A comparative analysis of practitioners’ experience in sediment remediation projects to highlight best practices
Zobia Jawed and Gail Krantzberg

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 (PAHs) and metals. The complex Randle Reef sediment remediation project is finally coming to fruition after more than 30 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 | decision-making process, Great Lakes areas of concern, Hamilton Harbour Remedial Action Plan, Randle Reef sediment remediation, sediment management

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 (PAHs), 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 water-bodies (Palermo et al. 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 7,645.549 m$^3$ 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 (MacDonald et al. 2000; Burton Jr 2002; Ehlers & Luthy 2003; Heise & Förstner 2006; Environment Canada & Ministry of the Environment and Climate Change 2008; Taylor & Owens 2009; Förstner & Salomons 2010; 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 (Sediment Priority Action Committee & Great Lakes Water Quality Board 1997; Zarull et al. 1999; MacDonald et al. 2000; Burton Jr 2002; Heise & Förstner 2006; Taylor & Owens 2009; Förstner & Salomons 2010).

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 (Sediment Priority Action Committee & Great Lakes Water Quality Board 1997; Zarull et al. 1999; MacDonald et al. 2000; Burton Jr 2002; Heise & Förstner 2006; Taylor & Owens 2009; Förstner & Salomons 2010).

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-USA GLWQA (Governments of Canada and the United States 2012). In August 2017, an update related to Canadian AOC status was provided by the Manager of Great Lakes AOCs, Environment and Climate Change Canada as follows:

‘In terms of the status of contaminated sediments remaining unmanaged in AOCs, 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 19 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 et al. 2007); Toulon Bay, France (Tessier et al. 2013); Sydney Harbour, Australia (McCready et al. 2006); and Thermaikos Gulf, Northern Greece (Christophoridis et al. 2009).

Numerous organizations and governments are working towards the development of policies and technical guidance...
designed to address contamination in the most highly contaminated sediment management (Zarull et al. 1999; Förstner & Salomons 2010). 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 2007; 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 & de Deckere 2005; Crane 2003; Brooke 2004; Brils 2008; Demetropoulos 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, 26 are in the USA, 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 (Government of Canada and the United States Environmental Protection Agency 1995; Crane 2012). 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 connected to the lake by a single ship canal across the barrier sandbar that forms the bay. 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 2012, 2016). In 1987, Hamilton Harbour was formally designated as AOC (Figure 1). 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). This site has a presence of historic contaminants such as metals, PAHs, PCBs, and other hazardous chemicals which have been released into the
harbour, leading to extensive sediment contamination. 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 m³ of contaminated sediment located at the southwest corner of Hamilton Harbour (Milani & Grapentine 2016; Bay Area Restoration Council 2017). The Randle Reef site is approximately 60 hectares, which is equivalent to 120 football fields, in size (Graham 2011; Hall & O’Connor 2012, 2016; Randle Reef Sediment Remediation Project – Technical Task Group AECOM Canada Ltd & Environment Canada 2012). Randle Reef sediment contains PAHs in very high concentrations in coal tar (Randle Reef Sediment Remediation Project – Technical Task Group et al. 2012; Hall & O’Connor 2016). Total PAH concentrations in sediments have been reported to exceed 1,000,000 µg/kg. According to Canadian Council of Ministers of the Environment (2014), the interim standard quality guideline (ISQG) should be 41.9 µg/kg in freshwater and 86.7 µg/kg in marine water. However, in the case of Randle Reef, the PAH concentration exceeded 800,000 µg/kg 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 & Ministry of the Environment and Climate Change 2008; Environment Canada 2010; 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 m³ of the most highly contaminated sediment. Approximately 445,000 m³ of contaminated sediment surrounding the ECF will be dredged and placed inside the
facility for a total containment of 585,00 m³. Another 110,000 m³ of less contaminated sediment will be capped using both thin layer capping and isolation capping techniques, for a total of 695,000 m³ 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 $139 million. 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 damage associated with contaminated sediment continue, and are 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 was 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 (Boyle & Oceans Institute of Canada 1990; Renn & Finson 1997; Sediment Priority Action Committee & Great Lakes Water Quality Board 1997; Beierle & Konisky 1999; Zarull et al. 1999; Zarull et al. 2001; Krantzberg 2003; Hall & O’Connor 2012, 2016):

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. A total of 17 agencies were interviewed, eight of them were decision-makers and nine of them were participants.

