ENVIRONMENT CANADA

IRVING WHALE SEDIMENT REMEDIATION OPTIONS EVALUATION - FORMER IRVING WHALE SITE SOUTHERN GULF OF ST. LAWRENCE

PROJECT NO. 80283/12961

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IRVING WHALE SEDIMENT REMEDIATION OPTIONS EVALUATION
FORMER IRVING WHALE SITE
SOUTHERN GULF OF ST. LAWRENCE

PREPARED FOR

ENVIRONMENT CANADA

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in Association with the Irving Whale Site Remediation Steering Group

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EXECUTIVE SUMMARY

Jacques Whitford Environment Limited (JWEL) and JWEL's subcontractor CanTox Environmental were retained by Environment Canada on behalf of the Irving Whale Site Remediation Steering Group to evaluate potential remedial options for the polychlorinated biphenyl (PCB)-impacted sediments at the site where the *Irving Whale* barge came to rest on the sea floor in the Gulf of St. Lawrence. The barge sank in 1970 approximately 60 km north-east of North Point, Prince Edward Island, and 100 km west of the Magdalen Islands, Quebec. The PCB contamination of sediments resulted from leakage from the closed loop heating system of the *Irving Whale* after its sinking, and during the removal of the barge in 1996. The data available to date limit the scope of the study to the area immediately surrounding the footprint of the barge.

Project Objectives

The objective of the project is to prepare a report which consists of the following:

- Identification of sediment remediation options and associated techniques for the former *Irving Whale* site, including no further remedial action;

- Evaluate the technical merits, limitations, costs, environmental and health risks/benefits, availability of resources and other identified considerations of each technique under consideration; and

- Propose the most effective mechanism/approach for providing a presentation of the evaluation results for the options under consideration.

Evaluation Methodology

This study follows a five step process to determine appropriate remediation options and techniques to remediate PCB impacted sediments around the site of the former Irving Whale barge. The necessary steps to achieve these objectives are as follows:

Step 1	Establish Site Conditions
Step 2	Determination of Remedial Objectives - Review of Ecological and Human Health Risks
Step 3	Identification of Viable Remedial Options

Step 4 Screening of Remedial Options and Techniques
Step 5 Detailed Evaluation of Options

In total, six general criteria have been established in consultation with the stakeholders, encompassing statutory requirements as well other gauges to determine overall feasibility and acceptability of various options. These criteria are divided into two classes:

- Threshold Criteria: A pass/fail class criteria. If an option fails one of the threshold criteria, then it is not evaluated further.

- Balancing Criteria: Criteria that must ultimately be weighed against each other in order to determine the best remedial solution.

All options and associated techniques must meet the Threshold Criteria in order to be considered further in the Balancing Criteria.

The positive aspects (pros) and negative aspects (cons) as well as any important considerations are identified for a number of aspects within each of the balancing criteria (except cost).

Current Risks and Remediation Objective

As part of the study team, CanTox reviewed their earlier, pre-lift risk assessment (1996) and evaluated the findings in light of the new data. This work provided an update on the current risks and provided a revised sediment remediation objective. Based on this analysis, it was concluded that:

- No population level adverse effects would be anticipated for male and female snow crabs or for benthos in the Gulf of St. Lawrence, as a result of the PCB sediment contamination within and around the barge footprint area

- Adverse effects may be possible for individual female snow crabs, but there is no available data to determine the effects.

- Adverse effects are expected on an individual level for sedentary benthic species within and around the barge footprint area. However, there is no data available to show the possible effects.

- All snow crab tissue concentrations were below 2.0 μg PCB/g tissue Canadian human consumption guidelines, as such no adverse effects from human consumption of snow crab are expected.

The CanTox risk evaluation has determined that a remedial objective for this specific site of 1 mg/kg is protective of benthic communities in the study area.

Remediation Options

Three viable remedial options were identified:

1. Option 1: No further remedial action

2. Option 2: In-situ containment, consisting of the placement of an aggregate "cap" over sediments with PCB concentrations greater than 1 mg/kg.

3. Option 3: Removal and disposal, consisting of the dredging of sediments with PCB concentrations greater than 1 mg/kg, the separation of the water from the solids, volume reduction and ultimately disposal in an out-of-province licensed facility.

These three options satisfy the pass/fail "screening" (or threshold) criteria in that they are (a) technically feasible, (b) provide overall protection of human health and the environment, and (c) are compliant with applicable regulations and requirements.

The study methodology used four additional "balancing criteria", including effectiveness, risk reduction, other considerations (socio-economic, community perception, stakeholder acceptance), and ultimately, cost. The options were contrasted against each other by the identification of pros and cons of each option under several aspects of each criterion.

The terms of reference of the study did not involve the identification of a preferred option, instead, for each of the three viable options, JWEL has provided a summary of the most important aspects for consideration, presented in the following table:

Table E-1 Summary Table of Various Options

	Option 1 No Further Remediation Action	Option 2 Capping	Option 3 Dredging and Disposal
Summary of Technique	• No active remediation • Mid- or long-term monitoring and study	• Containment of sediments with concentrations greater than 1 mg/kg with aggregate blanket; post-construction monitoring	• Removal of sediments with concentrations greater than 1 mg/kg. Destruction of PCBs; post-construction monitoring
Protection of human health and environment, Implementability, Compliance with policies and regulations	• All options are protective of human health and snow crab populations • "No further remediation action" option requires acceptance of some residual risk to sedentary benthic community in and around the footprint area. • Capping and dredging will cause total removal of existing benthic community within the 1 mg/kg isopleth, but a new benthic community will be reestablished over time. • All options are technically feasible, proven and practical. • All options comply with applicable policies and regulations.		
Effectiveness of Technique	• No reduction in contaminant volume. Further studies reduce the uncertainty regarding effects on female snow crab and benthic organisms. • Contaminants will continue to be spread in Gulf • Monitoring required	• Capping is demonstrated technology that could be completed in one construction season, but adverse weather conditions will result in costly downtime. • Placement of geotextile is a complex technology • Use of local surface dump barges could result in project extending over several seasons. • No reduction in contaminant volume • May result in spread of PCB during construction • Not designed for full containment of contaminants, some spreading will continue to occur • Monitoring and possible maintenance required	• Dredging is a demonstrated technology that can be completed in one construction season, but adverse weather conditions will result in costly downtime. • Transportation of contaminated water volumes of this magnitude and subsequent dewatering has not been well demonstrated on similar projects of this nature. • Significant reduction in contaminant volume, although not designed for removal of all PCB material; some spreading will continue to occur • Only short-term monitoring required, no maintenance required
Reduction in Risk to Human Health and Environment Compared to Existing Conditions	• No adverse human health effects • No adverse effects on male snow crab or snow crab population. • Only current adverse effects are to benthic biota and possibly female snow crabs within area of concern. • Option maintains existing localized low-risk state	• No adverse human health effects • No adverse effects on male snow crab, or snow crab population • Objective of containing sediments that cause adverse effects to benthic biota met, however complete removal of biota is caused by construction, with new benthic community reestablished over time. • Some reduction of risk expected to local benthic organisms, however, PCBs outside of cap will continue to migrate	• No adverse human health effects • No adverse effects on male snow crab or snow crab population • Objective of removing sediments that may cause adverse effects to benthic biota met, however complete removal of biota is caused by construction, with new benthic community reestablished over time. • Some reduction of risk expected to local benthic biota, however, PCBs outside of dredged area will continue to migrate • Some very small increased risk to humans from exposure to PCB material during the dewatering and transportation work.
Other Considerations (stakeholder acceptance, perception and socio-economic issues)	• Option not universally accepted by PAC members, but is accepted by certain individuals as long as option is protective of human health and the environment • PAC members want fishery closure to be justified or adjusted based on science	• Option not universally accepted by PAC members a) since it is not optimal solution, or b) since it exceeds what needs to be done	• Some PAC members feel that this is the optimal method, while others consider that it exceeds what needs to be done
	• All PAC members want a decision made on the option immediately		
Capital Costs	$96,000	Bottom Dump Barge: $5.5 to $8 million Drop Tube Placement: $7.6 to $12.4 million	$19 to $24.5 million
Annual Costs	~$60,000/yr (monitoring)	~$134,000/yr (monitoring only, maintenance may be required if cap damaged)	~$60,000/yr (monitoring)

Note: Tables 7.1, 7.2 and 7.3 provide more detail on the effectiveness of each option.

