AN EXAMINATION OF SEDIMENT MANAGEMENT PROCESSES IN THE GREAT LAKES AND THE USE OF A DECISION SUPPORT SYSTEM (DSS) FRAMEWORK FOR SEDIMENT REMEDIATION PROJECTS

AN EXAMINATION OF SEDIMENT MANAGEMENT PROCESSES IN THE GREAT LAKES AND THE USE OF A DECISION SUPPORT SYSTEM (DSS) FRAMEWORK FOR SEDIMENT REMEDIATION PROJECTS

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Dissertation Abstract: "An Examination of Sediment Management Processes in the Great Lakes and the use of a Decision Support System (DSS) Framework for Sediment Remediation Projects"

Great Lakes Areas of Concern (AOC) are designated geographical locations within the Great Lakes Basin with particularly degraded environmental conditions. There is a consensus among diverse sectors in the Great Lakes Basin that contaminated sediment is a major environmental problem and a key factor in many of the impairments of the human and nonhuman uses (beneficial uses) of the Great Lakes. This case study examines Randle Reef in the Hamilton Harbour (AOC) which is the largest Canadian contaminated sediment site in the Great Lakes containing 695,000 m^3 of sediment contaminated with polycyclic aromatic hydrocarbons (PAH) and metals. The cleanup of the Randle Reef site is a major step in the process to restore Hamilton Harbour and remove it from the list of AOCs. The Randle Reef sediment remediation project is finally coming to fruition after more than thirty years of study, discussion, collaborations, and debate.

As in the case of Randle Reef, environmental decisions are often complex and multi-faceted and involve many stakeholders with competing (sometimes conflicting) priorities or objectives representing exactly the type of problem that humans are poorly equipped to solve unaided. When professionals encounter complex issues, they often attempt to use approaches that simplify the complexity so that they can manage the problem at hand. During this process, valuable information may be lost, opposite points of view may be ignored and elements of uncertainty may be overlooked. A systematic methodology that combines both quantitative and qualitative data from scientific or engineering studies of risk, cost, and benefit, as well as stakeholder objectives and values to rank project alternatives, has yet to be fully developed for contaminated sediment decision-making.

The main goal of this Ph.D. research was to develop a Decision Support System (DSS) framework to aid the complex decision-making in sediment remediation. The proposed DSS framework incorporates the five key themes that, through research, were found to be the most relevant for sediment remediation projects. These themes are 1)participation of appropriate actors with common objectives; 2)funding and resources; 3)decision-making process; 4)research and technology development; and 5)public and political support. There was a need to gather relevant information and data from various sources to develop the required DSS framework. For this purpose, expert interviews were conducted, responses were collected through a public survey, Qualitative Document Analysis (QDA) was performed on available policy and research documents, and a review was undertaken of how other jurisdictions have employed DSS to aid their decision-making process. The final DSS framework has six key components as follows: 1)data module; 2)communication module; 3)document module; 4)knowledge module; 5)tools module; and 6)DSS optimization module. This generic framework can assist practitioners in developing more systematic and structured decisions for sediment remediation by incorporating an Integrated Information Management System (IIMS) along with a DSS optimization module. This IIMS+DSS method can aid the decision-making process by making it documented, reproducible, robust, transparent and provide a coherent framework to explore and analyze available alternatives in an attempt to reach the preferred solution promptly.

Preface

This sandwich Ph.D. Dissertation consists of four research publications submitted to research journals. The primary author is Zobia Jawed in all the four research publications along with Dr. Gail Krantzberg, who served as a co-author for these papers as well as Ph.D. Research supervisor.

Zobia Jawed is the main contributor to all the research papers. Her contributions included design, conduct, analysis and write-up for all the four publications. Dr. Gail Krantzberg provided invaluable guidance/inputs throughout this Ph.D. research as well as provided ideas and edits to the publications, as necessary.

Zobia Jawed will obtain necessary copyright permissions from publishers for McMaster University as required.

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Sandwich Dissertation Table of Contents

Chapter 1: Introduction 1

Chapter 2: Public Participation in Sediment Remediation Projects: Encouraging Transparent Decision-Making 8

Chapter 3: A Comparative Analysis of Practitioners' Experience in Sediment Remediation Projects to Highlight Best Practices 36

Chapter 4: Using Qualitative Document Analysis to Understand Sediment Remediation Policies in North America 85

Chapter 5: A Decision Support System Framework for Contaminated Sediment Management 124

Chapter 6: Conclusions and Recommendations 153

Chapter 7: References 157

Chapter 1: Introduction

Introduction

The North American Great Lakes and their connecting rivers make up the largest freshwater system in the world with a total water surface area of nearly 95,000 square miles. The Great Lakes contain approximately 24.6 quadrillion liters of water, which is roughly 18-20% of the world's freshwater supply (Government of Canada and the United States Environmental Protection Agency, 1995). The Great Lakes are also essential for creating recreational opportunities, enhancing biodiversity, and creating areas for people to enjoy nature. Hence, it is important to maintain the quality of the Great Lakes to support ecosystem services (Government of Canada and the United States Environmental Protection Agency, 1995). Historically, one of the challenges facing the effective management of the Great Lakes ecosystem has been the presence of toxic compounds largely as the result of industrial and agricultural build-up along the shores of the lakes over the past decades (T. Crane, 2012; Government of Canada and the United States Environmental Protection Agency, 1995). There is a consensus among diverse sectors in the Great Lakes Basin that contaminated sediment is a major environmental problem and a key factor in many of the impairments of the beneficial uses of the Great Lakes (T. Crane, 2012; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997).

At the turn of the 20th century, there was an increased recognition of the need to approach water resources management and development in shared Canadian-U.S. waterbodies. This recognition led to the signing of the Boundary Water Treaty of 1909, which also established an International Joint Commission (IJC) to settle trans-boundary water disputes (Governments of Canada and the United States, 1909). The IJC recognized "remediation and management of sediment contaminated with persistent toxic substances" as one of its 1995-1997 program priorities (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997).

To further address pollution in the Great Lakes, the Great Lakes Water Quality Agreement was first signed in 1972 (later amended in 2012) between Canada and the United States. The goal of Annex 1 of the Canada-United States Great Lakes Water Quality Agreement is to work towards remediating and restoring designated Areas of Concern (AOC) around the Great Lakes. These are areas where human and other activities have severely degraded water quality and ecosystem health (Environment Canada, 2017). Each of the AOCs has developed a Remedial Action Plan (RAP) to restore the beneficial uses in the Great Lakes (Environment Canada, 2017). In the RAP process, government and stakeholders work together to restore the environmental quality of the AOCs through three phases: planning, implementation, and monitoring (Governments of Canada and the United States, 2012).

Problem Definition

By 1920, the waters of Hamilton Harbour were impacted by major contamination issues resulting in swimming and fishing closures (Freeman, 2006). However, it was not until the early 1960s that the Provincial government started to look at the conditions of the Harbour (Hall & O'Connor, 2012). In 1985, the Ontario Ministry of the Environment and Climate Change (MOECC) formally recognized the water quality issues in the Hamilton Harbour, identifying the need for a sediment remediation project at the Randle Reef site (Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2012). This project has consisted of many phases ranging from: problem identification, quantification of the problem and issues, defining remediation alternatives and selection of preferred alternatives, engineering design, and preparation of comprehensive environmental assessment, securing the funding and related funding agreements, public consultation and plans for monitoring to ensure beneficial impairments are restored (Randle Reef Sediment Remediation Project- Technical Task Group, AECOM Canada Ltd., & Environment Canada, 2012). The remediation plan involves the construction of a 6.2 hectare Engineered Containment Facility (ECF) over 140,000 m^3 of the most highly contaminated sediment. Approximately 445,000 m^3 of polycyclic aromatic hydrocarbons (PAH) and metal contaminated sediment surrounding the ECF will be dredged and placed inside the facility for a total containment of 585,000 m^3. Another 110,000 m^3 of less contaminated sediment found in other areas of the harbour will be capped in situ using both thin layer capping and isolation capping techniques, resulting in a total of 695,000 m^3 of sediment being managed (Bay Area Restoration Council, 2017). Remediation of the Randle Reef site began in 2016 and is expected to be completed by 2022 (Graham, Hartman, Joyner, Kim, & Santiago, 2017).

It took more than 30 years from the time the problem was formally identified until site remediation began at the Randle Reef site. Environmental decisions are often complex and multi-dimensional and involve many stakeholders with sometimes conflicting objectives representing exactly the type of issue that humans are not adequately trained to resolve. Mostly, when organizations come across such complex issues, they attempt to use approaches that simplify the complexity of the issues so that they can manage the problem at hand. This simplification process results in the loss of valuable information, which might otherwise have served a critical role in the decision-making process. A systematic methodology to combine both quantitative and qualitative data from scientific and engineering studies of risk, cost, and benefit, as well as stakeholder objectives and values to rank project alternatives, has yet to be fully developed for contaminated sediment decision-making.

Although each environmental remediation problem is unique and requires a site-specific analysis, many of the critical decisions are similar, at least in structure. This has led many practitioners to attempt to develop standard methods. As part of the standardisation process, attempts have been made to codify specialist expertise into decision support tools or Decision Support Systems (DSS). This activity is intended to facilitate reproducible, robust and transparent decision-making.

Need for Decision Support System in Sediment Remediation Projects

A DSS is an interactive system that helps practitioners use data, documents, knowledge, and models to solve simple or complex problems alike and make decisions (Power & Sharda, 2009). These DSS systems are built to support individuals in the decision-making process (Angehrn & Jelassi, 1994; Power & Sharda, 2009). DSSs have shifted over time from solving semi-structured problems to solving complex issues (Beynon, Rasmequan, & Russ, 2002; Courtney, 2001; McCown, 2002; Rauscher, 1999). The decision-making process for the Randle Reef sediment remediation project was very complex as it involved a myriad of social, economic, environmental and other issues that needed to be addressed.

In the literature, several case studies are present that mention decision support tools for selection between different remediation alternatives for site and/or groundwater remediation in general (Beames, Broekx, Lookman, Touchant, & Seuntjens, 2014; Cappuyns & Kessen, 2012; Jordan & Abdaal, 2013; Marcomini, Suter, & Critto, 2009;

Reddy & Adams, 2015). However, none of these case studies focus on the major themes that are considered important in sediment remediation nor do they consider the optimization of these themes for effective decision-making.

Several studies have indicated that there are five key themes that are frequently identified as obstacles when dealing with remediation of contaminated sediment sites (Beierle & Konisky, 1999; Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2016; Hall & O'Connor, 2012; Jawed & Krantzberg, 2017a; Krantzberg, 2003; Li, Jiao, Xiao, Chen, & Liu, 2017; Read, Bates, Wood, & Linkov, 2014; Renn & Finson, 1991; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Zarull, Hartig, & Krantzberg, 2001; Zarull et al., 1999). These themes are:

1. participation of appropriate actors with common objectives;
2. funding and resources;
3. decision-making process;
4. research and technology development;
5. public and political support.

Research Objectives and Research Plan

The main goal of this Ph.D. research was to develop a DSS framework to aid the complex decision-making in sediment remediation by incorporating the five key themes that we found are most relevant.

To achieve this goal, the following research steps were carried out:

1. Public surveys were conducted to understand involvement of the public in the Randle Reef project and highlight opportunities for improvement in public participation for future environmental cleanup projects. This information formed

key input on how a DSS should take advantage of involving the public at all stages of the project as discussed in Chapter 2 titled “Public participation in sediment remediation projects: encouraging transparent decision-making”.

2. Expert interviews were conducted with professionals from organizations (who are/were involved) to identify the nature of performance in the five themes as identified above that are essential for successful action. This is discussed in detail in Chapter 3 titled “A comparative analysis of practitioners' experience in sediment remediation projects to highlight best practices”.
3. Qualitative Document Analysis (QDA) was performed on selected sediment remediation policy documents and research papers so as to analyze how well each of the five key themes are addressed in these documents. The findings and methodology are discussed in Chapter 4 titled “Using Qualitative Document Analysis (QDA) to understand sediment remediation policies in North America”.
4. A DSS framework was developed based on findings from Chapters 2, 3 and 4 for achieving a holistic, integrated and efficient strategy for sediment remediation projects by incorporating the five key themes into the DSS framework. This is discussed in Chapter 5 titled “A Decision Support System (DSS) framework for contaminated sediment management”.

Chapter 2: Public Participation in Sediment Remediation Projects: Encouraging Transparent Decision-Making

Public Participation in Sediment Remediation Projects: Encouraging Transparent Decision-Making

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Abstract

The Great Lakes region provides an excellent opportunity to research public participation in environmental decision-making because the area has a history of active public involvement in the ecosystem restoration efforts. There is a consensus among diverse sectors in the Great Lakes Basin that contaminated sediment is a major environmental problem and a key factor in many of the impairments of the beneficial uses of the Great Lakes. Our case study examines the Hamilton Harbour Area of Concern (AOC) which has developed a Remedial Action Plan (RAP) to restore beneficial uses in the AOC. Although the Great Lakes Water Quality Agreement states that all RAPs should include the public consultation, it does not dictate how this consultation should take place. This paper describes the public involvement in the Randle Reef Project, a contaminated sediment zone within the Hamilton Harbour AOC, and highlights opportunities for improving public participation in future environmental cleanup projects. Based on the public survey that was conducted in the City of Hamilton and surrounding areas in Ontario, the findings suggest that few citizens were aware of this contamination issue in Hamilton Harbour and that they would have liked to be more involved. Moreover, the public would like to have a greater role in future environmental projects using new technologies and methods to facilitiate their engagement.

Key Words: sediment remediation; remedial action plan; Great Lakes Areas of Concern; public engagement; public participation; public opinion

Introduction

Public participation is increasingly recognized as a significant element of environmental planning and decision-making (Applegate, 1998; Beierle & Konisky, 1999; Bradbury & Branch, 1999; Carr, Loucks, & Blöschl, 2013; Coglianese, 1997; De Stefano, 2010; Irvin & Stansbury, 2004; Luyet, Schlaepfer, Parlange, & Buttler, 2012; Lynn & Busenberg, 1995; Renn, Webler, & Wiedemann, 1995; Yosie & Herbst, 1998). It is important to improve existing participatory methods further to ensure that such participation continues to accomplish both the goals of government agencies and the expectations of the public. The limitations of traditional processes and the exploration of new methods have been the focus of much analysis, from both the academic and professional communities (Applegate, 1998; Bradbury & Branch, 1999; Coglianese, 1997; Lynn & Busenberg, 1995; Renn & Finson, 1991; Yosie & Herbst, 1998).

Too often public involvement in decision-making is reactive, occurring after a decision has been reached (Konisky & Beierle, 2001). The type of individuals and groups who become engaged in public processes vary substantially depending on the public engagement method that is employed (Konisky & Beierle, 2001). This has raised the question of who should be participating. A key/common critique of many participatory processes is that, too often, participation is limited to representatives of interest groups. Restricting access to these stakeholders only, who have been categorized as the “usual suspects” (Applegate, 1998) or “inside-the beltway” regulators (Hadden, 1995), reinforces a pluralist model of policy making in which interest group representatives serve as substitutes for the public. Participation theorists counter that average citizens are the best judges of their interests, and have the capacity to learn the skills necessary to take part in governance (Fiorino, 1990). Further, support for the role of citizens comes from the risk perception and communication literature, which has demonstrated that lay people's opinion of risk often differs from risk perceptions of experts (Krimsky & Golding, 1992). To properly account for all values and preferences, some argue that citizens should be given a stronger voice in environmental decision-making processes (National Research Council, 1996).

The result of participatory methods is largely dependent on the type of procedure in use, which defines the role of participants themselves (Konisky & Beierle, 2001). Some participatory methods are set up for the main purpose of community engagement and information exchange, such as a study circle (M. McCoy, 1996). A study circle mainly consists of eight to twelve people who meet over a period of weeks or months to address public concerns in a collaborative manner. Other processes, such as public advisory groups, aim to produce a consensus that is acceptable to the majority of the participants, who are involved in the development of recommendations for decision-making and planning the implementation activities. Some participatory processes empower citizens to have a high degree of influence on agency decision-making, whereas others limit that influence significantly (Konisky & Beierle, 2001). Much of the discussion in the public participation literature argues that citizens should be granted more power in decision-making (Applegate, 1998; Fiorino, 1990), and others point out that the degree of citizen decision-making authority should be contingent upon the characteristics of the problem at issue (J. C. Thomas, 1990).

Collaborative watershed management groups do not function according to specific guidelines, but rather operating procedures are generally determined at initial group meetings and reflect the desires of the selected groups and individuals involved (Konisky & Beierle, 2001). Many efforts evolve significantly over time as group composition changes and different issues arise. Some participatory processes focus on the facilitation of information exchange and development of policy prescriptions, whereas collaborative watershed management efforts typically move beyond visioning and planning exercises to the implementation of concrete initiatives, ranging from cleanup and restoration efforts to resource use issues (Konisky & Beierle, 2001). These approaches encourage a group of multi-interested stakeholders to work jointly with government agency officials to co-determine the management of resources in a watershed. Similarly, in terms of decision-making authority, the processes range from those that generally have negligible influence on government agencies (study circles), to those that advise government agencies (round table discussion), to those that reach a decision to implement actions outside of usual government decision-making process (collaborative watershed management) (Konisky & Beierle, 2001; Lesh, 1995; United States Environmental Protection Agency, 1991b).

Increased attention to the public participation is powered by optimism about how public involvement can enhance the effectiveness and responsiveness of environmental management decisions. Involving the public has several practical, philosophical, and ethical benefits. Some of the more important reasons for involving the public in environmental planning efforts in the Great Lakes region include: educating participants, improving the substantive quality of decisions, incorporating public values into decision-making, reducing conflict, and building trust (Beierle & Konisky, 1999).

Great Lakes Remedial Action Plans

The Great Lakes region provides a fertile area for research on public participation because of the extensive environmental protection efforts underway and because the region has a history of active public involvement in decision-making (Grima, 1983). Historically, the Great Lakes have been contaminated from industrial and agricultural activities within the basin. This has resulted in the accumulation of toxins in the Great Lakes (T. Crane, 2012; Government of Canada and the United States Environmental Protection Agency, 1995). There is a consensus among diverse sectors in the Great Lakes Basin that contaminated sediment is a major environmental problem and a key factor in many of the impairments of the beneficial uses of the Great Lakes (T. Crane, 2012; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). An early estimate was that there were over 90 million cubic meters of contaminated sediment in the Great Lakes (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). These estimates were developed at an early stage of this study and may be out of date as there are no revised estimates available. Therefore, these values should be considered only in terms of the order of magnitude.

The Great Lakes Remedial Action Plan (RAP) process was designed to address contamination in the most highly polluted rivers and bays around the Great Lakes. These are called Areas of Concern (AOC) where water quality and ecosystem health have been severely degraded by human and other activities (Environment Canada, 2017; Governments of Canada and the United States, 1987, 2012; Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1989). Each AOC has developed a RAP to restore the beneficial uses in that location (Environment Canada, 2017). In the RAP process, government and stakeholders work together to restore the environmental quality of the AOCs through three phases: planning, implementation, and monitoring (Governments of Canada and the United States, 2012).

Although the RAP process was initiated through an international agreement (Governments of Canada and the United States, 1987, 2012), state and provincial agencies have taken the lead in running the projects (Konisky & Beierle, 2001). The lead agencies have shared the bulk of the substantive work on the RAPs with local citizens' advisory committees. Most RAPs have supplemented public participation through the use of advisory committees, with outreach to a wider audience through public meetings, newsletters, and other mechanisms (Beierle & Konisky, 1999). The local orientation of the RAPs was intended to facilitate implementation by ensuring local ownership and building local capacity (Beierle & Konisky, 1999). Many RAP processes stalled in the implementation phase because of a lack of financial resources, withdrawal of lead agency coordination, and the difficulty and expense of dealing with contaminated sediments—a problem common to most AOCs (Beierle & Konisky, 1999; Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2012; Krantzberg, 2003; Renn & Finson, 1991; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997).

Sediment Remediation Projects and Public Participation

It is more challenging to build the public support for contaminated sediment remediation as compared to other environmental issues because contaminated sediment is an "invisible" problem (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). Moreover, there can be several reasons for lack of public support, including (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997):

- lack of knowledge and understanding that contaminated sediment is contributing to environmental damages;
- lack of consensus regarding which remedial method is best for a given situation; and
- discouragement due to slow progress in achieving cleanup (due to shortage of funds; delays due to contractual negotiations; delays due to lack of industrial cooperation).

There is no hesitation to believe that strong public and local support is essential for contaminated sediment projects. There is strong agreement that the RAP process is an effective tool to gain public and local support for sediment remediation (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). RAPs offer a consensus-based, multi-stakeholder approach to build the public support and understanding. The most successful example of this has been through the Collingwood Harbour RAP where stakeholders were equal partners in problem identification, goal setting, review of options, and selection of remedial actions for removal of contaminated sediment and restoring uses (Grover & Krantzberg, 2012; Krantzberg, 2003; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). Such success stories need to be shared and encouraged elsewhere. Based on the Collingwood Harbour RAP experience, it is important for RAPs to communicate complex databases in simple terms. This will help provide the necessary tools to help the public select and lobby for preferred remedial options (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). Sediment management decisions can have substantial environmental and economic consequences. Due to their complexity, efforts should be made to communicate complex technical facts, uncertainties, risk assessments, and other tools used in the decision-making process to the public and stakeholders in an easily understandable way (Skei, 2007).

Randle Reef Case Study

In 1985, the Ontario Ministry of the Environment and Climate Change (MOECC) formally identified the water quality issues in the Hamilton Harbour confirming the need for a sediment remediation project at the Randle Reef site (Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2012). In 1987, Hamilton Harbour was formally designated as an AOC. A detailed study was carried out in 1989 to investigate the sediment contamination in Hamilton Harbour and to assess the seriousness of the contamination (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1989). The RAP for Hamilton Harbour ultimately identified three high priority sites (Randle Reef, the Ottawa street boat slip, the Dofasco boat slip) that required active intervention due to acute toxicity (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992). Subsequently, further investigation indicated that the Ottawa Street boat slip was not severely contaminated as compared to other two sites (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992). Of the two remaining remedial efforts, the Randle Reef area is a project between Stelco and various government agencies while the Dofasco boat slip is a privately funded project of ArcelorMittal Dofasco. Randle Reef is by far the larger of these two projects, with approximately 695,000 m^3 of contaminated sediment located between Pier 15 and Pier 16 of the Hamilton Harbour (Graham et al., 2017; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012) (Figure 1).

Figure 1: Hamilton Harbour Area of Concern

(Hamilton Port Authority, 2013)

Randle Reef is one of the most contaminated sediment sites in Canada (Environment Canada, 2010; Graham, 2011; Graham et al., 2017). The site has been described as "a spill in slow motion" due to the continuing slow spread of contaminants across the Harbour and uptake into the food chain of the Harbour ecosystem (Bay Area Restoration Council, 2017; Graham et al., 2017).

Randle Reef is contaminated with coal tar and subsequently contains very high concentrations of polycyclic aromatic hydrocarbons (PAHs) (Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). The PAH concentrations exceeded 800 parts per million in some of the sediment cores collected at the site, concentrations only exceeded at the Sydney Tar Ponds in Nova Scotia - a hazardous waste site that consisted of 700,000 tonnes of PAH- contaminated sediments (Environment Canada, 2010; Government of Canada, 2012; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). Levels of many metals (especially iron) in the Randle Reef sediment exceed MOECC “severe effect levels”, and detectable levels of polychlorinated biphenyls (PCBs), dioxins and furans and organochlorines are present (Environment Canada, 2010; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). The contamination problem is compounded by wave action from ships berthing nearby and redistributing the sediments across the Harbour floor (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1989; Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). This issue was partially addressed through restrictions on ship movement in and around the area.

The key actors involved in the development and implementation of the Randle Reef remediation plan includes Environment and Climate Change Canada - Ontario Region, MOECC, the City of Hamilton, the Hamilton Port Authority, Stelco, the City of Burlington, and the Regional Municipality of Halton. These organizations were engaged in a series of bilateral and multilateral discussions over many years. They also helped to form the core membership of a Randle Reef Remediation Steering Committee with other invited stakeholders (Hall & O'Connor, 2012).

Objectives of this Research

The aim of this research was to better understand how the public was engaged in the various phases of the Randle Reef sediment remediation project from problem definition to action plan implementation. With this understanding, the aim was to recommend methods to improve the public engagement process in future environmental projects. To achieve this understanding, a public survey was undertaken to collect responses from residents in the City of Hamilton and surrounding areas.

Sample Frame and Selection

For this study, the sample frame was identified as residents of the City of Hamilton and surrounding areas (Region of Halton and Region of Niagara Falls). Also, other concerned residents who have a keen interest in environmental issues were part of the sample frame. All respondents were treated equally and same survey was used to collect responses.

The following strategies were implemented to reach the sample frame and improve survey response:

1. Post survey link to social media websites (Facebook pages, LinkedIn, twitter feeds). To reduce social bias as a result of inclusion of family and friends, a new Facebook account was created about the project and linked with appropriate professionals and individuals.

2. Solicit survey participation at local events in the City of Hamilton (such as festivals, fund raising events, seminars, conferences).

Confidentiality

Complete anonymity of response was provided so that no individual could ever be identified after survey completion. No personal information was collected that could identify any individual or their address during or after the survey completion. Some basic demographic information was collected and maintained for research purposes such as area of residence (e.g. city) and age group.

Public Survey Methodology

An online survey technique was mainly employed using SurveyMonkey® to effectively engage a broad cross section of the public. In a limited number of cases during direct interaction with respondents, the survey was also completed using Microsoft Word or by having printed copies completed by the respondents. The survey comprised of closed questions to ensure consistency in responses between large groups of people. Closed questions are those in which respondents can select from a range of possible answers such as rating, scaling, or yes/no. A major benefit of closed questions is that responses are easily coded and analyzed and are relatively clear to the respondent. It was deemed not reasonable to ask direct questions to the public about their engagement for a project that was initiated in 1985. It was more appropriate to ask questions about how they would prefer to be engaged in future environmental projects and what engagement tools/techniques would be preferable (news, social media, and others).

At the end of the survey, a comment box was provided to allow the provision of any information not captured by the closed format question.

The web survey was opened in February 2015 and continued collecting data until September 2016.

Table 1: Survey Sample Size Requirements

Population size	**>500,000 people (e.g. population of Hamilton)**
Margin error	5%
Confidence Interval	95%
Required sample size	384
Estimated response rate	15-20%

(Raosoft Inc., 2004)

Survey Results and Discussion

The survey questions were developed in consultation with various faculty members from the Department of Engineering and Public Policy and the Department of Earth and Environmental Sciences, McMaster University. A formal approval from McMaster Research and Ethics Committee was also obtained before the start of the survey.

All members of the public were asked structured and consistent questions to ensure that the data could be coded, analyzed and compared effectively. To meet the objective of the study, the survey questions were grouped into the following four sections:

Section 1: General Information: In this section, questions were asked related to age, place of residence and length of residence, and any prior affiliation with institutions related to the Randle Reef project.

A total of 398 complete and valid responses were collected over the survey period. Responses were considered valid when they met the following criteria:

1. Adults of age 18 or above
2. Residents of City of Hamilton, City of Burlington, City of St. Catharines / Region of Niagara Falls, or those who are concerned about the Randle Reef project

55.5% of responses came from residents of the City of Hamilton, 8.3% from the City of Burlington, 5.3% from St. Catharines / Niagara Falls, 5.0% from the City of Brantford, and the remaining from surrounding areas (Table 2). The median number of years respondents lived in their household was 12.5 years.

Table 2: Response Rate by City of Residence

City of Residence	Response Percent	Response Count
Hamilton	55.5%	221
Burlington	8.3%	33
St. Catharines /Niagara Falls	5.3%	21
Brantford	5.0%	20
Mississauga	4.8%	19
Brampton	3.8%	15
Toronto	7.3%	29
London	2.0%	8
Others (combined)	8.0%	32
Total number of responses		398

Table 3 below shows the age distribution of the survey respondents.

Table 3: Age Distribution of respondents:

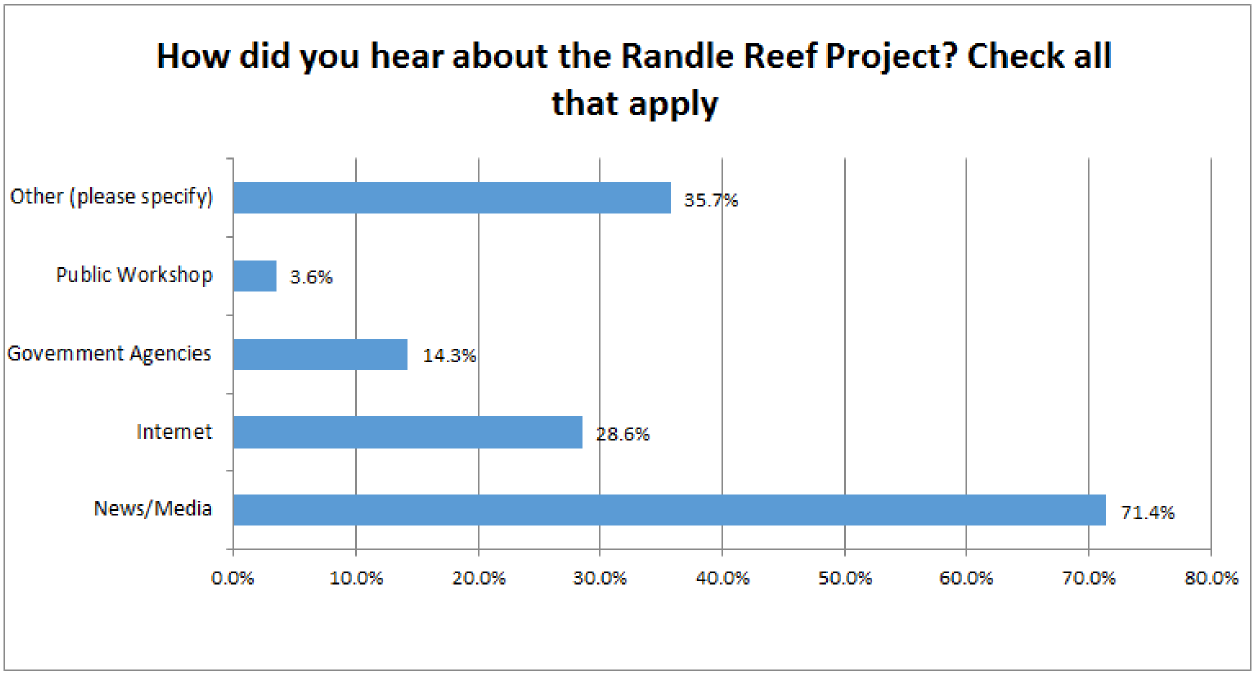
Age Group	Response Percent	Response Count
Below 18	0.0%	0
18 to 25	26.4%	105
26 to 50	49.1%	195
51 to 65	22.6%	90
66 or older	1.9%	8
Total number of valid responses		398

76.4% of people responded that they did not have any affiliation with any of the following: Environment Canada and Climate Change, MOECC, Hamilton/Burlington Conservation Authority, municipal government (Hamilton, Burlington), Hamilton Port Authority, Environment Hamilton, or Stelco.

Section 2: Knowledge about the Randle Reef Sediment Remediation Project: In this section, respondents were asked whether they had prior knowledge about the Randle Reef project. For respondents indicating yes to this question, subsequent questions asked that they describe how they first heard about the project, whether they were provided with sufficient information about the project and whether this information was useful to keep them informed about the status and development throughout the project.