In this study, 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 restricted to those people 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 2).

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 et al. 2005). 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 into 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. There were total of 17 professionals interviewed, each representing an agency.

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 shown in Table 1.

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 to 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 m³ 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. Eighteen per cent 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 3). 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

**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 leadership role was well-defined for this project.](image-url)

**Figure 3** Leading role for Randle Reef sediment remediation project.
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 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% 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 3). An additional 12% strongly believed so. Agency 17 agreed that the leadership role was clearly defined and stated that ‘leadership was with Environment and Climate Change 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 (Krantzberg 2005; Bridges et al. 2006; Luyet et al. 2012). We concur with this finding and suggest the lack of a 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 (Syme & Sadler 1994; Stem & Fineberg 1996; Gerrits & Edelenbos 2004; Slob et al. 2008; Oen et al. 2010; Voinov & Bousquet 2010).

Funding and resources

Funding constraints have been an obstacle to progress, reported by a number of authors dealing with sediment remediation projects in North America (Boyle & Oceans Institute of Canada 1990; Renn & Finson 1993; Sediment Priority Action Committee & Great Lakes Water Quality Board 1997; Beierle & Konisky 1999; Zarull et al. 1999; Krantzberg 2003; Hall & O’Connor 2012). 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 (for example Black River, Ohio) (McGrath 1995; Zarull et al. 1999; United States Environmental Protection Agency 2017b, 2017c). In Canada, there are no Superfund type funding programs 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 did not feel that this one was a current discharge – it was a legacy problem – so they argued it did not 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 4). 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 4). For example, Agency 2 strongly believed in the funding arrangement and stated: ‘in broad terms, the funding was based on Federal, Provincial and community (one-third 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.

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 5).

**Decision-making process**

There are significant economic, ecological, and social issues that are involved in addressing the contaminated sediment problem (Sediment Priority Action Committee & Great Lakes Water Quality Board 1997; Zarull et al. 1999; Read et al. 2014). 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 (Zarull et al. 1999; Bridges et al. 2012; Bridges & Gustavson 2014; United States Environmental Protection Agency 2017b). 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

![Figure 5](https://iwaponline.com/wqrj/article-pdf/54/1/10/520810/wqrjc0540010.pdf)
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 and Climate Change Canada agreed to include them in the Environmental Assessment, delaying the decision by years. Once there was a decision, the delays surrounded 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 Canada and the United States, complex contaminated sediment sites pose difficult technical and policy challenges (Zarull et al. 1999; Zarull et al. 2002; United States Environmental Protection Agency 2005; Harclerode et al. 2016), which have resulted in the slow pace of sediment remediation (Price et al. 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-economic 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, 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 2012, 2016).

It is found that only four of the 17 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 (Figure 6). This is because not all the stakeholders were identified and invited at the beginning of the 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 and Climate Change 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.

When the experts were interviewed for the second decision-making process around the selection of the ECF, nine out of 17 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 17 stakeholders did not support the selection process to reach the final decision (Figure 7). 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.’

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 8). 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 m 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 et al. 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).

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).

**Figure 8 |** Use of engineered containment facility at Randle Reef, Hamilton Harbour.
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) (Linkov et al. 2004; Poch et al. 2004; Kiker et al. 2005; Marcomini et al. 2009; Menzie et al. 2009; Read et al. 2014; Azapagic et al. 2016; Mourhir et al. 2016; Murla et al. 2016; Teasley et al. 2016; Clarke et al. 2017; Liu et al. 2017). 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 9). Those who had no prior knowledge about DSSs had no idea if such systems could be beneficial for sediment remediation projects.

Public and political support

For any remediation project to move forward, all 17 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 12 of these stakeholders believed that the public was well-informed and engaged during the Randle Reef sediment remediation project (Figure 10).

