuse of a contaminated site is often challenging because the objective of remediation and the objective of reuse are not always in alignment and may even be in opposition of each other. The objective of remediation is to address contamination associated with the site to protect human health and the environment. While, the objective of reuse is to redevelop the site in a timely fashion in order to enhance the potential return on investment. Due to perceived conflict among these two objectives, the fate of contaminated sites often results in underuse. SURF believes this conflict can be addressed by implementing the sustainable reuse concept during site cleanup. Holland et al. (2013) states this "collaborative process will allow accelerated regulatory site closure, cleanup cost reduction, optimization of site's natural environmental conditions, local economy gains (e.g., through the creation of local jobs), and greater consideration of the public's needs and concerns."

Holland et al. (2013) discussed the numerous socio-economic benefits from sustainable re-use, including: (1) benefits to the public sector, including the reuse of previously developed land that is currently vacant (i.e., Brownfields and "greyfield" sites), urban in-fill areas and transit-oriented projects; (2) general beneficial consequences from sustainable reuse of these types of sites, including protection of undeveloped land (i.e. "greenfields), creation of employment opportunities and expanded tax base, development of infrastructure and renewable energy resources, and ecosystem enhancement; and (3) benefits to the community, including infrastructure enhancement, reduction in urban blight, an increase in the health of neighborhoods, and an increase in the economic value of the property.

The social and economic impacts of a remediation project are also intimately linked to water resources. In 2013 SURF published *Groundwater Conservation and Reuse at Remediation Sites* with the objective of stimulating a more holistic view of the groundwater associated with remediation projects and to promote conservation and beneficial reuse of this vital natural resource. Water plays a crucial role in a community's wellbeing, especially in water stressed regions. The reuse of treated groundwater is often inhibited due to social constraints, such as public perception, economics, and actual and perceived liabilities. In order for sustainable reuse of treated groundwater to be successful remediation professionals must coordinate with local municipalities and regulators to educate stakeholders and develop appropriate permits. The guidance presents several case studies highlighting the successful reuse of treated groundwater for agricultural, industrial, and potable use. Each case study highlights the social and economic benefits to the local and regional communities from reusing treated groundwater (SURF, 2013).

Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from environmental regulatory agencies, tribes, and public and industry stakeholders. In 2011, ITRC published *Green and Sustainable Remediation: State of the Science and Practice* and *Green and Sustainable Remediation: A Practical Framework*. These documents present a framework "to help users incorporate sustainability factors into site management decision making". ITRC promotes incorporating sustainable practices throughout a contaminated site's life cycle, from site assessment through remediation and redevelopment. The ITRC Guidance presents three levels of conducting a sustainability assessment for remedial projects, ranging from simple to complex. A Level 1 Evaluation identifies, implements, and evaluates best management practices (BMPs) at each stage of a project to reduce impacts to the triple bottom line. Examples of BMPs include using local vendors, electronic deliverables, *in* *situ* screening and treatment technologies, renewable energy, recycling, treated material reuse, and reduced sample volume. Level 2 Evaluation combines the selection and implementation of BMPs with a footprint evaluation. Level 3 evaluation combines the selection and implementation of BMPs with a life cycle assessment (LCA). The three levels were developed to facilitate implementation of sustainable practices on a wide array of project types.

The following categories of social indicators are presented in the ITRC Guidance: impacts on human health and safety; ethical and equity considerations; impacts in neighborhoods and/or regions; community involvement and satisfaction; compliance with policy objectives; and strategies, uncertainty, and evidence. The ITRC framework also notes the importance of understanding the socio-cultural impacts of remedial processes and actions, and if conducted during the project planning stage, can lead to a reduction in antagonistic working relationships, increase community involvement, and facilitate negotiation and selection of remedies that are consistent with community needs.

ASTM International issued the *Standard Guide for Integrating Sustainable Objectives into Cleanup.* The document released in 2013, guides users to focus on the socio-economic benefits of site cleanup and land reuse. ASTM International emphasizes that each site entails different and unique contexts, and thus flexibility is imperative for successful integration of site-specific socio-economic concepts. The scalable framework helps users achieve sustainability through the use of BMPs, which are categorized by core dimensions. Social core dimensions include community involvement, economic impacts to the local community, enhancements of individual human environments, and local community vitality.

Europe

Several guidance documents on incorporating and addressing sustainable indicators of remediation activities have been developed by European organizations. These documents were developed as a collaborative effort among governmental, private, and professional organizations such as the Common Forum (CF) on Contaminated Land in Europe, International Committee on Contaminated Land (ICCL), Network for Industrially Contaminated Land in Europe (NICOLE), SuRF-UK, SuRF Italy, and International Organization for Standardization (ISO). Since the development of frameworks was a collaborative process, differences in sustainability indicators and tools are not as prevalent, as was identified with U.S. frameworks. In addition, the triple bottom line dimensions represented in European frameworks are closer to an integrated approach, as compared to U.S. frameworks.

Common Forum (CF) on Contaminated Land in the European Union (EU), initiated in 1994, is a network of contaminated land policy makers and advisors from national ministries and Environment Agencies in EU Member States. CF's general objectives are to share knowledge and experiences on contaminated land management between its members and other stakeholder communities, and to develop new and efficient strategies for the management and remediation of contaminated sites and land reuse with respect to "sustainable resource protection". Every other year CF members with their equivalents from around the world meet as the **International Committee on Contaminated Land (ICCL)** to discuss site management and sustainable remediation.

Network for Industrially Contaminated Land in Europe (NICOLE), is a European Network comprised of industry and service providers, as well as individual academics. It initiated a Sustainable Remediation Working Group in 2008. This group published a *Sustainable Remediation Road Map* in 2010 with further supporting guidance in 2012 (NICOLE, 2012). NICOLE defines a sustainable remediation project as one that represents the best solution when considering environmental, social and economic factors, as agreed upon by stakeholders. Similar to the concept of risk management and risk assessment, NICOLE divides sustainable remediation into two inter-related components:

1. *Sustainability management:* the discipline of integrating sustainability assessment into contaminated land management decision making
2. *Sustainability assessment:* the process of gaining an understanding of possible outcomes across all three elements (environmental, social and economic) of sustainable development.

In the context of the EU, sustainability assessment is a tool that supports sustainability based decision-making within a management plan, and also utilized to review and verify sustainability performance during the implementation of remediation. The aim of a sustainability assessment is to build trust and consensus between stakeholders. NICOLE states that the earlier stakeholders consider sustainability principles, the more opportunities there are to improve sustainable outcomes and so provide greater benefit.

European policy on contaminated site management has evolved since the 1990s and is now entering a 4th generation of so called “risk-informed and sustainable land management” which integrates three key principles: (1) being risk-informed, (2) managing adaptively, and (3) taking a participatory approach. In 2013, the CF and NICOLE (2013) published *a Joint Statement on Risk-based & Sustainable Remediation*, published in nine European languages. The Joint Statement highlights goals to (1) define and highlight key messages of sustainable remediation as a concept; (2) promote the concept through a visible commitment from all parties, Europe wide; (3) encompass a broader uptake of sustainable remediation principles, approaches and tools by everyone, and (4) link to the wider European policy arena and provide thematic strategies (NICOLE, 2011 and 2012; CF and NICOLE, 2013).

SuRF-UK is the United Kingdom’s (UK) equivalent to the Sustainable Remediation Forum founded in the U.S. SuRF-UK’s mission is to improve the UK’s understanding of sustainable remediation and functions as a series of initiatives managed by the not-for-profit organization Contaminated Land: Applications in Real Environments (CL:AIRE) beginning in 2006. SuRF-UK has a small steering group which includes consultants, academics, responsible parties, and regulators. Publications and supporting activities use stakeholder workshops to ensure engagement with the entire remediation community (CL:AIRE, 2009, 2010, 2011, and 2014).

The SuRF-UK Framework is the most widely used sustainable remediation guidance in the EU, Australia, and New Zealand. SuRF-UK defines sustainable remediation as the practice of demonstrating, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than its impact, and that the optimum remediation solution is selected through the use of a balanced decision-making process.

To date SuRF-UK publications include the *Sustainable Remediation Framework* (2010) and *Guidance on Sustainability Indicators* (2011) based on 15 overarching categories comprised of the triple bottom line. The framework lists five overarching social categories to evaluate during a sustainability assessment of remedial activities: (1) human health and safety; (2) ethics and equality; (3) neighborhoods and locality; (4) communities and community involvement; and (5) uncertainty and evidence (CL:AIRE, 2011). Owing to the synergistic effects among the social and economic sphere, overarching categories representing the economic dimension are also relevant to the social aspect of sustainable remediation. The economic overarching indicator categories are: (1) direct economic costs and benefits; (2) indirect economic cost and benefits; (3) employment and employment capital; (4) induced economic costs and benefits; (5) project life-span and flexibility. The framework stresses that the indicators are integral to the communication and promotion of sustainable development to stakeholders. This framework also recommends decision support techniques that can be performed as part of a sustainability assessment to evaluate social and economic indicators. These techniques include scoring/ranking systems (including multi-criteria decision analysis), best available techniques, cost-benefit analysis, cost effectiveness analysis, financial risk assessment, industrial ecology, and quality of life assessment (Bardos et al., 2011a; CL:AIRE, 2010).

SuRF-Italy is an initiative carried out by a group of Italian public and private organizations, operating in the remediation sector, aimed at (1) promoting remediation actions at local and regional levels, through stakeholder involvement; (2) disseminating the successful experiences and world-wide best practices; and (3) increasing the momentum of sustainability concepts for economic, social and environmental benefits. SuRF-Italy defines sustainable remediation as ‘”the process of remediation and management of a contaminated site, aimed at identifying the best solution, which maximize the environmental, social and economic benefits, through a balanced decision process, agreed by stakeholders”. Currently, SuRF-Italy is working on developing a technical document suggesting operative criteria and practices for evaluating impacts to the social dimension of remediation and redevelopment activities, in concurrence with economic and environmental ones. Recommendations will be provided on key dimensions such as objective setting, indicator selection, option appraisal and selection, technologies, and BMPs in order to support sustainable remediation applications in a project-specific and a balanced way (SuRF-Italy 2014).

International Organization for Standardization (ISO) Technical Committee 190’s Subcommittee 7 (TC190/SC7/WG12) working group on sustainable remediation has defined sustainable remediation as an approach that eliminates and/or controls unacceptable risks in a safe and timely manner, and optimizes the overall environmental, social, and economic benefits of the remediation work. The ISO document on sustainable remediation would be publicly ‘visible’ and accessible in all countries and, and therefore, would allow an international collaboration to take place to ensure maximum benefit is gained. In addition, for those organizations operating across national borders, ISO guidance would help create a standard approach or at least a shared understanding around the world. While it recognizes the importance of the social dimension alongside the economic and environmental as well as governance issues, it does not propose a list of social, or other, indicators. This reflects both the lack of consensus on such a list and the dynamic state of thinking on useful indicators.

The ISO document concludes that the need for remediation is determined by risk assessment and the process of choosing the remediation strategy involves seeking the viable strategy that will deliver the best overall environmental, social and economic benefits from the remediation work (Harclerode et al., 2015a).

Canada

While there are no Canadian specific frameworks for integrating sustainability into cleanup activities, there are a number of initiatives by the remediation industry and at all levels of government (e.g., municipal, provincial, national) that can be used to supplement the protection of human health and the environment with the consideration of broader social benefits as well as transparency and citizen involvement in the remediation decision-making process.

Sustainable Remediation Forum Canada (SuRF Canada) which was developed in 2010 plays a leading role in the promotion of sustainable remediation in Canada. SuRF

Canada defines sustainable remediation as remediation that considers the environmental, social and economic impacts of a project to ensure an optimal outcome, while being protective of human and environmental health, both at a local level and for the larger community (http://www.surfcanada.org/). SuRF Canada's primary objective is to provide a forum for various stakeholders in remediation (e.g., industry, government agencies, environmental groups, consultants, and academia) to collaborate, educate, advance, and develop consensus on the application of sustainable practices throughout the life-cycle of remediation projects, from site investigation to closure. SuRF Canada is currently finalizing a white paper that summarizes the current context (regulatory, industry, social, etc.) and associated drivers and barriers to sustainable remediation in Canada. The paper highlights the role of stakeholder involvement in ensuring an optimal outcome and provides recommendations on policies and initiatives that are critically needed to advance the practice of sustainable remediation. The paper also includes a compilation of Canadian case studies of green and sustainable remediation projects (Harclerode et al., 2015a).

Federal Contaminated Sites Action Plan (FCSAP) developed a decision-making framework to address the lack of attention given to the social dimension of sustainable remediation (Government of Canada, 2014). The framework includes a tool to integrate triple bottom line dimensions into remediation. The Sustainable Decision Support Tool (SDST), which is not available to the public, is based on the tool GoldSET designed by Golder and Associates (also not available to the public, see Golder.com). The SDST is both quantitative and qualitative, with the following social indicators: cultural heritage, public and worker safety, project duration, quality of life during the project, public benefits, and the federal government's image. The tool uses a scoring and rating system to evaluate each social indicator in relation to the "level of concern to the federal government" versus the "level of concern to stakeholders," for each proposed remedial alternative (Klassen, 2012).

Taiwan

SuRF Taiwan and the **Taiwan Environmental Protection Administration** are working together to develop guidance to incorporate and evaluate sustainable principles during remediation activities. In the guidance, the social dimension of the triple bottom line is categorized into two core dimensions supported by a list of principles to consider during a sustainability assessment. The first core dimension, human health and safety, is comprised of the following principles: human health and risk before remediation, human health risk during remediation (considering both local residents and site workers), risk of accidental injury, avoidance of secondary contamination, and prevent exposure pathways. The second core dimension, social justice and acceptance, is comprised of the following principles: stakeholder participation, information disclosure, considering remedial related effects on local residents, and preserve cultural heritage. These principles are used to develop BMPs that can be implemented to alleviate social impacts of remediation activities. In general, human health and safety is primarily addressed by performing a human health risk assessment to understand the current health risk to local residents and evaluate the health risks among the remediation alternatives. Common social indicators evaluated include worker operation and traffic accidental risks, and site activity related effects including noise, odor, and vibration (Harclerode et al., 2015a).

Common Themes

As presented in the previous sub-sections, the identification of indicators varies among countries and organizations, as well as within countries themselves. In 2015, the SURF Social Aspects Technical Initiative developed ten main societal impact categories based on a literature review of sustainable remediation frameworks at an international level. The intention of developing the social impact categories is, during the project planning stage, to provide remediation professionals with a checklist to assist with identifying and defining social indicators that are predominately impacted by site-related activities. Once site-specific social indicators have been identified, stakeholders can determine the applicable metrics and tools to evaluate impacts to the social dimension. As stated previously, the triple bottom line dimensions are interrelated and, therefore, lead to impact categories that have an overlap of sustainability dimensions. Therefore, the societal impact categories listed below may be represented under the environmental and/or economic dimension of sustainability in other sustainable remediation frameworks (Harclerode et al., 2015).

Main Societal Impact Categories

1. **Health and Safety** of site workers and the surrounding community including, but not limited to, the alleviation, prevention or mitigation: of contamination risks on-

site, generation of emissions and dust, and hazards of construction and operation of remedial systems.

2. **Economic Vitality** by contracting local vendors and resources, developing and investing in new skilled training and education, and incorporating redevelopment into the remediation strategy selection.

3. **Stakeholder Collaboration** to identify beneficial and undesirable impacts, to discuss perceived risks, to develop future land use and design, and to help aid in assessment goals and indicators used in the assessment in order to maximize buy-in for the eventually implemented remediation strategy.

4. **Benefits Community at Large** by promoting the community's quality of life, including increased property value, social and human capital, reuse of treated media/materials to meet community needs, and redevelopment of the property.

5. **Alleviate Undesirable Community Impact** at the neighborhood and locality scale, including noise, traffic, odor, congestion, business disruptions, compromising local heritage and cultural concerns.

6. **Social Justice** during urban revitalization, through increased housing availability for all community members, widened access to employment opportunities, and reused brownfields for equitable use throughout the community.

7. **Value of Ecosystem Services and Natural Resources Capital** altered by site activities and consumption, reuse of treated media, and restoration of ecosystems,

hydrological functions, fauna and indigenous flora habitat, in ways that enhance local quality of life and otherwise address societal challenges.

8. **Risk-Based Land Management and Remedial Solutions** to distribute additional resources (e.g., energy, raw materials) in a manner to effectively address the site-specific human health, environmental justice, and community issues associated with contaminated sites.

9. **Regional and Global Societal Impacts**, such as long-term, chronic public health impacts and financial implications (e.g., mitigating effects of climate change and limited water resources) due to the generation of emissions and consumption of non-renewable resources.

10. **Contribution to Local and Regional Sustainability Policies and Initiatives**, such as renewable energy initiatives, climate change legislation (e.g., carbon-trading economy and climate adaptation), eco-job strategies, regional land use policies, regional and local sustainability objectives (e.g., ecological restoration goals, water use), and sustainable resource consumption.

Currently, the majority of sustainability assessments conducted on remediation projects evaluate local, and to a lesser extent, global environmental impacts, project implementation cost, and, occasionally, local community impacts from proposed remediation activities. Due to the complexity of the concept of sustainability, stemming from the interrelations among the three dimensions of the triple bottom line, relevant and applicable indicators are often lost in the current assessment process (Ridsdale, 2015).

1.2. Problem Statement

The remediation sector has recently been given the added responsibility of implementing remedial activities that are sustainable: a practice known as sustainable remediation. The three main facets of sustainable remediation, often referred to as the triple bottom of sustainability, are the environment, society and economy. Over the last several years, the remediation sector has responded robustly by publishing guidance and white papers, as well as developing footprint and LCA tools to evaluate the environmental impacts incurred during remediation of contaminated sites. While, tools and methodologies to evaluate social, including socio-economic, impacts from remediation activities are scarce. Furthermore, the paucity of established social impact tools is seen by the remediation community as an obstacle to conducting a comprehensive sustainability evaluation (Harclerode et al., 2015a,b, 2013; Hou and Al-Tabbaa, 2014a; Hou et al., 2014; Reddy et al., 2014; Ridsdale, 2015).

An extensive literature review of sustainable remediation frameworks and publications suggests three knowledge gaps exist among the sustainability assessments being performed for remediation projects.

Knowledge Gap I: Most sustainable remediation publications and assessment tools focus on the remedial action stage of a contaminated site's life cycle. There are few studies that include sustainability assessments of the variety of techniques and technologies implemented during site characterization (e.g., Phase II environmental site assessments, remedial investigations and pre-design investigations).

Knowledge Gap II: The majority of sustainable remediation publications and assessment tools focus on evaluating the environmental impact of a contaminated site's life cycle and minimally, if at all, on related socio-economic impacts. Economic evaluations are often limited to a cost benefit analysis of project implementation, while a measurement methodology for evaluating the societal impacts of a remediation project is practically non-existent.

Knowledge Gap III: The role of risk perception in stakeholder engagement has not been explored in existing sustainable remediation frameworks. Rather, has been identified as a barrier to implementing sustainable practices without a proposed solution to address it.

1.3. Research Significance and Objectives

This study aims to address some of the knowledge gaps related to conducting a comprehensive sustainability assessment for a remediation project. More specifically,

1. Develop a methodology to quantify the socio-economic impacts of a contaminated site's lifecycle (i.e., site characterization and remedial action stages) using the social cost of environmental metrics.

2. Conduct a LCA to determine which components and techniques are significantly contributing towards environmental impacts in a site-specific scenario. Extend the results of the LCA to incorporate the socio-economic cost evaluation methodology developed under Task 1.

3. Develop and implement a survey to evaluate the role of risk perception in stakeholder engagement.

In order to address the first knowledge gap, an environmental footprint analysis was conducted for three different case study sites, each representing a specific stage within a remediation project's life cycle. Among the case studies, project life cycle stages represented include site characterization, remedy implementation with associated long term monitoring, and optimization of a remedial system. The results of the footprint analysis was then extended to quantify global socio-economic impacts arising from each remedial activity by monetizing the emissions and energy consumption through the integration of the social cost of environmental metrics. A sensitivity analysis was conducted to evaluate how different social discount rates and carbon prices influence quantified monetized global impacts. The case study site used to address the second knowledge gap was a sediment remedial design consisting of excavation, dredging, and *in situ* treatment. A sediment contaminated site was chosen to conduct the LCA since the majority of publications on LCAs conducted for remediation projects are focused on technologies considered for remediating residual sources areas impacted by dense non-aqueous phase liquid (DNAPL) and groundwater plumes. A sensitivity analysis was conducted to evaluate how site-specific life cycle inventory (LCI) parameters were influencing the results of the environmental impact analysis. The results of the LCA were extended to quantify global socio-economic impacts using the cost evaluation methodology. Lastly, the third knowledge gap was addressed by developing and implementing an in-person survey to identify risk perception factors that influenced residents' level of concern for mitigating their exposure to elevated concentrations of lead in household paint and historic fill material. Evaluating and integrating risk perception of stakeholders into outreach efforts allows for greater insight and ultimately, benefits the community by protecting its members from environmental hazards. Additional literature review conducted for each knowledge gap are presented along with each case study evaluation presented in subsequent chapters.

1.4. Organization of the dissertation

The above mentioned research objectives were achieved and research findings were organized in the form of various chapters in this dissertation. Each chapter covers one research objective as follows:

- Chapter 2 entitled, "Estimating social impacts of a remediation project life cycle with environmental footprint evaluation tools", quantified the costs borne by society, in terms of environmental, economic, and societal impacts, resulting from site characterization and remediation activities. The results the study demonstrated that costs borne by society from a remediation project are significant and metric specific. The study also highlighted the benefits of conducting a sustainability assessment at the site characterization stage, in addition to the remedial design stage, using environmental footprint analysis tools, cost benefit analysis, and an evaluation of costs borne by society.
- Chapter 3 entitled, "Quantifying global impacts to society from the consumption of natural resources during environmental remediation activities", presents a

method to integrate the social cost of carbon emissions into carbon footprint evaluations to quantify global impacts to society. The study evaluated the monetized societal benefits from quantifying carbon emission impacts of the proposed cleanup approaches and alternative scenarios. The results suggest societal impacts based on monetized carbon emissions can be reduced by 27% by optimizing the case study remediation processes. The sensitivity analysis results elucidated how variation in carbon prices and social discount rates can influence cleanup decisions for remediation projects.

- Chapter 4 entitled, “Comparison of sustainability evaluation tools for contaminated sediment remediation”, evaluated the environmental and global socio-economic impacts of three common sediment remediation technologies (i.e., excavation, dredging and *in situ* treatment) using LCA, environmental footprint analysis, and societal cost analysis. The study did not find a significant difference between the overall conclusions of the environmental footprint and LCA methodologies. However, incorporation of social cost metrics were deemed useful in normalizing environmental impacts for comparison, as well as identifying components of the remedial design that were designated as major, secondary, and low impact contributors to environmental, social, and economic effects. Thus, study results provided supporting data on where to focus remedial design optimization efforts, including consideration of remedy components related to mobilization, engineering controls (e.g., silt curtain and turbidity curtain), and dewatering.

- Chapter 5 entitled, "Evaluation of the role of risk perception in stakeholder engagement to prevent exposure in an urban setting", identified risk perception factors that influenced residents' level of concern for mitigating their exposure to elevated concentrations of lead. Risk perception factors were assessed by conducting an in-person survey at public green spaces. The results of the study provided insight and recommendations to refine public outreach efforts that would communicate actual risk to lead and overcome "optimism bias" exhibited by the community.
- Chapter 6 entitled, "Research study conclusions", presents the overall conclusions, environmental management application, policy implications, limitations of the study, future research, and closing statement of the dissertation research presented herein.

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Chapter 2

ESTIMATING SOCIAL IMPACTS OF A REMEDIATION PROJECT LIFE CYCLE WITH ENVIRONMENTAL FOOTPRINT EVALUATION TOOLS

(This chapter has been published in the journal, Remediation)

Abstract

This chapter presents a methodology to calculate the social cost of sustainability metrics with environmental footprint evaluation tools. Measuring the impacts of a remediation project on society is challenging because the methods by which these impacts can be measured have not been established. To perform a complete sustainability assessment of a project's life cycle, costs borne by society in terms of environmental, economic, and community impacts must be evaluated. Two knowledge gaps have been identified among the sustainability assessments currently being performed during a remediation project's life cycle: (1) lack of methodologies available to evaluate impacts on the socio-economic aspects of remediation; and (2) lack of sustainability assessments conducted during the site characterization stage. Sustainability assessments were conducted on two case studies using the methodology proposed in this paper: one during the site characterization stage and the other during remedial action. The results of this study demonstrated that costs borne by society from a remediation project are significant and metric specific. This study also highlighted the benefits of conducting a sustainability assessment at the site characterization stage using environmental footprint analysis tools, cost benefit analysis, and an evaluation of costs borne by society.

2. Introduction

Sustainable remediation (SR) protects human health and the environment during a remediation project's life cycle, while maximizing its environmental, economic, and social benefits (triple bottom line) (Butler, 2011; Favara et al., 2011; Holland et al., 2011; and Miller et al., 2010). In 2010, the U. S. Environmental Protection Agency (USEPA) developed the Superfund Green Remediation Strategy to reduce greenhouse gas (GHG) emissions and other negative environmental impacts that may occur during a site remediation project (e.g., generation of harmful waste products and depletion of natural resources). The strategy recommended developing white papers that focus on the incorporation of SR practices under existing laws and regulations (USEPA, 2010a). Over the last several years, the remediation sector has responded robustly by publishing guidance documents and white papers, as well as developing environmental footprint and life cycle assessment (LCA) tools to evaluate the environmental, economic, and social impacts incurred during characterization and remediation of contaminated sites (Favara et al., 2011). An extensive literature review of SR publications suggests two knowledge gaps exist among the sustainability assessments being performed for remediation projects. The first section of this chapter will introduce and address those knowledge gaps: (1) the lack of methodologies available to evaluate the socio-economic impacts of remediation, and (2) the lack of sustainability assessments conducted at the site characterization stage. The second section of this chapter introduces a methodology to quantify the socio-economic impacts of a remediation project life cycle. This section includes two case studies, one at the site characterization stage and a second at the remedial action stage. The third section describes and discusses the results of the case studies. The fourth section covers the conclusions and challenges faced during the study, and the last section discusses the need for future research.

Knowledge Gap Number 1

In the remediation industry, the value of a project is defined by improvements in human welfare resulting from site characterization and cleanup actions (Holland et al., 2011; Lee et al., 2009). The majority of SR publications and assessment tools focus on evaluating the environmental impact of a remediation project and minimally, if at all, on related socio-economic impacts. The 2011 Interstate Technology & Regulatory Council (ITRC) *Technical/Regulatory Guidance –Green and Sustainable Remediation: A Practical Framework* presents a problem statement which includes the following: “remedial activities often focus on site-specific risks that were not developed in consideration of external social and economic impacts beyond identified environmental impacts in order to protect human health and the environment” (ITRC, 2011a). Social costs are often not included in a site remediation impact assessment (Favara et al., 2011; Lee et al., 2009). To perform a complete sustainability assessment of a project’s life cycle, costs borne by society in terms of environmental, economic, and community impacts must be included. Evaluation of the social impacts of a remediation project is challenging because a measurement methodology has not been established.

Knowledge Gap Number 2

Most SR publications and assessment tools focus on the remedial stage of a remediation project's life cycle. There are few studies that include sustainability assessments of the variety of techniques and technologies implemented during site characterization (e.g., Phase II environmental site assessments, remedial investigations, and pre-design investigations). Technical guidance incorporating sustainability elements and transparent decision-making is lacking within remediation initiatives, especially at the site-planning and remedial-investigation stage (site characterization). Historically, risk assessment has been the only technique used to evaluate potential environmental and human health impacts during the remedial investigation and feasibility study stages (Favara et al., 2011). In November 2011, the ITRC published a technical/regulatory guidance establishing a practical framework for SR implementation to optimize all phases of site remediation, from site characterization to project closeout. Case studies appended to the guidance presented SR practices implemented throughout a remediation project's life cycle. Out of the 10 case studies, only two elaborated on SR practices implemented during site investigation activities, but did not include sustainability assessments or evaluation of socio-economic impacts at the site characterization stage. In addition, the EPA finalized guidance in 2012 for a methodology to quantify green remediation metrics associated with environmental cleanups. This guidance also has a strong focus on the remedial action rather than the site characterization stage (USEPA, 2012a).

Interest in sustainable practices during a remediation project is not limited to certain regulators. At the company level, corporate social responsibility policies can motivate sustainability practices throughout the site remediation process (Lee et al., 2009). Practices that reduce impacts to the triple bottom line can be implemented without sacrificing data quality, project schedule, or budget (Holland et al., 2011; Favara et al., 2011; Lee et al., 2009). Examples of such SR practices include processes that are less energy-intensive, generate fewer harmful waste streams, streamline sampling efforts to reduce mobilization costs, and use *in situ* screening technologies to reduce analytical costs.

The objective of this study was to introduce a methodology to calculate the social cost or benefit of sustainability metrics, by means of environmental footprint evaluation tools in the context of two case studies based on existing remediation projects.

2.1. Methods

A case-study approach was used to meet the objectives of this research. The two case studies employed are described below:

2.1.1. Case Study 1 - Optimizing Site Characterization for Sustainability by a Phased Focused Field Investigation

Site characterization is an essential early step in managing and remediating a contaminated site, and a good opportunity to integrate SR practices into the project life cycle. This case study involved comparing a phased focused investigation and a conventional investigation. A phased focused approach streamlines sampling efforts in order to reduce mobilization and planning events that are geared towards conducting subsequent field actions. A phased focused investigation can improve efficiency and reduce negative environmental, economic, and social impacts of a remediation project by identifying areas of greatest concern and using minimally invasive site surveys and direct image screening tools. In comparison, a conventional approach makes use of iterative sampling and laboratory analytical programs, thereby spreading the investigative efforts across several mobilization and planning events. A conventional investigation can often prolong the life cycle of the remediation project and its associated environmental, economic, and social impacts.

The case study data set was gathered during the characterization phase at a former petroleum bulk storage and distribution site occupying approximately 23 acres. The property was developed in the 1890s and previously used as a lumber yard, machine shop, door, sash and blind factory, coal and lumber yard, and petroleum bulk storage facility. Later uses included oil storage and bulk petroleum sales. The objective of the site characterization was to determine the extent of the on-site petroleum plumes. SR practices implemented during site characterization included geophysical methods to identify historical infrastructure and the ultraviolet optical screening tool (UVOST) to delineate light non-aqueous phase liquid (LNAPL) and focus the sampling efforts. UVOST technology uses a laser to induce fluorescence of polycyclic aromatic hydrocarbons present in petroleum LNAPL, whose concentration is semi-quantified by measuring the florescence intensity in real time. The conventional investigation was a hypothetical alternative approach, which would have employed a drill rig and sample analysis at an off-site commercial laboratory to provide the same information. **Table 2-1** summarizes the field investigation parameters for the two scenarios presented in Case Study 1.

Table 2-1: Case Study 1 - Phased Focused Approach: Sustainability Assessment Parameters

LNAPL Site Characterization Environmental Footprint Analyses Parameters		
	Conventional Investigation	**Phased Focused Investigation**
Field Days	12	8
Soil Boring Footage	304	140
PVC Well Footage	570	180
UVOST Screening Footage	0	560
Analytical Soil Samples	80	9
Analytical Groundwater Samples	51	20

2.1.2. Case Study 2 - Evaluating Sustainability of an Interim Remedial Option at an Urban Brownfield Redevelopment Project

The remedial action selection, design, and implementation stage of a remediation project is a vital step toward incorporating SR practices. The impacts of a remedial technology on the environment are important data for remedial alternative selection. In this case study, *in situ* thermal remediation was one of the proposed remedies for an interim remedial option (IRO) at an urban brownfield redevelopment project encompassing an 85-acre municipal landfill. The data set was gathered during the pre-design investigation. The IRO was chosen to target chlorinated benzene source material within the unsaturated zone and migrating plume. The planned IRO implementation consisted of the following:

- Installing a total of 45 co-located electrical resistivity heating and vapor extraction wells to a depth of 57 feet below ground surface (bgs).
- Treating extracted vapors with granular activated carbon.
- Annual monitoring, post thermal remediation, by sampling 10 groundwater screening points advanced to approximately 50 feet bgs using direct-push drilling techniques. The temporary groundwater screening points would be re-installed for each monitoring event.

Since the IRO has not been implemented, the social cost estimate converted these future costs and returns to present year values.

2.1.3. Environmental Impact Evaluation

An environmental footprint analysis was performed for each case study with the Navy Facilities Engineering Command (NAVFAC) SiteWise™ program (NAVFAC, 2011). Inputs for the analysis were obtained from lithological borings, field results reports, field notes, and engineering data provided by CDM Smith.

2.1.4. Economic Impact Evaluation

A cost-benefit analysis was conducted for Case Study 1 using existing engineering data and invoices. Due to confidentiality issues, the cost of each line item is not presented. A cost-benefit analysis was not conducted for Case Study 2 because a sustainability assessment was only performed on the chosen IRO for the site.

2.1.5. Social Impact Evaluation

Cost borne by society due to environmental, economic, and social impacts was calculated by identifying the social monetary values associated with the environmental footprint analysis metrics. For this evaluation, social costs were taken from the documents focused on emissions and energy described below. Social costs are often based on integrated assessment models which combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single framework. The social costs of some environmental metrics are presented at several discount rates. In general terms, a discount rate is a method of aggregating a series of future net benefits and costs into an estimate of present value (Field, 2001). All things being equal, applying a higher discount rate results in lower future social costs and vice versa. For example, the social cost of carbon dioxide (CO_2) emissions per metric ton in 2010 and 2050 at a 5 percent discount rate is $11 and $27, respectively; while the social cost of CO2 emissions in 2010 and 2050 at a 2.5 percent discount rate is $52 and $98, respectively (USG, 2013). The social cost of carbon at a 2.5 percent discount rate represents the costs society will endure in the future in present dollar values. Because the social cost is higher in the future, it essentially stresses the importance to mitigate the environmental factor causing the social costs now versus in the future.

The social cost of CO_2 emissions, calculated by the U. S. Government Interagency Working Group on Social Cost of Carbon in 2013, represents "monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change." Four values representing the social cost of CO_2 were presented in the report: three values were based on the average social cost of CO_2 from three integrated assessment models at discount rates of 2.5, 3, and 5 percent, and the fourth value represented the 95th percentile social cost of CO_2 estimated across all three models at a 3-percent discount rate. The integrated assessment models included the Dynamic Integrated Climate and Economy (DICE), Policy Analysis of the Greenhouse Effect (PAGE), and Climate Framework for Uncertainty, Negotiation and Distribution (FUND). These models are used in the Intergovernmental Panel on Climate Change's (IPCC's) assessment reports (e.g., IPPC's 2000 Special Report on Emission Scenarios). Out of the four discount rates used by U.S. Government, the estimated social cost of CO_2 at a 3-percent discount rate, which was chosen because the social rate of time preference in last three decades has averaged around 3 percent in real terms (Federal Circular A-941)[1] and was most often used in prior studies (e.g., (Anthoff and Toi, 2013).

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[1] This 2003 Circular provides the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis and is available at http://www.whitehouse.gov/omb/circulars_a004_a-4

The social cost of methane (CH_4) and nitrous oxide (N_2O) emissions calculated by EPA's National Center for Environmental Economics in 2012 represents "the present value of the future damages that would arise from an incremental unit of CH_4 and N_2O (typically one metric ton) being emitted in a given year." The social cost of CH_4 and N_2O presented in this case study is based on its greenhouse damage potential[2], and encompasses impacts from climate change on all relevant market and non-market sectors, including agriculture, energy production, water availability, human health, coastal communities, and biodiversity. Four values representing the social cost of CH_4 and N_2O were presented: three values were based on the average social cost from the DICE economic model and the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) at discount rates of 2.5, 3, and 5 percent, and the fourth value represented the 95th percentile social cost of CH_4 and N_2O across both models at a 3 percent discount rate. The MAGICC climate model has been used in IPCC reports (e.g., IPPC's 2000 Special Report on Emission Scenarios). Out of the four discount rates used by Marten et al. (2012), this study estimated the social cost of CH_4 and N_2O at the 3 percent discount rate.

The social costs of nitrogen oxides (NO_x), sulfur dioxide (SO_2), and coarse particulate matter (PM_{10}) emissions calculated by Muller and Mendelsohn (2010)

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[2] Marten et al. (2012) evaluated the use of global warming potentials to convert marginal non-CO_2 GHG emission reductions into CO_2 equivalent (-e) reductions using the social cost of CO_2. They concluded that this conversion can lead to substantial errors for the abatement benefits of individual gases. Based on this observation, social cost of individual gases was used rather than the social cost of CO_2-e.

represent the consequences of emissions from air quality modeling, exposure, dose-response, and valuation based on the Air Pollution Emission Experiments and Policy (APEEP) Model. This model uses emission data from the EPA. The consequences include, but are not limited to, health effects, reduced crop and timber yields, materials depreciation, lost recreation services, and reduced visibility. A majority of the social costs from these emissions are due to impacts on human health, especially premature mortality. The APEEP model attributes a dollar value to the mortality rates from exposures to fine particles and ozone. The 10,000 pollution sources in the model comprise individual, grouped point, and ground-level sources identified by the EPA. Muller and Mendelsohn (2010) presented the social costs of these emissions in terms of marginal damages of emissions across the United States at different quantiles (1st, 25th, 50th, 75th, 99th, and 99.9th). Marginal damage is the incremental loss of net benefits to society resulting from the production of one additional ton of NO_x, SO_2, and PM_{10} emissions. The 1st and 99.99th percentiles represent the lowest- marginal damage and highest-marginal damage, respectively. The marginal damages of emissions near the 50th percentile are found in suburban locations and small urban areas, while highest marginal damages are located in the largest metropolitan areas (Muller and Mendelsohn 2010). The average social cost of NO_x, SO_2, and PM_{10} emissions at the 50th percentile were used to perform the social impact evaluation, since both case study sites are located in small urban areas.

The social cost of total energy use estimated by Greenstone and Looney (2011) represents the non-carbon social costs from fossil fuel electricity generation. In contrast, the *carbon* social costs from electricity generation were already accounted for in the CO_2 emissions discussion above. The non-carbon social impacts from energy use include, but are not limited to, health costs, shortened life spans, higher military expenditures and foreign policy constraints, and expensive environmental clean-ups. The non-carbon social costs were calculated from the monetized costs resulting from emissions of SO_2, NO_x, $PM_{2.5}$, and PM_{10} from existing natural gas and coal power plants, assuming the value of a statistical human life of $6 million (in year 2000 US dollars). The price of a statistical life is based on a 2010 National Research Council report that assessed external costs and benefits that are associated with the production, distribution, and use of energy. The non-carbon social costs do not include "upstream" social impacts resulting from mining, drilling, construction, and other activities that are not directly associated with electricity generation (Greenstone and Looney 2011).

Impacts on other components of society, such as the immediate ecosystem, property value, lost or reduced income by the local community due to site cleanup activities, and aesthetic value are important factors to consider while evaluating the impact to society from a remediation project. However, the social costs estimated here do not capture these attributes due to paucity of data.

To calculate social cost, each sustainability metric calculated through an environmental footprint analysis were multiplied by the associated unit social cost using the formula:

Environmental Footprint Analysis Sustainability Metric	X	Unit Social Cost of Sustainability Metric	=	Costs Borne by Society

The sustainability metrics generated from these footprint analyses and the associated social costs included the components described below.

- *GHG Emissions:* The GHG emission footprint calculation in SiteWise^{TM} includes CO_2, CH_4, and N_2O emissions, based on EPA's 2008 Climate Leaders Program Direct Emissions from Stationary Combustion Sources report (NAVFAC, 2011). In the United States, GHG emissions consist of more than 99 percent CO_2 and less than 1 percent CH_4 and N_2O (USEPA, 2008). Additional GHG contributors, such as water vapor, ozone, and chlorofluorocarbons were not included in the total emissions calculated by either NAVFAC or EPA. GHG emissions are quantified in metric tons. In order to calculate the social cost of GHG emissions, the per ton emission values were broken down into CO_2, CH_4, and N_2O. The estimated value was then monetized using social costs drawn from the U. S. Government Interagency Working Group on Social Cost of Carbon (2013) and EPA's National Center for Environmental Economics (2012). In 2010, the social cost of CO_2, CH_4, and N_2O were estimated to be \$33, \$810, and \$13,000 per metric ton, respectively. The significantly higher social cost estimates for an additional ton of CH_4, or N_2O relative to CO_2 can be attributed to significantly larger radiative forcing generated by CH_4 or N_2O (USG, 2013; Marten and Newbold 2012). Radiative forcing is the amount of radiated energy received by the earth in relation to the energy radiated back into space. CH_4 and N_2O cause positive radiative forcing by decreasing the amount of radiated energy sent back to space, in turn warming the earth's atmosphere more than the same quantity of CO_2 (Kump et al., 2011).

The social cost of GHG emissions per metric ton estimated at 2010 prices and blended for the expected ratios of CO_2, CH_4, and N_2O is:

$$(0.99\times\$33 \text{ per metric ton of } CO_2) + (0.005\times\$810 \text{ per metric ton of } CH_4) +$$

$$(0.005\times13{,}000 \text{ per metric ton of } N_2O) = \$101.72$$

The 2010 social cost of GHG emissions was scaled up to the 2012 level using the U. S. inflation calculator (http://www.usinflationcalculator.com/). This calculator uses the latest U. S. government consumer price index, released on August 15, 2013, to adjust for inflation over time. The cumulative rate of inflation from 2010 to 2012 is 5.3 percent.