1.0 INTRODUCTION

Jacques Whitford Environment Limited (JWEL) was retained by Environment Canada on behalf of the Irving Whale Site Remediation Steering Group to evaluate potential remedial options for the polychlorinated biphenyl (PCB)-impacted sediments at the site where the *Irving Whale* barge came to rest on the sea floor in the Gulf of St. Lawrence. The Steering Group is chaired by Environment Canada with membership from three federal departments, including Fisheries and Oceans, Transport Canada, and Public Works and Government Services Canada, as well as the Magdalen Island PAC and Prince Edward Island PAC. The barge sank in 1970 approximately 60 km north-east of North Point, Prince Edward Island, and 100 km west of the Magdalen Islands, Quebec at a depth of approximately 67 metres (Figure 1.1). The PCB contamination of sediments resulted from leakage from the closed loop heating system of the *Irving Whale* after its sinking, and during the removal of the barge in 1996. However, it is speculated that much of the PCB loss occurred at the time of the sinking The detailed location of the former *Irving Whale* barge site, within the Gulf of St Lawrence is provided by Gilbert *et. al.* (1998).

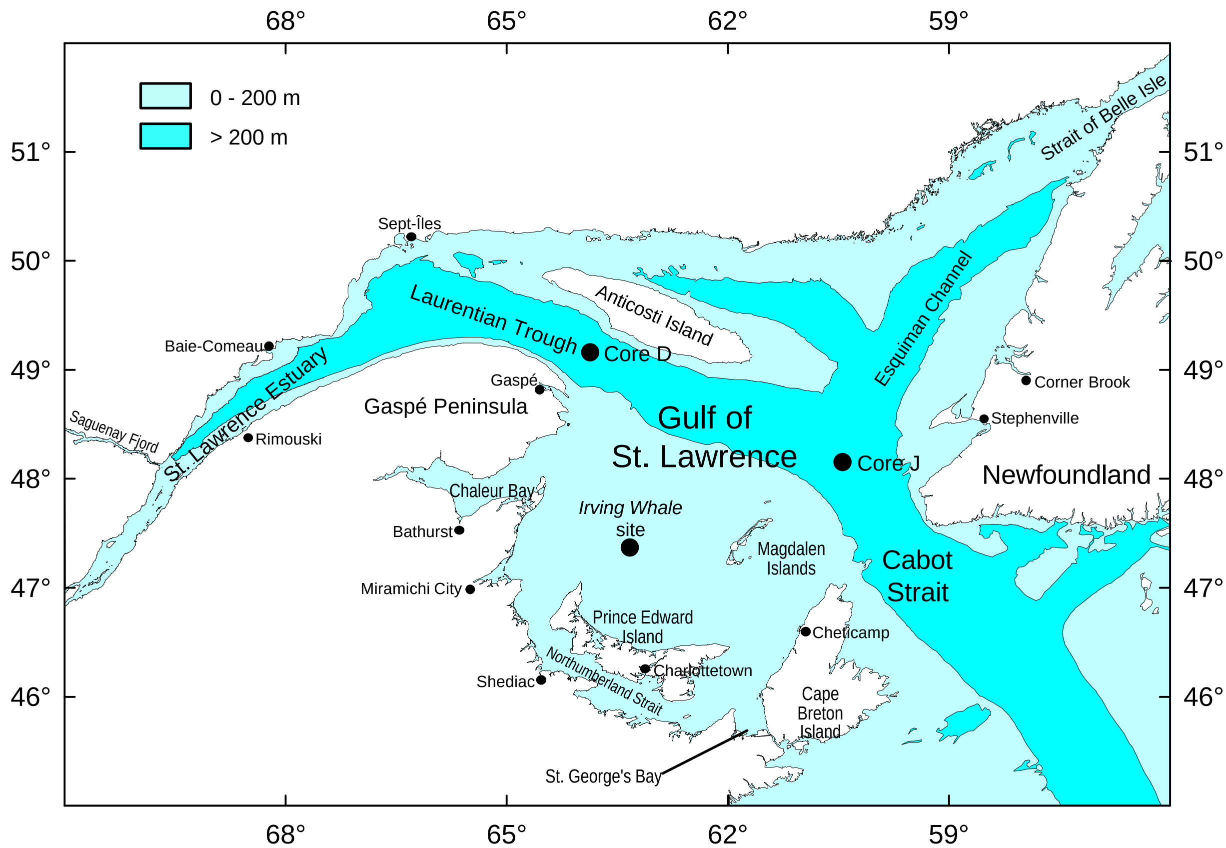

Figure 1.1 Location of the site where the barge *Irving Whale* sank on September 1970, in the southern Gulf of St. Lawrence. (From Fisheries and Oceans Canada and Environment Canada, 1997)

The Terms of Reference (TOR) of the study are provided in Appendix A. The data available to date limit the scope of the study to the area immediately surrounding the footprint of the barge. The following areas are referenced throughout the text and are defined here for clarity:

- Barge Footprint: The area directly below the vessel's resting place on the seafloor, approximately 80 m by 15 m.

- Study Area: The area defined by previous sediment and biota sampling efforts, approximately 20 km by 20 km centred around the barge footprint.

- Detailed Study Area: Detailed information on sediment quality is defined in an area limited to approximately 200 m by 200 m.

- Fishing Exclusion Zone: The 10 km by 10 km zone, centred around the barge footprint, defined by Department of Fisheries and Oceans (DFO) as a zone where fishing is not permitted.

The word "sediment" is referred to throughout the report. To many, this word implies certain physical properties, however, unless specifically defined otherwise, "sediment" is used in the report in reference to all unconsolidated material on the seafloor, including gravel, sand and finer particles. Where necessary, finer particles, often associated with the word "sediment" will be referred to as "fines", "silt" or "clay".

The following report contains background summary information from various studies conducted at the site, and an evaluation of potential options for remediating and/or managing the PCBs currently on-site.

1.1 Project Objectives

The objective of the project, as outlined in the TOR (see Appendix A), is to prepare a report which consists of the following:

- Identify sediment remediation options, including no further remedial action and associated specific techniques for the former *Irving Whale* site;

- Evaluate the merits and limitations of each option including technical, environmental and health risk/benefit, availability, cost and other identified considerations; and

- Propose the most effective mechanism/approach for providing a presentation of the evaluation results for the options under consideration.

1.2 Approach to Option Identification and Evaluation

This study follows a five step process to determine appropriate remediation options and techniques to remediate PCB impacted sediments around the site of the former Irving Whale barge. The steps are:

Step 1 Establish Site Conditions
Step 2 Determine Remedial Objectives by Review of Ecological and Human Health Risks
Step 3 Identify Viable Remedial Options

Step 4 Screen Remedial Options and Techniques Against Mandatory Criteria
Step 5 Evaluate Options in Detail

The detailed methodology for following this process is described in Section 2.0. Site conditions are presented in Section 3 and the remedial objectives are presented in Section 4. Section 5 identifies the basic viable options (Step 3) which could be applied to the site, and the screening and detailed evaluation of the criteria are presented in Sections 6 and 7 respectively. The findings of the detailed evaluation are summarized in Section 8.

2.0 STUDY METHODOLOGY

This study provides an analysis of various options for addressing PCB impacted sediments around the former Irving Whale site. In order to undertake this analysis, it is necessary to define the following:

- Appropriate remedial objectives; and
- A framework to identify, screen and evaluate in detail, viable and appropriate options and technologies.