When agencies were asked whether they believed the government was making transparent and open decisions for environmental projects in general (Figure 11), 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 were 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 17 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 17 stakeholders believed that the public was provided with sufficient information about the Randle Reef sediment remediation project (Figure 11). All the stakeholders agreed with the need to continue to improve public engagement methods for future environmental projects. Twenty per cent 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 15% supported the use of opinion surveys to engage the public in the future (Figure 12). 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 (Beierle & Konisky 1999, 2001; Beierle & Cayford 2002; Ansell & Gash 2008; Michels & De Graaf 2010; Michels 2011; Cox 2012).

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.’

**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 (Hamilton Harbour Remedial Action Plan Writing Team & Rodgers 1989; Hamilton Harbour Remedial Action Plan Writing Team & Rodgers 1992; Hamilton Port Authority 2013; Graham et al. 2017). More than 30 years have passed...
since the contamination was identified yet remediation has just begun. This waste continues to threaten public health, contaminate fish and wildlife, and restrict the use of the waterfront. 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 2007; 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.

**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; Slob et al. 2008; Luyet et al. 2012; Rizzo et al. 2016). 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 clean up 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 et al. 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.

**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 the 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, the 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 et al. 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).

**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 (Preble 2005; Rawlins 2008; Waters et al. 2009; Oen et al. 2010; McCoy & Morgan 2012). 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.

**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).

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; Li et al. 2017).

One of the key recommendations 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 (Beierle & Konisky 1999, 2001; Beierle & Cayford 2002; Stringer et al. 2006; Ansell & Gash 2008; Michels & De Graaf 2010; Michels 2011; Cox 2012; Li et al. 2017). 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 (Rowe & Fewer 2000; Abelson et al. 2003; Waters et al. 2009; Gurstein 2011; Mergel 2012).

CONCLUSIONS

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 (Holland et al. 2011; Beames et al. 2014; Read et al. 2014; Azapagic et al. 2016). 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.

ACKNOWLEDGEMENTS

The authors wish to thank all the agencies and stakeholders and especially Mr John Hall, RAP Coordinator (retired) for his invaluable guidance and support throughout this project. The authors also wish to extend thanks to Dr John Eyles, Professor at McMaster University, for his guidance and inputs for the design of the interview questionnaire. We also thank Dr Lynda Lukasik, Director of Environment Hamilton, for establishing contacts with various stakeholders. Finally, I would like to extend my thanks to Dr Peter M. Chapman for his numerous edits and suggestions.

REFERENCES

Abelson, J., Forest, P.-G., Eyles, J., Smith, P., Martin, E. & Gauvin, F.-P. 2005 Deliberations about deliberative methods: issues in the design and evaluation of public participation processes. Soc. Sci. Med. 57 (2), 239–251.

Ansell, C. & Gash, A. 2008 Collaborative governance in theory and practice. J. Public Adm. Res. Theory 18 (4), 543–571.

Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of
Australia and New Zealand 2000 Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, pp. 1–103.

Azapagic, A., Stamford, L., Youds, L. & Barteczko-Hibbert, C. 2016 Towards sustainable production and consumption: a novel decision-support framework integrating economic, environmental and social sustainability (DESIREs). Comput. Chem. Eng. 91, 93–103.

Bates, M. E., Sparrevik, M., De Lichy, N. & Linkov, I. 2014 The value of information for managing contaminated sediments. Environ. Sci. Technol. 48 (16), 9478–9485.

Bay Area Restoration Council 2017 Randle Reef. Retrieved from www.randlereef.ca/.

Beames, A., Broekx, S., Lookman, R., Touchant, K. & Seuntjens, P. 2015 Sustainability appraisal tools for soil and groundwater remediation: how is the choice of remediation alternative influenced by different sets of sustainability indicators and tool structures? Sci. Total Environ. 470, 954–966.

Beierle, T. C. & Cayford, J. 2002 Democracy in Practice: Public Participation in Environmental Decisions. Resources for the Future, Washington, DC.

Beierle, T. C. & Konisky, D. M. 1999 Public Participation in Environmental Planning in the Great Lakes Region. Resources for the Future, Washington, DC.