27.1% of people indicated they had prior knowledge of the Randle Reef sediment remediation project. Figure 2 depicts how people reported they were made aware of the project:

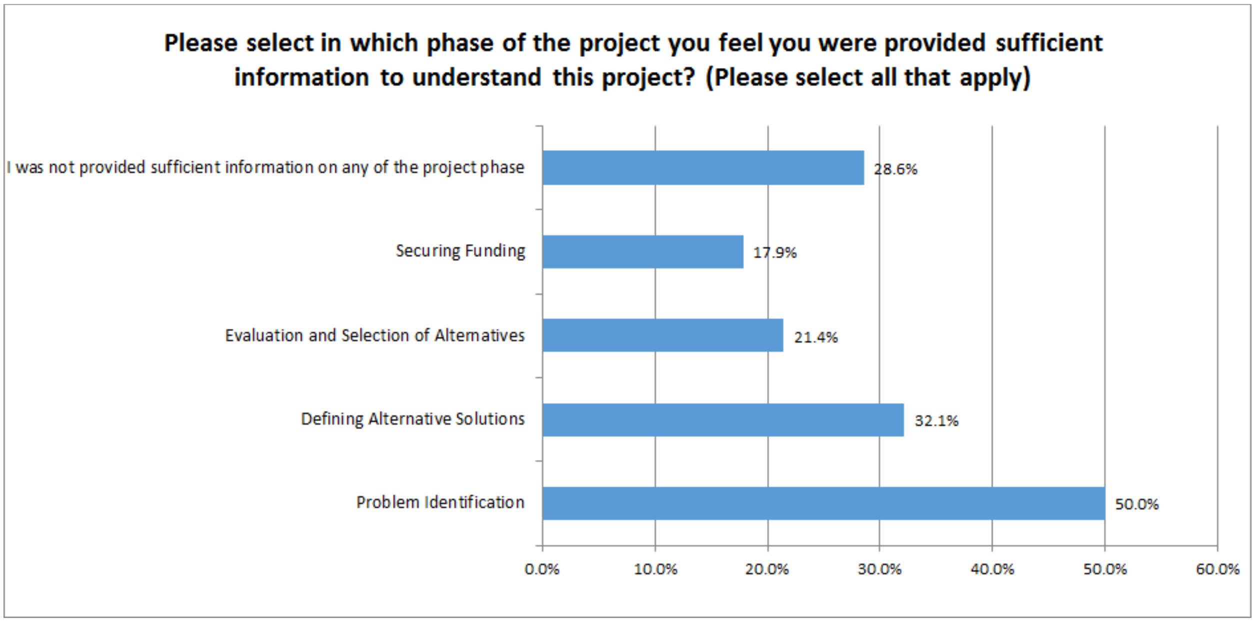
Figure 2: Knowledge about Randle Reef Project



It is evident that those who were aware of this project tended to learn through news or media posting. 35.7% of people heard about the project through other means (e.g. friends/family, co-workers, class lecture, research article). 28.6% of people learned about it through the internet. 14.3% heard about the project through government agency announcements. It should be noted that a very few people (3.6%) heard about the project through public workshops that were held during the Randle Reef project development.

Figure 3 shows the stages at which information was provided to members of the public who had prior knowledge about the Randle Reef project.

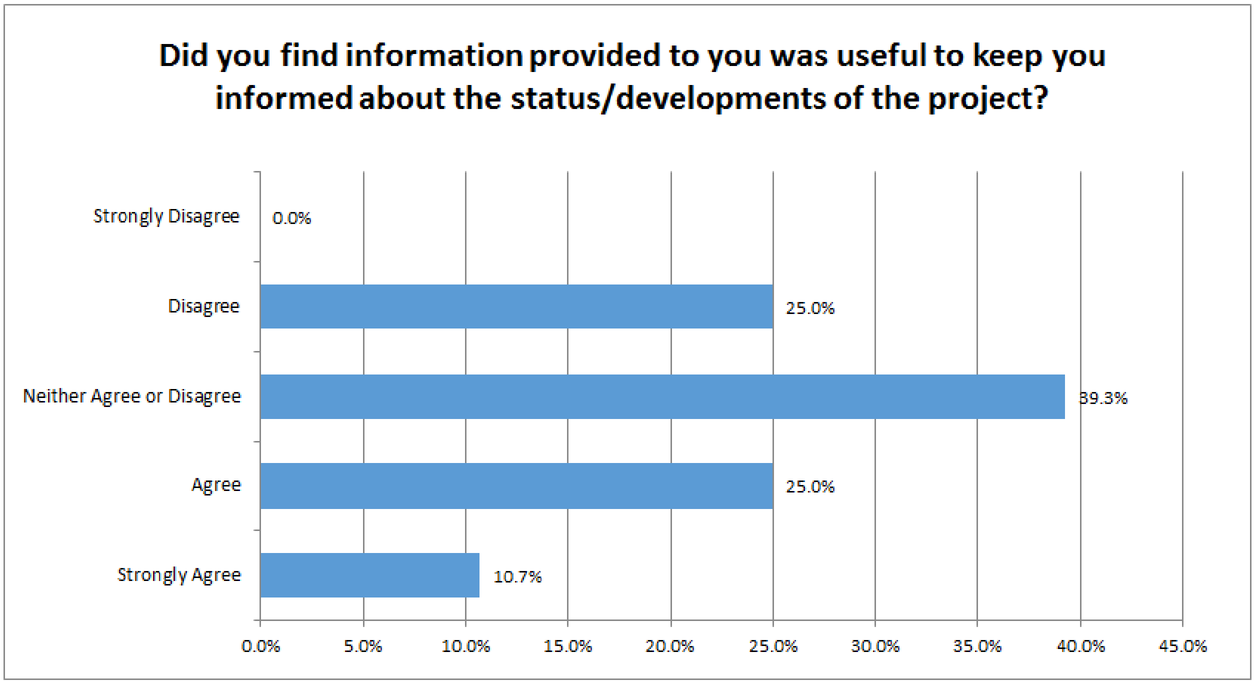
Figure 3: Phases of the Project and dissemination of Information to the Public



50% of respondents reported they were provided sufficient information during the problem identification phase, followed by defining the alternative solutions (32.1%) and the evaluation phase (21.4%). Only 17.9% noted they were provided sufficient information in the phase of securing the funding. 28.6% of people reported they were not provided adequate information during any phase of the project.

When asked whether the information provided was useful to keep them informed of the status and developments of the project, 25.0% disagree and 39.3% were not sure, 25.0% reported they agreed, and 10.7% strongly agreed (Figure 4).

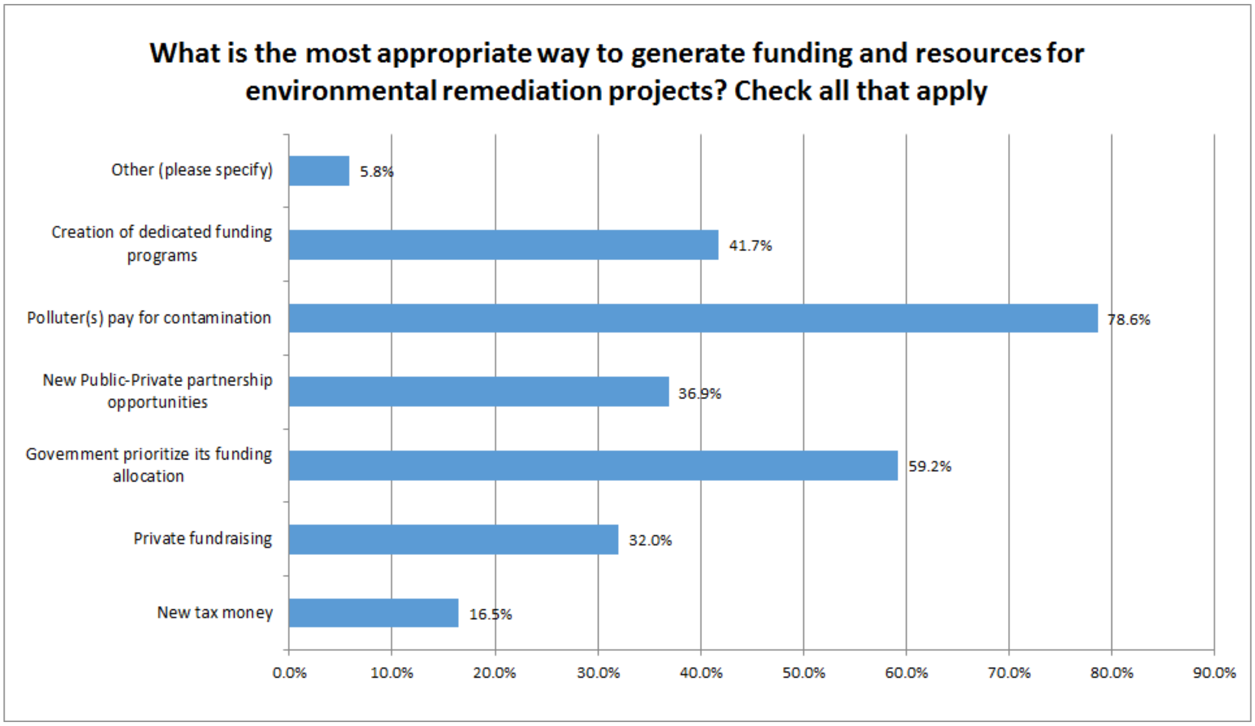
Figure 4: Information related to Status/Development of the Project



Section 3: Future Outlook of Environmental Sediment Remediation: In this section, respondents were asked their opinions on the most appropriate ways to collect the funding and resources for environmental remediation projects. They were also asked if they would like to be involved, and in what capacity, in the environmental decision-making process of future projects and at what capacity they would prefer. Lastly, they were asked whether there is a need for government to improve the level of public involvement in environmental projects and, if so, how this should be achieved.

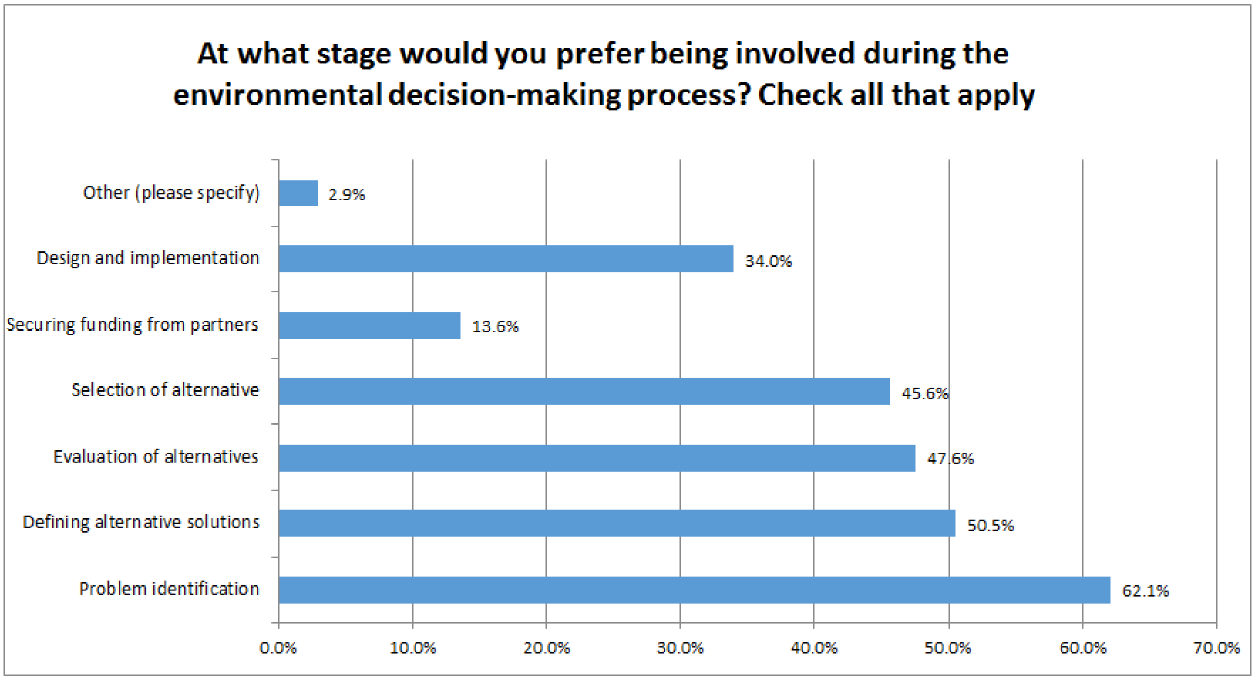
Figure 5 shows that 78.6% of respondents reported they felt it is more appropriate that polluter(s) pay for the cleanup. 59.2% respondents reported that the government should prioritize/reallocate its funding. 41.7% respondents reported they would support the creation of a dedicated funding program to deal with environmental remediation and 32% supported private fundraising. 36.9% supported the public-private partnerships. The support for new tax money to fund environmental remediation was low at 16.5%. 5.8% reported other measures such as the implementation of insurance programs, foreign investment and other unspecified mechanisms.

Figure 5: Funding and Resources for Environmental Projects



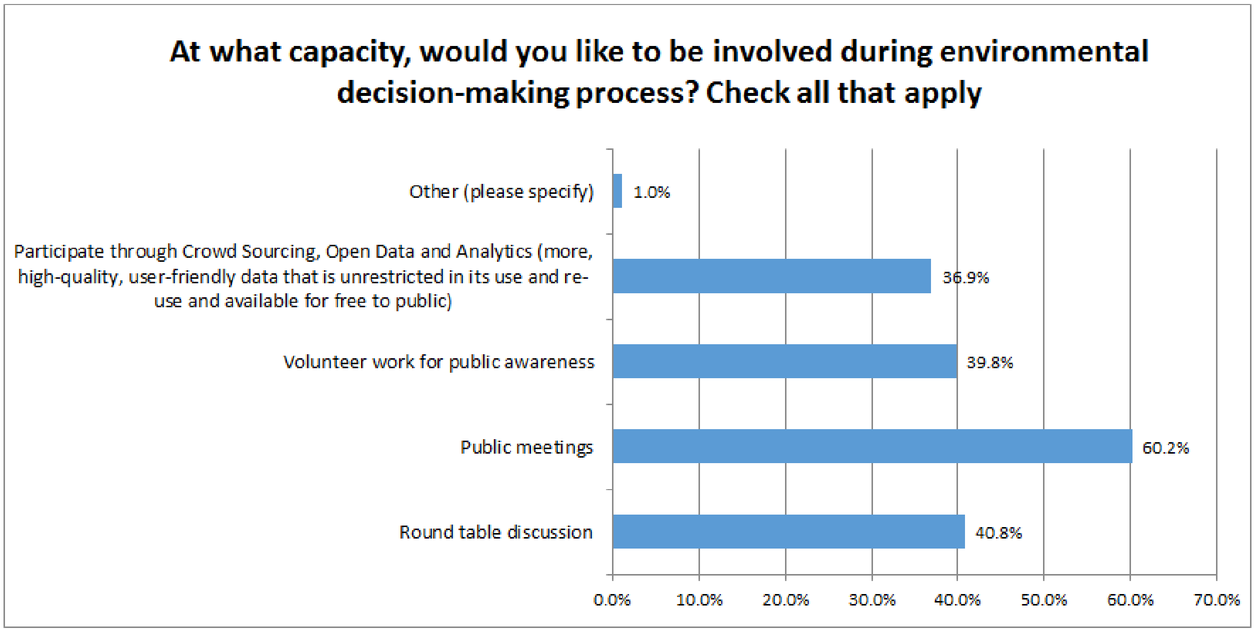
When asked the respondent's preference for involvement during the environmental decision-making process, 62.1% reported their preference to be during the problem identification phase followed by alternative solutions (50.5%), evaluation of alternatives (47.6%), and selection of alternatives (45.6%). 34.0% would like to be involved during the design phase, and only 13.6% reported a desire for involvement during the phase of securing the funding (Figure 6).

Figure 6: Environmental Decision-Making Process and Public Preference



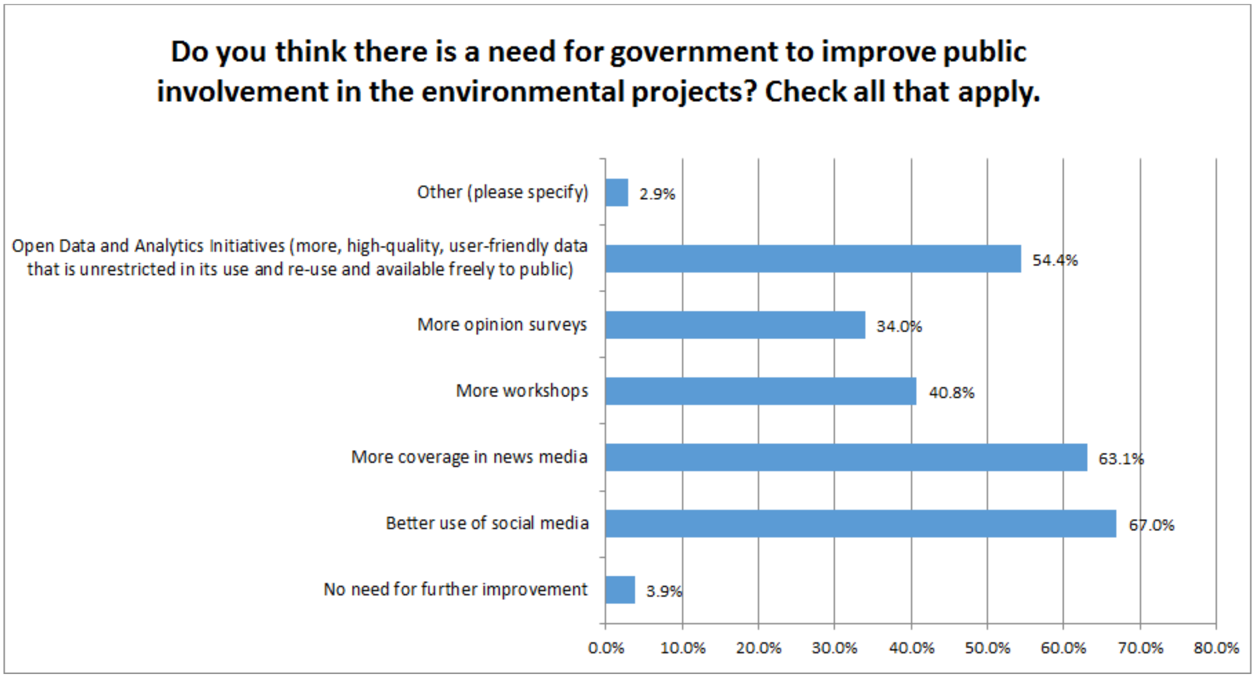
As shown in Figure 7, 60.2% of respondents reported their preference for engagement to be at public meetings followed by round table discussions (40.8%). 39.8% preferred doing volunteer work and getting involved in the decision-making process. 36.9% reported a preference for being engaged using technology, crowd sourcing, and analytics. It is interesting to note that many people still support getting directly involved through interactive public meetings. 3.0% reported they either do not want to be involved or would like to assess the impact of this project on their community before considering their level of involvement.

Figure 7: Environmental Decision-Making Process and Role of the Public



When asked about the need for the government to improve opportunities for public involvement in environmental projects and how, 96.1% reported they believe there is a need for further improvements. 67.0% supported better use of social media followed by traditional news media (63.1%). 54.4% supported using open data and analytics, 40.8% supported using more workshops, and 34.0% supported more opinion surveys. 2.9% reported other means such as advertisement outside of conventional media, more opportunity to volunteer, and getting students involved starting in their early school grades (Figure 8).

Figure 8: Advancements in Public Involvement for Environmental Projects



Discussion

In recent years, development of environmental law and policy has been going through transformation in governance models, moving from central state, top-down regulation to more transparent, local decision-making processes involving non-governmental organizations, concerned citizens, private firms and community interest groups (Abbott, 2012; Carr, Blöschl, & Loucks, 2012; Driessen, Dieperink, Laerhoven, Runhaar, & Vermeulen, 2012; Holley, Gunningham, & Shearing, 2013; Newig, 2007; Newig & Fritsch, 2009; Rauschmayer, Paavola, & Wittmer, 2009; Wesselink, Paavola, Fritsch, & Renn, 2011; Xavier, Komendantova, Jarbandhan, & Nel, 2017). However, there are still opportunities on the implemenation side where decisions regarding implementation of environmental law and policy are still top down. In the case of Randle Reef, part of the challenge seemed to be a lack of law or policy to effectively address the problem and this drove the need for an innovative, stakeholder approach.

The findings of the public survey support the need to improve public participation in environmental decision-making projects for this case study. Most respondents were not aware of the Randle Reef project, which suggests the need for a better public education and outreach program when dealing with environmental projects. The value of public engagement has been emphasized by many scholars (Dinica, 2017; Holley et al., 2013; Newig & Fritsch, 2009; Xavier et al., 2017), who argue that there is a need to involve the public through careful planning at early stages of any environmental project to realize the benefits of public participation. These benefits include public acceptance and public perception that is more in line with overall project objectives and goals. These outcomes help to encourage political support and government funding.

A significant number of people first heard about the Randle Reef Project through formal (e.g. research articles) or informal means (e.g. Friends, coworker, and class lectures), although traditional news/media services played a central role in providing information to the public. There is an opportunity to improve outreach through social and classroom based interaction (Innes & Booher, 2004), such as presentations, guest speakers, public forums, and adult learning classes. Public participation should go beyond traditional approaches by including a multi-pronged approach consisting of interactions among the public and other key players who collaboratively produce results. This could include an alternative practice framework, creating forums and avenues to provide platform for discussions, incorporating agency decision processes, and provide training and financial support to the public outreach staff (Innes & Booher, 2004).

The survey results also found that the public is often engaged at the problem identification phase, however, the level of engagement drops at other stages of the project, especially during the funding allocation phase. When it comes to providing sufficient information about the project to keep the public engaged, 25% of people reported they did not agree, while 39.3% reported they were neutral (totalling 64.3%). Given that the majority of the funding, in this case, was from taxpayers' money, it would seem reasonable to engage the public in all aspects of the sediment remediation project and to ensure sufficient detail is provided in support of the project at its various phases.

The survey results also showed that a significant number of people supported the concept that the polluter pays for the remediation costs or that government should reallocate its funding without imposing more taxes on the public, an outcome consistent with what other researchers have found (Cordato, 2001; Mahaseth, 2017). People were less likely to support any new taxes to fund the remediation programs.

The survey also revealed greater participation potential from the public in future environmental decision-making projects with a significant percentage of respondents sharing a desire to be involved in most phases of the project. People expressed an interest in being involved in public meetings, round-table discussions, and to serve as volunteers. As such, we concur with Burby (2003) that policy planners should encourage broader public involvement by directly inviting more groups to take part in the planning process and by providing opportunities for open communication in which agencies both inform and listen to concerned citizens (Burby, 2003).

Very few people were satisfied with the current level of government involvement in public engagement. Their preference would be for government agencies to invest more in social media and other innovative tools to better engage people, as also found by (Innes & Booher, 2004). People support better use of social media, more news coverage, and Open Data Analytics as methods for government agencies to engage the public. Many organizations and government agencies around the world are moving towards Open Data initiatives to empower citizens, change how government works, and improve the delivery of public services by opening data to people, researchers and others to develop their own analysis, insights, and digital products (Gurstein, 2011; Molloy, 2011; Murray-Rust, 2008). The main idea behind this approach is that faster, easier and unrestricted access to government data and analysis tools is provided to the public to support evidence-based policy, and promote greater transparency and accountability (Government of Ontario, 2017; Meijer, Conradie, & Choenni, 2014; O'Hara, 2012). The government could make the contaminated sediment remediation planning and implementation more effective by engaging the public with access to up-to-date information and data bases through an open source initiative.

Conclusions

The findings of this study verify that there is a considerable desire on the part of the public to be more engaged in the environmental decision-making process. Environmental projects are getting more complex, and the public is demanding to be more involved in nearly all stages of the decision-making process (Francis-Nishima, 2003) since the public is concerned about how and where their tax dollars are spent as well as concerns about their health and the environment. Therefore, one of the key recommendation of this study is that public engagement should become a fundamental strategy for environmental remediation projects while ensuring that the public is effectively kept informed and engaged during all stages of the decision-making process. We further recommend that the governance process involves research and investment in better methodologies and tools such as Open Data Analytics and social media that can effectively engage the public while not exclusively relying on traditional or informal approaches.

Acknowledgements

The authors wish to thank Dr. Lynda Lukasik, Director of Environment Hamilton, for her ideas and suggestions to improve the public survey responses and use of social media to promote this survey, Dr. John Eyles, Professor at McMaster University, for his invaluable advice and support on framing the public interview questions and Mr. John Hall, retired Remedial Action Plan Coordinator for Hamilton Harbour, for his role in reviewing and providing feedback on the public survey.

Chapter 3: A Comparative Analysis of Practitioners' Experience in Sediment Remediation Projects to Highlight Best Practices

A Comparative Analysis of Practitioners' Experience in Sediment Remediation Projects to Highlight Best Practices

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Abstract

The Randle Reef contaminated site, located in the southwest corner of Hamilton Harbour, is approximately 60 hectares in size. This site contains approximately 695,000 m^3 of sediment contaminated with polycyclic aromatic hydrocarbons (PAH) and metals. The complex Randle Reef sediment remediation project is finally coming to fruition after more than thirty years of study, discussion, collaborations, stakeholder consensus-building, and debate.

This paper unravels the reasons behind the delays associated with implementing sediment management at the Randle Reef site. In-depth interviews with experts and professionals from organizations who are/were involved in the project were conducted to identify the nature of performance in five theme areas that are important for successful action namely: 1) participation of appropriate actors with common objectives; 2) funding

and resources; 3) decision-making process; 4) research and technology development; and 5) public and political support.

It is evident from this study that the hurdles to progress with addressing contaminated sediment sites involve technical, political, regulatory as well as social challenges. We offer potential solutions and a series of recommendations based on experts' first-hand experience with the management of such complex sites to inform how future remediation projects can overcome obstacles.

Key Words: Hamilton Harbour Remedial Action Plan; Great Lakes Areas of Concern; Randle Reef Sediment Remediation; Sediment Management; Decision-making Process

Introduction

Sediment is an essential element of freshwater ecosystems and plays a key role in the physical movement, chemical partitioning, and biological fate of metals, trace organic pollutants, and nutrients (Zarull et al., 1999). Information on sediment quality shows that throughout North America the contaminants typically found in sediment include toxic and bioaccumulative substances, such as metals, polycyclic aromatic hydrocarbons (PAH), semi-volatile organic chemicals (SVOCs) and others (Great Lakes Water Quality Board, Water Quality Programs Committee, Sediment Subcommittee, Assessment Work Group, & International Joint Commission, 1988; United States Environmental Protection Agency, 2005).

Contaminated sediment continues to be a significant environmental problem that impairs the use of many waterbodies (Palermo, Hinchee, Porta, & Pellei, 2001). Within the United States, the Superfund program uses its Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority, in collaboration with other Environmental Protection Agency (EPA) programs and authorities, to clean up sediment sites that pose undesirable risks to human health and ecological systems (United States Environmental Protection Agency, 2017b). As of September 2015, the Superfund program has supported the selection of remedial options at 71 contaminated sediment sites, where the chosen remedial option addressed more than 10,000 cubic yards of contaminated sediment (United States Environmental Protection Agency, 2017c). The degree of the contaminated sediment issue in the United States is massive in both its logistical scope and the overall projected costs of remediation (Palermo et al., 2001). Contaminated sediment is a significant concern for the following reasons (Burton

Jr, 2002; Ehlers & Luthy, 2003; Environment Canada & Ministry of the Environment and Climate Change, 2008; Förstner & Salomons, 2010; Heise & Förstner, 2006; MacDonald, Ingersoll, & Berger, 2000; Taylor & Owens, 2009; United States Environmental Protection Agency, 2017a):

- Exposure to contaminated sediments can result in decreased survival, reduced growth, or impaired reproduction in benthic invertebrates and fish.
- The bioavailability of contaminants in surficial sediment and contaminants released into the pore water and water column through biotic and abiotic processes in the sediment layer provides an opportunity for bioaccumulation. Once transferred to biota, contaminants may accumulate (bioaccumulate) if no mechanism exists for their elimination and may exert negative effects on the organism if concentrations reach toxic levels. As some organic chemicals (e.g. methyl mercury; dichloro-diphenyl-trichloroethane (DDT); polychlorinated biphenyls (PCBs); 2,3,7,8 Tetrachlorodibenzo-p-dioxin (TCDD)) move up the food chain through three or more trophic levels, increases in concentrations occurs for each level, such that biomagnification can occur.
- There could be scenarios where human health concerns can be linked to dermal contact with contaminated sediment (e.g. swimming), or through the consumption of fish with high levels of contaminants that do not biomagnify (e.g. PAH, lead (Pb), cadmium (Cd)). Additionally, human exposure to contaminants may result in absorption across the gut wall, the skin, and the lining of the lungs resulting in potential risk to human health.

While contaminated sediment does not represent a specific-use impairment under the Great Lakes Water Quality Agreement (Governments of Canada and the United States, 2012), a variety of beneficial use impairments have been documented in association with contaminated sediments. For example, fish consumption advisories have negatively impacted commercial and food fisheries in many areas (Burton Jr, 2002; Förstner & Salomons, 2010; Heise & Förstner, 2006; MacDonald et al., 2000; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Taylor & Owens, 2009; Zarull et al., 1999).

Contaminated sediment also threatens the viability of many commercial ports through the imposition of restrictions on dredging of navigational channels and disposal of dredged materials. Sometimes there are restrictions put in place for ship movement, as has happened in Hamilton Harbour (Burton Jr, 2002; Förstner & Salomons, 2010; Heise & Förstner, 2006; MacDonald et al., 2000; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Taylor & Owens, 2009; Zarull et al., 1999).

In the Great Lakes basin, for example, sediment quality issues and concerns were identified in 42 out of the 43 areas of concern (AOCs) that have been identified under the Canada-US GLWQA (Governments of Canada and the United States, 2012). In August 2017, an update related to Canadian AOCs status was provided by the Manager of Great Lakes Areas of Concern, Environment Canada as follows:

"In terms of the status of contaminated sediments remaining unmanaged in Areas of Concern, I can only speak to the remaining Canadian AOCs. From the information- I have available, Nipigon Bay and Severn Sound are the only AOCs that do not have contaminated sediments. Contaminated sediment management plans are in place or being implemented in all of the other Canadian AOCs except for the Canadian portions of the St. Marys River and St. Clair River and Port Hope Harbour where plans are either being developed or awaiting implementation."

This matter is not limited to the Great Lakes. For example, such issues and concerns have been identified in nineteen areas within the Sado Estuary, on the west coast of Portugal (Caeiro et al., 2009). Similar problems have also emerged in 31 regions of China (Li et al., 2017), at Lake Ketelmeer in the Netherlands (Jonker & Smedes, 2000), and in Naples Harbour in Southern Italy (Sprovieri et al., 2007). Sediment contaminated with metals is also a concern in Kaohsiung Harbor, Taiwan (Chen, Kao, Chen, & Dong, 2007); Toulon Bay, France (Tessier et al., 2011); Sydney Harbour, Australia (McCready, Birch, & Long, 2006); and Thermaikos Gulf, Northern Greece (Christophoridis, Dedepsidis, & Fytianos, 2009).

Numerous organizations and governments are working towards the development of policies and technical guidance documents to better address the challenges associated with contaminated sediment management (Förstner & Salomons, 2010; Zarull et al., 1999). For instance, quality of sediment is addressed in the United States by several state and federal programs and regulations, including the National Environmental Policy Act; the Clean Water Act; the Marine Protection, Research, and Sanctuaries Act; and the CERCLA (National Research Council, 2001; United States Environmental Protection Agency, 2017b). Within the European Union, the Water Framework Directive (WFD) contains far-reaching provisions intended to secure and manage water resources, and largely by implication, sediment, at the river basin scale (Brils, 2008; Brils & de Deckere, 2003; J Brooke, 2004; Jan Brooke, 2004; M. Crane, 2003; Demetropoulou et al., 2010).

Within Canada, the 2007 Canada-Ontario Decision Making Framework for Assessment of Great Lakes Contaminated Sediment uses an ecosystem-based approach to assess sediment and considers possible effects on benthic and other aquatic organisms, including the potential for contaminants to biomagnify up the food chain (Environment Canada & Ministry of the Environment and Climate Change, 2008). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000 Guidelines) provide guidance on fresh and marine water quality management issues including sediment quality information in both New Zealand and Australia (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000). The ANZECC 2000 guidelines were revised to integrate multiple lines of evidence in a weight-of-evidence framework to be used in decision-making in cases where the results from chemistry and toxicity testing are ambiguous. This highlights some of the latest developments in international approaches to sediment quality assessment (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, 2000).

Great Lakes Contamination and Randle Reef Sediment Remediation Project

The Great Lakes Remedial Action Plan (RAP) process was designed to address contamination in the most highly polluted rivers and bays around the Great Lakes. These AOCs are the areas where the water quality and ecosystem health have been severely damaged by industrial, agriculture and human activities (Environment Canada, 2017). Under the Great Lakes Water Quality Agreement of 1987, AOCs in Canada and the United States were formally identified (Governments of Canada and the United States, 1987). Of the 43 original AOCs in Canada and the United States, twenty-six are in the U.S., 12 are located in Canada, and five are bi-national because they border both countries. Each AOC has developed a RAP to restore the beneficial uses in the Great Lakes (Environment Canada, 2017). To date, seven AOCs have been 'delisted' – meaning that all of the impaired beneficial uses have been restored - and two have been designated to be in recovery status (International Joint Commission, 2017).

