THE PATH TO A RECOMMENDED REMEDIATION STRATEGY FOR OTTAWA RIVERBED SEDIMENT

Technical and Non-Technical Factors to be Considered in Effective Remediation Decision-Making Using Risk-Based Assessment

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ABSTRACT

There are many factors that influence how a remediation decision is made. Fundamentally, a risk-based, methodical consideration of potential, or actual, impacts to human health and the environment should form the basis of a defensible remediation solution. However, in addition to evaluation of the technical aspects in an assessment, it is also imperative to success to ask the community what they *perceive* the risks and effects of the contamination to be. "Perceived risks are as tangible as 'real' risks as far as the decision making process is concerned" [1].

This paper considers the factors required for an effective remediation decision-making assessment process. This process will be employed to determine a recommended remediation strategy for contaminated sediment in the Ottawa River adjacent to Atomic Energy of Canada Limited's (AECL) Chalk River Laboratories (CRL) site. This is one of the legacy liabilities currently being managed by AECL under the Nuclear Legacy Liabilities Program (NLLP) funded through Natural Resources Canada.

1. BACKGROUND

1.1 Background on the issue

Process water from Chalk River Laboratories' (CRL's) operational activities enters the Ottawa River via the Process Outfall. Water from the Process Outfall discharge has been tested since the 1950s and the effluent has met, and continues to meet, regulatory requirements. Atomic Energy of Canada Limited (AECL) has also been sampling and analyzing riverbed sediments adjacent to, upstream and downstream of the Process Outfall periodically since the early 1950s.

A detailed examination of Ottawa River sediment was initiated in 2001 to better quantify liabilities associated with the long-term management of the CRL site. In 2005 July, during routine sampling, a particle about the size of a grain of sand was discovered in the riverbed with a radioactivity level approximately ten times higher than previously measured in similar particles. Radiological analysis determined that the particle exceeded the regulatory exemption quantity for Cs-137(with 3.4×10^5 Bq of Cs-137), and was therefore considered reportable. The Canadian Nuclear Safety Commission (CNSC) was notified of the particle discovery on 2005 August 26, and since then AECL has continued to report progress to the CNSC on all Ottawa Riverbed Remediation (ORR) Project activities, including discoveries of particles of interest.

Generally, the region of the riverbed affected by Process Outfall discharge is adjacent to the CRL site and occupies an area approximately 400 m long by 200 m wide in water 8 to 30 m deep.

Sediment core samples indicate that the low-level contamination (mainly ^{137}Cs and ^{90}Sr) is within the top 15 cm of the sediment [2]. Lower activity sediments from recent operations overlie higher activity sediments from earlier operations. Radiological contamination generally exists in two forms: contaminated riverbed silts and coarser active particles that are relatively scarce [3]. The active particles can be linked to the period of operation of the now shutdown National Research Experimental (NRX) reactor (1947-1992) based on the depths they are found in the sediments, as well as the particle characteristics [4]. These studies have also shown elevated levels of mercury in the area, which is being considered in the assessment of risk from the contaminated sediment.

1.2 Background on the Ottawa Riverbed Remediation (ORR) project

The ORR project was initiated in 2006 and since then, the project team has been progressively working to characterize and assess the affected offshore area of contaminated riverbed sediment. Incorporation of a directed approach based on good-practice sediment remediation guidance has been brought into the assessment. Factors generally recommended for consideration in effective remediation decision-making have also been used to guide the remediation assessment and planning process.

Technical aspects of the assessment include historical review, sediment characterization, determination of Contaminants of Potential Concern (COPCs), evaluation of the physical stability of the sediment, study of aquatic communities, contaminant bioaccumulation and sediment toxicity. All of these aspects contribute to the development of a Conceptual Site Model (CSM), which identifies and qualifies the feasible contaminant exposure pathways and receptors.

The ORR project differs from other legacy remedial efforts at the CRL site in that the contamination under consideration is in the Ottawa River, i.e., in the public domain. All other legacy liabilities of this nature from CRL's operations are located within the site's boundaries, where access is controlled. Therefore, in addition to the evaluation of the technical facets of this problem, it will also be imperative to success to ask the community what they *perceive* the risks and effects of the contamination to be, and to address their concerns and include them in decision-making, where possible. Public and stakeholder concerns have been shown to influence remediation decisions, sometimes markedly [1].

Comprehensive human health and ecological risk assessments are underway. If the risks from the contamination in its current state are deemed to be significant, remediation goals (e.g., end-states and clean-up criteria) will be developed to meet management objectives. Also, a decision analysis process will be developed that considers the contamination in its current state, as well as changes in risk factors resulting from the various feasible remediation options. The technical assessment results will be interpreted and the remediation decision-making process will be complimented by the consideration of non-technical factors. Finally, a recommended remediation strategy and implementation plan will be established. An overview of how all of this information will tie together, as well as a chronology of the project, is provided in this paper.

2. THE ORR REMEDIATION ASSESSMENT PLAN

The ORR remediation assessment plan is generally based on the United States National Research Council's Recommended Framework for Risk Management (Figure 1). Figure 1 illustrates that the major steps to evaluate results, define the problem, analyze the risks, assess options, make decisions and implement a strategy are all centered on ongoing community and stakeholder involvement (a non-technical factor).

Figure 1. National Research Council - Recommended framework for risk management taken from [5] * Conceptual Site Model (CSM) blocks added by author.

More specific sediment remediation guidance from the United States Environmental Protection Agency (US EPA) [5], the Ontario Ministry of the Environment (MOE) [6], as well as other regulatory and scientific bodies [7], [8], [9], [10], was incorporated to ensure all aspects requiring consideration were brought into the greater planning effort. In Figure 2, the detailed information required to accomplish these major steps is linked together and elaborated on in Sections 2.1 through 2.4. Contaminated sediment assessment using a weight-of-evidence approach is a complex endeavor and this is exemplified in Figure 2. The colours of the information requirement blocks in Figure 2 co-ordinate with the assessment areas shown in Figure 1, with the CSM as a foundation for remediation options assessment and recommendation of a final remediation strategy.