This section of the report provides details on the methodology used to accomplish the above. The results of each of these analysis steps are described in later sections.

2.1 Establishing Remedial Objectives

Prior to evaluating the technical, financial and logistical aspects of each option, Step 2 of the study process involves establishing the existing risks posed to humans or the environment by the PCBs in sediments. This allows the following to be determined:

- current requirements for action

- risk-based targets to be achieved by remedial action

A review of the most recent sediment and biological data at the site is undertaken. The ecological risk assessment (ERA) completed by CanTox in 1996, before the lifting of the barge (CanTox, 1996), is re-evaluated in light of this new data and a revised remedial objective for PCBs in sediments is derived. The full evaluation is contained in Appendix B and summarised in Section 3.

This information allows for the determination of the area and volume boundaries around the site for required remedial action, which is carried forward into the option screening and analysis.

2.2 Identification of Viable Options

Step 3 of the study process involve identification of viable options. Identification of available PCB remediation technologies was based upon both JWEL's previous project experience in Nova Scotia, Canada and the United States, literature review, discussions with local and international dredging contractors, recent work on PCBs undertaken by Public Works and Government Services Canada (PWGSC) as well as off-shore oil and gas projects.

Implementability

All options can be divided into two broad classes of options: those that enable removal of the contaminant and those that isolate the contaminant from contact with humans or the environment. Within each of these classes exist a large number of technical approaches. In order to reduce the total number of techniques that are carried forward for analysis, the first screening involves the identification of those specific technical approaches that are viable (or "implementable"). A viable approach involves the use of methods that are *technically feasible, have proven effective in commercial use and are practical for implementation at this site*.

2.3 Option Review and Screening - Threshold Criteria

All viable options and the associated component techniques that could be used for each, are evaluated with consideration to a variety of legal, social and financial factors in Step 4 of the study process. In total, five general criteria (in addition to "implementability") have been established in consultation with the stakeholders, encompassing statutory requirements as well other gauges to determine overall feasibility and acceptability of various options. In Sections 6 and 7, all options and associated techniques are evaluated against two broad classes of criteria:

- Threshold Criteria: These criteria are mandatory. Evaluation is on a pass/fail basis. If an option fails one of the threshold criteria, then it is not evaluated further.
- Balancing Criteria: Criteria that must ultimately be weighed against each other in order to determine the best remedial solution.

In addition to "implementability", the two mandatory Threshold Criteria include:

- Overall protection of Human Health and the Environment; and
- Compliance with applicable regulations and requirements.

These threshold criteria are defined below.

2.3.1 Overall Protection of Human Health and the Environment

This criterion addresses whether an option provides adequate protection and describes how risks posed through each pathway are eliminated, reduced or controlled through various techniques. Spacial limits of the scope of these actions are dictated in this study by the PCB remedial objective.

2.3.2 Compliance with Applicable Regulations and Requirements

This threshold criterion considers how the policy of the federal government and federal and provincial environmental legislation would apply to the three remedial options under consideration.

As the proponent of the project, Environment Canada and the Government of Canada must give overriding and due consideration to its *Toxic Substances Management Policy* (1995) in conjunction with other legislation including the following:

- *Canadian Environmental Assessment Act;*
- *Canadian Environmental Protection Act;*
- *Fisheries Act*; and,
- *Transportation of Dangerous Goods Act*.

Provincial legislation that may be applicable to one or more of the options include:

- New Brunswick *Clean Environment Act*.

2.4 Detailed Screening - Balancing Criteria

In Step 5 of the study process, those options that passed the mandatory Threshold Criteria, were then evaluated using the following Balancing Criteria:

- Effectiveness
- Risk reduction
- Cost
- Other Considerations (i.e. socio-economic benefits or disadvantages, stakeholder acceptance)

The positive aspects ("pros") and negative aspects ("cons") are identified within each of the criteria (except cost). This analysis is contained in Section 7 of the report. A detailed description of each balancing criterion is described below.

The original terms of reference for this study also included the consideration of potential liability in the event of ineffective remediation and agreement with federal government policies. However, liability was not considered in this evaluation as it would require extensive project description information that is not available at this time and should be reviewed at a later stage. The aspect of agreement with federal government policies is covered under the Threshold Criterion of Compliance with Applicable Regulations and Requirements.

2.4.1 Effectiveness

To compare the effectiveness of each option, the following aspects are considered:

- <u>Timely achievement of remedial objective</u>: how quickly does the option achieve the desired result?

- <u>Maintenance of remedial objective</u>: how well does the option maintain the desired result over a specified time frame?

- <u>Containment of contaminant mass</u>: does the option contain or remove contaminant mass?

- <u>Reduction in contaminant volume</u>: does the option reduce the PCB volume?

- <u>Requirements for monitoring and/or maintenance</u>: is there a requirement for monitoring the system or maintenance to ensure that the option performs as specified?

Effectiveness is evaluated in terms of time frame. Effectiveness during implementation and over time was considered by evaluating the adequacy of the technique in the short term, the medium term and the long term, as described below:

Short-term effectiveness: This time period is defined as the adequacy of the option or technique during implementation or construction. For each technique, monitoring data gathered from previous projects are used and compared against the known or predicted risks from these effects.

Mid-term effectiveness: This period covers the time immediately following implementation, and including a subsequent period of 5-10 years.

Long-term effectiveness and permanence: This time frame is generally defined as the life expectancy of an engineered structure. This generally is an evaluation of the permanence of the structure (i.e. cap) beyond a ten year period.

2.4.2 Risk Reduction

The pros and cons of the risk reduction of each option are evaluated against the current (1997 data) human and ecological health risks, which are described in detail in Section 4 of the report, considering the following aspects:

- Avoidance of short term physical impacts to the local habitat (short term)
- Reduction in adverse ecological effects compared to current (1997) post-lift conditions (mid and long term)
- Reduction in adverse human health effects compared to current (1997) post-lift conditions (mid and long term)

2.4.3 Cost

This criterion compares estimated capital, operational and maintenance costs associated with the overall option. It identifies a range of capital cost estimates and the approximate cost to undertake annual maintenance or monitoring. Included in the cost analysis is an estimate of the Canadian and foreign content.

2.4.4. Other Considerations

This evaluation compares the pros and cons of socio-economic benefits and disadvantages (expressed as concepts and dollar values, where possible), community perception of the environment, and stakeholder acceptance of options. A central element in preparing and analysing this criteria was the presentation and discussion of a series of questions with the PAC members on the Steering Group.

3.0 SITE DESCRIPTION

Step 1 of the study process involves providing a general description of the conditions around the former Irving Whale site. The information contained in this section has been summarized from several sources referenced in Section 9.0.

The location of the barge footprint is 47° 22' 09" N latitude and 63° 19' 46" W longitude, situated in the south-western Gulf of St. Lawrence, approximately 60 km north-east of North Point, Prince Edward Island, and 100 km west of the Magdalen Islands, Quebec.

At the time of its sinking, the *Irving Whale* barge contained 4,270 tonnes of Bunker C fuel oil (as cargo), 7,500 kilograms (kg) of PCBs, and 1,900 kg of chlorobenzenes (in the associated heating system). The barge sank on September 7, 1970. The barge was recovered and transported to Halifax on July 30, 1996 for decontamination. During the period in which the barge rested on the seafloor, it has been estimated that approximately 5,700 kg of PCBs were lost to the environment and approximately 220 kg PCB was recovered from the sediment immediately following the lift. It was estimated 150 to 350 kg of PCB's are present in sediments within an area of 62,500 m^2 around the barge footprint in 1997 (Gilbert, *et. al*., 1998). Figure 3.1 shows the barge footprint, and sediment concentration contours.