- *NO_x Emissions: NO_x* emissions are quantified in metric tons. The footprint tool-estimated NO_x was monetized using social cost values drawn from Muller and Mendelsohn (2010). In 2002, the social cost of NO_x was estimated at \$250 per metric ton using the 50^{th} quantile marginal damages of emissions (Muller and Mendelsohn, 2010), which was also scaled up to 2012 level.
- *SO_x Emissions: SO_x* emissions quantified in metric tons were monetized using social cost values drawn from Muller and Mendelsohn (2010). In

2002, the social cost of SO_x was $970 per metric ton using the marginal damages of emissions estimated at the 50^{th} quantile (Muller and Mendelsohn, 2010), which was scaled up to the 2012 level as before.

- *PM_{10} Emissions:* PM_{10} emissions were estimated in metric tons and monetized using Muller and Mendelsohn (2010). In 2002, the social cost of PM_{10} was estimated to be $170 per metric ton using the marginal damage of emissions estimated at 50^{th} quantile (Muller and Mendelsohn, 2010), which was scaled up to the 2012 level as well.
- *Total Energy Used:* The total energy used is quantified in millions of British thermal units (MMBTUs). The non-carbon social costs of fossil fuel use were estimated to be $0.034 per kilowatt hour (kWh) in 2000 (Greenstone and Looney 2011) as before. The non-carbon social cost of total energy estimated at 2012 prices was $0.04 per kWh or $0.11.76 per MMBTU (using the conversion factor of one kWh equals 0.0034 MMBTUs). **Table 2-2** displays the unit social cost of each metric adjusted to their estimated 2012 values. A sensitivity analysis evaluating the effect of the discount rate on the costs borne by society is discussed later in this chapter.

Table 2-2: Unit Social Cost of Environmental Impact Metrics

Social Impact Metric	Societal Cost in 2012
GHG (per metric ton)[1]	$107.10
NOx (per metric ton)[2]	$319.06
SO_2 (per metric ton)[2]	$1,237.94
PM_{10} (per metric ton)[2]	$216.96
Total Energy (MMBTUs)[3]	$11.76

Sources: [1]- USG, 2013; Marten and Newbold, 2012; [2]- Muller and Mendelsohn, 2010; [3]- Greenstone and Looney, 2011.

2.2. Results and Discussion

This research calculated sustainability metrics with associated social costs. Assigned dollar-value social costs have not been developed for several sustainability metrics, such as water usage, so they were not included. Because the field investigation (Case Study 1) was conducted in 2012, the social impacts were calculated for that year. The IRO (Case Study 2) has not been conducted to date; however, for the purpose of this case study evaluation the calculations were performed as if the thermal treatment was applied in 2012, and the annual monitoring events occurred from 2013 through 2015.

2.2.1. Case Study 1 - Phased Focused Site Characterization

Table 2-3 presents a summary of the results from the environmental footprint analysis, which shows a significant reduction in environmental impacts for a phased focused site characterization approach compared to conventional characterization methods.

Table 2-3: Case Study I - Phased Focused Approach: Environmental Impact Evaluation

A. Sustainability Metrics

Site Characterization Alternatives	GHG Emissions (metric ton)	Total Energy Used (MMBTUs)	Water Usage (gallons)	NO_x Emissions (metric ton)	SO_x Emissions (metric ton)	PM_{10} Emissions (metric ton)
Conventional Investigation	9.05	1.18E+02	1.11E+02	2.00E-02	2.03E-03	6.34E-04
Phased Focused Investigation	5.84	7.31E+01	1.11E+02	1.15E-02	1.20E-03	5.85E-04

B. Relative Impact

Site Characterization Alternatives	GHG Emissions	Total Energy Used	Water Usage	NO_x Emissions	SO_x Emissions	PM_{10} Emissions
Conventional Investigation	High	High	High	High	High	High
Phased Focused Investigation	Medium	Medium	High	Medium	Medium	High

By implementing a phased focused site characterization compared to a conventional approach, the environmental impact showed a reduction of 35 percent in GHG emissions, 38 percent in total energy use, 43 percent in NO_x emissions, 41 percent in SO_x emissions, and 8 percent in PM_{10} emissions. The relative impact rating generated by SiteWise™ was reduced from high to medium in all environmental impact categories except PM_{10} emissions and water usage. The results suggest that GHG emissions, total energy used, and water used are responsible for the greatest environmental impacts. The total amount of NO_x, SO_x, and PM_{10} emissions produced for both site characterization approaches were far below one metric ton.

Table 2-4 presents the cost-benefit analysis, which shows a 38 percent reduction in project implementation costs by conducting a phased focused approach, versus a conventional LNAPL investigation.

Table 2-4: Case Study I – Phased Focused Approach: Economic Impact Evaluation of Project Implementation

Line Item	Conventional Investigation	Phased Focused Investigation
Subcontractor Costs	$31,336.00	$33,937.00
Analytical Costs	$44,278.00	$10,478.00
Consultant Costs	$37,180.00	$24,882.00
Grand Total	***$112,794.00***	***$69,297.00***

The total cost of analytical services was reduced by 77 percent, largely due to a decrease in numbers of soil and groundwater samples submitted to the laboratory by making use of *in situ* screening tools and a phased focused sampling approach. The reduction in the number of field days resulted in a 34 percent reduction in the cost of consulting services. On the other hand, the subcontractor cost increased by 8 percent, as the UVOST technology is more expensive than a drill rig for the collection of soil and groundwater samples. The increase in subcontractor cost did not outweigh the cost savings from the decreased analytical and consulting services expenses.

Table 2-5 presents the costs borne by society for the two site characterization approaches, which shows a net reduction of 37 percent for the phased focused approach compared to a conventional investigation.

Table 2-5: Case Study I – Phased Focused Approach: Costs Borne by Society

Site Characterization Alternatives	GHG Emissions	Total Energy Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Costs Borne By Society
	metric ton	MMBTU	metric ton	metric ton	metric ton	Total Dollars
Conventional Investigation	$969.26	$1,387.68	$6.38	$2.51	$0.14	$2,365.97
Phased Focused Investigation	$625.46	$859.66	$3.67	$1.49	$0.13	$1,490.40

The majority of the savings towards the cost borne by society were realized through reduced GHG emissions (41 percent reduction in costs borne by society) and total energy used (58 percent reduction in costs borne by society). The cost borne by society from the NO_x, SO_x, and PM_{10} emissions was minimal: NO_x and SO_x emissions were below $10, while PM_{10} emissions were under $0.15.

The first case study results suggest that the phased focused field approach would have significantly lower environmental, economic, and social impacts than a conventional field approach.

2.2.2. Case Study 2 - In Situ Thermal IRO

Table 2-6 presents the results from the environmental footprint analysis, which indicates that the majority of the environmental impacts occur during the construction and thermal treatment stages, as opposed to post-treatment monitoring.

Table 2-6: Case Study II – In Situ Thermal IRO: Environmental Impact Evaluation

***In-Situ* Thermal IRO**	**GHG Emissions (metric ton)**	**Total Energy Used (MMBTUs)**	**NO_x emissions (metric ton)**	**SO_x Emissions (metric ton)**	**PM_{10} Emissions (metric ton)**
Thermal Treatment - ERH	2.99E+03	5.81E+04	3.70E+01	2.60E+01	1.60E+00
Annual Monitoring	8.71E-01	1.13E+01	7.81E-03	3.70E-04	1.16E-04

Table 2-7 presents the costs borne by society from the *in situ* thermal remediation IRO, including the cost of annual monitoring.

Table 2-7: Case Study II – In Situ Thermal IRO: Costs Borne by Society

In-Situ Thermal IRO	Year	GHG Emissions	Total Energy Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Costs Borne By Society
		(metric ton)	(MMBTU)	(metric ton)	(metric ton)	(metric ton)	Total Dollars
Thermal Treatment - ERH	2012	$320,229.00	$683,256.00	$11,805.22	$32,186.44	$347.14	$1,047,823.80
Yearly Monitoring	2013	$94.91	$135.37	$2.54	$0.47	$0.03	$233.31
	2014	$97.76	$139.44	$2.61	$0.48	$0.03	$240.31
	2015	$100.69	$143.62	$2.69	$0.49	$0.03	$247.52

The costs were calculated by multiplying the environmental impact metrics by the social cost for the year the impact occurred. The social impacts show that the thermal treatment stage results in a significantly higher cost compared to the post-treatment annual monitoring, just as observed for the environmental footprint above. Overall, the sustainability metrics that contribute the greatest social impact are total energy used, GHG, NO_x, and SO_x emissions, with total energy used and GHG providing the greatest contribution by one order of magnitude or more.

An annual 3 percent discount rate was applied in order to capture the future social costs from the monitoring stage in 2014 and 2015. The costs during each subsequent annual monitoring event appear to be increasing, although they are equal if the discount rate is assumed to be a proxy for future inflation. Furthermore, the costs transferred to the future years can be interpreted as social impacts due to the continuous output of emissions and use of energy and water resources. To best serve society, every effort should be made to decrease the remedial action duration in order to reduce the accumulation of impacts from emissions and resource use over time.

In both case studies, the results indicate that total energy used and GHG emissions contributed the most to the costs borne by society. Thus, any improvements that focus on reducing the total energy used and GHG emissions during a remediation project's life cycle would have significant positive impact on society. In addition, the evaluation illustrated that social impacts are metric specific. Future research may explore the roles of different sustainability metrics and how they might individually and collectively impact social costs. From an environmental management perspective, reducing the number of sustainability metrics might lead to a faster and less expensive evaluation; however, ignoring less influential sustainability metric(s) might result in an under-estimation of social costs.

2.2.3. Sensitivity Analysis

A sensitivity analysis was conducted to evaluate how the choice of discount rate affects the calculated social costs of environmental metrics. As previously illustrated, GHG emissions was one of the major contributors to the costs borne by society. The GHG emission footprint calculation in SiteWise™ includes CO_2, CH_4, and N_2O emissions. The literature presented the social costs of these emissions at discount rates of 2.5, 3, and 5 percent. **Table 2-8**, column 2 shows the 2012 social costs of GHG emissions per metric ton at 2.5 percent, 3 percent, and 5 percent discount rates. The difference in social cost of GHG emissions between a 2.5 and 3 percent discount rate was relatively small, approximately $50. However, the 5 percent discount rate resulted in approximately $70 to $120 less than the 3 percent and 2.5 percent discount rates, respectively.

Table 2-8: Sensitivity Analysis of the Social Cost of Greenhouse Gas Emissions and Costs Borne By Society from Case Study 1

Discount Rate	**2012 Social Cost of GHG Emissions**	**2012 Costs Borne By Society: Phased Focused**	**2012 Costs Borne By Society: Conventional**
	(per metric ton)	**(total dollars)**	**(total dollars)**
2.5%	$165.29	$1,830.23	$2,892.59
3%	$107.10	$1,490.40	$2,365.97
5%	$31.84	$1,050.88	$1,684.86

Table 2-8, columns 3 and 4 show the calculated social costs by the phased focused and conventional investigations, respectively, using the GHG values in column 2 as well as the social costs of NO_x, SO_x, PM_{10} emissions, and total energy used[3] presented previously. The highest costs borne by society calculated for both investigation approaches were obtained using a 2.5 percent discount rate, while the lowest costs were obtained with the 5 percent discount rate. The range of costs borne by society was large, spanning a difference of approximately 58 percent.

The sensitivity analysis illustrates how significantly the social costs can vary by using one discount rate over the other. Lower discount rates suggest that society is

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[3] The literature used to identify the social cost of NO_x, SO_x, and PM_{10} emissions, as well as total energy used did not calculate their associated social cost at varying discount rates. Therefore, the social costs of these metrics were not varied for this analysis.

placing more weight on the future, while a higher discount rate places more weight on the present. The social costs for the environmental metrics presented in this case study represent social impacts both in the short and long term. However, there appears to be more weight on long-term social impacts such as the effects of climate change and human health. In addition, economists argue that discount rates should proxy market transactions in which people reveal how they actually make intertemporal tradeoffs. This tradeoff is a process by which consumers make decisions based on benefits and costs that include both the present period and future consequences flowing from today's decisions (Field, 2001). Lower discount rates should be used when calculating costs borne by society for a remediation project, to take into account current market transactions and place more weight on long-term social impacts as represented by the social cost of environmental metrics.

2.3. Conclusions

The remediation sector has approached sustainability assessments by conducting environmental footprint analyses and LCAs. These approaches have failed to capture the impact to the social and economic aspects of remediation and, therefore, do not address the triple bottom line of sustainability. This chapter presented a methodology to identify the costs borne by society from a remediation project's life cycle. Limitations of this case study include a lack in literature diversity and data gaps associated the social cost of environmental metrics, which prevented us from capturing the full extent of the costs borne by society. However, this study is a starting point that motivates future research aimed at developing more comprehensive social cost estimates. As such, it is important that environmental researchers and professionals begin to identify, update, and account for the socio-economic factors that are impacted by remediation activities.

In addition, this study shows that the costs borne by society from a contaminated site remediation project can be significant and, therefore, continued effort should be made to minimize these costs. Potential strategies to minimize or offset social costs by implementing risk-based cleanups, natural attenuation optimization, remedial approaches to reduce mass flux/mass discharge, re-use of remediated soil and groundwater, and property redevelopment, among others, can be explored. Our results demonstrate that SR practices during the site characterization stage (e.g., phased focused investigations, etc.) are an improvement over conventional, costly lab-based remedial investigations. The results can also serve as supporting documentation for conducting a sustainability assessment at the site characterization stage to reduce environmental and social impacts.

This study broke new ground, and consequently faced several challenges. The first challenge arose during the literature review to identify social costs associated with sustainability metrics. Since a single source containing social costs for all sustainability metrics does not exist, several sources were used, each of which relied upon different models for calculating costs. The challenge lies with the sustainability assessor to determine which sources and models to use for a social impact evaluation. Does the assessor choose a source that uses a well-established model, or sources that use the same model for several metrics? Does the assessor take an average of several sources instead of relying on just one? For this study, sources where a government agency was either the author or source of the data. EPA was among the authors for calculating the social cost of CO_2, CH_4, and N_2O emissions. The social costs of NO_x, SO_x, and PM_{10} emissions were based on the APEEP model, which used emission data from the EPA. Finally, the social cost of energy used incorporated data presented in the 2010 U. S. Government Interagency Working Group on Social Cost of Carbon.

In the literature, social costs were presented at different quantiles (e.g., 25^{th} vs. 50^{th} quantile) or at different discount rates (e.g., 3 percent vs. 5 percent). How does the assessor go about choosing the best option? As shown in the sensitivity analysis, the selection of a discount rate can have a significant effect on the cost borne by society calculation.

The second challenge was the lack of source material to determine the social cost for some of the environmental footprint metrics. The NAVFAC SiteWise™ tool calculates environmental impacts for water consumption, risk of fatal accident, and risk of injury. SiteWise™ calculates GHG emissions in terms of CO_2, CH_4, and N_2O, but additional GHG contributors such as ozone and water vapor are not included in its output. Due to the lack of source material and the unknown social impact from ozone and water vapor, the full extent of the GHG cost borne by society based on the limited SiteWise™ metrics could not be calculated.

Another challenge lies with the possibility of offsetting costs borne by society. For example, the second case study calculated the social cost from total energy used, GHG, NO_x, and SO_x emissions at approximately \$683, 256.00, \$320,000, \$11,800, and

$32,000 for construction and application of thermal treatment. In order to offset the costs borne by society, the responsible party would have to “pay back” society a significant amount. Potential approaches for offsetting costs borne by society include purchasing of carbon and renewable energy credits, donations towards causes affecting the local community, and investing in the local community by creating employment opportunities. Social benefits from successful cleanup of the contaminated media, site redevelopment, and/or re-use of remediated soil and groundwater might also assist in offsetting the costs borne by society. Such estimates should be included in future social impact evaluations. From an environmental management perspective, it would be advantageous to develop remedial approaches that have low social costs by implementing technologies and approaches that produce low GHG, SO_x, and NO_x emissions and use less energy.

Lastly, the social costs used for the social impact evaluation were derived from environmental, social, and economic models. The social or socio-economic cost/benefit related to an increase in property value and quality of life by local communities has not been represented in this case study.

Future research should assist the remediation sector in developing a comprehensive list of social costs for environmental impact metrics. Future work should also explore sensitivity analyses of available sources to narrow down and clearly define which social cost value to use and why (e.g., investigate social cost of CO_2 at various discount rates). The valuation of water resources and insurance valuation for accidents could be an interesting extension of this work. Additional research could also focus on developing methodologies to assess socio-economic costs and benefits related to increased property value and societal quality of life in local communities.

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Chapter 3

QUANTIFYING GLOBAL IMPACTS TO SOCIETY FROM THE CONSUMPTION OF NATURAL RESOURCES DURING ENVIRONMENTAL REMEDIATION ACTIVITIES

(This chapter has been published in the journal, Journal of Industrial Ecology)

Abstract

Environmental remediation activities often require the management of large volumes of water and the consumption of significant amounts of local natural resources, including energy and fossil fuels. Traditionally, proposed remedial approaches for a specific cleanup scenario are evaluated by overall project implementation cost, timeframe of the cleanup, and effectiveness to meet cleanup goals. A new paradigm shift, referred to as sustainable remediation, has influenced the remediation industry to consider environmental, social, and economic impacts from cleanup activities. An environmental footprint analysis is the most common method to evaluate environmental implications of cleanup approaches. Presently, these footprint tools do not associate the environmental implications with global impacts. In this article, the method has been extended to integrate the social cost of carbon emissions to quantify global impacts. The case study site is a former aircraft parts manufacturing facility which caused chlorinated solvent contamination in soil and groundwater beneath the building. A groundwater pump-and-treat system was initially installed, followed by its gradual phase out with concurrent phase in of in situ bioremediation. The case study evaluates the monetized societal

benefits from quantifying carbon emission impacts of the proposed cleanup approaches and alternative scenarios. Our results suggest societal impacts based on monetized carbon emissions can be reduced by 27% by optimizing the remediation processes. The sensitivity analysis results elucidate how variation in carbon prices and social discount rates can influence cleanup decisions for remediation projects.

3.1. Introduction

Remediation is the process of containing or removing contamination from the environment. An array of technologies currently used today were developed in the mid-1970s through the 1990s to clean up contamination, including groundwater pump-and-treat, soil excavation, waste incineration, and promotion of biological and chemical reactions within the subsurface (*in situ*) to encourage degradation of contaminants. Over the past four decades, the decision making process to select a site-specific cleanup technology has moved from a cost-centered approach to technology feasibility and risk-based approaches (Pollard et al., 2004). Today the remediation industry is progressing toward incorporation of sustainability benchmarks into the decision making process to evaluate environmental and cost implications from remedial actions. This concept, referred as sustainable remediation, identifies, catalogs, and addresses impacts to the environment, society, and economy (i.e., the triple bottom line of sustainability) during cleanup activities (Hadley and Harclerode, 2015; USEPA, 2012a, 2010; ITRC, 2011a, 2011b; Reddy et al., 2011; Bardos et al., 2011a,b; Ellis and Hadley, 2009; Pollard et al., 2004).

A commonly implemented sustainable remediation practice is to choose and design a remediation process that consumes the least amount of natural resources (Hadley and Harclerode, 2015; USEPA, 2012a, 2010a; ITRC, 2011a,b; and Ellis and Hadley, 2009). Remediation activities typically consume large amounts of energy, water, and other natural resources both on and off site. On-site resource consumption occurs on a specific local scale, defined by the contaminant boundaries. Off-site consumption occurs during transportation activities involving site workers and bulk supplies (such as treatment chemicals, construction materials, and specialized equipment). Even though the majority of natural resources are consumed on a relatively local scale during cleanup, the consumption of these resources have both local and global impacts.

Currently, footprint analysis tools are used to assess environmental implications associated with cleanup activities. Environmental metrics commonly evaluated include emissions of greenhouse gases (GHG), nitrogen oxides (NO_x), sulfur oxides (SO_x), and coarse particulate matter (PM_{10}), as well as the total energy and water consumed (NAVFAC, 2013; USEPA, 2012a). Presently, these tools do not link the environmental footprint results with global impacts. For example, GHG emissions contribute to climate change, which is an inherently global process (Field et al., 2014). Life cycle impact assessment tools, such as the United States Environmental Protection Agency (USEPA) Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare, 2002), make the link between environmental metrics and global impacts. However, detailed life cycle assessment (LCA) is rarely applied to remediation projects, thereby missing the link between cleanup activities (e.g., resource consumption) and global impacts.

In addition to assessing environmental implications from cleanup activities, consideration of social and economic effects while deciding the remediation option is typically limited to the cost of project implementation, community acceptance, and sometimes worker health and safety risk (Hadley and Harclerode, 2015; NAVFAC, 2013; USEPA, 2012a). Apart from workers' accident risk, there are many other socio-economic factors that could be considered, including quality of life, property values, ability to reuse property, economic vitality, cultural resources, and related externality cost (i.e., social cost of environmental metrics) (Bohmholdt, 2014; Harclerode et al., 2013; Holland et al., 2013; and Oughton, 2013). These socio-economic factors are currently not included in the decision-making process, largely due to lack of readily available supporting information that can be used to evaluate them. In addition, environmental regulators (e.g., U.S. Environmental Protection Agency [EPA]) resist incorporation of sustainable remediation principles largely because they are bound by the constraints of regulatory processes, protocols, and preferences, and are focused on the act of remediation rather than its long-term and global implications (Hadley and Harclerode, 2015).

In order to address this knowledge gap, we propose a method that links environmental footprint analysis metrics to global socio-economic impacts. The method consists of scaling up quantified environmental metrics using non-market valuation techniques to arrive at monetized values of societal dis-amenities (i.e., harm, such as chronic human health impacts and stress on water availability), arising from various remedial approaches. Monetized societal dis-amenities are evaluated using social cost benefit (SCBA) analysis methodology. Recently, Bohmoldt (2014) and Harclerode et al. (2013) have used this method to identify remedial approaches that can have the least socio-economic impacts arising due to natural resources used in the remedial process. This case study builds upon the proposed method by assessing how the variation in carbon prices and social discount rates can influence the SCBA and in turn the cleanup decision for a specific contaminated site.

The proposed method is one step closer than current practice to an integrated impact assessment approach that considers interrelations among the triple bottom line elements. These inter-linkages are represented by the social cost of environmental metrics used to conduct the SCBA. The assessment is considered "integrated" because the results of the footprint analysis act as direct inputs for the socio-economic impact evaluation. Pope et al. (2004) suggested that the sum of an integrated impact assessment incorporating the inter-linkages among the triple bottom line objectives will create a whole greater than the sum of its parts. The proposed method provides an opportunity to move toward such an integrated evaluation approach and creates more sustainable contaminated site clean-ups (Hadley and Harclerode, 2015).

Herein we demonstrate, through a remediation case study, how global impacts can be integrated into the triple bottom line and showcase how local consumption of natural resources can be efficiently utilized through an example of monetizing GHG emissions.

The supporting methodologies and information will be made readily available for industry use and advancement.

3.2. Methods

A carbon footprint analysis was conducted for a remediation project using existing engineering data and invoices to quantify GHG emissions in terms of carbon dioxide equivalents (CO_2-eq) for different remedial approaches. The carbon footprint analysis was extended to quantify global impacts arising from each remedial process by monetizing the emissions using social cost of carbon dioxide (CO_2) values. For this study, global impacts quantified in terms of monetized CO_2-eq values are considered as the cost borne by society due to local consumption of resources during cleanup activities. A sensitivity analysis was conducted to evaluate how different social discount rates and carbon prices influence the monetized value of global GHG emission impacts. Carbon prices were researched from a number of sources, including work by USEPA and the United States Government (USG) Interagency Working Group on Social Cost of Carbon (USG, 2013), as well as market values of carbon drawn from California's Greenhouse Gas Cap-and-Trade Program (C2ES, 2014), Regional Greenhouse Gas Initiative (RGGI) (C2ES 2014), Quebec's Carbon Market (C2ES, 2014), and Synapse Energy Economics, Inc. (Synapse) *2011 Carbon Dioxide Price Forecast* (Johnston, 2011).

3.2.1. Case Study Site

The case study site is a former aircraft parts manufacturing facility that left chlorinated solvent volatile organic compound (VOC) contamination within the shallow aquifer (i.e., groundwater) directly beneath the factory building. Historically, the most common approach to cleanup and/or control of groundwater contamination is the use of a pump-and-treat (P&T) system (SURF, 2013), whereby contaminated groundwater is pumped from the subsurface, purified by above-ground equipment, and discharged to a sewer or surface water drainage channel. The case study P&T system ran the contaminated groundwater through an aerator to remove VOCs by volatilization, and then granular activated carbon (GAC) to remove the remaining VOCs by absorption. A soil vapor extraction (SVE) system was also installed to remove VOCs from the unsaturated (vadose) zone, which encompasses the dry soils above the water table. The extracted vapor was passed through the GAC to remove VOCs before being discharged to the atmosphere. Operation of the SVE system was only necessary from 1997 through 1999, when it reached its cleanup objective.

The P&T system greatly decreased the footprint of the VOC contamination within the groundwater and reduced their concentrations. However, removal efficiencies of VOCs declined over time, which ultimately led to the consideration of an alternative method, enhanced anaerobic bioremediation, in which food-grade chemicals are added to the groundwater to stimulate the existing native bacteria to break down the VOCs and create non-toxic end products. The poor performance and decline of chemical removal efficiency with time is a common problem with P&T systems and thus an important issue for site remediation (ITRC, 2011c; McGuire et al., 2006; Newell et al., 2006; Geosyntec, 2004; and Mackay and Cherry, 1989). In addition, P&T involves the management of large quantities of water, and can consume large amounts of energy from fossil fuel powered utilities over several years to decades or more (Conroy et al., 2014; SURF, 2013; USEPA, 2010a). Furthermore, P&T systems in their later stages become very inefficient, using large amounts of energy to remove small additional increments of contaminant mass. While on the other hand, bioremediation is far less energy and resource intensive, and yet is very effective particularly with lower contaminant starting concentrations, such as encountered at the end of a P&T system's useful life. The replacement of the P&T system with bioremediation reduced the amount of energy and volume of water consumed, and the overall cost of remedy implementation. The active bioremediation was monitored by measuring contaminant concentrations and other natural chemical and biological characteristics of the aquifer throughout the treatment program.

Once the *in situ* bioremediation began, vinyl chloride (VC) was generated temporarily in the groundwater as part of the TCE break-down process. VC is the most toxic of the chlorinated ethylene compounds. Chlorinated VOCs present in groundwater also have the ability to volatilize from the subsurface into overlying buildings, potentially degrading indoor air quality (ITRC 2007). It was only after VC began to appear in August 2005 that the SVE system was re-activated — at a lower vapor flow rate — to act as a sub-slab depressurization system (SSDS), to capture VC before it could potentially migrate into the building and negatively impact indoor air quality.

In order to compare global socio-economic impacts between groundwater pumping and in-place bioremediation, GHG emissions values arrived by a carbon footprint analysis were monetized with a variety of CO_2-eq prices. In addition, the difference in the volume of water utilized and amount of resources consumed were also quantified for each remedial scenario.

The first remedial scenario (I) encompasses the initial treatment system (P&T) operating throughout the contaminated site's life cycle, from 1997 through 2009. SVE was run for just two years, as described above. Site activities conducted under scenario I include groundwater sampling, replacing spent GAC, and operating the P&T and SVE systems. These activities are considered as "operation and maintenance" (O&M) of the remedial system.

Scenario II encompasses the transition from the P&T system to the *in situ* bioremediation approach, better suited to groundwater contaminant conditions at the time. Site activities conducted under scenario II included O&M of the P&T system, followed by its phase-out and simultaneous replacement with bioremediation and subsequent activation of the SSDS. The P&T system was sequentially shut down by turning off one pumping well at a time, while simultaneously injecting into the aquifer food-grade treatment chemicals to sustain the native bacteria. The bioremediation approach started with an upgradient injection. Groundwater flow naturally moved the treatment chemicals into the immediately downgradient (in the direction of groundwater flow) portion of the contaminated aquifer. The first pumping well, also located downgradient, was shut off to avoid removing the treatment chemicals from the groundwater. Injection of additional bio-treatment chemicals proceeded further downgradient over the next few years, and additional pumping wells were taken off line as the treatment chemicals reached those areas as well.

The timeline for each remedial scenario is presented in **Figure 3-1**.

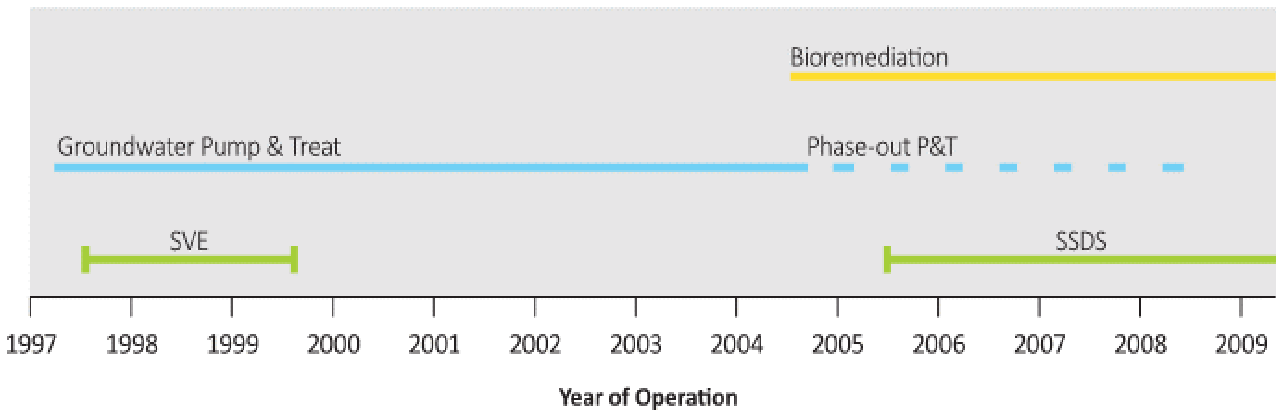


Figure 3-1: Remedial Scenario Timeline*. Scenario I encompasses the O&M of the P&T and SVE system from 1997 to 2009. Scenario II encompasses O&M of the initial remedial system, followed by its phase-out and replacement with bioremediation and SSDS during the same time period.*

3.2.2. Local Consumption and Carbon Footprint of Remedial Scenarios

The carbon footprint for each remedial scenario, represented CO_2-eq, was calculated using primary data from engineering specifications and utility invoices. Engineering specifications include records of material use (e.g., treatment chemicals), number of road trips and total mileage accrued through personnel and materials transport, and logs of heavy machinery (e.g., drill rig) use. Data collected from utility invoices include the total amount of electricity used for operating remediation systems (in particular, blowers and pumps).

The results of the carbon footprint analysis estimate the total amount of GHG emissions from on- and off-site cleanup activities related to transportation, drilling, energy usage, and O&M of the remedial system. A breakdown of each scenario's activities included in the analysis is presented below. The construction of the on-site building to store equipment, as well as the installation of pumps and other infrastructure for the P&T and SVE/SSDS were not included in the footprint analysis. The carbon footprint is quantified as CO_2-eq of various GHGs based on their global warming potentials (C2SE, 2014).

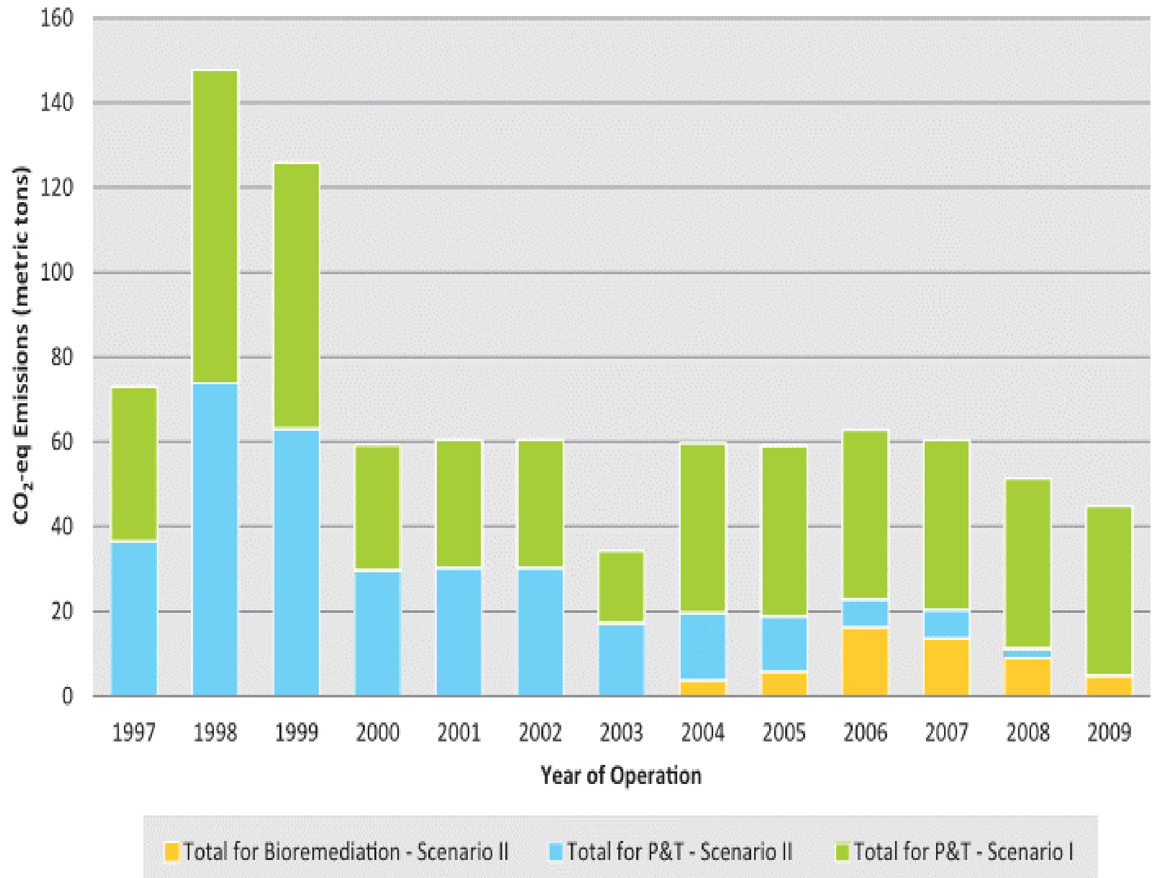
The carbon footprint related to electricity consumption was calculated for each remedial scenario. The total amount of energy consumed was estimated using average power consumption (measured in kilowatts) of the P&T and SVE/SSDS. The total amount of electricity consumed from December 2002 through March 2009 was obtained by summing up utility invoices. Prior to December 2002 (when utility invoices were not available), the average power consumption was estimated not only based on 2002-2009 use, but also in terms of engineering knowledge of similar systems and the operational period of the remedial system components. The bioremediation component associated with scenario II did not use any electricity. However, electricity was used by the P&T, during its phase-out, and by the SSDS in scenario II.

The carbon footprint related to the consumption of fuel from transportation (of site workers and bulk supplies) and drilling for both scenarios was also calculated. In scenario I, monthly visits to the site were required as part of the O&M of the P&T

system. The emissions (i.e., CO_2-eq) generated by traveling to and from the site, deliveries of GAC, and drilling activities were quantified. In scenario II, monthly O&M visits and shipment of GAC gradually decreased over time, starting in 2004, with gradual phase out of the P&T system due to incorporation of bioremediation. Drilling activities increased in 2004 to install injection wells and inject treatment chemicals into the aquifer to promote bioremediation. Additional transportation activities commenced in 2004 to transport the treatment chemicals to the site and investigation-derived waste off site. By 2009, overall fuel consumption was drastically reduced due to success of the bioremediation approach, resulting in a significant reduction in the amount of treatment chemicals and visits required for scenario II O&M.

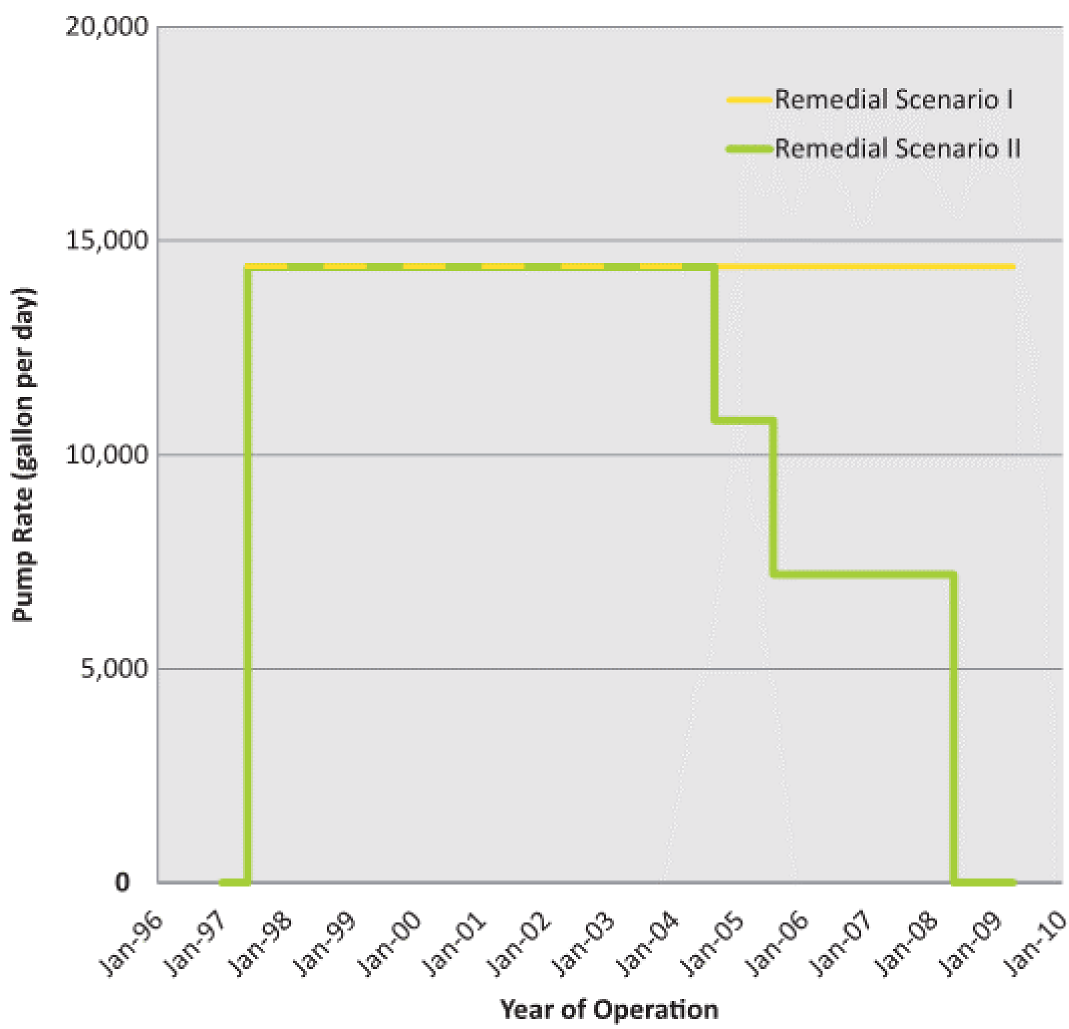
In addition to electricity and fuel usage, the CO_2-eq emissions related to GAC regeneration and natural gas use for the SSDS and the P&T system, respectively, were quantified. The methane produced from the bioremediation process was also measured and translated to CO_2-eq. Methane was measured from the SSDS off gas. The carbon footprint for each remedial scenario is presented **Figure 3-2**.

Figure 3-2: Carbon Footprint for Each Remedial Scenario. *Shows the total amount of CO2e emissions per year for each remedial scenario. The green bar represents scenario I (P&T system only), and the blue and red bars represent scenario II (P&T phase out and phase in bioremediation).*



The volume of water consumed under each remedial scenario was quantified and presented in **Figure 3-3**. P&T consumed a large volume of water constantly. Much less water was required for bioremediation as P&T was phased out, and nearly none after P&T termination in 2008.