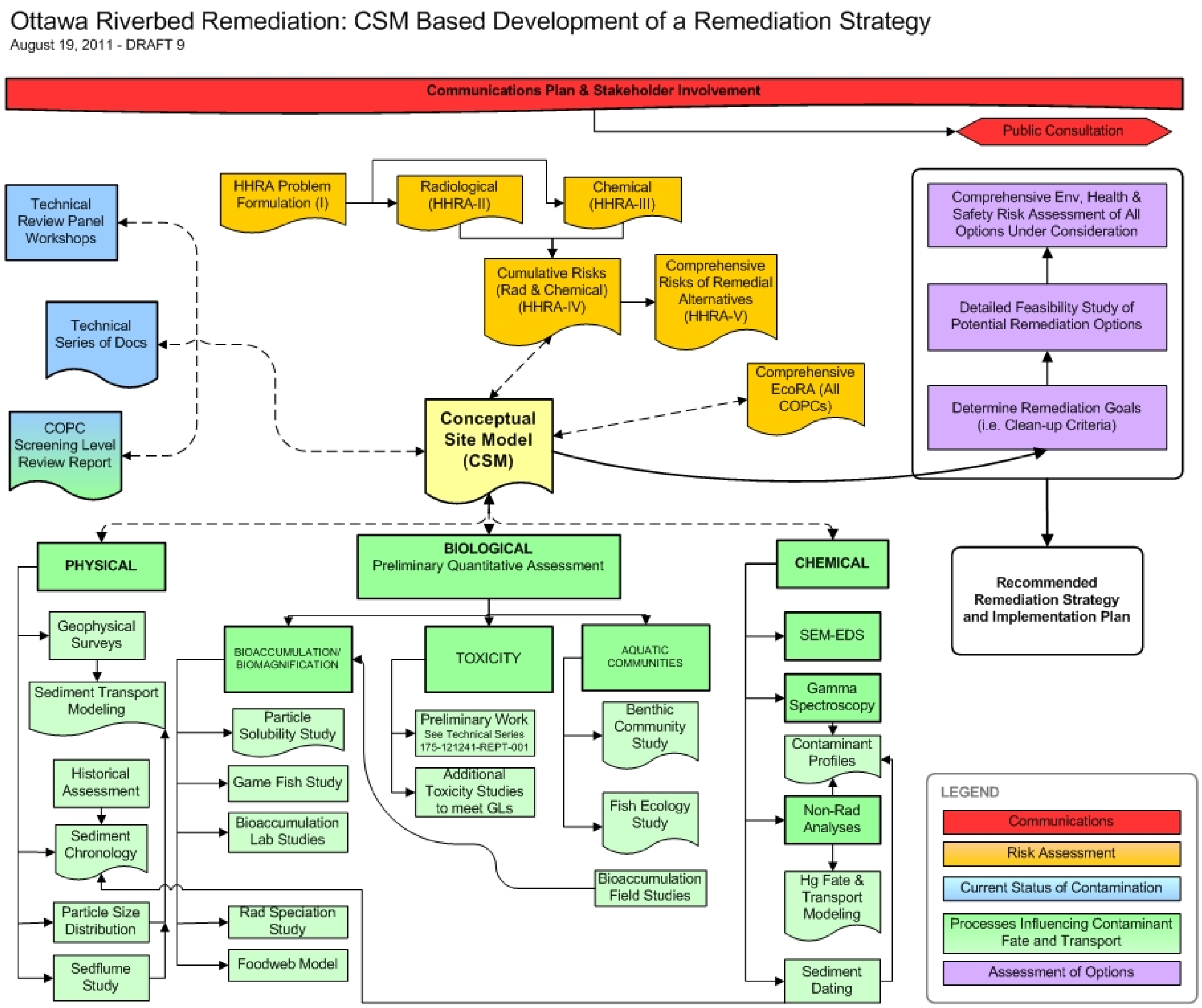

Figure 2. Detailed information required to recommend a remediation strategy for contaminated sediment in the Ottawa River adjacent to CRL. Colours co-ordinate to the assessment areas shown in Figure 1: the *National Research Council - Recommended Framework for Risk Management* with the Conceptual Site Model as a foundation for remediation options assessment and final strategy recommendation.

Figure 3 presents an estimated timeline to take the technical assessment to the point of recommending a remediation strategy. The timeline will operate in tandem with a public communication process to ensure that the public is fully informed and has the opportunity to provide input into decisions made along the way. Uncertainties are driven by the risks and assumptions detailed annually in the ORR project's Nuclear Legacy Liabilities Program (NLLP) contract. There is a potential for delays to the timeline if resources become constrained or otherwise need to be re-directed to deal with potential public and regulatory concerns as communication on the issue broadens.

Several of the tasks and deliverables indicated on the timeline (completed, underway or upcoming) for the ORR project are expanded on in the following sections.

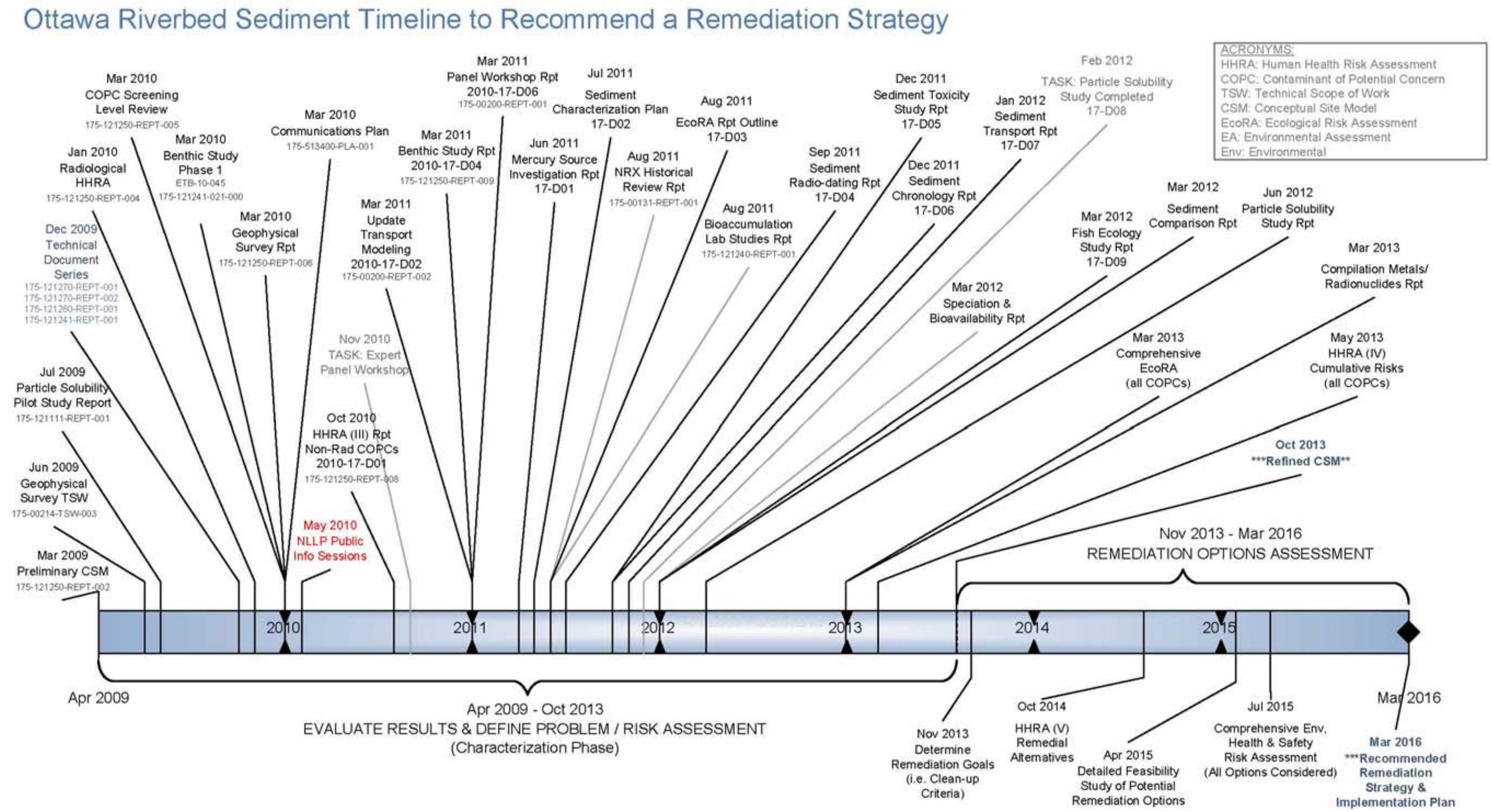

Figure 3. Timeline to determining a recommended remediation strategy for the Ottawa riverbed