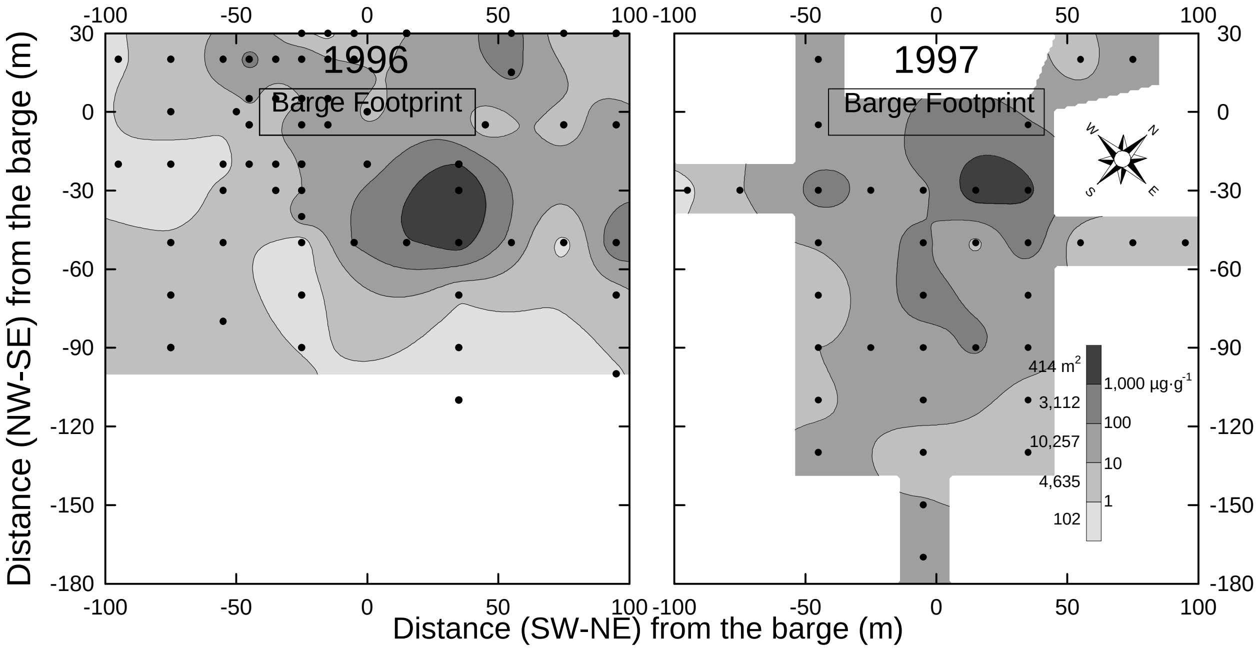

Figure 3.1 Distribution map of PCB concentrations (Aroclor 1242) in sediments around the *Irving Whale* site in October 1996 and in May and June 1997 from samples collected using a manned submersible. (from Fisheries and Oceans Canada and Environment Canada, 1997)

To put into perspective the mass loading from the *Irving Whale* as compared to other sources, it has been estimated that there are currently a total of approximately 6,000 kg of PCBs in the Gulf of St. Lawrence (at depths greater than 200 m) and approximately 24,000 kg of PCBs in the Lower Estuary (Gilbert *et al.*, 1998). Nevertheless, this mass is present at much lower concentrations than the concentrations observed at the *Irving Whale* site. Experiments in the literature have shown that PCBs can degrade under certain conditions, however, no attempt has been made to quantify the specific rate of destruction in the Gulf.

After the removal of the barge, there were several attempts to remediate sediments around the barge footprint. These efforts included the use of large capacity pumps to transfer contaminated sediments to steel lugger bins placed on the ocean bottom, and the manual collection of sediments using divers. It was reported that these methods caused resuspension of contaminated sediments and further spread the PCBs. There was also an attempt to use an airlift suction pump to transfer water and sediments into a barge at the surface. This method was somewhat successful, however, it was only able to retrieve 1 tonne of sediments for every 35 tonnes of water, and was found to be inefficient with the equipment and number of barges available at the time.

3.1 General Regional Information

The sea floor in the study area is relatively flat at approximately 60 to 80 metres below sea level. In the immediate area of the barge footprint, the depth of the sea floor is approximately 67 metres.

The average water current in the immediate vicinity of the site is approximately 0.5 knots and has an average temperature of between 1 ^{o}C to 1.5 ^{o}C, except in the autumn when the temperature can exceed 2 ^{o}C over the entire water column. The orientation and amplitude variability of the residual flow is relatively large in the vicinity of the site, and its pattern shows an almost closed loop with an amplitude reaching 7 cm/s in certain areas. Residual currents are oriented north-north-east toward the Laurentian Trough. In the late summer and early autumn, remnant hurricanes can occur in the area. As a result of the currents and weather patterns in the area, continuous resuspension and redeposition of sediments contaminated with PCBs is possible.

3.2 Physical Sediment Characteristics

The ocean bottom at the site is covered with mud, sand, scattered rocks and boulders. The sediments consist of a thin layer of sand (87 %), gravel (11 %) and clay (2 %) over sandstone bedrock. As shown in Figure 3.2, the thickness of unconsolidated material is highly variable around the footprint of the former barge, ranging from 1 mm to 200 mm (Fisheries & Oceans Canada (DFO) and Environment Canada (EC), 1996). During the 1997 sampling program, Environment Canada undersea video information showed the boulders to be relatively sparse with a range of sizes up to one metre in diameter.

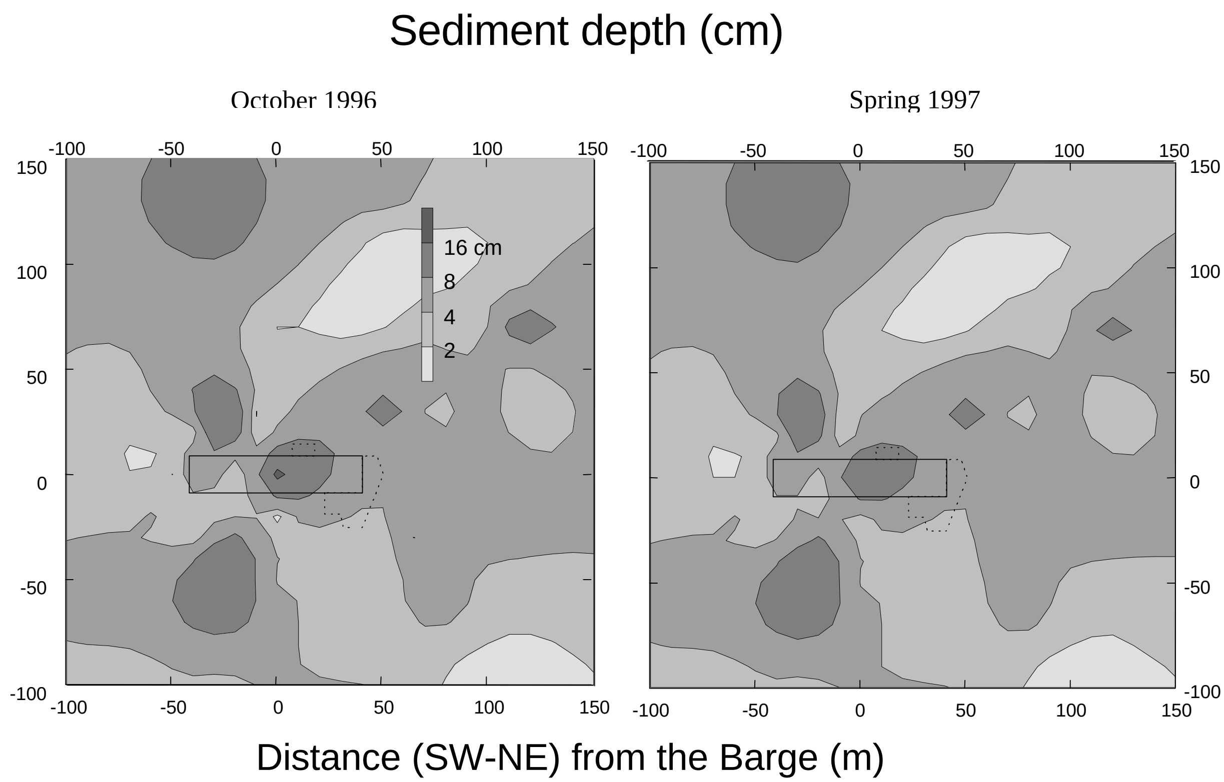

Figure 3.2 Distribution maps of Sediment Thickness Measured in October 1996 and Spring 1997 (from Fisheries and Oceans Canada and Environment Canada, 1997)