Historically, the waters of the Great Lakes have been adversely affected by industrial and agricultural activities (T. Crane, 2012; Government of Canada and the United States Environmental Protection Agency, 1995). There is agreement among various sectors in the Great Lakes Basin that contaminated sediment is a major environmental problem and the main cause of many of the impairments of beneficial uses within the Great Lakes (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). Hamilton Harbour, also known as Burlington Bay, lies at the western tip of Lake Ontario and is separated naturally from the lake by a sandbar. In 1985, the Ontario Ministry of the Environment and Climate Change (MOECC) formally identified the water quality issues in the Hamilton Harbour (an AOC in Hamilton, Ontario) resulting in the need for a sediment remediation project at the Randle Reef site (Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2016; Hall & O'Connor, 2012). In 1987, Hamilton Harbour was formally designated as AOC. The RAP for Hamilton Harbour identified three high priority sites in 1992 (Randle Reef, the Ottawa street boat slip, the Dofasco boat slip) that required active intervention due to acute toxicity at the site (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992). Subsequently, further investigation indicated that the Ottawa St. boat slip was not severely contaminated

(Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992). Of the two remaining, the Randle Reef area is a project between Stelco and government while the Dofasco boat slip is a private project of ArcelorMittal Dofasco. Randle Reef is the larger of these two projects, with approximately 695,000 m^3 of contaminated sediment located at the southwest corner of Hamilton Harbour (Bay Area Restoration Council, 2017; Milani & Grapentine, 2016). The Randle Reef site is approximately 60 hectares, which is equivalent to 120 football fields, in size (Graham, 2011; Hall & O'Connor, 2016; Hall & O'Connor, 2012; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). Randle Reef sediment contains PAHs in very high concentrations in coal tar (Hall & O'Connor, 2016; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). The PAH concentration exceeded 800 parts per million in some sediment cores (Environment Canada, 2010; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). Levels of many metals (especially iron) in the Randle Reef sediment exceed MOECC “severe effect levels”, and detectable levels of PCBs, dioxins and furans and organochlorines are present (Environment Canada, 2010; Environment Canada & Ministry of the Environment and Climate Change, 2008; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012).

The remediation plan involves the construction of a 6.2 hectare Engineered Containment Facility (ECF) over 140,000 m^3 of the most highly contaminated sediment. Approximately 445,000 m^3 of contaminated sediment surrounding the ECF will be dredged and placed inside the facility for a total containment of 585,000 m^3. Another 110,000 m^3 of less contaminated sediment will be capped using both thin layer capping and isolation capping techniques, for a total of 695,000 m^3 of sediment being managed (Bay Area Restoration

Council, 2017). Remediation of the site began in 2016, is currently underway and is expected to be completed by 2022 (Graham et al., 2017).

The estimated cost of this remediation project is approximately $139million. The federal and provincial government have agreed to provide $46.3-million each, with the expectation that the community contributes the remaining amount. The City of Hamilton is contributing approximately $14-million, Stelco is also contributing $14-million and the Hamilton Port Authority is contributing $14-million. The City of Burlington has agreed to contribute $2.3-million while Halton Region will provide $2-million for the remediation of the Randle Reef site (Bay Area Restoration Council, 2017).

Research Objectives

Remediation of contaminated sediment in the Great Lakes can take many years – in some cases more than 15 years - from the problem identification to actual implementation of remedial actions (Zarull et al., 2001). Such long delays are of significant concern, since the ecological and economic damages associated with contaminated sediment continue, sometimes irreversible (Zarull et al., 2001).

For the Randle Reef site, it took more than 30 years from the time the contamination problem was formally identified until the remediation would be initiated (Hall & O'Connor, 2016). To understand what contributed to the long process before active intervention began, the key themes were investigated that are frequently identified as obstacles when dealing with remediation of contaminated sediment sites as follows (Beierle & Konisky, 1999; Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2016; Hall & O'Connor, 2012; Jawed & Krantzberg, 2017a; Krantzberg, 2003; Renn & Finson, 1991; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Zarull et al., 2001; Zarull et al., 1999):

1)participation of appropriate actors with common objectives;

2)funding and resources;

3)decision-making process;

4)research and technology development;

5)public and political support.

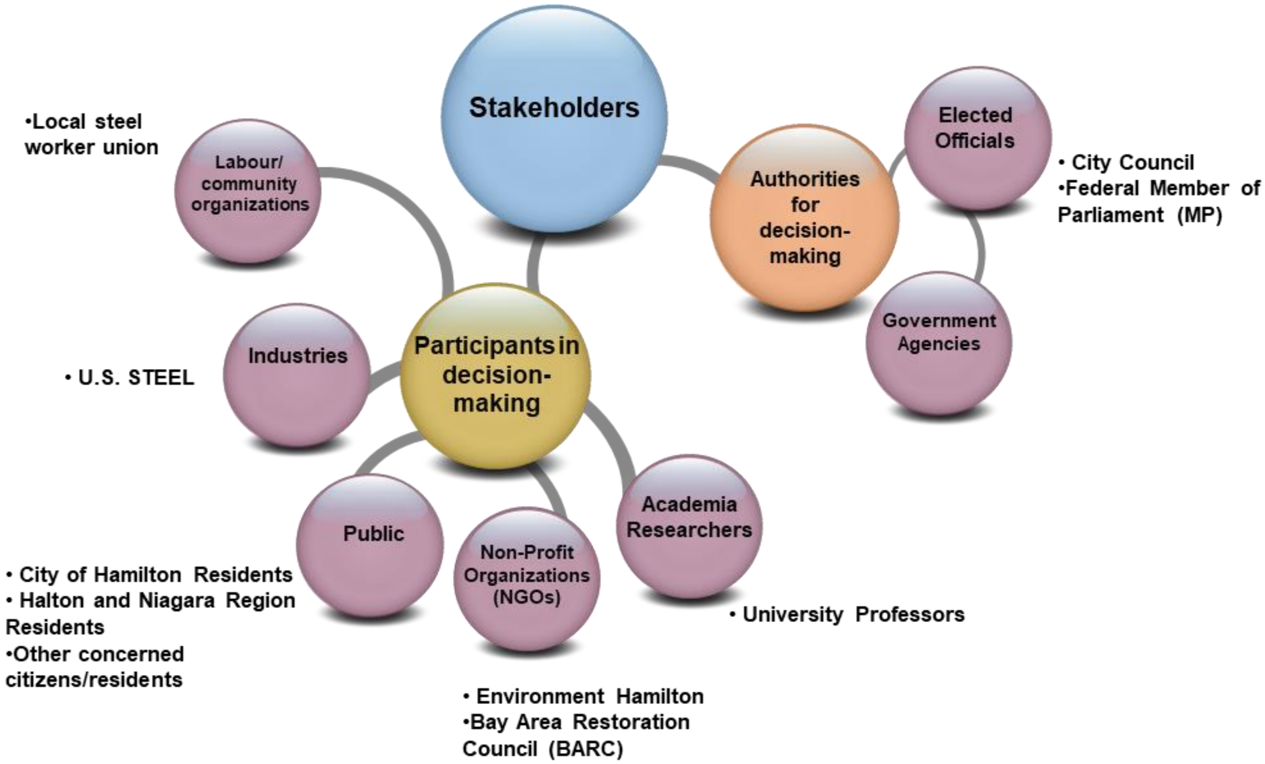
This research paper aims to understand how well the above themes were addressed in the Randle Reef sediment remediation project. For this purpose, in-depth interviews were conducted with experts and professionals from organizations and agencies who had first-hand knowledge of the Randle Reef sediment remediation project.

Design and Conduct of Expert Interviews

The sample group for this study was selected based on the direct and indirect involvement of a range of stakeholders in the Randle Reef remediation project. There were two different groups of stakeholders; the ones who were authorities in decision-making such as government agencies and elected officials and the ones who were participants in decision making such as industries, academic researchers, non-government organizations (NGOs) and the public.

In this study, in-depth interviews were conducted using an adapted version of the steps from '*A Guide for Designing and Conducting In-depth Interviews for Evaluation Input'* (Boyce & Neale, 2006). The interview sample size was limited with most of the sample (stakeholders) being those who played a significant role in the overall project. Therefore, a typical random sampling technique cannot be employed in this situation as inputs from these specific stakeholders were required. Instead, a stratified non-probability sampling technique was used to gain input from key project stakeholders who were directly or indirectly involved in this project or who were referred by other stakeholders as being a person or agency of significance (Figure 1).

Figure 1: Sample Frame and Selection Method



A formal letter was used to contact the stakeholders. Structured interview questions were designed, and all the stakeholders were asked consistent questions to ensure that data were coded, analyzed and compared properly. Audio-recorded or written interview responses were collected with consent from the stakeholders and transcribed accordingly (McLellan, MacQueen, & Neidig, 2003). These are verbatim transcriptions without any grammatical corrections. This was done to ensure there are no biases or new information introduced as a result of any editing. The questions that were posed to stakeholders were broken down ito five different themes as identified in the research objective. The names of stakeholders and/or organizations were not disclosed to encourage interviewees to provide accurate accounts of their experiences without any risk of being identified. Therefore, in this paper, each stakeholder is given a number ranging from agency 1 to 17, without disclosing their real names or positions within their organization.

Results and Discussion

Participation of Appropriate Actors with Common Objectives

The RAP program under the Great Lakes Water Quality Agreement is an initiative that requires the governments of Canada and the United States to develop and implement plans that address the problems in each of the AOC (Governments of Canada and the United States, 1987). When an area is designated as an AOC, the Great Lakes Water Quality Agreement requires RAPs to be developed in three stages (Governments of Canada and the United States, 1987) as follows:

Table 1: Remedial Action Plan Stages for the Hamilton Harbour (HHRAP)

Stage #	Title of Stage	Brief description of Stage
Stage 1	Environmental conditions and problem definition	This stage outlines the starting point for the AOC and identifies local Beneficial Use Impairments Stage 1 was completed in 1989 with a second edition produced in 1992
Stage 2	Goal, Options and Recommendations	This stage defines the remedial actions to clean up the AOC Stage 2 was completed in 1992, with an update in 2002

Stage 3	Evaluation of remedial measures and confirmation of restoration of uses	This stage allows for the designation of AOC to be removed once the beneficial uses are shown to be restored. Stage 3 will require long term monitoring information to show that beneficial uses are restored to make a case to the Federal government for delisting Hamilton Harbour as an AOC.

The process to develop the Hamilton Harbour Remedial Action Plan (HHRAP) was unique for its time. It employed a third-party facilitator with the government, scientists, and citizens who all participated at the same table and are referred as “Stakeholders.” A scientific Writing Team prepared reports on defining the problem, “Stage 1” (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1989), as well as developing the plan for remediation, “Stage 2” (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992) (Table 1).

With the submission of the Stage 2 report to governments, the institutional structure included the formation of the Bay Area Restoration Council (BARC) and Bay Area Implementation Team (BAIT). The BAIT is mandated to implement the remedial actions while BARC is mandated to monitor and promote RAP progress and report on action and inaction (Bay Area Restoration Council, 2017). BARC plays a critical role in engaging the community in the HHRAP, including raising awareness and engaging people in the Randle Reef remediation.

After a science-based proposal to incinerate 20,000 m^3 of the highest concentrations of PAH contaminated Randle Reef sediment at Stelco’s sintering plant was rejected by the community, a project advisory group (PAG) was formed in October 2001 (Hall & O'Connor, 2012). The goal of this group was to reach consensus on a final design and implementation of the Randle Reef cleanup. The PAG had representatives from 17 participating organizations and included scientists, citizens, consultants and government representatives (Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). The PAG recommended that a significantly higher volume of up to 675,000 m^3 of contaminated sediment be remediated. This increase in volume was deemed unfeasible for the incineration option and shifted the goal from the destruction of PAHs to the prevention of their impact on Hamilton Harbour. Afterward, when asked to choose between destroying the PAHs, removal of sediment, or containment within the Harbour, the consensus-based stakeholders eventually chose containment (Hall & O'Connor, 2016).

For this research paper, in-depth interviews were conducted with the selected stakeholders for the Randle Reef sediment remediation project regarding the leadership role for this project. 18% felt that the leadership role was not well-defined and another 29% of respondents stated they neither agree nor disagree that the leadership role was well-defined (Figure 2). Agency 7 did not agree that the leadership role was well-defined and stated that

"up until 2009 Hamilton Port Authority (HPA) was the lead for the project. In 2009, the HPA withdrew from that role as they believed the potential financial liabilities were beyond their capacity. After that it took about three years to negotiate the lead role with the project stakeholders/funding partners. As it is unusual for the federal government to lead a project on non-federal land as it was a protracted process for the federal government to confirm its leadership role on the project."

Agency 4 took a neutral stand and stated that "leadership shifted over time which is not unusual with a project of this magnitude. Sometimes, group members assumed leadership stances and pressed hard for a decision. Ultimately, the federal government fully took on the lead role. There was a strong Federal push to achieve 100 percent consensus among all the players which is a laudable goal. Unfortunately, this consensus goal was noticed by one of the key stakeholders and was used as a delay tool undermining the progress of the project."

It is also important to note that 41% of the stakeholders did believe that the leadership role was well-defined (Figure 2). An additional 12% strongly believed so. Agency 17 agreed that the leadership role was clearly defined and stated that "leadership was with Environment Canada from the beginning and followed right through the end and they are still part of this leadership role."

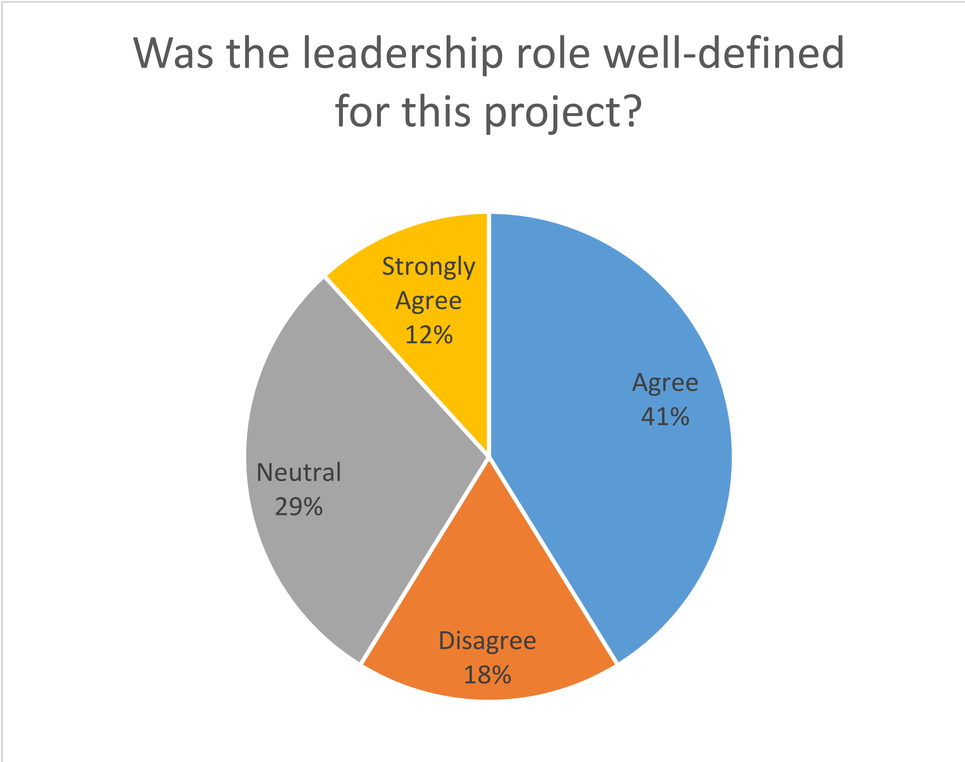
Upon analyzing the detailed transcription of the interview responses, we conclude that the answer to this question varied depending on the stage of the project. Currently, the project is in the implementation phase, and there is a consensus that the leadership role at this stage is well-defined. However, during the early stages such as the problem identification phase, not many agencies believed there was a clear leadership role. For example, Agency 2 stated that the

"leadership role changed over the course of the project. In terms of today, leadership role is fairly-well established… If you look in the past, I would disagree that there was a strong leadership role."

Few agencies believed that there was one strong leadership role throughout all the stages of this remediation project, as the level of leadership varied depending upon the stage of the project.

According to many scholars, remediation projects progress efficiently through effective stakeholder cooperation, collaboration and leadership (Bridges et al., 2006; Krantzberg, 2003; Luyet et al., 2012). We concur with this finding and suggest the lack of strong and effective leadership role, at least at the beginning, in the Randle Reef remediation project was one of the contributors to the delays in option selection and implementation. This is consistent with the observations of others who maintain that sediment remediation has struggled with strong and effective leadership in stakeholder management such as participant interaction and influence on decision-making (Gerrits & Edelenbos, 2004; Oen et al., 2010; Slob, Ellen, & Gerrits, 2008; Stem & Fineberg, 1996; Syme & Sadler, 1994; Voinov & Bousquet, 2010).

Figure 2: Leading Role for the Randle Reef Sediment Remediation Project



<u>Funding and Resources</u>

Funding constraints have been an obstacle to progress reported by a number of authors dealing with sediment remediation projects in North America (Beierle & Konisky, 1999; Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2012; Krantzberg, 2003; Renn & Finson, 1991; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Zarull et al., 1999). For many RAPs, securing the funding is often one of the single most important goals associated with RAP implementation (Zarull et al., 1999). In the United States, almost all the sediment remediation completed to date has been funded because of enforcement actions taken against polluters. The Superfund program has been responsible for funding most of the sediment remediation carried out in the United States (such as Bailey Waste Disposal, Texas; Batavia Landfill, New York; Sheboygan River and Harbour, Wisconsin; Love Canal, New York). However, enforcement actions are critical and have been successful under other regulatory authorities (example - Black River, Ohio) (McGrath, 1995; United States Environmental Protection Agency, 2017b, 2017c; Zarull et al., 1999). In Canada, there are no Superfund type funding program available and there are regulatory challenges to enforce remediation in legacy contaminated sediment sites. For example: there were initial attempts to apply the Federal Fisheries Act in the Randle Reef case. However, the government didn't feel that this one was a current discharge – it was a legacy problem – so they argued it didn't fit the 'discharge of a deleterious substance' category. Therefore, securing the funding on a voluntary basis with no legislative backing is particularly problematic and time consuming within the RAP process as evident in the Randle Reef case.

For the Randle Reef sediment remediation project, 12% of stakeholders disagreed, and an additional 18% strongly disagreed that the funding arrangement for this remediation project and distribution of costs among stakeholders was fair and/or equitable (Figure 3). For example, Agency 3 disagreed about fair and equitable funding contribution by all partners stating that

"province and federal governments invested heavily; I don't believe industry contributed their fair share."

Additionally, those who did not agree with the funding agreement suggested that the polluter pay approach would have been a better option if there was any legislative ability to seek cleanup dollars from the polluter. According to Agency 10, "original polluter was not held accountable. There was a dynamic there that you couldn't point fingers and say that you were accountable."

Agency 12 said that

"Federal, Provincial had the largest contribution and other stakeholders with smaller contribution; polluter pay approach would skew this little bit."

Another point raised by Agency 14 was that

"Steel company wasn't paying in proportion to their liability."

It is interesting though that 23% of the stakeholders agreed and an additional 38% strongly agreed that the funding arrangement and distribution among various agencies were fair and/or equitable (Figure 3). For example, Agency 2 strongly believed in the funding arrangement and stated

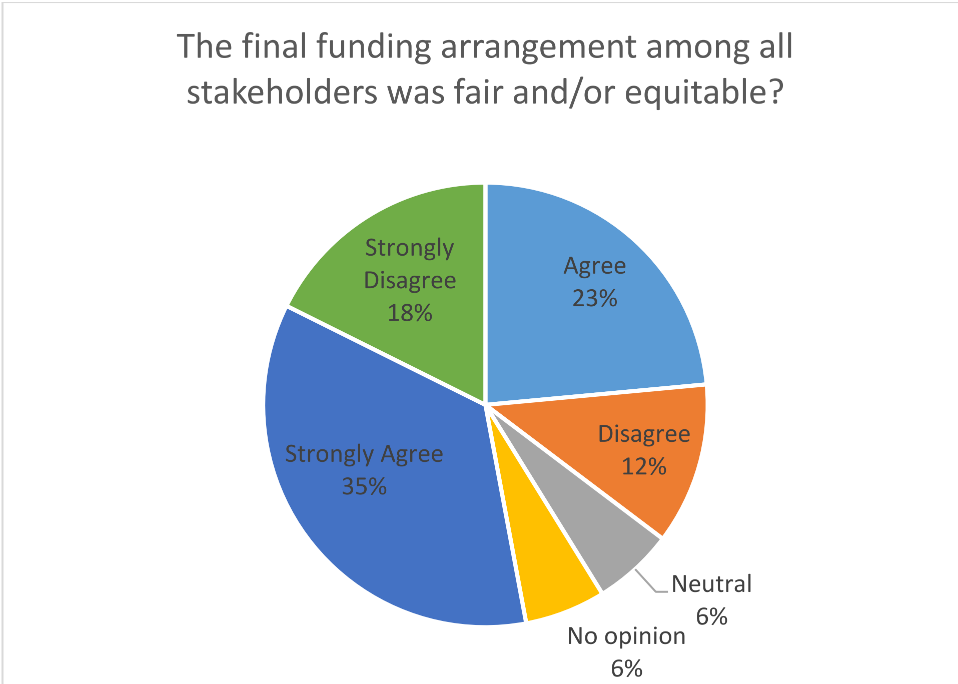
"in broad terms, the funding was based on Federal, Provincial and community (1/3rd contribution by each level of government). Within the community, the funding was negotiated fairly and everyone came to the table."

According to Agency 5, there was a long delay in securing the funding from all partners.

"It took six years to negotiate just with the local community, one-third contribution, which was by far the main reason for the slow development of the project."

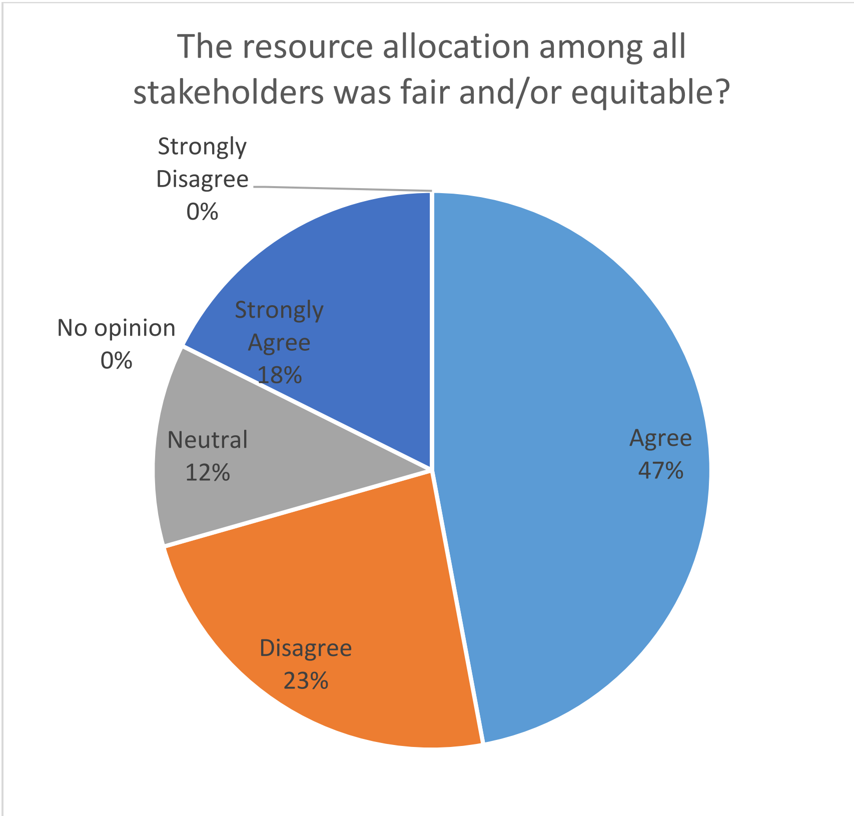
This shows that, notwithstanding the fact that about half of the Agencies believed in the funding formula, the negotiation of the funding was very challenging and time-consuming for this project.

Figure 3: Funding Arrangements and Distribution for the Randle Reef Sediment Remediation Project



A majority of stakeholders (65%) agreed that the resource allocation (such as in-kind support, staff time, etc.) among stakeholders/ organizations was fair and/or equitable, while 23% did not agree that the resources were properly allocated (Figure 4).

Figure 4: Resource Requirement and Distribution for the Randle Reef Sediment Remediation Project



Decision-making Process

There are significant economic, ecological, and social issues that are involved in addressing the contaminated sediment problem (Read et al., 2014; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Zarull et al., 1999). Management of contaminated sediment has become progressively resource intensive, with some projects costing anywhere from tens of millions to over a billion dollars (e.g., project costs for each of the Fox and Hudson River cleanup projects in the United States are pushing $1 billion). Further, many of these remediation projects also progress at a slow rate (Bridges & Gustavson, 2014; Bridges, Nadeau, & McCulloch, 2012; United States Environmental Protection Agency, 2017b; Zarull et al., 1999). For example, in

1997, the National Research Council (NRC) presented six case studies where there was a significant time lag between the identification of a problem and implementation of a solution (National Research Council, Committee on Contaminated Marine Sediments, Marine Board, & Commission on Engineering and Technical Systems, 1997). These time periods ranged from eight years (Hart and Miller Islands) to 20 years or more (e.g., Boston Harbor, Waukegan Harbor) (National Research Council et al., 1997).

For the Randle Reef sediment remediation project, it took more than 30 years from the time the problem was formally identified until the site remediation would be initiated: an ECF is in the construction stages and will take an additional seven years to complete followed by 15 years of monitoring (Bay Area Restoration Council, 2017). The process to arrive at a final remediation plan for this site had many phases as described above, and it is interesting to note that while some agencies acknowledged there were delays, others did not believe that there were delays associated with this project.

Agency 8 provided a well-written account explaining factors behind several delays throughout the project, some of which were reported as quite normal for a complex undertaking of this kind that has relatively little precedent. Some of the reasons provided by Agency 8 related to the “normal” delays are as follows (written response quoted below):

“1) Basic science questions: How bad is the problem (both geographically and contaminant levels) needed to be gently studied to avoid disturbing the slow-motion blobs from being disturbed and making a bad situation worse. Pollution concentration contours were eventually mapped during fair weather conditions.

2) Technology questions: What are the best practices (e.g. Sydney Steel in NS or Wisconsin cases)? How to remove sediment and decant contaminated water? Should the contaminant be removed and incinerated? Should the contaminant be contained and dealt with at a future date 100 years out?

3) Environmental Ethics: Does Hamilton have the right to transfer its contamination to another municipality's dump and air and watersheds?

4) Design of Remediation: It took a very long time and involved many scientists and engineers.

5) Cost Estimates: It took a lot of time and escalated over the decade plus long process.

6) Funding Partner Identification and Business Case Prep: As the project cost escalated way above the initial $70 million, there was a need to ask a lot of questions. Several partners took a lot of time to identify co-funders and their share."

Agency 8 also highlighted some of the unexpected delays which included (written response quoted below):

"1) Stelco was a key stakeholder. The Board replaced a skilled environmental staff person with a senior corporate lawyer. The lawyer appeared very knowledgeable and cooperative at first but it soon became clear that the Stelco Board had many other issues to deal with. In retrospect, it felt that Stelco's main goal at that time was to delay the process and perpetually deny any responsibility for the coal tar spill (situated near its sewer outfall and seawall). Every minute detail and process was questioned by Stelco seemingly at every meeting. This hard-corporate approach delayed the process significantly. Libel chill was in the air so people proceeded cautiously. Stelco did not accept any uncertainty in this unique project. The collision between Stelco's corporate approach and the RAP's collaborative approach ultimately caused delays.

2) There was a proposal for Stelco to burn the coal tar PAH's in their sintering plant as part of their contribution to resolving the contamination. The preliminary project was abandoned after the labour union strongly questioned the health and safety implications for its workers. This represented another setback.

3) Stelco at one point was to be a supplier for the pilings for the containment structure, but ultimately Stelco ran into severe financial difficulties and eventually went bankrupt.

4) As with any longer-term project, leadership changed although the core staff is constant throughout. Huge cost escalations occurred over time."

Agency 4 mentioned that the delays occurred because the "decisions were made with not all stakeholders at the table. For example, in an earlier proposal, the Stelco sintering plant was to be used to incinerate the contamination, but this was rejected when the Stelco Union Local 1005 objected. They were not part of the stakeholder group at that time. Another delay occurred when the cost of the project was underestimated." Agency 3 also believed that the delay occurred due to "the landscape kept changing because industry continued to put new options forward and Environment Canada agreed to include them in the Environmental Assessment, delaying the decision by years. Once there was a decision, the delays surrounding securing the local funding."

Agency 5 pointed out that there was

"no real driver to push the funding agenda. Too many separate silos, no collective approach".

Agency 7 said,

"the establishment of the stakeholder Project Advisory Group (PAG) in 2001 enabled an alternative, acceptable to the community, to be identified fairly quickly (2003). The 95% engineering design was done by 2008. It could have done more quickly if more funds were available but they were not. Canada and Ontario each committed to fund one-third of the project cost in 2007. It took six years to negotiate the local community, one-third contribution, which was by far the main reason for the slow development of the project."

Yet, there were agencies who believed that there were no delays and this is the normal timeline for sediment remediation project. For example, Agency 2 said,

"there are multiple funding partners to negotiate all the details. It is not really a delay but it is the amount of time it takes multiple parties to work together."

Agency 6 also shared the same opinion and said,

"as a multi-partnered project operating within a very public community-based Remedial Action Plan (RAP) process, much of the effort involved consultations and agreement with a multitude of groups. It takes time to organize large groups meetings where you are sure to have full attendance, especially when decisions are being made. Being a partnered project also meant having consensus on all major elements of the project. Engineering design of the ECF involved detailed reviews of numerous design elements that often resulted in delays on both the part of the Steering and Technical committee, as well as the consultant. With such a large and complex contamination project, there are many opportunities to encounter delays throughout the many components of the project. Studies have shown that fast sediment projects take 15 years, the average project takes 20 years. The Randle Reef project has taken 30 plus years, largely due to the scale and scope of the project and the various stakeholder interests on the project and within the context of the RAP process. It is more important to get the project right, rather than be driven by a timeline."

It is concluded that there were substantial differences in opinion about the causes of the delays with the Randle Reef project. Several agencies reported that there were no delays but rather a multi-partnered project which involved a complex negotiation process that took due time to finalize. Nevertheless, the fact remains there that the Randle Reef cleanup took more than 30 years to initiate.

Research and Technology

In the United States, complex contaminated sediment sites pose difficult technical and policy challenges (Harclerode, Macbeth, Miller, Gurr, & Myers, 2016; United States Environmental Protection Agency, 2005; Zarull, Hartig, & Krantzberg, 2002; Zarull et al., 1999), which have resulted in the slow pace of sediment remediation (Price, Spreng, Hawley, & Deeb, 2017; United States Environmental Protection Agency, 2017c).

As part of the management of contaminated sites, it is essential that the risk of harm from any potential contaminants be identified and assessed before remediation is deemed warranted and the methods for remediation are selected. Managing these identified risks involves both detailed and careful consideration of a complex set of physical, chemical, biological and socio-economical processes. This is because there exist large uncertainties related to these processes that could make it harder to accurately predict the future performance of remedies (Bridges & Gustavson, 2014). Much of the difficulty in addressing contaminated sediment sites stems from challenges associated with the uncertainties, and a systematic approach to addressing uncertainty would enable the project to make progress and achieve its risk management goals (Bridges et al., 2006; Bridges et al., 2012; Price et al., 2017).