Figure 3-3: Volume of Water Managed for Each Remedial Scenario. *The blue line represents scenario I, and the red line represents scenario II.*



3.2.3. Global Impacts from Local Consumption of Resources

3.2.3.1. Social Cost of Carbon

The local consumption of fuel, electricity, and other materials for the remedial approaches was used to estimate global impacts in terms of social cost of CO_2. The social cost of CO_2 emissions as per the USG Interagency Working Group on Social Cost of Carbon in 2013, represents:

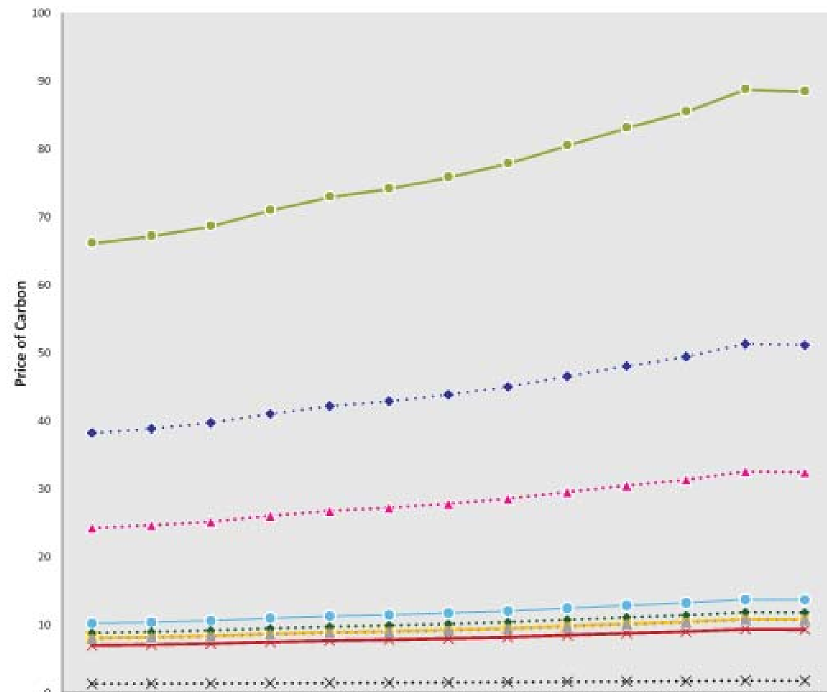
> "…monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change."

The USG social cost of carbon made use of integrated assessment models that combine climate processes, economic growth, and feedbacks between the climate and the global economy. The models included Dynamic Integrated Climate and Economy (DICE), Policy Analysis of the Greenhouse Effect (PAGE), and the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) (USG, 2013). These models are also utilized in the Intergovernmental Panel on Climate Change's (IPCC) assessment reports (IPCC 2000 Special Report on Emission Scenarios).

The social cost of an environmental metric (e.g., CO_2) incorporates the private costs of that metric plus environmental externalities arising from its emissions. The private costs encompass production and manufacturing expenses. The externality value on the other hand represents the monetary value that can be assigned for societal dis-amenities such as long-term global impacts of climate change and associated sea-level rise that can be attributed to that metric. For example, the externality value of CO2 represents costs associated with mitigation of climate change impacts (USG, 2013; Greenstone and Looney, 2011).

The market price of carbon is another metric that incorporates externalities (i.e., societal damages), and represents prices set for carbon trading (cap-and-trade) or carbon taxation programs. **Figure 3-4** shows several published market values and social costs of CO_2 from the literature. In order to adjust for inflation over time, the cost of CO_2 across several years was converted using the USG consumer price index. Several sources have developed values for the market price of CO_2, as shown on **Figure 3-4**, including California Greenhouse Gas Cap-and-Trade Program, RGGI, Quebec's Carbon Market, and Synapse (C2ES, 2014; Johnston, 2011). Based on these sources, the market values of CO_2 in 2009 ranged from $1.80 to $12.44 metric tons.

Figure 3-4: Social Cost and Market Prices of CO_2



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CA GHG Cap-&-Trade (metric ton)	6.99	7.10	7.26	7.50	7.71	7.84	8.01	8.23	8.51	8.78	9.03	9.38	9.34
Regional GHG Initiative (RGGI) (metric ton)	1.35	1.37	1.40	1.45	1.49	1.51	1.55	1.59	1.64	1.69	1.74	1.81	1.88
Quebec's Carbon Market (metric ton)	6.99	7.10	7.26	7.50	7.71	7.84	8.01	8.23	8.51	8.78	9.03	9.38	9.34
USG Social Cost - 5.0% Discount Avg. Yr. (metric ton)	8.10	8.22	8.40	8.69	8.93	9.08	9.28	9.53	9.85	10.17	10.46	10.86	10.82
USG Social Cost - 3.0% Discount Avg. Yr. (metric ton)	24.29	24.67	25.21	26.06	26.79	27.23	27.85	28.59	29.56	30.51	31.38	32.58	32.47
USG Social Cost - 2.5% Discount Avg. Yr. (metric ton)	38.27	38.87	39.73	41.06	42.21	42.90	43.88	45.05	46.57	48.08	49.45	51.34	51.16
USG Social Cost - 3.0% Discount 95th Percentile Year	66.24	67.28	68.76	71.07	73.05	74.25	75.94	77.97	80.61	83.21	85.58	88.86	88.55
Synapse High Bound Price Forecast (short ton)	10.25	10.41	10.64	11.00	11.31	11.49	11.76	12.07	12.48	12.88	13.25	13.76	13.71
Synapse Mid Bound Price Forecast (short ton)	8.86	9.00	9.20	9.51	9.77	9.93	10.16	10.43	10.78	11.13	11.45	11.89	11.84
Synapse Low Bound Price Forecast (short ton)	8.03	8.16	8.34	8.62	8.86	9.00	9.21	9.45	9.77	10.09	10.38	10.78	10.74

Year

In addition to having several literature sources of carbon prices to choose from, these prices are often presented at various discount rates, also shown on **Figure 3-4**. The USG Interagency Report quantified the social cost of CO2 using three discount rates (2.5%, 3%, and 5%). A lower discount rate means society places higher value on future impacts (e.g., climate change and chronic human health impacts). While a higher discount rate means society places higher value on present impacts (e.g., daily traffic congestion and general inconvenience due to site activities taking place). This effect is because a high discount rate implies that a dollar in the near term is more valued than in the future, and vice versa (Bohmholdt, 2014; Field, 2001). We suggest using a lower discount rate to evaluate cleanup scenarios, since the environmental metrics (e.g., GHG emissions) used in footprint analyses are associated with long-term or intergenerational societal impacts. For example, CO2 emissions generated over time are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change (USG, 2013). Therefore, the dollar value associated with the social cost is more valued in the future, than in the near term, to mitigate forthcoming impacts of cumulative emissions (e.g., sea level rise due to climate change), thus supporting the use of a lower discount rate.

A sensitivity analysis was conducted using a variety of sources for carbon prices, as well as several different discount rates. The sensitivity analysis is important because it demonstrates the influence these critical selections have on the estimated costs borne by society and ultimately the cleanup decision for a specific remediation project.

3.2.3.2. Non-Carbon-Emission Social Cost of Energy Use

Greenstone and Looney (2011) calculated the non-carbon-emission social cost of electricity that was generated by burning fossil fuels. This social cost was calculated from the externality costs (i.e., monetized damages) resulting from emissions of sulfur dioxide (SO_2), NO_x, fine particulate matter ($PM_{2.5}$), and PM_{10} from existing natural gas and coal fired power plants. Note that their calculation did not include "upstream" social impacts resulting from mining, drilling, construction, and other activities that are not directly associated with electricity generation. Thus, their study estimated an externality cost (i.e., monetized societal dis-amenities) of $0.036 per kilowatt (kW) in 2010 U.S. dollars, which represents "health costs, shortened life spans, higher military expenditures and foreign policy constraints, and expensive environmental clean-ups". The private cost associated with the production and manufacturing of electricity use was excluded to avoid double counting because this value is already accounted for in the cost of energy usage represented by the social cost of carbon (i.e., private plus externality cost).

3.2.3.3. Social Cost of Additional Environmental Metrics

Muller and Mendelsohn (2010) monetized the social cost of NO_x, SO_x, and PM_{10} emissions in 2002 U.S. dollars at $250, $970, and $170 per metric ton, respectively, for sources located in suburban locations and small urban areas. USEPA's National Center for Environmental Economics monetized the social cost of methane (CH_4) and nitrous oxide (N_2O) emissions in 2010 U.S. dollars at $810 and $13,000 per metric ton, respectively (Marten and Newbold, 2012). This study only quantified emissions in CO_2-

eq and therefore the social cost of these additional metrics was not incorporated into the cost analysis.

Further, impacts to other components of society, such as ecosystem services, property value, lost or reduced income by the local community due to site cleanup activities, and aesthetic and cultural value, are also relevant factors to consider. In this study, we do not capture these values due to lack of literature data or calculation protocols beyond energy, fuel, and water use.

3.2.3.4. Costs Borne By Society

In order to make the linkage between local consumption and related global impacts, we quantified the costs borne by society from CO_2-eq emissions generated by electricity, fuel, and materials (e.g., GAC) use for each remedial scenario. The costs borne by society for each year of remediation were calculated using the following formula:

$$CBS_t = (CO_2\text{-}eq_t \times SCC_t) + (kWh_t \times SCNC_t)$$

in which,

CBS_t = costs borne by society for year t of system operation

CO_2-eq_t = total amount CO_2-eq emissions in metric tons for year t of operation

SCC_t = social cost of carbon per metric ton in year t

kWh_t = total amount of electricity in kilowatt hours used in the year t

$SCNC_t$ = social cost of non-carbon-emissions per kilowatt hour in year t

The value of the costs borne by society in 1997 US dollars, the year remediation began at the site, was calculated using:

$$V_{1997} = \sum [(CBS_t) / (1 + DR)^{t-1997}]$$

in which,
$\sum$, the summation is over the years 1997 through 2009
V_{1997} = value, in 1997 US dollars
t = the year the CBS was accrued
DR = discount rate

For comparison purposes, the costs borne by society in 1997 US dollars (V_{1997}) was converted to 2014 US dollars using the U. S. government consumer price index. **Table 3-1** shows the costs borne by society for each remedial scenario using the Greenstone and Looney (2011) non-carbon-emission social cost of fossil fuel electricity generation, and the USG social cost of CO_2 at 2.5%, 3%, and 5% discount rates.

As previously stated, we suggest using a lower discount rate when conducting a social cost benefit analysis for a remediation project to represent long-term and intergenerational societal dis-amenities. To demonstrate, we compared the difference in the estimated social and market costs of CO_2 between the two remedial scenarios. **Table 3-2** shows the costs borne by society, excluding non-carbon-emission social costs, for each remedial scenario using the USG social cost of CO_2 at2.5% and 5% discount rates and the market value of CO_2 based on California's Greenhouse Gas Cap-and-Trade Program, RGGI, Quebec's Carbon Market, and Synapse Energy Economics, Inc. (Synapse) 2011 Carbon Dioxide Price Forecast at a 2.5% discount rate. Various market prices of carbon were included in this analysis because, presently, there is no absolute market for carbon and these sources provide a range of possible values.

Table 3-1 : Costs Borne By Society (CBS) for Each Remedial Scenario: *U.S. Government (USG) Interagency social cost of carbon at 2.5%, 3%, and 5% discount rates (DR). P&T = Scenario I and Bio = Scenario II.*

	CBS 2.5% DR		**CBS 3% DR**		**CBS 5% DR**	
Year	**P&T: USG 2.5%**	**Bio: USG 2.5%**	**P&T: USG 3.0%**	**Bio: USG 3.0%**	**P&T: USG 5%**	**Bio: USG 5%**
1997	$2,065.76	$2,065.76	$1,312.72	$1,312.72	$440.64	$440.64
1998	$4,078.07	$4,078.07	$2,578.76	$2,578.76	$848.34	$848.34
1999	$3,391.63	$3,391.63	$2,133.73	$2,133.73	$688.48	$688.48
2000	$1,557.09	$1,557.09	$975.03	$975.03	$308.79	$308.79
2001	$1,551.18	$1,551.18	$966.61	$966.61	$300.16	$300.16
2002	$1,514.20	$1,514.20	$939.07	$939.07	$286.19	$286.19
2003	$838.91	$838.91	$518.13	$518.13	$155.47	$155.47
2004	$1,907.80	$932.96	$1,171.10	$573.15	$342.63	$168.40
2005	$1,860.94	$877.73	$1,136.97	$536.71	$326.16	$154.67
2006	$1,816.66	$1,031.59	$1,104.50	$627.67	$311.35	$177.67
2007	$1,772.30	$902.44	$1,072.37	$546.55	$296.54	$151.93
2008	$1,728.14	$484.90	$1,040.31	$292.47	$281.83	$80.08
2009	$1,685.66	$203.89	$1,009.79	$122.69	$268.06	$33.37

***Table 3-2: Social and Market Price of Carbon for Each Remedial Scenario:** Social cost of carbon based on the USG Social Cost at 2.5% and 5% Discount Average per Year. Market price of carbon based on California's Greenhouse Gas (CA GHG) Cap-and-Trade Program, Regional Greenhouse Gas Initiative (RGGI), Quebec's Carbon Market (QCM), and Synapse Energy Economics, Inc. (Synapse) 2011 Carbon Dioxide Price Midbound Forecast. DR = discount rate*

	Social Cost of Carbon		Social Cost of Carbon		Market Price		Market Price		Market Price		Market Price		Market Price	
	P&T: USG 2.5% DR	Bio: USG 2.5% DR	P&T: USG 5% DR	Bio: USG 5% DR	P&T: CA GHG	Bio: CA GHG	P&T: RGGI	Bio: RGGI	P&T: QCM	Bio: QCM	P&T: Synapse 2.5% DR	Bio: Synapse 2.5% DR	P&T: Synapse 2.5% DR	Bio: Synapse 2.5% DR
1997	$2,061.44	$2,061.44	$436.31	$436.31	$376.52	$376.52	$72.72	$72.72	$376.52	$376.52	$389.66	$389.66	$432.95	$432.95
1998	$4,133.06	$4,133.06	$853.23	$853.23	$754.95	$754.95	$145.67	$145.67	$754.95	$754.95	$781.34	$781.34	$868.15	$868.15
1999	$3,513.44	$3,513.44	$707.88	$707.88	$642.02	$642.02	$123.81	$123.81	$642.02	$642.02	$664.26	$664.26	$738.07	$738.07
2000	$1,667.32	$1,667.32	$328.27	$328.27	$304.55	$304.55	$58.88	$58.88	$304.55	$304.55	$315.30	$315.30	$350.33	$350.33
2001	$1,708.32	$1,708.32	$328.20	$328.20	$312.04	$312.04	$60.30	$60.30	$312.04	$312.04	$322.84	$322.84	$358.71	$358.71
2002	$1,693.89	$1,693.89	$317.82	$317.82	$309.56	$309.56	$59.62	$59.62	$309.56	$309.56	$320.12	$320.12	$355.69	$355.69
2003	$958.48	$958.48	$175.42	$175.42	$174.96	$174.96	$33.86	$33.86	$174.96	$174.96	$181.20	$181.20	$201.33	$201.33
2004	$2,242.38	$1,095.04	$400.73	$195.69	$409.65	$200.05	$79.14	$38.65	$409.65	$200.05	$423.87	$206.99	$470.97	$229.99
2005	$2,261.51	$1,065.11	$394.46	$185.78	$413.26	$194.63	$79.64	$37.51	$413.26	$194.63	$427.41	$201.30	$474.90	$223.67
2006	$2,277.89	$1,291.78	$262.97	$219.97	$415.97	$235.90	$80.07	$45.41	$415.97	$235.90	$430.52	$244.15	$478.36	$271.28
2007	$2,285.65	$1,161.82	$257.59	$193.13	$417.38	$212.16	$80.43	$40.88	$417.38	$212.16	$432.10	$219.65	$480.11	$244.05
2008	$2,315.13	$647.37	$375.69	$105.05	$422.98	$118.28	$81.62	$22.82	$422.98	$118.28	$437.69	$122.39	$486.32	$135.99
2009	$2,250.75	$270.10	$356.48	$42.78	$410.91	$49.31	$79.19	$9.50	$410.91	$49.31	$425.30	$51.04	$472.55	$56.71
Total	$29,369.26	$21,267.17	$5,195.05	$4,089.53	$5,364.75	$3,884.93	$1,034.95	$749.63	$5,364.75	$3,884.93	$5,551.60	$4,020.23	$6,168.44	$4,466.92

3.3. Results and Discussion

3.3.1. Carbon Footprint

The total amount of CO_2-eq emissions generated from the local consumption of natural resources for each remedial scenario is presented in **Figures 3-2** and **3-5**. The overall carbon footprint of the initial remediation system decreased by approximately 86.5 % after phasing out the P&T system and replacing it with bioremediation. The amount of CO_2-eq emissions generated for individual elements of the project were also quantified for each remedial scenario, as shown on **Figure 3-5**. A footprint analysis of separate processes in a remedial system identifies which component(s) contribute the most and least towards specific environmental impacts. In scenario I (P&T system only), approximately 78 % of the CO_2-eq emissions were generated from electricity consumption. In scenario II (P&T system phase-out and introduction of bioremediation), electricity and fuel usage each contributed to approximately 50% of the (greatly reduced) CO_2-eq emissions. Such carbon footprint results are typically used to re-design and improve the system components and practices that are generating the majority of CO_2-eq emissions. For example, solar panels and fuel-efficient vehicles could be substituted to reduce the consumption of electricity and fuel.

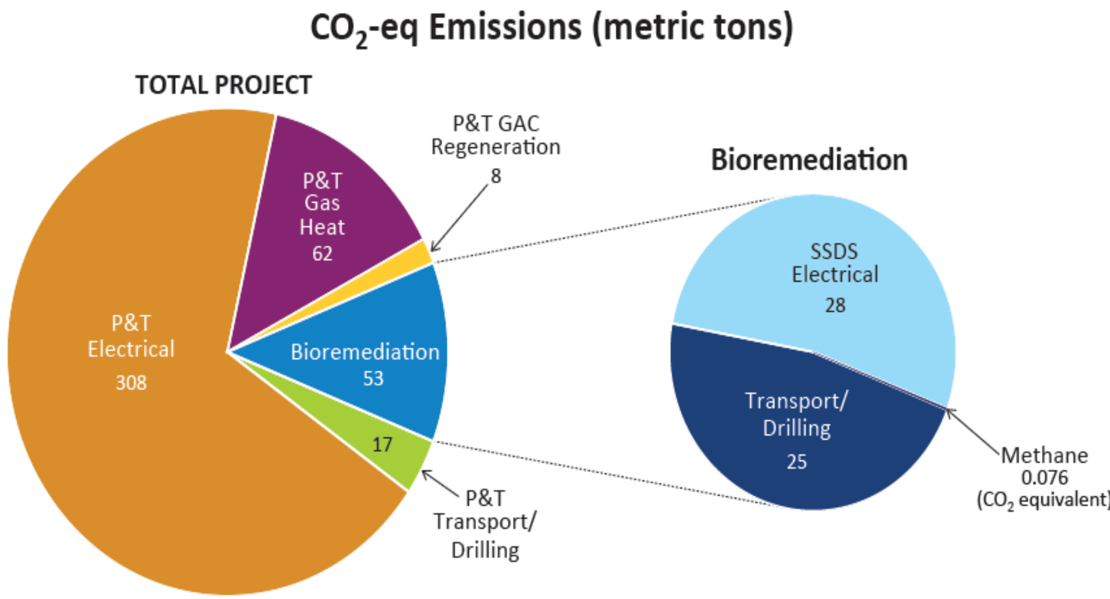


Figure 3-5: Carbon Footprint for Remedial System Components. *Shows the amount of CO2e emissions generated from the consumption of fossil fuels and energy for each remedial system component. Methane was measured in the SSDS off gas.*

3.3.2. Costs Borne By Society

The social cost of an environmental metric links local consumption of natural resources to monetized global impacts. As shown in **Table 3-1**, the costs borne by society, represented by the social costs of CO_2-eq and non-carbon emissions from electricity generation, decreased over time by phasing out the P&T system and incorporating bioremediation. The cumulative social cost calculated using a 2.5 % discount rate is $29,894.67 for scenario I, and $21,792.59 for scenario II; a difference of $8,102.08 (i.e., an overall 27% reduction in monetized global impacts).

To put the costs borne by society from remedial activities into a broader context, the monetized global impacts calculated for scenarios I and II at a 2.5% discount rate were used to predict the costs society may bear from cleaning up the remaining hazardous waste sites in the United States. USEPA projected a total of 169,000 hazardous waste sites will require clean up between 2004 and 2033, excluding small underground storage tank sites (USEPA, 2012b). These site cleanups vary dramatically due to the size of the property and the amount of time required to remove and/or contain the contamination. The case study site is relatively small compared to a typical remediation project. In order to use the case study site as a broad representation of typical cleanup sites, the costs borne by society (using a 2.5% discount rate) from scenarios I and II was scaled up five folds to get a lower and ten folds to get a higher range for an average per-site social cost of remedial activities. Thus, the rough average per-site social cost of remediation might be:

- Scenario I: $150,000 to $300,000
- Scenario II: $110,000 to $220,000

Estimated remediation-related social costs for the remaining 169,000 hazardous waste sites would range between $19 billion and $51 billion. This calculation illustrates that CO_2-eq emissions from the local consumption of resources as part of remedial activities over an extended period of time has the potential to be a significant contributor to monetized global impacts.

3.3.3. Choosing an Appropriate Discount Rate

Table 3-1 shows the costs borne by society for each remedial scenario using various discount rates for the USG social cost of carbon. The discount rate can have a significant effect on the calculated social costs (i.e., monetized global impact). In 2014 US dollars, the difference between the monetized global impacts from the P&T system over the life cycle of the remedial process, using 2.5% and 5% social cost of carbon discounts rates, is $23,985.21. This substantial difference highlights the importance in understanding and incorporating the appropriate discount rate in a SCBA.

By considering a lower discount rate in a SCBA, more weight is placed on long-term, intergenerational impacts. This is simply illustrated by the calculated social costs using a 5% discount rate ($4,089.53 to $5,195.05, Table 2), and with a 2.5% discount rate ($21,267.17 to $29,369.26, **Table 3-2**). Then compare the market value of CO_2-eq ($749.63 to $6,168.44, **Table 3-2**). The higher discount rate places more weight on short term impacts, and therefore the costs borne by society using the USG social cost of CO_2 at a 5% discount rate is closer in value with the total market value of CO_2-eq than the social cost of CO_2 at 2.5% discount rate. The social cost of carbon at a 2.5% discount rate is more representative of increases in the social cost of carbon over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in the response to worsening climate change over time (USG, 2013).

3.3.4. Social Cost vs. Market Price of CO_2 Evaluation

Table 3-2 presents the monetized global damages of CO_2-eq for each remedial scenario, using the USG social cost of carbon at 2.5% and 5% discount rates and several market prices of CO_2. In 2009, the social cost of carbon for replacing P&T with bioremediation ($270.10, USG 2.5% discount rate) is less than the total *market* price of CO_2 for maintaining the P&T system for three out of the four carbon price regimes ($410.91 to $472.55) This analysis shows that the monetized global impacts of the reduced-footprint remedial system eventually became lower than the cost of the old system. Social planners and remediation decision makers could use this comparative analysis to set sustainability goals for system optimization.

The total market value of CO_2 using the RGGI carbon price ranged from $749.63 to $1,034.95. The average total market value of CO_2 of the three other carbon price regimes (California GHG Cap-and-Trade, Quebec's Carbon Market, and Synapse) ranged from $4,078.932 to $5,632.65. The difference in the total market value between RGGI and an average of three other carbon regimes is 82%. Each carbon regime is representative of a specific geographic region and the associated carbon price for each regime is influenced by regional policy, sustainability objects, and stakeholder input. As stated earlier, there is no absolute market for carbon. Therefore careful consideration should be taken in identifying a representative market price of carbon to use for a CBA. The market price used for the analysis should be representative of the site's geographic location and the stakeholder's sustainability objectives.

The cumulative total market price of CO_2-eq (in 2014 US dollars) for scenario I ranged from $1,034.95 to $6,168.44; and for scenario II it ranged from $749.63 to $4,466.92. The long-term potential benefits from reducing the cumulative market cost of CO_2 for a specific project can include a reduction in the required emission credits to be purchased for operating the system, and the affordability to use "saved" CO_2 emission credits to install a system at another cleanup site.

3.3.5. Water Footprint

The literature search did not find a representative social cost of water to include in the cost borne by society calculations. Therefore, the monetized global impacts for each remedial scenario are underestimated due to this missing information.

We found that the amount of water consumed (**Figure 3-3**) was substantially decreased, and ultimately reduced to zero, by phasing out the P&T system and phasing in bioremediation. This decreasing trend parallels the reduction in costs borne by society from enhancing the remedial approach at the case study site. This aspect of reducing local consumption is of particular global importance in regions that are water stressed. The Sustainable Remediation Forum (SURF) recently published guidance on implementing groundwater conservation and reuse practices at remediation sites (SURF, 2013). In alignment with SURF's Guidance, this case study shows the benefits from implementing groundwater conservation practices by transforming the remedial action from an *ex situ* remedy (i.e., removing contaminated media from the subsurface) to an *in situ* remedy (i.e., treating contaminated media in place).

The impact to the triple bottom line from the consumption and management of water resources is not typically evaluated during remedy selection, and remains a knowledge gap within the remediation industry. In addition, treated groundwater extracted to the subsurface is often discharged to a local sewer instead of being re-used. The practice of reusing treated groundwater is uncommon due to several challenges, including public perception, liabilities, water balance and reliability issues, and economic considerations (e.g., additional treatment required prior to reuse) (SURF, 2013). However, the SURF 2013 guidance presented several case studies that illustrated the successful re-use of treated groundwater for agricultural, industrial, ecosystem restoration, and drinking water purposes. The development of social costs of varying water resources would enable social planners and remediation decision makers to incorporate the value of water conservation and re-use efforts into the SCBA. Near-term further research should be directed at developing this metric.

3.4. Conclusion

Remedial practices consume large amounts of natural resources, over long periods of time on a local scale. Although the contamination is treated, the consumption of these resources also results in harmful emissions (e.g., GHG). And the emissions in turn are linked to global harm such as climate change and sea-level rise. Quantification of these global damages in monetary terms provides a measurement tool and an argument for more vigilant environmental stewardship that can be appreciated by a broad swath of society. However, such global costs are not factored into remedy selection; instead only CBA of the project is considered and therefore, socio-economic and long-term environmental impacts are lost. This study presented a simplified approach towards an integrated sustainability assessment for remediation projects, thus enabling stakeholders to move towards the triple bottom line of cleanup activities with fairly simple calculations free from expensive, specialized software.

We demonstrated that a socio-economic impact assessment can support improvement of existing remedial systems and identify new approaches that contribute the least towards monetized global impacts. An environmental footprint analysis in combination with SCBA can be used by social planners and remediation decision makers to not only choose a more sustainable cleanup approach, but to also set and achieve targeted sustainability goals, such as a 20% decrease in monetized global impacts (i.e., costs borne by society) from on-site electricity consumption. Furthermore, the concept of monetized impacts can be used to convince various stakeholders and decision makers to pursue more globally sustainable cleanup remedies.

Technologies that reduce costs borne by society have long term, beneficial supply chain impacts including reduced taxpayer and federal funds required to address global damages. P&T systems are the selected cleanup remedy for a majority of contaminated legacy sites. The industry needs to reconsider long term operation of P&T systems and potential phase out scenarios to reduce natural resource consumption, subsequent global impacts, and project implementation cost. Potential reuse opportunities for the treated groundwater should also be evaluated. Incorporation of reuse methods can assist in mitigating water scarcity concerns and provide lower cost water sources for alternative uses (Lenker et al., 2014; SURF, 2013). Lenker et al. (2014) presents the “value of integrating groundwater conservation and reuse practices into remediation projects to increase their sustainability, and to protect and conserve water resources for future generations”.

In addition to enhancing existing systems, global impacts due to resource consumption should be considered prior to remedial action selection. In contrast, the current practice favored by regulatory agencies in the US is to include such concerns only after the remedy has been chosen. Consideration of resource consumption this late in the project life cycle can result in global impacts that could have been reduced if not avoided altogether. A fully integrated sustainability evaluation allows alternative remedies to be compared more quantitatively and confidently (Hadley and Harclerode, 2015). The remediation industry should consider the development of a flexible, resilient cleanup approach that incorporates a variety of technologies over the project life cycle that use the least resources possible and mitigate socio-economic impacts from continued GHG emissions and water consumption.

As shown in this study, careful consideration should be taken when choosing a carbon price and discount rate for a SCBA. The carbon price and discount rate should be representative of the environmental metrics being used and project objectives. We suggest using a lower discount rate for a remediation project SCBA to incorporate intergenerational and cumulative impacts represented by environmental metrics. Since an absolute market for carbon currently does not exist, we suggest conducting a sensitivity analysis using various market values or calculating an average market value representative of the project's regional characteristics and stakeholders' sustainability objectives.

Of course, environmental footprint analysis and social cost of environmental metrics are not limited to remediation projects. The methodology presented here could be used by a diverse array of industries. Our analysis could also be extended to incorporate non-market valuation methods, such as willingness to pay and hedonic valuation, to address socio-economic impacts not representative of environmental metrics (e.g., property value and aesthetic value of green-space).

Lastly, future research is needed to fill in the data gap of environmental metrics without a social cost, such as water consumption. Analysis of climate models, economic growth frameworks, and valuation methods could be used to quantify such social costs. For example, the wastewater treatment sector has developed a methodology to monetize water. Further research is necessary to determine if the methodology is relevant or can be modified to serve the remediation industry. An extensive literature review of the value of environmental metrics beyond social costs, such as the value of ecosystem services, should also be conducted.

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Chapter 4

COMPARISON OF SUSTAINABILTY EVALUATION TOOLS FOR CONTAMINATED SEDIMENT REMEDIATION

Abstract

Environmental and socio-economic impacts arising from common sediment remediation and management activities were evaluated using an integrated sustainability assessment approach at a polychlorinated biphenyl (PCB)-contaminated case study site. Environmental impacts were quantified using both footprint analysis and life cycle assessment methodologies. The results of both tools were extended to quantify monetized global impacts from emission generation and resource consumption by integrating the social cost of environmental metrics. Sensitivity analyses were conducted to evaluate how varying inventory parameters and social cost metrics influenced the results of the sustainability assessment. The study did not find a significant difference between the overall conclusions of the environmental footprint and life cycle assessment (LCA) methodologies. However, incorporation of social cost metrics were deemed useful in normalizing environmental impacts for comparison, as well as identifying components of the remedial design that were designated as major, secondary, and low impact contributors to environmental, social, and economic effects. Thus, the results provided supporting data on where to focus remedial design optimization efforts. In addition, the results of the sustainability assessment revealed the importance of considering mobilization, engineering controls (e.g., silt curtain and turbidity curtain), and dewatering

as major impact contributors. The results also demonstrated the vital role site-specific inventory parameters have on influencing the results of the sustainability assessment, thus highlighting the importance of conducting site-specific assessments in lieu of extrapolating findings from previous studies.

4. Introduction

Sediment management, the process of coordinating dredging activities in the coastal zone for the purposes of retaining sand in the littoral system, is essential to maintaining navigable waterways, shoreline ecosystems, and beach nourishment projects (USACE, 2012a, 2002). During management activities, one may encounter sediment contaminated with chemicals including heavy metals (Bates et al., 2015). Under this scenario, sediment management is extended to include remediation activities to address risks posed to human and environmental health. In addition, sediment management including remediation is required at numerous designated contaminated sites around the globe (European Sediment Research Network [SedNet], 2004; USEPA, 2015), including 66 Tier 1 Superfund Sites in the United States (i.e., a site that manages at least 10,000 cubic yards or five acres of contaminated sediment) (USEPA, 2015). Additional challenges encountered during sediment management activities include balancing economic and social concerns, regulatory and policy issues, heterogeneous geomorphology, adjacent land use activities, and competing waterway uses (Read et al., 2014).

To overcome these challenges, the environmental community is exploring the concept of sustainable sediment management, “a comprehensive approach for addressing the long-term conservation of sediments within a watershed to maintain current and future beneficial uses while addressing regional environmental, economic, and social objectives" (Bridges et al., 2012). This concept is in alignment with sustainable remediation, which considers the three integrated dimensions of the triple bottom line (i.e., environment, society, and the economy) during cleanup and management of contaminated sites (International Standards Organisation [ISO], 2015; Interstate Technology and & Regulatory Council [ITRC], 2011a; Network for Industrially Contaminated Land in Europe [NICOLE], 2010; Sustainable Remediation Forum [SURF], 2009; SuRF-Italy, 2014; and SuRF-UK, 2010). Both sustainable sediment management and sustainable remediation compliment the United States Army Corps of Engineers (USACE) regional sediment management (RSM) strategy; a "systems approach to *deliberately* manage sediments in a manner that maximizes natural and economic efficiencies to contribute to sustainable water resource projects, environments, and communities" (USACE, 2012b). Contaminated sediment, however, is not managed under USACE RSM, but rather by complimentary regulatory programs (e.g., United States Environmental Protection Agency [USEPA] Superfund) (USACE, 2002). In contrast, SedNet has made headway in Europe with integrating the concepts of RSM and sustainable remediation to achieve sustainable sediment management encompassing remediation activities (SedNet, 2004). The integration of sustainable practices into sediment management allows for streamlining broader organizational sustainability goals among complimentary governmental agencies. This will likely result in the efficient use of resources (both financial and natural) and maximization of benefits to stakeholders.

For the purpose of this paper, the term "sediment management" referenced herein also includes remediation activities.

Environmental life cycle assessment (LCA) and multi-criteria decision analysis (MCDA) are the most commonly used tools to evaluate and integrate sustainable practices and management of contaminated sediments (Bates et al., 2015; Hou et al., 2014; Kiker et al., 2008; Linkov and Seager, 2011; Read et al., 2014; SedNet, 2004; Sparrevik et al., 2010, 2011; and Yatsalo et al., 2007). Environmental LCAs systematically tracks energy, resource, and environmental implications for a product or process using a cradle-to-grave approach (ISO, 2006). LCAs performed for sediment contaminated sites focus on comparing environmental impacts among proposed risk management and remedial strategies (e.g., soil washing, natural recovery, capping, dredging) (Choi et al., 2016; Hou et al., 2014; and Sparrevik et al., 2010, 2011), as well as major system components, including placement of dredged material (Bates et al., 2015) and amendments applied for *in situ* treatment (e.g., clay, limestone, and activated carbon) (Sparrevik et al., 2011).

Even though LCA has been shown to successfully evaluate environmental implications of sediment management activities, this tool is rarely utilized during industry practices. One explanation may be the lack of non-land applications (Sparrevik et al., 2011) and remedial technology components (Hou et al., 2014) in available life cycle inventory (LCI) databases. The lack of available LCI data can result in costly and time consuming assessments; therefore, LCA is not commonly performed due to budget constraints. The remediation community has responded to this financial obstacle by developing environmental footprint evaluation tools specifically designed for remediation projects (NAVFAC, 2011; USEPA, 2016a, 2012). These footprint tools often require half the amount of financial resources to perform in comparison to LCA. However, until recently, remediation footprint tools faced a similar obstacle in lacking input parameters unique to sediment management technologies. In September 2015, Naval Facilities Engineering Command (NAVFAC) released Version 3.1 of the SiteWise™ environmental footprint evaluation tool, which includes sediment remediation input parameters (e.g., silt curtain materials, watercraft operation, and sediment management components associated with dredging, capping, staging and drying). To the best of the authors' knowledge, a comparison of LCA and SiteWise™ Version 3.1 results for a sediment remediation project has not been published to date.

Current LCA and footprint evaluation tools used by the remediation industry fall short for proper evaluation of social and economic impacts on sediment management. Over the last five years, remediation practitioners have started to perform comprehensive sustainability assessments of risk management and remedial strategies by integrating complimentary methodologies from the environmental economics and social science disciplines (Harclerode et al., 2015a). As stated previously, MCDA has been widely used to identify and integrate stakeholder needs into remedial objectives. Hou et al. (2014) developed a hybrid LCI, for evaluating sediment remediation technologies, based on the United Kingdom's (UK) socioeconomic input-output data, including employment, compensation for employees, and worker fatality and injuries. Lemming et al. (2010)

extended a LCA, for evaluating source remediation technologies, to include the market cost of carbon and the human health risk and cost (based on Denmark Gross Domestic Product [GDP]) associated with exposure to residual contamination and remediated media. In the United States, environmental footprint analyses have been extended to quantify global impacts arising from remedial activities by monetizing emissions and energy consumption and integrating the social cost of environmental metrics (Harclerode et al., 2015b, 2013; Bohmholdt, 2014). NAVFAC's SiteWise^{TM} tool quantitatively evaluates worker safety and accident risk metrics and has a placeholder to qualitatively evaluate (i.e., low, medium or high) community impacts and lost ecological resources (NAVFAC, 2015).

In this case study, we evaluated the environmental and global socio-economic impacts of three common sediment remediation technologies: excavation, dredging and *in situ* treatment. All three technologies comprise the overall remediation strategy for the case study site. Thus, this study does not seek to compare sustainable attributes among the three technologies, but serves to compare outcomes between LCA or the SiteWise^{TM} Version 3.1 footprint evaluation tool to determine environmental and global implications of site activities. Both environmental assessments have been extended to quantify monetized global impacts using the social cost of environmental metrics. The use of social cost metrics, specifically carbon, is encouraged by the USEPA (2016b) and US federal agencies (USDOE, 2011) to estimate the climate benefits of the decision-making process, following United States Executive Order 12866 – Regulatory Planning and Review (USG, 2013).

4.1. Methods

4.1.1. Case Study

The sustainability assessment was conducted on a remedial design developed to manage polychlorinated biphenyls (PCBs) contaminated sediment within two adjacent coastal inlets connected to the Atlantic Ocean. The main source of PCBs was the former transformers which were located farther inland. The contaminated site was historically used to build and test aircraft. Other potential sources of PCBs include historic site operations and releases during building demolition. PCBs were identified at concentrations above 50 milligrams per kilogram (mg/kg) (maximum of 3,600 mg/kg); thus, they were subject to disposal requirements under the federal Toxic Substances Control Act (TSCA) and regulations promulgated thereunder, primarily at 40 Code of Federal Regulations 761. The sediment also contained polycyclic aromatic hydrocarbon (PAH) and heavy metal contamination.

The planned remedial action is a multi-remedy approach consisting of excavation, dredging, and *in situ* treatment with activated carbon. In addition, dewatering of sediment, disposal of investigation derived waste, and installation of engineering controls to control migration of sediment (i.e., silt curtain and turbidity curtain) are considered major components of remedy implementation.

4.1.2. Sustainability Assessment

The sustainability assessment is comprised of a multi-method approach to evaluate the environmental, social, and economic impacts from remedial activities. Environmental impacts were evaluated using both environmental footprint and LCA methods. Social and economic impacts were evaluated using a societal cost analysis, consisting of integrating the social cost of environmental metrics into the footprint analysis and LCA.

The environmental footprint analysis was conducted using the NAVFAC SiteWise^{TM} program Version 3.1 (NAVFAC, 2015), which is the first version of this tool to include sediment remediation components. The LCA was conducted using SimaPro software. The societal cost analysis was conducted using methodologies presented in Harclerode et al. (2015b, 2013).

The goal of the sustainability assessment is to identify components of the design that contribute the most towards environmental, social, and economic impacts from remedial activities. The functional unit is the cleanup goal of managing PCB contaminated sediment where the lateral extent is above 50 mg/kg and vertical extent is above 0.676 mg/kg. The remedial goal of 0.676 mg/kg minimizes the need for return dredging within the impacted area during full remedy construction. The timeframe for the assessment inventory is unrestricted to evaluate both short- and long-term impacts.

The scope of the sustainability assessment is to include all major remedial activities to be conducted on site and off site associated with both coastal inlets, herein referred to as Area of Concern (AOC) 1 and AOC 2. AOC-1 is associated with the coastal inlet along the southwestern boundary of the site, and AOC-2 is the coastal inlet along the southeastern boundary. The greatest detected concentrations of PCBs and PAHs were observed within AOC-2 along the shoreline and in shallow sediment near the outfalls of the Site. Elevated metal concentrations, primarily cadmium, were observed within AOC-1, and in the deeper sediments of AOC-2. Both inlets flow towards the apex of a river which connects to the Atlantic Ocean. This includes consumption of raw materials and natural resources during materials acquisition, production, use stages, and end-of-life processes. An overview of the remedial action components is summarized in **Table 4-1**. Primary data regarding energy and material consumption during each remedial activity was compiled from engineering data and vendor invoices originally used to prepare the design documentation. Assumptions and input parameters for the environmental footprint analysis and LCA are provided as Supplemental Information (SI) in Tables SI and S2.