3.3 Physical Oceanography of the Site

The sediments on the site may be transported by natural processes which include tide and storm currents. Wave motions are probably less important due to the depth of the site. Tidal current in the area is of the order 0.2 m/s. Storm currents may approach 3 % of wind speed, thus, a gale of 20 m/s wind may produce additional currents of 0.6 m/s for a period of hours to days. Sediment transport theories suggest that transport rates will vary with a power of the velocity so storm events may play an important role in determining the occasion and direction of transport of material in the Gulf of St. Lawrence (Mark McNeil, pers. comm.).

Since the removal of the barge on July 30, 1996, it appears that the local sediments within a few hundred metres of the site have become coarser and more loosely compacted. This suggests that the barge created a lee which enhanced deposition of fine grained sediments (Gilbert *et al*, 1998). Since the barge was removed, some of these sediments have been mobilised by natural processes. These sediment composition observations are based on surveys conducted by DFO and Environment Canada in the fall of 1996 and the spring of 1997(Gilbert *et al*, 1998). Meteorological records from the Charlottetown Airport covering the ice free part of this period suggest that fall 1996 and spring 1997 winds were somewhat weaker than average with relatively few occurrences of strong storm events.

3.4 Habitat Characteristics

It is important to understand the characteristics of the habitat at the site in order to properly undertake an evaluation of risks and to put any remedial objective in the context of the larger Southern Gulf area.

No site-specific habitat assessment has been carried out at the site. Based on a review of the literature available on the characteristics of the habitat in the Southern Gulf, including the information prepared by Environment Canada and DFO, the following general conclusions respecting the local habitat can be made:

- The habitat at the Irving whale site is not unique. The characteristics of the habitat and expected species at the site are very similar to those expected in a large percentage of the Southern Gulf.

- By its very nature, this non-unique habitat (described above) does not lend itself to produce a higher than average density of benthic populations.

While it is recognized that the former Irving Whale site is located in the midst of the snow crab fishing zone, it is not spatially a significant portion of the area (present fishing closure area ~0.26% of the Area 12 fishery).

4.0 DETERMINATION OF REMEDIAL OBJECTIVES FOR THE SITE

4.1 Background, Context and Objectives

Step 2 of the study process involves determining an appropriate remedial objective. Risk assessment is a tool that is commonly used at contaminated sites to quantify actual risks to humans and ecological species in order to make effective decisions about the management of these risks. Risk assessment is undertaken in accordance with the federal *Toxic Substances Management Policy*. When the broader issues of background risks, achievable remedial objectives, and socio-economic concerns are considered, risk assessment can be used to determine appropriate remediation criteria at contaminated sites.

Ecological risk assessment can be focussed on the following endpoints:

- individual effects
- population effects (species populations within and beyond the affected area);
- community effects (likely include populations of multiple species); or
- ecosystem effects (rarely if ever, undertaken due to its complexity).

In the determination of remedial objectives, it is considered more appropriate to focus remedial criteria towards the protection of populations, as population-level effects are a more measurable and relevant indicator of ecosystem health (i.e., as indicated in examples provided in CCME, 1994).

Before the Irving Whale was lifted, a detailed ecological risk assessment was conducted in 1996 by CanTox to evaluate the potential risks from PCB-contaminated sediment to critical aquatic receptors and to develop site-specific sediment remediation criteria for indigenous biota at the *Irving Whale* site (CanTox, 1996). The present risk evaluation, carried out by CanTox and contained in Appendix B, has re-evaluated the current risks based on the most current data available (Gilbert *et al*., 1998).

The objectives of the present risk evaluation were:

- Review the current risks imposed by the study area using post-lift sediment and biological data;
- Re-evaluate the 1996 Ecological Risk Assessment conclusions; and
- If necessary, define a remedial objective and criterion.

The next sections provide a summary of the findings of the present risk evaluation.

4.2 Current Risk Conditions at the Site

The current assessment of post-lift data presented in this report (Appendix B), considered three receptors a) snow crabs, b) the benthic community in the sediment and c) humans (albeit indirectly). This assessment concluded that:

- Adverse effects are suspected for the sedentary benthic community within and around the barge footprint area only.

- No adverse effects from exposure to PCBs in the study area are expected for individual male snow crabs.

- As female snow crabs tend to be less mobile than males, and are more likely to remain in a given area than males, they would be expected to incur higher exposures to chemicals in sediment. Therefore, if females were to spend a significant amount of time in the vicinity of the barge footprint, their risk would be expected to be higher than that of males. However, as no female snow crab tissue concentrations are available, there is insufficient data with which to make conclusions regarding potential risk to female snow crabs. Despite this uncertainty, the lack of significant risk for male snow crab suggests that even adverse effects on individual females would not be expected to cause adverse effects at the population level. It should be noted however, that the risk potential to female crabs should be quantified in future monitoring programs to determine potential effects on individual crabs.

- All snow crab tissue concentrations were below 2.0 µg PCB/g tissue Canadian human consumption guidelines, as such no adverse effects from human consumption of snow crab are expected.[1]

The CanTox study concluded that while it is difficult to extrapolate the risk estimates to a larger boundary than the study area (such as the Gulf of St. Lawrence), based on a qualitative consideration of the results of the current risk assessment, the findings of the most recent monitoring program (Gilbert *et al.*, 1998), and other key issues, <u>no population level adverse effects would be anticipated for male and female snow crabs or for benthos in the Gulf of St. Lawrence</u>, as a result of the PCB sediment contamination within and around the barge footprint area. <u>It should be noted however, that this statement is based on a limited amount of data</u>.

4.3 Remediation Criterion

The CanTox risk evaluation has determined the following:

- no remedial action is required to protect human health, therefore no sediment remediation criterion is required for this purpose;

[1] Female snow crabs are not fished for human consumption in the area.

- no remedial action is required to protect the snow crab population, therefore no sediment remediation criterion is required for this purpose, subject to the continued monitoring of effects at the site; and

- the potential exists for adverse effects to the benthic community if sediment concentrations exceed 1 mg/kg. This concentration has been identified in some sediment in and around the barge footprint.

If remediation is necessary an appropriate remedial objective for the site would therefore be either to remediate sediment in and immediately around the barge footprint to less than a remediation criterion of 1 mg/kg or to otherwise isolate any sediment exceeding this 1 mg/kg level from the benthic community, in order to reduce the risk to the local benthic community from potential adverse effects.

The decision to remediate at a contaminated site and final remedial objectives should involve considerations other than the application of sediment quality criteria alone (DFO and EC, 1997). PCB sediment quality criteria are conservative values that are generally based on toxicity to sensitive species that may comprise a small portion of a given community or ecosystem. Other environmental impacts associated with remediation may be of greater ecological importance than PCB contamination (Dexter and Field, 1989). Key considerations in establishing remedial objectives include background concentrations and the nature and size of the affected area within the ecosystem.