<u>Note</u>*: *Dates are subject to change based on resource and funding availability and/or if new information becomes available (i.e., project risks and assumptions require modification)

2.1 Community and stakeholder involvement

Some preliminary communications planning occurred early in the project when the active particle issue was first identified. A communications plan for the project was documented in 2010 and formulated the rationale, objectives and description for internal and external ORR project communications. Notably, the rationale includes ensuring stakeholder awareness of ORR project developments and objectives and building stakeholder confidence in the remediation program. The project is working towards fulfilling the objectives of the plan.

There has been ongoing communication with the primary regulatory agency, the CNSC, on this issue since 2005 August when the first active particle above exemption quantity was discovered. AECL has committed to keep the CNSC generally informed of the project's progress and formally reports all active particles that exceed the regulatory exemption quantity [11].

AECL's Environmental Stewardship Council (ESC) was conceived in 2006. It is a group of invited community stakeholders, such as representatives from local municipal and aboriginal governments, non-governmental and environmental organizations, as well as AECL participants and other observers. The objective of the ESC is to build a working relationship and create opportunities for open dialogue between community stakeholders and CRL in order that decisions taken by site management consider a wide range of community viewpoints. The ESC has received regular updates on ORR project progress since 2007 March and their input and opinions are highly valued.

Overview information in the form of a fact sheet [12] about the project was provided to the general public as part of the NLLP Public Information Sessions held in May 2010. Additional focus on engaging the public further is anticipated to be initiated in 2012.

Meanwhile, the focus on peer review of the project's plans and assessment work continued with a Technical Review Panel Workshop, hosted at CRL from November 29th – December 1st, 2010 [13]. A similar workshop, held in 2007, reviewed the preliminary information available at that time and broadly considered the feasibility of monitored natural attenuation as a remedial option for the site [14]. The 2010 Workshop focused more specifically on evaluating the detailed technical work completed to date to characterize the issue, the proposed path forward and providing face-to-face feedback to AECL staff. Review and assessment of specific remedial options was not within the scope of Workshop discussions.

The objectives of the Workshop were to:

- Assess the appropriateness of the current path forward, information collected and conclusions made to date based on the available data;
- Develop a consensus opinion on the state of the issue to the extent practicable;
- Delineate areas of disagreement or large uncertainty requiring additional assessment for resolution; and
- Identify major data gaps that need to be filled and potential methods to fill data gaps.

Five acknowledged external experts in relevant areas of nuclear site sediment remediation, mercury fate and transport, toxicology, quality protocols, communication strategy, and human health and ecological risk assessment attended the Workshop. Overall, the Workshop was successful and the Panel was impressed with the quality of the scientific work and the scope and thoroughness of the remediation assessment conducted thus far. A final report was issued documenting the deliberations of the Panel Workshop [13]. In order to optimize the project as it moves forward, gaps were prioritized and suggested resolutions and recommendations were made in the general areas of Project Management, Communications, Characterization and Risk. Two of the gaps identified in the Workshop related to communications.

The Panel recommended that additional public engagement techniques be considered. Consensus was that there could be a significant risk to the overall success of the project in that even a technically sound recommended remediation option might not be accepted by a community if they felt their concerns were not adequately requested or addressed. This point is further elaborated on in Section 3.1.1.

The Workshop also recognized that there is lack of published studies on ORR project technical work in peer-reviewed journals. The Panel felt that much of the ORR work completed to date would be of great interest and benefit to the scientific community. Future efforts related to improving communications will include continued presentations at conferences and working to publish scientific journal articles in order to invite further peer review and provide resultant acceptance and/or scrutiny of the work and plans going forward.

2.2 Evaluating results and defining the problem in the Conceptual Site Model

A CSM defines the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources through exposure pathways to receptors.

For sediments, the CSM is considered to be an important element for evaluating potential risks to human health and the ecosystem, evaluating risk reduction approaches and making informed risk-based decisions on remediation methods. The initial CSM is typically a set of hypotheses derived from existing data that provides an overview of the site and may reveal information gaps that support the collection of new data [5]. The CSM is an integral aid to the project in identifying what information is required to assess the contamination issue.

The ORR Preliminary CSM [15] examined information available to date, assessed the potential contaminant exposure pathways and receptors, and made recommendations for additional studies to fulfill gaps. The CSM process is iterative, as the models are refined when new information is gained or uncertainties are reduced. Inputs include historical review, contaminant and site characterization, evaluation of the physical stability of the sediment, study of aquatic communities, contaminant bioaccumulation potential, and sediment toxicity. The information gathered as the Preliminary CSM is refined will support the completion of comprehensive human health and ecological risk assessments (see Section 2.3).

2.2.1 <u>Historical site investigation</u>

Evidence suggests that active particles found in the riverbed are a result of historical fuel operations that occurred in the now shutdown National Research Experimental (NRX) reactor (1947-1992). This is based on the depths at which the particles are found in the sediments, as well as the particle characteristics [16]. Active particle contamination in the riverbed is heterogeneously distributed and of variable characteristics. In order to further substantiate the source, and to better understand the specific causes of particle release from the reactor facility, an historical review of NRX operations was carried out. This review identified specific fuel failure events that would have lead to particle release to the Ottawa River through the Process Outfall. Although modern reactor designs employ closed loops for cooling the reactor fuel rods, the NRX reactor employed “once-through” cooling. This practice involved river water flowing through the fuel channels then being returned to the Ottawa River with limited provision for control of radioactive particles.

The NRX historical review revealed that a significant amount of fuel particulate would have been generated during a major reactor accident that occurred in 1952. During this event, a significant number of fuel rods overheated to the point of melting and fragmentation. It is also evident from the records that individual fuel rod failures continued to occur over time as fuel rods aged. Damaged rods were promptly removed from the reactor core, but in some cases fuel particulate would have been released to the cooling system. The frequency of these fuel failure events declined towards the later years indicating, overall, that the particulate releases to the Ottawa River generally declined during the later years of NRX reactor operations. Ongoing monitoring of the Process Outfall discharges suggests that concerning levels of contamination are not continuing to be released and the effluent is meeting all regulatory requirements [17].