Beierle, T. C. & Konisky, D. M. 2001 What are we gaining from stakeholder involvement? Observations from environmental planning in the Great Lakes. Environ. Plann. C Gov. Policy 19 (4), 515–527.

Black, P. & Stockton, T. 2009 Basic steps for the development of decision support systems. In: Decision Support Systems for Risk-Based Management of Contaminated Sites (Al. Marcomini, G. W. Suter II & A. Crito, eds). Springer USA, Boston, MA, pp. 1–27.

Boyce, C. & Neale, P. 2006 Conducting In-Depth Interviews: A Guide for Designing and Conducting In-Depth Interviews for Evaluation Input. Pathfinder International Tool Series Monitoring and Evaluation – 2, Pathfinder International, Washington, DC, pp. 3–12.

Boyle, D. E. & Oceans Institute of Canada 1990 Weighing the Options: Identifying Harbour-use Goals. Oceans Institute of Canada, Halifax, NS.

Bridges, T. S. & Gustavson, K. 2014 Risk management for contaminated sediments. In: Processes, Assessment and Remediation of Contaminated Sediments. Springer Science & Business Media, New York, pp. 197–226.

Bridges, T. S., Apitz, S. E., Evison, L., Keckler, K., Logan, M., Nadeau, S. & Wenning, R. J. 2006 Risk-based decision making to manage contaminated sediments. Integr. Environ. Assess. Manag. 2 (1), 51–58.

Bridges, T. S., Nadeau, S. C. & McCulloch, M. C. 2002 Accelerating progress at contaminated sediment sites: moving from guidance to practice. Integr. Environ. Assess. Manag. 8 (2), 331–338.

Brils, J. 2008 Sediment monitoring and the European water framework directive. Ann. Ist. Super. Sanita 44 (3), 218–223.

Brils, J. & de Deckere, E. 2003 Sednet – an evolving network aimed at sustainable sediment management. J. Soils Sediments 3 (3), 127–128.

Brooke, J. 2004 The EU Water Framework Directive – a wake up call. In: Paper Presented at the 39th DEFRA Flood and Coastal Management Conference.

Burton Jr, G. A. 2002 Sediment quality criteria in use around the world. Limnology 3 (2), 65–76.

Caeiro, S., Costa, M. H., DelValls, A., Repolho, T., Gonçalves, M., Mosca, A. & Painho, M. 2009 Ecological risk assessment of sediment management areas: application to Sado Estuary, Portugal. Ecotoxicology 18 (8), 1165–1175.

Canadian Council of Ministers of the Environment 2014 Canadian Environmental Quality Guidelines. Available from: www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/.

Chen, C.-W., Kao, C.-M., Chen, C.-F. & Dong, C.-D. 2007 Distribution and accumulation of heavy metals in the sediments of Kaohsiung Harbor, Taiwan. Chemosphere 66 (8), 1431–1440.

Christophoridis, C., Dedepsidis, D. & Fytianos, K. 2009 Occurrence and distribution of selected heavy metals in the surface sediments of Thermaikos Gulf, N. Greece. Assessment using pollution indicators. J. Hazard. Mater. 168 (2), 1082–1091.

Clarke, N., Bizimana, J.-C., Dile, Y., Worqlul, A., Osorio, J., Herbst, B. & Williams, J. 2017 Evaluation of new farming technologies in Ethiopia using the integrated decision support system (IDSS). Agric. Water Manag. 180, 267–279.

Cox, R. 2012 Environmental Communication and the Public Sphere. Sage Publications, Los Angeles, London, New Delhi, Singapore, Washington DC, Boston.

Crane, M. 2003 Proposed development of sediment quality guidelines under the European Water Framework Directive: a critique. Toxicol. Lett. 142 (3), 195–206.

Crane, T. 2012 Great lakes – great responsibilities. In: Great Lakes (V. I. Grover & G. Krantzberg, eds). Science Publishers, Boca Raton, FL, pp. 13–43.