4.4 Requirements for Additional Data

The conclusions provided above are conservative with respect to the uncertainties identified in the study (see details in Appendix B) above. To reduce the uncertainty, the following actions could be undertaken:

- Review of the most recent sediment and biota sampling program. These data will be available by August, 1998. The data presented in Gilbert *et al.,* (1998) showed that PCB profiles in sediments and biota are clearly changing based on a comparison to the previous year's sampling results. If this trend has continued over the winter of 1997, estimates of risk, as reported in the current assessment may change. In addition, this would allow for the current spatial distribution of PCB sediment contamination to be established.

- Further sampling and monitoring of snow crabs including the collection of digestive gland and muscle tissue data from female snow crabs to quantitatively assess the risk potential to females that might incur greater exposures than males, due to less mobility (Dufour, 1988).

- Future snow crab monitoring should account for different age classes and seasonal changes in the physiological condition of crabs, as these may affect contaminant dynamics within snow crab tissues.

- Collection of ambient background data from reference sites, to better assess whether sediment and snow crab concentrations in the area of concern are elevated over background.

- Collection of more snow crab samples from beyond the 10 km x 10 km fishing exclusion zone.

- Additional information regarding benthic invertebrate populations (*i.e.*, species diversity; abundance; PCB body burdens etc.) for the area around the barge footprint and a suitable reference location are required to evaluate the costs and benefits of remedial efforts to protect this group of organisms.

- Further sediment monitoring should analyze samples for particle size, and Total Organic Carbon, as these factors can have a major influence on PCB bioavailability to benthic organisms.

- Tissue residue data, coupled with Principle Components Analysis data should be collected for organisms at various trophic levels to determine the extent of PCB entry into the Gulf of St. Lawrence ecosystem.

- The exclusion zone should remain in place until further monitoring is conducted to ensure the trend of decreasing PCB concentrations in the sediments continues.

Some of these recommendations may not be necessary if further remediation of the site is carried out.

4.5 PCB Contaminated Area and Volume

In March 1997, (DFO and EC) issued a Status Report following the raising of the Irving Whale. Within that document, it was reported that the sediment thickness within a 200m x 200m zone around the barge footprint ranged between 1 cm to 16 cm. A 1997 survey conducted by the DFO (Gilbert, *et al*., 1998) resulted in an estimation of 150 to 350 kg of PCBs in sediments, which vary in thickness from 1 mm to 200 mm over the underlying sandstone bedrock, within an area of 62,500 m^2 around the barge footprint. Information presented in the 1998 Fisheries and Oceans Status Report shows the sediment study area of 20,000 m^2 contained from 155 to 280 m^3 of contaminated sediment. This area is bounded by an isopleth of approximately 5 mg/kg PCB in sediment.

As outlined in Section 4.3 above, sediment concentrations in excess of 1 mg/kg may pose adverse effects to the benthic community. Based on the information of the 1997 DFO and EC[2] report, the area bounded within the 1 mg/kg isopleth is very roughly estimated to be bounded by an area 200m by 200m or 40,000 m^2. No volume estimates were calculated for this larger area and it is assumed for this report that an area twice the size of the initial 20,000 m^2 study zone will contain twice the sediment volume. Using the higher end volume calculated in the 1998 report by EC of 280 m^3, the revised volume estimate bounded within the 1 mg/kg isopleth is approximately 600 m^3. For the purposes of this study, 600 m^3 volume and 40,000 m^2 area estimates have been carried forward to evaluate the potential remediation options.

Previous environmental studies of contaminated sediments involving material containing fines have shown that much of the contamination is found bound to the finer sediment fractions (i.e., very fine sands, silt, clay and naturally present organic particles)[3]. Thus, it is possible that a large fraction of the sediment is relatively clean and could be treated by conventional volume reduction techniques. However, following the lifting of the barge in 1996, free phase product pools were reported to be recovered from the immediate area around the barge footprint (pers.comm, Dr. Tay, EC). It is therefore possible that free phase PCB product may still be present in some localized sand deposits within interstitial pores.

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2 Scientific Assessment of the PCB Contamination in Sediments and Biota Around the Site of the Sinking of the Barge Irving Whale, Status, Fisheries and Oceans et al, 1997.

3 Remediation of the Harbour Elbug, The Netherlands, L. van Geldermalsen, Sediment Remediation 95, Windsor, Ontario.

5.0 IDENTIFICATION OF VIABLE OPTIONS

Step 3 of the study process involves the identification of viable options on the basis of "implementability".

Three general classes of options encompass all remediation approaches. These include:
1. No further remediation action (Option 1);
2. In-situ containment of PCB contaminated sediments (Option 2); and,
3. Removal of PCB contaminated sediments (Option 3).

Each of these options could be implemented using a number of techniques. Potential techniques are evaluated in this section to identify viable ways to implement each of the three general options, considering availability, proven nature of the technology, and past performance. Techniques which pass this screening criterion are considered in further detail in subsequent sections of this report under the Threshold and Balancing Criteria.

5.1 Option 1: No Further Remediation Action

This option would not provide for any further remediation of the PCB contaminated sediments, which would be left in their present state. There are no site enhancement or modification issues associated with this option. As noted in Section 4, minor uncertainties may need to be addressed through a further round of sampling to confirm the assumptions made in the risk assessment. Institutional controls may be required including ongoing physical, chemical and biological monitoring to identify movement or alteration in concentration and distribution of PCBs and to identify future change in conditions which may pose unacceptable risks to local benthic organisms.

5.2 Option 2: In-Situ Containment

This approach would involve leaving the PCB contaminated sediments designated within the 1 mg/kg contour in-place and containing them in-situ. After containment within the 1 mg/kg contour area, a significant area of sediments would remain which would not be remediated. Two basic approaches were considered for this option:

- Capping using either surface discharge or precision placement methods; and
- In-situ solidification.

5.2.1 Capping

Under the capping option, a granular fill cover would provide a permanent mechanism to prevent future exposure or erosion of PCB contaminated sediment. Prior to undertaking the capping program, a high resolution pre-construction survey would need to be completed to define the capping zone and place remote locator markers on the bottom to assist in positioning the ships and cap material accurately. A cap composed of varying sizes of aggregate would be placed over the area bounded by the 1 mg/kg isopleth contour.

Special precautions would be necessary to protect the very thin contaminated sand layer from becoming re-suspended with aggregate impact; this is particularly difficult to control using surface discharge techniques. Sediment loss within the 1 mg/kg isopleth could be controlled using a geotextile placed over the sediments using a sub-surface deployment system. After the geotextile is placed, a lift of aggregate would be applied to a depth of 600mm above the geotextile. Ideally this aggregate would be well graded, containing a range of sand and gravel size material. An additional 500 mm of armour stone up to 150 mm in diameter would be placed over the first lift of aggregate to provide scour protection from the 0.5 knot currents.

Capping has been effectively demonstrated for use on contaminated sediments both in the Portland Disposal Site, Casco Bay, and Massachusetts Harbour, United States to cover contaminated ocean sediments at depths over seventy metres. These caps were placed over thick contaminated dredge spoil mounds in areas within 25 kilometres of shore. There are no examples of applying this technology to thin contaminated sediment layers (under 160 mm thick) located at distant off-shore, deep ocean sites. It is reasonable to assume these techniques are applicable to the Irving Whale site. Following implementation, a long term physical, chemical, and biological performance monitoring program would be required to determine effectiveness of the cap cover in containing PCB contaminated sediments. In addition, this option may require on-going and periodic maintenance of the cover material if erosion occurs.

Precision Placement Techniques

Precision placement of aggregate caps is also a common technology used by pipeline and telecommunication companies to lay underwater pipes and cables. This technique can be completed using ships equipped with a "drop-tube" extending from surface to the ocean bottom. More specialised systems add a dispersion nozzle on the end of the drop-tube to provide more even placement of material. Drop tube techniques have been used for many years in deep ocean sites up to several hundred meters deep (Figure 5.1). Ships equipped with these devices are commercially available internationally. Local expertise using drop tube methods is available although appears to be limited to shallow (30 meter depth) ocean port areas. Larger ships with aggregate holds up to 10,000 tonne capacity are available internationally and have been used on deep ocean sites such as this one. Discussions with several large international dredging contractors revealed that although these systems have been used to cap contaminated sediments, the primary purpose of these systems was to provide a highly accurate placement technique to deep ocean sites. Dredging firms have operated this equipment in seas up to Force 7 with wave heights from two to three metres.