Historical and current sources of the only non-radiological COPC identified in Ottawa River sediment, mercury [18], have also been examined. At this stage of the investigation, historical coal use and storage for CRL Powerhouse operation appears to be the most likely historical source of the Hg peak measured in the Ottawa River adjacent to CRL. Current day mercury releases in process effluent water and in airborne releases from Powerhouse combustion of bunker C fuel oil do not appear to be significantly impacting Ottawa River mercury concentrations [19].

2.2.2 Contaminant characterization

In addition to the active particles, bulk radioactivity in the sediment is also elevated above background and this can be generally attributed to CRL’s sixty-plus years of operation as a nuclear research facility. The spatial extent of the contamination has been determined through a series of sampling campaigns employing a variety of methods and various statistical analyses [16], [19], [20], [21]. In order to define the COPCs, contaminant concentrations have been statistically compared to background levels and generic sediment screening criteria provided in good-practice guidance [18].

COPCs identified in CRL sediment include both heterogeneously distributed sand-sized radioactive particles, and bulk contaminated silts containing radioactivity and mercury. The location of the CRL site and the areas of concern are shown on Figure 4.

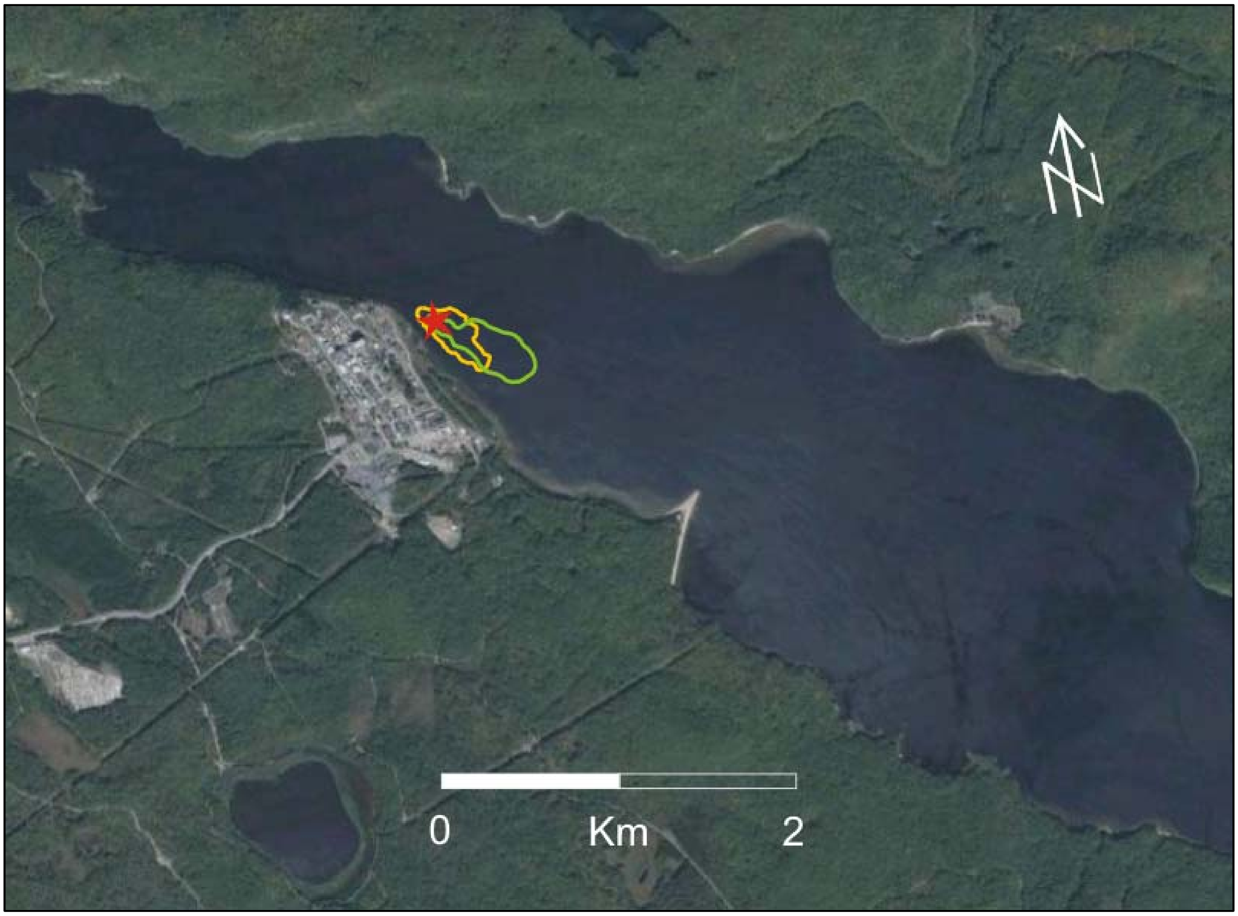

Figure 4. The CRL site on the Ottawa River and the areas of concern. The red star is the location of the Process Outfall. The general area of elevated radioactivity is outlined in yellow, while the area of elevated mercury concentrations is outlined in green (Lee and Hartwig, in preparation).

2.2.2.1 Radioactive contaminant characterization

The region of the riverbed directly affected by Process Outfall effluent was originally identified by a Gamma Probe Survey. This study used a combination GPS/software system to collect data while towing a Geiger Mueller detector behind a slowly moving boat. The data was used to produce a reconnaissance map of relative gamma radioactivity. The area of elevated radioactivity was defined as approximately 400 m long and 200 m wide in water 8 to 30 m deep [2], [20]. This information was then used to guide the selection of coring locations to measure radioactivity at depth. This work provided an inventory of the radioactivity and identified the types of radionuclides in the sediment. Sediment core samples have indicated that the low-level contamination (mainly ^{137}Cs and ^{90}Sr) is within the top 15 cm of the riverbed sediment [2], [16], [20]. Lower activity sediments from recent operations overlie higher activity sediments from earlier operations, indicating recent operations are 'cleaner' and natural sedimentation is beginning to mitigate the issue [3].

2.2.2.2 Non-radioactive contaminant characterization

Studies and the COPC screening level review have also shown elevated levels of mercury in the area [18], [19], [21]. Although mercury concentrations exceeded generic sediment screening levels even in upstream and downstream areas of the river unaffected by CRLs operations, levels were statistically elevated adjacent to the CRL site. The mercury footprint extends less than a kilometre downstream and is roughly one third of the river's width (the full width of the river adjacent to the CRL site is about 1200 m) (Figure 4).

2.2.3 Site characterization

Although this contamination is in the public domain, because the sediments of concern are in deep water (~8-30 m), they are in a naturally protected, poorly accessible state that prevents exposure to humans. The affected area is also limited in extent, thereby limiting the potential for ecological effects at a community level. This is further detailed in the Risk Assessment sections, 2.3.1 and 2.3.2.