Table 4-1: Remedial Action Components

Remedy Technology/ Component	**Major Input Parameters**		
	AOC 1	**AOC 2**	**Process**
Mobilization/ Engineering Controls	800 linear feet of turbidity curtain; 500 linear feet of silt curtain; 1,140 tons of raw materials	1800 linear feet of turbidity curtain; 1,050 linear feet of silt curtain; 14.5 tons of raw materials	Silt/turbidity curtain materials (i.e., geotextile membrane, polyethylene pipe, polystyrene, and steel) plywood, filter log, and raw materials (i.e., asphalt and gravel)
Excavation	26,500 cubic yards of sediment	------	Excavator operation, steel sheeting, and transport of sediment to staging/dewatering areas
Reconstruction and Stabilization	18,680 cubic yards of raw materials	------	Excavator and loader operation, and raw materials (i.e., soil, gravel and sand)

Remedy Technology/ Component	**Major Input Parameters**		
	AOC 1	**AOC 2**	**Process**
Reconstruction	------	5,125 cubic yards of raw material	Excavator operation, watercraft/barge operation, and raw materials (i.e., sand)
Dredge	4,600 cubic yards of sediment	12,400 cubic yards of sediment	Excavator/crane operation, watercraft/barge operation, and transport of sediment to staging/dewatering areas
In Situ Treatment	------	250 tons of activated carbon	Watercraft/barge operation, conveyor belt system for distribution, activated carbon
Dewatering	113,000 gallon of water; 2,028 tons of coagulant; 36,000 square foot pad	82,000 gallons of water; 3,198 tons of coagulant; 27,00 square foot pad	System materials, including activated carbon, polyvinyl chloride pipe, geotextile membrane, treatment materials (i.e., coagulant polydiallyldimethylammonium chloride [polyDADMAC] and raw materials (i.e., gravel)
Investigation derived waste (IDW) disposal and transport	3,562,000 tons of waste material	2,934,970 tons of waste material	Transport of excavated sediment, water, and debris; and landfill operations

Life cycle inventory data for the remedial system (e.g., production of steel, plastic, excavator operation, lorry and coastal transport) were primarily based on average technology data from the Ecoinvent life cycle unit process database Version 2.2 (Ecoinvent, 2010). Due to specific input parameters not available in the Ecoinvent Database, the following databases were used: (1) United States Life Cycle Inventory (USLCI) Database was used for the galvanized steel sheet, wood fiber, electricity grid, and natural gas input parameters; and (2) European Reference Life Cycle Database

(ELCD) for the steel hot rolled section input parameter. Remedial design parameters (e.g., coir log - erosion control device comprised of coconut fibers, silt fence and coagulant) for which no data are found in Ecoinvent or other general LCI databases were each designed as a process using generic data from the Ecoinvent database. The process inventory for each of these parameters is provided in SI Table S2. The life cycle impact assessment method is ReCiPE. Both the Ecoinvent database and ReCiPE impact assessment method were used in previous LCA studies evaluating sediment management (Bates et al., 2015; Sparrevik et al., 2011).

The environmental footprint of each remedial component was assessed using NAVFAC's SiteWise™ tool. SiteWise™ is a stand-alone tool developed jointly by the U.S. Navy, the U.S. Army, the USACE, and Battelle that assesses the environmental footprint of a remedial alternative/technology in terms of a consistent set of metrics, including: (1) greenhouse gas (GHG) emissions; (2) energy use (total energy use and electricity from renewable and non-renewable sources); (3) air emissions of criteria pollutants (total emissions and on site emissions) including nitrogen oxide (NO_x), sulfur oxide (SO_x), and coarse particulate matter (PM_{10}); (4) water consumption; (5) resource consumption (e.g., landfill space and top soil use); and (6) worker safety (risk of fatality, injury and lost hours) (NAVFAC, 2015). The SiteWise™ tool does not have input parameters for plywood, filter logs, coir logs, coagulant, and dewatering pad materials. Therefore, the CO_2, PM_{10}, and sulfur dioxide (SO_2) emissions for these materials calculated as part of the LCA were accounted for under the "other known on site activities" category in the SiteWise™ tool.

The societal cost analysis quantifies the costs borne by society, which evaluates costs associated with monetized global impacts from emissions and resource consumption during remedial activities (Harclerode et al., 2015b, 2013). Monetized global impacts represent the monetary value that can be assigned for societal disamenities (damages) associated with an incremental increase in emissions and resource consumption. These societal disamenities and their associated unit social costs are listed in **Table 4-2**.

The social cost of environmental metrics used for this analysis was obtained from literature presented in **Table 4-2**. The United States Government (USG) Interagency Working Group on Social Cost of Carbon (2013) and USEPA (Marten et al., 2015) quantified the social cost for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) for the years 2015 and 2020 (in 2007 US dollars) at discount rates of 2.5, 3, and 5 percent. A lower discount rate means society places higher value on future impacts (e.g., climate change and chronic human health impacts), while a higher discount rate means society places higher value on present impacts (e.g., daily traffic congestion and general inconvenience due to ongoing site activities). The social costs with a discount rate of 2.5 percent were used in the societal cost analysis since the environmental footprint metrics (e.g., GHG emissions) used in this sustainability assessment are associated with long-term and even intergenerational societal impacts (Harclerode et al., 2015). Muller and Mendelsohn (2010) quantified the social cost of NO_x, SO_x, and PM_{10} (2002 US$) in quantiles ($1^{st}$, 25^{th}, 50^{th}, 75^{th}, 99^{th}, and 99.9^{th}) based on the environmental setting of the project and geographic distribution of existing nearby point sources. For example, a high quantile represents an area densely populated by point sources of NO_x, SO_x, and PM_{10} emissions. The case study site is located within a metropolitan area. Spatial patterns of ground sources of fine particulate matter and SO_2 prepared by Muller and Mendelsohn (2010) identify the case study site within the 99th social cost quantile. The non-carbon social cost of energy is a set cost value quantified in 2000 US$ by Greenstone and Looney (2011), based on monetized damages resulting from emissions of SO_2, NO_X, fine particulate matter ($PM_{2.5}$), and PM_{10}, but not carbon compounds. All social cost values were adjusted for inflation over time using the United States Government Consumer Price Index.

Table 4-2: Social Cost Metrics

Environmental Metric		**Societal Disamenities**	**Unit Social Costs (2015 US $)**	
Greenhouse Gas	Carbon Dioxide (CO_2)	Long-term global impacts of climate change, including changes in net agricultural productivity, human health, property damages from increased flood risk, and the lost value of ecosystem services (USG, 2013).	$64.01	per metric ton
	Methane (CH_4)	Long-term global impacts of climate change, including changes in agriculture, energy production, water availability, human health, coastal communities, and biodiversity (Marten and Newbold, 2012; Marten et al., 2015).	$1,616.57	per metric ton
	Nitrous Oxide (N_2O)		$22,227.75	per metric ton

Environmental Metric		**Societal Disamenities**	**Unit Social Costs (2015 US $)**	
Criteria Pollutants	Total Nitrogen Oxides (NO_x)	Long-term societal impacts, including health effects, reduced crop and timber yields, materials depreciation, lost recreation services, and reduced visibility (Muller and Mendelsohn, 2010).	$1,100	per metric ton
	Sulfur Oxides (SO_x)		$4,130	per metric ton
	Particulate Matter (PM_{10})		$1,960	per metric ton
Energy Consumption (non-carbon social cost)		Long-term societal impacts, including health costs, shortened life spans, cost of environmental mitigation, and broad impacts of climate change (Greenstone et al., 2011).	$14	per million British Thermal Units (MMBTU)

To calculate costs borne by society, we multiplied selected sustainability metrics calculated either through the environmental footprint analysis or LCA by the associated unit social cost using the following formula (Harclerode et al., 2015b, 2013):

Environmental Footprint Analysis Sustainability Metric ***X*** *Unit Social Cost of Sustainability Metric* = *Costs Borne by Society*

Figure 4-1a: AOC-1: Remedial Design: Normalized Mid-Point Environmental LCA Metrics

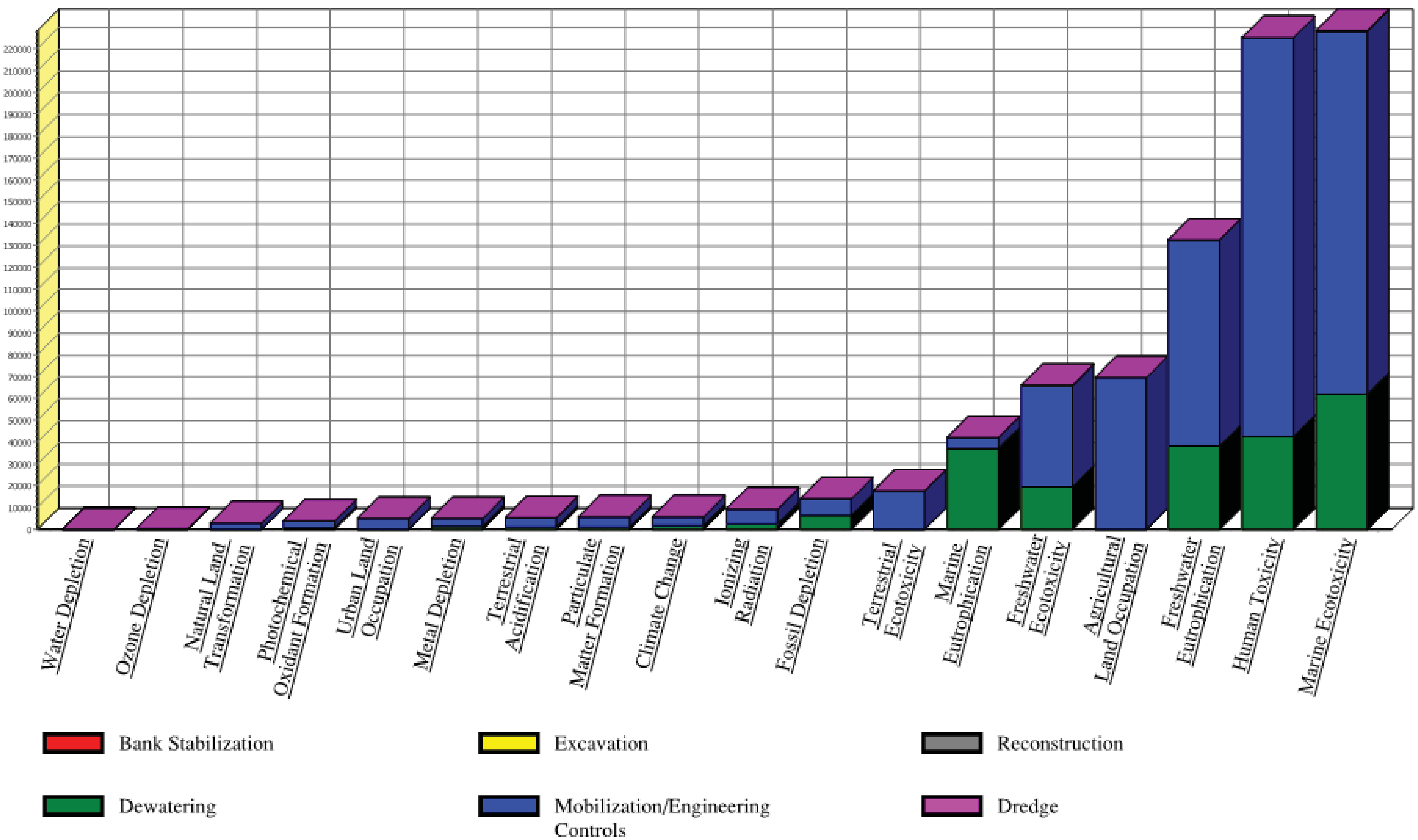


Figure 4-2b: AOC-2: Remedial Design: Normalized Mid-Point Environmental LCA Metrics

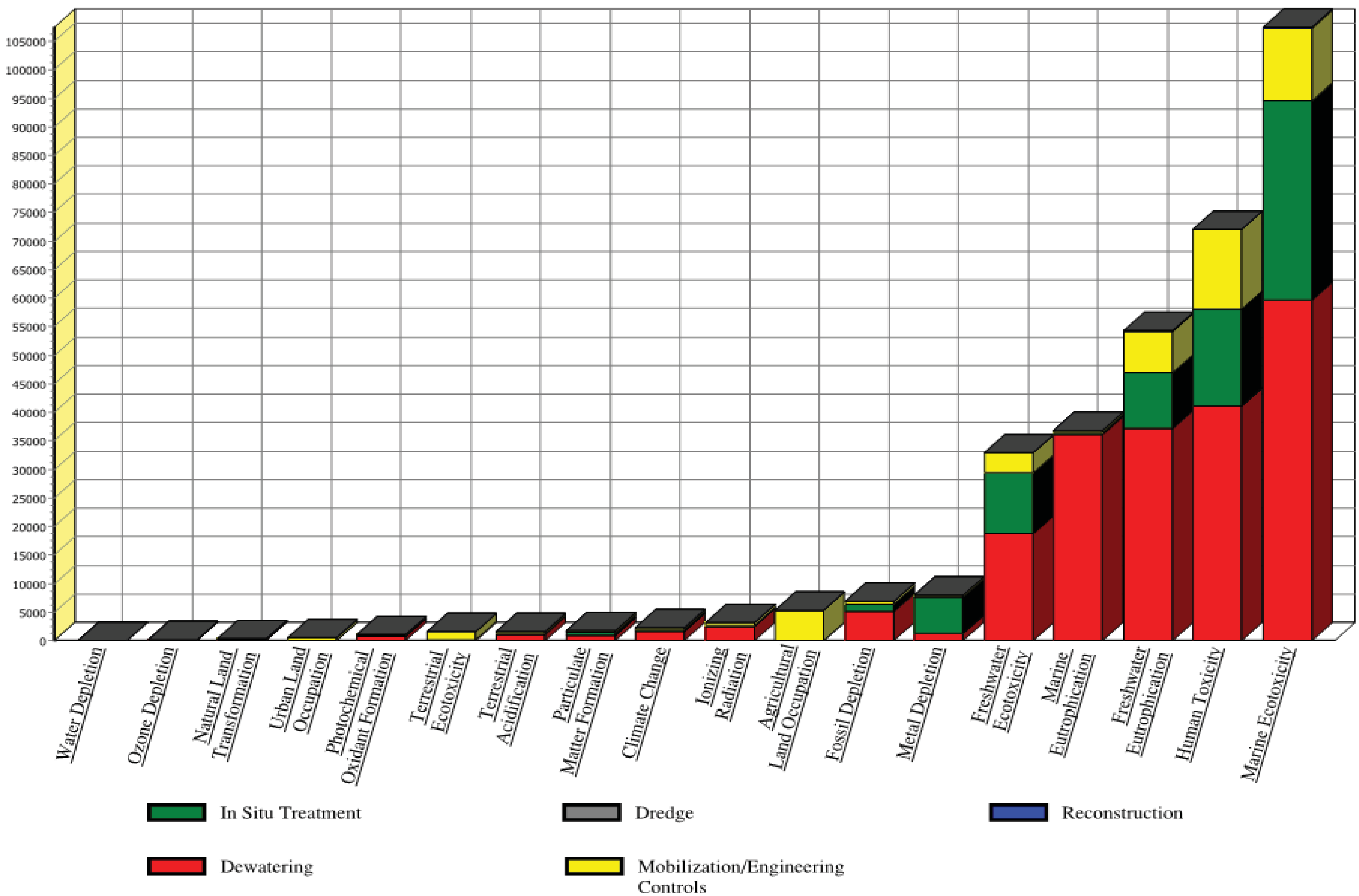
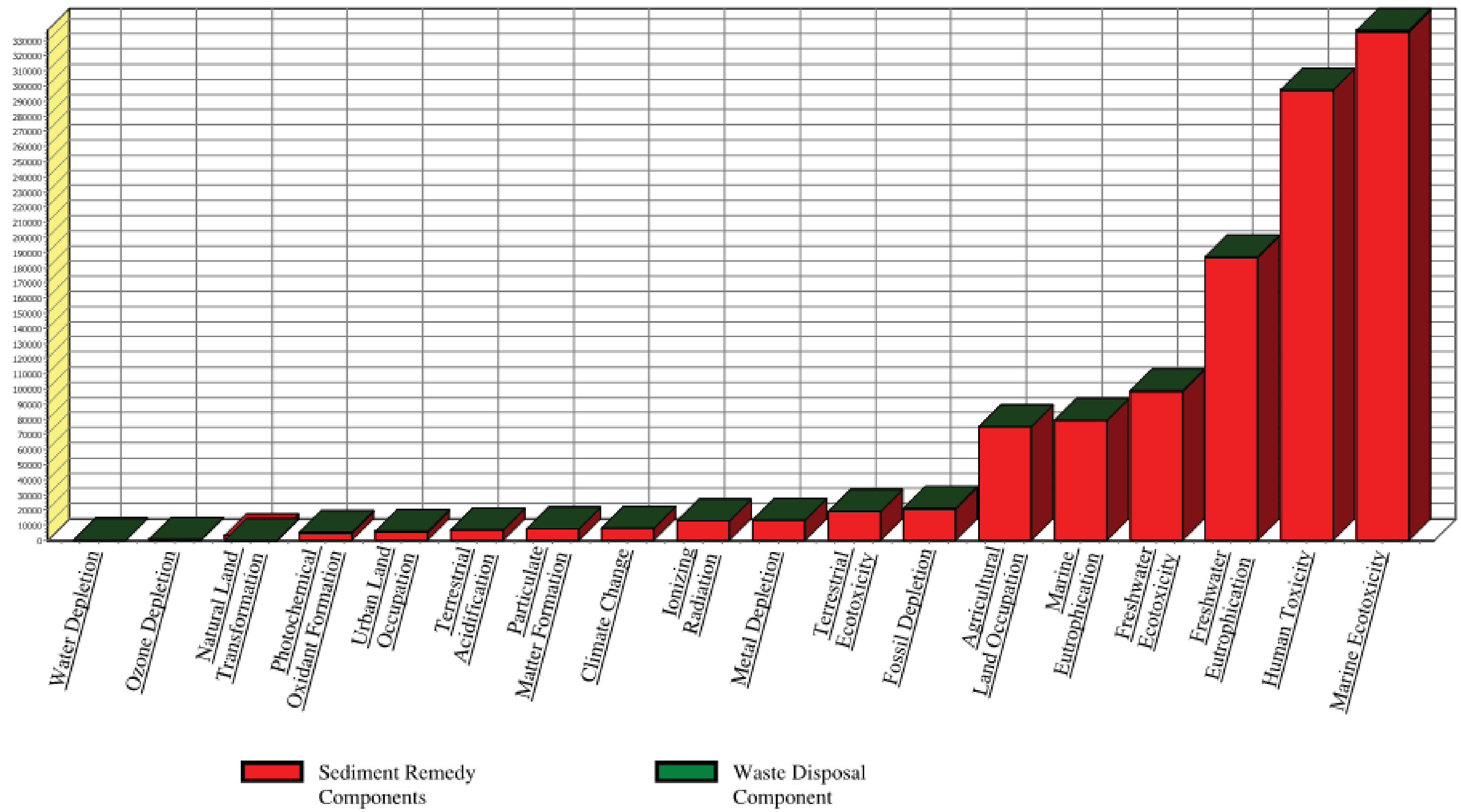


Figure 4-3: Remedial Design and Waste Dispoal: Normalized End-Point Environmental LCA Metrics



4.2. Results and Discussion

4.2.1. Life Cycle Assessment Results

Normalized mid-point impact values of each remedial component quantified for AOC-1 and AOC-2 are shown in **Figures 4-1** and **4-2**, respectively. Mid-point impact categories reflect the relative potency of sustainability metrics (e.g., carbon dioxide emissions and chlorofluorocarbon emissions) at a common midpoint (e.g., climate change and ozone depletion) within the cause-effect chain (Curran, 2006). For both AOCs, impacts to marine ecotoxicity, human toxicity, and freshwater eutrophication were the dominant impact categories. The mobilization/engineering controls and dewatering components of the remedial design contribute the most towards environmental impacts. The *in situ* treatment component is also a major impact contributor in AOC-2. The disposal of investigation derived waste (i.e., sediment, water, and debris) was not a major impact contributor, likely due to the volume of waste material generated compared to the amount raw materials consumed.

Mobilization/engineering controls was the primary contributor to impacts followed by dewatering for AOC-1, and the complete opposite was found for AOC-2. **Table 4-1** shows the differences in the quantity of major input parameters for each remedial component between the AOCs. For the mobilization/engineering control component, AOC-1 consumes a greater amount of raw materials (e.g., gravel and plywood) and requires less linear footage of the turbidity/silt curtain, as compared to AOC-2. For the dewatering component, AOC-2 consumes more coagulant than AOC-1, however, AOC-2 generates less wastewater and requires a smaller dewatering pad (consisting of polyvinyl chloride pipe and geotextile membrane). In addition, the *in situ* treatment using activated carbon was also a major contributor to impacts under AOC-2. The *in situ* treatment component also consisted of watercraft/barge operation and a conveyor belt system for distributing the amendment. Other remedial components that included watercraft/barge operations, such as dredging and reconstruction, were not identified as major impact contributors. Based on this comparison, the consumption of raw materials (e.g., plywood and gravel) and amendments (e.g., coagulant and activated carbon) are the primary drivers to environmental impacts from site remedial activities.

4.2.2. LCA Sensitivity Analysis

The consumption of plywood is driving environmental impacts associated with the mobilization/engineering control component for both AOCs (SI Figure 1S). If the plywood input parameter is removed from this remedial component, the input parameters driving environmental impacts from mobilization and installation of engineering controls vary among the two AOCs. The consumption of gravel becomes the primary input driver for AOC-1 and the turbidity curtain for AOC-2 (SI Figure 2S). Processed materials (e.g., polypropylene, high density polyethylene, and galvanized steel) were identified as primary impact drivers for the turbidity and silt curtain subcomponents (SI Figures 3S and 4S). As shown on **Table 4-1**, AOC-1 consumes a greater amount of raw materials, primarily gravel in this scenario, and has less linear footage of curtain, as compared to AOC-2. Based on this comparison, AOC-specific input parameters (e.g., raw material consumption and length of silt curtain) influence subcomponents that are identified as major contributors to environmental impacts. Overall, the timber mats (i.e., plywood) were concealing other AOC-specific input parameters of the mobilization/engineering control component that were also driving environmental impacts.

If the plywood input parameter is removed from this remedial component, dewatering and *in situ* treatment become the major impact contributors (SI Figure 5S). For the dewatering component, the use of coagulant is driving environmental impacts during water treatment (SI Figure 6S). On the other hand, the use of a hopper is driving environmental impacts for *in situ* application instead of the quantity of activated carbon used (SI Figure 7S). If carbon is replaced by the coagulant polyDADMAC used during the dewatering process, the use of the hopper is still the primary impact driver (SI Figure 7S). However, the amendment has a larger contribution to the overall environmental impact. The Ecoinvent inventory parameter used for the hopper, *"industrial machine, heavy, unspecified, at plant,"* may not accurately represent the vessel-mounted spreader or equipment used to distribute the amendment. However, based on the available LCI databases, this input parameter was determined to be the most applicable.

In order to identify additional AOC-specific components that were driving environmental impacts, plywood, amendments (i.e., carbon and coagulant), and the hopper were removed from the impact assessment. In this scenario, dewatering becomes the major impact contributor for both AOCs (SI Figure 8S) and polyethylene is the primary impact driver (SI Figure 9S).

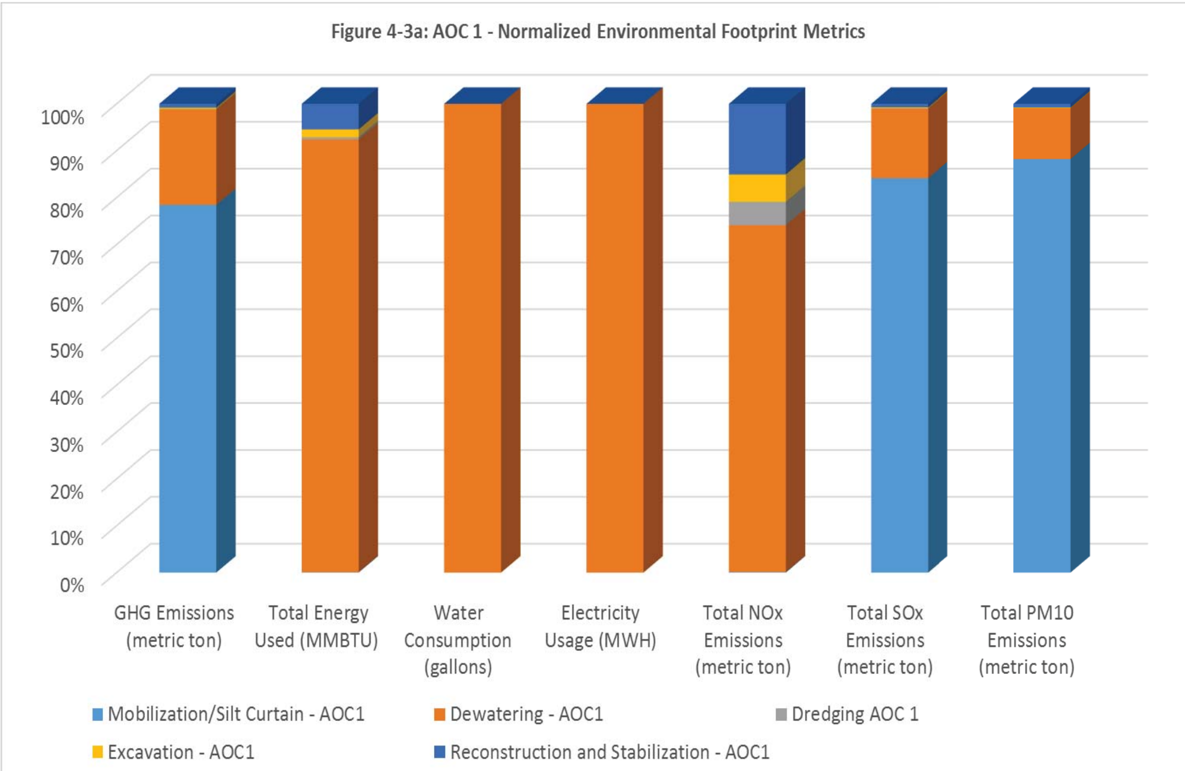
4.2.3. Environmental Footprint Results

Normalized sustainability metric values from SiteWise™ (e.g., percent allocation of greenhouse gas and NO_x emissions) for each remedial component quantified for AOC-1 and AOC-2 are shown in **Figure 4-3**. Similar to the LCA evaluation, the mobilization/engineering controls and dewatering components of the remedial design are the primary contributors to environmental footprints for both AOCs. In addition, the dewatering component plays a greater role as an impact contributor in AOC-2, as compared to AOC-1.

Input parameters that fall into the “equipment use and miscellaneous” category are driving the environmental footprint for the mobilization/engineering controls component (SI Figure 10S). Impacts from the turbidity/silt curtain is accounted for under the “material production” category of the SiteWise™ tool (NAVFAC, 2015), while impacts from the plywood and filter log materials are accounted for under the “miscellaneous” category. Similar to the LCA, the consumption of plywood is the primary environmental footprint driver for the mobilization/engineering controls component.

Consumables are the primary input parameters driving the environmental footprint for the dewatering and *in situ* treatment components (SI Figure 11S and 12S). These findings are complimentary to the LCA evaluation and sensitivity analysis, in which amendments and polyethylene were identified as main contributors to environmental impacts for these two components. In contrast to the LCA evaluation, equipment use (i.e., the hopper) was not identified as a primary environmental footprint contributor under the *in situ* treatment component. The “sediment capping” sub-component under the “equipment use” category of the SiteWise^{TM} tool was used to enter parameters for the *in situ* treatment. Input parameter choices include a selection of capping methods (i.e., surface, mechanical, or pipeline release), types of fuel (diesel or biodiesel), and sizes for the supporting vessel (i.e., large research vessel or small/medium light craft). Under the surface release capping option, a hopper barge is included as a default within the sediment capping sub-component, thus “surface release” was used for this case study analysis. Equipment used for the mechanical and pipeline capping method are a crawler crane and a hydraulic dredge head, respectively. Based on findings from the LCA and footprint evaluations, the SiteWise^{TM} tool may be underestimating environmental impacts from the hopper or the Ecoinvent LCI input parameter for the hopper may not be reflecting site remedial activities accurately.

Figure 4-4: Normalized SiteWise™ Impacts



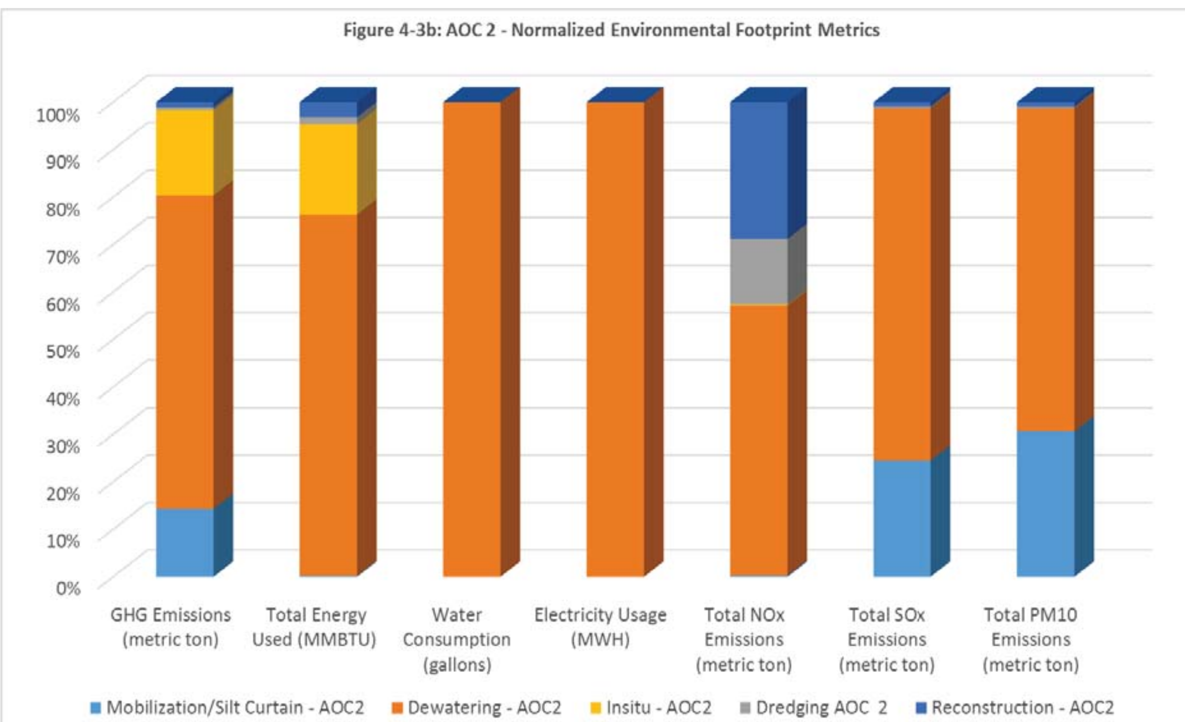
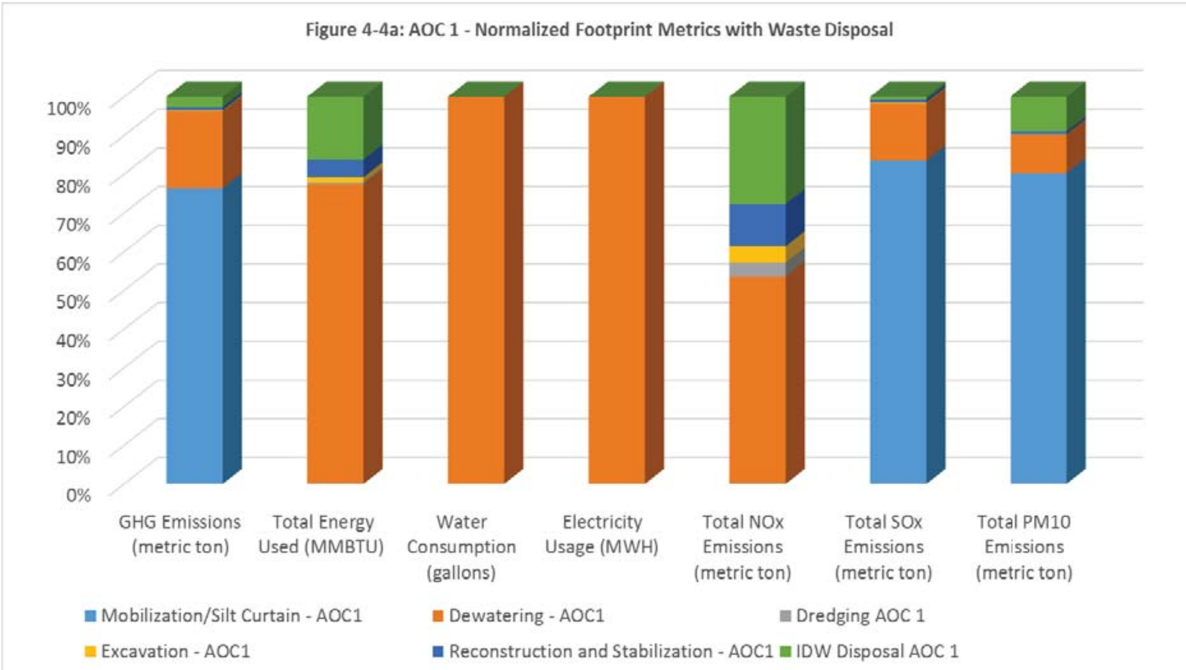


Figure 4-5: Normalized SiteWise™ Impacts with Disposal



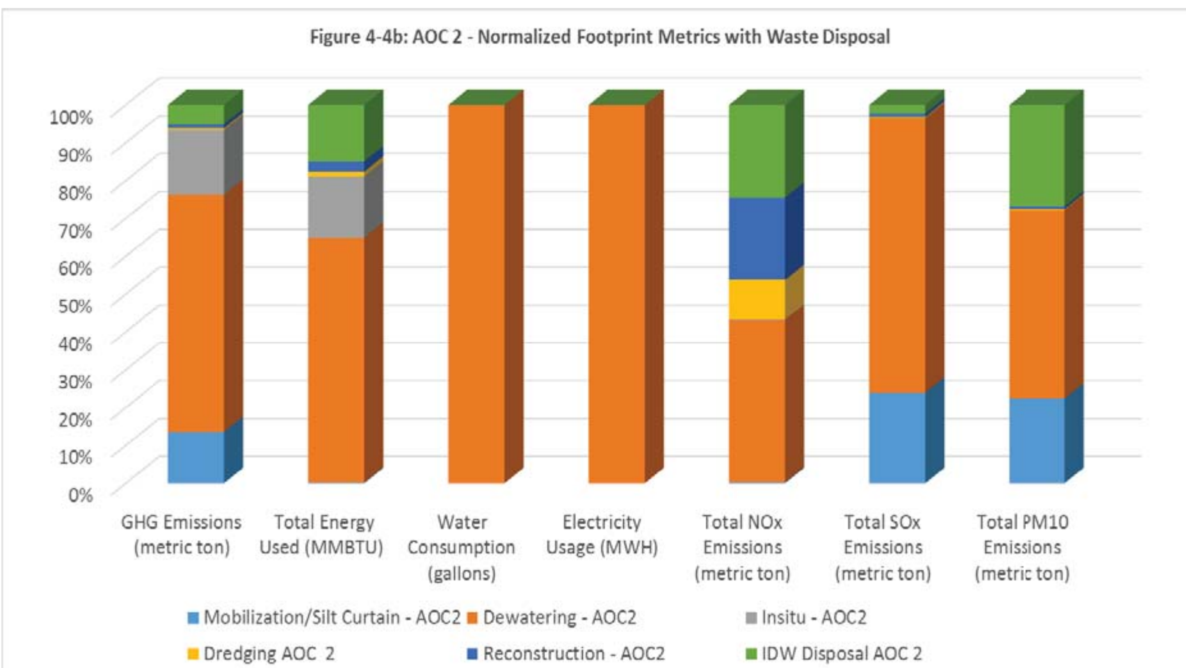


Table 4-3: Global Monetized Impacts

	Footprint Evaluation											
Remedial Component	**GHG Emissions (metric ton)**	**GHG Emissions (metric ton)**	**Total Energy Used (MMBTU)**	**Total Energy Used (MMBTU)**	**Total NOx Emissions (metric ton)**	**Total NOx Emissions (metric ton)**	**Total SOx Emissions (metric ton)**	**Total SOx Emissions (metric ton)**	**Total PM10 Emissions (metric ton)**	**Total PM10 Emissions (metric ton)**	**Monetized Global Impacts**	**Allocation of Impacts (Percentage)**
Area of Concern 1												
Mobilization/ Engineering Controls	2.61E+04	$ 4,766,273	5.93E+01	$ 830	8.24E-03	$ 9	1.51E+02	$ 623,683	6.27E+01	$ 122,896	$ 5,513,692	65.27%
Dewatering	6.78E+03	$ 1,237,199	7.15E+04	$ 1,000,450	5.02E+00	$ 5,518	2.67E+01	$ 110,309	7.72E+00	$ 15,122	$ 2,368,599	28.04%
Dredging	3.00E+01	$ 5,482	3.81E+02	$ 5,334	3.39E-01	$ 373	6.03E-02	$ 249	1.90E-02	$ 37	$ 11,475	0.14%
Excavation	8.92E+01	$ 16,292	1.29E+03	$ 18,033	3.96E-01	$ 436	3.49E-01	$ 1,442	7.50E-02	$ 147	$ 36,349	0.43%
Reconstruction and Stabilization	2.79E+02	$ 50,901	4.23E+03	$ 59,151	1.02E+00	$ 1,125	1.38E+00	$ 5,690	5.67E-01	$ 1,111	$ 117,978	1.40%
Waste Disposal	9.13E+02	$ 166,777	1.50E+04	$ 209,989	2.60E+00	$ 2,862	1.32E+00	$ 5,436	7.02E+00	$ 13,758	$ 398,822	4.72%
										SubTotal	*$ 8,446,916*	*100%*
Area of Concern 2												
Mobilization/ Engineering Controls	2.02E+03	$ 368,405	1.30E+02	$ 1,826	1.85E-02	$ 20	1.16E+01	$ 48,026	4.84E+00	$ 9,477	$ 427,755	10.38%
Dewatering	9.31E+03	$ 1,699,057	5.36E+04	$ 750,804	3.76E+00	$ 4,139	3.52E+01	$ 145,506	1.08E+01	$ 21,073	$ 2,620,579	63.58%
Insitu	2.53E+03	$ 462,288	1.34E+04	$ 187,604	1.46E-02	$ 16	6.60E-03	$ 27	7.48E-04	$ 1	$ 649,936	15.77%
Dredging	8.12E+01	$ 14,823	1.03E+03	$ 14,422	9.16E-01	$ 1,007	1.63E-01	$ 673	5.13E-02	$ 101	$ 31,026	0.75%
Reconstruction	1.55E+02	$ 28,254	2.23E+03	$ 31,268	1.91E+00	$ 2,098	4.25E-01	$ 1,753	1.44E-01	$ 283	$ 63,656	1.54%
Waste Disposal	7.53E+02	$ 137,474	1.24E+04	$ 173,146	2.15E+00	$ 2,362	1.09E+00	$ 4,488	5.79E+00	$ 11,358	$ 328,827	7.98%
										SubTotal	*$ 4,121,779*	*100%*

Table 4-3: Global Monetized Impacts

LCA Evaluation							
CO_2 equivalents uivalents (metric tons)	**CO_2 equivalents (metric tons)**	**SO_2 equivalents (metric tons)**	**SO_2 equivalents (metric tons)**	**PM10 equivalents (metric tons)**	**PM10 equivalents (metric tons)**	**Monetized Global Impacts**	**Allocation of Impacts (Percentage)**
Area of Concern 1							
2.61E+04	$ 1,673,517	1.51E+02	$ 624,632	6.27E+01	$ 122,988	$ 2,421,137	68.69%
1.31E+04	$ 840,276	4.68E+01	$ 193,325	1.53E+01	$ 29,907	$ 1,063,509	30.17%
3.15E+01	$ 2,014	1.49E-01	$ 615	6.46E-02	$ 127	$ 2,756	0.08%
4.30E+01	$ 2,755	1.98E-01	$ 817	9.73E-02	$ 191	$ 3,763	0.11%
7.20E+01	$ 4,608	4.46E-01	$ 1,841	2.22E-01	$ 434	$ 6,883	0.20%
2.88E+02	$ 18,459	1.68E+00	$ 6,953	7.50E-01	$ 1,469	$ 26,881	0.76%
					SubTotal	$ 3,524,929	100.00%
Area of Concern 2							
2.02E+03	$ 129,605	1.17E+01	$ 48,289	4.84E+00	$ 9,489	$ 187,384	13.62%
1.09E+04	$ 699,086	3.91E+01	$ 161,580	1.28E+01	$ 25,024	$ 885,691	64.35%
2.67E+03	$ 170,973	9.17E+00	$ 37,887	6.28E+00	$ 12,302	$ 221,162	16.07%
8.51E+01	$ 5,445	4.03E-01	$ 1,663	1.75E-01	$ 343	$ 7,450	0.54%
1.94E+01	$ 1,240	1.32E-01	$ 543	6.38E-02	$ 125	$ 1,909	0.14%
7.80E+02	$ 49,906	4.55E+00	$ 18,800	2.03E+00	$ 3,972	$ 72,678	5.28%
					SubTotal	$ 1,376,274	100%

Lastly, the footprint evaluation also identified reconstruction/stabilization as having a notable contribution to the total NO_x emissions (**Figure 4-3** and **4-4**). The LCA ReCiPE mid-point impacts do not include a quantification of NO_x emissions and, therefore, may be underestimating the environmental impacts from reconstruction and stabilization. In addition, the footprint evaluation identified waste disposal as having a significant contribution to the overall environmental footprint (**Figure 4-4)**, while the LCA did not identify reconstruction/stabilization or waste hauling components as major impact contributors. The assumptions built into the SiteWise™ tool and the LCA inventory database and impact methods vary, and are most likely the source of discrepancies between the tools.