Figure 5.1 Precision Placement of Aggregate

For deep ocean deployment of geotextiles, dredging firms in Europe such as VanOord ACZ, have developed simple frame and rack systems which sit on the ocean floor and un-spool geotextiles using ship-board cables and winches. Typically, the use of geotextiles have been used in undersea applications to cover soft sediments with poor bearing capacity. These systems can deploy the geotextile directly in advance of the spreader nozzle, or modified geotextiles with concrete ballast blocks can be woven directly into fabric for earlier deployment. Although the few instances of deep ocean caps have not employed geotextiles in their design, none have had the unique conditions exhibited by the Irving Whale in which the sediment is a very thin depth (less than 160 mm) underlain by bedrock. Geotextiles have been used in Canada for capping shallow contaminated sediment in Halifax Harbour, NS and Georgetown Harbour in PEI.

Although precision placement techniques may be applicable to the Irving Whale Site, a pilot trial would be useful to determine whether the thin sediment depth would pose unforeseen problems.

Surface Discharge Techniques

Discharge of material onto the ocean floor has been undertaken for many years using barges specifically designed for the task. Two basic surface discharge barges are commonly available in the Atlantic provinces: side discharge barges and split-bottom barges. The capacity of these vessels typically range from 100 m^3 to 750 m^3. Traditionally, accuracy of discharge has not been critical for these vessels as they were intended for discharge of sediment dredge spoil into the ocean. Studies by the US Army Corps of Engineers off the coast of Maine have shown these vessels must be positioned with very high accuracy before attempting to discharge the capping material. Modelling of cap material dispersion under the effects of ocean currents is also an essential requirement for a successful operation.

Based on discussions with several dredging companies, this method is considered to have a high potential for non-performance because of loss of contaminated sediment, displaced upon impact of cap material. Several contractors were also concerned that this method would require significant amounts of extra material to allow for dispersion through the water column. Areas not protected by geotextile beyond the 1 mg/kg isopleth would also be subject to significant re-suspension as the cap material arrives at the bottom. Although the applicability is less certain than precision placement, this technique has been carried forward for analysis at the request of the Steering Group.

5.2.2 In-Situ Solidification

In-situ solidification of deep ocean contaminated sediment has not been demonstrated on a commercial basis. Although the method is technically achievable under no-current conditions, there would be a high potential for the contaminated fine material to be lost while attempting to add and mix the cementitious material. Alternative approaches to this technique would involve removal of the sediment from the bottom, dewatering and recovering the sand, gravel and contaminated fines, mixing the cementitious material and returning the slurry to the ocean bottom. The material being dumped back into the ocean would contain PCBs in excess of the 0.1 Ocean Disposal criteria. This technique was removed from further consideration as it was not commercially viable and would likely fail to meet regulatory requirements.

5.2.3 Options Carried Forward for Further Consideration

Based on the review above, in-situ capping using surface discharge and precision placement techniques are considered viable options and are considered further under Threshold and Balancing Criteria in subsequent sections of this report.

5.3 Option 3: Sediment Removal and Disposal

The third option to address residual PCBs in sediment is to recover the impacted materials. PCB impacted sediments would be dredged from the ocean bottom and returned to shore for treatment. Within this option, there are several aspects which, for the purposes of this report, are termed operational components. These include the following:

- Removal;
- Dewatering;
- Volume Reduction;
- Transport; and,
- Final Disposal/Destruction.

5.3.1 Removal

A variety of technologies are available for recovering sediments off the ocean floor. However, only a limited few are capable of lifting the sediments to surface over a depth of up to eighty meters as found on this site. Most dredging technologies are available for removal of sediments can be divided into four general categories:

- bucket technologies
- cutter technologies
- suction technologies
- pump technologies

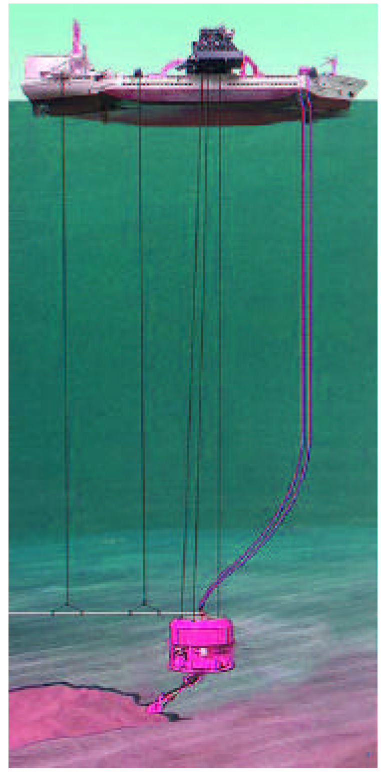

Figure 5.2 Remotely Operated Dredging Unit

A summary of capabilities and limitations for various commercially available dredge technologies as applied to deep ocean sediment recovery is presented in Appendix C.

Dredge equipment was generally compared against the following criteria:

- Ability to handle slurries with low solids (sediment) content;
- Ability to recover material in deep sites (over 65 meters);
- Ability to remove thin layers of sediment;
- Accuracy in positioning the dredge heads;
- Ability to work in seas with four metre waves;
- Relative potential to cause sediment re-suspension around the dredge head;
- Equipment is demonstrated on a commercial basis, and,
- Equipment can handle a range of sediments including rocks and cobbles.

Potential dredging technologies which did not fulfill the criteria outlined above were subsequently eliminated from further consideration (Appendix C). Based on the review, the following technologies were considered viable for use in recovering impacted sediments:

- Dustpan Dredger
- Pneuma/Oozer Dredging System
- Airlift Technology

A description of dredging technologies which could be utilized for this work are described in Appendix C. A general configuration of a remotely operated dredging unit is presented in Figure 5.2.

5.3.2 Dewatering

During the recovery operation, a significant volume of water and sediment would be generated. Because the water would contain a significant amount of contaminated suspended sediment, it would need to be treated prior to release. This would necessitate dewatering to separate impacted sediment from water. Four methods were considered for the dewatering component. These included:

- Land-based systems using chemical flocculation combined with simple gravity separation;
- Land-based systems using chemical flocculation combined with mechanical separation;
- Land-based systems using chemical flocculation combined with sand bed filtration and activated carbon polishing; and
- Sea-based technologies for dewatering on the ocean.

<u>Land-Based Systems</u>

The first general approach for this component would be to transport the water and dredged material to a land-based processing area and dewater the sediments. Although the dredge ship has a large holding capacity, it is assumed that a "shuttle barge" would be used to transfer most of the recovered sediment and water to shore. It is highly probable that the majority of PCBs would be associated with the fine particles in the sediment matrix which tend to remain in suspension and require special dewatering techniques to settle them out. Prior to undertaking this work, further study on the PCB content associated with various sediment grain sizes would be necessary. It is possible that the majority of the sand and gravel would not require treatment and could be discharged directly back into the ocean or landfilled.

1. Chemical Flocculation With Gravity Separation

This technique has been used for treating water containing contaminated suspended sediments for many years. The process involves a two stage operation. In the first stage, gravity is used to drop the sand and gravel fraction out and allowing the water containing contaminated suspended sediments to pass into a second treatment cell. To remove the fine suspended contaminated sediments, the water would need to be treated with a flocculent which would chemically bind to the fine material and allow it to settle more readily. Although there are a variety of chemical flocculents commercially available, only a limited number are effective on salt water at a temperature of 3^{o} Celsius. The flocculated sediment would then pass through a settling chamber where they would fall to the bottom and clean water would pass out, ultimately discharging back into the ocean. This method would require continuous sampling and monitoring to ensure that residual PCB concentrations in the effluent met federal discharge criteria. As there is only approximately two percent fine material in the existing sediments, the total recovered volume after flocculation would be small (2% of 600 m^3, or 12 m^3 total). This could be collected in a closed transport truck and removed from site for treatment.