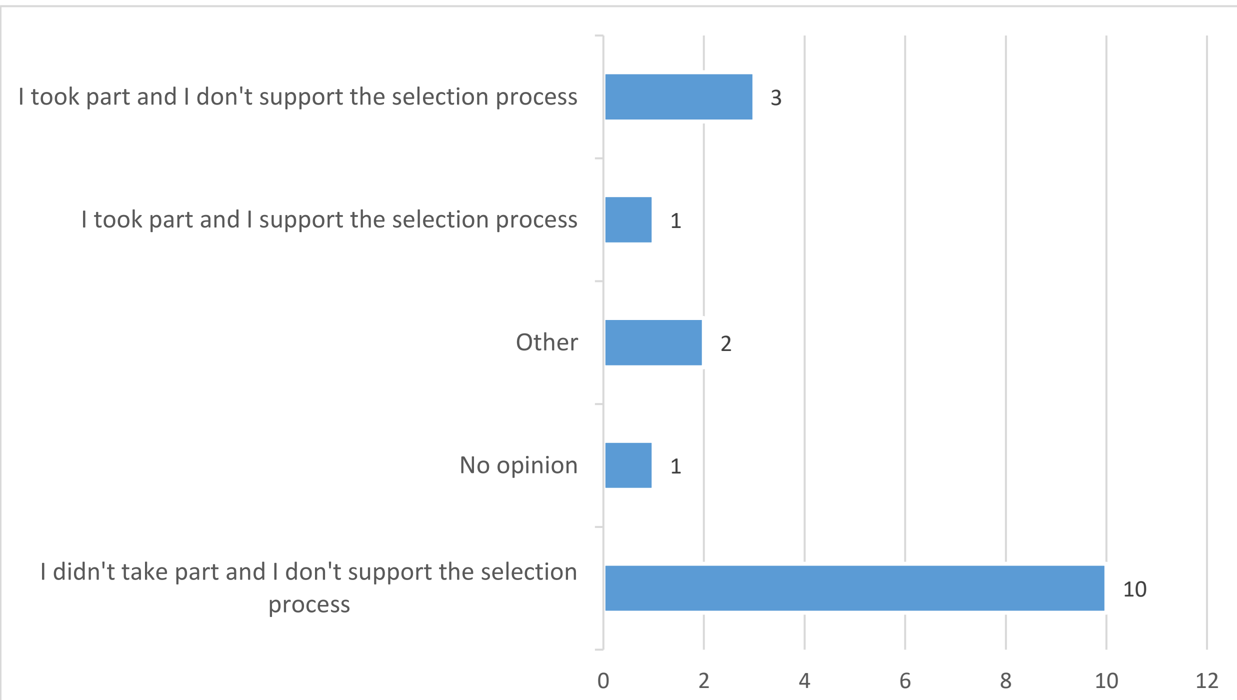
The Randle Reef project was no different when it comes to slow pace of sediment remediation at the site. Two separate decision-making processes occurred to select a remediation option for the site. The first decision-making processes took place in 1990, when the sintering plant option was chosen and then rejected due to risks to local air quality and concerns about public health (Hall & O'Connor, 2016). In April 2002, after careful consideration of the advantages and disadvantages of each of the remediation options, the PAG recommended the in-situ containment and construction of the ECF option as the preferred remediation approach (Hall & O'Connor, 2016; Hall & O'Connor, 2012).

It is found that only four of the seventeen stakeholders took part in the selection process when the sintering plant option was selected and only one of these four supported the decision-making process. Ten stakeholders did not participate in the selection process and did not support the selection process. Agency 6 mentioned that

“the sinter plant option was the result of a comprehensive study report. I was asked to lead the sinter plant project and was not part of the selection process. $5 million was announced by Environment Canada in support of this project which was intended to capture the worst of the contamination. I believe the selection process involved the RAP and BARC organizations, but not the broader public (i.e. community citizen groups). I was involved in the development of the project to the Environmental Assessment stage. It was rejected by Stelco Union, and we then solicited a broader public/agency review of options (PAG) that lead to the current project."

A majority of stakeholders did not support the selection process for the sintering plant option. Given its unpopularity among a clear majority of stakeholders, the sintering plant option should have been eliminated from further consideration at an earlier stage while evaluating other options, therefore avoiding unnecessary project delays. However, this was not the case and it resulted in significant delays regarding selection of alternatives.

Figure 5: Selection Process to reach the decision of Sintering Plant



"Other" included: I was not involved till a later date or un-specified reasons

When the experts were interviewed for the second decision-making process around the selection of the ECF, nine out of seventeen stakeholders took part in the selection process, and they all supported the process to reach the final decision. Agency 17 mentioned that "selection process involved all stakeholders at one table, and all equally contributed towards consensus. There were some who did not agree with the decision, and there was one stakeholder who walked away from the table. Another person replaced the person. But the vast majority of stakeholders approved the recommendations for the ECF."

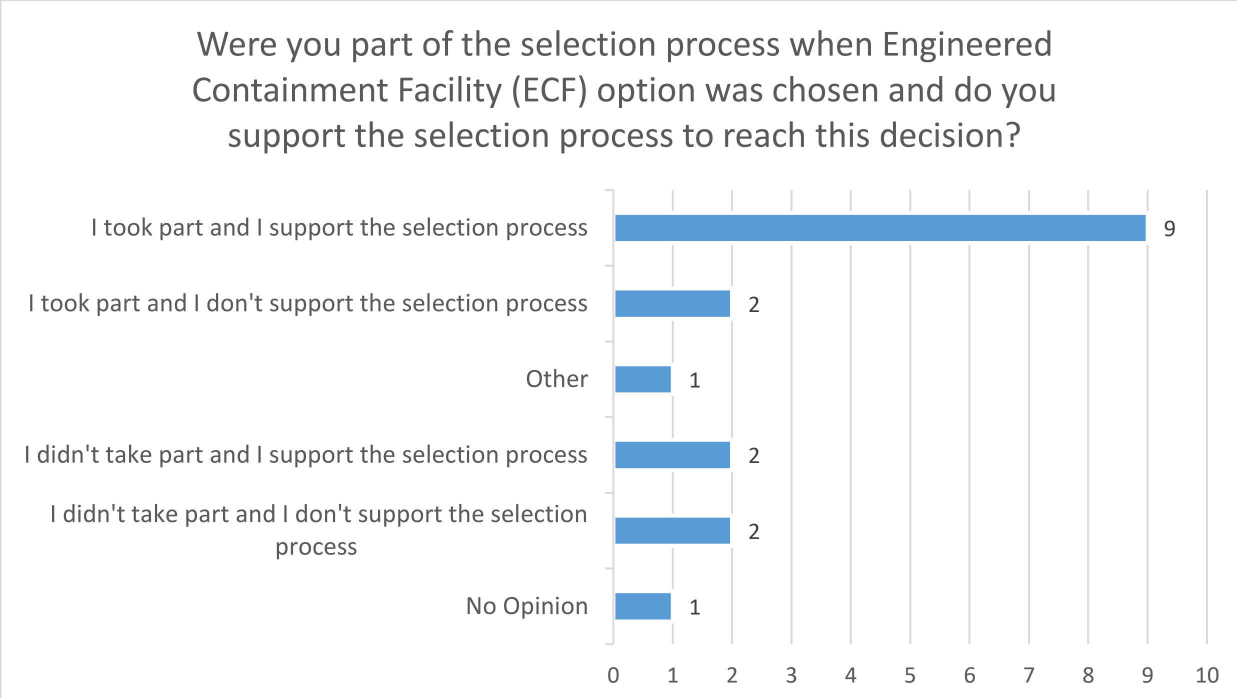
Overall, four out of seventeen stakeholders did not support the selection process to reach the final decision (Figure 6). Agency 10 did not support the selection process and mentioned that

"more openness and transparency would help. As a participant, we noticed that everything shifted gears and it still not clear what made the shift from complete removal to a new selected method."

Agency 14 shared similar thoughts and stated that

"because there were better alternatives dealing with sediments instead of burying it. We could have work on this project incrementally from the worst sites."

Figure 6: Selection Process to reach Engineered Containment Facility Decision



“Other” included: I was not involved till a later date or un-specified reasons

When the experts were questioned about their support for the ECF, 70% of stakeholders supported the use of this technology at the Randle Reef site (Figure 7). The remediation project will involve constructing a 6.2-hectare facility covering the most contaminated sediment, then dredging and placing the remaining less toxic sediment within the facility covered by a multi-layered environmental cap. The facility will be made of double steel sheet pile walls with the outer walls being driven to depths of up to 24 metres into the underlying sediment (Bay Area Restoration Council, 2017).

Agency 4 supported the use of an ECF and mentioned that

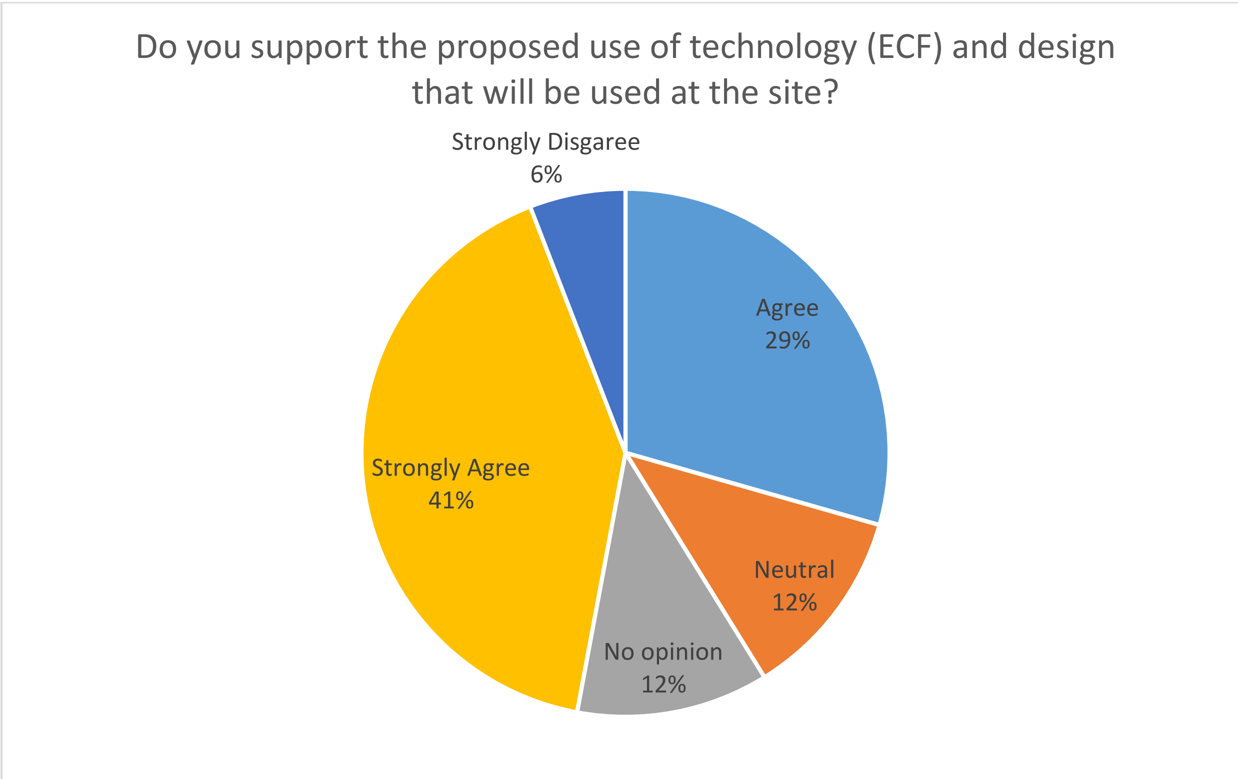
“as a sustainable solution, this option provides an economic benefit to the containment facility, and a strong incentive for the Hamilton Port Authority to take on the management of this facility for many years into the future.”

Agency 7 also supported the use of an ECF to contain the contaminated sediment and stated that:

"this is the affordable and environmentally acceptable of all possible options. As an example, removal and disposable is estimated to cost more than $500 million and poses high risk during transportation."

Sediment management decisions and technology options are complex and require careful consideration before selecting a technological decision (Bates, Sparrevik, De Lichy, & Linkov, 2014). Some of the issues and challenges relate to quantity as well as quality issues, comprising subjects such as contamination, legislator requirements, risk perception and assessment, source control, the final destination of dredged material, public acceptance, cost, and timelines. The final management strategy, apart from economic and social factors, mainly involves engineering elements such as technical feasibility, contaminant reduction, and permanence of remedial options like capping, in situ treatment, and dredging and disposal (Förstner & Salomons, 2008, 2010; Price et al., 2017).

Figure 7: Use of the Engineered Containment Facility at the Randle Reef, Hamilton Harbour



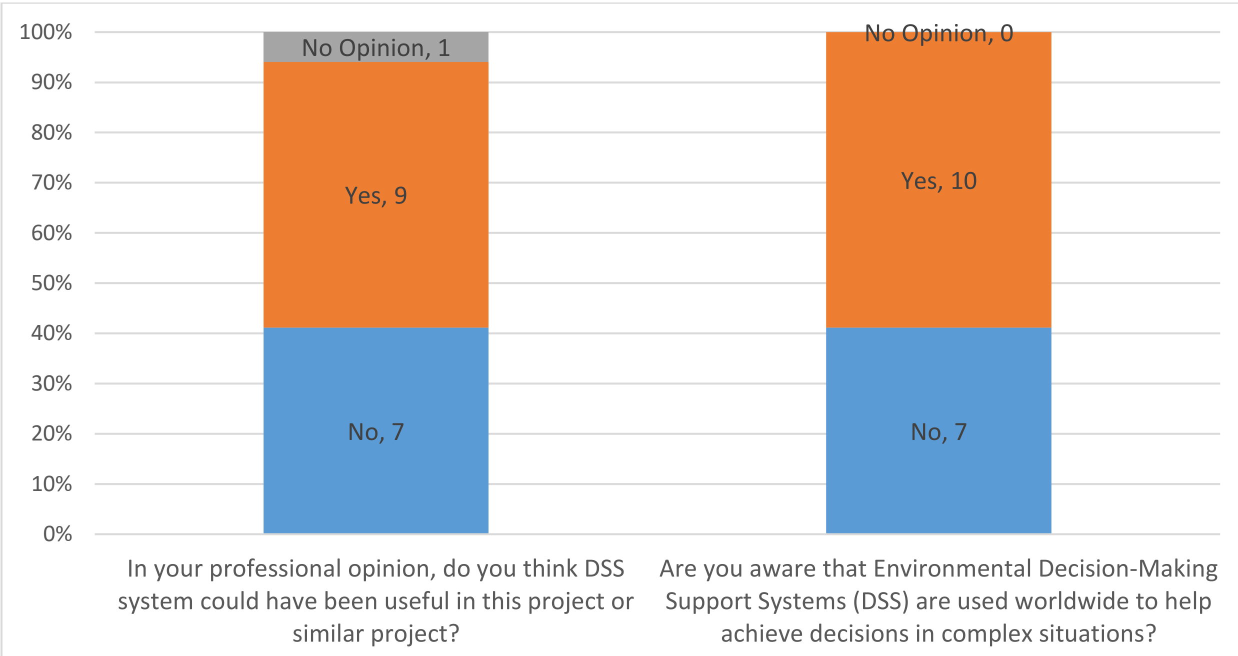
Decision-Support System

According to Black & Stockton (2009), due to increased awareness of the seriousness of environmental problems, people look to scientists to provide solutions. One way that scientists are endeavoring to meet this challenge is to develop efficient computational methods and tools that simplify environmental analysis and problem-solving (Black & Stockton, 2009; Power & Sharda, 2009; Read et al., 2014). Environmental problems may include revitalization of contaminated sites, evaluation of the impacts of ecological risk, and effective management of inland and coastal water. Approaches to effective problem solving for these types of problems can involve the development of Decision Support

Systems (DSSs) (Azapagic, Stamford, Youds, & Barteczko-Hibbert, 2016; Clarke et al., 2017; Kiker, Bridges, Varghese, Seager, & Linkov, 2005; Linkov et al., 2004; Liu, Delibasic, Butel, & Han, 2017; Marcomini et al., 2009; Menzie, Booth, Law, & von Stackelberg, 2009; Mourhir, Rachidi, & Karim, 2016; Murla et al., 2016; Poch, Comas, Rodríguez-Roda, Sanchez-Marre, & Cortés, 2004; Read et al., 2014; Teasley, Kwon, Gentle, & Pierce, 2016). A DSS is an interactive system that helps practitioners use data, documents, knowledge, and models to solve simple or complex problems alike and make decisions (Power & Sharda, 2009). The DSSs are intended to facilitate reproducible, robust and transparent decision-making (Power & Sharda, 2009).

Nine out of 17 stakeholders had prior knowledge about DSSs, and ten stakeholders believed that this additional tool could benefit future sediment remediation projects (Figure 8). Those who had no prior knowledge about DSS had no idea if such systems could be beneficial for sediment remediation projects.

Figure 8: Knowledge about Decision-making Support System and Use of the DSS for Sediment Remediation project



Public and Political Support

For any remediation project to move forward, all seventeen stakeholders interviewed firmly agreed that public and political support is crucial. Agency 7 said:

> "A project like this, it is completely vital."

Agency 8 mentioned:

> "Need full commitment from several municipalities and all senior governments before the funding appropriation can flow."

Agency 15 said:

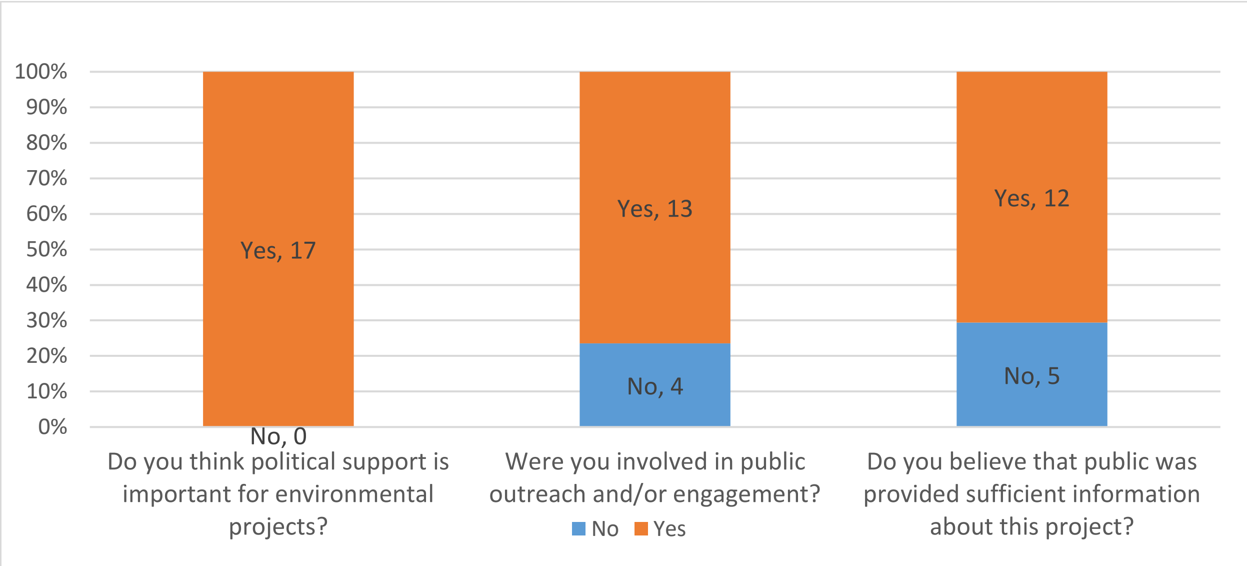
> "Government in this case is giving more than 2/3 money of the project, federal and provincial cabinets had to support, council from Hamilton and Burlington had to support and Halton region as well. Political support at all three levels was important."

Agency 6 said:

"Without the political will, there is no funding, and no project on government led initiatives. You need to have political support on a government run project."

Thirteen stakeholders were involved in the public outreach/engagement. At least twelve of these stakeholders believed that the public was well-informed and engaged during the Randle Reef sediment remediation project (Figure 9).

Figure 9: Public and Political Support for the Randle Reef Sediment Remediation Project



When agencies were asked whether they believed the government was making transparent and open decisions for environmental projects in general (Figure 10), six of the stakeholders agreed, six disagreed and five had a neutral response. For example, Agency 4 mentioned that transparency is variable and often reflects the party that is in power, although certain legal requirements must be followed such as the requirements of the provincial *Environmental Bill of Rights* (EBR), regardless of the party in power. Through EBR on-line registry postings, the government of Ontario engages the public regarding any environmentally significant decision-making, and any public input received becomes part of the government decision-making process. EBR postings apply to government initiatives and private sector activities requiring provincial approval. In the case of Randle Reef, EBR postings was not made available for public comments because it was not a provincially led project. Agency 2 mentioned that the

"idea of openness and transparency that I know we resist because of risk and fear. Increasingly, the government has to come to these basic requirements because these are fundamentals to us."

Agency 10 stated that

"for less complex projects, everyone comes together around the table and happy about it. When problems are more challenging, more politically charged, this is where transparency and openness becomes an issue. Randle Reef will be a good example where there is a lack of transparency and openness."

Agency 16 stated that

"we have a history of relatively weak environmental assessments and ministry intervention. We did successfully receive environmental assessment (very rare) for a site adjacent to this land. We have regulations, and we give exemptions and which doesn't make sense."

Eight out of seventeen stakeholders agreed that the public is engaged well and their opinions are respected in environmental projects. Agency 8 mentioned that

"the RAP is a prime example of how highly engaged the Hamilton public is in creating a better future. Randle Reef is a subsidiary implementing the action of the RAP that first started in a big public meeting at the Hamilton Convention Centre in 1986. BARC and Hamilton Environmental Network and Citizens at City Hall (CATCH) are ever vigilant and raise issues on a wide range of topics with varying degrees of success. BARC gives regular annual updates in its reporting system." CATCH is a volunteer community group that encourages public participation in Hamilton.

Five stakeholders disagreed, and five had neutral responses. Agency 3 mentioned that

"in the end, the decision is driven by government. The public is engaged, but not necessarily listened to for advice."

Eleven out of seventeen stakeholders believed that the public was provided with sufficient information about the Randle Reef sediment remediation project (Figure 10). All the stakeholders agreed with the need to continue to improve public engagement methods for future environmental projects. 20% of the stakeholders supported the use of workshops and round table discussions to engage the public, 16% supported news outlets and use of social media, 15% supported the use of open concept data sharing through online portals and 13% supported the use of opinion surveys to engage the public in the future (Figure 11). They viewed it as vital that the public should be engaged at all stages of decision-making for future environmental projects, as the public feels more involved and appreciated when their opinions are heard and incorporated into the decision-making process. Many authors have pointed to the importance of public engagement for successful environmental decision making (Ansell & Gash, 2008; Beierle & Cayford, 2002; Beierle & Konisky, 1999, 2001; Cox, 2012; Michels, 2011; Michels & De Graaf, 2010).

As Agency 2 mentioned in the interview,

"Government and the public sector workers are in the business to gain the trust and confidence of the people they serve. That is our bottom line. Forget about all the services we provide. The private sector is there to make a profit and the public sector is there for people. This is why we exist. This is how we should behave."

Figure 10: Engaging Public and Promoting Transparency for Future Environmental Projects

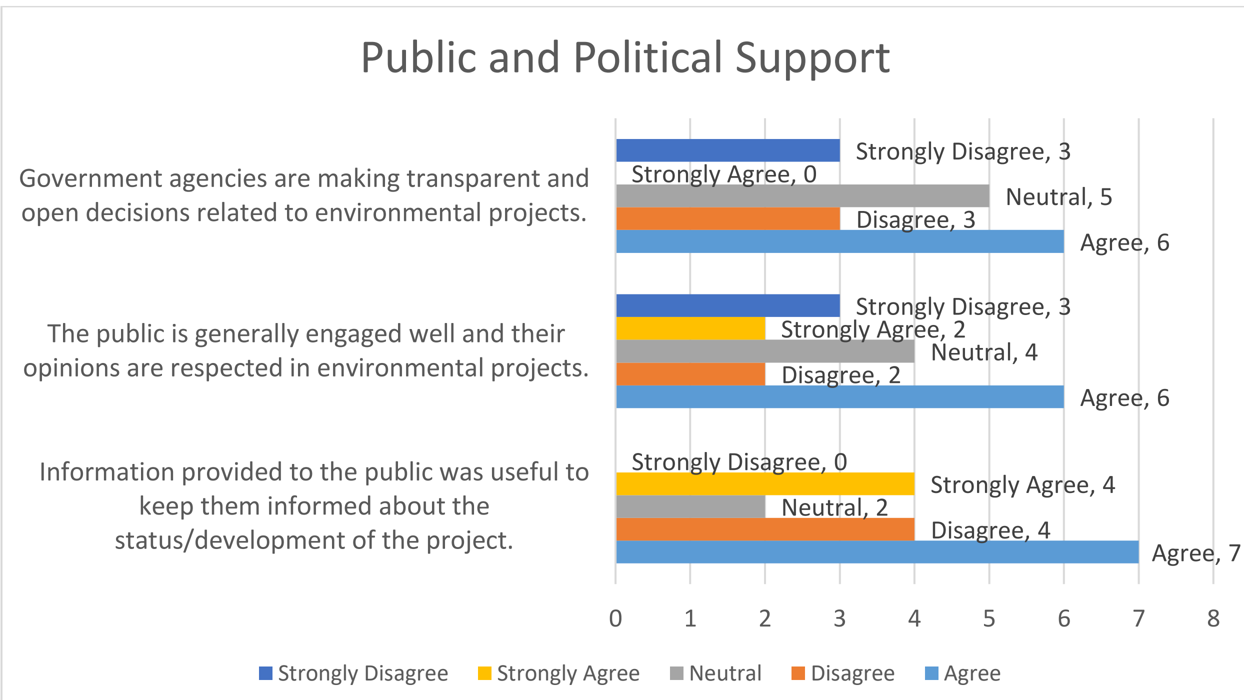
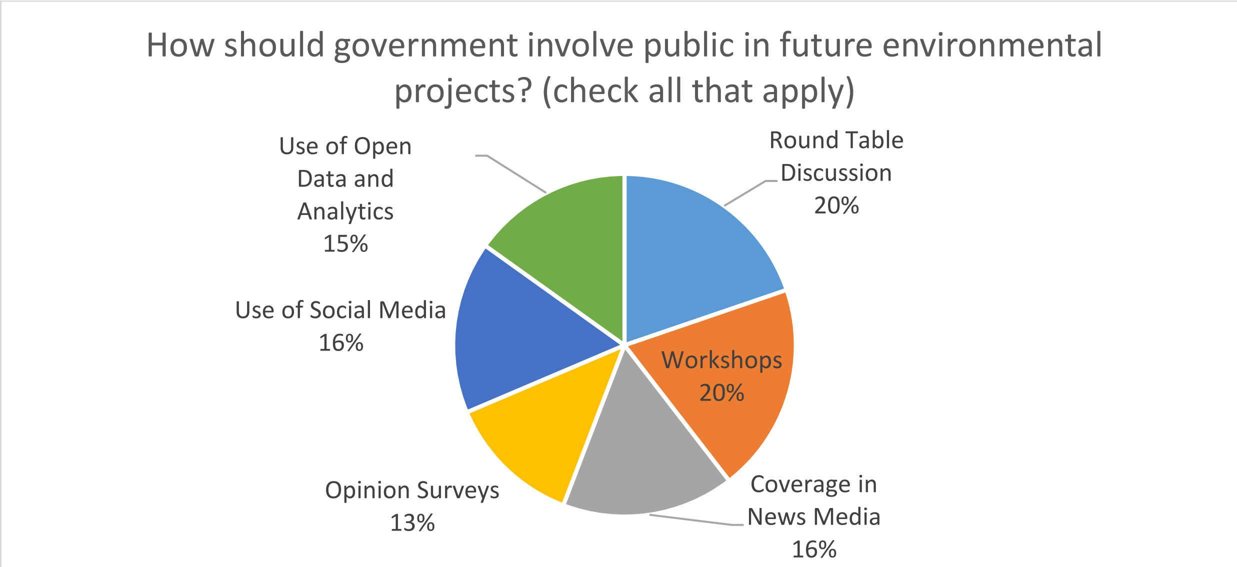


Figure 11: Methods to Improve Public Engagement in Future Environmental Projects



Recommendations

Randle Reef is one of the most toxic sediment sites in Canada, as a consequence of generations of hydrocarbon-contaminated industrial waste entering Hamilton Harbour (Graham et al., 2017; Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1989; Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, 1992; Hamilton Port Authority, 2013). More than 30 years have passed since the contamination was identified yet remediation has just begun. Many scientists, government officials, politicians, industries, and community members came together to address this long-standing contamination. The complex Randle Reef project is finally moving forward after many years of study, collaboration, discussion, and debate. It is a key ingredient in the ultimate de-listing of Hamilton Harbour as a Great Lakes AOC under the Canada- United States Great Lakes Water Quality Agreement.

Based on the expert interviews of those who were directly or indirectly involved with the Randle Reef sediment remediation project, it is evident that the hurdles to progress at contaminated sediment sites involve technical, political, regulatory as well as social challenges. Projects related to contaminated sediment sites involve a complex array of public and private organizations and interests (Read et al., 2014). These include a few or many potentially responsible parties, many government agencies and programs with differing authorities and mandates, private consultants and engineering companies supporting either public or private interests, and a myriad of other stakeholders (National Research Council, 2001; United States Environmental Protection Agency, 2005). The social dynamics among these parties substantially contribute to the complexity of such projects along with variability in site characteristics and cleanup goals of the remediation project. This paper highlights the five major themes, which are key elements to address to ensure more timely and effective management of contaminated sites. The five themes and the main recommendations to optimize these stages are listed below.

1) Participation of Appropriate Actors with Common Objectives

It is important that sediment remediation projects are undertaken with the guidance of strong leadership, and that the transition of leadership roles in various stages of the project is planned and transparent. One of the key ingredients in the successful remediation efforts at Collingwood Harbour in Ontario, Canada was the strong and directed leadership which resulted in steady progress in the selection of remedial measures, their implementation, and the recovery of the ecosystem (Krantzberg, 2003). Since the management of contaminated sediment sites is complex due to the mix of public and private stakeholders involved and their varying interests in the project outcome, the partners should optimize solutions to meet cleanup goals. This can be achieved by articulating clear and meaningful goals early in the process to unite the team. This gives the group the means to overcome conflicts and obstacles during the development and implementation of the plan (Krantzberg, 2003; Luyet et al., 2012; Rizzo et al., 2016; Slob et al., 2008). Some of the experts from the Randle Reef sediment remediation project stated that the federal and provincial government roles and responsibilities ebbed and flowed. Therefore, government roles should be negotiated and clear from the outset.

Most regions in China have taken measures to manage contaminated sites despite the large divergence in stakeholder perspectives. Thirty-one regions within China agree that cooperation between different stakeholders including governmental departments, polluters, developers, consulting/ remediation companies, the public and non-profit organizations influences the effectiveness and the way contaminated sites are managed (Li et al., 2017). There are other promising stories like the Chemical Commodities Inc. Superfund site in Olathe, Kansas where coordination and collaboration with diverse organizations and strong working relationships with site agencies, potentially responsible parties, and other community members led to a cleanup of the site in 2012. The site is now a pollinator habitat garden and serves as a sanctuary for monarch butterflies and other vital pollinators (United States Environmental Protection Agency, 2015). Another remarkable Superfund site worth mentioning here is the St. Paul Waterway Superfund site in Tacoma, Washington where the remediation of the site was achieved by an innovative collaboration between industry, state and federal regulatory agencies, native tribes, community leaders and environmental groups (Sherman, 2011).

There are other successful stories from Europe, Australia, New Zealand and other parts of the world, where remediation projects are a success due to cooperation and collaboration among stakeholders (Oen et al., 2010; Pérez, Sánchez, & Van Liedekerke, 2015; Rizzo et al., 2016; Smith & Nadebaum, 2016). Therefore, it can be reasonably concluded that coordination and collaboration between stakeholder groups is critical for success of complex remediation projects.

Furthermore, in Canada, there is a need for stronger legislation identifying corporate responsibility that clearly identifies and delineates responsibility and ensures the polluter pay principle applies.

2) Funding and Resources

More realistic approaches are required to estimate the remediation costs and account for future cost estimate increases. The project should not be undervalued with the hope that a lower cost will make it easier to fund the project because it will not. It may be easier to “sell” the project to the politicians and the public with a preliminary underestimated cost. However, it can ultimately be very problematic, especially when project team must revisit and re-negotiate the higher cost estimates for funding approvals from each participating agency.