Bathymetric and other geophysical surveys have been conducted and are providing input to refine the modeling of physical sediment transport potential. Initial modeling, based on general sediment type, has indicated that the sediment will remain in this protected location even during the occurrence of extreme wind, wave and flood scenarios [22]. Empirical measurements were taken in the summer of 2011 to measure site-specific sediment erosion by applying a controlled shear stress to the surface of extracted sediment cores. The final report is pending; however, preliminary results were positive and correlated well with the mathematical modeling. Thus far, the conclusion is that the sediment is cohesive and is highly unlikely to be transported downstream to accessible areas.

In addition, detailed geophysical characterization of the sediment is currently underway. This will refine our understanding of contaminant stability as related to binding affinity and the potential for contaminant desorption from re-suspended sediments.

2.2.4 Bioaccumulation, aquatic community evaluations and toxicity studies

The Ontario MOE's sediment remediation guidance incorporates a weight-of-evidence approach incorporating multiple lines of evidence to provide a direct assessment of sediment quality and the potential for degradation of the local aquatic community [6].

The MOE's decision-making framework begins with determination of the site-specific COPCs by comparing concentrations of above-background contaminants to sediment screening levels (steps 1-3 of the framework, [6]). Subsequently, in the preliminary quantitative assessment phase (Figure 5), evaluations of contaminant bioavailability (and biomagnifications) potential, sediment toxicity and aquatic community structure are performed. This method provides direct assessment of overall sediment quality and the potential for degradation to the aquatic community. However, in the case of multiple COPCs, it does not link concentrations of individual contaminants to biological detriment.

Work currently underway for the ORR project includes ongoing bioaccumulation studies, aquatic community surveys, and toxicity studies which will assess the contaminated area and compare it to reference sites considered to be unaffected by CRL's operations.

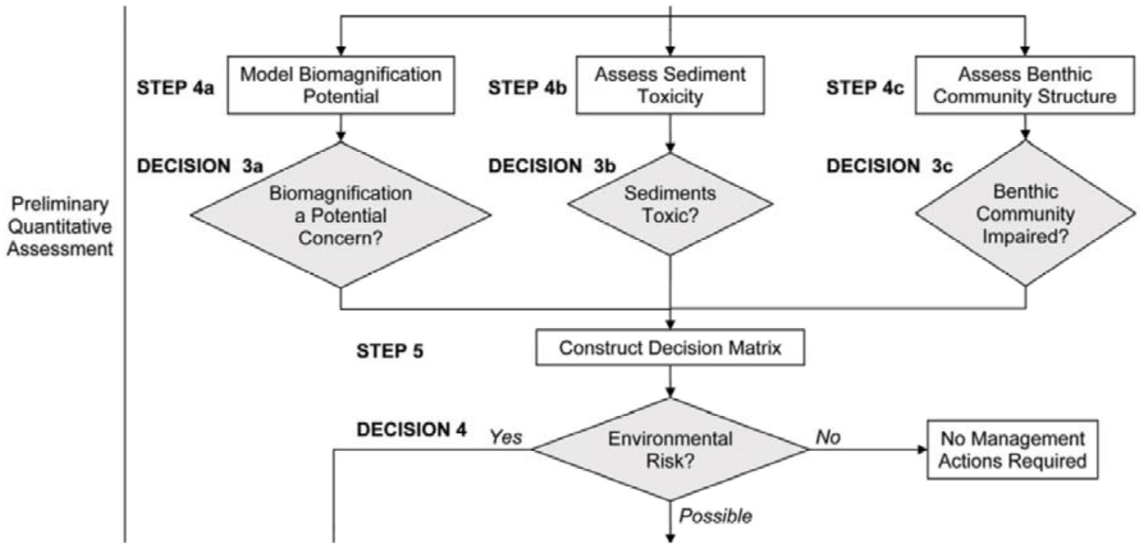

Figure 5. Preliminary quantitative assessment (steps 4-5, decisions 3-4 from the Ontario MOE's decision-making framework for contaminated sediments [6]).

Bioaccumulation studies examining metal uptake in chironomids and/ or amphipods exposed to adjacent sediment have shown cadmium, copper and tin may have the potential to bioaccumulate into benthic organisms. These studies suggested that lead, mercury, molybdenum and uranium may require further evaluation [25].

An assessment of the Ottawa River benthic communities was performed in 2009 and 2010. Studies compared the frequency of occurrence and abundance of the highly sensitive benthic invertebrate *Hexagenia* between different depth and sediment zones, as well as among sites upstream, downstream, and adjacent to the area of concern. The study determined that contamination within the area of concern has no significant impact on *Hexagenia* occurrence or abundance [26].

When considering non-radiological contaminants, benthic organisms are typically the aquatic receptor presumed to be most affected by sediment contamination because they reside and feed in the sediment. However, it is widely accepted that fish are a more sensitive receptor to radioactivity than benthic organisms (i.e., invertebrates are much more radio-resistant than vertebrates) [24]. Therefore fish community studies are presently underway to add to our understanding of potential aquatic community impairment from the sediment contamination.

Preliminary in-lab short-term toxicity tests have generally reported comparable survival and growth in both upstream reference and Process Outfall sediments. However, chronic exposures using a sensitive invertebrate, *Hyalella azteca*, suggested slight biological impairment in the Process Outfall sediments as compared to upstream reference sediments [27]. Additional comprehensive testing was recently completed following the recommendations of the Ontario MOE's "Guideline's for Identifying, Assessing and Managing Contaminated Sediments in Ontario: An Integrated Approach" [6] and will be reported on in the near term.

As mercury is typically a contaminant associated with bioaccumulation (i.e., its concentrations tend to increase as it moves up the food chain), this was also specifically examined in recent mercury source investigation work. It is noteworthy that even though total mercury levels were found to be elevated adjacent to CRL, mercury bioavailability is inferred to be quite low as indicated by low methyl mercury levels in surface water and sediment [19].

2.3 Analyzing risks

According to the US EPA [5], a Human Health Risk Assessment (HHRA) and an Ecological Risk Assessment (EcoRA) must be performed at contaminated sediment sites. The risk assessment should define the primary exposure pathways represented in the CSM and result in an improved understanding of the actual risks posed via these pathways. Without this key understanding, it is difficult to make an informed decision regarding an effective remedial path forward at a sediment site.

2.3.1 Human Health Risk Assessment (HHRA)

The protection of humans from health risk should be a priority when assessing environmental contamination. This approach is especially prevalent in the nuclear industry and although it is not an integral part of the general guidance provided for sediment remediation, human health risk was an early focus of the ORR project work.

The potential risk to humans from the sediment contamination is being assessed through a series of HHRAs. Figure 6 outlines the ORR project HHRA program, which involves a sequence of assessments that consider refinements to the CSM as the remediation project advances. The goal of the risk assessment program is to provide realistic estimates of potential risks to members of the public for alternative remediation solutions, enabling an informed and risk-optimal decision/recommendation for remediation of the contaminated site.