4.2.4. Comparison of Using Environmental Impact Tools to Aid the Decision Making Process

Environmental impact (footprint) evaluations are primarily conducted for two reasons: (1) to identify which remedial approach has the overall least and most environmental impacts; and (2) to identify which components of the selected remedy contribute the most toward environmental impacts. The results of the impact evaluation are then used to aid in the selection of a sustainable remedy and to optimize remedy components to alleviate unsustainable impacts. In general, the results of the SiteWise™ tool and the LCA method were comparatively similar in identifying remedial approaches that were considered a major contributor to environmental impacts. Therefore, the results of both methods would inform decision makers in a similar manner during remedy selection. This conclusion is important for the remediation community because the amount of labor hours and associated costs to conduct a footprint analysis compared to LCA is significantly lower. Therefore, the evaluation of environmental impacts between proposed remedial approaches can be incorporated into the decision making process with relatively low level of effort.

The main difference between the results of the footprint evaluation and the LCA is the identification of remedy components as secondary impact contributors that should be optimized to reduce the overall environmental footprint. The SiteWise™ tool identified reconstruction/stabilization and waste disposal as secondary impact contributors, while the LCA did not. This difference between the SiteWise™ tool and the LCA method aids decision makers in an inconsistent manner when identifying remedy components that should be optimized to achieve a sustainable outcome. Users of the SiteWise™ tool would allocate funds and labor to evaluate sustainable best management practices that can be implemented to optimize the reconstruction/stabilization and waste disposal components, in addition to the mobilization/engineering controls, dewatering, and *in situ* treatment components. While, users of the LCA tool would only allocate funds and labor to optimize the mobilization/engineering controls, dewatering, and *in situ* treatment components.

By relying solely on the results of the environmental footprint or LCA, decision makers are faced with uncertainty pertaining to which secondary remedial components are driving unsustainable impacts and should invest efforts in optimization. A societal cost analysis can be performed to overcome this uncertainty by extending the environmental impact evaluation to integrate the social cost of environmental metrics (presented in the subsequent section). The integration of a societal cost analysis normalizes the metrics into one monetary unit for ease of comparison, reducing uncertainty in decision-making, and alleviating trade-offs among environmental metrics (e.g., tons of CO_2 versus tons of NO_x) and impact categories (e.g., climate change versus ozone depletion). In addition, it enables decision makers to develop sustainable solutions as opposed to environmentally friendly ones.

4.2.5. Societal Cost Analysis

Both the SiteWise^{TM} tool and the LCA method quantify sustainability metrics and therefore have common indicators (i.e., CO_2, SO_x, and PM_{10}) to aid in comparison of costs borne by society quantified under each assessment. The results of the societal cost analysis are presented in **Table 4-3**. Under all remedial components, GHG (or carbon for the LCA) emissions and energy consumption contribute the most towards monetized global impacts (i.e., societal disamenitites). Complimentary to the findings of the environmental footprint evaluation and LCA, the cost analysis identified the mobilization/engineering controls, dewatering, and *in situ* treatment components as the major contributors to monetized global impacts. In addition, the primary contributor to global impacts is the mobilization/engineering controls component for AOC-1 and the dewatering component for AOC-2.

In contrast, the monetized global impacts quantified from the environmental footprint evaluation for AOC-2 waste disposal are relatively similar to the monetized impacts quantified for mobilization/engineering controls. Under AOC-2 for both the footprint evaluation and the LCA evaluation, the percent allocation of global monetized impacts for waste disposal is relatively comparable to the mobilization/ engineering controls and *in situ* treatment. The footprint evaluation also identified reconstruction/stabilization as one of the main contributors to total NO_x emissions. Based on the societal cost analysis, this remedial component is not a significant contributor to monetized global impacts for either AOC. By extending the footprint evaluation to include the social cost of environmental metrics, remediation practitioners can focus resources to optimize the design of remedial components that were identified as major (i.e., dewatering and mobilization/engineering controls) and secondary (i.e., *in situ* treatment and waste disposal) global impact contributors, while having confidence and certainty in not optimizing low impact contributors (i.e., reconstruction/stabilization).

4.2.6. Costs Borne by Society Sensitivity Analysis

Environmental sustainability metrics differ between the SiteWise™ tool and the ReCiPE LCA impact assessment method. The footprint evaluation quantifies NO_x emissions and includes CH_4 and N_2O in the quantification of GHG emissions; while, the ReCiPE LCA impact assessment method quantifies CO_2 equivalent emissions and does quantify NO_x emissions. A sensitivity analysis (SI Table S3) was performed to determine if the conclusions of the societal cost analysis would change if the costs borne by society were quantified using only the sustainability metrics both tools have in common. The results of the sensitivity analysis did not identify any modifications to the overall findings of the societal cost analysis, with one exception. The monetized global impacts from waste disposal for AOC-2 in the modified societal cost analysis were comparatively less than the mobilization/engineering controls component, and likely would not be considered a primary contributor to global impacts under this evaluation.

Both tools quantify sustainability metrics that currently do not have associated social costs including, but not limited to, water consumption, chlorofluorocarbon emissions (indicator of ozone depletion), 1,4-dichlorobenzene (indicator of human toxicity), land use/loss, and nutrient loads (e.g., phosphorous and nitrogen equivalents). Financial implications to society from long-term damages from these metrics are currently not accounted for in the societal cost analysis. Therefore, monetized global impacts for the remedy are underestimated. However, the findings of the cost analysis still inform remediation practitioners regarding which remedial components and sustainability metrics (e.g., carbon emissions and energy usage) should be optimized to reduce long-term global environmental and socio-economic damages from the remedial action.

4.3. Conclusion

The overall findings of the sustainability assessment led to concurrent conclusions with either the SiteWise™ footprint evaluation tool or the LCA ReCiPE impact assessment method. Integration of societal cost analysis into the sustainability assessment helped to define remedial components as major, secondary, and low impact contributors to environmental, social, and economic effects. In addition, the integrated sustainability assessment also provided supporting data suggesting that optimization efforts focus on waste disposal and not on reconstruction/stabilization activities.

The footprint evaluation tool required outputs from the LCA to accurately incorporate environmental impacts from amendments, streambank controls (e.g., filter log and coir logs), and natural resources (e.g., plywood) not included in the default parameters. The use of two tools is not ideal for conducting a sustainability assessment due to conflicting assumptions between the methodologies. However, we did not identify significant differences or changes in conclusions based on the incorporation of LCA outputs in the footprint tool. In addition, the integration of the social cost of environmental metrics normalized the varying environmental metric outputs into one unit (dollars) for ease of comparison.

A majority of the literature on LCAs conducted on sediment remediation projects focuses on comparing amendments, *in situ* and *ex situ* alternatives, and sediment containment options. The LCAs rarely take into consideration the environmental and socio-economic implications of supporting components, such as the silt curtain and dewatering process. This study highlights the importance of considering these components in a sustainability assessment for a sediment remediation project. In addition, the study demonstrated the vital role site-specific parameters have in influencing the results of a sustainability assessment. The primary impact contributor to AOC-1 versus AOC-2 differed due to variations in natural resources and amendments consumed. Therefore, findings from sustainability assessments for a specific site should be not easily transferable and extrapolated to another site. Literature on identifying which remedial alternatives that have greater negative sustainability impacts is important to guide the remediation community toward sustainable sediment management, as well as to push research toward more sustainable amendments, material substitutes, etc. However, a site-specific evaluation should always be performed to assist with the decision-making process.

Lastly, normalized mid-point impact values generated by LCA can result in a decision making process that requires trade-offs between impact categories. For example, one remedial alternative may be a major contributor to marine ecotoxicity, while a second alternative may be a major contributor to climate change. This scenario forces decision-makers to choose whether a contribution to marine ecotoxicity is more or less important than a contribution to climate change. Multi-criteria decision analysis (MCDA) has been shown to assist in identifying sustainability goals among stakeholders to support this type of decision making process. However, a societal cost analysis, as presented in this study, normalizes the impact categories into one unit (dollars) to facilitate the decision-making process. As stated previously, future research is needed to develop cost values for commonly used metrics, in addition to emissions and energy, and will be vital to moving towards a more holistic and comprehensive sustainability assessment.

In closing, the choice of method used to evaluate environmental impacts from remedial activities directly influences optimization efforts identified to reduce those impacts. Therefore, it is highly recommended to extend the environmental impact evaluation by integrating social costs to normalize environmental metrics and provide a comprehensive data set to aid the decision making process. Overall, it is vital to consider social and economic impacts of remedial activities in conjunction with environmental impacts to alleviate trade-offs and ultimately achieve a sustainable solution.

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Chapter 5

EVALUATION OF THE ROLE OF RISK PERCEPTION IN STAKEHOLDER ENGAGEMENT TO PREVENT EXPOSURE IN AN URBAN SETTING

(This paper has been accepted in the journal, Journal of Environmental Management)

Abstract

Stakeholder engagement is a vital sustainable remediation practice for obtaining useful feedback and identifying societal needs. Evaluating and integrating risk perception of stakeholders into outreach efforts allows for greater insight and ultimately, benefits the community by protecting its members from environmental hazards. In this study, we identified risk perception factors that influenced residents' level of concern for mitigating their exposure to elevated concentrations of lead in household paint and historic fill material. Risk perception factors were assessed by conducting an in-person survey at public green spaces. After analyzing responses, survey participants indicated that their perception of risk to exposed lead was mostly influenced by the presence of hazardous materials in close proximity to their residence, the ability to address pollution, and awareness, interest, and individual accountability in mitigating environmental risks. Responses also revealed that residents considered risk of lead and soil pollution as less menacing than the presence of more immediate and perceptible risks posed by factors such as air and water pollution. In addition, the community seemed to exhibit "optimism bias" and did not identify itself at high risk to susceptible and immediate hazards, including lead exposure. This lack of concern over lead exposure created a significant obstacle to community participation in state-led education and outreach programs. By

integrating risk perception analysis and increasing stakeholder engagement, we can bring more attention to this issue, educate the public about the threat of lead pollution, and efficiently use financial resources to implement a more sustainable solution.

5. Introduction

Sustainable remediation considers the three integrated dimensions of the triple bottom line (i.e., environment, society, and the economy) during cleanup and management of contaminated sites (International Standards Organisation [ISO], 2015; Interstate Technology and & Regulatory Council [ITRC], 2011; Network for Industrially Contaminated Land in Europe [NICOLE], 2010; Pope et al., 2004; Sustainable Remediation Forum [SURF], 2011; SuRF-Italy, 2014; and SuRF-UK, 2010). A sustainability assessment can be conducted to identify beneficial and detrimental impacts to these dimensions from remediation and preventative activities (ISO, 2015; ITRC, 2011; SURF, 2011; SuRF-UK, 2010). One of the potential benefits of considering the social impacts of remedial activities is increased stakeholder engagement and community empowerment (Harclerode et al., 2015; Risdale, 2015). In view of the numerous benefits conferred by stakeholder engagement, it is widely considered a sustainable remediation best management practice (ASTM, 2013; ISO, 2015; ITRC, 2011a; NICOLE, 2010; SURF, 2011; SuRF-UK, 2010). In addition, stakeholder engagement is required by regulatory entities internationally (ASTM, 2013; Cundy et al., 2013; Harclerode et al., 2015a; ISO, 2015; Mazmanian and Kraft, 2009; REVIT, 2007; Rizzo, 2015; and USEPA, 2005).

The concept of “stakeholder participation” has come to occupy an important place in environmental management (Reed, 2008). A stakeholder can be defined as any organization, group, or individual who takes an interest in a project, can influence project outcomes, and may be affected by project activities (Cundy et al., 2013). Stakeholders’ perceived risk associated with environmental protection and management activities can directly affect the success of remediation and preventative activities (Bickerstaff, 2004; Harclerode et al., 2015a; SURF, 2009; SURF, 2013; Vandermoere, 2008; Weber et al., 2001). Risk can be understood as the relationship between the probability of harm associated with an activity and vulnerability of exposed elements (i.e., people, buildings, and environment) (Slovic 1987, 2003; UN-ISDR, 2002). Risk perception, as defined by the Royal Society’s landmark report on risk, involves, “people’s beliefs, attitudes, judgements and feelings, as well as the wider cultural and social dispositions they adopt towards hazards and their benefits” (Pidgeon et al., 1992, p. 89). Risk perceptions are influenced by a wide array of factors; among them, knowledge, vulnerability, capability to respond to hazards and demographics.

Vulnerability is a “combination of exposure and sensitivity to perturbations or external stresses and adaptive capacity or resilience to a hazard or stressor (Adger, 2006; Cutter, 2003; and Glatron and Beck 2008). Glatron and Beck (2008) identified three main factors of social vulnerability based on the work of D’Ercole (1996): (1) perception of risks; (2) the knowledge and management of risks (e.g., geography and history of local hazards; preventative information); and (3) constraining factors (e.g., location of the person and socio-demographic characteristics). Communities vulnerable to environmental and health risks are often concentrated in low-income, underserved, disenfranchised, ethnically diverse, and marginalized communities (Bickerstaff, 2004; Bullard, 1990; Coughlin, 1996; and Slovic, 1997, 2000). Systematic overestimation of risk, associated with a sense of hopelessness, is common among individuals who are divorced, have low incomes, and unemployed (Boholm, 1998). This “sense of hopelessness” is also correlated with individuals in “positions of less power and control, benefit less from many technologies and institutions, are more vulnerable to discrimination and therefore see the world as more dangerous” (Finucane et al., 2000, p. 161). Vulnerable populations that have a “sense of hopelessness” often do not view themselves as having the ability to bring about change and address hazards present within their community. Paradoxically, an individual’s sense of their ability to bring about change through behavior has little imperative to do so (Bickerstaff and Walker, 2001). Therefore, vulnerable populations within a community who perceive themselves as agents of change may not actually participate in risk mitigation activities.

In addition, perceptions of risk vary between different groups of people. Individuals with a higher education, more power, and greatest socio-economic advantage tend to underestimate risk (Boholm, 1998). White males have a lower risk perception to environmental hazards than non-white males and females (Bickerstaff, 2004; Slovic, 1997, 2000; Wester Herber, 2004). Women tend to express higher risk perception of threats to the environment, and that this tendency is particularly strong with regard to pollution and risk to health from local facilities (Davidson and Freudenburg, 1996). Among ethnic sub-groups, Asian Americans usually rate risks as low, while African

Americans tend to rate risks as high. Women and non-white males are a common demographic among individuals expressing a "sense of hopelessness" (Bickerstaff, 2004).

Experts and the general public often disagree on the severity of risk attached to a situation (e.g., a remediation project) because each individual assigns a different significance to various factors that influence risk (Slovic et al., 2004; Bickerstaff, 2004). Studying risk perception can help environmental managers improve the efficacy of the relevant practices. The amount of risk that individuals associate with possibly harmful activities affects their attitudes toward environmental remediation for such issues, including preferences for government management of hazards affecting personal safety and public health (Gerber and Neeley, 2005). In addition, individual assessment of risk affects what precautionary and mitigation efforts he or she may take to reduce personal harm from exposure to environmental hazards (Flynn et al., 1999).

Internationally, stakeholder engagement is practiced as an effective tool for mitigating community and individual exposure to contaminated media (Chappells et al., 2014; Wiséen and Herber, 2007). A hybrid "bottom-up/top-down" approach to stakeholder engagement can be performed to address the role of perceived risk in determining whether or not the implementation of remediation and preventative activities are successful (Koontz et al., 2004; Kootnz and Newig, 2014; and Margerum, 2011). The "bottom-up/top-down" approach seeks to combine expert and public knowledge and tackle common misperceptions to collaboratively address environmental issues

(Chappells et al., 2014; Innes and Booher, 2010; Weber, 2003; Weible et al., 2004; and Wiséen and Herber, 2007). Surveys, interviews, and other forms of stakeholder engagement (e.g., multi-criterion decision analysis and social network analysis) can be undertaken to identify factors contributing to the stakeholders' perceptions of risk management. Once factors are identified, decision makers can provide direct support and education to communicate actual risk and overcome inaccurate perceived risk (Bickerstaff, 2004; Harclerode et al., 2015a; and Palma-Oliveira and Gaspar, 2004). In addition, having a comprehensive understanding of stakeholders' perceptions of risk allows remediation decision-makers to effectively communicate and promote legitimacy and compliance with policies and protective measures (Botzen et al., 2009).

5.1. Study Objective

The role of public risk perception in environmental management has been investigated internationally for a wide range of hazards, including water and noise pollution (Preston et al., 1983; Chappells et al., 2014), air pollution (Bickerstaff, 2004), climate adaptation (Grothmann and Patt, 2005; Patt and Schroter, 2008; and Tam and McDaniels, 2013), and multi-hazard environments (e.g., flood, crime, and toxic chemical release) (Gerber and Neeley, 2005; Lindell and Hwang, 2008). Recently, research on climate change has involved analysis of the role that risk perceptions play in inhibiting or encouraging adaptive action by individuals and institutions alike (Leiserowitz 2006, 2005; Kahan et al., 2012).

Relatively few studies have evaluated how risk perception factors specifically affect preferences towards government action to manage potential public health and personal safety hazards (Gerber and Neeley, 2005). Existing studies provide little understanding of the basis of risk perception variation between places and social groups (Bickerstaff, 2004). In addition, discussions on the role of stakeholder engagement as a sustainable remediation practice have tended to focus heavily on identifying societal level needs and remedial goal prioritization, and rarely on identifying the need to understand individual behavior and life style choices to successfully implement and maximize the benefit of risk management.

For the present study, we surveyed residents in a diverse urban community impacted by non-point source lead pollution. The principal goal was to identify risk perception factors influencing these stakeholders' responses to mitigating their exposure to household paint and historic fill material containing elevated concentrations of lead. Non-point source pollution can be defined as pollution that originates from multiple sources over a relatively large, diffuse area that is not introduced into a receiving entity from a standard outlet (USEPA, 2010b). Widespread distribution of lead, a recalcitrant compound, may be present in the form of paint, historic fill material, historic leaded gasoline (Zakrzewski, 2002, p. 204-205), and/or deteriorating pipes. Eradicating multiple sources of recalcitrant, non-point source pollutants within a large-scale residential setting can be technically and financially infeasible, requiring stakeholder engagement to play a dominant role in risk management. We hope this study illustrates the importance of evaluating and incorporating risk perception into remedial decision-making to promote the effective use of financial resources for maximizing the benefit of public outreach activities, thus driving a more sustainable solution.

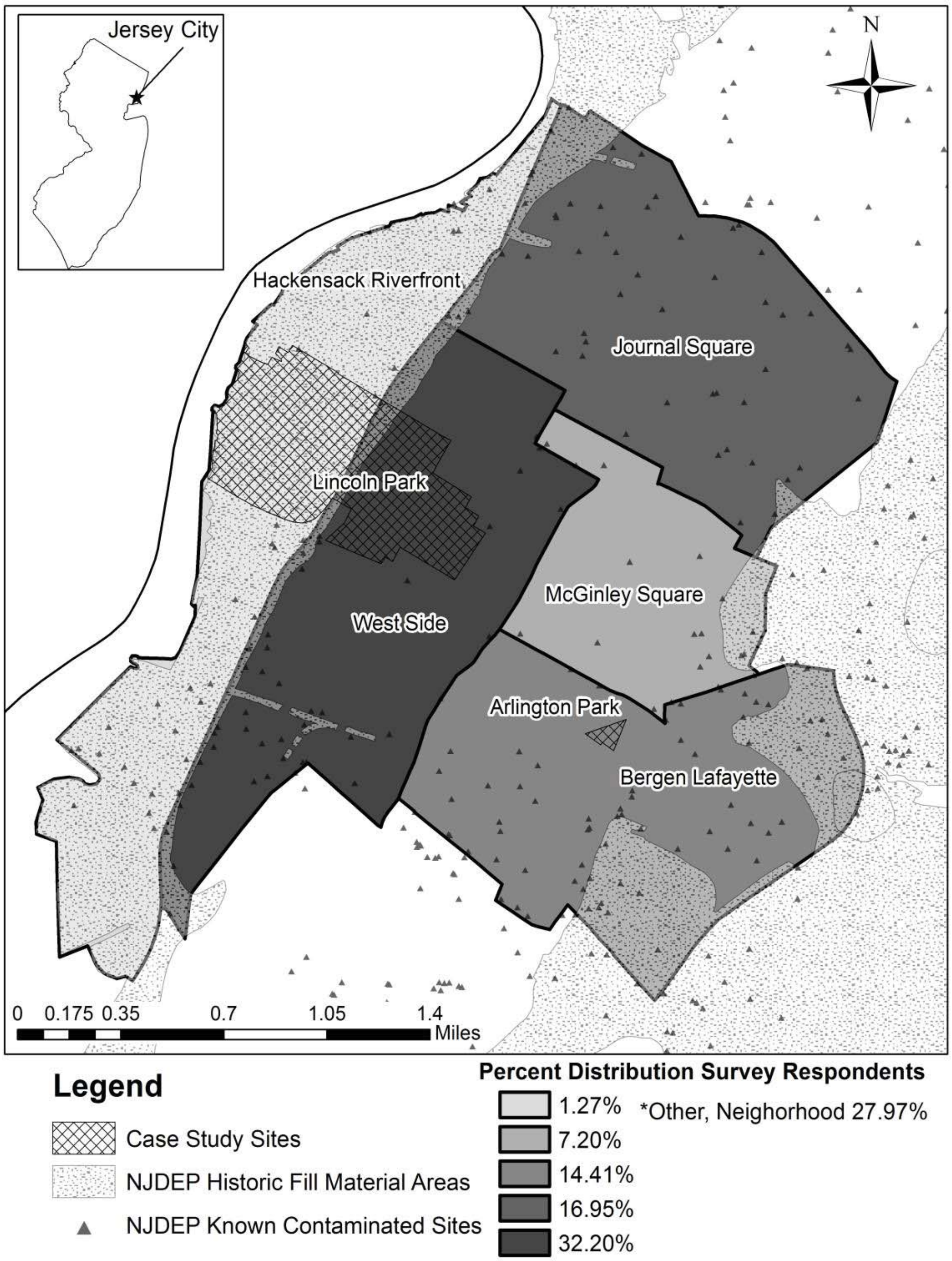
5.2. Methods

5.2.1. Case Study

Communities throughout the United States, as well as internationally, are currently subjected to residential lead exposure via paint and surface soils. The United States Department of Housing and Urban Development, as well as state and municipal departments of health, provide public outreach support and technical assistance to communities for mitigating residential lead exposure (CDC, 2015; CJC, 2007a; and NJDOH, 2009).

Jersey City was chosen as the case study site due to the presence of widespread non-point source lead pollution and an active public outreach campaign by the municipal health department to empower residents to prevent and mitigate exposure. Jersey City is part of the New York metropolitan area, bounded to the east by the Hudson River and Upper New York Bay and to the west by the Hackensack River and Newark Bay. Historically, Jersey City was a dock and manufacturing town. The City is impacted by historic, legacy contamination, including lead-based paint and historic fill. Buildings in Jersey City may still contain leaded paint if erected prior to 1971, after which leaded paint was banned for residential use in New Jersey, and subsequently nationwide in 1978. Statewide, approximately 30.2% of housing units were built before 1950 (CDC, 2015). The New Jersey Department of Environmental Protection (NJDEP) historical fill map of Jersey City is presented in **Figure 5-1**.

Figure 5-1: – Case Study Sites and Respondent Distribution



Jersey City has been conducting lead screening of residents, primarily children, since 1958 (CDC, 2015). The Department of Health and Human Services established a Childhood Lead Poisoning Prevention Program, which provides blood screening for lead, case management for children who are lead poisoned, environmental intervention support, and education and awareness on lead risks and hazards to the community (CJC, 2007a). While conducting this survey, respondents indicated that before their child first started school, the municipal health department hosted lead prevention seminars and conducted blood screening on the child.

5.2.2. Sampling Approach

We chose public green spaces for the surveys because of their accessibility. These spaces are open to the public and provide an opportunity to reach a diverse sample population. Lincoln Park and Arlington Park were selected as case-study sites because of their location between two NJDEP designated historic fill areas, the western portion of Lincoln Park and Liberty State Park to the east, shown on **Figure 5-1**. In addition, based on the age of residential structures in the area and the history of Jersey City, it was assumed that structures containing lead-based paint were present within close proximity of the parks.

Jersey City is considered one of the most diverse community populations in the United States (CJC, 2007b). The *City of Jersey City* website states that the City is, “composed of substantial communities of Jewish, Italian, Cuban, Filipino, Polish, Indian, Irish, Puerto Rican, Dominican, African, Arab, and Asian descent.” Jersey City is the second-most populous city in New Jersey and is Hudson County's largest city. As of 2014, Jersey City's Census-estimated population was 262,146.

The survey sample contained 244 respondents with the demographic distribution presented in **Table 5-1**. Distribution characteristics can be considered similar to the 2010 census (USCB, 2015). For this study, sensitive populations were identified and were comprised of the following distribution: 19.26% of the respondents have at least one child under 3 years of age; 44.67% have at least one child between 3 and 12 years of age; 10.66% have at least one child between 13 and 17; and 10.66% were or had a senior citizen over the age of 65 residing at the household.

Table 5-1: Demographic Distribution of Sample Population

Demographic Category	Variable	Composition of Sample (%)	US Census, 2010 (%)
Gender	Male	42.92	49.4
	Female	57.08	50.6
Ethnicity	Caucasian	16.32	21.5
	Asian or Pacific Islander	15.90	23.7
	Hispanic	29.29	27.6
	African American	30.13	25.8
	"Other" ethnicity	8.36	---
Age	30 and younger	29.75	---
	31 to 40	35.54	
	41 to 50	21.49	
	51 to 65	11.57	
	Older than 65	1.65	
Highest Level of Education	Elementary School	5.53	---
	High School	20.43	84.8 High School Graduate or higher
	Some College	25.96	
	College graduate and above	48.09	42.0 Bachelor's Degree or higher

Demographic Category	Variable	Composition of Sample (%)	US Census, 2010 (%)
Approximate Family Gross Income	Less than $22,000	28.05	*median household income $58,206
	$22,000 to $49,999	29.86	
	$50,000 to $89,999	23.98	
	Greater than $90,000	18.10	
Employment Status	Employed/Self-Employed	67.38	---
	Homemaker	9.87	
	Unemployed	14.59	
	Student	4.72	
	Retired	3.43	
Residency Status	Owns and Lives at Property	22.22	30.0
	Owns the Rental Property	17.95	---
	Tenant	59.83	___________
Resided at Current Residence	Less than a year	17.72	85.2 living in same house 1 year and over
	1 to 5 years	44.30	
	5 to 10 years	15.19	
	Over 10 years	22.36	
Average Number of Residents in Household		3.56	2.59

*18.4-percent of the population is below the poverty level

5.2.3. The Questionnaire

The questionnaire consisted of two parts: the risk perception section and a section requesting socioeconomic data. Risk perception questions included qualitative answer categories to evaluate factors influencing perception of risk to lead exposure, as well as to conduct a risk analysis of various hazards that community stakeholders may encounter. The questions were based on a literature review of risk perception in a remediation context, discussions with a technical expert team consisting of an environmental economist, a remediation consultant, and a social scientist, as well as a pilot survey. A copy of the survey is provided in Supplementary Material.

The study is based on data collected via an in-person survey conducted two to four days per week between May and August 2015 in Lincoln and Arlington Parks. We solicited responses from all park visitors 18 years of age and older whom we encountered at the study sites. Each day of the week and time of day (i.e., morning, afternoon, and early evening) was represented during the survey event. Respondents were also asked to identify their neighborhood of residence. Spatial distribution of respondents by neighborhood is presented in **Figure 5-1**.

Compared to other modes, in-person surveys provide some distinct advantages. For example, they allow the researcher to collect detailed and relatively complete information, increase survey response rate, explain a question if required, keep the respondent focused, and maintain data quality by avoiding ambiguous markings or illegible handwriting, among others (Doyle, 2005). The use of in-person surveys is relatively common in the environmental management and public health literature. Vandermoere (2008) employed an in-person survey to examine the relationship between risk perception and the need for remediation among stakeholders exposed to soil pollution. Weber et al. (2001) evaluated the perception of risk to heavy metals in soil and the use of various remedial technologies (e.g., bioremediation, excavation, and chemical treatment). In-person surveys have also been utilized to understand individual behavior and life style choices of fisherman catching fish on designated Superfund Sites (Burger and Gochfeld, 1991).

5.2.4. Risk Analysis

As people are exposed to hazards, the community and broader society reacts, directly impacting an individual's risk perception of those hazards. Perceived risk is either heightened or diminished by exposure and societal influences. Risk attenuation occurs when experts judge hazards as relatively serious, even while the community does not and pays comparatively little attention to that risk. Risk amplification occurs when experts assess a hazard as carrying a significant degree of risk, and the community, and sometimes broader society, perceives it as a major concern. Risk amplification is usually triggered by a single event (Lewis and Tyshenko, 2009; Kasperson and Kasperson, 1996). Risk attenuation is commonly associated with hazards from complex problems, such as regional interactions over long periods of time. The degree of attenuation or amplification influences the ripple effect of that risk (i.e., how the public, experts, policy makers, media, and broader society conduct risk management strategies) (Kasperson and Kasperson, 1996). In this study, the risk analysis was conducted to assess how individuals perceived their risk of lead paint exposure and soil pollution relative to other hazards they may encounter and, therefore, put the perceptions of lead-based paint and soil pollution into perspective. Results of the risk analysis were also used to identify if risk attenuation or risk amplification was occurring.

The respondents were asked to rate on a scale from 1 to 5, "How serious of a risk does the following pose to you?" and, "How would you rate the following risk to the average person living in New Jersey?" Respondents were asked to rate death, injury, property damage, terrorist attack, flood damage, burglary, house fire, traffic accident, asbestos exposure, lead paint exposure, air pollution, water pollution, and soil pollution. On this scale, 1 represented no risk (i.e, “not at all risky”); 3 was a moderate option (i.e., “moderately risky”); and 5 represented high risk (i.e., “extremely risky”). Similar scales have been successfully used to assess perceived health and environmental risks (Botzen, 2009; Gerber and Neeley, 2005; Hurd and McGarry, 1995; and Kunreuther et al., 2001). A percentage distribution analysis (Botzen, 2009) was conducted for this study to assess perceived likelihoods of risks to listed hazards.

5.2.5. Factors Influencing Risk Perception

The success of public outreach in motivating community members to prevent and mitigate exposure to a risk is based on site-specific physical, psychological, sociological, and demographic characteristics. Identifying these risk perception factors among the population allows agencies to implement outreach activities, refine education material, and determine modes of delivery that maximize benefits to the community and meet specific needs of the targeted public (Bickerstaff, 2004; Palma-Oliveira and Gaspar, 2004; REVIT, 2007; USEPA, 2005).

Individual risk perceptions are shaped by interactions of a variety of personal, social, and institutional factors. Bickerstaff (2004) presented three key dimensions of risk perception factors based on socio-cultural and psychological research: place and locality, agency and power, and trust and communication.

We used the Pearson correlation analysis (Tam and McDaniels, 2013) and the gamma measure of association test (Fischhoff et al., 2010) to evaluate the relationship between perceived risk and key dimension factors. Correlation analyses give insight into how different variables relate to one another. Such results can indicate the directional relationship between variables, along with the magnitude and significance of that relationship. Pearson correlation analysis was used to evaluate questions posed with nominal variables consisting of "yes" and "no" as potential answers. These variables are considered nominal because there is not an intrinsic ordering to the potential responses. The gamma measure of association test was used to evaluate questions posed with ordinal variables, in which potential answers were classified in a specific order (e.g., not at all (1), very little (2), somewhat (3), and to a great extent (4)).

5.2.6. Demographics

Stakeholder engagement and public outreach efforts should cater to the specific needs of each individual and stakeholder group impacted. The public consists of a wide range of individuals including, but not limited to, potentially responsible parties, demographic sub-populations, members of special interest groups, and policy-makers. This mosaic of individuals and groups brings a range of ideas to their understanding of risk and risk-based decisions (Bickerstaff, 2004; Wester and Herber, 2004; USEPA, 2005). Several studies indicate that perceptions of risk vary among different demographic groups (Hakes and Viscusi, 1997; Botzen, 2009). Low-income, underserved, disenfranchised, and ethnically diverse communities like Jersey City are subject to environmental and health problems (Bullard, 1990; Coughlin, 1996). The socioeconomic variables included in this study are the age of the respondent, gender, education level, type of household, approximate gross family income, employment status, and residency status.

The ordinal logistic regression model (Tate et al., 2003) was used to estimate more reliable coefficients by controlling for relevant variables. Given that survey responses were measured on an ordinal scale, this approach was considered appropriate to analyze the data. This model accounts for the order between the levels, as opposed to the actual distance. It estimates similar parameters and produces n-1 number of intercepts, fitting a succession of parallel logistic curves to the cumulative probabilities. The econometric model can be specified as:

$$P(y \leq k) = F(\alpha k + X\beta) \text{ for } k = 1, \ldots, m - 1 \qquad (1)$$

$$F(x) = \frac{1}{(1+e^{-x})} = \frac{e^{x}}{(1+e^{x})} \qquad (2)$$

where m represents the number of response levels in each survey question and F(x) is the standard logistic cumulative distribution function.

The analysis was conducted using the stepwise regression method and our model (equation 1) with lead paint exposure and soil pollution exposure as dependent variables. JMP software was used to determine the covariates (independent variables) that optimize the model. Accordingly, we formulated alternative and reference groups to narrow down the demographic characteristics that exhibited a significant correlation with exposure to lead-based paint and soil pollution.

Figure 5-2: Risk Analysis

5.3. Results and Discussion

5.3.1. Risk Analysis

Figure 5-2 presents the results of the risk analysis. For a majority of the hazards evaluated, respondents generally perceived risk to these hazards as moderately risky for individuals, but more so for the average New Jersey resident. For instance, the respondents rated their risk of being exposed to lead based paint as generally lower compared to the average person living in New Jersey. This is unexpected due to the ongoing public outreach efforts conducted by the municipal health department on preventing and mitigating lead exposure. These results could have been influenced by the "optimism bias" (Weinstein, 1987), which has been well documented in studies on risk perception. "Optimism bias" may be at work when respondents consider themselves less susceptible to risks than others. The "optimism bias" seemingly occurring here could have been amplified by the relatively young age of the average respondent (De Joy, 1989).

The analysis also suggests that risk perception of lead paint exposure and soil pollution are indicative of "risk attenuation" (Lewis and Tyshenko, 2009; Kasperson and Kasperson, 1996), wherein abstract and seemingly remote risks are outweighed by more immediate and perceptible ones (such as air and water pollution). The respondents' heightened perception of risk appeared to be related to their awareness of these risks being endemic in urban areas (Bickerstaff and Walker, 2001). Another possible explanation could be the effect of the "availability heuristic," proposed by Tversky and Kahneman (1974), which points to the exaggerated effect that recent events related to hazards (e.g., terrorist attacks or a house fire) can have on the perception of risks in everyday life. More distant and slowly unfolding risks, such as chronic, long-term exposure to lead, could be overshadowed by adverse events that have been prominent in public discourse.

Table 5-2: Correlations among Key Risk Perception Factors (nominal scale)

Key Dimensions	*Risk Perception Factors*	Lead Paint Exposure		Soil Pollution	
		Individual			
		Chi Square	p	Chi Square	p
Place and Locality	Aware of Polluted Site w/in Two Blocks	3.32	0.506	9.19	0.057*
Place and Locality	Aware of Polluted Site w/in Neighborhood	5.87	0.209	6.57	0.161
Trust and Communication	Aware of Lead Exposure Damage Vital Systems	3.05	0.549	6.95	0.139
Trust and Communication	Aware of Developmental Issues from Lead Exposure	2.20	0.700	10.29	0.036**
Place and Locality	Grow Plants for Consumption	2.38	0.666	0.70	0.952
Place and Locality	Grow Plants for Decoration	10.82	0.029**	8.91	0.064*
Agency and Power	Purchase Top Soil for Gardening	3.74	0.442	6.47	0.167
Place and Locality	Plant Directly in Ground	3.76	0.439	4.85	0.303
Place and Locality	Residents Interact with Garden/ Grass	0.87	0.930	5.22	0.266
Place and Locality	Pets Interact with Garden/Grass	4.42	0.352	2.59	0.628
Place and Locality	Soil Tested For Lead	3.06	0.931	5.84	0.666
Place and Locality	Paint Test for Lead	12.31	0.138	4.26	0.833
Place and Locality	Lead Pollution Identified in Soils	5.71	0.680	11.58	0.171
Place and Locality	Lead Pollution Identified in Residence	8.49	0.387	5.71	0.680
Agency and Power	Measures Taken to Mitigate Lead	5.99	0.648	6.01	0.646

Note: Correlation analysis was conducted using Pearson. ***p <0.01, **p<0.05, *p <0.10

Table 5-3: Correlations among Key Risk Perception Factors (ordinal scale)

Key Dimensions	*Risk Perception Factors*	Lead Paint Exposure		Soil Pollution	
		Individual			
		correlation coefficient	95% CI	correlation coefficient	95% CI
Place and Locality	Going to Get Worse in the Future - Household Pollution	0.348*	[0.211 - 0.486]	0.483*	[0.354 - 0.613]
Place and Locality	Going to Get Worse in the Future - Community Pollution	0.360*	[0.221 - 0.500]	0.513*	[0.387 - 0.639]
Trust and Communication	Heard or Read about Pollution in the Jersey City Area	0.309*	[0.190 - 0.429]	0.297*	[0.165 - 0.429]
Trust and Communication	Interest in Learning More about Pollution in the Jersey City Area	0.121	[-0.032 - 0.275]	0.230*	[0.082 - 0.379]
Trust and Communication	Individual's Responsibility to be Aware of Env. Risks and Address Them	0.196*	[0.047 - 0.344]	0.217*	[0.077 - 0.358]
Trust and Communication	How Sensitive is the Environment to Human Activities	0.104	[-0.075 - 0.282]	0.277*	[0.099 - 0.454]
Trust and Communication	Human Population's Impact on the Environment	0.122	[-0.080 - 0.324]	0.230*	[0.026 - 0.435]
Agency and Power	Ability to Address – Household Pollution	0.366*	[0.231 - 0.501]	0.449*	[0.319 - 0.579]
Agency and Power	Ability to Address – Community Pollution	0.296*	[0.153 - 0.439]	0.458*	[0.330 - 0.586]

Note: Correlation analysis conducted using gamma measure of association test, *p<0.05.
CI = confidence interval

5.3.2. Key Dimensions of Risk Perception

The relationship between key risk perception factors (Bickerstaff, 2004) and perceived risk to lead paint exposure and soil pollution for individual respondents is presented in **Tables 5-2** and **5-3**. In **Table 5-2**, the chi square statistic is used to evaluate whether distributions of nominal variables differ from each other. Significant correlations are represented by p-values less than 0.10. In **Table 5-3**, significant correlations are represented by correlation coefficients that fall within the 95-percent confidence level, in which the range does not include zero. By identifying these significant correlations, we can determine which factors have the greatest influence on risk perception. We can then focus on these factors when developing a plan to spread public awareness and limit the harmful impact of exposed lead.

The same set of factors were correlated to perceived risk of lead paint exposure and soil pollution, which included:

- Growing plants for decoration *(place and locality)*;
- Having the ability to address both household and community pollution *(agency and power)*;
- Heard and read about pollution in the Jersey City area *(trust and communication)*;
- Understanding the responsibility of the individual to be aware of and to address environmental risk *(trust and communication)*; and
- Sense of a personal safe space and belief that household and community pollution are going to get worse in the future *(place and locality)*.

Additional factors were correlated to perceived risk of soil pollution only, which included:

- Awareness of a polluted site within two blocks of the property *(place and locality)*;
- Awareness of developmental issues from lead exposure *(trust and communication)*;

- Interest in learning more about pollution in the Jersey City area *(trust and communication)*;
- Sensitivity of the environment to human activities; and
- Human population's impact on the environment.

The results of the correlation analysis suggest that individual respondents hold themselves accountable and perceive themselves as having the ability to address environmental risks within their household and community. Therefore, public outreach focused on risk management of lead would encourage respondents to prevent and mitigate their exposure. In addition, hearing and reading about pollution would most likely heighten their awareness of risk from lead exposure and would motivate them to undertake precautionary and mitigation efforts to reduce personal harm (Flynn et al., 1999). Wiséen and Herber (2007) found that when a substance was subject to public and media attention, it was positively linked to a higher risk perception. They saw the media as an important delivery mode for transferring information to a large audience (i.e., community). The results of our risk analysis indicate that the community members believe that they are at less risk to lead exposure than the average New Jersey resident. By using media, such as local newsletters and participation in community events (such as farmers markets and fairs), the municipal health department can raise the community's awareness of exposed lead and the health threats it poses.

Respondents mostly agreed that household pollution, including lead paint exposure and soil pollution, is going to worsen in the future. However, respondents did not correlate lead exposure to damaging vital human systems (e.g., neurological and circulatory). Respondents only correlated detrimental developmental effects from lead exposure with soil pollution and not with paint. Chronic lead exposure via paint can cause permanent health and developmental effects (CDC, 2015). Therefore, there appears to be a disconnect between the perceived danger of exposure to lead based paint and its actual detrimental health impacts. It is common for individuals who acknowledge the presence of a hazard to deny that it will cause harm to them personally. Individuals who believe they have the power and ability (e.g., politically and economically) to address a hazard, paradoxically have little imperative to do so (Bickerstaff, 2004). Individuals are also inclined to accept a risk when it is voluntary (Bickerstaff, 2004; Burger et al., 1991; Pflugh et al., 1999). These mindsets may be reflective of "optimism bias," which seemed to be a contributing factor in the risk analysis, as many respondents underestimated the potential dangers of lead exposure.