One of the issues that was repeatedly raised by stakeholders involved in the Randle Reef sediment remediation project was the lack of prompt confirmation of financial support for the project. We suggest that the local community (the City of Burlington, City of Hamilton, Hamilton Port Authority and others) could have come forward much earlier with a commitment of funds. However, according to Agency 7, they were unwilling to do this until there was a final project design and cost estimate that had gone through at least two peer reviews.

It is recommended that criteria be developed to determine equitable funding among polluters, government, and the local community if the polluter pay principle turns out to not be a feasible option. For example: polluter pay principle is no longer a feasible option if the responsible parties are not identified.

Within the United States, Congress passed the CERCLA or Superfund in 1980, giving the EPA the funds and authority to clean up polluted sites. This program was considered the most relevant law for contaminated site management especially given its specific provisions for remediation fund and liability (Gu, Yan, Zhou, Guo, & Li, 2007; United States Environmental Protection Agency, 2017b). The Superfund program defined the liability of persons responsible for site remediation, created a tax on the chemical and petroleum industries, established a trust fund for cleanup when no responsible party could be identified and provided broad Federal authority to respond directly to releases of hazardous substances (United States Environmental Protection Agency, 2017b). Through a series of measures and plans, EPA, along with the New York State Department of Environmental Conservation, successfully contained and secured the wastes disposed of in Love Canal in Niagara Falls, New York (the first Superfund site) so that the contamination is no longer leaking into surrounding soils and groundwater (United States Environmental Protection Agency, 2017b).

3) Decision-making Process

For the Randle Reef sediment remediation project, it was repeatedly suggested that more openness and transparency with all the stakeholders would have significantly helped identify and lock in the project goals. Open dialogue, communication and the trust between partners is necessary for successful resolution of difficult decisions (C. McCoy & Morgan, 2012; Oen et al., 2010; Preble, 2005; Rawlins, 2008; Waters, Burnett, Lamm, & Lucas, 2009). There is also a need for tighter meeting scheduling and turnarounds as suggested by some of the stakeholders.

It is also critical that criteria are developed that are equitable and mutually agreeable to allow participants to evaluate the potential application of a remediation option and that non-feasible or controversial options are eliminated at the early stages of the project to avoid further delays. There needs to be a balance struck – to ensure openness and transparency and not to predetermine outcomes by limiting the options the stakeholders are allowed to consider and provide input on.

4) Research and Technology Development

Future research and development work should consider the following:

- Understanding of the chemical fate, distribution, and behaviour of various contaminants.
- Better risk identification, assessment and measurement of contaminants and identifying most feasible and cost-effective technology for remediation.
- Further work is also necessary to understand implications and linkages between sediment contamination and human health impacts, (including routes of exposure, and long-term exposure effects), ecological health, the economic and social costs

and benefits of having and cleaning up contaminated sediment, and the development and demonstration of environmentally and economically cost-effective technologies.

- A well-informed discussion and consensus among technical staff and local stakeholders regarding how far conditions must shift to be deemed acceptable cannot be achieved without first agreeing on how conditions should be measured. There is a need for technical consistency and rigor in monitoring across all Canadian AOCs (George & Boyd, 2007).

5) Public and Political Support

Many of these contaminated sediment sites do not have a final deadline to work towards. Therefore, having non-negotiable deadlines like any other engineering/design project could be one important step towards implementing the management actions promptly. Information disclosure, outreach and education and public participation must be applied together to improve the diversity of persuasion and encouragement (Cox, 2012; Jawed & Krantzberg, 2017b; Li et al., 2017).

One of the key recommendation of this study is that public engagement should become a fundamental strategy for ensuring the prompt and effective execution of environmental remediation projects. Ensuring that the public is kept informed and engaged during all stages of the decision-making process will not only promote transparency in the various stages of decision-making throughout the project, it will also keep the public on board and supportive at critical stages of the project to help it progress in a timely manner (Ansell & Gash, 2008; Beierle & Cayford, 2002; Beierle & Konisky, 1999, 2001; Cox, 2012; Jawed & Krantzberg, 2017b; Li et al., 2017; Michels, 2011; Michels & De Graaf, 2010; Stringer et al., 2006). It is further recommended that investments be made in research and modern tools/ methodologies such as social media, crowd sourcing and Open Data Analytics in addition to the usual methods such as workshops and roundtable discussions to further advance effective engagement of the public and promote transparency in government decision-making (Abelson et al., 2003; Gurstein, 2011; Jawed & Krantzberg, 2017b; Mergel, 2012; Rowe & Frewer, 2000; Waters et al., 2009).

Conclusion

There is no single formula or solution for managing these contaminated sediment sites, due to their complexity and the variation in site characteristics. Additionally, there are complex considerations that must be made to reach a balance between social, economic, and environmental aspects during and after the project completion (Azapagic et al., 2016; Beames et al., 2014; Holland et al., 2011; Read et al., 2014). However, this paper brings forward the accounts of experts and professionals with first-hand experience in the management of such complex sites, who provided invaluable experiences and suggestions which can significantly benefit future remediation projects and help overcome obstacles.

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Chapter 4: Using Qualitative Document Analysis to Understand Sediment Remediation Policies in North America

Using Qualitative Document Analysis to Understand Sediment Remediation Policies in North America

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Abstract

This research paper presents the results of Qualitative Document Analysis (QDA) performed on selected sediment remediation policy documents so as to analyze how well each of the following themes are addressed: participation of appropriate actors with common objectives; allocation of funding and resources; decision-making processes; research and technology development; public engagement and support. Additionally, we reviewed selected research papers in the area of sediment remediation and assessed them against the same five themes. A comparative analysis was then performed between policy documents and research papers to reveal any gaps and opportunities.

Our analysis showed the need for sediment remediation guidance documents to improve and address significant contributors to successful decision-making and implementation outcomes particularly in the main areas including defining participation of appropriate actors with common objectives, the benefits of public engagement and support, and clarification of processes for the allocation of funding and resources. This could result in more timely and collaborative decision-making for contaminated sediment management.

Key Words: Contaminants; sediment remediation; sediment management; Areas of Concern; collaborative decision-making; qualitative document analysis

Introduction

According to the United States Environmental Protection Agency (2005), “Contaminated sediment is soil, sand, organic matter, or other minerals that accumulate on the bottom of a water body and contain toxic or hazardous materials at levels that may adversely affect human health or the environment” (United States Environmental Protection Agency, 2005). These contaminants can degrade water quality and adversely affect benthic organisms as well as human health. Although some contaminants break down, others are persistent, and some organic contaminants can accumulate in the fatty tissues of organisms, and concentrate up the food web in a process known as biomagnification (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). Organic contaminants in sediment typically adsorb to fine sediment particles and exist in the pore water between sediment particles. Metals also adsorb to sediment and may bind to sulfides, ferrous oxides, and other ligands in the sediment. Many contaminants persist for years or decades because they do not degrade or degrade very slowly in the aquatic environment.

Case Study: The North American Great Lakes and the Issue of Contaminated Sediment

The North American Great Lakes and their connecting rivers make up the largest surface freshwater system in the world with a total water surface area of nearly 95,000 square miles. The Great Lakes Basin contains approximately 24.6 quadrillion liters of water, which is roughly 18-20% of the world’s freshwater supply (Government of Canada and the United States Environmental Protection Agency, 1995). These unique natural resources provide exceptional recreational opportunities, unmatched aesthetic beauty, and diverse ecological habitat. Hence, it is important to maintain the quality of the Great Lakes to support ecosystem services (Government of Canada and the United States Environmental Protection Agency, 1995). Historically, the Great Lakes have been contaminated from industrial and agricultural activities within the basin. This has resulted in the accumulation of toxins in the Great Lakes (T. Crane, 2012; Government of Canada and the United States Environmental Protection Agency, 1995).

At the turn of the 20th century, there was an increased recognition of the need to approach water resources management and development in shared Canadian-United States waterbodies. This recognition led to the signing of the Boundary Water Treaty of 1909, which also established an International Joint Commission (IJC) to settle trans-boundary water disputes (Governments of Canada and the United States, 1909). The IJC recognized “remediation and management of sediment contaminated with persistent toxic substances" as one of its 1995-1997 program priorities (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997).

The Great Lakes Remedial Action Plan (RAP) process was designed to address contamination in the most highly polluted rivers and bays around the Great Lakes. These are called Areas of Concern (AOC) where water quality and ecosystem health have been severely degraded by human and other activities (Environment Canada, 2017). Of the 43 original AOCs in Canada and the United States, twenty-six were in the United States, 12 in Canada, and five were bi-national and shared between both countries. To date, seven AOCs have been delisted, and two have been designated to be in recovery status (International Joint Commission, 2017). In August 2017, an update related to Canadian

AOCs status was provided by the Manager of Great Lakes Areas of Concern, Environment Canada as follows:

"In terms of the status of contaminated sediments remaining unmanaged in Areas of Concern, I can only speak to the remaining Canadian AOCs. From the information- I have available, Nipigon Bay and Severn Sound are the only AOCs that do not have contaminated sediments. Contaminated sediment management plans are in place or being implemented in all of the other Canadian AOCs except for the Canadian portions of the St. Marys River and St. Clair River and Port Hope Harbour where plans are either being developed or awaiting implementation."

Each AOC has developed a RAP to restore the beneficial uses in the Great Lakes (Environment Canada, 2017). In the RAP process, government and stakeholders work together to restore the environmental quality of the AOCs through three phases: planning, implementation, and monitoring (Grover & Krantzberg, 2012).

There is a consensus among diverse sectors in the Great Lakes Basin that contaminated sediment is a major environmental problem and a key factor in many of the impairments of the beneficial uses of the Great Lakes (Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997). In Canada, contaminated sediment management projects have been completed for the St. Lawrence River (Cornwall), Niagara River, Detroit River, Bay of Quinte and the Peninsula Harbour Areas of Concern. Randle Reef in the Hamilton Harbour AOC is the largest Canadian contaminated sediment site in the Great Lakes, and remediation is currently underway (Bay Area Restoration Council, 2017; Environment Canada, 2017).

Sediment Remediation and Key Components

According to Fisheries and Oceans Canada (2014), remediation is an "improvement of a contaminated aquatic site to prevent, minimize or mitigate damage to human health or the environment; an activity undertaken to correct an unacceptable existing condition (e.g., treating or moving polluted sediment). Remediation involves the development and application of a planned approach that removes, destroys, contains, or otherwise reduces the availability of contaminants to receptors of concern" (Fisheries and Oceans Canada, 2014).

The five common remedial approaches are: Monitored Natural Recovery, in-situ biotransformation, in-situ treatment, capping, and sediment dredging (Reible & Shepard, 2014). Challenges to sediment remediation include the scope of contamination, technical limitations, and costs associated with cleanup (Reible & Shepard, 2014).

Key themes are frequently identified in the literature that are considered important for successful remediation of contaminated sediment (Beierle & Konisky, 1999; Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2016; Hall & O'Connor, 2012; Krantzberg, 2003; Li et al., 2017; Pérez et al., 2015; Read et al., 2014; Renn & Finson, 1991; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Zarull et al., 2001; Zarull et al., 1999). These are as follows:

1) Participation of appropriate actors with common objectives;

2) Funding and resources;

3) Decision-making process;

4) Research and technology development;

5) Public engagement and support.

Research Objectives

This research employed the Quality Document Analysis (QDA) technique to compile and analyze various government policy documents (Bowen, 2009; Regan, MacDonald, Allan, Martin, & Peroff-Johnston, 2014; Sustainable Services at Scale (Triple-S), 2012) so that patterns and inconsistencies can be understood among various government plans and practices in the context of sediment management in Canada and the United States to illuminate opportunities to improve decision making performance in the future.

Qualitative Document Analysis

Qualitative Document Analysis is a systematic process that is used as a tool for analyzing documents and assessing printed and/or electronic documents (Altheide, Coyle, DeVriese, & Schneider, 2008; McLellan et al., 2003). Similar to other analytical methods in qualitative research, the key benefit of QDA are achieved by ensuring the data is thoroughly examined and interpreted to elicit meaning, gain understanding, and develop empirical knowledge (Corbin & Strauss, 2008; McLellan et al., 2003). QDA is typically used in conjunction with other research methods to triangulate the study findings (Denzin, 1973). This means more than one source of evidence points to the same conclusion through different data sources and methods ensure that the findings have credibility by reducing potential bias in one given method (Bowen, 2009; Patton, 1990, 2005).

Qualitative Document Analysis can serve a variety of purposes as follows (Bowen, 2009; Miles, Huberman, & Saldana, 2013):

1. Provide data on the context and historical insight
2. Reveal information contained in documents that raise questions that need to be asked and addressed as part of the study
3. Illuminate supplementary research data not available through other sources
4. Provide a means of tracking changes and development over time
5. Analyze materials in a way to verify findings or corroborate evidence from other sources

Overview of Methodology

The QDA process in this study involved the following five key steps which were adapted from (Sustainable Services at Scale (Triple-S), 2012) and (Regan et al., 2014):

Step 1) Setting inclusion criteria for documents

The review process included the following steps. First, policy documents were reviewed such as guidelines, manuals, handbooks, or procedural documents related to environmental remediation projects to assess how each of the identified themes was reflected in such documents within Ontario and the United States. A comprehensive list of documents was retrieved from various government websites (such as Environment Canada, Ministry of the Environment and Climate Change, the United States Environmental Protection Agency, United States Army Corps of Engineers). These documents were short-listed based on their relevance and importance to sediment remediation or contaminated sites projects. These were also chosen to reflect a good mix of temporal distribution (consisting of both recent and older policy documents) to assess how approaches have evolved. A triangulation technique was employed starting with a single document and kept adding and analysing more recent documents, in the order of publication date, until there were no significant changes observed to the overall findings.

Second, selected research papers were reviewed and assessed against the same five themes that are obstacles in accelerating remediation of contaminated sites. These research papers are selected because they specifically discuss how sediment management decisions are currently made and address the question of how decisions should be made in the future to accelerate progress at contaminated sediment sites. This was mainly done to validate the findings (if any) of policy documents against those of the selected research papers and, more importantly, to identify whether the selected research papers have demonstrated any evolution in addressing the five key themes.

A comparative analysis was carried out on policy documents and research papers to reveal any gaps and opportunities. The following selected United States and Canadian policy documents were reviewed:

1. Framework for Addressing and Managing Aquatic Contaminated Sites under the Federal Contaminated Sites Action Plan (FCSAP) (Chapman, 2011)
2. A Federal Approach to the Contaminated Sites (Government of Canada, 1999)
3. Canada-Ontario Decision-Making Framework for assessment of Great Lakes contaminated sediment (Environment Canada & Ministry of the Environment and Climate Change, 2008)

4. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (United States Environmental Protection Agency, 2005)
5. Guidance for Environmental Site Assessments under Ontario Regulation 153/04 (Association of Professional Geoscientists of Ontario, 2011)
6. Assessment and Remediation of Contaminated Sediments (ARCS) Program (United States Environmental Protection Agency, 1994)
7. Handbook - Remediation of Contaminated Sediments (United States Environmental Protection Agency, 1991a)

Additionally, we reviewed the following research papers:

8. Risk-Based Decision Making to Manage Contaminated Sediments (Bridges et al., 2006)
9. Accelerating Progress at Contaminated Sediment Sites: Moving from Guidance to Practice (Bridges et al., 2012)

Step 2) Collecting documents

All the above documents were first identified based on the inclusion criteria (Step 1) and then obtained through general internet research, online and paper research articles from various libraries, as appropriate.

Step 3) Assessing key project themes

Each policy document was analyzed based on the five project themes identified above to evaluate how well it describes and considers each of the themes:

- **Participation of appropriate actors with common objectives**: In this theme, we examined how the level of involvement among various stakeholders was defined and elaborated upon, and how various roles, accountability, and leadership among various stakeholders was assigned.

- **Funding and Resources**: In this theme, we analyzed policy documents about the funding arrangements and resource allocation among various groups of stakeholders.
- **Decision-making Process**: In this theme, we sought to identify any reference to decision-making processes and whether there were any tools or methodologies related to facilitation of decision making.
- **Research and Technology Development**: In this theme, we determined the extent to which the documents described the evaluation, usage, and implementation of emerging new technology to gain efficiencies in remediation while reducing costs and timelines.
- **Public Engagement and Support**: In this theme, we analysed the processes used to engage the public and gather their input during the various phases of the sediment remediation project.

<u>Step 4) Coding documents and setting scoring criteria</u>

The QDA technique, including both quantitative and qualitative scoring, was adapted from (Bowen, 2009). QDA analysis was performed in three iterative steps as follows:

1. Skimming (superficial examination) including word counts and match phrases
2. Reading (through examination)
3. Interpretation

The quantitative analysis involved step 1 and step 2, while qualitative analysis involved step 2 and step 3 throughout this paper.

Quantitative analysis, which includes word count, when used in conjunction with a qualitative method, helps to validate the findings (Clark, Creswell, Green, & Shope, 2008; Olsen, 2004) as to how well a policy document is performing in the key areas of the themes as discussed above. Table 1 presents the words that were identified and indexed for each of the policy themes.

Table 1: Policy Themes and Associated Word Search

Themes	Relevant Word Search
Participation of appropriate actors with common objectives	Common objectives, stakeholder, participation, partners, roles, responsibilities, accountability, leadership, transparency
Funding and Resources	Funding, funds, resource, costs, resource allocation, financial, economics, cost-benefit
Decision-making Process	Decision, decision-making process, methodology, facilitation, conflict, conflict-resolution, conflict resolution.
Research and Technology Development	Technology, research, tool, innovation, reducing cost, reducing timeline, efficiencies.

Public engagement and support	Public, public engagement, public support, public outreach, public interview, public opinion, general public.

We point out that variation of a particular word was considered and indexed, for example, responsibility or responsibilities, reducing cost or cost reduction, efficiencies or efficiency. All variations were searched and indexed. The total scores of each theme reflected the individual sums of all word counts within each category.

For qualitative analysis, the strength of each policy theme in the document was categorized and scored. This method was adapted from (Sustainable Services at Scale (Triple-S), 2012):

1. **Good = 3**; include clear and consistent references to practice related to the theme and would give sufficient information to the reader.
2. **Fair = 2**; Presence of practice associated with the theme with some details but not enough to conclusively provide a score of "good."
3. **Limited = 1**; Indicate only a brief or very limited reference to practice related to the theme.
4. **None/Unclear = 0**; no information provided related to the theme

Step 5) Verification and Analysis

This step involves verification of various quantitative and qualitative scores to analyze and establish common patterns by ensuring there is a general consistency between the two methods and that any deviations are justified.

Results and Discussion for Policy Documents

Document 1: Framework for Addressing and Managing Aquatic Contaminated Sites under the Federal Contaminated Sites Action Plan (FCSAP) (Chapman, 2011)

In the qualitative analysis, the Framework for Addressing and Managing Aquatic Contaminated Sites under the Federal Contaminated Sites Action Plan (FCSAP) scored an overall average of 1.4 (Figure 1). For the theme of the decision-making process, this document scored “good.” The funding and resources allocation scored "fair" as the level of discussion contained in the document did not warrant a "good" score. There were some limited references to the participation of appropriate actors with common objectives as well as research and technology development. Therefore, a "limited" score of 1 was given to these two themes. There was no evidence or discussion regarding public engagement and support, thereby scoring a "none" in this theme.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed consistent results with those of the qualitative analysis (Figure 2). Therefore, the findings can be validated between the two approaches.

Figure 1: Document 1 Qualitative Data Analysis

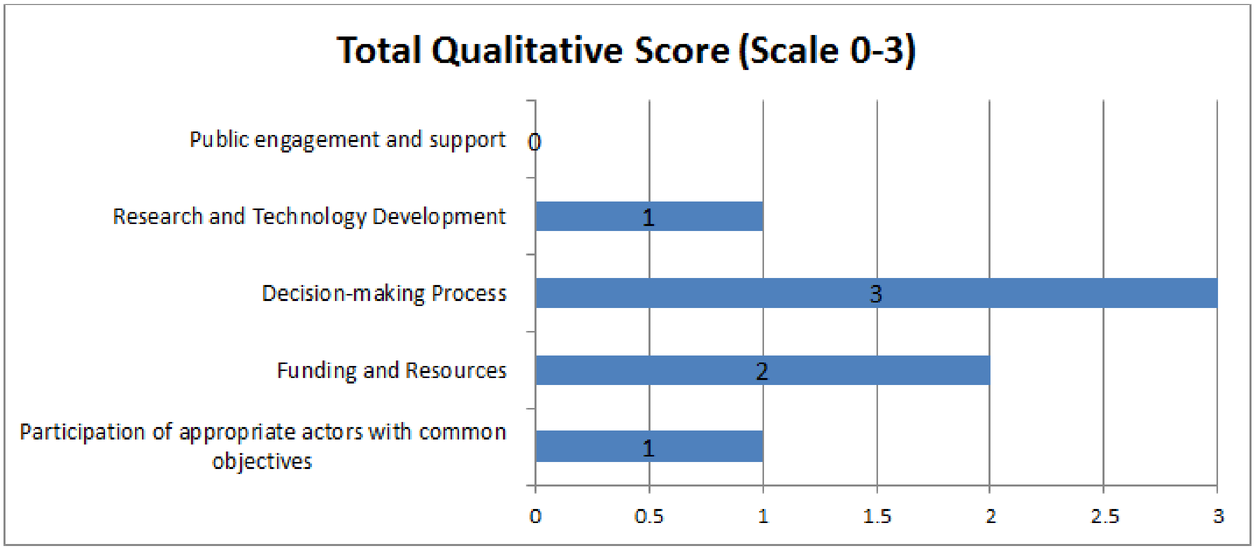
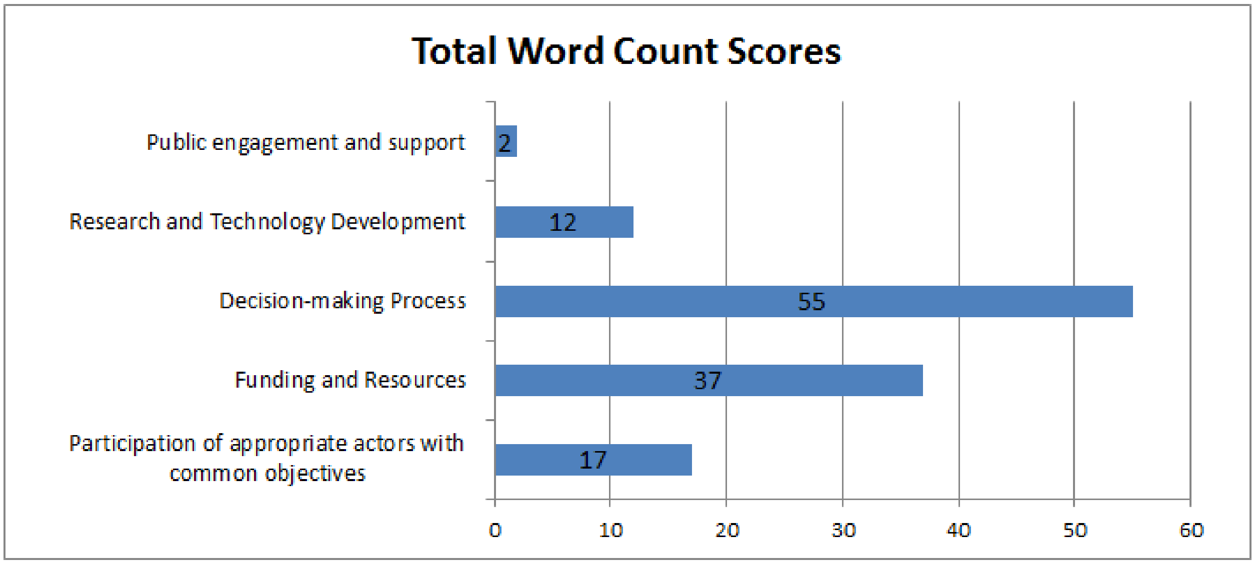


Figure 2: Document 1 Quantitative Data Analysis



Document 2: A Federal Approach to the Contaminated Sites (Government of Canada, 1999)

This document incorporates a risk-based approach to the management of contaminated sites. In the qualitative analysis, this document scored an overall average score of 1.2 (Figure 3) with a "fair" score for the funding and resources as well as research and technology as there were not sufficient discussion and elaborated process on these themes to provide a score of "good." Although the funding and resources were mentioned several times in the document (as evident in the word count), the context was behind the implementation of the risk based approach as opposed to allocating the funding and resources appropriately between various partners or actors.

The themes for public engagement and support as well as decision-making process scored a "limited" as these topics were minimally mentioned. The participation of appropriate actors with common objectives scored a "none" as there was no mention of any process or steps on this item.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis except the words funding and resources, which were used in a different context as discussed in the above paragraph (Figure 4). Therefore, the findings can be validated between the two approaches.

Figure 3: Document 2 Qualitative Data Analysis

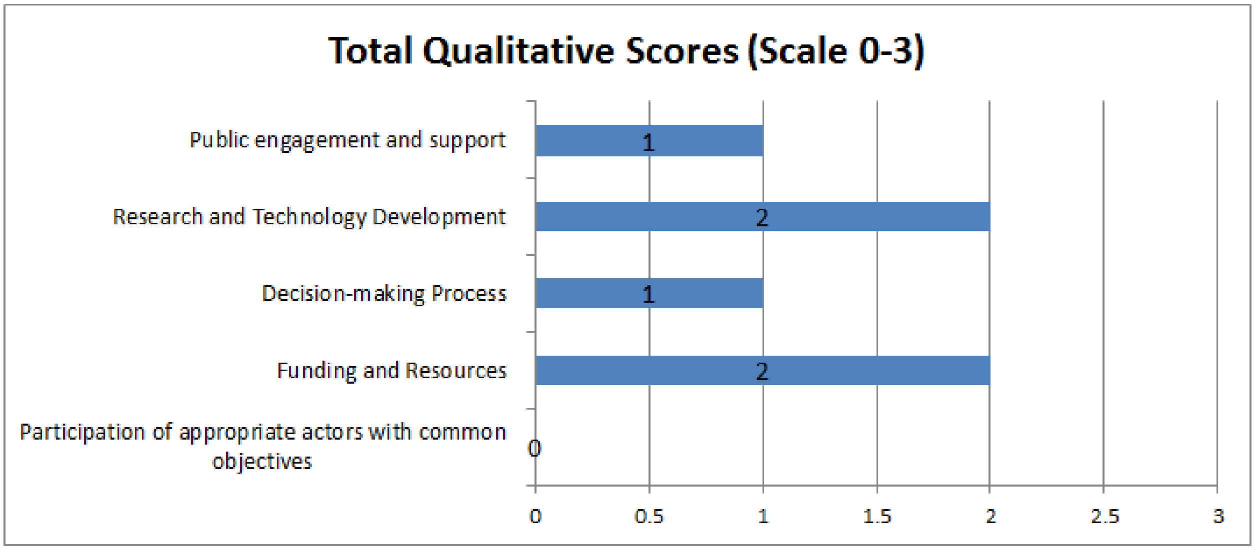
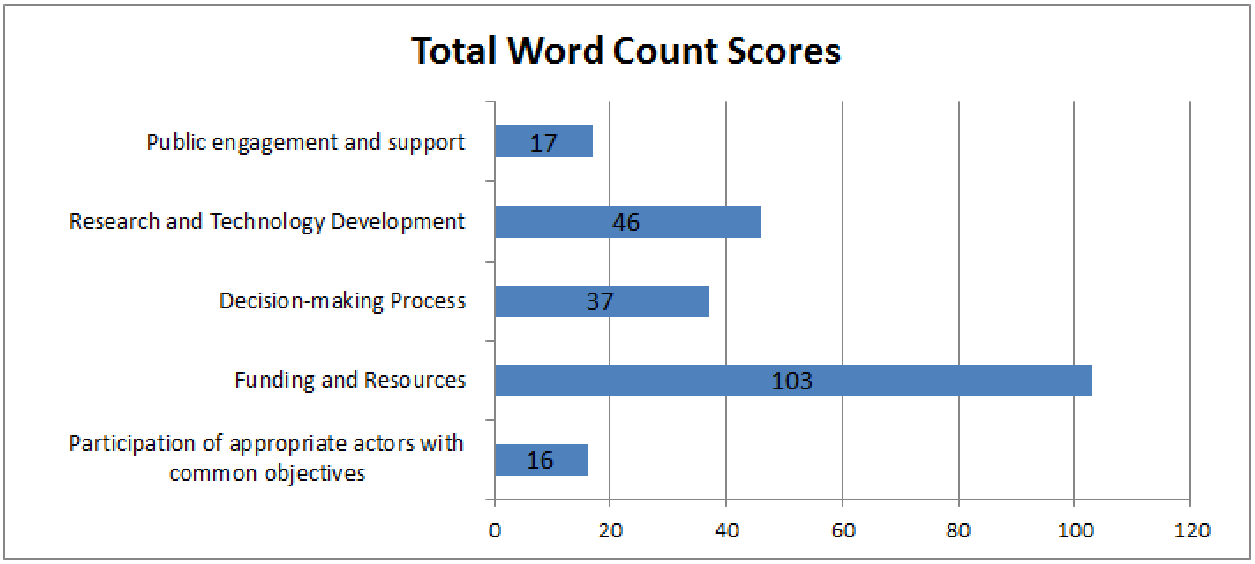


Figure 4: Document 2 Qualitative Data Analysis



Document 3: Canada-Ontario Decision-Making Framework for Assessment of Great Lakes Contaminated Sediment (Environment Canada & Ministry of the Environment and Climate Change, 2008)

This framework provides step-by-step science-based guidance for assessing risks posed by contaminated sediment and provides specific direction on next steps in making sediment management decisions. The framework is primarily concerned with risks to the environment but considers human health concerns associated with bio magnification of contaminants.

In the qualitative analysis, this document scored an overall average score of 0.6 (Figure 5). A "fair" score was given to the theme of the decision-making process, which outlines specific steps, decision-making, and decision-points for the assessment of Great Lakes contaminated sediment, as evident in the title of the document. Participation of appropriate actors with common objectives scored a "limited" score. The remaining themes, namely public engagement and support, research and technology development, as well as the funding and resources, all scored "none" as there was no mention or discussion related to these topics or any process for these themes noted in the document.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis except the words in funding and resources, which were used in a context not related to the funding and resource allocation among stakeholders (Figure 6). Therefore, the findings can be validated between the two approaches.