Demetropoulou, L., Nikolaidis, N., Papadoulakis, V., Tsakiris, K., Koussouris, T., Kalogerakis, N. & Theodoropoulos, K. 2010 Water framework directive implementation in Greece: introducing participation in water governance – the case of the Evrotas River Basin management plan. Environ. Policy Gov. 20 (5), 336–349.

Ehlers, L. J. & Luthy, R. G. 2005 Peer Reviewed: Contaminant Bioavailability in Soil and Sediment. ACS Publications, Washington, DC.

Environment Canada 2010 Cleaning up the Great Lakes. Retrieved from: www.ec.gc.ca/doc/eau-water/grandslacs-greatlakes_e.htm.

Environment Canada 2017 Great Lakes Areas of Concern. Retrieved from: www.ec.gc.ca/rafs-pas/.

Environment Canada & Ministry of the Environment and Climate Change 2008 Canada-Ontario Decision-Making Framework
for Assessment of Great Lakes Contaminated Sediment. Retrieved from: http://publications.gc.ca/collections/collection_2010/ec/En164-14-2007-eng.pdf.

Förstner, U. & Salomons, W. 2008 Trends and challenges in sediment research 2008: the role of sediments in river basin management. *J. Soils Sediments* 8 (5), 281-283.

Förstner, U. & Salomons, W. 2010 *Sediment Research, Management and Policy*. Springer Nature, Switzerland, pp. 1440–1452.

George, T. K. & Boyd, D. 2007 Limitations on the development of quantitative monitoring plans to track the progress of beneficial use impairment restoration at Great Lakes Areas of Concern. *J. Great Lakes Res.* 33 (3), 686–692.

Gerrits, L. & Edelenbos, J. 2004 Management of sediments through stakeholder involvement. *J. Soils Sediments* 4 (4), 239–246.

Governments of Canada and the United States 1987 *Great Lakes Water Quality Agreement (1978) as Amended by Protocol Signed November 18, 1987*. Retrieved from: www.ijc.org/files/tiny_mce/uploaded/GLWQA_e.pdf.

Governments of Canada and the United States 2012 *Great Lakes Water Quality Agreement*. Retrieved from: http://www.ijc.org/en_/great_lakes_water_quality.

Government of Canada and the United States Environmental Protection Agency 1995 *The Great Lakes: An Environmental Atlas and Resource Book*, 3rd edn. National Service Center for Environmental Publications (NSCEP), USA and Canada.

Graham, M. 2011 Examination of Generated Residuals at Randle Reef and the Advantages and Disadvantages of Residuals Estimation in General. Paper presented at the Battelle Memorial Institute, Columbus, Ohio.

Graham, M., Hartman, E., Joyner, R., Kim, K. & Santiago, R. 2017 Environmental monitoring to guide and assess the effectiveness of Randle Reef sediment remediation on the recovery of Hamilton Harbour. *Aquat. Ecosyst. Health Manag.* 20. doi:10.1080/14654998.2017.1316658.

Great Lakes Water Quality Board, Water Quality Programs Committee, Sediment Subcommittee, Assessment Work Group & International Joint Commission 1988 *Procedures for the Assessment of Contaminated Sediment Problems in the Great Lakes: International Joint Commission*. Great Lakes Regional Office, Windsor, Ontario.

Gu, Q. B., Yan, Z. G., Zhou, Y. Y., Guo, G. L. & Li, F. S. 2007 Critical review of superfund act and environmental management of superfund sites. *Res. Environ. Sci.* 20 (5), 84–88.

Gurstein, M. B. 2011 Open data: empowering the empowered or effective data use for everyone? *First Monday* 16 (2).

Hall, J. & O’Connor, K. M. 2012 Remedial Action Plan Case Study. In: *Great Lakes Lessons in Participatory Governance* (V. I. Grover & G. Krantzberg, eds). Science Publishers, Boca Raton, FL, pp. 257–267.

Hall, J. & O’Connor, K. 2016 *Hamilton Harbour Remedial Action Plan Process: Connecting Science to Management Decisions*. Taylor & Francis, UK.

Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, K. 1989 *Hamilton Harbour RAP Stage 1 – Environmental Conditions and Problem Definition*. Canada-Ontario Agreement Respecting Great Lakes Water Quality, Ontario.