Current public outreach efforts of the municipal health department provide material explaining the detrimental health effects of lead exposure and how to identify, prevent, and mitigate exposure. As shown in **Table 5-2**, lead testing and mitigation measures conducted at an individual's residence did not have a significant correlation to risk perception. This may be due to the misbelief that lead exposure will not harm oneself nor one's family. Based on these results, stakeholder engagement should be incorporated to strengthen the connection between being able to address environmental risks and understanding the subsequent long-term health benefits of avoiding lead exposure.

Lastly, the results indicated that respondents who know of a polluted site in close vicinity to their residence are more likely to have higher risk perceptions of lead, especially soil pollution. Therefore, public outreach efforts would likely benefit the community by notifying and educating community members about the presence of lead-impacted structures in close proximity to their households. Once they are aware of lead-impacted areas nearby, residents may take advantage of free testing for lead in their homes and other preventative services provided by the municipality. Outreach should be thoughtfully executed, possibly with the help of trusted community partners (e.g., church and other non-governmental organizations) to avoid panic within the community.

5.3.3. Demographics

The socioeconomic variables and their respective levels used for this analysis are presented in **Table 5-4**. Demographic variables that significantly influenced respondents' perceived risk to lead paint exposure and soil pollution are presented in **Tables 5-5** and **5-6**. Significant correlations are reflected by p-values less than 0.10. Sub-populations assigning different levels of risk to each hazard emerged within the sample population. To be successful, stakeholder engagement must cater to the specific needs of each demographically defined group impacted by a hazard. This may require several types of approaches to meet corresponding needs (Bickerstaff, 2004; Wester-Herber, 2004; Wester- Herber and Warg, 2004; USEPA, 2005).

5.3.4. *Lead Paint Exposure*

Table 5-4: Socioeconomic Variables Evaluated

Socioeconomic variable	**Data type**	**Data levels**
Gender	Nominal	Male (1) Female (2)
Ethnic group	Nominal	Caucasian (1) Asian or pacific islander (2) Hispanic (3) African-American (4) Other (5)
Age	Nominal	30 and younger (1); 31-40 (2); 41-50 (3); 51-65 (4); Older than 65 (5)
Number of people in the household	Count	---
Type of household	Nominal	Husband-wife family (1); Male household, other family (2); One person, nonfamily (3); Female household, other family (4); Two or more people, nonfamily (5)
Have children younger than 3 years old	Nominal	No (0); Yes (1)
Highest level of education completed	Ordinal	Elementary school (1); High school (2); Some college (3); College graduate and above (4)
Gross family income	Ordinal	Less than $22,000 (1); $22,000-$49,999 (2); $50,000-$89,000 (3); Greater than $90,000 (4)
Employment Status	Nominal	Employed/self-employed (1); Homemaker (2); Military (3); Unemployed (4); Student (5); Retired (6)
Residency status	Nominal	Owns and lives at property (1); Owns the rental property (2); Tenant (3).
Duration in current residence	Ordinal	Less than a year (1); 1-5 years (2); 5-10 years(3); Over 10 years (4)

Table 5-5: Demographic Variables of Risk Perception to Lead Paint Exposure

Variable		**Estimate (regression coefficient)**	**Chi Square**	**p**
Ethnic group {5&3&4-1&2}		0.18	1.68	0.195
Age {1&2-3&4&5}		-0.16	1.22	0.270
Age {1-2}		0.22	1.94	0.163
Type of household {1&5&2-4&3}		0.36	6.95	0.008***
Gross family income{1-2&3&4}		-0.37	5.49	0.019**
Employment Status {2&4&1&5-6}		0.70	2.58	0.109
Employment Status {2&4-1&5}		0.33	4.14	0.042**
Duration in current residence {1-2&3&4}		-0.38	4.11	0.043**
Duration in current residence {2&3-4}		0.32	3.69	0.055*
Duration in current residence {2-3}		-0.33	3.12	0.077*
Whole Model Test Parameters				
Model	Log Likelihood	Degrees of Freedom (DF)	ChiSquare	p
Difference	17.08215	10	34.16	0.000***

Note: *** significant at <0.01 level; ** p<0.05; * p<0.10; See **Table 5-4** for corresponding numerical variables. The Log Likelihood tests goodness of fit of the model. It tests whether the regression coefficients are all simultaneously zero. The p value indicates whether each regression coefficient is zero (p value < 0.1 indicating that the value is significant). The results conclude that the model itself is significant.

Results suggest that respondents' assessment of their own risk from lead paint is affected by gross family income, type of household, employment status, and how long the respondent has lived at their current residence. Compared to a single person or a female headed household, respondents that belong to a male headed household or larger households are likely to attribute lower risk to lead paint exposure. This finding aligns with previous studies identifying a lower risk perception to environmental hazards in males than in females (Bickerstaff, 2004; Slovic, 1997, 2003; Wester Herber, 2004).

Respondents who are students or employed are likely to consider lead paint exposure as more risky, compared to homemakers and those who are unemployed. In addition, lower income households (below $22,000 a year) attribute more risk to lead paint exposure than those with a higher income. Respondents, who are currently unemployed or retired reflect socio-economic marginality and often assess risk differently than other sub-populations (Bullard, 1990; Coughlin, 1996).

Compared to respondents who have lived in their homes for more than a decade, shorter-term residents are likely to consider lead paint exposure as less risky. However, if we break down the years of residence further, those living in houses for less than a year attribute more risk to lead exposure than those who have exceeded one year of residency. The lead risk perception is also higher for households that have been residing in their home between 1 to 5 years versus between 5 to 10 years. Hazards that are regional and present over long periods of time are often perceived as less risky (Kasperson and Kasperson, 1996). These results further suggest the presence of an “optimism bias” and “risk attenuation,” in which a significant portion of the respondents do not perceive themselves at a high risk to lead exposure.

5.3.5. Soil Pollution Exposure

Table 5-6: Demographic Variables of Risk Perception to Soil Pollution

Variables	**Estimate (regression coefficient)**	**Chi Square**	**P**
Gender [1]	0.08	0.41	0.52
Ethnic group {3-4&2&1&5}	0.35	4.35	0.04*
Ethnic group {4&2&1-5}	0.39	2.87	0.09**
Have children younger than 3 years old [0]	-0.20	1.70	0.19
Employment Status {2&4&1&5-6}	0.61	3.10	0.08**
Employment Status {2&4-1&5}	0.31	4.25	0.04*
Duration in current residence {1&2&3-4}	0.27	2.74	0.10**
Duration in current residence {1&2-3}	-0.44	5.79	0.02*
Duration in current residence {1-2}	-0.27	2.33	0.13

Whole Model Test Parameters				
Model	Log Likelihood	Degrees of Freedom (DF)	Chi Square	P
Difference	10.30838	9	20.62	0.015**

Note: *** significant at <0.01 level; ** p<0.05; * p<0.10; See **Table 5-4** for corresponding numerical variables. The results of the Log Likelihood test conclude that the model itself is significant.

Results suggest that respondents' assessment of their risk to soil pollution is affected by their ethnicity, employment status, and how long the respondent has lived at their current residence. Respondents who identified themselves as Hispanic or under the "other ethnicity" category are likely to consider exposure to soil pollution as less risky compared to Caucasian, Asian or Pacific Islander, or African-American respondents. Among ethnic sub-groups, Caucasians and Asian Americans usually rate risks as low, while African Americans tend to rate risks as high (Bickerstaff, 2004; Slovic, 1997, 2003). The African American respondents for this case study, however, are likely to consider soil pollution as less risky. Moreover, results showed that retired people, employed/self-employed, homemaker, unemployed, and students are likely to attribute lower risk to soil pollution.

Compared to respondents who have lived in their homes for more than a decade, shorter-term residents are likely to consider soil pollution as less risky. Furthermore, respondents that have lived in their house for less than five years are likely to consider exposure to soil pollution as more risky. These findings mirror the lead paint exposure results and reiterate the presence of an "optimism bias" and "risk attenuation."

5.3.6. Overall Findings

The findings indicated that sub-populations are present among the respondents, each assessing their risk to lead paint exposure and soil pollution differently:

Lead Paint Exposure

- Perceived Risk as Low: Male and larger family households, homemakers, unemployed, higher income, and resided at current residence between 5 to 10 years
- Perceived Risk as High: Female, single person, student, unemployed, lower income, and resided at current residence between 1 and 5 years

Soil Pollution

- Perceived Risk as Low: Hispanic, Other (ethnicity), retirees, employed/self-employed, homemaker, unemployed, students, and resided at current residence over 10 years

- Perceived Risk as High: Resided at residence less than 5 years

Overall, there are some similarities among the sub-populations that perceive risk to lead paint exposure and soil pollution at the same level (i.e., low versus high), including employment status and duration of residency. However, several differences were identified among the sub-populations. For instance, type of household significantly influenced risk perception of lead paint exposure and not soil pollution. These findings suggest that target stakeholder groups are defined uniquely by the risk (hazard) being evaluated. Stakeholder groups that severely underestimate their risk of different hazards require focused attention and more vigorous outreach to change their views to reflect actual risk.

Respondents living at their current residence for more than 5 years also seem to be unconcerned about lead paint risk. This is alarming since newly established families likely have children under the age of three, and belong to the segment of respondents with greatest actual risk from lead paint and soil contamination. The results could not identify a significant correlation between risk perception and households with children younger than three years old. The opposite would be expected, knowing that early childhood exposure to lead causes detrimental health effects (CDC, 2015). In addition, 60% of the respondents were tenants (see **Table 5-1**) and may not have control over preventative and mitigation activities at their residence. During the survey, a small number of respondents indicated challenges to soliciting landlords to test and mitigate lead paint exposure at their residence, and often moved due to non-response. The findings suggest that stakeholder engagement for vulnerable sub-populations needs to be refined to meet their specific needs, such as landlord communication support and education on detrimental effects of lead exposure to sensitive populations (e.g., children under the age of three).

5.4. Conclusion

Residents' perceived risk to lead paint exposure and soil pollution appears to be overshadowed by the presence of more immediate and perceptible risks (such as air and water pollution). In addition, the community exhibits "optimism bias" and the majority of residents do not identify themselves at high risk to susceptible and immediate hazards, including lead exposure. The underestimation of the immediate threat from lead contamination creates a significant obstacle to community participation in municipal-led education and outreach programs.

Based on this analysis, we recommend that decision-makers address the community's "optimism bias" by emphasizing that everyone has the ability to address environmental risks associated with lead, and that doing so will subsequently improve long-term health, especially for more vulnerable sub-population groups (residents living in Jersey City more than 5 years, tenants, and households containing children under 3 years of age). In addition, stakeholder engagement could clearly identify hazardous materials in close proximity to residences. More residents would likely take advantage of outreach (e.g., testing) activities if they were aware of nearby buildings containing elevated concentrations of lead. This may also encourage more landlord-tenant communication. In addition, risk managers should consider using media and participating in community events to spread greater awareness of risk to lead.

Since the community believes it has the ability to address environmental risks, additional “bottom-up” stakeholder engagement approaches should be considered. Community leaders should provide interactive opportunities where residents can participate in testing and mitigation activities to prevent future exposure. For example, the municipality could team with a local youth group, church, or other community groups to mitigate lead sources in public areas (e.g., sand and repaint chipped paint areas). The knowledge and hands-on experience would give residents the proper instruction to conduct similar mitigation efforts within their own households. Finally, the heterogeneity of individual stakeholder groups must be taken into consideration when developing risk management activities in order engage all representative stakeholders.

5.5. References

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Chapter 6

RESEARCH STUDY CONCLUSIONS

6. Overall Conclusion

Incorporation of methodologies from the environmental economics and social science disciplines into existing environmental impact evaluations performed by the remediation community is relevant and necessary to assess impacts to the triple bottom line (i.e., environmental, social, and economic). Consideration of triple bottom line impacts throughout the remediation project's life cycle ultimately results in short-term and long-term cost savings to both the responsible party and society. In addition, it has direct and indirect impacts on the quality of life for the local community and global society.

Historically, environmentalism does not take into account alleviating socio-economic costs and environmental justice issues. As evidenced in our present political environment, climate change impacts will have the greatest impact on socio-economically disadvantaged communities (i.e., cannot afford to relocate to areas not impacted by climate change). These indirect consequences of consuming limited natural resources and emitting chemicals into the atmosphere can be incorporated into a sustainability assessment using the social cost of environmental metrics. Unfortunately, there is an overall trend toward underestimating externality cost from greenhouse gas emissions and a backlash to using social cost metrics. This research study stresses the importance of using and refining these metrics to accurately reflect how human activities are leading to costs borne by society.

In addition, this research study touched upon how the social and economic dimensions of the triple bottom line can be the drivers for implementing sustainable practices. More often than not, the remedial or risk management approach implemented on a contaminated site directly impacts the quality of life for socially vulnerable populations, both in the short and long terms. In the risk perception case study, short term impacts to the community from mitigating lead exposure include reductions in lead levels in blood, learning disability in children, and costly medical bills. Long term quality of life impacts from lead mitigation include a decrease in the indirect effects of lead related health problems (e.g., learning disabilities linked to lower education status and increased crime rates). The limited resource that needs to be used in a sustainable manner in socially driven remediation and mitigation efforts is often money.

Traditionally, the remediation community has placed more weight on evaluating the environmental dimension of remedial activities and isolating the social dimension to stakeholder engagement. In addition, green remediation and sustainable remediation practices have been implemented primarily at the remedial selection and design stage, with little regard to long-term preventative and mitigation strategies. The conclusions of this research study stress the importance of shifting the remediation community's sustainability efforts towards integrating and embracing the interconnectivity among the triple bottom line dimensions throughout the project life cycle, thus efficiently utilizing limited resources (natural and financial) and continuously improving upon society's quality of life to achieve a true sustainable state.

6.1. Environmental Management Application

Human activities, including remediation, have both beneficial and detrimental impacts towards the environment, society, and economy. The balancing of these impacts are essential in maximizing benefits while minimizing costs both short and long-term. Evaluating and incorporating long-term benefits and costs of remediation can be challenging and may require further integration of complementary disciplines, including environmental economics and social science.

As presented in Chapters 2 through 4, methodologies commonly used in environmental economics can be incorporated into a footprint evaluation or life cycle assessment (LCA) to quantify long-term global impacts from resource consumption and chemical emissions (e.g., climate change and human health impacts). These global impacts have significant financial implications on our society, particularly in mitigating and repairing damage caused by climate change. Such effects are also apparent in funding now required to build systems and infrastructure, beyond remediation, resilient to climate change impacts (e.g., sea level rise or extended drought). In a holistic view of remediation, reducing resource consumption and emissions not only alleviates short-term environmental and financial impacts for the remediation sector, but also reduces long-term environmental and financial impacts to society.

As presented in Chapter 5, methodologies from the social science discipline can assist remediation professionals with stakeholder engagement and evaluating long-term impacts (both beneficial and detrimental) from risk management activities. Stakeholder engagement is a vital sustainable remediation best management practice that results in successfully managing and integrating stakeholder needs into remediation, identifying drivers and barriers to sustainable remediation, empowering the community (e.g., take ownership of maintaining a redeveloped parcel), and addressing challenges posed by risk perception to re-use of treated impacted media, mitigation of household risks (e.g., lead-based paint), and alternative cleanup approaches.

Regardless of the methodologies used and level of evaluation for implementing sustainable practices, early consideration and development of sustainability objectives during project planning is essential. Similar to the site characterization and remediation techniques implemented during remedial activities, the tools used to conduct a sustainable remediation assessment are based on site-specific variables or contexts (including legal and regulatory contexts), that are unique to every project. Successful consideration of the social dimension during a sustainability assessment is a core part of an integrated assessment that helps all stakeholders involved identify the most sustainable, viable strategy for remediating a site (Harclerode et al., 2015a).

6.2. Policy Implications

It is evident from the numerous frameworks and research studies issued over the last decade, that sustainable remediation is an integral practice in risk management, including cleanup activities and preventative measures. None of the established frameworks to date are required or enforced by regulatory agencies at an international level. Therefore, the implementation of comprehensive sustainable remediation assessments are limited, especially in the U.S. The findings of this research study highlight resources, both natural and financial, that can be saved by conducting comprehensive sustainability evaluations of cleanup activities throughout the project life cycle. Thereby supporting the issuance of policies mandating the incorporation of sustainable remediation practices to maximize benefits to all stakeholders and alleviate detrimental impacts to global society.

In Chapters 2 through 4, the social cost of environmental metrics were used to quantify global monetized impacts from site-specific cleanup activities. The use of social cost metrics, specifically carbon, is encouraged by the United State Protection Agency (USEPA) (2016b) and U.S. Department of Energy (DOE) (2011) to estimate the climate benefits of the decision-making process, following *United States Executive Order 12866 – Regulatory Planning and Review*. The findings of this research present a cost effective methodology to incorporate EO 12866 into the remedial decision-making process by using the results of established environmental footprint and life cycle assessment (LCA) tools. In addition, individual case study evaluations using the proposed methodology resulted in identifying opportunities to incorporate sustainable solutions as part of optimization efforts for existing resource-heavy remedial systems (e.g., groundwater pump and treat). The use of social cost metrics in the decision-making process is often criticized for not accurately representing financial damages society will endure from chemical emissions and resource consumption; and in turn not frequently utilized in cost benefit analysis. Two negative outcomes arise from not utilizing social cost metrics: (1) long term, intergenerational socio-economic impacts are not accounted for in the decision making process; and (2) research is not performed to develop more accurate social costs, because decision-makers are simply not using these metrics. It is the hope of this study that the case studies presented herein provide confidence and less uncertainty in using social cost metrics drive innovation in this area of environmental economics, and foster future, more widespread use of sustainability evaluations in remediation projects.

In Chapter 5, the case study showcased how integration of risk perception analysis in stakeholder engagement can help identify obstacles and address them to maximize beneficial outcomes of risk management activities. Financial resources available to conduct pollution prevention and mitigation efforts within a localized community are dwindling. In order to efficiently use limited financial resources, while simultaneously benefiting all stakeholders within a community, policies can be issued to consider and incorporate risk perception analysis as part of preventative measures.

Sustainable remediation expertise is widely accessible in academia, consulting companies, regulatory agencies, and private organizations. Remediation decision-makers should take advantage of these experts to choose not only appropriate tools and methodologies, but to also assist in identifying experts from other disciplines (e.g., ecology, urban planning, economics, sociology, and anthropology) that can address site-specific social concerns and accurately characterize the remediation context (Harclerode et al., 2015a).

6.3. Limitations of the Study

The research study presented herein was not without its limitations, as presented below. However, these limitations did not diminish meeting the study’s objectives and overall outcomes of each case study evaluation.

Environmental Impact Evaluation: Remedial design parameters (e.g., timber mats, *in situ* amendments, and silt fence) are not available in general life cycle inventory (LCI) databases and environmental footprint tool inputs (not including the silt fence parameter). In order to account for these design parameters in the LCA case study evaluation, the inputs were developed as a process using generic data from the LCI database. For the environmental footprint analysis, chemical emissions for these design parameters were calculated as part of the LCA and accounted for under the "other known onsite activities" category in the footprint tool. The lack of available remediation-specific inventory data can lead to inaccuracies in environmental impact outputs associated with specific remedial components.

Social-Economic Impact Evaluation: Both the LCA and footprint tools quantify sustainability metrics that currently do not have associated social cost including, but not limited to, water consumption, chlorofluorocarbon emissions (indicator of ozone depletion), 1,4-dichlorobenzene (indicator of human toxicity), land use/loss, and nutrient loads (e.g., phosphorous and nitrogen equivalents). Financial implications society endures from long-term damages represented by these metrics are currently not accounted for in the societal cost analysis. Therefore, monetized global impacts quantified for the remedy are underestimated. In addition, the social costs used for the social impact evaluation were derived from environmental, social, and economic models. The social or socio-economic cost/benefit related to an increase in property value and quality of life by local communities has not been represented in this research study.

Risk Perception Evaluation: According to the 2010 U.S. Census (USCB, 2015) for Jersey City, New Jersey, 1.4-percent of the population is comprised of "other" ethnicity and 23.7-percent is "Asian or pacific islander". During the in-person survey, individuals whose primary language was Arabic, French, or Indian were unable to participate in the survey. Even though the sample population distribution characteristics were considered similar to the 2010 U.S., the results of the study may not accurately reflect those sub-populations. In addition, the case study evaluation is based on results collected during in-person surveys. Two sets of 250-mailings were sent out to reach residents who do not frequent the case study sites (e.g., Lincoln and Arlington Parks), however only approximately 10-percent of the mailed surveys were returned. Due to the limited response from the mailings, these surveys were not included in the analysis; and therefore, the study results may not accurately reflect sub-populations that do not visit designated recreational areas within the community

6.4. Future Research

As the international community advances its understanding of sustainable remediation and moves towards a multi-disciplinary, integrated objectives-led assessment approach, it is important to acknowledge and encourage future research in this subject (Harclerode et al., 2015a).

Environmental Impact Inventory: A major data gap exists among the generic input parameters available in LCI databases and footprint tools, specifically used in common remedial design components (e.g., amendments for *in situ* treatment, coir and filter logs for bank stabilization, and dewatering pad materials). The lack of inventory data leads to greater uncertainty in the assessment results and inconsistency among assessments performed by different parties. Future research is needed to develop generic input parameters that are currently missing. In addition, remediation professionals should require vendors with proprietary information (e.g., amendments) to provide downstream chemical emission and resource consumption data for consideration in the sustainability assessment.

Value of Social Cost Metrics: The literature on social cost metrics is limited and often not site specific. Social costs need to be developed for common environmental metrics to account for financial implications due to chlorofluorocarbon emissions (indicator of ozone depletion), 1,4-dichlorobenzene (indicator of human toxicity), land use/loss, and nutrient loads (e.g., phosphorous and nitrogen equivalents). In addition, research is needed to assist remediation professionals in estimating site-specific social costs that can be incorporated into societal cost analysis evaluations. Particularly, data gaps exist for monetizing societal benefits and dis-amenities associated with remediation's impacts on water consumption/availability, ecosystem services, urban services, and social and human capital.

Role of the Values-Beliefs-Norms Theory in Risk Perception: The values-beliefs-norms (VBN) theory identifies factors that influences an individual's awareness of the beneficial consequences related to environmental stewardship and perceived responsibility to avert detrimental consequences of non-environmentally friendly behavior (Lind et al., 2015; Stern, 2000; Stern et al., 1999). Application of the VBN theory can assist in explaining variance in policy support, environmental citizenship, and ecological risk perception (i.e., severity in a ecosystem's risk to a hazard) among individuals and subpopulations within a community (Dietz et al., 2005; Stern, 2000). Slimak and Dietz (2006) states "the theory postulates that values, and especially concern with the well-being of other humans and the biosphere (i.e., altruism), are at the core of environmental perceptions" (pp. 1691). Based on the risk perception study, individuals' perceive themselves as being responsible to be aware of and address environmental risks associated with lead-based paint. Application of the VBN theory can assist the municipal health department in further understanding the community's value (morality) variables correlated to these risk perception factors and ultimately use the results of this analysis to help address the community's "optimism bias". Slimak and Dietz (2006) also applied this theory to evaluate differences in ecological risk perception between lay public, experienced public, and risk professionals (i.e., assessors and managers). Similar to Slimak and Dietz (2006, this case study observed the dichotomy in the severity of perceived risk related to lead-based paint between the lay public and risk professionals. Therefore, the results of a VBN theory study can also help better understand and close this gap.

Risk Perception of Lead-Impacted Drinking Water: The risk perception study focused on evaluating factors that were contributing to resident's risk perception toward lead-based paint and lead-impact soils. Future research is needed to understand factors contributing to a vulnerable community's perception of risk associated with lead-impacted drinking water. Specifically, once mitigation approaches are implemented to remediate lead in drinking water, research is needed to better understand risk perception factors influencing whether community members regain trust in the municipal water supply or manifest an overestimation of risk and subsequently do not use the public water source.

Risk Perception of Reuse: The layman's perception of risk for reusing treated media, such as remediated groundwater or soil, often inhibits reuse. Future research is needed to understand factors contributing to society's perception of the risk associated with reuse. An increased knowledge base on this subject will assist remediation practitioners in educating stakeholders and addressing community concerns pertaining to reuse.

Integrated, Objective-led Assessment: The development and performance of an integrated assessment approach for remediation sites is needed to evaluate interrelations among the three dimensions of the triple bottom line. This methodology attempts to value the effects, identify beneficial interventions, and fully expose unavoidable tradeoffs (Pope et al., 2004). The development of this approach should consider integration and evaluation of qualitative and quantitative data sets. Future research is needed to expand and/or combine existing assessment frameworks into one single approach to address trade-off concerns.

6.5. Closing Statement

This research study identified sustainability metrics and evaluation tools from the environmental economics and social science disciplines that are easily transferable to remediation projects. The methodologies presented herein can be used at any phase of a project's life cycle and to evaluate any type of technological and management strategy implemented to mitigate risk. These metrics and tools help alleviate trade-offs among the triple bottom line components during remediation. In addition, they provide an opportunity to address transparency and uncertainty in using sustainability as an evaluation criterion during the decision making process.

It is imperative to incorporate sustainable practices into existing, as well as new, remediation projects to avoid irreversible changes to our ecological systems and improve upon our quality of life. In order to achieve sustainability through remediation, decision makers and stakeholders must engage sustainability experts and take advantage of multidisciplinary tools to ensure scientific integrity and comprehensive analysis are driving the decision-making process. In addition, placing value on the interconnectedness of the triple bottom line elements in research and development efforts will ensure the field of remediation will follow a sustainable path.

Lastly, remediation professionals play a role as environmental stewards and advocates of sustainable development. The remediation sector is often viewed as a small player in business, and is an unwanted cost threatening profitable gains. Therefore, little effort and funds are provided to consider sustainability in this context. As environmental stewards, remediation professionals are responsible for not letting long term benefits of sustainability be overshadowed by short term financial gains and unwillingness to collaborate with stakeholders. Remediation professionals have a unique opportunity to educate society, including local communities, on the benefits of sustainability and creating a vehicle for incorporating sustainability in complementary sectors (e.g., wastewater treatment, climate change resilience, and urban development). It is the hopes of this research to inspire and equip remediation professionals with knowledge to implement sustainable remediation practices throughout the project life cycle, in a "business as usual" manner.

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Chapter 7

BIOGRAPHY

Ms. Harclerode is an environmental scientist with an interdisciplinary academic and research background in sustainable remediation and assessments. She specializes in the development and application of integrated assessment approaches to comprehensively define sustainability objectives and evaluate environmental, social, and economic impacts of remedial activities (e.g., technologies and redevelopment). Specifically, she is experienced in life cycle assessment, environmental footprint analysis, cost benefit analysis (CBA), social CBA, and community surveys. In addition, Ms. Harclerode has over ten years of experience in implementing remedial investigations/feasibility studies, environmental site assessments, vapor intrusion evaluations, Brownfields assessments, and green and sustainable remediation best management practices for federal, state, and private clients. Ms. Harclerode is also an Institute of Sustainable Infrastructure EnvisionTM Sustainability Professional and a Technical Initiative Lead for the Sustainable Remediation Forum (SURF).

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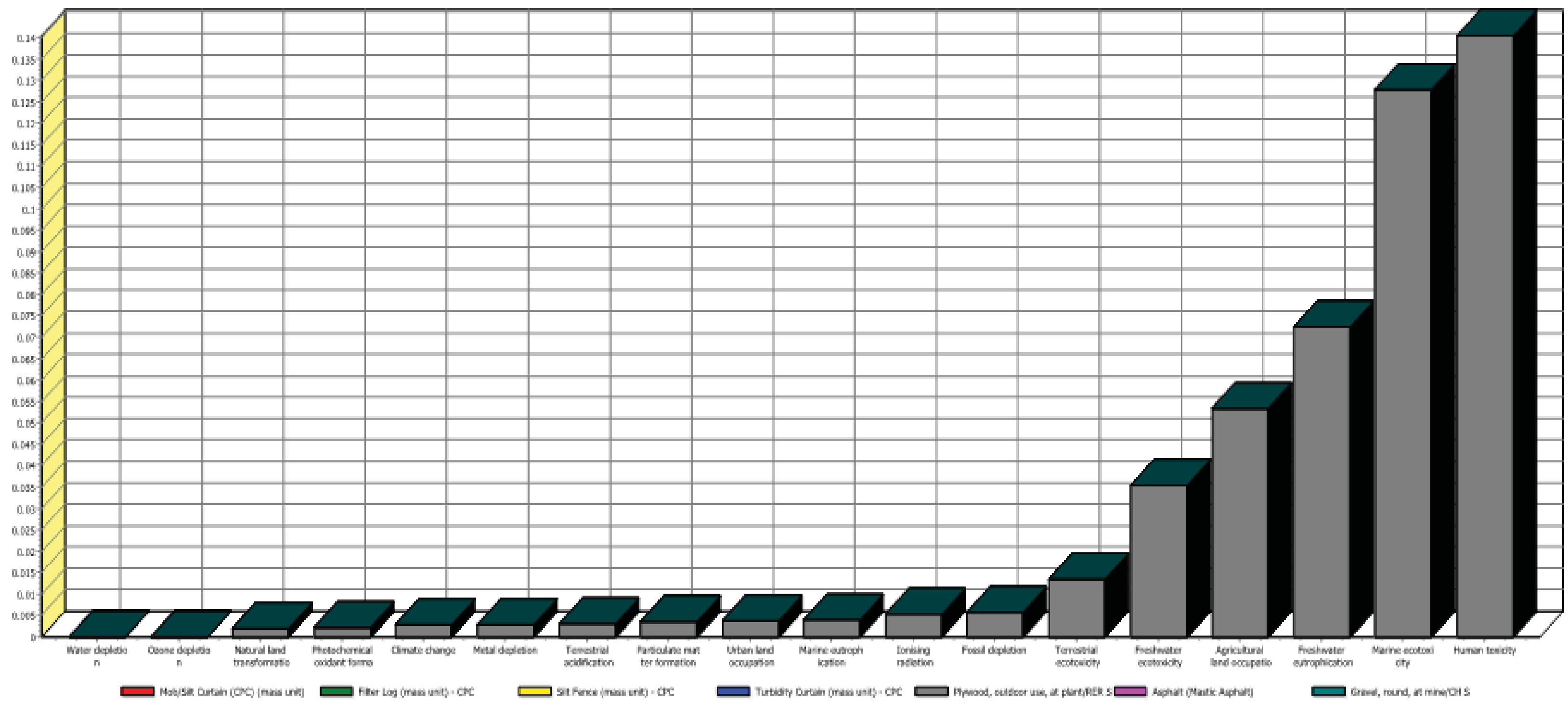
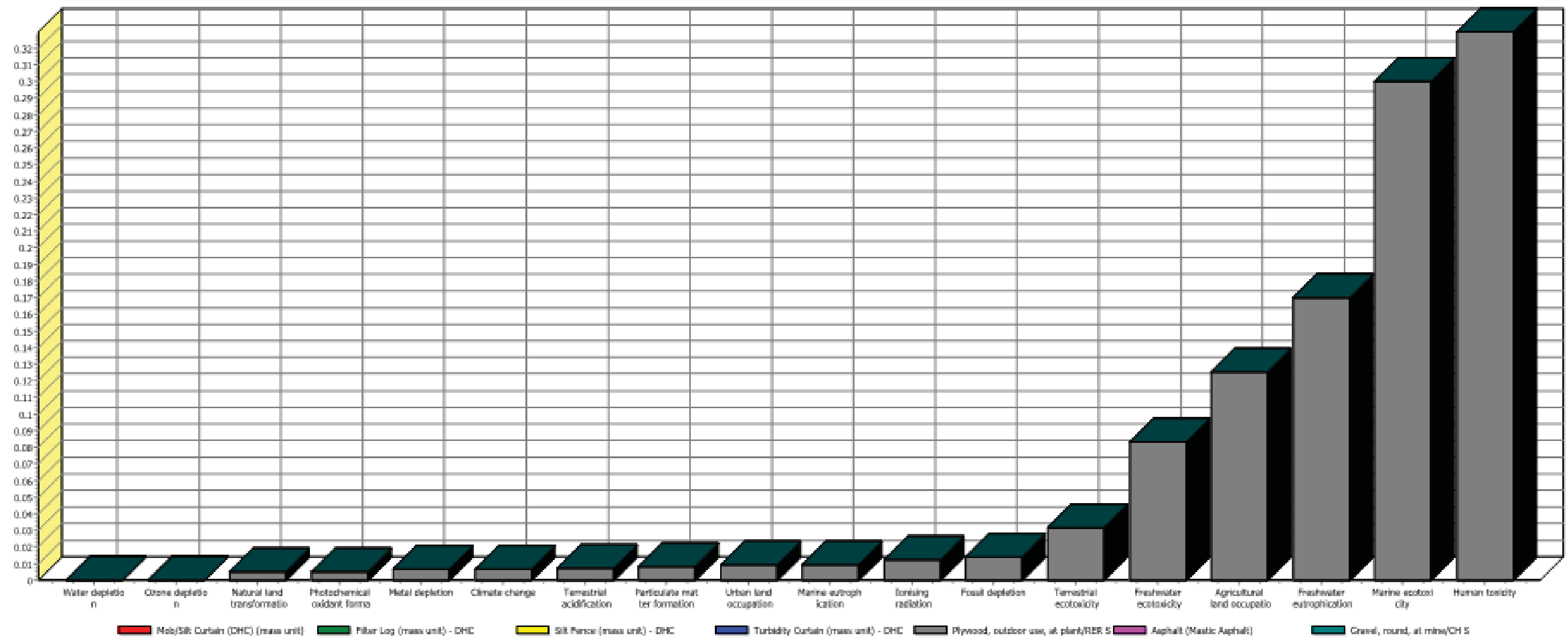
Chapter 4 ~ Supplemental Information

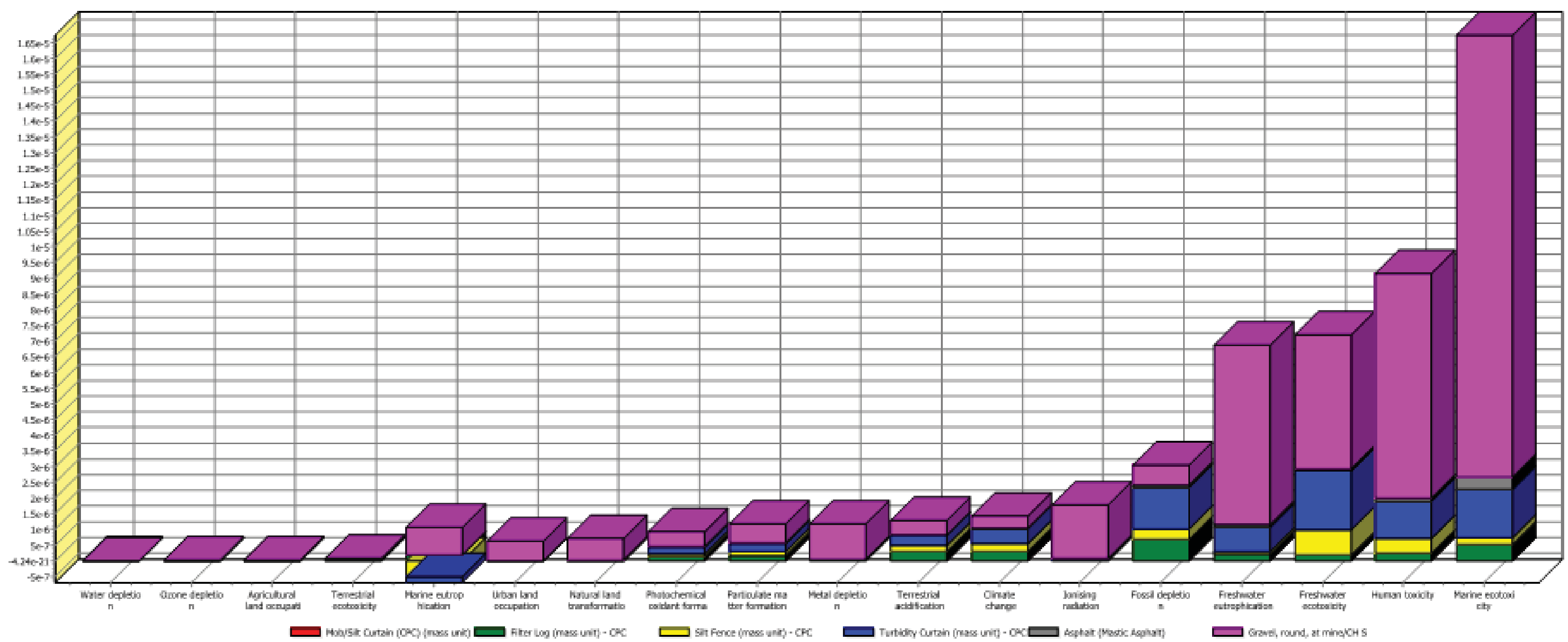
Supplemental Figure 1Sa - Normalized Impacts - AOC1-Mobilization/Engineering Controls with Plywood Parameter



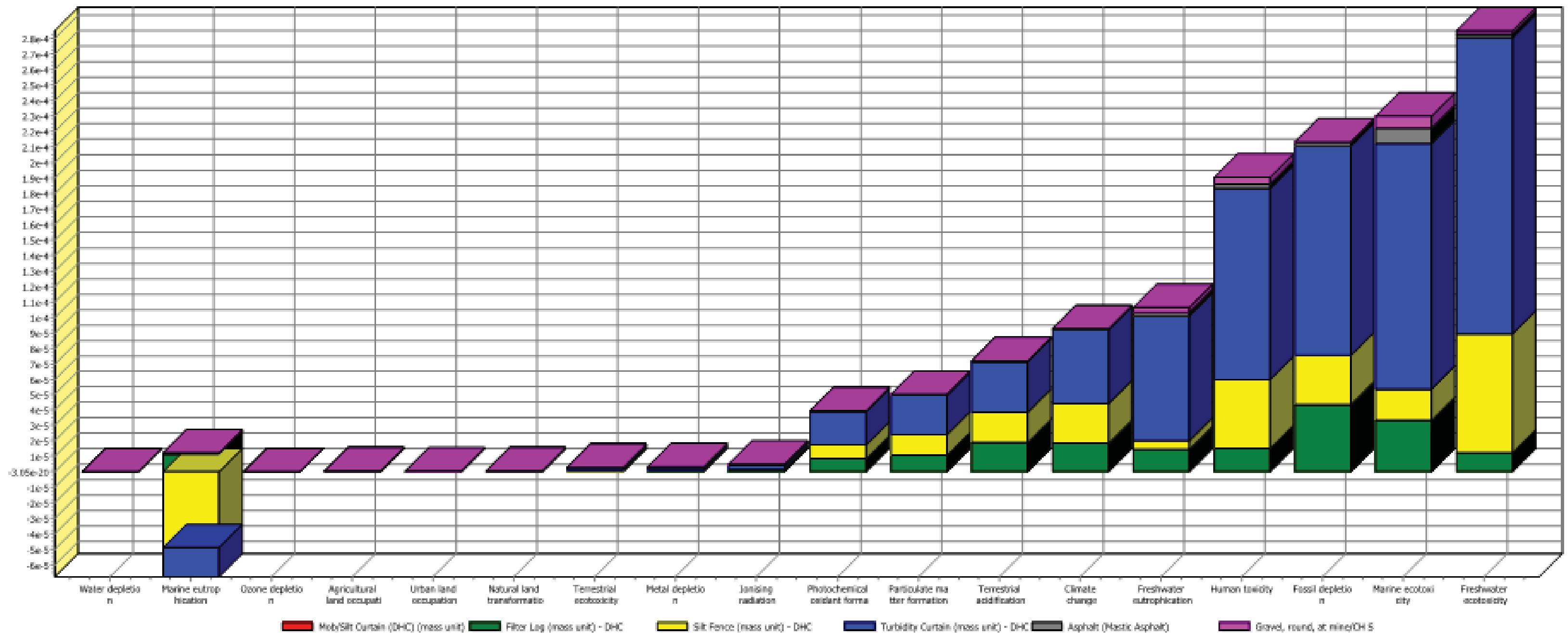
Supplemental Figure 1Sb - Normalized Impacts – AOC2-Mobilization/Engineering Controls with Plywood Parameter