Figure 5: Document 3 Qualitative Data Analysis

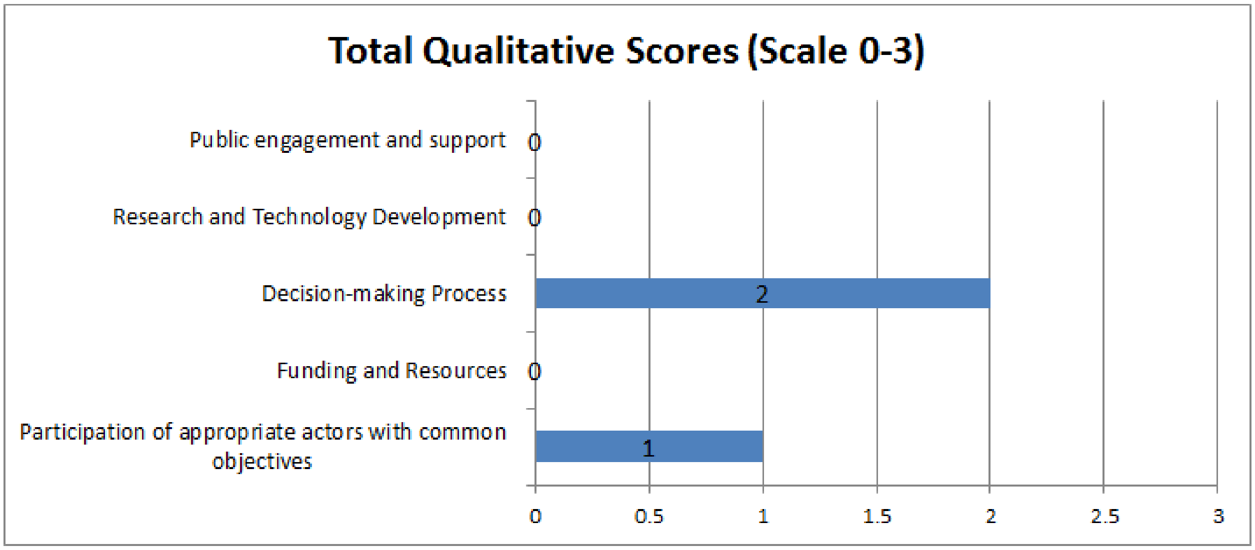
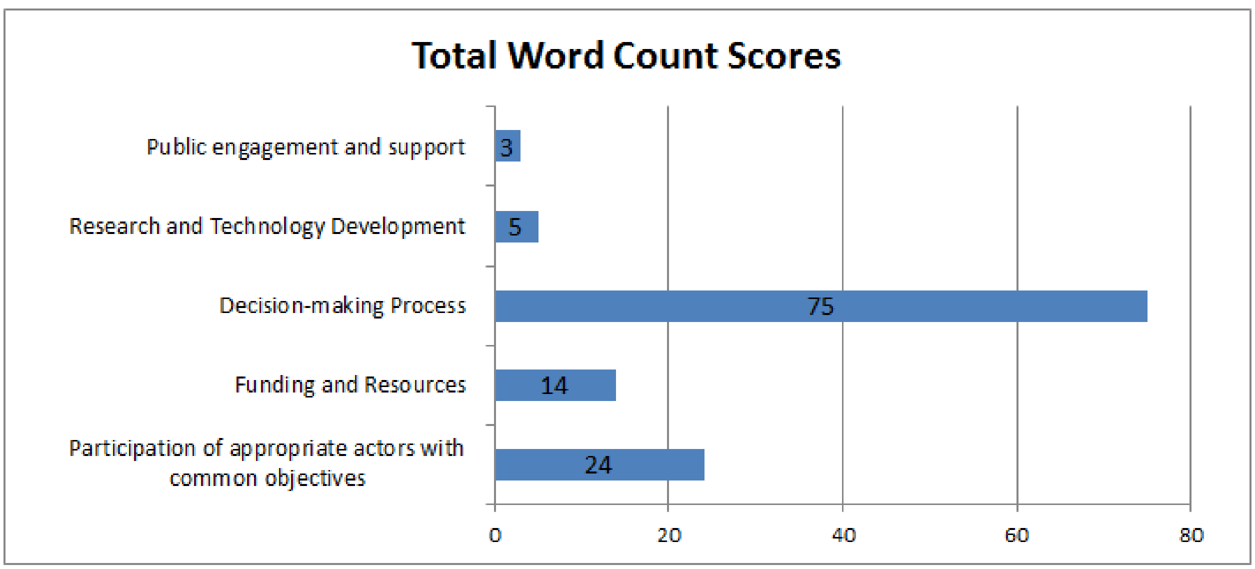


Figure 6: Document 3 Quantitative Data Analysis



Document 4: Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (United States Environmental Protection Agency, 2005)

This guidance document provides technical and policy guidance for project managers and management teams making remediation decisions for contaminated sediment sites. Although aspects related to site characterization and risk assessment are addressed, the guidance focuses on considerations regarding feasibility studies and remedial selection for contaminated sediment.

In the qualitative analysis, this document scored an overall average score of 1.4 (Figure 7). A "fair" score was given to the theme of the decision-making process, which has a section dedicated to the decision-making process for the contaminated sediment remediation. The same was the case for public engagement and support, which scored a "fair" because the document discussed a number of steps to that need to be undertaken to secure public awareness and inputs.

All other themes, namely research and technology development as well as the funding and resources, scored a "limited" as there were no detailed discussions or processes related to these topics noted in the document.

The quantitative analysis (Figure 8) which was carried out using specific word searches and counts within each category revealed some deviations from the qualitative analysis and there could be explanations as follows.

The funding and resources scored the highest word count score (320) but did not score well in the qualitative analysis stage. The reason is that the words "cost" and "resources" were used in the context of cost and resource of implementing various treatment options and not in the context of the funding and resource allocation among different partners. Similarly, the word counts for theme research and technology development appear not to be consistent with the qualitative score because these words were used in the narrow context of various treatment options and were not intended to bring innovations to either the decision-making process or the sediment remediation project.

Figure 7: Document 4 Qualitative Data Analysis

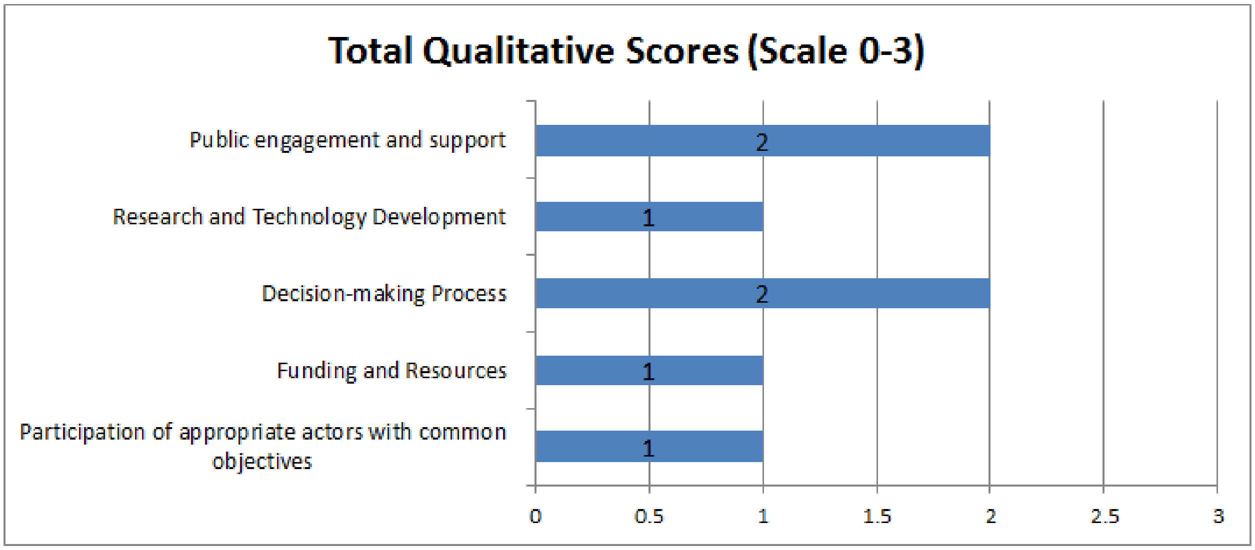
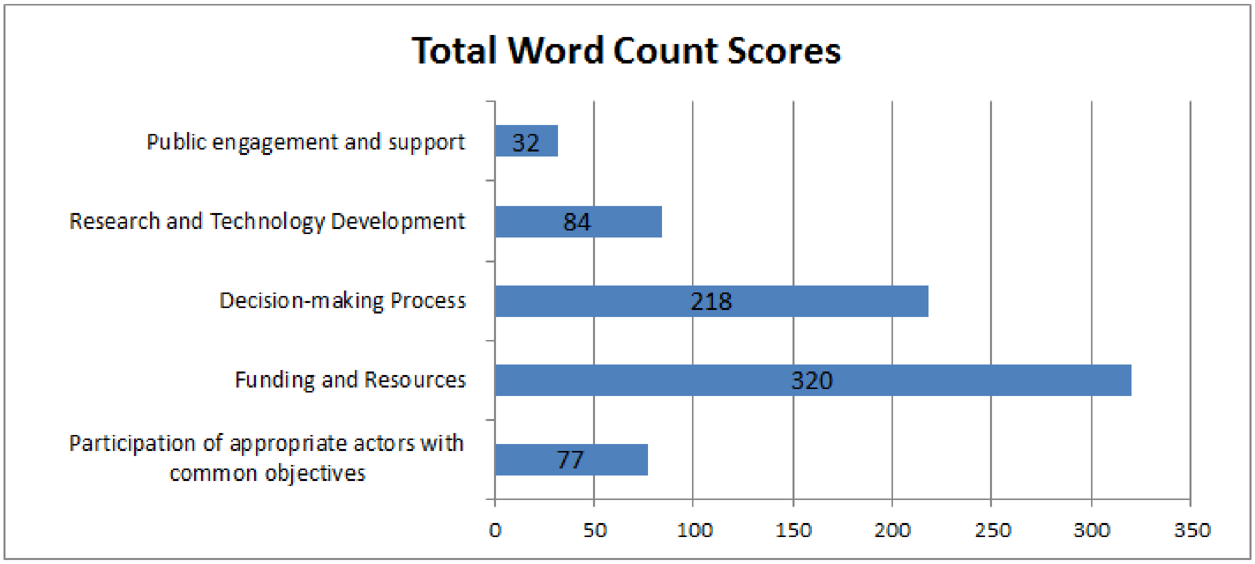


Figure 8: Document 4 Quantitative Data Analysis



Document 5: Guidance for Environmental Site Assessments under Ontario Regulation 153/04 (Association of Professional Geoscientists of Ontario, 2011)

This document provides technical and operational guidance for conducting an environmental site assessment (ESA) to meet the requirements of Ontario Regulation 153/04. The document describes the procedures that should be followed to meet the phase one and phase two ESA requirements for submitting a Record of Site Condition (RSC) to the Ontario Ministry of the Environment and Climate Change (MOECC) on completion of the phase one or phase two ESA.

In the qualitative analysis, this document scored an overall average score of 0.8 (Figure 9) with a "fair" score in the decision-making process. The document contains several process charts and steps to reach a decision regarding the assessment of environmental sites. This document scored a "limited" score for public engagement and support, as well as research and technology development. This is because the document only mentions consideration for public comments/awareness, identifying best tools and efficient process to perform coring, sampling and/or drilling to conduct particular types of sampling. It should be noted that the provincial process for brownfields assessment, does provide options for the public to comment using the Environmental Bill of Rights (EBR) registry (which is applied in the Province of Ontario). The document did not mention the funding and resources and participation of appropriate actors with common objectives at all, therefore getting a score of "none."

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis with the exception of the words in participation of appropriate actors with common objectives, which were used in a context of drilling and sample coring and not related to the themes (Figure 10). Therefore, the findings can be validated between the two approaches.

Figure 9: Document 5 Qualitative Data Analysis

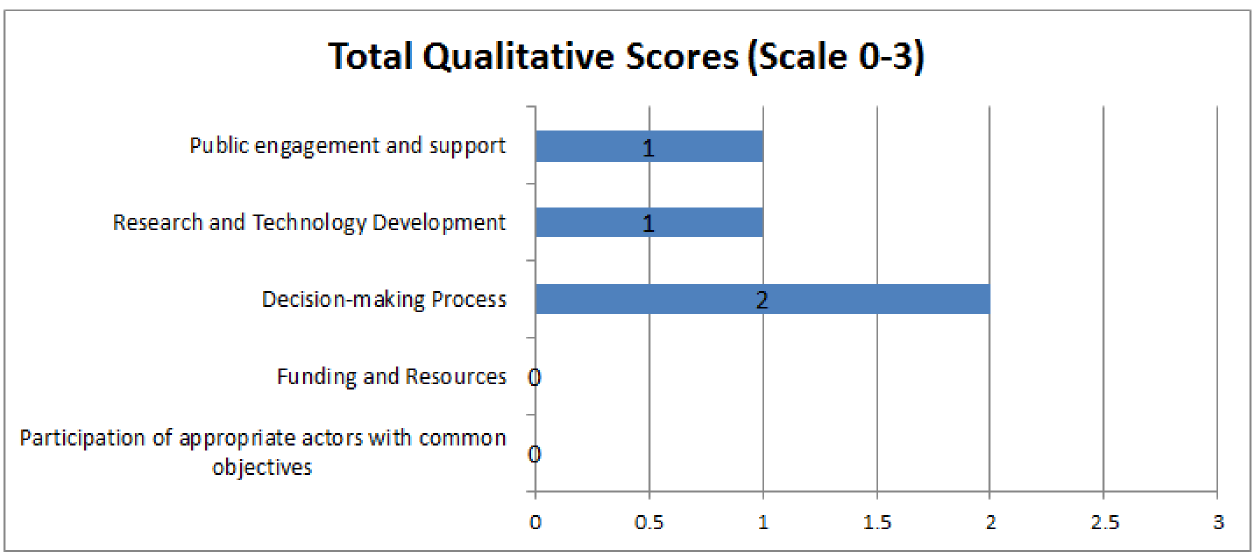
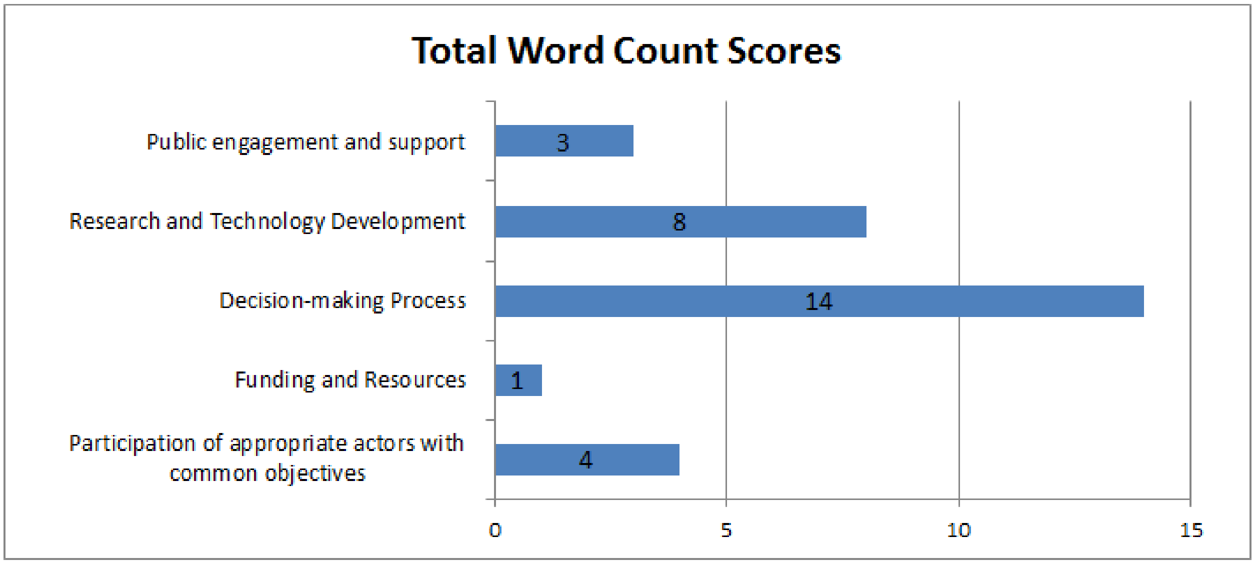


Figure 10: Document 5 Quantitative Data Analysis



Document 6: Assessment and Remediation of Contaminated Sediments (ARCS) Program (United States Environmental Protection Agency, 1994)

This report presents major findings of the Assessment and Remediation of Contaminated Sediments (ARCS) Program. The objective of the ARCS program was to develop an integrated, comprehensive approach to assessing the extent and severity of sediment contamination, evaluate the risks associated with that contamination, and select appropriate remedial responses.

This report achieved an overall average qualitative score of 1.6 with a “good” score on the themes of research and technology development and public engagement and support (Figure 11). There are detailed sections outlining investigation, use and implementation of new technologies not only to achieve effective remediation but also to save time and costs. This document also places high importance on the need for effective public engagement and outreach programs as part of any sediment remediation project. This document scored a "limited" on decision-making process as it did not discuss the significance and details of an effective decision-making process when multiple stakeholders are involved. This document also scored a “limited” in participation of appropriate actors with common objectives because it merely outlines roles and responsibilities in an organizational setting without identifying stakeholders and decision-makers. This document scored a "none" in the funding and resources because it did not mention any reference or discuss the importance of the allocation of the funding and resources among various stakeholder groups.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis except the words in the theme of the funding and resources (Figure 12). This is because the document discussed the funding in a different context related to costs, resources, and effectiveness of various sediment remediation technologies which were captured in this theme through a word search.

Figure 11: Document 6 Qualitative Data Analysis

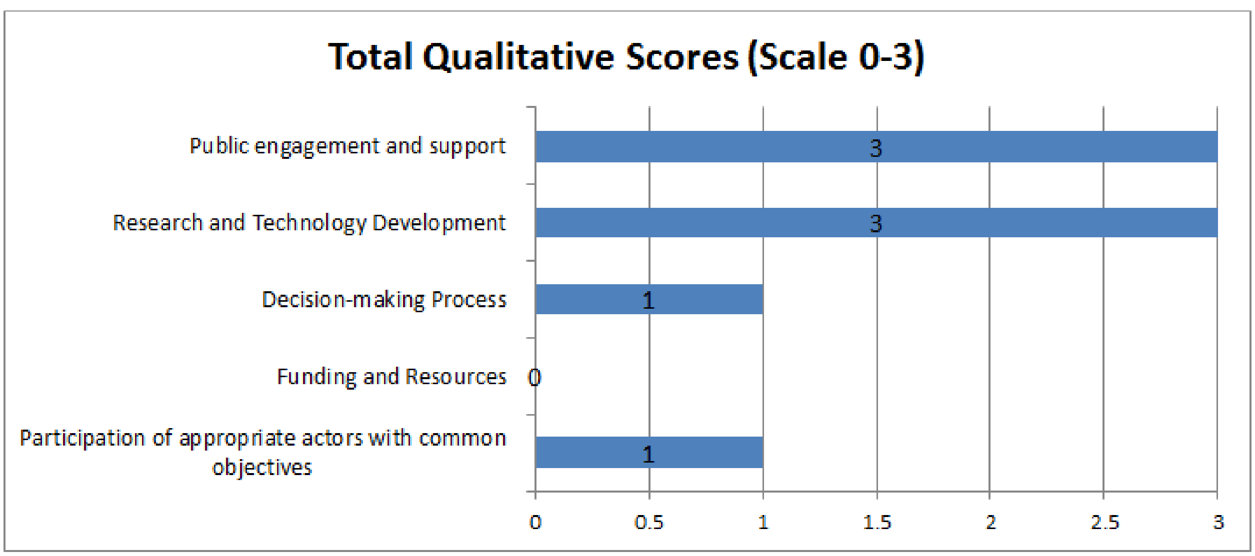
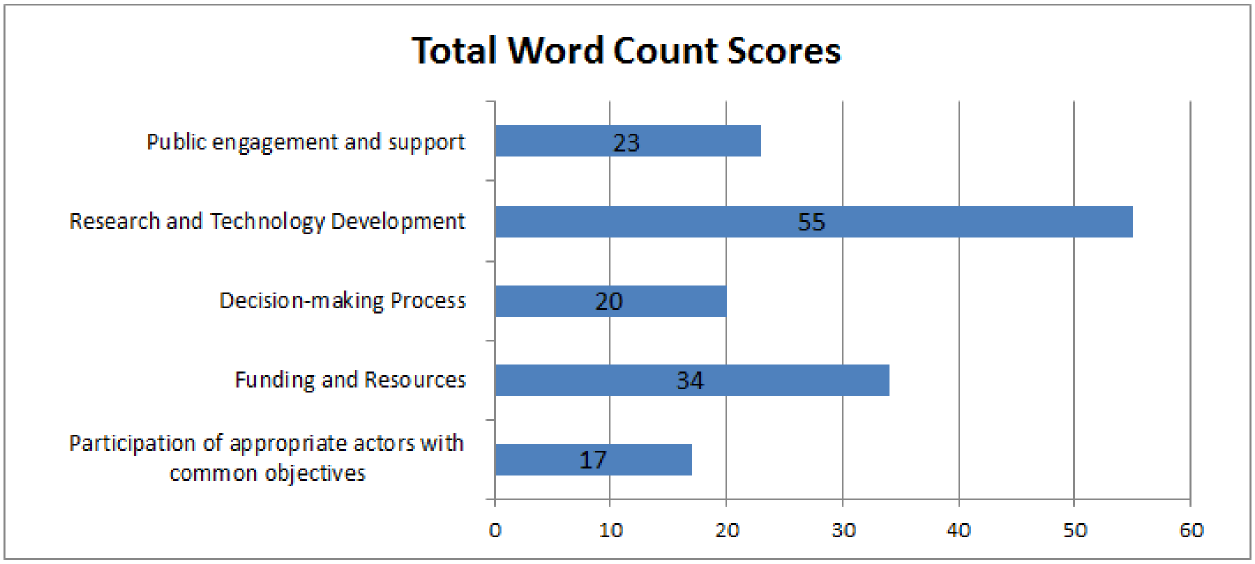


Figure 12: Document 6 Quantitative Data Analysis



Document 7: Handbook - Remediation of Contaminated Sediments (United States Environmental Protection Agency, 1991a)

This handbook focuses on small site contaminated sediment remediation with an emphasis on treatment technologies. The purpose of this handbook is to provide a technical resource document for various government, consulting, engineering, and scientific organizations who are responsible for the management of contaminated sediments.

This document achieved an overall average qualitative score of 0.8 with a “good” score in the theme of research and technology (Figure 13). This is because the document provided a detailed discussion of some of the technologies used during various phases of a sediment remediation. The handbook scored a “limited” in the themes of funding and resources and decision-making process. This is because, in terms of the funding and costs, it mainly focuses on technology implementation costs and efficiencies without discussion of cost sharing amongst groups of stakeholders. Also, the document did not discuss the decision-making process between groups of stakeholders. The document scored a “none” in the themes of participation of appropriate actors with common objectives as well as public engagement and support because it did not provide any mention of these themes.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis except the words in the theme of the funding and resources (Figure 14). This is because costs and resources were discussed in the context of treatment technologies and type of remediation.

Figure 13: Document 7 Qualitative Data Analysis

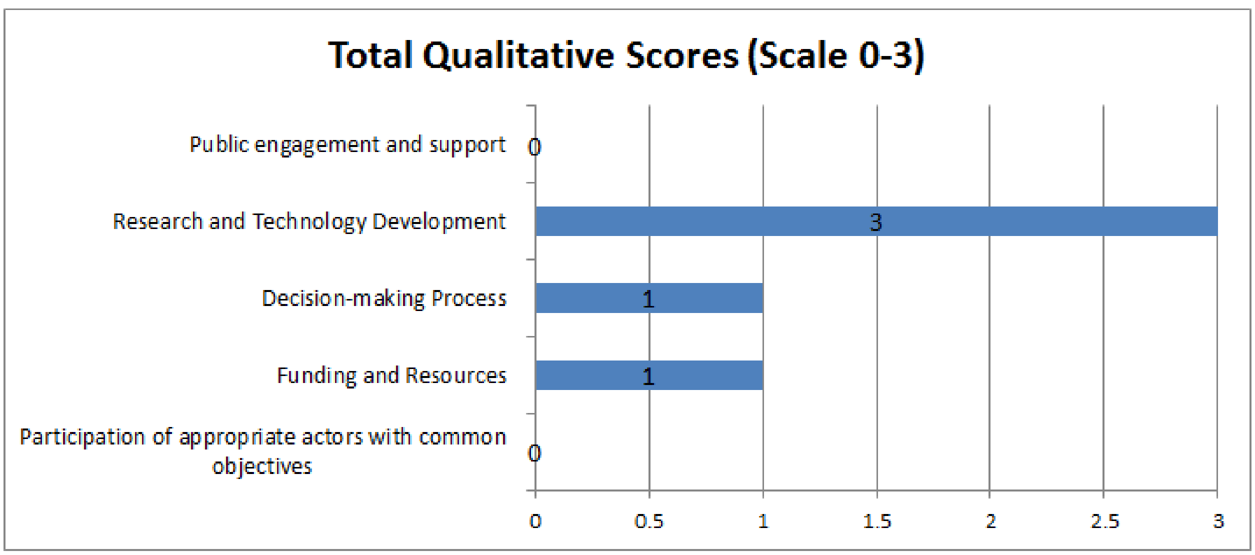
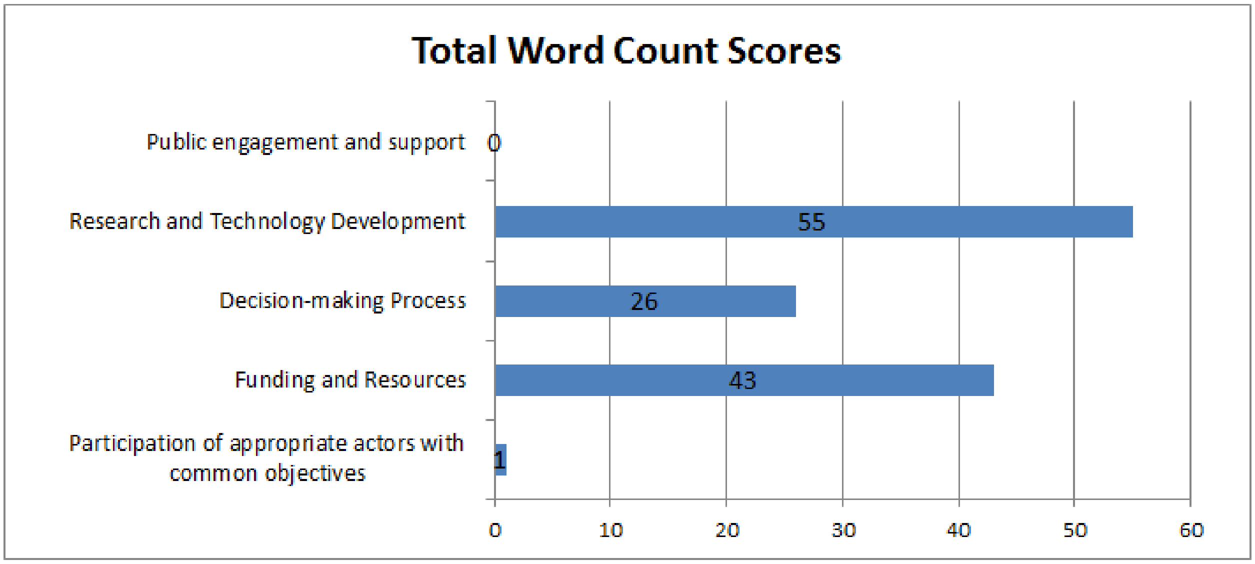


Figure 14: Document 7 Quantitative Data Analysis



Comparative Analysis of Policy Documents

Figure 15 shows that the most commonly occurring theme in the documents was "decision-making process," which scored an average of 1.7. In four out of seven documents, the theme "decision-making process" scored either “fair” or “good.” The remaining documents scores for this theme was “limited” (Figure 16). This implies that in general, these documents place high importance on the need for a well-defined decision-making process when it comes to environmental remediation. The second most common theme was "research and technology development" with an average score of 1.6. There were some inconsistencies between how each of the seven policy documents scored on this theme; two documents scored “good,” one document “fair,” one document “limited” and one document "none." This means not all policy documents put emphasis on research and technology to improve the environmental remediation process and reduce timelines and costs. Older policy documents (documents 6 and 7) put more emphasis on research and technology when compared to the more recent policy documents. "Public engagement and support" scored an average of 1. As shown in Figure 16, four out of seven documents scored either "limited" or "none." This means most policy documents do not place any importance on engaging the public during environmental remediation projects.

"Funding and resources" was the second lowest occurring theme with an average score of 0.9. Five out of seven documents either scored “limited” or “none” in this theme suggesting a general lack of importance placed on the allocation of the funding and resource among various stakeholder group in environmental remediation projects (Figure 16). The lowest scoring theme was "participation of appropriate actors with common objectives" with an average score of 0.6. It becomes evident that participation of appropriate actors with common objectives was not given importance in environmental remediation guidance documents.

This means that there is a significant lack of importance placed on defining roles and responsibilities among actors with common objectives in the guidance documents.

Figure 15: Total Average Scores of Qualitative Analysis for Policy Documents

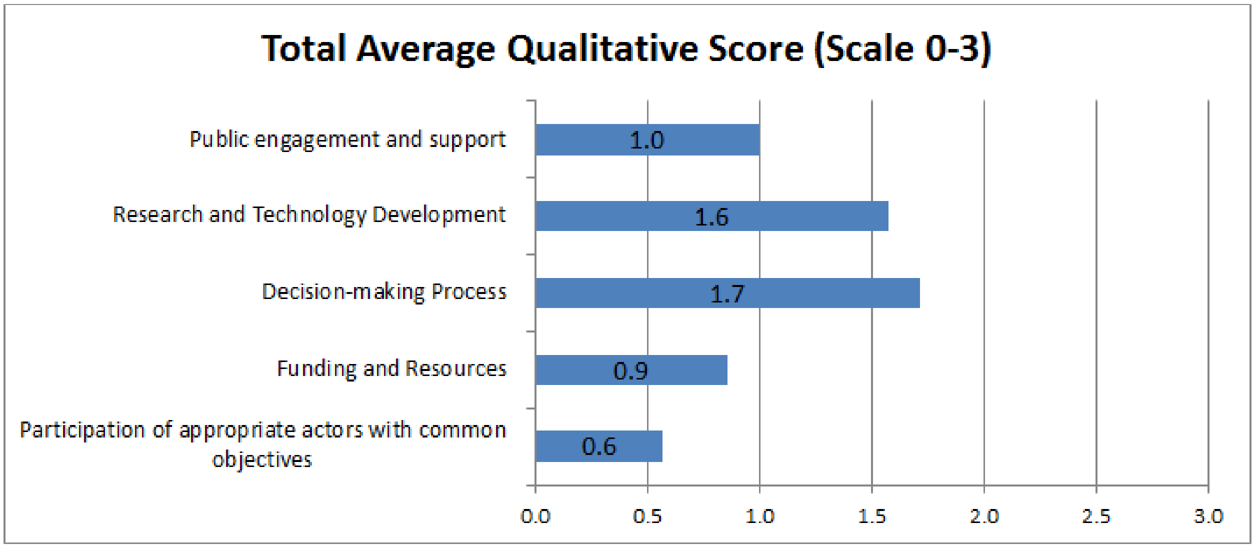
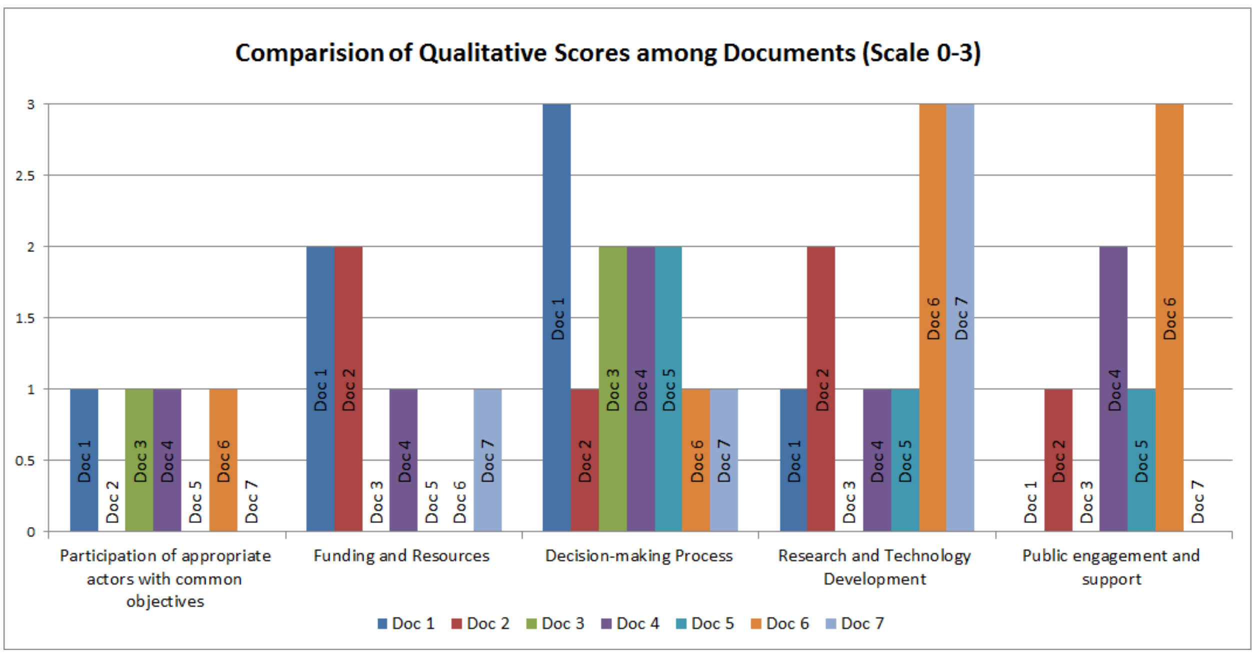


Figure 16: Comparison of Qualitative Scores among Policy Documents



Results and Discussion for Selected Research Papers

Document 8: Risk-Based Decision Making to Manage Contaminated Sediments (Bridges et al., 2006)

This is a discussion paper which provides a summary of discussions held among several experts who served on a panel at the Third Battelle International Conference on Remediation of Contaminated Sediments held in New Orleans, Louisiana, USA, in January 2005. In this paper, the experts review how sediment management decisions are currently made and address the question of how management decisions should be made in the future.