Hamilton Harbour Remedial Action Plan Writing Team & Rodgers, K. 1992 *Remedial Action Plan for Hamilton Harbour: Goals, Options and Recommendations, Stage 2*. Canada-Ontario Agreement Respecting Great Lakes Water Quality, Ontario.

Hamilton Port Authority 2013 *Hamilton Harbour Area of Concern*. Hamilton Port Authority, Hamilton, Ontario.

Harclerode, M. A., Macbeth, T. W., Miller, M. E., Gurr, C. J. & Myers, T. S. 2016 Early decision framework for integrating sustainable risk management for complex remediation sites: drivers, barriers, and performance metrics. *J. Environ. Manage.* 184, 57–66.

Heise, S. & Förstner, U. 2006 Risks from historical contaminated sediments in the Rhine basin. *Water Air Soil Pollut.* 6 (5–6), 625–636.

Holland, K. S., Lewis, R. E., Tipton, K., Karnis, S., Dona, C., Petrovskis, E. & Hook, C. 2011 Framework for integrating sustainability into remediation projects. *Remediation J.* 21 (3), 7–38.

International Joint Commission 2017 *Great Lakes Areas of Concern*. Retrieved from: http://ijc.org/en_/aoc/AOC_Intro.

Jonker, M. T. & Smedes, F. 2000 Preferential sorption of planar contaminants in sediments from Lake Ketelmeer, The Netherlands. *Environ. Sci. Technol.* 34 (9), 1620–1626.

Kiker, G. A., Bridges, T. S., Varghese, A., Seager, T. P. & Linkov, I. 2005 Application of multicriteria decision analysis in environmental decision making. *Integr. Environ. Assess. Manag.* 1 (2), 95–108.

Krantzberg, G. 2003 Keeping remedial action plans on target: lessons learned from Collingwood Harbour. *J. Great Lakes Res.* 29 (4), 641–651. doi:http://dx.doi.org/10.1016/S0380-1330(03)70467-5.

Li, X., Jiao, W., Xiao, R., Chen, W. & Liu, W. 2017 Contaminated sites in China: countermeasures of provincial governments. *J. Clean. Prod.* 147, 485–496.

Linkov, I., Varghese, A., Jamil, S., Seager, T. P., Kiker, G. & Bridges, T. 2004 Multi-criteria decision analysis: a framework for structuring remedial decisions at contaminated sites. In: *Comparative Risk Assessment and Environmental Decision Making* (I. Linkov & A. B. Ramadan, eds). Springer, Switzerland, pp. 15–54.

Liu, S., Delibasic, B., Butel, L. & Han, X. 2017 Sustainable knowledge-based DSS: perspectives, new challenges and recent advance. *Ind. Manag. Data Syst.* 117 (7), 1318–1322.

Luyet, V., Schlaepfer, R., Parlane, M. B. & Buttler, A. 2012 A framework to implement Stakeholder participation in environmental projects. *J. Environ. Manage.* 111, 213–219.

MacDonald, D. D., Ingersoll, C. G. & Berger, T. 2000 Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Arch. Environ. Contam. Toxicol.* 39 (1), 20–31.
Marcomini, A., Suter, G. W. & Critto, A. 2009 Decision Support Systems for Risk-Based Management of Contaminated Sites. Springer, New York, NY.

McCready, S., Birch, G. F. & Long, E. R. 2006 Metallic and organic contaminants in sediments of Sydney Harbour, Australia and vicinity – a chemical dataset for evaluating sediment quality guidelines. Environ. Int. 32 (4), 455–465.

McGrath, R. 1995 Managing sediment remediation costs. Pollut. Eng. 27 (7).

McLellan, E., MacQueen, K. M. & Neidig, J. L. 2001 A state of the art overview of contaminated sediment remediation in the United States. In: Paper Presented at the Proceedings of the International Conference on Remediation of Contaminated Sediments.

Pérez, A. P., Sánchez, S. P. & Van Liedekerke, M. 2005 The Remediated Sites and Brownfields – Success Stories in Europe. European Commission, Joint Research Centre, Brussels.