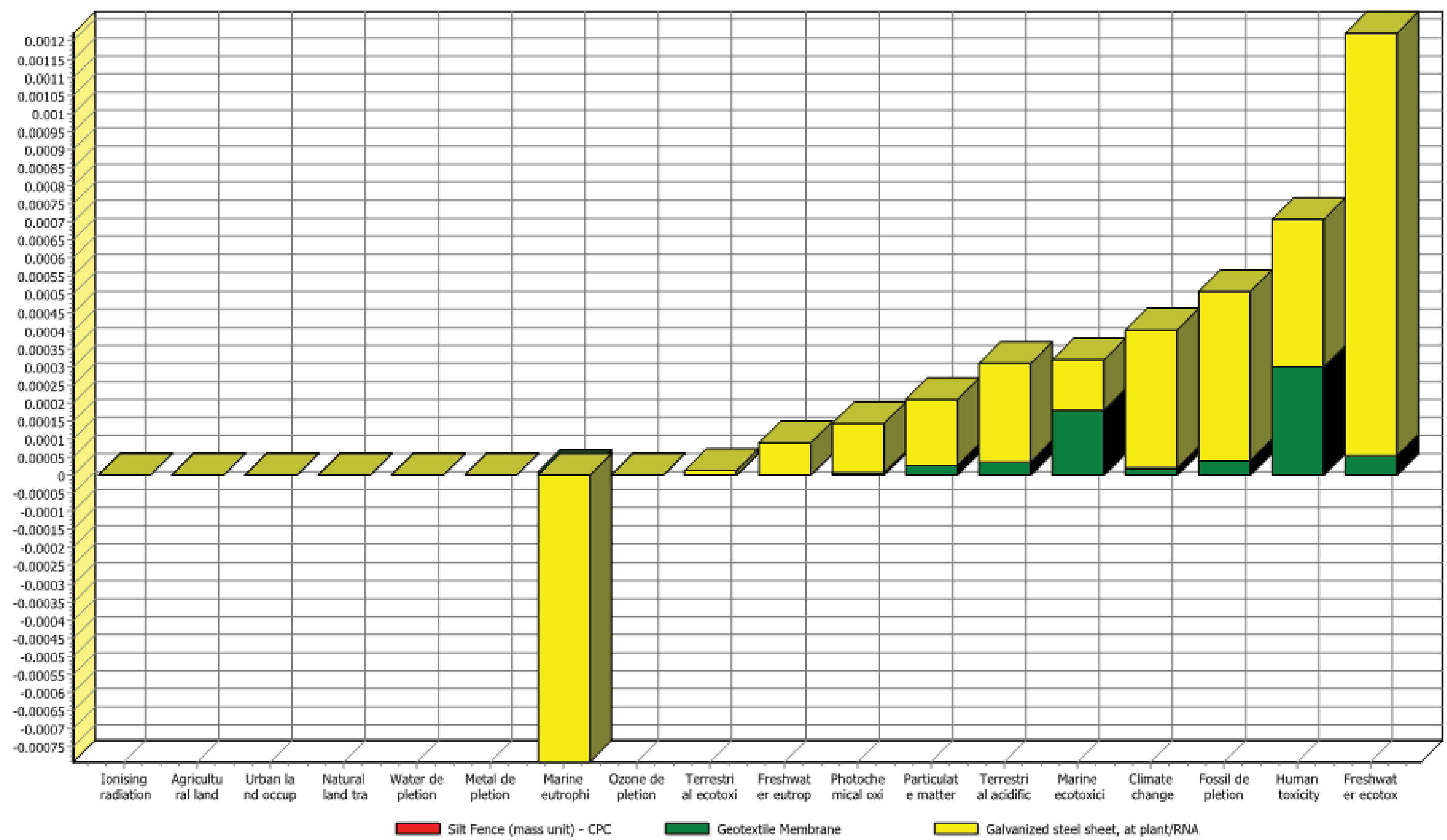
Supplemental Figure 2Sa - Normalized Impacts – AOC1-Mobilization/Engineering Controls without Plywood Parameter



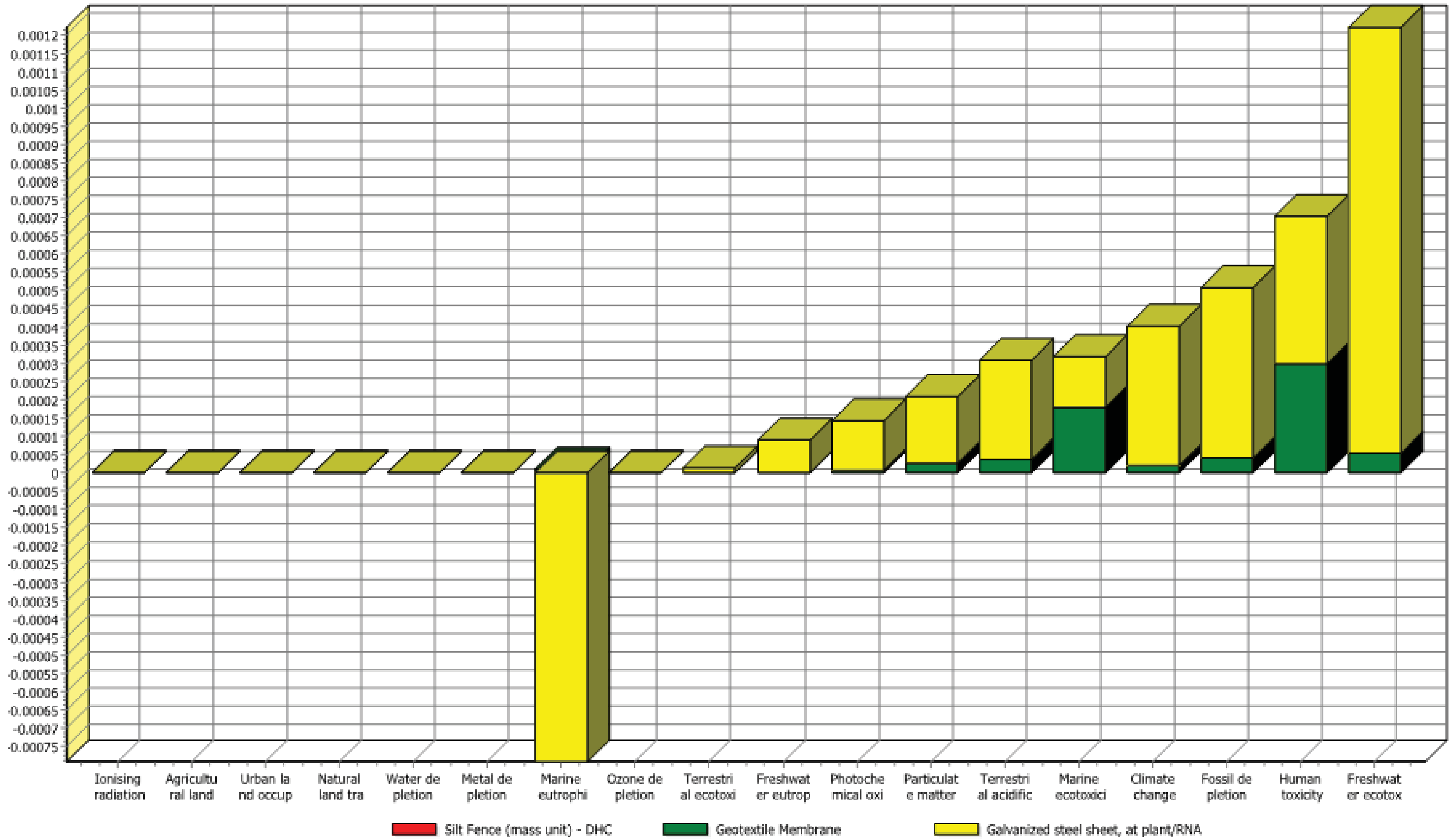
Supplemental Figure 2Sb - Normalized Impacts – AOC2-Mobilization/Engineering Controls without Plywood Parameter



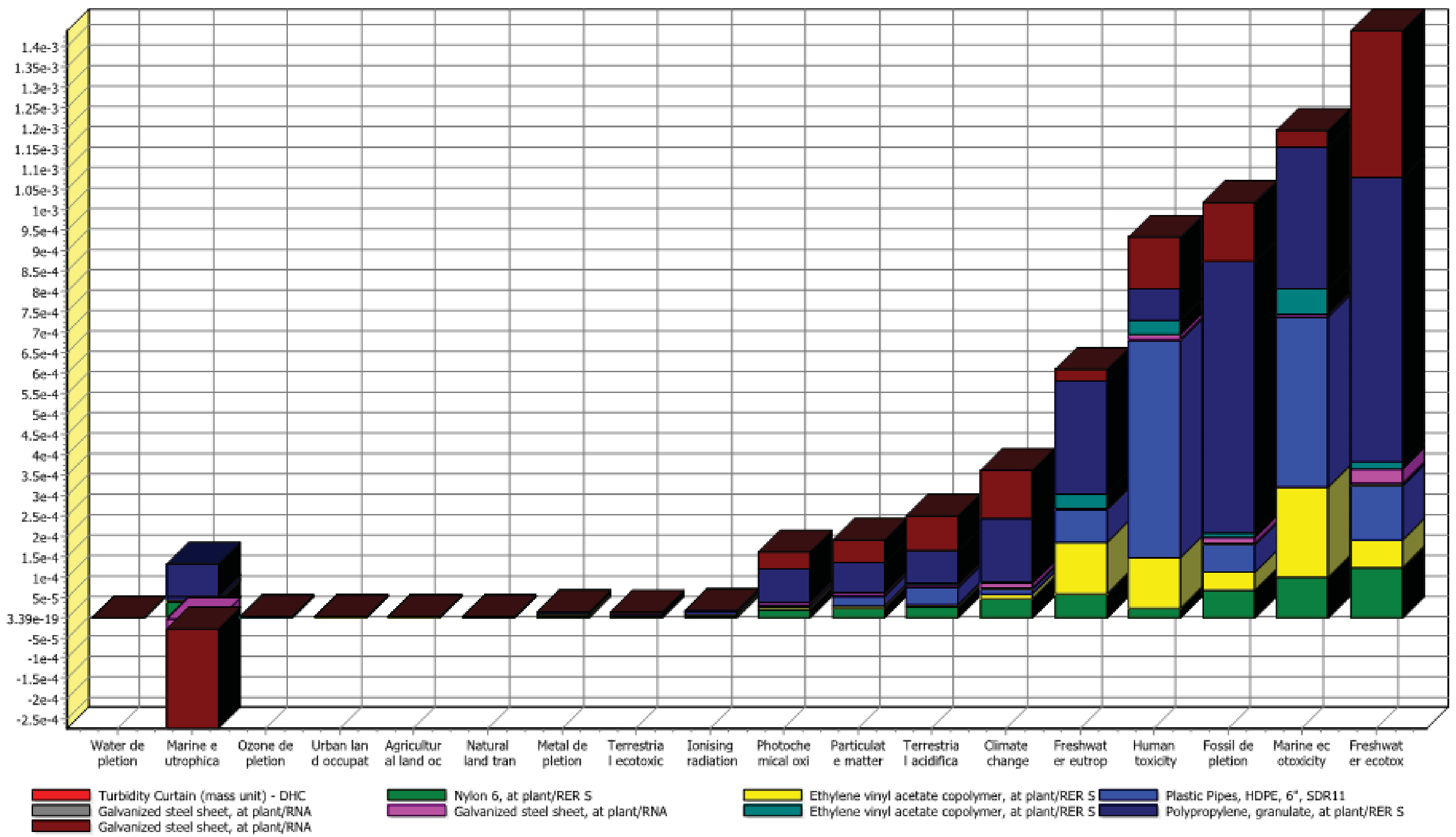
Supplemental Figure 3Sa - Normalized Impacts – AOC1-Silt Curtain



Supplemental Figure 3Sb - Normalized Impacts – AOC2-Silt Curtain

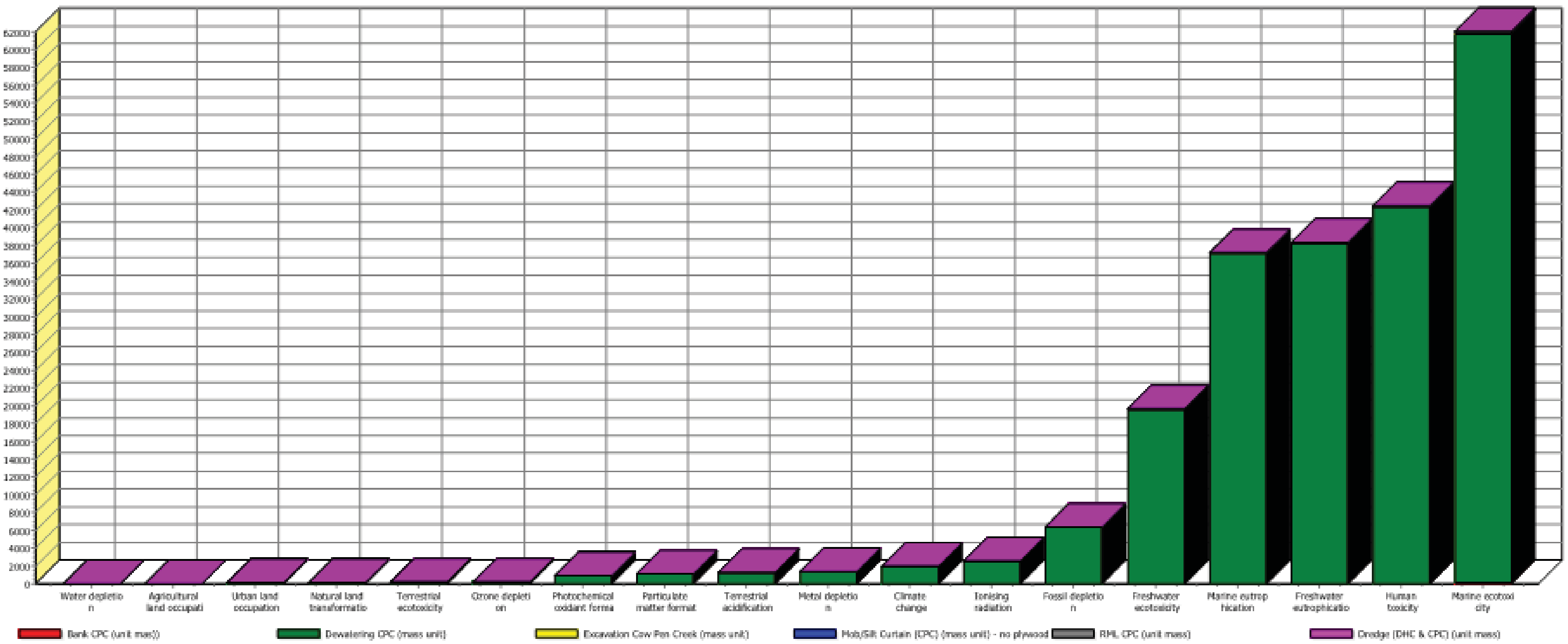


Supplemental Figure 4Sa - Normalized Impacts – AOC1-Turbidity Curtain \

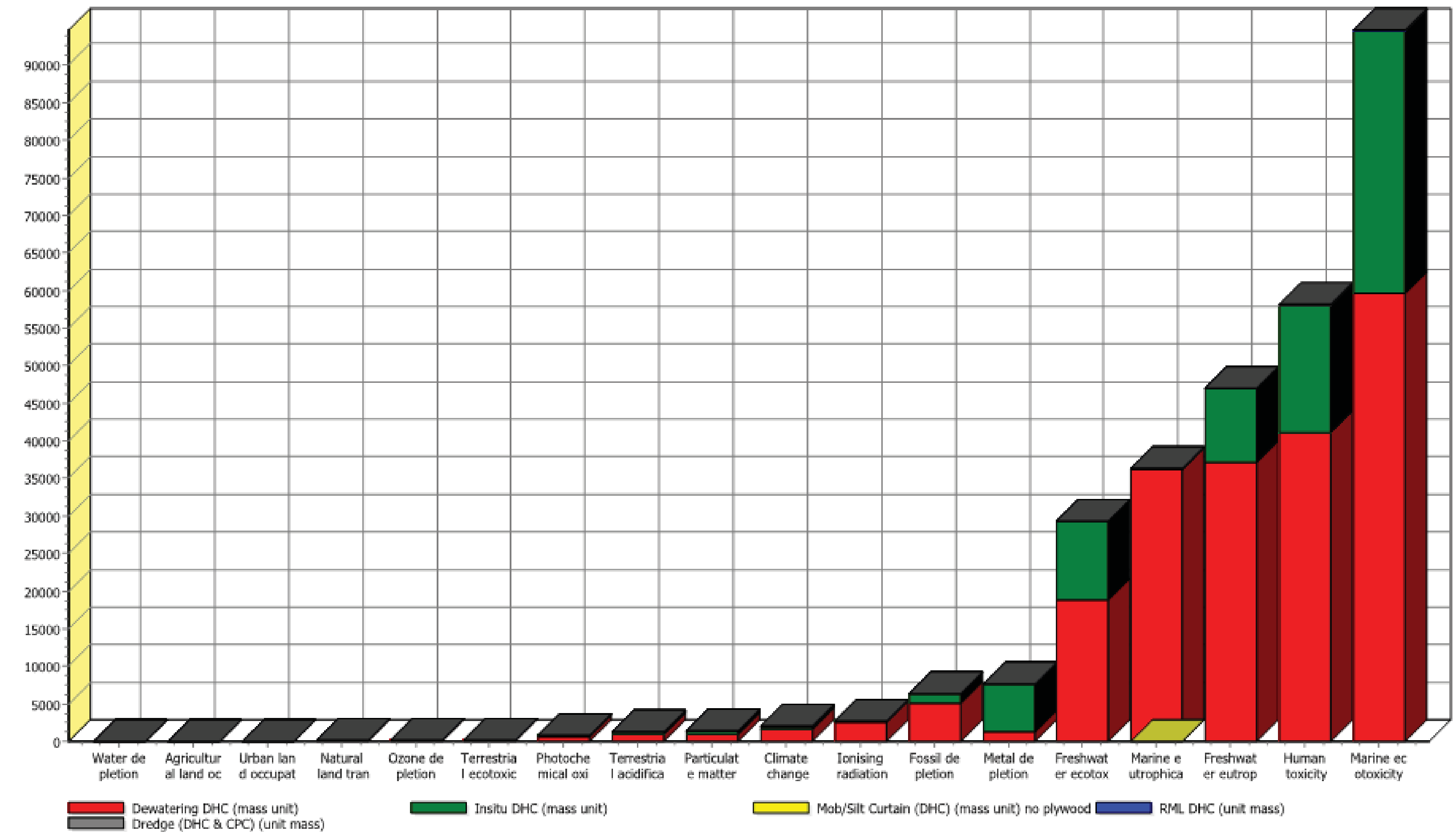


Supplemental Figure 4Sb - Normalized Impacts – AOC2-Turbidity Curtain

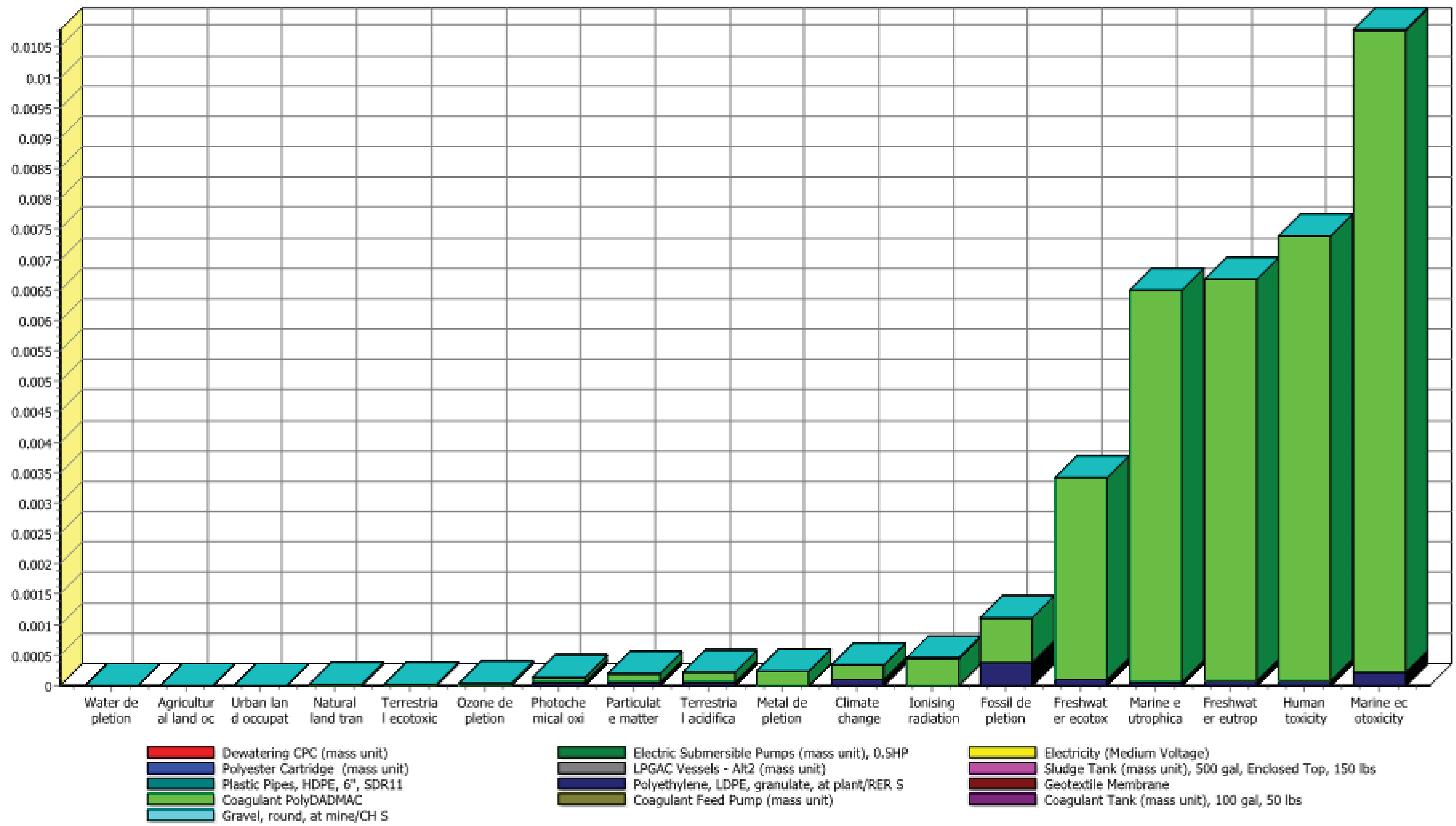
Supplemental Figure 5Sa - Normalized Impacts – AOC1-Remedial Approach without Plywood



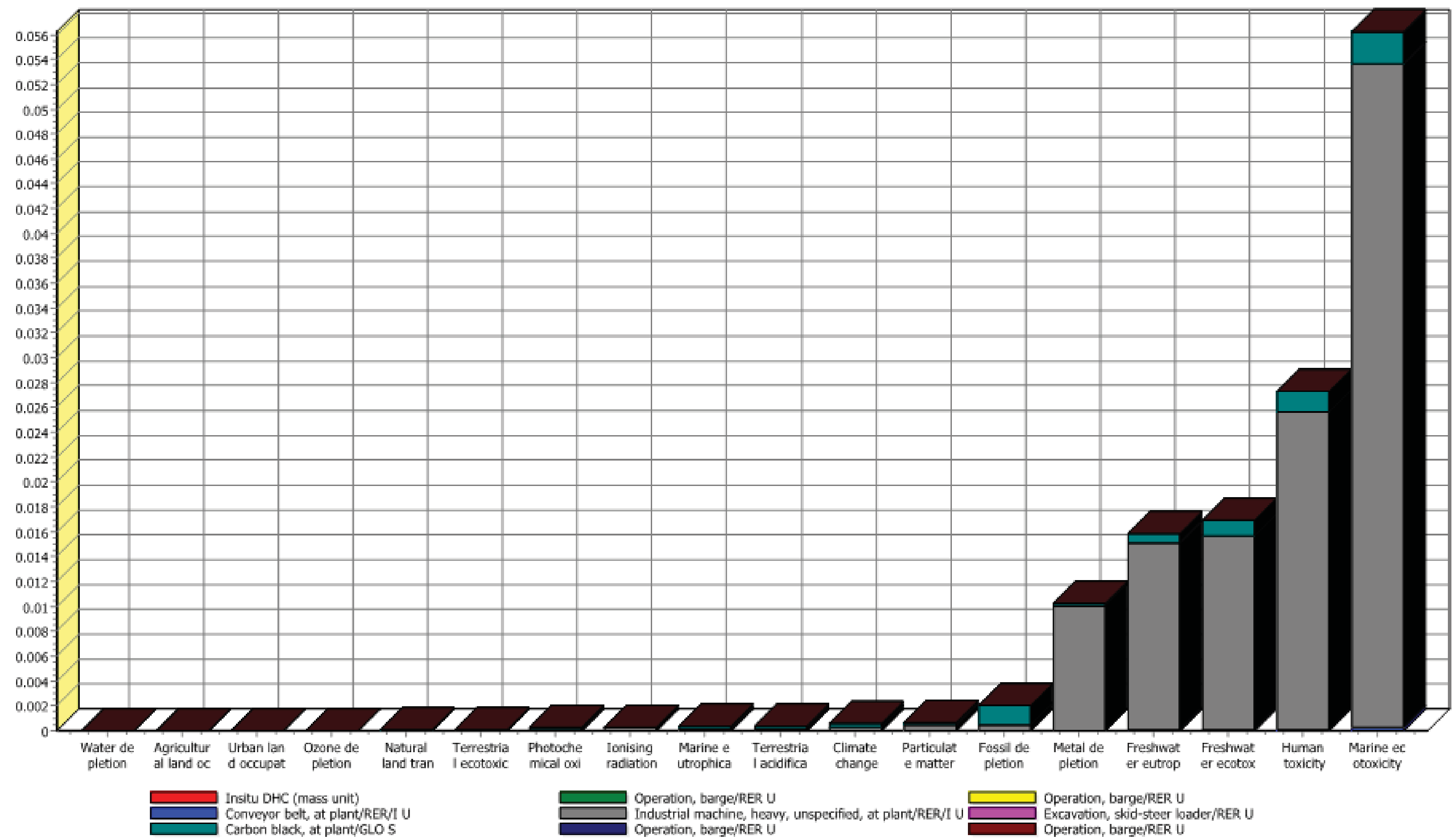
Supplemental Figure 5Sb - Normalized Impacts – AOC2-Remedial Approach without Plywood



Supplemental Figure 6Sa - Normalized Impacts – AOC1-Dewatering Component

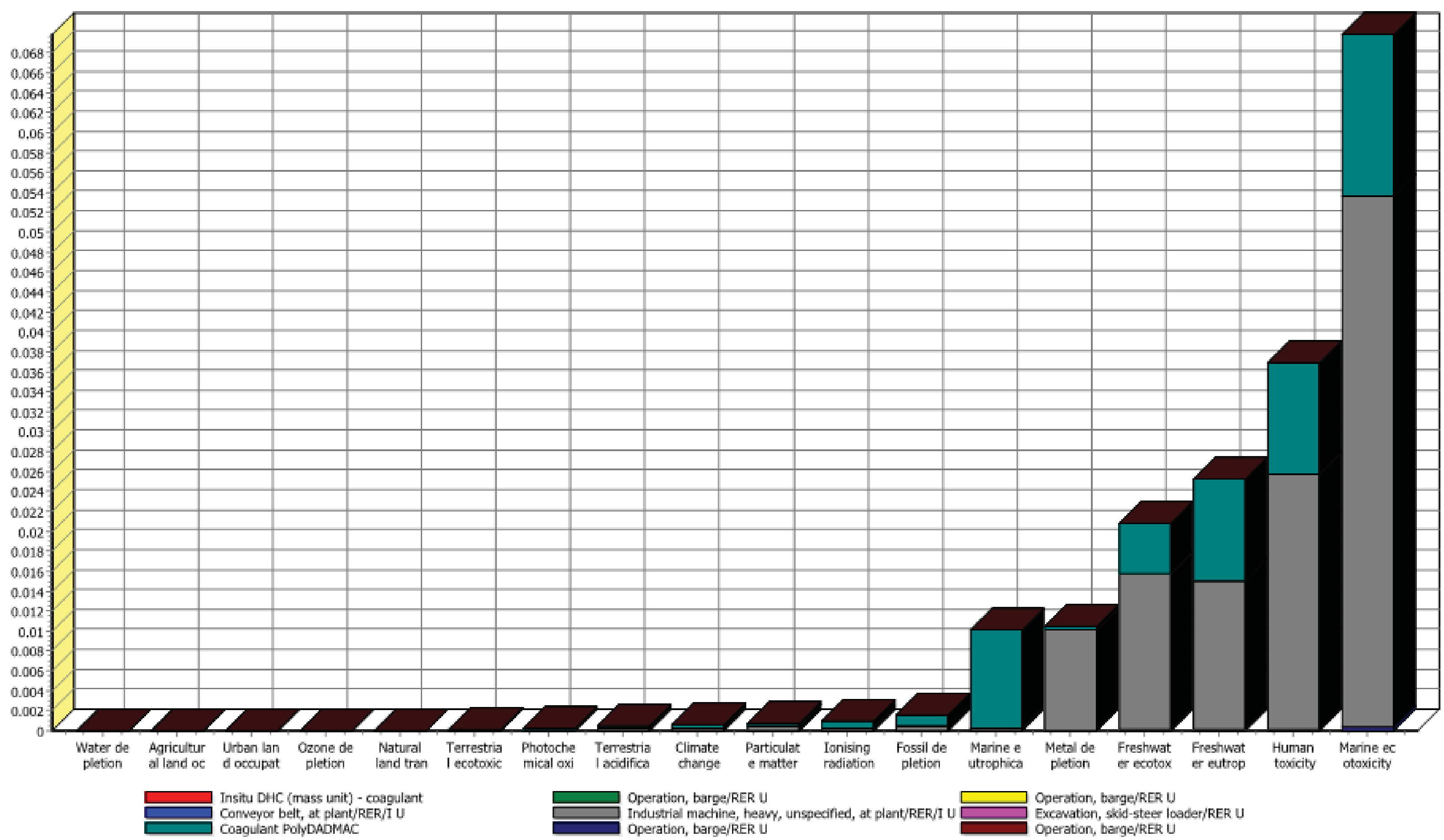


Supplemental Figure 6Sb - Normalized Impacts – AOC2-Dewatering Component

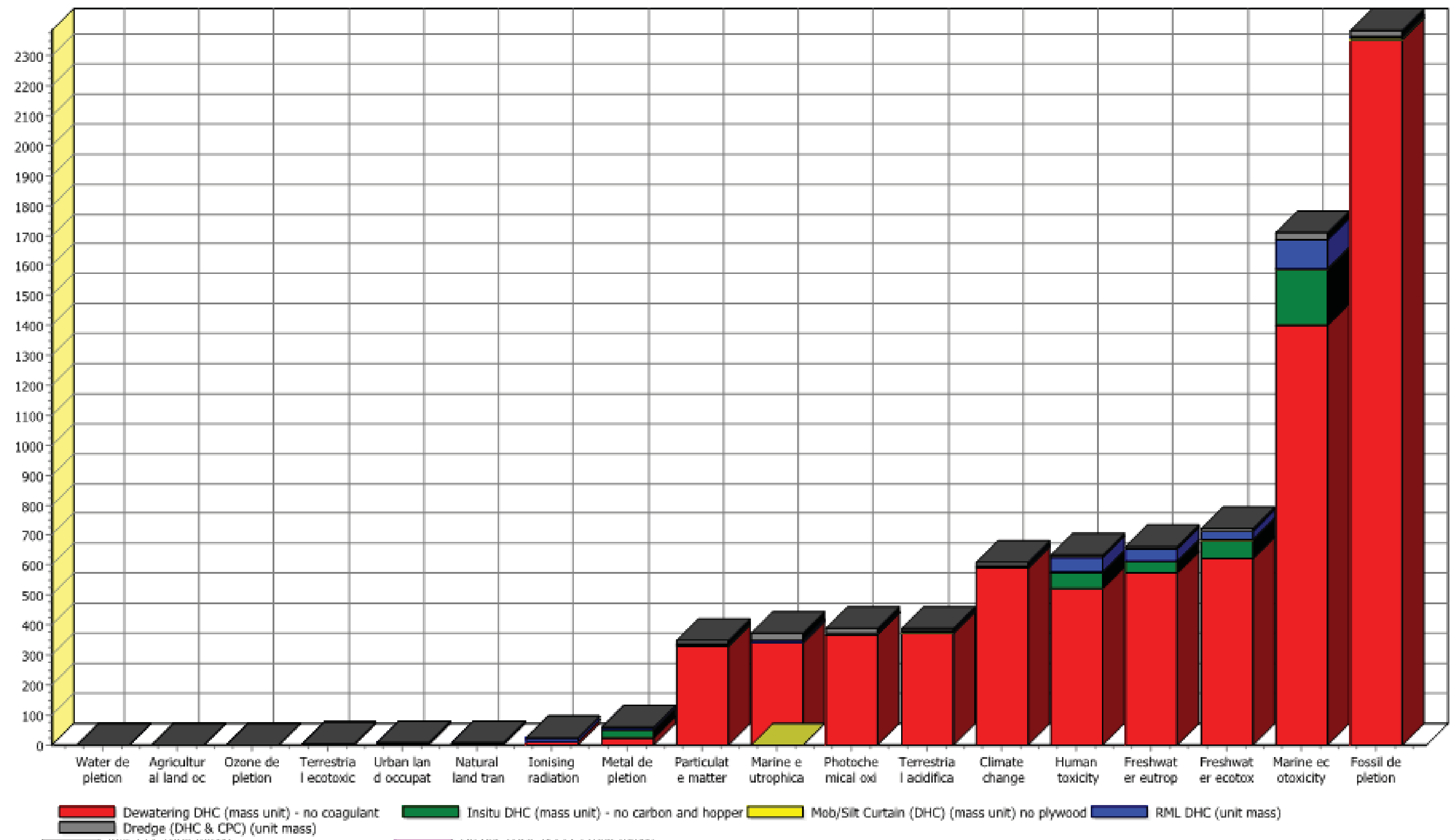


Supplemental Figure 7Sa - Normalized Impacts – AOC2-In Situ Component with Carbon

Supplemental Figure 7Sb - Normalized Impacts – AOC2-In Situ Component with Coagulant

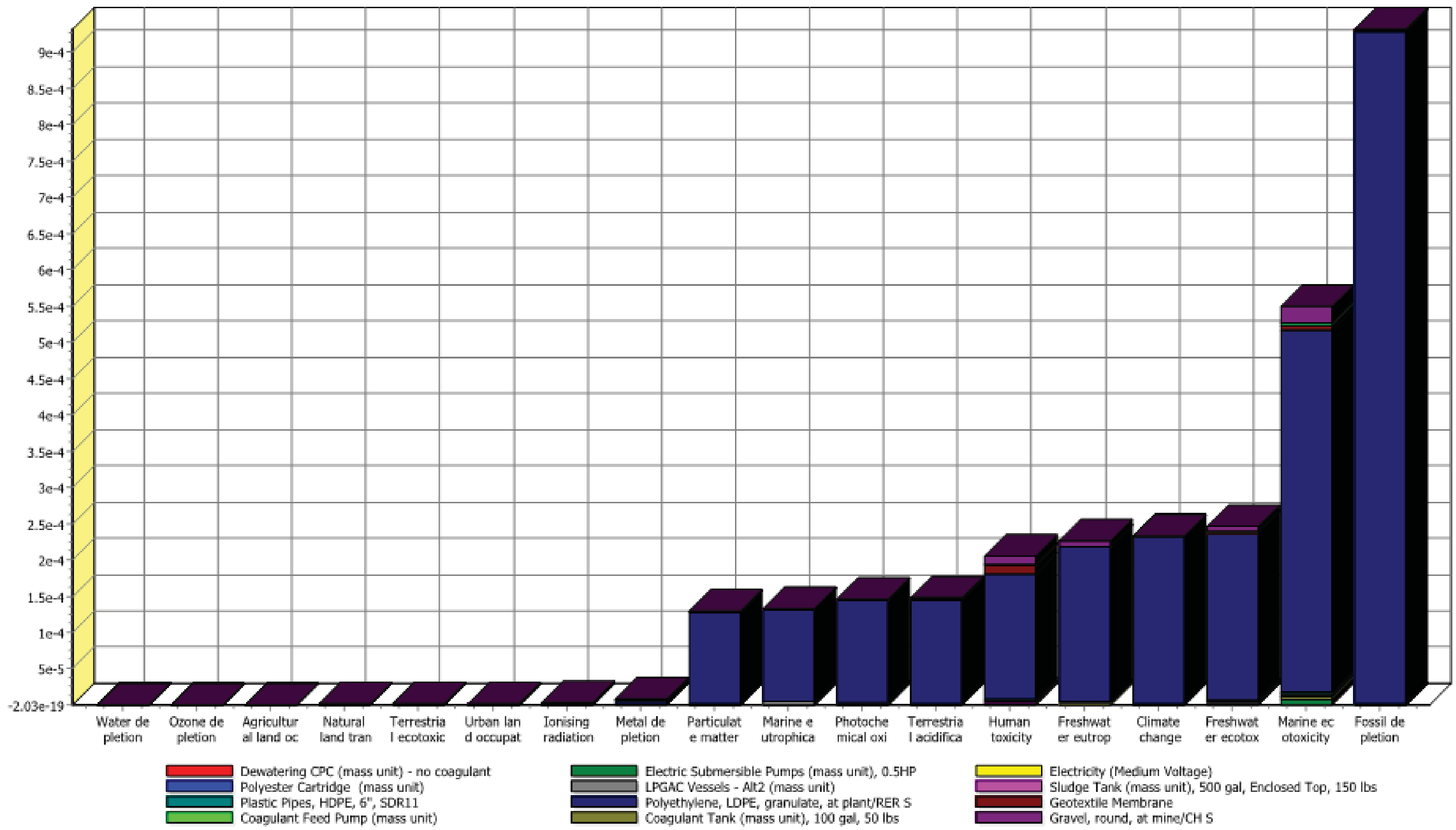


Supplemental Figure 8Sa - Normalized Impacts – AOC1-Remedial Design without Plywood, Amendment, and Hopper

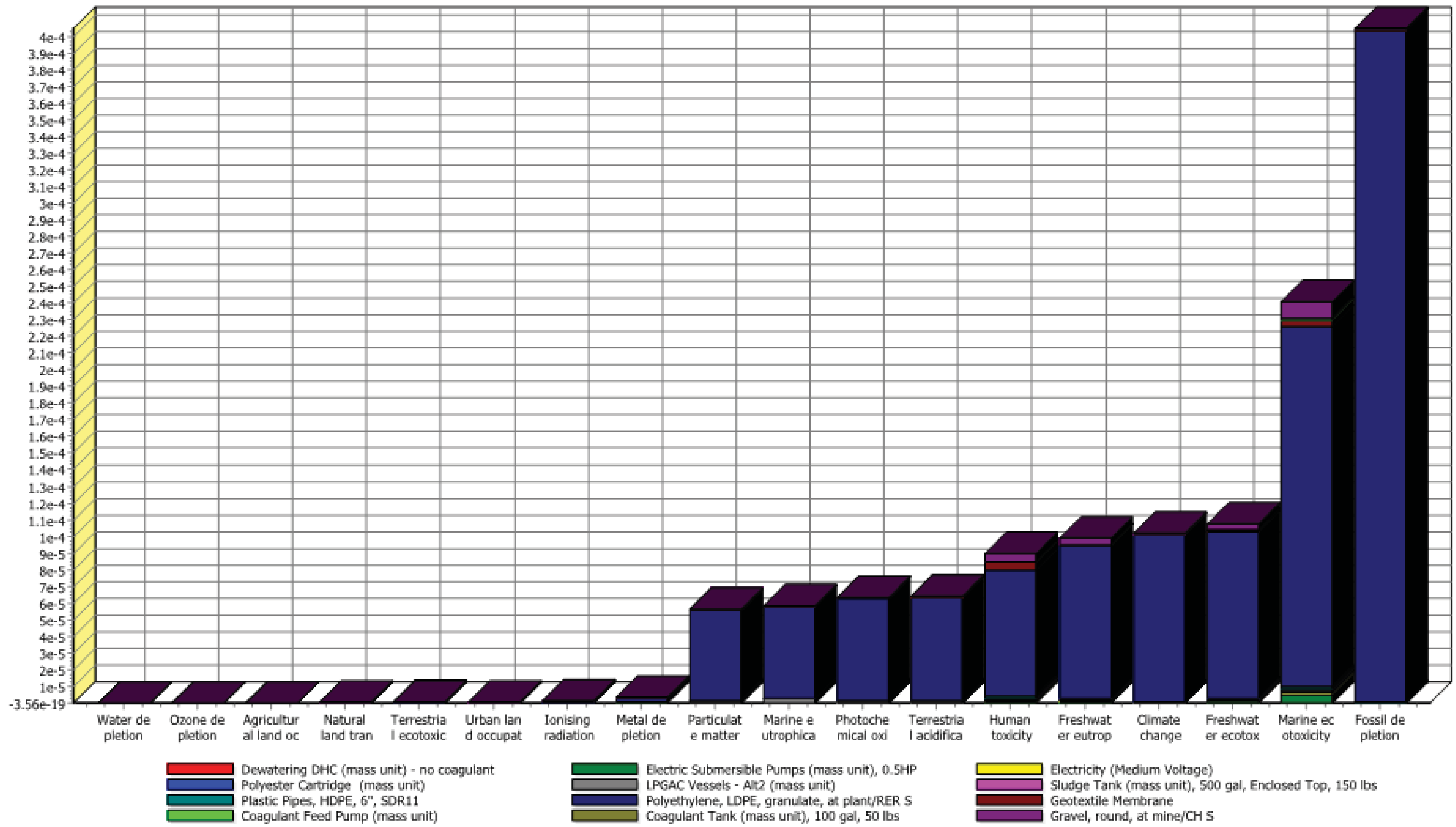


Supplemental Figure 8Sb - Normalized Impacts – AOC2-Remedial Design without Plywood, Amendment, and Hopper