This paper achieved an overall average qualitative score of 1.4 with a “good” score on the theme of "decision-making process." The paper gives very high importance to an effective decision-making process for a sediment project to succeed (Figure 17). The paper scored “fair” on "participation of appropriate actors with common objectives." This is because, although various stakeholders, decision-makers, and non-decision-makers were identified and their general roles and responsibilities were outlined, there was no discussion on how common objectives could be achieved between the diverse groups. The paper scored “limited” for both the "funding and resources" and "research and technology" because in most cases, costs, funding, and resources were discussed in the context of the task of remediation rather than allocation of the funding and resources among various groups of stakeholders. Similarly, there was little discussion on how to improve the decision-making process through employing innovation, research, and technology. The paper scored “none” in "public engagement and support" as it did not mention this theme in any relevant context.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis except the words in the theme of the funding and resources which scored less in the qualitative analysis (Figure 18). The reason, as mentioned above, is that in this theme, the funding and resources were discussed in the context of the direct or indirect site remediation costs and not regarding allocation or cost sharing between various groups.

Figure 17: Document 8 Qualitative Data Analysis

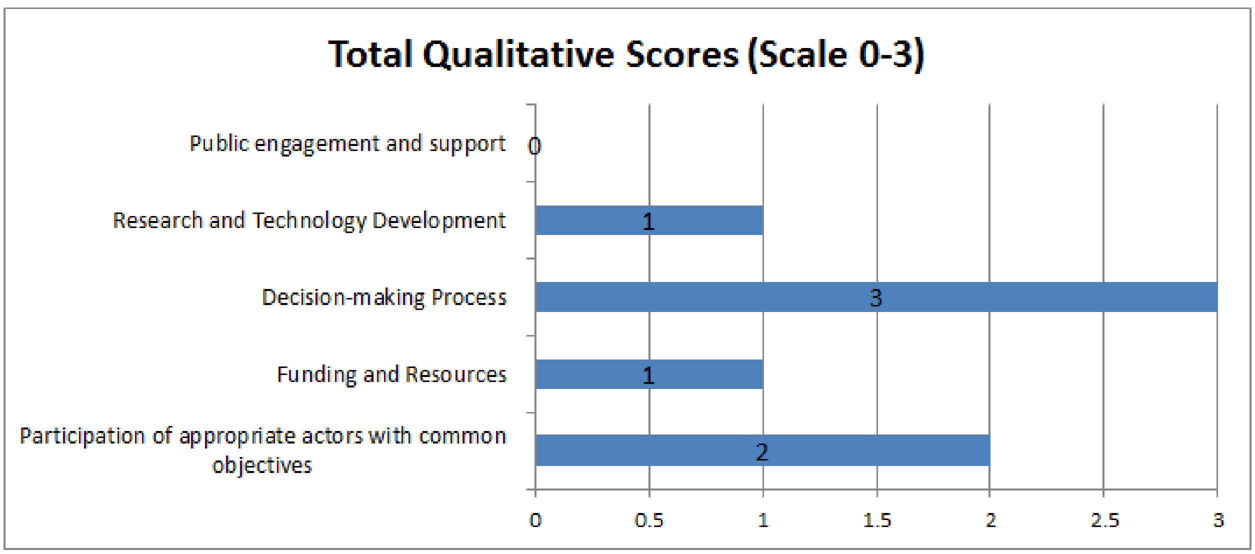
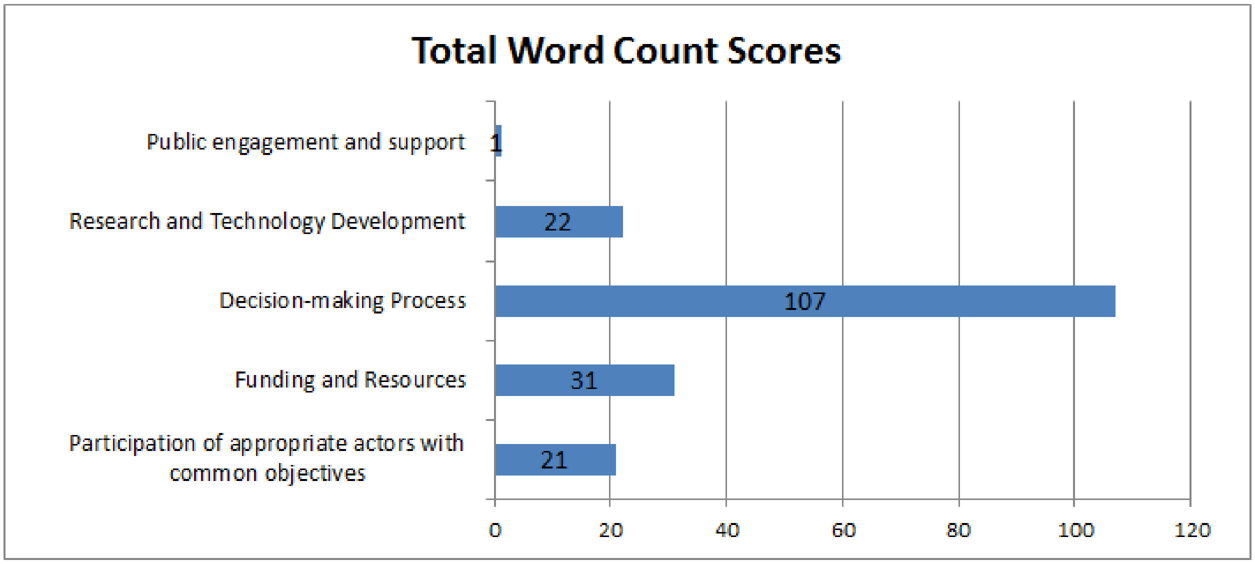


Figure 18: Document 8 Quantitative Data Analysis



Document 9: Accelerating Progress at Contaminated Sediment Sites

Moving from Guidance to Practice (Bridges et al., 2012)

The purpose of this research paper was to identify opportunities to fast track the progress of remediation contaminated sediment sites. A workshop was held in the United States among experienced experts from government, industry, consulting, and academia. The workshop participants identified five key tasks that would fast track the progress and increase the effectiveness of risk management at contaminated sites. These tasks included 1) development of a detailed and explicit project vision and accompanying objectives; 2) strategic engagement of stakeholders in a more direct and meaningful process; 3) optimization of risk reduction, risk management processes; 4) an incentive process that encourages and rewards risk reduction; and 5) pursuit of sediment remediation projects as a public–private collaborative enterprise.

This paper achieved an overall average qualitative score of 1.8 with a “good” score for each of the themes of "participation of appropriate actors with common objectives" and "decision-making process" (Figure 19). This paper has sections dedicated to identifying specific processes and steps to reach consensus among various stakeholders with competing objectives as well as reaching effective decision-making process to optimize risk reduction, risk management processes, and remedy selection at the contaminated sites. This paper scored "limited" on each of the three remaining themes namely "public engagement and support," "research and technology development," and the "funding and resources" due to lack of a detailed discussion on any of these topics.

The quantitative analysis which was carried out using specific word searches and counts within each category revealed mostly consistent results with those of the qualitative analysis except the words in the theme of the funding and resources (Figure 20). This paper discusses costs, funding, and resources in the context of project implementation and remediation costs and not in the context of cost sharing among various groups. Therefore, the score of the funding and resources appears high in the quantitative analysis as opposed to the qualitative analysis.

Figure 19: Document 9 Qualitative Data Analysis

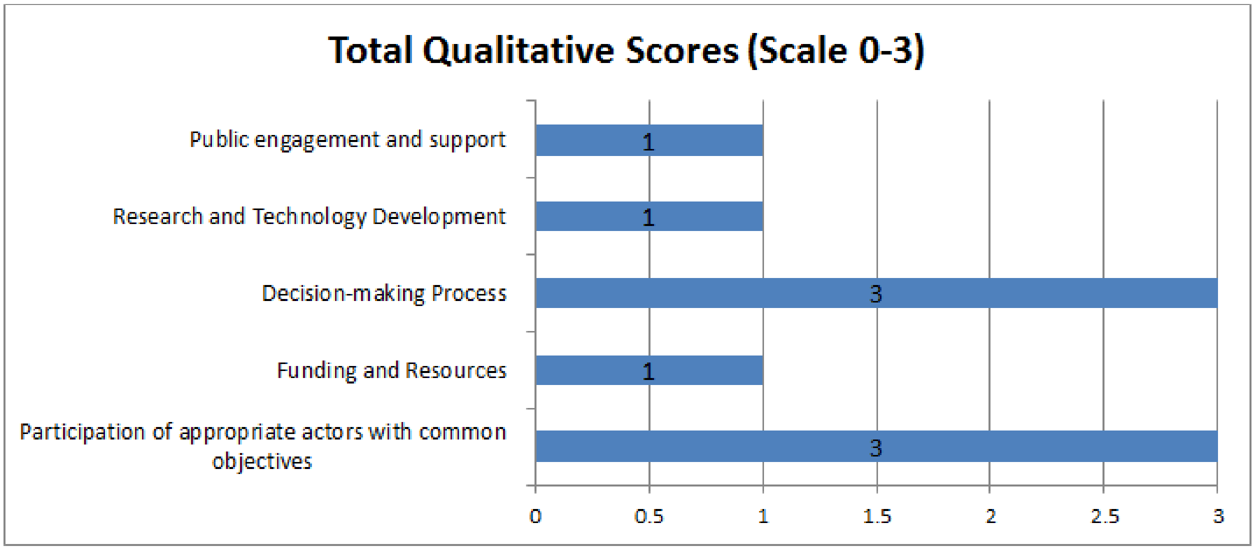
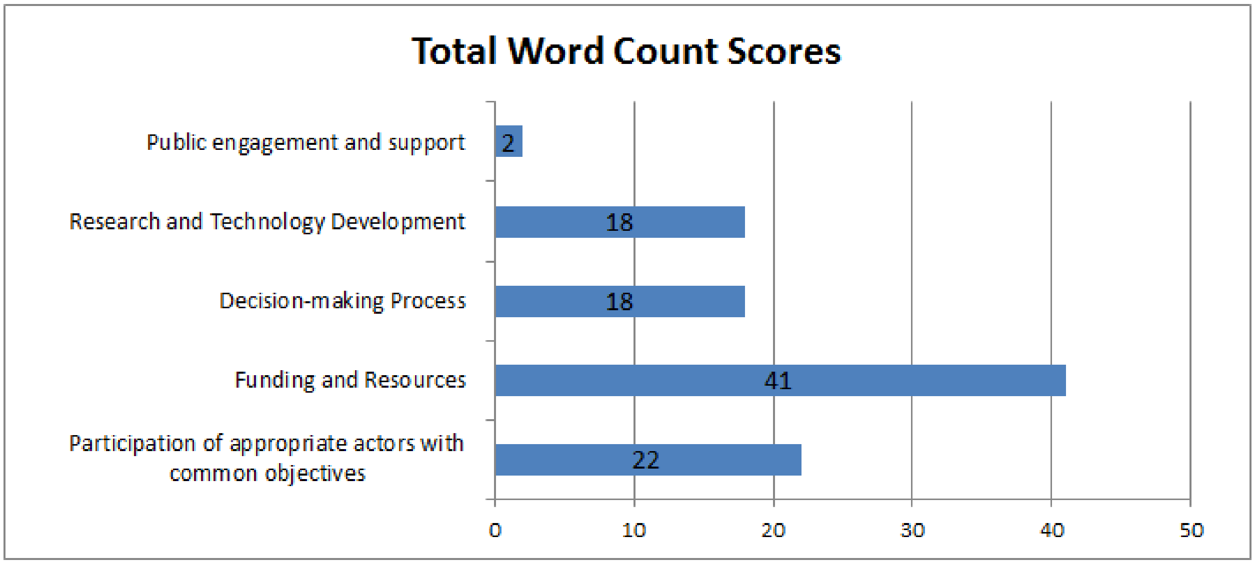


Figure 20: Document 9 Quantitative Data Analysis



Comparative Analysis of Policy Documents and Research Papers

The two research papers are unique in the sense that they conducted interviews with experts and agencies to identify the gaps and what should be done to manage contaminated sites better. The research papers placed very high importance on an effective decision-making process which is also in-line with the policy documents. However, the research papers also placed great importance on the "participation of appropriate actors with common objectives", which was not the case with the policy documents. In fact, the theme of "participation of appropriate actors with common objectives" was the least discussed in the policy documents. We believe this is an important issue that future policy documents could put more emphasis on. It is interesting to note that the research papers, just like the policy documents, did not place importance on "public engagement and support "or the "allocation of the funding and resources among a various group of stakeholders." This is in contrast to numerous authors who have emphasized the importance of engaging the public in environmental projects (Applegate, 1998; Beierle & Cayford, 2002; Beierle & Konisky, 1999; Bradbury & Branch, 1999; Carr et al., 2013; Coglianese, 1997; Cox, 2012; De Stefano, 2010; Irvin & Stansbury, 2004; Jawed & Krantzberg, 2017b; Li et al., 2017; Luyet et al., 2012; Lynn & Busenberg, 1995; Renn et al., 1995; Rowe & Frewer, 2000; Skei, 2007; Yosie & Herbst, 1998).

In recent years, environmental law and policy has been going through transformation in governance models, moving from central state, top-down regulation to more transparent, local decision-making processes involving non-governmental organizations, concerned citizens, private firms and community interest groups (Abbott, 2012; Carr et al., 2012; Driessen et al., 2012; Holley et al., 2013; Newig, 2007; Newig & Fritsch, 2009; Rauschmayer et al., 2009; Wesselink et al., 2011; Xavier et al., 2017). It is worth noting that there has been an evolution in how stakeholders (now also termed communities of interest) are involved. Originally the ecological risk assessment paradigm kept scientists and stakeholders separate. However, this approach is recently changing, and the importance of engaging the public is being recognized. There is a need to fully integrate risk assessors and communities of interest into the risk-management processes (Selck et al., 2017). Therefore, it is reasonable to expect that such evolution would be adequately reflected in future government policy documents or in their updates.

Conclusions and Recommendations

The comparative analysis of selected policy documents revealed that there is a significant lack of importance placed on defining roles and responsibilities among actors with common objectives in the guidance documents. However, the two selected research papers put high importance on the same theme. This is an important issue that needs to be addressed by future policy documents.

Our analysis demonstrated the need for sediment remediation guidance documents to improve and address important contributors to successful decision-making and implementation outcomes particularly in the main areas including defining roles and responsibilities of stakeholders, the benefits of public engagement and support, and clarification of the allocation of the funding and resources. This could result in more timely and collaborative decision-making for contaminated sediment management.

Acknowledgements

The authors wish to thank Dr. John Eyles, Professor at McMaster University, for his guidance and inputs to establish Quality Document Analysis method. We also thank Dr. Lynda Lukasik, Director of Environment Hamilton, for her review and valuable comments.

Chapter 5: A Decision Support System Framework for Contaminated Sediment Management

A Decision Support System Framework for Contaminated Sediment Management

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Abstract

Often, environmental decisions are complex and multi-faceted and involve many stakeholders with competing (sometimes conflicting) priorities or objectives presenting exactly the type of problem that humans are poorly equipped to solve unaided. A systematic methodology to combine both quantitative and qualitative data from scientific, engineering, technological, and economic studies of risk, cost, and benefit, as well as stakeholder objectives and values to rank project alternatives, has yet to be fully developed for contaminated sediment decision-making.

This paper develops a Decision Support System (DSS) framework for contaminated sediment management projects incorporating the five key themes that we found are most relevant. These themes are: 1) participation of appropriate actors with common objectives; 2) funding and resources; 3) decision-making process; 4) research and technology development, and 5) public and political support.

Operationally, our proposed DSS framework has six key components as follows: 1) data module; 2) communication module; 3) document module; 4) knowledge module; 5) tools module; and 6) DSS optimization module. This generic framework can assist practitioners in developing more systematic and structured decisions for sediment remediation by incorporating an Integrated Information Management System (IIMS) along with a DSS optimization module. This IIMS+ DSS method can aid the decision-making process by making it documented, reproducible, robust, transparent and provide a coherent framework to explore and analyze available alternatives in an attempt to reach the preferred solution promptly.

Key Words: Decision Support System (DSS); sediment remediation; Great Lakes Areas of Concern; environmental decision-making; Multi-Criteria Decision Analysis (MCDA); Integrated Information Management System (IIMS)

Introduction

Great Lakes Areas of Concern (AOC) are geographic locations where significant impairment of "beneficial uses"[1] of the Great Lakes or their tributaries has occurred. In the Great Lakes basin, for example, sediment quality issues and concerns were identified in 42 out of 43 AOCs that have been identified under the Canada-United States Great Lakes Water Quality Agreement (Governments of Canada and the United States, 2012). This matter is not limited to the Great Lakes. For example, such issues and concerns have been identified in nineteen areas within Sado Estuary, West Coast of Portugal (Caeiro et al., 2009). Similar problems have also emerged in 31 regions of China (Li et al., 2017); Lake Ketelmeer, the Netherlands (Jonker & Smedes, 2000); Naples Harbour, Southern Italy (Sprovieri et al., 2007). Sediment contaminated with metals is also a concern in Kaohsiung Harbor, Taiwan (Chen et al., 2007); Toulon Bay, France (Tessier et al., 2011); Sydney Harbour, Australia (McCready et al., 2006); and Thermaikos Gulf, Northern Greece (Christophoridis et al., 2009). In Europe, there are more than 2.5 million potentially contaminated sites and out of this approximately 14% will require remediation efforts (Panagos, Van Liedekerke, Yigini, & Montanarella, 2013; van Liedekerke, Prokop, Rabl-Berger, Kibblewhite, & Louwagie, 2014).

When it comes to decision-making regarding the management of contaminated sediment, what is needed is an integration of knowledge from many disciplines (Huysegoms & Cappuyns, 2017). Effective management of contaminated sites requires numerous decisions regarding a suite of scientific, technical, economic, and social concerns along

1- Beneficial use impairments (BUIs) means "a change in the chemical, physical, or biological integrity of the Great Lakes system sufficient to cause any of the 14 use impairments or other related uses covered by Article IV such as the microbial objective for waters used for body contact recreational activities" (GLWQA, 2012).

with compliance with a regulatory need, and prioritization of resources. Each factor has its own diversity of decisions that need to be made. These include human health risks, ecological risks, economic costs, the technical feasibility of proposed remedial actions, and the value society places on remediation and reuse of these contaminated areas (Fischer et al., 2017; Read et al., 2014).

Complexity of Environmental Decision-making

Decision-making in the face of uncertainty and involvement of multiple stakeholders with different interests and objectives which keep changing over time, is a challenging element in environmental management with significant economic implications (Alvarez-Guerra, Canis, Voulvoulis, Viguri, & Linkov, 2010; Alvarez-Guerra, Viguri, & Voulvoulis, 2009; Courtney, 2001; Read et al., 2014). Scientific research has shown that humans are poorly equipped to solve multi-layered problems (also termed as “wicked problems”) (Courtney, 2001; Kiker et al., 2005; McDaniels, Gregory, & Fields, 1999; Zijp, Posthuma, Wintersen, Devilee, & Swartjes, 2016). Mostly, when people encounter complex issues, they attempt to use approaches that simplify the complexity so that they can manage the problem at hand. During this process, valuable information may be lost, conflicting points of view may be discarded, and elements of uncertainty may be disregarded or simplified. It could be reasonably expected that stakeholders on their own will often have challenges making informed and thoughtful choices in a complex environmental decision-making context/scenario involving value trade-offs and uncertainty (Bridges et al., 2012; McDaniels et al., 1999; Read et al., 2014).

Although each environmental remediation problem is unique and requires a site-specific analysis, many of the key decisions are similar, at least in structure. This has led many practitioners to attempt to develop standard methods. One type of standarisation method that has been used increasingly in environmental decision-making is Multi-Criteria Decision Analysis (MCDA) (Linkov & Moberg, 2017; Linkov et al., 2004; Sparrevik, Barton, Oen, Sehkar, & Linkov, 2011). The method allows for preferences and performance about different management alternatives to be assessed in a clear, formal way that is both mathematically rigorous and transparent to stakeholders (Linkov & Moberg, 2017). MCDA process is broken down into five key steps as follows:

1. Problem Identification: The problem is defined in terms of relevant stakeholders and overall structure
2. Problem Structuring: Various alternatives and criteria are defined
3. Model Assessment and Building: The alternatives and criteria are given quantitative values. The alternatives are then scored against the criteria. Stakeholders also weight criteria according to the value or importance they put on that criterion.
4. Model Application: The criteria weights and alternative scoring are used in an MCDA model to provide a decision about the best alternative according to the data given. There are many different types of MCDA models such as Multi-Attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP), and Outranking. Each model works differently but essentially combines the preference and scoring information to make the decision.
5. Planning and Extension: Once the model has been run, the output can be used to make decisions or inform further planning.

The MCDA method alone cannot provide a holistic solution to all aspects of sediment remediation projects, and it is evident by the fact that formal applications of MCDA in the management of contaminated sites is rare (Kiker et al., 2005). Therefore, it is recommended that MCDA is used in conjunction with other methods for more effective, efficient, and credible decision-making (Kiker et al., 2005). Other methods could possibly include tools such as Decision Support Systems (DSS) (Aronson, Liang, & Turban, 2005; Beynon et al., 2002; Bhargava, Power, & Sun, 2007; Clarke et al., 2017; Delpla et al., 2014; Filip, 2008; Giove, Brancia, Satterstrom, & Linkov, 2009; Kharbat & Sultan, 2017; Power, 2007). The DSSs are intended to facilitate reproducible, robust and transparent decision-making (Power & Sharda, 2009).

Review of Decision Support System (DSS) and its Applications around the Globe

A DSS is an interactive system that helps practitioners use data, documents, knowledge, and models to solve simple or complex problems alike and make decisions (Power & Sharda, 2009). In the literature, there are five generic types of DSS which are identified including communications-driven, data-driven, document-driven, knowledge-driven and model-driven DSS (Bhargava et al., 2007; Power, 2007, 2008). These DSSs are built to support individuals in making decisions, not to make the decision itself (Angehrn & Jelassi, 1994; Power & Sharda, 2009). DSSs are regularly used by decision-makers all over the world for management of various environmental issues (Aronson et al., 2005; Delpla et al., 2014; Power & Sharda, 2009). For example, some of the applications where DSS has been used (Sullivan, 2004) include:

• Optimization of pesticide and irrigation applications to maximize crop yield.

• Minimization of financial risks for large construction projects.

• Minimization of financial risks for remediation of contaminated sites.

• Optimization of the use of groundwater resources.

DSSs have shifted over time from solving semi-structured problems to solving complex issues (Beynon et al., 2002; Courtney, 2001; McCown, 2002; Rauscher, 1999; Shim et al., 2002). The characteristics of a complex problem is that stakeholders cannot easily agree on the problem definition, and options for solutions are not clear (Rittel & Webber, 1973). To solve such complex problems, a collectively accepted solution is required. Therefore, the focus should be on achieving consensus on the problem formulation and problem resolution, based on discussions with stakeholders, to incorporate their perspectives (Mateus, e Costa, & Matos, 2017; Shim et al., 2002) and to ensure that all applicable variables and constraints are incorporated in the analysis (Shim et al., 2002). While this is not intended to be a comprehensive coverage, below are some examples where a DSS was successfully used to resolve complex environmental issues:

Example 1: In Europe, environmental policies are promoting the development and implementation of renewable energy technologies, such as grid-connected photovoltaic solar energy. To select the optimal locations for grid-connected photovoltaic power plants, Geographic Information System (GIS) based DSS was utilized in Europe to facilitate this decision-making process. This DSS system integrated MCDA with GIS and incorporated other considerations such as climate change and environment (Carrion et al., 2008).

Example 2: The sustainable management of brownfields is a complex multi-dimensional decision process, and there is a need to use models further to integrate the dilemmas of multiple values and conflicting views in solving sustainability issues (Bello-Dambatta, Farmani, Javadi, & Evans, 2009). Most recommended processes for the sustainable management of brownfield sites include MCDA methodology, where the involvement of stakeholders in decision making may result in more socially acceptable choice, better conflict management and increased trust among stakeholders (Linkov, Sahay, Kiker, Bridges, & Seager, 2005). However, there are few real-world applications of these approaches published in the literature (Bello-Dambatta et al., 2009; Linkov et al., 2005), especially involving group decisions (Kiker et al., 2005) and related DSSs (Carlon, Critto, Ramieri, & Marcomini, 2007; Carlon, Hope, & Quercia, 2009). A study in Portugal used MCDA in combination with a DSS to make management decisions for brownfield sites (Mateus et al., 2017). The study selected a group of key stakeholders and structuring of the problem was carried out during a decision conference by use of several DSSs (namely M-MACBETH, MACBETH Voting, and Web-MACBETH) to support the engagement and participation of the group of stakeholders and to collect from them their preference and assessments of feasibility of the actions along with the weights of the respective criteria. The stakeholder group represented a community that had to come to a consensus on the best steps to implement sustainable redevelopment of brownfield sites involving multiple values and conflicting objectives.

Example 3: The State of Michigan provides economic benefits and legal avenues for local government and developers to purchase brownfield sites for redevelopment purposes. To properly select the site concerning redevelopment plans, a significant amount of information is required related to development incentives; land capability; public goals; and environmental concerns such as site contamination and environmental quality. A unique GIS based DSS (called Smart Places®) was developed to assist local government and developers in this process by providing access to state, regional, and local geospatial databases, several informational and visualization tools, and assumptions useful in providing a better understanding of issues, options, and alternatives in redeveloping brownfields (M. R. Thomas, 2002).

Example 4: Problems with contaminated sites restoration include site characterization and data processing, evaluation of the risk, and choice of proper remediation technologies. To resolve these complex environmental issues, a DEcision Support sYstem for the REqualification of contaminated sites (DESYRE) was built to support stakeholders in order to establish a better understanding of the rehabilitation process and to choose the optimal solution. The DSS is based on a GIS framework and integrates environmental and technological databases, risk assessment models, and multi criteria procedures. It is composed of five modules: (1) characterisation, (2) risk, (3) socio-economical and (4) technological analysis, and (5) decision. In this specific DSS, framework, the MCDA tools were used twice. Firstly, the MCDA tool assigned a score to each technology based on the selected criteria and secondly, when decision-makers evaluated each remediation scenario proposed by the experts in a group scenario (Carlon et al., 2007).

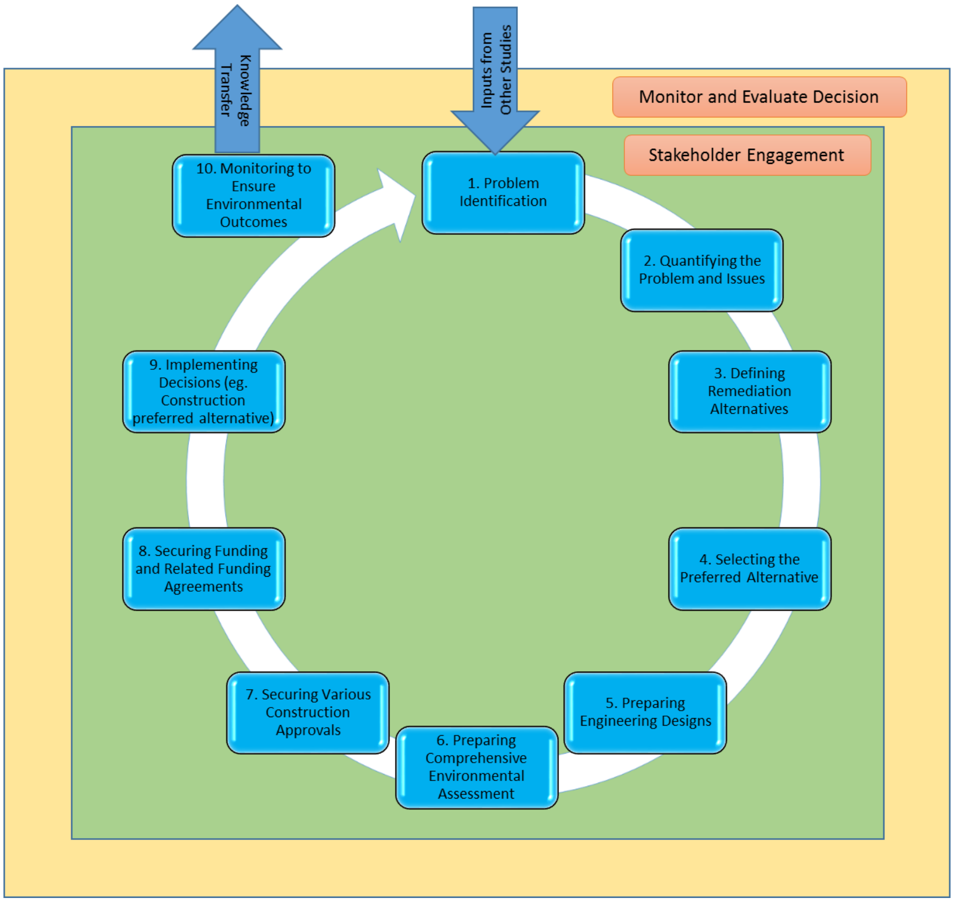
The jurisdictional review reveals that agencies around the world are increasingly employing DSSs to support their decision-making process in environmental projects. These DSSs have been used to provide various capabilities such as visualization, information dissemination, data analysis, public engagement, MCDA, and cost benefit analysis. Therefore, there is strong evidence to argue that such DSS capabilities are warranted in advancing sediment remediation projects to make the remediation process more robust while benefiting from the many attributes a DSS can offer.

Randle Reef Case Study and the need to for Decision Support System (DSS)

The Randle Reef contaminated sediment site, located in the southwest corner of Hamilton Harbour in Ontario, Canada, is approximately 60 hectares in size. This site contains approximately 695,000 m^3 of sediment contaminated with polycyclic aromatic hydrocarbons (PAH) and metals (Graham, 2011; Hall & O'Connor, 2016; Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012).

The Randle Reef sediment remediation project consisted of many phases (Figure 1) from problem identification, quantification of the problem and issues, defining remediation alternatives and selection of preferred alternatives, engineering design, and preparation of comprehensive environmental assessment, securing the funding and related funding agreements, legal considerations, public consultation and plans for future monitoring to ensure beneficial use impairments are restored (Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012).