Poloni, D., Grapentine, L. 2019 Innovations in democratic governance: how does citizen participation contribute to a better democracy? Int. Rev. Admin. Sci. 77 (2), 275–293.

Michels, A. 2011 Innovations in democratic governance: how does citizen participation contribute to a better democracy? Int. Rev. Admin. Sci. 77 (2), 275–293.

Michels, A. & De Graaf, L. 2010 Examining citizen participation: local participatory policy making and democracy. Local Govem. Stud. 36 (4), 477–491.

Milani, D. & Grapentine, L. 2016 Prioritization of sites for sediment remedial action at Randle Reef, Hamilton Harbour. Aquat. Ecosyst. Health Manage. 19 (2), 150–160.

Mourhir, A., Rachidi, T. & Karim, M. 2016 A generic decision support system for environmental policy making: attributes, initial findings and challenges. In: Advances and New Trends in Environmental and Energy Informatics (J. M. Gomez, M. Sonnenschein, U. Vogel, A. Winter, B. Rapp & N. Giesen, eds). Springer, Switzerland, pp. 297–315.

Murla, D., Gutierrez, O., Martinez, M., Suñer, D., Malgrat, P. & Poch, M. 2016 Coordinated management of combined sewer overflows by means of environmental decision support systems. Sci. Total Environ. 550, 256–264.

National Research Council 2001 A Risk-Management Strategy for PCB-Contaminated Sediments. National Academies Press, Washington, DC.

National Research Council, Committee on Contaminated Marine Sediments, Marine Board & Commission on Engineering and Technical Systems 1997 Contaminated Sediments in Ports and Waterways: Cleanup Strategies and Technologies. National Academies Press, Washington, DC.

Oen, A. M. P., Sparrevik, M., Barton, D. N., Nagothu, U. S., Ellen, G. J., Breedveld, G. D. & Slob, A. 2010 Sediment and society: an approach for assessing management of contaminated sediments and stakeholder involvement in Norway. J. Soils Sediments 10 (2), 202–208.

Palermo, M. R., Hinchee, R., Porta, A. & Pellei, M. 2001 A state of the art overview of contaminated sediment remediation in the United States. In: Paper Presented at the Proceedings of the International Conference on Remediation of Contaminated Sediments.

Pérez, A. P., Sánchez, S. P. & Van Liedekerke, M. 2005 The Remediated Sites and Brownfields – Success Stories in Europe. European Commission, Joint Research Centre, Brussels.

Poch, M., Comas, J., Rodríguez-Roda, I., Sanchez-Marre, M. & Cortés, U. 2004 Designing and building real environmental decision support systems. Environ. Model. Softw. 19 (9), 857–873.

Power, D. J. & Sharda, R. 2009 Decision support systems. In: Springer Handbook of Automation (S. Y. Nof, ed.). Springer, Berlin, pp. 1539–1548.

Preble, J. F. 2005 Toward a comprehensive model of stakeholder management. Bus. Soc. Rev. 110 (4), 407–431.

Price, J., Spreng, C., Hawley, E. L. & Deeb, R. 2017 Remediation management of complex sites using an adaptive site management approach. J. Environ. Manage. 204, 738–747.

Randle Reef Sediment Remediation Project – Technical Task Group, AECOM Canada Ltd & Environment Canada 2012 Randle Reef Sediment Remediation Project: Comprehensive Study Report. Environment Canada, Ontario, Canada.

Rawlins, B. 2008 Give the emperor a mirror: toward developing a stakeholder measurement of organizational transparency. J. Public Relations Res. 21 (1), 71–99.

Read, L., Bates, M. E., Wood, M. D. & Linkov, I. 2014 Operationalizing Sustainable Sediment Management through a Decision Analytic Framing of the Triple Bottom Line. In: Paper Presented at the 5th Joint Nordic Meeting on Remediation of Contaminated Sites, Stockholm, Sweden.

Renn, O. & Finson, R. 1991 The Great Lakes Clean-up Program: A Role Model for International Cooperation? European University Institute, European Policy Unit.