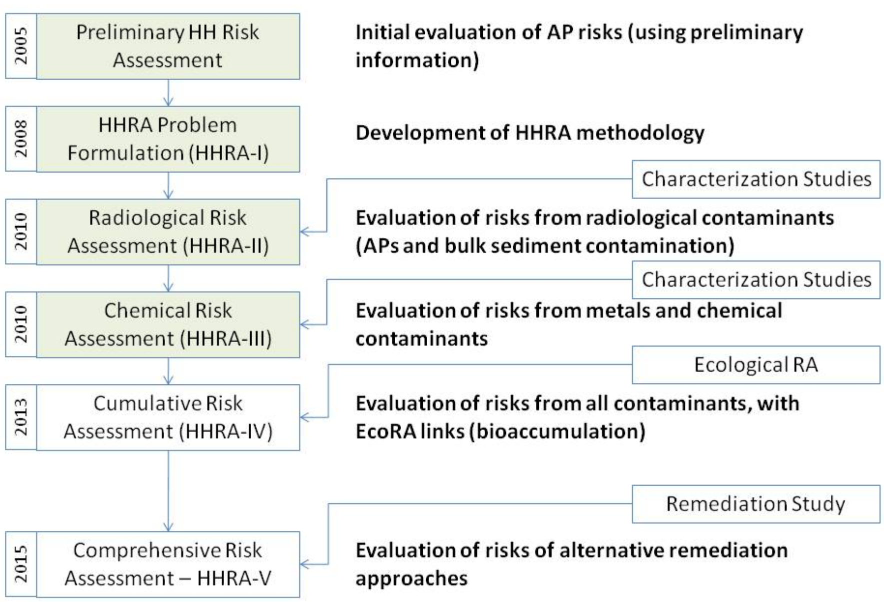

Figure 6. The Ottawa Riverbed Remediation project Human Health Risk Assessment program.

The HHRA work completed to date has assessed the risks associated with current uses of the Ottawa River under the current contaminant conditions. Because the contaminated sediments occur in relatively deep water (8 to 30 m depth), there is no route for people to be exposed to the contamination on a routine basis. It is conceivable, however, for people to come into contact with the sediments in several unique circumstances (e.g., drawing sediment into a boat from an anchor), but these exposure events are improbable. With respect to the risks from active particulate, calculations determined there would be a small increase in lifetime dose if an individual were to inadvertently ingest (highly unlikely) an active particle of the maximum concentration collected to date (3.4×10^5 Bq of Cs-137), assuming the particle was completely dissolved in the gastro-intestinal tract (unlikely). The overall lifetime risk of detrimental effects from active particle exposure was within the acceptable range according to Health Canada [28], [29].

Numerous comprehensive downstream beach and shoreline surveys on both shores of the Ottawa River have been completed since 2005 and have not detected any radioactive particles [30], [31], [32]. The absence of particles in accessible locations with public occupancy is obviously favourable with respect to preventing human exposure. These findings add certainty to the vertical contaminant distribution observed from the core sampling data and were expected based on the location of the discharge, which is deep and offshore under conditions which favour sedimentation [2], [16], [20]. Robust geophysical surveys of the riverbed have been incorporated into the updated report on sediment transport modeling [22]. The results suggested that particle deposition should be limited to the deep water region of elevated activity and that the riverbed is stable (see Section 2.2.3). The potential risks to humans from elevated concentrations of mercury in sediments in the affected region of the riverbed have also been assessed [33]. The evaluation concluded that under present conditions, sediment and surface water mercury concentrations do not pose unacceptable risks to members of the public. However, potentially unacceptable risks from mercury were predicted from frequent consumption of fish, particularly by toddlers and women of childbearing age. It is known that there are elevated mercury concentrations in this reach of the Ottawa River. Therefore, it is entirely possible that the elevated concentrations of mercury in these fish are representative of this regional issue and that the contaminated sediment adjacent to CRL has little impact on local mercury concentrations. Also notable is that the mercury HHRA supports the existing fish consumption recommendations provided by Ontario Ministry of Natural Resources as adequate for the protection of human health from Ottawa River fish containing mercury at these levels (i.e., as long as the fish consumption guidelines are followed, risks from mercury in fish will be mitigated) [33]. Additional environmental modeling of the mercury in the sediment is currently underway and will provide insight into the potential bioavailability of the mercury adjacent to the CRL site to river biota and thus up the food chain to humans. As mentioned above in Section 2.2.4, preliminary results indicate that mercury bioavailability is low in the system because associated methyl mercury levels are low [19].

Aside from assessment of the risks from the contamination in its current state, consideration will be given to how the current state can be affected by high river flow events and how the remedial strategies that may be employed would alter this level of risk. As already stated, there are no probable, direct exposure pathways for humans to encounter this contamination. However, if a high river flow event resulted in the erosion and redistribution of contaminated sediment to shoreline regions of the river, the risk profile would change. Similarly, if the river sediment was dredged and brought to the surface, an exposure pathway to workers would be introduced. Although the potential for effects or harm to an individual from ingesting an active particle would remain the same, bringing the contamination to the surface could markedly increase the *probability* of exposure and thereby change the risk to human health.

The HHRA will consider these risks in the Comprehensive Risk Assessment, currently planned for 2015 (see Figure 3 and Figure 6).

2.3.2 Ecological Risk Assessment (EcoRA)

Ecological risks from the contaminated sediment must also be considered to meet due diligence obligations and follow good-practice for sediment remediation. Typically, sediment remediation decisions are made with ecological risks being a main driver. Although the affected area adjacent to CRL is small in physical area, levels of radioactivity and mercury are above background and therefore potential impacts to local biota must be examined.

Generally, the COPC screening level review used sediment screening levels (e.g., the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life [34], the Ontario MOE Lowest Effect Levels [6]) as the first line of comparison to determine if parameter concentrations were at a level where they may be of concern in the environment and likely to be associated with a measurable biological response [35]. If concentrations were above screening levels, sediment concentrations were then compared to appropriate unaffected reference sites within this reach of the Ottawa River to determine if concentrations were significantly above background [18].

It is important to note that screening levels are not intended to be an indicator of site-specific risk. As well, it is widely accepted that sediment chemistry (particularly the bulk dry weight of metals) alone is neither sufficient to accurately predict biological effects, nor an appropriate measure of metal toxicity [23].

Mercury is a good example of site-specific comparisons causing complications in the case of the Ottawa River. Although mercury concentrations are clearly elevated in the sediment adjacent to CRL, background levels in areas not affected by AECL's operations also exceed the generic screening criteria. Therefore, the generic screening criteria available for mercury are not applicable for use at this site. General consensus demands that site-specific values be developed for remediation targets if subsequent evaluation determines that ecological risk is likely.