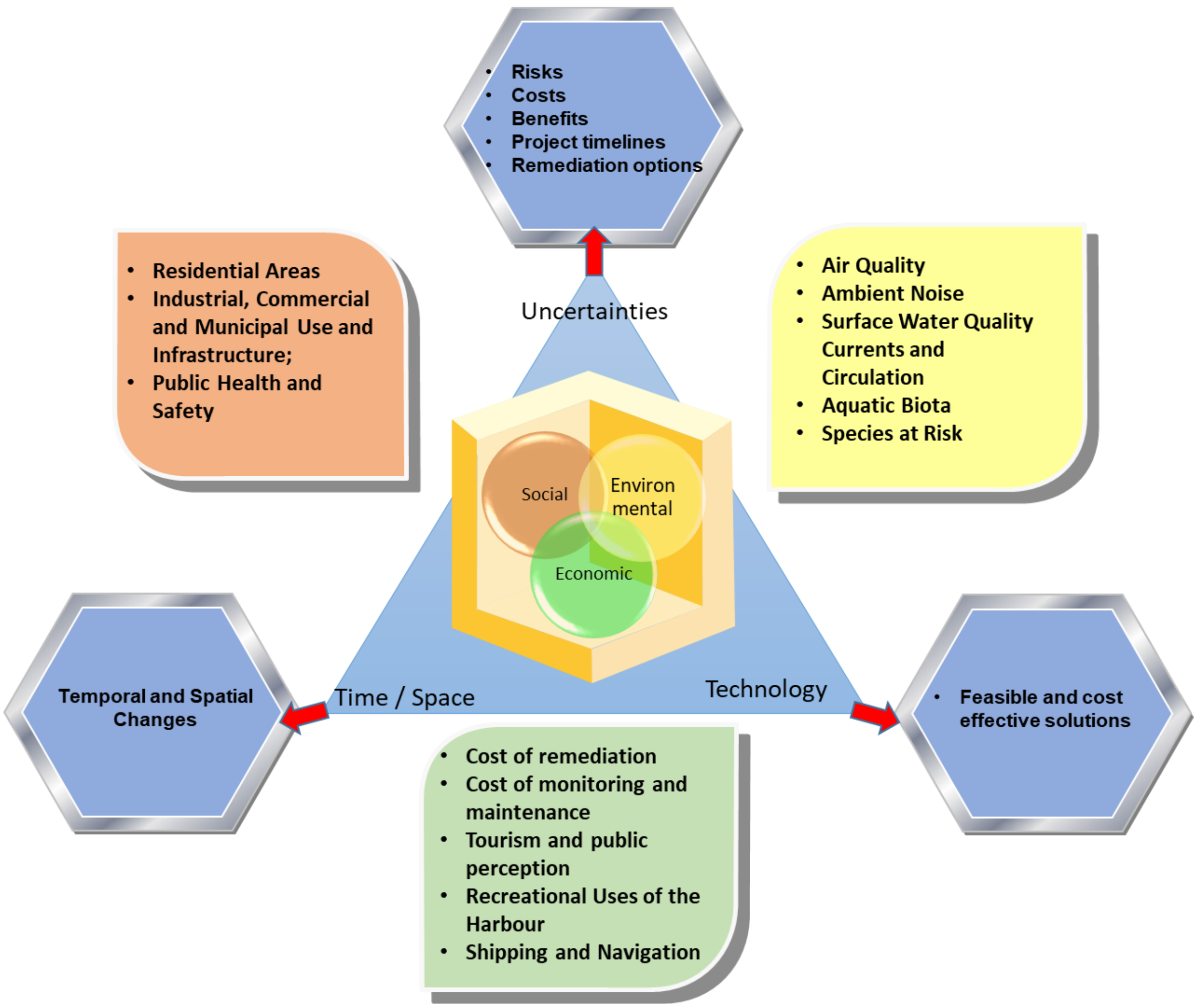
Figure 1: Phases of the Randle Reef Sediment Remediation Project



The remediation plan involves the construction of a 6.2 hectare Engineered Containment Facility (ECF) over 140,000 m^3 of the most highly contaminated sediment with PAH and metals (Bay Area Restoration Council, 2017). The site was identified as a principal target of Harbour restoration objectives in the late 1980s and early 1990s, and after many years of discussion and negotiations among various stakeholders, the site is finally going through remediation efforts to restore the beneficial uses in the Hamilton Harbour. Remediation of the site began in 2016, is currently underway and is expected to be completed by 2022 (Graham et al., 2017).

The most effective strategy to remediate contaminated sites like Randle Reef is often unclear to the various stakeholders. Processes to set priorities and come to agreements are lacking, hampering the articulation and implementation of possible solutions promptly (Jawed & Krantzberg, 2017a).

Figure 2: Complexity and Considerations in the Randle Reef Sediment Remediation Project



The Randle Reef sediment remediation project was very complex as it has a myriad of social, economic, environmental and other issues that needed to be addressed as shown in Figure 2. For example, regarding environmental issues, many considerations needed to be addressed such as surface water quality and aquatic biota (Randle Reef Sediment Remediation Project- Technical Task Group et al., 2012). There are also other competing and sometimes intersecting economic and social considerations. These needed to be balanced within the constraints of time, project uncertainties/risks, and available technology. Because of this complexity, there is a need for a user-friendly interface, such as a DSS that can address these complex interrelated issues to help manage these remediation issues.

A number of studies have indicated that there are five key themes that are frequently identified as obstacles when dealing with remediation of contaminated sediment sites (Beierle & Konisky, 1999; Boyle & Oceans Institute of Canada, 1990; Hall & O'Connor, 2016; Hall & O'Connor, 2012; Jawed & Krantzberg, 2017a; Krantzberg, 2003; Li et al., 2017; Read et al., 2014; Renn & Finson, 1991; Sediment Priority Action Committee & Great Lakes Water Quality Board, 1997; Zarull et al., 2001; Zarull et al., 1999). These are:

1) participation of appropriate actors with common objectives;

2) funding and resources;

3) decision-making process;

4) research and technology development;

5) public and political support.

A recent study by Jawed and Krantzberg (2017a) was undertaken through which interviews were conducted with various stakeholders and experts who have direct involvement in the Randle Reef sediment remediation project to understand the decision-making processes within the context of the five themes mentioned above. Stakeholders identified several significant hurdles within these themes that could not be effectively addressed through traditional decision-making processes. Some of the identified hurdles in the critical phases of the project were:

- Roles and responsibilities were not well-defined at various stages of the project
- Lack of equitable funding agreements and subsequent difficulty in obtaining funding
- Lack of representation of all relevant stakeholders
- Challenges in selecting the technology and agreement on a preferred remediation option
- Challenges in gaining public and political support
- Lack of effective communication among the group of stakeholders and the broader public

Stakeholders also identified the need for an effective DSS that not only optimizes the five themes but also addresses the identified hurdles early in the project to avoid potential delays. Sediment remediation decisions of the future may include social, environmental, and economic concerns, and be much more “wicked”, complex and interconnected than those of the past (Courtney, 2001; Read et al., 2014; Reible & Shepard, 2014). Although, the decision-making process may be extremely complex, it would certainly benefit from better decision-making tools. It is unlikely that any single person will have the knowledge to perform all the analysis required in supporting the overall decisions about the management of contaminated sediment remediation. It is also apparent that there are many decisions (e.g. what risk levels are acceptable, who are the key stakeholders, what is a public preference, what technologies should be used) that need to be made before remediation can take place. Therefore, DSSs used for sediment remediation projects must embrace procedures that can deal with this complexity and go beyond the traditional decision-making processes.

This paper aims to provide a structured framework for a DSS for contaminated sediment remediation projects that takes into consideration the challenges identified through the stakeholder interviews within the five key themes identified above.

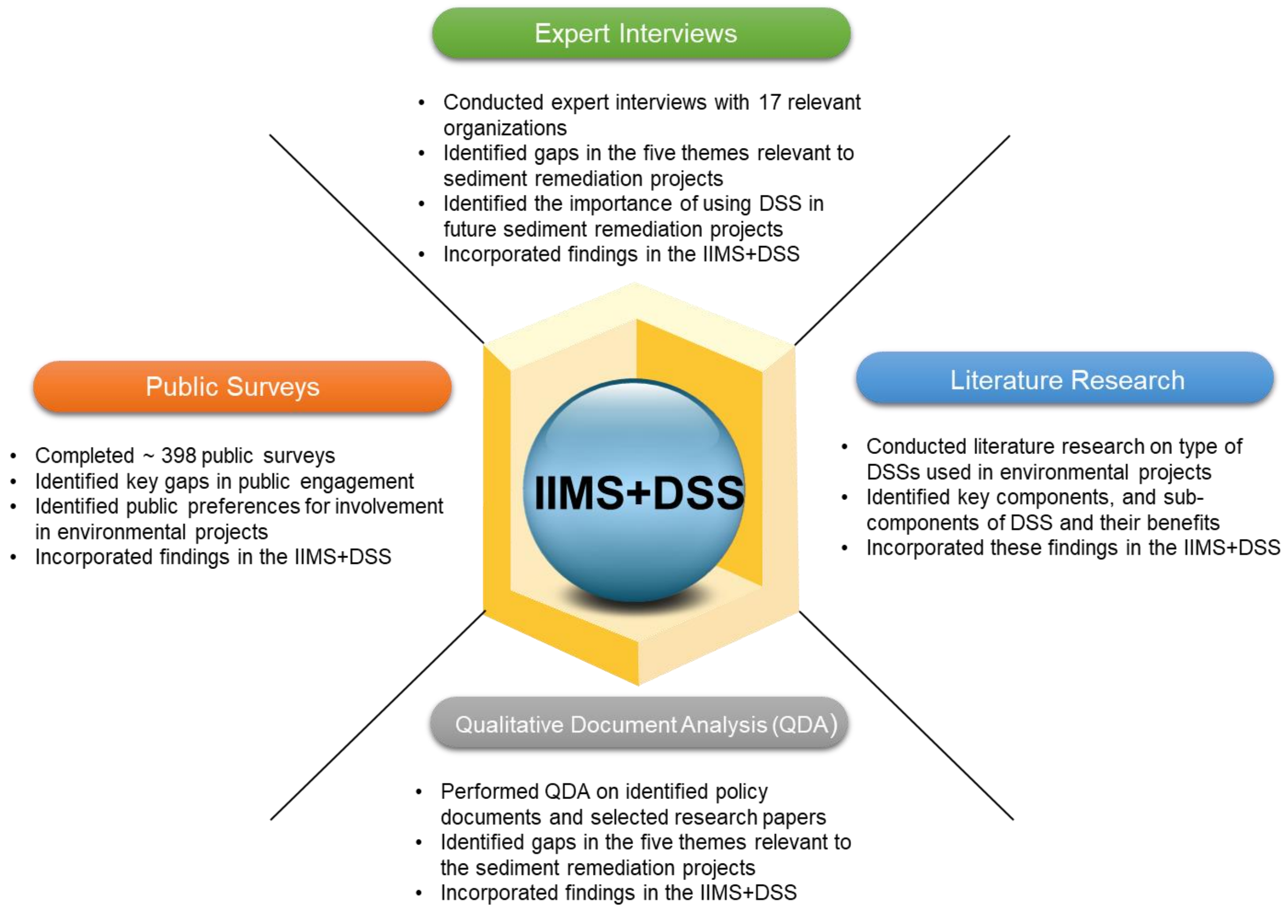
Process to Develop a Decision Support System (DSS) Framework

To develop a DSS framework for sediment remediation, the following multi-pronged research steps were carried out (Figure 3):

1. Public surveys were conducted to investigate public involvement in the Randle Reef project and highlight opportunities for improvement in public participation for future environmental cleanup projects. This information formed key input on how a DSS should take advantage of involving the public at all stages of the project
2. Interviews were conducted with experts and professionals from organizations (who are/were involved in the Randle Reef project) to identify the nature of performance in the five themes as identified above that are essential for successful action. These findings were incorporated into the suggested DSS framework.
3. Qualitative Document Analysis (QDA) was performed on selected sediment remediation policy documents and research papers so as to analyze how well each of the five key themes is addressed in these documents. The findings formed inputs to the proposed DSS framework.

4. A literature review was conducted to identify various types of DSSs, their components and sub-components, and their functionalities. This information was used to develop a suitable DSS framework for sediment remediation projects.

Figure 3: DSS Framework Development Process



Proposed Decision Support System (DSS) Framework for Sediment Remediation in North American Context

The purpose of a DSS is to provide structured information that can be used to support environmental decisions. It is essential for a DSS to take the appropriate information from all the available data and synthesize this information to provide knowledge useful to the decision process.

The DSS can be configured to store codified expert knowledge and expertise that can be easily retrievable for processing and referencing. The DSS is an efficient method to solve the problem using stored information with the objective of utilizing established rules or crucial decision-making issues (Sullivan, 2004).

Studies by Power (2004) and Courtney (2001) describe essential components and functionalities of a DSS that could be applied to complex sediment remediation projects. Increasingly agencies are incorporating DSSs that include information technology with storage, management, retrieval, analysis, and reporting functionalities to address their decision-making process (Power & Sharda, 2009). Modern DSSs are interactive computer-based systems or sub-systems designed to support the ability of decision-makers to make efficient use of various built-in systems consisting of communication technologies, documents, data, knowledge, and/or various models/tools to identify and solve specific problems, complete decision process tasks, and make robust decisions (Power & Sharda, 2009). These DSS systems and sub-systems consisting of various information technology components and tools provide a holistic approach to aid complex decision-making processes (Power, 2008; Power & Kaparthi, 2002; Power & Sharda, 2009).

Therefore, for this study, an information technology based DSS consisting of an Integrated Information Management System (IIMS) component and a Decision Support System (DSS) optimization module co-existing termed as “IIMS+DSS” is recommended as depicted in Figure 4. The IIMS component consists of a series of information management systems modules each for data, knowledge, communication, document, and tools while the DSS module has sub-modules to optimize each of the five key themes identified as being crucial to consider in sediment remediation projects. While the IIMS component helps provide efficient collection, organization, analysis, retrieval, and sharing of information for each of its sub-modules, the role of the DSS optimization module is to take the information available from the IIMS and other sources, and help generate strategies to reach a decision in the five key themes. These individual modules are described in detail below.

Figure 4: Features of Integrated Information Management System (IIMS) and Decision Support System (DSS)→ "IIMS+ DSS"

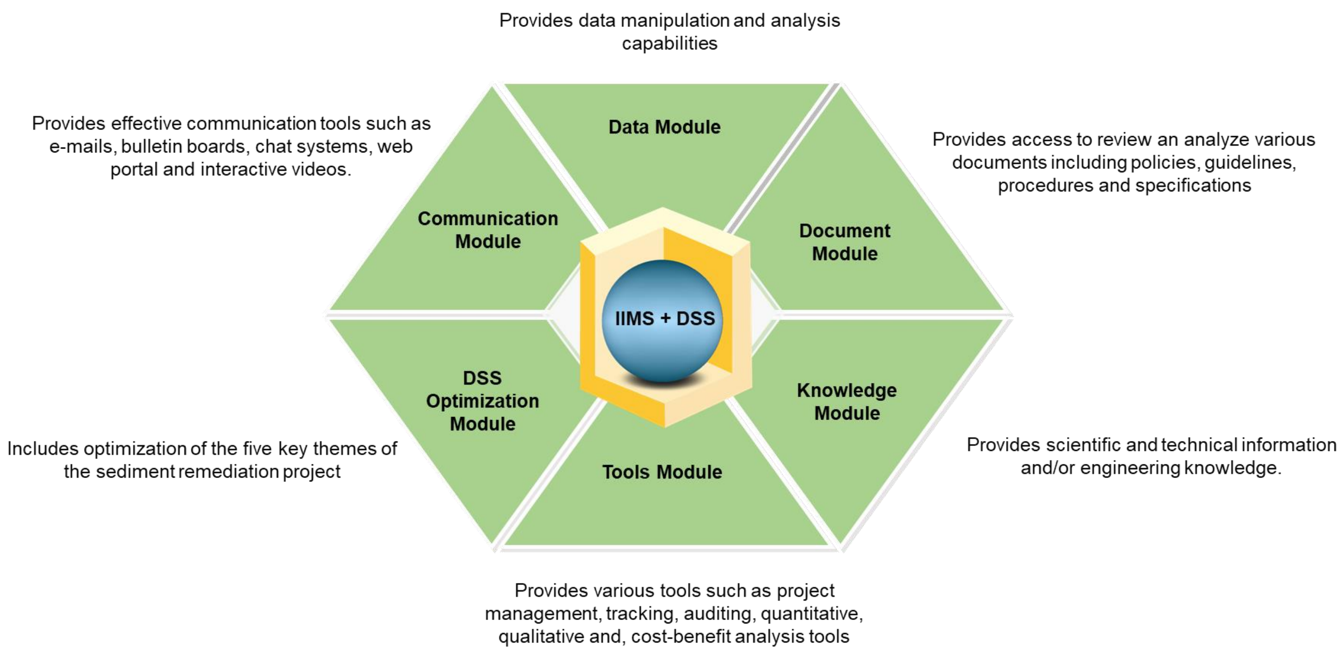


Figure 4 outlines the framework of recommended components of the IIMS+DSS, which essentially contains five information technology elements and one DSS optimization module as follows:

1. ***Communication module***; helps establish various communications protocols in the project and includes communication and collaboration supported by technologies such as e-mails, bulletin boards, chat systems, and interactive videos. This module can also be used to communicate all aspects of a project at each phase effectively to ensure up-to-date information is available and disseminated to everyone in real time, as necessary. Video conferencing and secure data transfer protocols may also be implemented in this module to conduct project meeting remotely with team members regardless of where they are located, and share sensitive or confidential material to team members securely. A sub-component of the communication module can be dedicated to public communications and interactions through the external facing website, Environmental Bill of Rights (EBR) postings (if warranted), and an interactive web portal. EBR postings are specific to Ontario, Canada for engaging public and there are very specific legislated requirements around when acts, policies or instruments need to be posted to the provincial EBR on-line registry. These engagement tools can help broaden organizational decision-making and facilitate communications among a wide variety of stakeholders and the public.

2. ***Data module;*** provides access to tools to manipulate large sets of data. In this module, data of various types, including temporal, spatial, qualitative, and quantitative, can be collected and stored. This module can also have the capability to connect to large data warehouses and can house both static, and time-series historical data to analyze various trends and patterns. This module should also allow an extraction, manipulation, analysis, and reporting of data to support project needs.

3. ***Document module***; provides means to collect, retrieve and analyze documents, such as project documentations, minutes of meetings, guidelines, policies, procedures, and regulations. The establishment of documented processes, procedures, and metrics is the key component of this module. The DSS is expected to enhance transparency (i.e. all parameters, assumptions, and data used to reach the decision should be clearly documented) and to ensure that the decision-making process itself is documented.

4. ***Knowledge-based or Scientific Knowledge module***; suggests necessary actions within a specific domain. In this module, technical, scientific, and engineering knowledge from various related studies, and projects can be stored for quick reference and design considerations. Risk information (e.g. Ecological Risk Assessment information) is obtained and centrally housed in this module and is considered in various phases of the project. This module is also suited for knowledge transfer for succession planning, talent management, and employee training. The knowledge-based module may also be configured to include community-based knowledge for legacy contaminated projects. Often long term community members have awareness of historical environmental issues that the experts may not currently know about.

5. ***Tools module***; provides access to project management, quantitative, qualitative and cost-benefit analysis tools and other models. This module can help provide comprehensive suites of project management tools to set milestones, establish activities, track progress, identify and resolve project management issues, and all other elements of effectively managing the project. This module can also provide additional models and tools to evaluate options, alternatives and uncertainties during various project stages and can also be used to provide open data analytics and mathematical

models in a dedicated web server for stakeholders or the public to run with their assumptions and scenarios, and provide valuable feedback to the project team.

6. ***DSS Optimization module***; optimizes the five key themes of sediment remediation project based on the knowledge obtained through expert interviews and considerations compiled by Jawed and Krantzberg (2017a). These themes include 1-participation of appropriate actors with common objectives; 2-funding and resources; 3-decision-making process; 4- research and technology development; and 5- public and political support. These considerations are outlined in Figure 4 and explained in Stage 2 below.

The proposed decision-making framework consists of five stages as follows (Figure 5):

Stage 1: Project Initiation: In this stage, the project objectives, scope, and terms of reference are defined and documented. Relevant policies, guidelines, and procedures are researched and documented, and any gaps are identified. Such gaps may need to be addressed during the life cycle of the project. Improved conformance to regulations, by-laws, policies, and standards is achieved through a comprehensive review of such documents at this early stage of the project. In this stage, inputs from other frameworks such as Ecological Risk Assessment as well as best practices and lessons from other jurisdictions is also obtained and considered as part of the project and could become a good starting point for Stage 2 optimization.

Stage 2: Integrated information management system (IIMS) and DSS optimization module (IIMS+DSS): This is the heart of the DSS system framework. In this stage, a comprehensive suite of information technology systems is developed, and various project parameters and research are gathered and managed by the integrated module. Development of the DSS begins with the identification of project stakeholders, the creation of project team, and definition of their expected roles and responsibilities including management, implementation, and specialized function. A documented term of reference of each team ensures everyone is aware of their respective responsibilities and general workload expectations within the DSS system. The DSS optimization module addresses the five key themes of the sediment remediation project while taking into consideration specific considerations identified by the experts. These five key themes and special considerations are depicted in Stage 2 of Figure 5 and detailed below.

Stage 2A: DSS for Participation of Appropriate Actors with Common Objectives: establishes a process for listing of all relevant stakeholder groups that need to participate at various stages of the project. This module generates strategies to ensure that key stakeholders and their level of participation (e.g. participation stage of the project) are identified and represented at the beginning of the project. A leader is identified for each stage of the project to facilitate stakeholder consultation and management of decision-making process. This role could be served by one individual or different individuals depending on their expertise. This module ensures transparency and rationale for any leadership role (or changes in the role) throughout the life cycle of the project. This module establishes a process for project succession planning and securing/implementing knowledge transfer in case of role changes and staff turnovers within each stakeholder group. This module applies to all phases of the sediment remediation project.

Stage 2B: DSS for Research and Technology: establishes a process for early identification of technological challenges and range of available solutions that could be considered by the project committee. This module establishes a technical advisory committee (TAC) to address key questions related to technology, basic science, risk assessment (including new risk information) site characterization, remedial options, design options, and any other technical challenge and hurdles. Technical specifications, costs, and effectiveness of various available alternatives for the project (and from other relevant studies) is available as part of this module to the TAC for their consideration. This module is most pertinent to the phases of the sediment remediation project which deal with problem identification, and defining and evaluating alternatives.

Stage 2C: DSS for Decision-Making Process: establishes a process for the formation of the multi-partnered project team and project manager/leader with clear delineation of roles and responsibilities. This module helps generate strategies to reach agreement on timelines for various phases of the project and identify and recommend tools, techniques, and options to keep the project on time and within budget. A balance between corporate interests and those of government agencies as well as collaboration between all stakeholders is targeted within this module. This DSS module applies to all phases of the sediment remediation project.

Stage 2D: DSS for Funding and Resources: establishes a process to assist in developing an early and reliable range of estimates of project remediation costs through review and recommendation by the TAC. This module generates strategies to set targets and achieve equitable cost sharing among all partners at various levels within government agencies and private entities. An aggressive negotiation schedule is implemented for early agreement on a cost sharing formula and targets to reach a mutually agreeable (compromise) solution by all parties. This module considers the application of, for example, the polluter pay approach and crowd funding to secure funds from non-traditional sources. This DSS module is mostly applicable to the phases of the project that deal with selection of alternatives and securing funding.

Stage 2E: DSS for Public and Political Support: establishes a process to facilitate seeking and achieving public and political support. This module helps generate strategies to inform the public during all stages of the project and to achieve broader public support using the following approaches:

- Both proxy public (focused group) and public (open public invitations) meetings
- Traditional engagement tools such as newspapers, web-based methods for government to solicit public input, workshops, roundtables, stakeholder groups, project advisory groups.
- Innovative engagement tools such as social media, open-data analytics, crowd sourcing methods
- Dedicated project website and interactive public portal to engage public and receive their input at various project phases

This DSS module applies to all phases of the sediment remediation project.

Stage 3: Multi-Criteria Decision Analysis (MCDA): In this stage, it is recommended that MCDA analysis be performed when there is a range of alternatives that require analysis to reach the preferred alternative. This is done through the assignment of weights for each option and sub-option. These weights are obtained through expert opinion or relevant research from other jurisdictions, as appropriate and vary from project to project.

Stage 4: Optimized DSS strategy: Once a preferred alternative is selected with a defined course of action obtained from the DSS optimization module and through MCDA analysis, an optimized DSS strategy is developed. This strategy is reviewed to ensure all known gaps are addressed, and considerations are included. It should be recognized that by the time the optimized DSS strategy is developed, one or more project parameters may have changed due to the passage of time or any other reason. For this purpose, it would be prudent for the TAC to undertake a revision loop into the IIMS + DSS module to ensure the optimized DSS strategy remains valid.

Stage 5: Implementation of DSS strategy: In this stage, the final optimization strategy is implemented and decisions executed. Continual improvement of processes occurs through formal process reviews (audits) and corrective actions.

Once a DSS system is setup and in place having the above-identified stages, ongoing communication and training support are both key to the successful implementation of a DSS. A communication plan to support the DSS is revised annually. A general awareness training about the DSS is recommended for its potential users (e.g. project team) at the beginning of the project to explain why, how, and when a DSS should be used and its potential benefits.

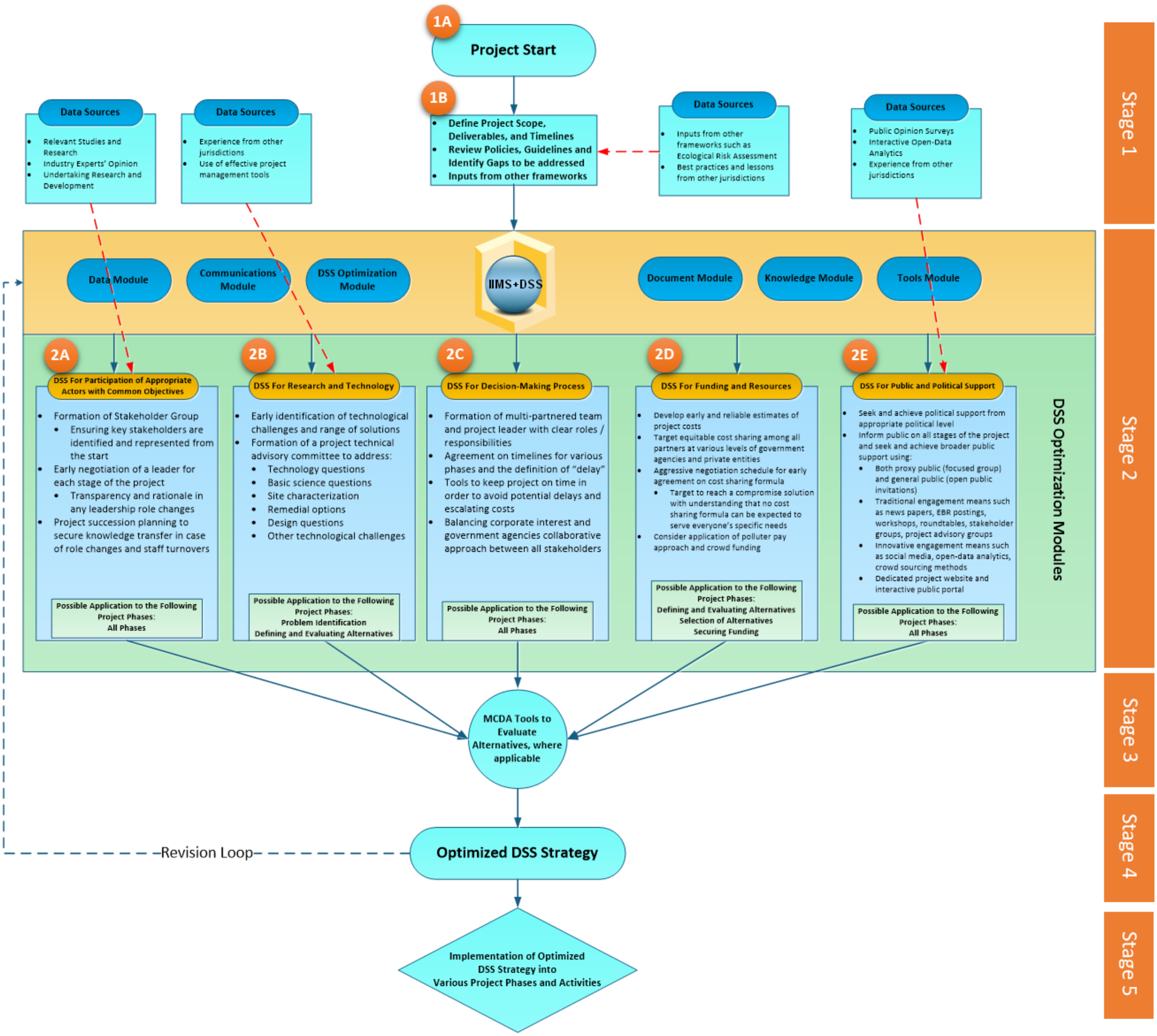
It is envisioned that by combining the elements of the IIMS and DSS optimization tools as described above, the project team and all stakeholders have a unified DSS tool that provides shared benefits as described below:

- Everyone has access to the same up to date information, scientific research, and project documentation and decisions
- Decisions are based on standard and consistent information

- Roles and responsibilities are clearly identified and transparent, and accountability is well-understood
- Clear communication method between the group of stakeholders and the public is established
- Potential risks, uncertainties are determined, rated, assessed and continuously addressed
- One stop shop for total project management, tracking, and audits

In short, the DSS methods aid the decision-making process by making it transparent, documented, reproducible, robust, and provide a coherent framework to explore and analyze available alternatives to reach the preferred solution (Sullivan, 2002).

Figure 5: Proposed Integrated Information Management System (IIMS) and Decision Support System (DSS) for Sediment Remediation Projects



Conclusion

Environmental decision-making is complex and involves multidimensional considerations and constraints along with multiple stakeholders with different interests and objectives. These complex issues cannot be effectively addressed by a traditional decision-making process and require a more structured and evidence-based decision support system. The main purpose of a DSS is to provide structured information that can be used to support environmental decisions. Contaminated sediment management projects have all the hallmarks of complex undertakings which could greatly benefit from a carefully designed DSS system. We are proposing an integrated information management system with a DSS optimization module which houses all the key information about the project (policies/guidelines, scope, technical information, scientific data, tools and methods) in a unified and easily accessible place. The benefit of such a system is that it makes the decision-making process transparent, documented, reproducible, robust, and provides a coherent framework to explore and analyze available alternatives to reach the preferred solution. A DSS system is as good as the information it contains, therefore, there is a need to continuously monitor and update the information/tools early in and during the project, thereby making sure the DSS remains up to date, robust and effective for a particular project.

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Chapter 6: Conclusions and Recommendations

Conclusions and Recommendations

The conclusions and recommendations of this research are divided into four parts based on the four related studies conducted in the context of this sandwich Ph.D. Dissertation as follows:

Part 1 (Public Surveys): The first part deals with the conclusions drawn from the public survey research. The findings of public survey research confirm that there is a considerable desire on the part of the public to be more engaged in the environmental decision-making process. One of the key recommendations of this study is that public engagement should become a central strategy for environmental projects while ensuring that the public is effectively kept informed and engaged during all stages of the decision-making process. Several studies have emphasized (as identified in Chapter 2) that public participation should go beyond traditional approaches by including a multi-pronged approach consisting of interactions among the public and other key players who collaboratively produce results. Therefore, it is recommended that the governance process should involve research and investment in better methodologies and tools such as Open Data Analytics and Social Media that can effectively engage the public while not solely relying on conventional or casual approaches. This multi-pronged engagement process ensures that members of the public from all facets of life and age groups have sufficient opportunity to participate in the preferred method of engagement.

Part 2 (Expert Interviews): The conclusion of the second part is drawn from expert interview research. There is no silver bullet solution when it comes to managing complex contaminated sediment sites. This research gathered in-depth accounts from experts and professionals, who had first-hand experience with the management of the Randle Reef sediment remediation project, and who provided invaluable experiences and suggestions which can significantly benefit future remediation projects and help overcome obstacles in the five areas as follows: 1)participation of appropriate actors with common objectives; 2)funding and resources; 3)decision-making process; 4)research and technology development, and 5)public and political support. Sediment remediation projects can be successfully executed if the obstacles in these five areas are identified and addressed during various phases of the project.

Part 3 (Qualitative Document Analysis): The conclusions of the third part is drawn from Qualitative Document Analysis (QDA) research on selected policy and research documents. Firstly, policy documents were reviewed such as guidelines, manuals, handbooks, or procedural documents related to environmental remediation projects to assess how each of the identified themes was reflected in such documents within North America. Secondly, selected research papers were reviewed that discuss how to carry out environmental remediation best and assessed these papers against the same five themes. The research papers were found to consistently emphasize the "participation of appropriate actors with common objectives," which was not the case with the policy documents. In fact, the theme of "participation of appropriate actors with common objectives" was least discussed in the policy documents therefore, confirming a gap exists between these two type of documents. Therefore, the policy documents have an opportunity to address this gap in future iterations. This demonstrates that there is a need for sediment remediation guidance documents to improve and address important contributors to successful decision-making and implementation outcomes. This is important in the main areas including defining roles and responsibilities of stakeholders, the benefits of public engagement and support, and clarification of the allocation of funding and resources.

Part 4 (Recommended DSS Framework): In this part, a Decision Support System (DSS) was developed which consists of an integrated information management system (IMS) with a DSS optimization module. Such integrated systems make the decision-making process more transparent, well documented, reproducible, robust, and provide a coherent framework to explore and analyze available alternatives to reach the optimal or preferred solution. The proposed DSS framework has six key components as follows: 1) data module; 2) communication module; 3) document module; 4) knowledge module; 5) tools module; and 6) DSS optimization module. The DSS optimization module optimizes the five keys themes (as identified in part 2 of the conclusion above), which is crucial for sediment remediation projects. This generic framework can assist practitioners in developing more systematic and structured decisions for sediment remediation projects. This is best achieved by a custom-built software application rolled out firstly in a pilot test environment which is continuously improved to incorporate recommendations to achieve a more robust version.

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