Rizzo, E., Bardos, P., Pizzol, L., Critto, A., Giubilato, E., Marcomini, A. & Smith, G. 2016 Comparison of international approaches to sustainable remediation. J. Environ. Manage. 184, 4–17.

Rowe, G. & Frewer, L. J. 2000 Public participation methods: a framework for evaluation. Sci. Technol. Human Values 25 (1), 3–29.
Smith, G. & Nadebaum, P. 2016 The evolution of sustainable remediation in Australia and New Zealand: a storyline. *J. Environ. Manage.* 184, 27–35.

Sprovieri, M., Feo, M. L., Prevedello, L., Manta, D. S., Sammartino, S., Tamburrino, S. & Marsella, E. 2007 Heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenyls in surface sediments of the Naples harbour (southern Italy). *Chemosphere* 67 (5), 998–1009.

Stem, P. C. & Fineberg, H. V. 1996 *Understanding Risk: Informing Decisions in A Democratic Society*. National Research Council, Committee on Risk Characterization National Academy Press, Washington, DC.

Stringer, L., Dougill, A., Fraser, E., Hubacek, K., Prell, C. & Reed, M. 2006 Unpacking ‘participation’ in the adaptive management of social–ecological systems: a critical review. *Ecol. Soc.* 11 (2), 39.

Syme, G. J. & Sadler, B. S. 1994 Evaluation of public involvement in water resources planning: a researcher-practitioner dialogue. *Eval. Rev.* 18 (3), 523–542.

Taylor, K. G. & Owens, P. N. 2009 Sediments in urban river basins: a review of sediment–contaminant dynamics in an environmental system conditioned by human activities. *J. Soils Sediments* 9 (4), 281–303.

Teasley, R., Kwon, N., Gentle, J. & Pierce, S. 2016 Watermark: An open-source platform for federated decision support systems and applications to integrated environmental problems. In: *8th International Congress on Environmental Modelling and Software*, Toulouse, France.

Tessier, E., Garnier, C., Mullot, J.-U., Lenoble, V., Arnaud, M., Raynaud, M. & Mounier, S. 2011 Study of the spatial and historical distribution of sediment inorganic contamination in the Toulon bay (France). *Mar. Pollut. Bull.* 62 (10), 2075–2086.

United States Environmental Protection Agency 2005 *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. Retrieved from: www.epa.gov/nscep.

United States Environmental Protection Agency 2015 *Buzzing with Life: Environmental Education and Stewardship (The Chemical Commodities, Inc. Superfund Site in Olathe, Kansas)*. Retrieved from: www.epa.gov.

United States Environmental Protection Agency 2017a *Sediments: Risk Assessment*. Retrieved from: https://clu-in.org/contaminantfocus/default.focus/sec/Sediments/cat/Risk_Assessment/p/1.

United States Environmental Protection Agency 2017b *Superfund Program*. Retrieved from: www.epa.gov/superfund.

United States Environmental Protection Agency 2017c *Superfund: Contaminated Sediments*. Retrieved from: www.epa.gov/superfund/superfund-contaminated-sediments.

Voinov, A. & Bousquet, F. 2010 Modelling with stakeholders. *Environ. Model. Softw.* 25 (11), 1268–1281.

Waters, R. D., Burnett, E., Lamm, A. & Lucas, J. 2009 Engaging stakeholders through social networking: how nonprofit organizations are using Facebook. *Public Relations Rev.* 35 (2), 102–106.

Zarull, M., Hartig, J. H., Krantzberg, G., Burch, K., Cowgill, D., Hill, G. & Sherbin, I. G. 1999 Contaminated sediment management in the Great Lakes basin ecosystem. *J. Great Lakes Res.* 25 (2), 412–422.

Zarull, M., Hartig, J. & Krantzberg, G. 2001 Contaminated sediment remediation in the Laurentian Great Lakes: an overview. *Water Qual. Res. J. Can.* 36 (3), 351–365.

Zarull, M., Hartig, J. & Krantzberg, G. 2002 Ecological benefits of contaminated sediment remediation. *Rev. Environ. Contam. Toxicol.* 174, 1–18.

First received 12 June 2017; accepted in revised form 19 October 2018. Available online 16 November 2018