Numerous studies evaluating and characterizing Ottawa Riverbed sediment and the local environment have been completed since the 2005 particle discovery, including those mentioned above in Section 2.2.4. The results of these studies will build upon the initial COPC screening evaluation and be incorporated into a comprehensive EcoRA projected for completion in 2013.

2.4 Assessing options, making decisions and implementing a strategy

If the human health and ecological risks from the contamination are deemed to be significant, the riverbed site will be identified as a candidate for remedial action. Effort will go into the development of mitigative site-specific remediation goals (i.e., clean-up criteria) based on developed short- and long-term site management objectives[1].

International guidance for contaminated sediment management suggests three main options (or combinations thereof) for dealing with this type of contamination, including mechanical dredging, capping or monitored natural attenuation (i.e., leave the sediments undisturbed *in situ*).

[1] It was identified in the Technical Review Panel Workshop that AECL has not yet established well defined "management objectives" for the site as a whole or the areas of concern in this project, either long-term or current [13].

Clearly, all remediation strategies must be technically assessed in terms of feasibility and risk before a final recommended remediation strategy and implementation plan can be realized [15].

It is currently forecasted that the characterization phase of this remediation project will be completed in 2014 with the documentation of a more quantitative CSM (Figure 3). Monitoring of the contaminated sediment will be ongoing throughout the subsequent remediation options assessment phase to verify the continued validity of conclusions drawn in the CSM and risk assessments regarding contaminant characterization and stability.

From 2013 to 2016, the remediation options assessment phase of the project plan will occur. A decision analysis process will be developed to consider the options for effectively mitigating any hazards from the contamination in its current state. There will be a comprehensive evaluation of the environmental, health and safety risks associated with the various feasible remediation options. There are also several non-technical factors that will require consideration in the decision-making process. These are expanded upon in the remainder of this paper.

A recommended remediation strategy decision and plans for implementation are forecasted to be made by April 2016, assuming that uncertainties associated with potential public concern or with other assumptions, risks or dependencies do not cause delays.

Once a remediation strategy is recommended, if required, an environmental assessment under the Canadian Environmental Assessment Act (CEAA) will be initiated, federal approvals will be sought and implementation of the remedial strategy will commence.

3. REMEDIATION DECISION MAKING

There is a paradox in the general assumption that removing contamination from the environment is good. This can be a very simplified and dangerous perspective on remediation and may be hazardous in and of itself. For example, it may be naïve to believe that retrieving radioactive wastes from the ground or dredging a riverbed to collect contaminated sediment will always improve the situation. Without a comprehensive understanding of how changes will affect risks to the environment and to workers from the contamination, remedial actions can result in more harm than good.

The remediation decision-making process is iterative and can be complex, especially when dealing with the unknowns of historical legacy areas. There are many considerations that must go into an effective and defensible decision to remediate a contaminated site. Fundamentally, risk-based, methodical consideration of potential or actual (measured) impacts on human health and the environment from the contamination in question should form the basis of the remediation strategy decision (i.e., technical factors).

At this stage, the plan for the ORR project has been formed on a technical basis and technical factors are being thoroughly assessed as outlined in the preceding sections of this paper. However, there are several other, often under-assessed, secondary factors that may influence the ultimate determination of a remedial strategy. Consideration of these factors can influence the assessment and result in a decision to proceed with a remediation option that is not necessarily scientifically the most practicable.

The project timeline (Figure 3) indicates that the remediation options assessment phase will commence in 2013 and within approximately 3 years of that time, the project will recommend a remediation strategy and implementation plan. The following sections elaborate on some of the factors that will require consideration in this phase.

3.1 Non-technical factors influencing risk management and remediation decisions

As discussed, environmental remediation projects have traditionally focused on technical risks only. However, in a practical sense, other risk categories such as operational, commercial and people-related risks are interrelated [36].

While risk assessment involves the identification, quantification and characterization of threats to human health and the environment, risk management centers on the processes of communication, mitigation and decision-making (see Figure 7).

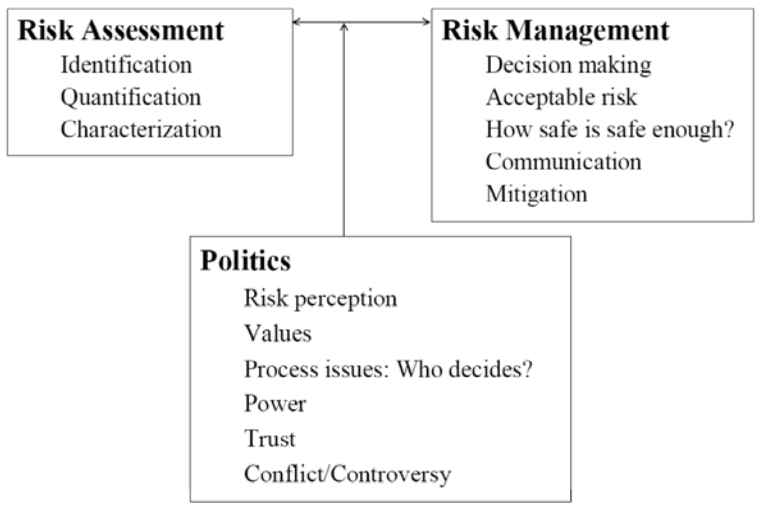

Figure 7 . Slovic and Weber's description of the components of risk analysis [37].

According to the IAEA [1], achieving an integrated remediation strategy will be aided by using an iterative approach between these "two concurrent and interwoven levels of decision making: one which is concerned with the justification of the remedial action, based mainly on radiological and other risk or impact criteria, and another one concerning the development and implementation of an overall satisfactory remediation strategy in the wider social and institutional context." This can be considered Risk Management. Non-technical factors that may require consideration for the ORR project include socio-economic considerations; regulatory requirements; project implementation-related risks, such as ongoing operational resource requirements; public/stakeholder perception and participation; cost and funding; and stewardship issues, such as future site use. Several of these are touched on in the subsequent discussion, whereas others will become more prevalent for consideration in future years when the project is closer to recommending a remediation strategy.

According to the US EPA's Risk Management Principles [5], because contaminated sediment sites often involve difficult technical and social issues, early and meaningful stakeholder and community involvement is critical from the site characterization and risk assessment phases through to the remedy evaluation/selection/implementation phases. At this stage of the ORR project, this is the most relevant non-technical factor that needs to be addressed in the near term.

3.1.1 Stakeholder participation

AECL is a federal crown corporation and a nuclear facility; therefore, its operations are regulated by a major stakeholder, the CNSC. Since the first active particle was discovered and reported in 2005-06, the ORR project has provided ongoing progress updates to the CNSC. The CNSC provides feedback on the studies conducted, as well as the planned path-forward. This feedback is taken into consideration by the project team. The regulatory commitment on this issue is that discovered active particles exceeding the applicable exemption quantity in the CNSC's Nuclear Substances and Radiation Devices Regulations will be reported [11].

The federal Department of Fisheries and Oceans has also been informed of the situation, but has communicated that they do not need to become involved in the decision-making process until a remediation strategy is being recommended.