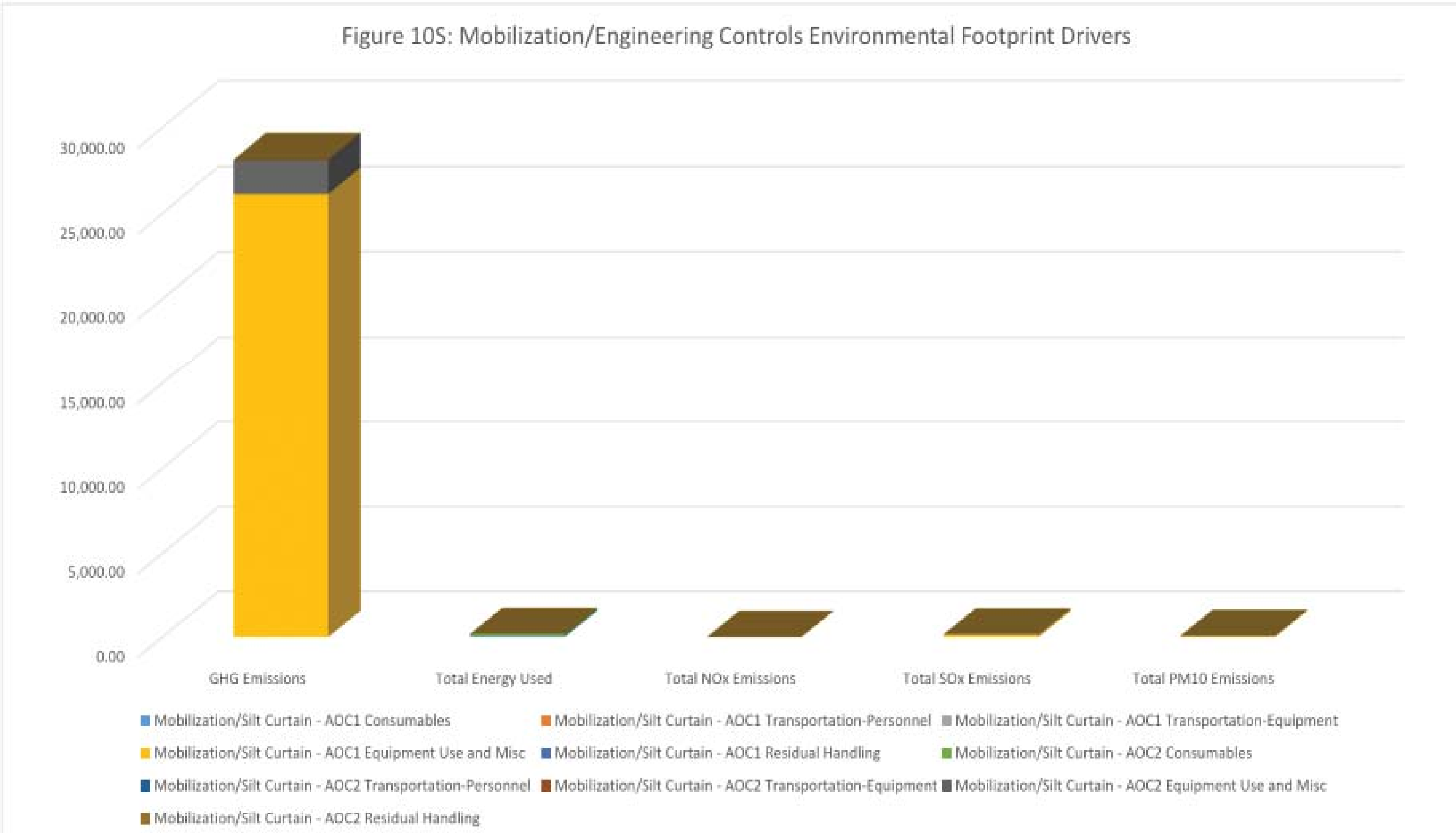
Supplemental Figure 9Sa - Normalized Impacts – AOC1-Dewatering Component without Plywood and Coagulant



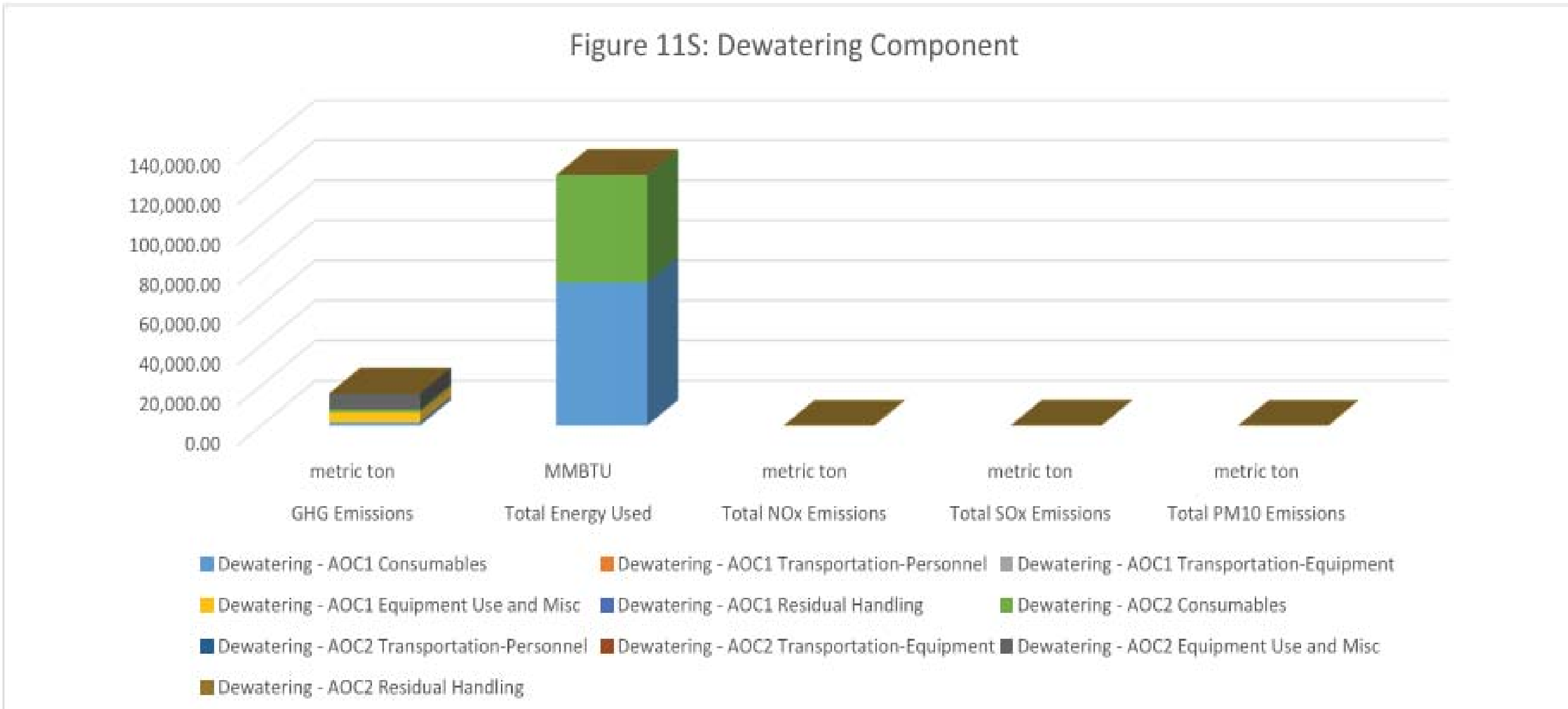
Supplemental Figure 9Sb - Normalized Impacts – AOC2-Dewatering Component without Plywood and Coagulant



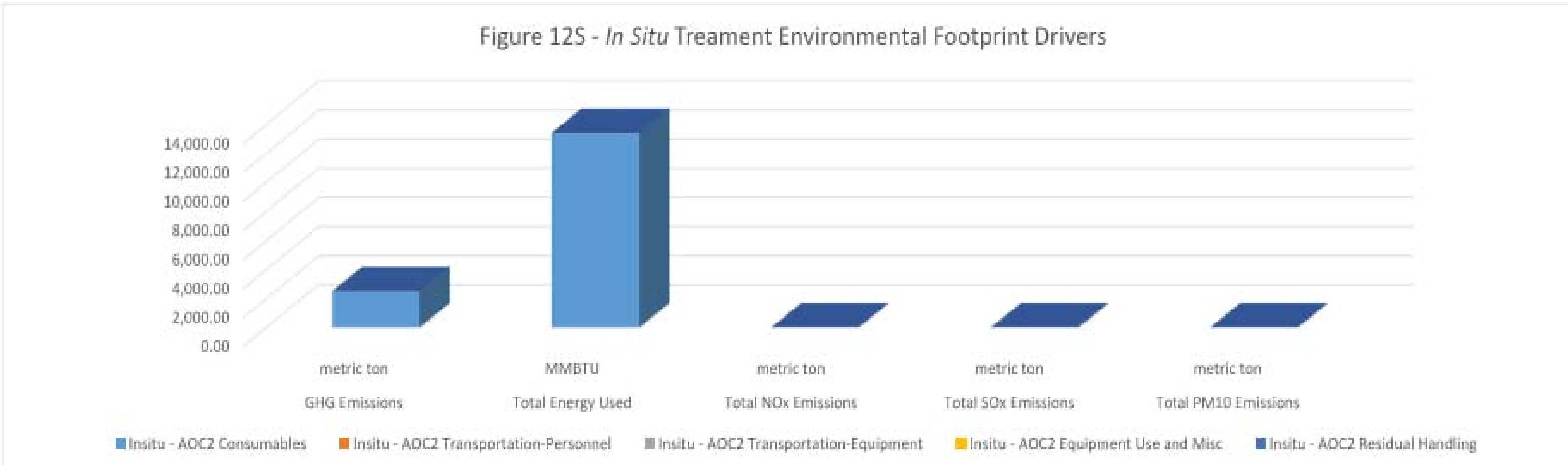
Supplemental Figure 10S



Supplemental Figure 11S



Supplemental Figure 12S



Supplemental Table 1S

Sitewise Inputs		LCA Inputs		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
AOC 1: Excavation				
Sediment Management (Staging and Drying)	Excavator, Diesel, 26,500 cu.yd, saturated sediment	Excavation , skid-steer loader/RER U	26500	cu.yd
Sediment Management (Staging and Drying)	Excavator, Diesel, 26,500 cu.yd, saturated sediment	Excavation, hydraulic digger/RER U	26500	cu.yd
Equipment Transportation - Dedicated Load Road	Diesel, 16t, estimated 6.66 miles to cover the 35200 feet (one way), return trips accounted separately	Operation, lorry > 16t, fleet average/RER U	70400	ft.
Equipment Transportation - Dedicated Load Road	Diesel, 16t, estimated 6.66 miles to cover the 35200 feet (one way), return trips accounted separately	Operation, lorry > 16t, fleet average/RER U	70400	ft.
Bulk Material Quantities	Steel, 71,760 lbs.	Steel hot rolled section, blast furnace and electric arc furnace	71760	lb.
AOC 1: Reconstruction and Stabilization				
Bulk Material Quantities	Gravel, 27028000 lbs.	Gravel, round, at mine/CH S	13514	ton
Bulk Material Quantities	Sand, 810000 lbs.	Sand, at mine/CH S	405	ton
Equipment Use, Earthwork	Excavator, Diesel, 6040 cu.yd	Excavation, hydraulic digger/RER U	6040	cu.yd

Sitewise Inputs		**LCA Inputs**		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
Equipment Use, Earthwork	Excavator, Diesel, 3300 cu.yd	Excavation, hydraulic digger/RER U	3300	cu.yd
Equipment Use, Earthwork	Loader/Backhoe, Diesel, 6040 cu.yd	Excavation , skid-steer loader/RER U	6040	cu.yd
Equipment Use, Earthwork	Loader/Backhoe,, Diesel, 3300 cu.yd	Excavation , skid-steer loader/RER U	3300	cu.yd
Bulk Material Quantities	Mulch, 696.96 lbs.	Wood fiber, softwood, green, at sawmill, INW/kg/RNA	696.96	lb.
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Coir Log - 16-inch	5880	ft.
Bulk Material Quantities	Gravel, 372000 lbs.	Gravel, round, at mine/CH S	186	tons
Bulk Material Quantities	Soil, 2710000 lbs.	topsoil	1355	tons
AOC 1 & AOC 2: Dredge				
Sediment Dredging - Mechanical, crawler crane (100 ton, 4 cy) two sets of equipment dredging 10,735 cu.yd each. Assume 3 support vessels for each. This input does not include extra excavators, so included excavators/loaders under Equipment Use, Earthwork.		Excavator, technology mix, 100 kW, Construction GL O	47041	ton
		Excavation , skid-steer loader/RER U	10,735	cu.yd
		Excavation, hydraulic digger/RER U	10,735	cu.yd
		Operation, lorry > 16t, fleet average/RER U	44000	ft.

Sitewise Inputs		**LCA Inputs**		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
		Operation, lorry > 16t, fleet average/RER U	44000	ft.
		Operation, barge/RER U	47041	tkm
		Excavation, hydraulic digger/RER U	21470	cu.yd
		Operation, barge/RER U	23520.5	tkm
		Operation, barge/RER U	23520.5	tkm
		Operation, barge/RER U (not best option for a tugboat" - water transport)	47041	tkm
AOC 2:Reconstruction				
Bulk Material Quantities	Sand, 1.3838e+7 lbs.	Sand, at mine/CH S	6919	ton
Watercraft Operation	Research Vessel (Large), 14 days x 8 hours a day = 112 hours	Operation, barge/RER U	6919	tkm
Equipment Use, Earthwork	Excavator, Diesel, 5125.185185 cu.yd	Excavation, hydraulic digger/RER U	5125.185185	cu.yd
Watercraft Operation	Research Vessel (Large), 14 days x 8 hours a day = 112 hours	Operation, barge/RER U	3459.5	tkm
Watercraft Operation	Research Vessel (Large), 14 days x 8 hours a day = 112 hours	Operation, barge/RER U	3459.5	tkm

Sitewise Inputs		LCA Inputs		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
Watercraft Operation	Research Vessel (Large), 14 days x 8 hours a day = 112 hours	Operation, barge/RER U (not best option for a tugboat" - water transport)	6919	tkm
AOC 2: In Situ Treatment				
Sediment Capping - Surface Release of 549 cubic yards, including Hopper Barge, scow tenders (support barge), and large research barge. The only item not accounted for is the powered activated carbon amendment. This input is under treatment materials, virgin GAC, 1.24e+6 lbs.		Operation, barge/RER U	620	tkm
		Operation, barge/RER U (not best option for a tugboat" - water transport)	620	tkm
		Conveyor belt, at plant/RER/I U (process bldg. equip infrastructure) = telebelt	8.1882	yd.
		industrial machine, heavy, unspecified, at plant = hopper	620	ton
		Excavation , skid-steer loader/RER U	549	cu.yd
		Carbon black, at plant/GLO S	620	ton
		Operation, barge/RER U	620	tkm
		Operation, barge/RER U (not best option for a tugboat" - water transport)	620	tkm
AOC 1: Dewatering				

Sitewise Inputs		**LCA Inputs**		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Electric Submersible Pumps, 0.5HP	60	kg
Equipment use, Pump Operation, Method 1 - Electrical Usage is Known	1041.92 wk	Electricity (Medium Voltage)	1041.92	kWh
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Polyester Cartridge Filter	2	kg
Material Production, Treatment Media	Virgin GAC, 910 kg of GAC in LCA input = 2006.21 lbs.	LPGAC Vessels - Alt. 2 (larger vessel)	1,907.38	kg
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Sludge Tank, 500 gal, Enclosed Top, 150 lbs.	138	kg
Bulk Material Quantities	HDPE, 353 lbs.	Plastic Pipes, HDPE, 6", SDR11	353	lb.
IDW Disposal AOC 1 (Sediment RD - AOC 1 & 2); Residue Disposal/Recycling	Weight per trip 28 tons; 15 trips; 150 miles per trip	Operation, lorry >28t, fleet average,/CH S	3,630	km
Bulk Material Quantities	LDPE, 2,110,320 lbs.	Polyethylene, LLDPE, granulate, at plant/RER S	2110320	lb.
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Geotextile Membrane	1517	kg
Bulk Material Quantitates	Gravel, 4334000 lbs.	Gravel, crushed, at mine/CH S	2,167	tons
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Coagulant PolyDADMAC	2,028	tons
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Coagulant tank	48	kg

Sitewise Inputs		LCA Inputs		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Coagulant feed pump	22	kg
AOC 2: Dewatering				
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Electric Submersible Pumps, 0.5HP	60	kg
Equipment use, Pump Operation, Method 1 - Electrical Usage is Known	651.2 kWh	Electricity (Medium Voltage)	651.2	kWh
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Polyester Cartridge Filter	2	kg
Material Production, Treatment Media	Virgin GAC, 4400.819176 lbs.	LPGAC Vessels - Alt. 2 (larger vessel)	1,907.38	kg
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Sludge Tank, 500 gal, Enclosed Top, 150 lbs.	138	kg
Bulk Material Quantities	HDPE, 353 lbs.	Plastic Pipes, HDPE, 6", SDR11	353	lb.
IDW Disposal AOC 1 (Sediment RD - AOC 1 & 2); Residue Disposal/Recycling	Weight per trip 28 tons; 11 trips; 150 miles per trip	Operation, lorry >28t, fleet average,/CH S	2,635	km
Bulk Material Quantities	LDPE, 1582740 lbs.	Polyethylene, LLDPE, granulate, at plant/RER S	1582740	lb.
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Geotextile Membrane	1137.781555	kg
Bulk Material Quantities	Gravel, 3250000 lbs.	Gravel, crushed, at mine/CH S	1,625	tons
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Coagulant PolyDADMAC	3,198	tons

Sitewise Inputs		**LCA Inputs**		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Coagulant tank	48	kg
Other Known Onsite Activities	LCA SiteWise Dewatering DHC Results	Coagulant feed pump	22	kg
AOC 1: Waste Disposal				
Residue Disposal/Recycling	Weight per trip 28 tons; 1365 trips; 150 miles per trip	Operation, lorry > 28t, fleet average/CH S	330,088	km
Residue Disposal/Recycling	Weight per trip 28 tons; 1 trip; 10 miles per trip	debris - wood	16	km
Residue Disposal/Recycling	Weight per trip 28 tons; 7 trips; 10 miles per trip	debris - concrete and rubble	103	km
Landfill Operations (Non-Haz)	38615.05 tons disposed in landfill	Landfill/CH U	38395	tons
AOC 2: Waste Disposal				
Residue Disposal/Recycling	Weight per trip 28 tons ; 1125 trips; 150 miles per trip	Sediment: Transport, lorry > 28t, fleet average/CH S	272,017	km
Residue Disposal/Recycling	Weight per trip 28 tons; 2 trips; 10 miles per trip	debris: Transport, lorry > 28t, fleet average/CH S	32	km
Residue Disposal/Recycling	Weight per trip 28 tons; 4 trips; 10 miles per trip	volume of soil piles: Transport, lorry > 28t, fleet average/CH S	57	km
Landfill Operations (Non-Haz)	31877.82 tons disposed in landfill	Landfill/CH U	31623	tons
AOC 2: Mobilization/Engineering Controls				
Silt Curtain Materials	1800 linear feet/ 3.5 feet in height	turbidity curtain	6,642	lb.

Sitewise Inputs		**LCA Inputs**		
Input Category	**Quantity/Unit**	**LCA Input**	**Quantity/Unit**	
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Plywood, outdoor use, at plant/RER S	3,121	m3
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	filter log	11,200	lb.
Silt Curtain Materials	1050 linear feet/ 3.5 feet in height	silt fence	3,138	lb.
-	-			
Bulk Material Quantities	Asphalt, 938 lbs.	asphalt (mastic asphalt)	938	lb.
Bulk Material Quantities	Gravel, 28,000 lbs.	gravel, round, at mine/CH S	14	tons
AOC 1: Mobilization/Engineering Controls				
Silt Curtain Materials	800 linear feet/ 3.5 feet in height	turbidity curtain	2,965	lb.
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	Plywood, outdoor use, at plant/RER S	40,572	m3
Other Known Onsite Activities	LCA SiteWise Dewatering CPC Results	filter log	8,000	lb.
Silt Curtain Materials	500 linear feet/ 3.5 feet in height	silt fence	1,494	lb.
Bulk Material Quantities	Asphalt, 1,688 lbs.	asphalt (mastic asphalt)	1,688	lb.
Bulk Material Quantities	Gravel, 1,140 lbs.	gravel, round, at mine/CH S	1,140	tons

<u>*Supplemental Table 2S*</u>

LCA Input	**Quantity/Unit**	
AOC 1: Silt Fence		
geotextile membrane	21	kg
galvanized steel sheet, at plant/RNA	1,448	lb
steel waste	1,448	lb
AOC 2: Silt Fence		
geotextile membrane	44	kg
galvanized steel sheet, at plant/RNA	3,041	lb
steel waste	3,041	lb
AOC 1: Filter Log		
Polyethylene, HDPE, granulate, at plant/RER S	1200	lb
Polyethylene waste	1200	lb
compost, at plant	6800	lb
Compost - final waste flow	6800	lb
AOC 2: Filter Log		
Polyethylene, HDPE, granulate, at plant/RER S	1680	lb
Polyethylene waste	1680	lb
compost, at plant	9520	lb
Compost - final waste flow	9520	lb
AOC 1: Turbidity Curtain		
nylon 6, at plant/RER S	45.35874641	kg
ethylene vinyl acetate copolymer, at plant/RER S	45.35874641	kg
plastic pipe, HDPE, 6", SDR11	141.2	lb
Galvanized steel sheet, at plant/RNA	18.16	lb
Galvanized steel sheet, at plant/RNA	95.25	lb
ethylene vinyl acetate copolymer, at plant/RER S	31.75	lb
polystyrene, granulate, at plant/RER S	1600	lb
Galvanized steel sheet, at plant/RNA	880	lb
plastic waste	45.35874641	kg
polyethylene waste - final waste flow	45.35874641	kg

LCA Input	Quantity/Unit	
plastic waste	141.2	lb
polyethylene waste - final waste flow	31.75	lb
polystyrene waste	1600	lb
AOC 1: Turbidity Curtain		
steel waste	993.41	lb
AOC 2: Turbidity Curtain		
nylon 6, at plant/RER S	102.0571794	kg
ethylene vinyl acetate copolymer, at plant/RER S	102.0571794	kg
plastic pipe, HDPE, 6", SDR11	317.7	lb
Galvanized steel sheet, at plant/RNA	40.86	lb
Galvanized steel sheet, at plant/RNA	190.5	lb
ethylene vinyl acetate copolymer, at plant/RER S	63.5	lb
polystyrene, granulate, at plant/RER S	3600	lb
Galvanized steel sheet, at plant/RNA	1980	lb
plastic waste	102.0571794	kg
polyethylene waste - final waste flow	102.0571794	kg
plastic waste	317.7	lb
polyethylene waste - final waste flow	63.5	lb
polystyrene waste	3600	lb
steel waste	2211.36	lb
Top Soil		
Known Input from nature, soil, unspecified, in ground		1 ton
Excavation , skid-steer loader/RER U	1	cu.yd
Excavation, hydraulic digger/RER U	1	cu.yd
Coir Log		
Loading Bails U	1	p
Bailing U	1	p
Husked nut harvesting, at farm/PH S	2.59	lb
Coconuts - Raw materials	2.59	lb

Supplemental Table 3S

	Footprint Evaluation						LCA Evaluation				
Remedial Component	**CO2 Emissions (metric ton)**	**Total SOx Emissions (metric ton)**	**Total PM10 Emissions (metric ton)**	**Monetized Global Impacts**	**Allocation of Impacts (Percentage)**		**CO2 eq (metric tons)**	**SO2 eq (metric tons)**	**PM10 eq (metric tons)**	**Monetized Global Impacts**	**Allocation of Impacts (Percentage)**
Area of Concern 1											
Mobilization/ Engineering Controls	$ 1,654,174.82	$ 623,683.45	$ 122,896.34	$ 2,400,754.61	78.29%		$ 1,673,516.93	$ 624,632.14	$ 122,988.39	$ 2,421,137.47	68.69%
Dewatering	$ 429,380.22	$ 110,308.61	$ 15,122.46	$ 554,811.29	18.09%		$ 840,275.91	$ 193,325.37	$ 29,907.37	$ 1,063,508.65	30.17%
Dredging AOC 1	$ 1,902.73	$ 249.00	$ 37.18	$ 2,188.91	0.07%		$ 2,013.91	$ 614.91	$ 126.68	$ 2,755.50	0.08%
Excavation	$ 5,654.34	$ 1,441.77	$ 147.09	$ 7,243.19	0.24%		$ 2,755.16	$ 817.26	$ 190.65	$ 3,763.07	0.11%
Reconstruction and Stabilization	$ 17,665.66	$ 5,690.30	$ 1,110.97	$ 24,466.93	0.80%		$ 4,607.86	$ 1,841.15	$ 434.15	$ 6,883.16	0.20%
Waste Disposal	$ 57,881.44	$ 5,436.34	$ 13,758.19	$ 77,075.97	2.51%		$ 18,458.51	$ 6,953.30	$ 1,469.13	$ 26,880.94	0.76%
Area of Concern 2											
Mobilization/ Engineering Controls	$ 127,858.08	$ 48,026.34	$ 9,476.81	$ 185,361.23	15.66%		$ 129,605.12	$ 48,289.10	$ 9,489.42	$ 187,383.64	13.62%
Dewatering	$ 589,671.95	$ 145,505.86	$ 21,072.96	$ 756,250.77	63.90%		$ 699,085.98	$ 161,580.38	$ 25,024.33	$ 885,690.70	64.35%
Insitu	$ 160,440.82	$ 27.27	$ 1.47	$ 160,469.55	13.56%		$ 170,973.40	$ 37,886.84	$ 12,302.23	$ 221,162.47	16.07%
Dredging	$ 5,144.42	$ 673.23	$ 100.53	$ 5,918.18	0.50%		$ 5,445.01	$ 1,662.55	$ 342.51	$ 7,450.07	0.54%
Reconstruction	$ 9,805.90	$ 1,753.23	$ 282.79	$ 11,841.92	1.00%		$ 1,240.47	$ 543.15	$ 124.99	$ 1,908.61	0.14%
Waste Disposal	$ 47,711.41	$ 4,487.83	$ 11,357.71	$ 63,556.95	5.37%		$ 49,906.34	$ 18,799.67	$ 3,972.09	$ 72,678.09	5.28%

Chapter 5 – Survey Documentation

Appendix A: Approval letter for the research study (survey) from IRB

MONTCLAIR STATE UNIVERSITY

Institutional Review Board
College Hall, Room 248
VOICE: 973-655-7583
FAX: 973-655-3022

April 2, 2015

Ms. Melissa Koberle
14 Magnolia Lane
Caldwell, NJ 07006

Re: IRB Number: **001660**
Project Title: **Investigating Risk Perception of Lead Contamination in Jersey City, New Jersey. (Dissertation Title: Evaluating Sustainable Aspect of Hazardous Waste Remediation)**

Dear Ms. Koberle:

After an expedited 7 review, Montclair State University's Institutional Review Board (IRB) approved this protocol on **March 23, 2015**. The study is valid for one year and will expire on **March 23, 2016**.

Before requesting amendments, extensions, or project closure, please reference MSU's IRB website and download the current forms.

Should you wish to make changes to the IRB-approved procedures, prior to the expiration of your approval, submit your requests using the Amendment form.

For Continuing Review, it is advised that you submit your form 60 days before the month of the expiration date above. If you have not received MSU's IRB approval by your study's expiration date, ALL research activities must STOP, including data analysis. If your research continues without MSU's IRB approval, you will be in violation of Federal and other regulations.

Please note, as the principal investigator, you are required to maintain a file of approved human subject's research documents, for each IRB application, to comply with federal and institutional policies on record retention.

After your study is completed, submit your Project Completion form.

If you have any questions regarding the IRB requirements, please contact me at 973-655-5189, reviewboard@mail.montclair.edu, or the Institutional Review Board.

Sincerely yours,

Dr. Katrina Bulkley
IRB Chair

cc: Dr. Pankaj Lal, Faculty Sponsor
Ms. Amy Aiello, Graduate School

montclair.edu

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Appendix B: Consent form for adults for the survey (page 1)

MONTCLAIR STATE UNIVERSITY

College of Science and Mathematics
Department of Earth and Environmental Studies
Voice: 973-655-4448
Fax: 973-655-4072

CONSENT FORM FOR ADULTS

Please read below with care. You can ask questions at any time, now or later. You can talk to other people before you participate in this survey.

Study's Title: Investigating Risk Perception of Lead Contamination in Jersey City, New Jersey. (Dissertation title: Evaluating Sustainable Aspects of Hazardous Waste Remediation)

Why is this study being done? The study will determine if residents are aware of lead contamination in soil and paint that may be present at their place of residence. If so, the study will also help identify actions taken by residents to address contamination issues.

What will happen while you are in the study? If you agree to be a participant, you will first have to read and sign this consent form. The attached survey has questions about your perception of risk around you and what you are doing with respect to these risks. Your responses will be written only. Lastly, if you agree, you will get a free screening of soil and/or paint at your residence to assess the levels of lead. This will require that you provide contact information and an appropriate day and time for screening. There will be no recording or taping made during the screening.

Time: The survey should take 15-20 minutes to complete. If you agree to a free screening, 2 members of the research team will be at your residence for about 30 minutes to collect samples.

Risks: You will not experience any physical, psychological, social, economic, criminal or civil liability, employability, or reputation risks as a result of participating in this study.

Although we will keep your identity confidential as it relates to this research project, if we learn of any suspected child abuse we are required by New Jersey state law to report that to the proper authorities immediately.

Benefits: There are no direct benefits to you for participating in the study.

Others may benefit from this study by understanding sources of lead contamination in your area.

Compensation There is no financial compensation for participating in the study. However, you have the opportunity for a free lead screening at your residence.

Who will know that you are in this study? You will not be linked to any presentations. We will keep who you are anonymous. Property location, owner and tenant information will not be published, or provided to a third party. Any contact information provided will only be for the purposes of sending researchers for free lead screening.

Do you have to be in the study?
You do not have to be in this study. You are a volunteer! It is okay if you want to stop at any time and not be in the study. You do not have to answer any questions you do not want to answer. Nothing will happen to you.

Appendix B: Consent form for adults for the survey (page 2)

MONTCLAIR STATE UNIVERSITY

College of Science and Mathematics
Department of Earth and Environmental Studies
Voice: 973-655-4448
Fax: 973-655-4072

Do you have any questions about this study? Phone or email Melissa Koberle, Doctoral Candidate, ML358N Montclair State University 1, Normal Avenue, Montclair, NJ 0743, email koberlem1@mail.montclair.edu, phone number: 917-575-1543 and Faculty Sponsor Dr Pankaj Lal, Assistant Professor Environmental Economics, ML358N Montclair State University 1, Normal Avenue, Montclair, NJ 0743 email lalp@mail.montclair.edu

Do you have any questions about your rights as a research participant? Phone or email the IRB Chair, Dr. Katrina Bulkley, at 973-655-5189 or reviewboard@mail.montclair.edu.

Future Studies
It is okay to use my data in other studies:
Please initial: ______ Yes ______ No

One copy of this consent form is for you to keep.

Statement of Consent
I have read this form and decided that I will participate in the project described above. Its general purposes, the particulars of involvement, and possible risks and inconveniences have been explained to my satisfaction. I understand that I can withdraw at any time. My signature also indicates that I am 18 years of age or older and have received a copy of this consent form.

______________________	______________________	__________
Print your name here	Signature	Date
______________________	______________________	__________
Name of Principal Investigator	Signature	Date
______________________	______________________	__________
Name of Faculty Sponsor	Signature	Date

Brochures on Household Lead Contamination :
I would like to receive informational brochures on household lead contamination:

Yes ______________ No ________________

Free Lead Screening Sign-Up :
I would like to be contacted for FREE lead screening at my residence.

Yes ______________ No ________________

My contact information is ____

Appendix C: Survey Questionnaire for the research study (page 1)

BACKGROUND INFORMATION

33. Employment Status: Are you currently….*(please check one)*					
Employed/Self-Employed	☐	Homemaker	☐	Military	☐
Unemployed	☐	Student	☐	Retired	☐
34. Residency Status. *(please check one)*					
Owns and Lives at Property	☐	Owns the Rental Property	☐	Tenant	☐
35. How long have you lived at the current residence?					
Less than a year	☐	1 to 5 years	☐		
5 to 10 years	☐	Over 10 years	☐		
36. Which neighborhood of Jersey City do you reside? *please check one)*					
Hackensack Riverfront	☐	West Side	☐	Bergen-Lafayette	☐
McGinley Square	☐	Journal Square	☐	Other	☐
37. Would you like a copy of the final report?		Yes	☐	No	☐

If you would like to receive the results of the study, you can opt for that and we will communicate them to you as soon as it is complete. Please complete this survey at your convenience and drop it in any mailbox; return postage is provided:

Dr. Pankaj Lal, Ph.D. Assistant Professor, Department of Earth and Environmental Studies, 1 Normal Avenue, 358N Mallory Hall, Montclair, NJ 07043

If you have any question or suggestion, please let us know.

****

THANK YOU FOR YOUR TIME

Please return the questionnaire in the self-addressed stamped envelope included in this mailing

This survey is approved by MSU Institutional Review Board #001660.

Investigating Risk Perception of Lead Contamination in Jersey City, New Jersey

The purpose of this study is to determine if occupants are aware of lead contamination in soil and paint that may be present at their place of residence. If so, identify actions being taken by the occupant to address the contamination. This information will be useful in identifying potential sources of lead contamination in the area.. Please complete this survey at your convenience and drop it in any mailbox; return postage is provided.

You were randomly selected to participate in this study. This questionnaire will not take more than 25 minutes. Your participation in this survey is voluntary. Any response you give will be confidential and it will not be linked to you.

For any question about the research or survey, contact: Principal Investigator Melissa Koberle, Phone: 917-575-1543; Email koberlem1@mail.Montclair.edu; or Pankaj Lal, PhD. Assistant Professor, Montclair State University, Montclair, 07043 Phone 973-655-3137; Email lalp@mail.montclair.edu.

THANK YOU FOR YOUR HELP!!!

Appendix C: Survey Questionnaire for the research study (page 2)

1. How serious of a risk does the following pose to **you**? *(please check one box for each item).*	Not at All Risky	Moderately Weak Risk	Moderately Risky	Moderately Strong Risk	Extremely Risky
Death	☐	☐	☐	☐	☐
Injury	☐	☐	☐	☐	☐
Property Damage	☐	☐	☐	☐	☐
Terrorist Attack	☐	☐	☐	☐	☐
Flood Damage	☐	☐	☐	☐	☐
Burglary	☐	☐	☐	☐	☐
House Fire	☐	☐	☐	☐	☐
Traffic Accident	☐	☐	☐	☐	☐
Asbestos Exposure	☐	☐	☐	☐	☐
Lead Paint Exposure	☐	☐	☐	☐	☐
Air Pollution	☐	☐	☐	☐	☐
Water Pollution	☐	☐	☐	☐	☐
Soil Pollution	☐	☐	☐	☐	☐

2. Do **you** have the ability to address the following? *(please check one box for each item).*	Absolutely No	Mostly No	Neither Yes or No	Mostly Yes	Absolutely yes
Crime	☐	☐	☐	☐	☐
Terrorism	☐	☐	☐	☐	☐
Flooding	☐	☐	☐	☐	☐
Accidents	☐	☐	☐	☐	☐
Household Pollution	☐	☐	☐	☐	☐
Community Pollution	☐	☐	☐	☐	☐

BACKGROUND INFORMATION

25. Are you male or female? ***(please check one)***

Male ☐ Female ☐

26. What is your ethnic group? ***(please check one)***

Caucasian ☐ Asian or Pacific Islander ☐

Hispanic ☐ African-American ☐

Other ______________________________

27. Your age ***(please check one)***

Younger than 30 ☐ 31 to 40 ☐

41 to 50 ☐ 51 to 65 ☐ Older than 65 ☐

28. Number of people in your household?

______________________ people

29. Please specify your type of household. ***(please check one)***

Husband-Wife Family ☐ Male Household, other family ☐ One person, nonfamily ☐

Female Household, other family ☐ Two or more people, nonfamily ☐

30. Identify Sensitive Residents. ***(please check one)***

Children under 3 years of age ☐ Childeren between 3 and 12 ☐

Children between 13 and 17 ☐ Senior Citizens, over the age of 65 ☐

31. Highest level of formal education attained. ***(please check one)***

Elementary school ☐ High school ☐

Some college ☐ College graduate and above ☐

32. What was your approximate gross family income (before taxes) in 2014?

Less than $22,000 ☐ $50,000 to $89,999 ☐

$22,000 to $49,999 ☐ Greater than $90,000 ☐

Appendix C: Survey Questionnaire for the research study (page 3)

21. Has lead pollution in paint been identified on your residence? *(Please check one)*

Yes	☐	No	☐

22. Have measures been taken to address lead pollution on your residence? *(Please check one)*

Yes	☐	No	☐

23. How sensitive is the environment to human activities? *(please check one box for each item).*	**Not At All**	**Very Little**	**Somewhat**	**To A Great Extent**
	☐	☐	☐	☐

24. What is the human population's impact on the environment? *(please check one box for each item).*	**Not At All**	**Very Little**	**Somewhat**	**To A Great Extent**
	☐	☐	☐	☐

Optional Comment:

3. How would you rate the following risk to the average person living in New Jersey? *(please check one box for each item).*	**Not at All Risky**	**Moderately Weak Risk**	**Moderately Risky**	**Moderately Strong Risk**	**Extremely Risky**
Death	☐	☐	☐	☐	☐
Injury	☐	☐	☐	☐	☐
Property Damage	☐	☐	☐	☐	☐
Terrorist Attack	☐	☐	☐	☐	☐
Flood Damage	☐	☐	☐	☐	☐
Burglary	☐	☐	☐	☐	☐
House Fire	☐	☐	☐	☐	☐
Traffic Accident	☐	☐	☐	☐	☐
Asbestos Exposure	☐	☐	☐	☐	☐
Lead Paint Exposure	☐	☐	☐	☐	☐
Air Pollution	☐	☐	☐	☐	☐
Water Pollution	☐	☐	☐	☐	☐
Soil Pollution	☐	☐	☐	☐	☐

4. The following is going to get worse in the future? *(please check one box for each item).*	**Absolutely No**	**Mostly No**	**Neither Yes or No**	**Mostly Yes**	**Absolutely yes**
Crime	☐	☐	☐	☐	☐
Terrorism	☐	☐	☐	☐	☐
Flooding	☐	☐	☐	☐	☐
Accidents	☐	☐	☐	☐	☐
Household Pollution	☐	☐	☐	☐	☐
Community Pollution	☐	☐	☐	☐	☐

Appendix C: Survey Questionnaire for the research study (page 4)

5. How much have you heard or read about the following in the Jersey City area over the past month?
(please check one box for each item).

	Absolutely No	Mostly No	Neither Yes or No	Mostly Yes	Absolutely Yes
Crime	☐	☐	☐	☐	☐
Terrorism	☐	☐	☐	☐	☐
Flooding	☐	☐	☐	☐	☐
Accidents	☐	☐	☐	☐	☐
Pollution	☐	☐	☐	☐	☐

6. Do you have an interest in learning more about the following in the Jersey City area?
(please check one box for each item).

	Absolutely No	Mostly No	Neither Yes or No	Mostly Yes	AbsolutelyY Yes
Crime	☐	☐	☐	☐	☐
Terrorism	☐	☐	☐	☐	☐
Flooding	☐	☐	☐	☐	☐
Accidents	☐	☐	☐	☐	☐
Pollution	☐	☐	☐	☐	☐

7. Are you aware of a polluted site within two blocks from your property?
(Please check one)

Yes ☐ No ☐

8. Are you aware of a polluted site within your neighborhood? ***(Please check one)***

Yes ☐ No ☐

9. Is it the individual's (your) responsibility to be aware of environmental risk and to address them? *(please check one box for each item)*	Absolutely No	Mostly No	Neither Yes or No	Mostly Yes	Absolutely yes
	☐	☐	☐	☐	☐

10. Can lead exposure damage the neurological, circulatory and other vital systems in humans ?
(Please check one)

Yes ☐ No ☐

11. Can lead cause developmental and learning problems among children? ***(Please check one)***

Yes ☐ No ☐

12. Do you grow plants for consumption on your residence?
(Please check one)

Yes ☐ No ☐

13. Do you grow plants for decorative purposes on your residence? ***(Please check one)***

Yes ☐ No ☐

14. Do you purchase topsoil for your gardening area? ***(Please check one)***

Yes ☐ No ☐

15. Do you plant directly in the ground (as opposed to a raised gardening bed)? ***(Please check one)***

Yes ☐ No ☐

16. Do you and/or your family play in the garden/grass on your residence?
(Please check one)

Yes ☐ No ☐

17. Do you have a pet that plays or lays in the garden/grass on your residence? ***(Please check one)***

Yes ☐ No ☐

18. Has the soil on your residence been tested for lead in the past? ***(Please check one)***

Yes ☐ No ☐

19. Has the paint within your household been tested for lead in the past? ***(Please check one)***

Yes ☐ No ☐

20. Has lead pollution in soils been identified on your residence? ***(Please check one)***

Yes ☐ No ☐