Once a remediation strategy is recommended, if required, an Environmental Assessment under the Canadian Environmental Assessment Act (CEAA) will be initiated and approvals will be sought. As AECL is in the federal jurisdiction, the Fisheries Act as well as the Canadian Environmental Protection Act (CEPA) will be considered. Since the Ottawa River borders Ontario and Quebec, both provincial governments will also be consulted on remedial decisions.

Aside from regulators and government representation, the public can also be considered a stakeholder in the ORR project for several reasons. Two of the most obvious are that the contamination is in the public domain and that AECL is a government (therefore, tax-payer) funded operation.

3.1.2 Public perception and trust

Technical risk assessment provides estimates of potential harm from hazards by employing theoretical models based on the fundamental assumption that <u>there cannot be risk without exposure</u>. That is, risk consists of the probability of an adverse event and the magnitude of its consequences. This is a logical assumption; however, the concept of risk contains elements of subjectivity that provide insight into the complexities of public perceptions [37].

Thus, in the case of the sediment contamination adjacent to CRL, we must ask: What is the probability that humans or environmental biota are being exposed to contaminants at a level that will be impacting their health? There may be as many factors involved in estimating the risk from this contamination as there are affecting the public's perception of those risks.

The IAEA suggests it is wise to begin to approach a remediation problem by finding out what people value about the site and surroundings concerned and what information on the project they would like to have. The community's perception of risk and the extent of their level of trust in the information sources describing the problem are fundamental. With respect to remediation, there is often an inherent level of existing 'trust' as the aim is to improve the situation (vs. siting of new facilities or waste repositories). However, if the company overseeing the remediation decisions is also the source of the contamination, there may be an initial lack of trust between them and other stakeholders [1]. There have been several cases where even though a remediation decision was a technically feasible improvement to the environmental situation, it was rejected by the public solely on the basis that they did not feel their concerns were invited into or addressed during the decision-making process. It is important to be transparent in remediation assessment plans early on in the effort to ensure community and stakeholder acceptance.

One of the main factors that differentiates the ORR project from other CRL legacy liability remediation issues is that the contamination in question is in the public domain. The sediment of the Ottawa River is not within the confines of the controlled areas of the site, nor does AECL oversee the care and use of the area. As a result, it is particularly important to consider what the community *perceives* the risks and effects of the contamination to be. Perception of risks can considerably differ from the risks as defined by scientific risk assessments and will garner the public's acceptance of the proposed remedial strategy.

As mentioned in section 2.1, there has been broad public dissemination of information for the ORR through presentations to the Environmental Stewardship Council, three public information meetings in local communities in May 2010 and a fact sheet posted on the NLLP website (http://www.nuclearlegacyprogram.ca/en/home_en.html). It has been shown that although fact sheets are effective in terms of providing information, they are not as effective at developing interest and providing involvement in an issue as activities like focus groups, interviews and briefings [1]. Additional public information and public participation activities on this project are recognized as important elements of future planned communications.

Dr. Frank Dennis, a participant in the ORR project Technical Review Panel Workshop in 2010, is a specialist in the management of contaminated land at nuclear sites and is a recognised UK expert in the management of radioactive particles in the environment. He was involved in evaluation, communication with stakeholders and advising management decision-making regarding the active particles that were released at the Dounreay facility on the northern shore of Scotland. The following quote from Dr. Dennis reiterates the importance of stakeholder engagement:

> *"My experience at Dounreay is that Regulator and stakeholder expectations, rather than sound scientific conclusions, may end up driving your remediation approach. You should spend almost as much time informing your stakeholders and getting their buy-in as you do on sound science." [13]*

People's perception of risks is often considerably different from the actual risks as calculated by experts. This has been especially prevalent in the public's acceptance of the nuclear industry, as shown by Slovic's groundbreaking risk perception research into the psychometric paradigm. In 1987 [38], he argued that anthropogenic radiation is a 'dread risk', perceived by the public as involuntary, invisible and uncontrollable. Years later in 1993 [39], he noted that even though technical risk assessments had shown that nuclear wastes could be safely stored in underground repositories, public perceptions held that the risks were 'immense and unacceptable'. Slovic attributed the limited effectiveness of risk communication and the resultant lack of acceptance of nuclear waste disposal to a lack of trust in the nuclear industry.

Placing focus on creating trust in the context of scientific uncertainty was a lesson-learned from Dounreay's experience during the stakeholder and public engagement process surrounding their active particle issue.

> *"Trust is critically important in environmental governance, particularly in the resolution of complex environmental problems - especially where there is a degree of uncertainty and where perceived risk can bear upon and influence the decision making process." [40]*

The six components required to build trust have been described in the context of conveying the risks associated with nuclear wastes (see Table 1, [41]). Unfortunately, these cannot be universally applied, as social and cultural context are always a factor [1]. According to Renn, "Trust relies on all five components, but a lack of compliance in one attribute can be compensated for by a surplus of goal attainment in another attribute." AECL has been successful in maintaining a respectable level of trust from the public and its stakeholders despite several significant public relations challenges over the past few years (e.g. major reactor repairs halting radioisotope production). This has been done by establishing transparency through a frequent and thorough communications program for ongoing operational issues. This program fosters the components of trust: faith, sincerity, consistency, fairness, objectivity and perceived competence. The outward flow of information is favourable; however, care must be taken to engage the community in decision-making relating to all topics that might affect, or be perceived to affect, the health and wellbeing of individuals and their surrounding environment. Retroactive risk communication (i.e., fire-fighting) quickly destroys public trust and is much less effective. It is generally accepted that the 'DAD', or Decide-Announce-Defend approach, to stakeholder communications is unreasonable and does not cultivate a high level of trust [42].

Table 1. The six components of 'trust' [41]

COMPONENT	DESCRIPTION
Perceived competence	degree of technical expertise in meeting institutional mandate
Objectivity	lack of biases in information and performance as perceived by others
Fairness	acknowledgement and adequate representation of relevant points of view
Consistency	predictability of arguments and behavior based on past experience and previous communication efforts
Sincerity	honesty and openness
Faith	perception of 'good will' in performance and communication

4. CONCLUSIONS

To ensure complex remediation decisions are risk-based and will serve to mitigate potential health and environmental impacts, risks must be comprehensively assessed through technical risk assessment. However, several non-technical factors must also be adequately considered in the overall risk management process. There are several methods available to generally guide project managers along these lines. Notably, there is an investment in planning, time, and resources required to do this effectively and management's support and understanding is fundamental to success.

The ORR project is thoroughly assessing the technical aspects associated with the contaminated sediments adjacent to the CRL site in the Ottawa River. This will allow for a comprehensive understanding of the actual risks to human health and the environment from this contamination. In addition, it is recognized that the path to effective risk management for this project must also include a focus on meaningful stakeholder and community involvement to consider how *perceived* risks might influence a recommended remediation strategy.

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