2. Chemical Flocculation With Mechanical Separation

This approach would be very similar to the first technique. However, after the free draining water is removed from the flocculated fines, further mechanical dewatering could achieve additional reduction in water content and reduce the volume of sediments to be transferred for treatment. Several mechanical dewatering systems are available including centrifuge, plate, or diaphragm presses. Centrifuge systems typically provide the most inexpensive and efficient means of dewatering this type of material. If sand and gravel are found to require treatment for PCBs, mechanical systems described above could be used to provide further dewatering. Mechanical equipment as noted above has been used to dewater contaminated, wet material on many sites in Canada and the United States over the past twenty years and are commercially available from many contractors.

3. Chemical Flocculation Combined With Sand Bed Filtration and Activated Carbon Polishing

This technique would be similar to the first technique. However, after the flocculent is added to the water, the mixture would be allowed to react and pass through a sand beds. After passing through the sand beds, residual organic material in the water could be polished through a carbon bed filter. Wastewater from the sand bed system would be discharged into the ocean and the spent sand and activated carbon would be sent to Quebec for disposal. This technique has been used on a variety of organic contaminants and is generally less expensive than plate presses or centrifuges due to the limited amount of mechanical equipment required. However, the effectiveness of this approach would depend on the distribution of PCB's within the recovered sediment matrix.

Sea-based technologies

Consideration was given to dewatering the recovered dredge material at sea. However, with the possible exception of the sand bed/activated carbon system, most of the techniques would be unlikely to keep pace with the incoming volume of water. Centrifuge systems could not be used at sea because of operational problems associated with ship movement. Although sand filtration methods described above are technically possible and commonly used for land based applications, the review of literature and discussions with international dredging companies did not identify instances where this technique was demonstrated on a commercial level at sea. As such, this technique was removed from further consideration. However, if Option 3 is selected as the preferred approach, further bench and pilot testing should be considered as this technique offers a considerable potential for time and cost savings.

At this time, it is recommended that sea-based dewatering should not be carried forward as a viable component technique. The following viable dewatering techniques are carried forward for further consideration:

- Land-based systems using chemical flocculation combined with simple gravity separation;
- Land-based systems using chemical flocculation combined with mechanical separation; and
- Land-based systems using chemical flocculation combined with sand bed filtration and activated carbon polishing.

5.3.3 Volume Reduction

Volume reduction is often an effective method of reducing the amount of contaminated material to be treated. Volume reduction techniques are used primarily to reduce the PCB destruction costs associated with the project. Several volume reduction technologies are commercially available to process contaminated soil and sediments. Typically the technologies are divided into two groups, those which provide particle size separation and those which physically remove the organic contaminant from the soil matrix. For the purposes of assessing costs, these techniques have been evaluated to determine if volume reduction may warranted. Prior to giving further consideration to these techniques in a full scale system, bench scale and pilot testing would be required to determine if the processes are totally effective in further reducing the contaminant volume to be treated. Detailed analysis of the PCB distribution within the sediment matrix (fine versus silty material) is also required.

Particle Size Separation Techniques

The first method of reducing the contaminated sediment volume is through particle size separation. As noted above, the dewatering process will remove much of the sand and gravel. The technique is based on the nature of contaminated organic material to preferentially bind to silt and clay particles. Subject to confirmatory testing, the sands and gravel fractions may be suitable to return to the ocean or landfilled. The small quantity of contaminated fine material would be sent for destruction.

Thermal Phase Separation

Thermal phase separation is a process that removes the PCB's from the soil using indirect heating. A typical system is shown in Figure 5.3. Typically, the contaminated material is placed into a large chamber. Heat is applied to the outside of the chamber, indirectly heating the contaminated sediment. The temperature is gradually increased inside the sediment chamber until the contaminants turn to vapour form. The contaminated gas vapours are subsequently removed from the chamber, condensed and recovered. The liquid PCB condensate is then transported to an incinerator for destruction. Currently, there is only one thermal desorption unit licenced to operate in Canada and is located in Quebec. Because of the small volumes of sediment involved, it is likely that the material would be transported to the thermal desorption unit and processed in Quebec. Although this unit is mobile, the costs associated with moving it to the site could not be justified for the small volumes of sediment involved.

Figure 5.3 Thermal Phase Desorption Unit

The following volume reduction techniques are considered viable and have been carried forward:

- Particle size separation; and

- Thermal Desorption.

5.3.4 Transportation

Three basic transportation modes were considered under this component. These included

- Ship;
- Road; and
- Rail

Ships and barges equipped with sealed water tanks would be required to move material from the site to land. Transport of low-level PCB contaminated sediment by barge has been undertaken for many years throughout the Atlantic provinces, typically during harbour dredging projects. However, the volume of contaminated water/sediment to be handled and treated under this project appears to be unprecedented. After processing, the contaminated sediments would be transported away for destruction. Several companies are licenced to move PCB material over 50 mg/kg across provincial borders by road and have done so for several years. Vehicles used for transportation of PCB wastes are specifically designed to handle the material. Depending on the volume of materials involved, transportation by rail would also be viable under existing Canadian legislation. All three modes of transportation have been carried forward for further consideration.

5.3.5 Final Disposal/Destruction

Three basic techniques were considered for this component. These included:

- Treatment;
- Landfilling; and
- Storage

<u>Treatment</u>

Several commercially available destruction technologies may be applied to PCB impacted sediments and are summarized in Appendix C. Chemical and biological technologies were not considered viable component alternatives for this project for various reasons, including: inability to comply with existing PCB regulations; technology is not commercially available; effectiveness of technologies not proven; and inability to effectively remediate the PCB contaminated sediments.

At this time, two licensed facilities are able to receive and destroy PCB impacted sediments: Bovar Environmental, in Swan Hills Alberta, and Bennett Environmental, Quebec. Because of its close proximity to the region, the Bennett Environmental facility is used to establish budgets for destruction costs. Both these facilities are carried forward for further consideration as viable components.

Landfilling

As there is in-place sediment with concentrations over 50 mg/kg, landfilling was removed from further consideration as there are no hazardous waste landfills in Canada licensed to receive it.

Storage

Federal legislation makes provision for PCB material, including sediments, to be stored in a registered storage site. The legislation outlines specific requirements for the construction of the containers, inventory monitoring, security etc. There are two options which can be considered for storing the material, 205 litre steel drums or modified steel ocean transport containers (approximately 35 m^3 capacity). Because of the volumes involved, steel drums would be expensive and require a significant area to store them as they cannot be stacked more than two drums high. The alternative is to use steel transport containers and place them in a registered storage facility. The total number of containers necessary for storing the material will be dependant upon whether the sand and gravels have PCB concentrations above 50 mg/kg.

Although this option is technically achievable and legally acceptable, it does not address the EC *Toxic Substance Management Policy*. This approach also incurs a long term annual maintenance cost associated with the monthly inspection and annual repairs to containers and the general storage facility compound.

5.3.6 Options Carried Forward for Further Consideration

Based on the review above, all components under Option 3 included viable techniques, and therefore are considered further under Threshold and Balancing Criteria in subsequent sections of this report. A summary of techniques considered further are as follows:

Recovery

- Dustpan Dredger;
- Pneuma/Oozer Dredging System; and
- Airlift Technology.

Dewatering

- Land-based systems using chemical flocculation combined with simple gravity separation;
- Land-based systems using chemical flocculation combined with mechanical separation; and
- Land-based systems using chemical flocculation combined with sand bed filtration and activated carbon polishing;

Volume Reduction

- particle size separation; and
- Thermal Desorption.

Transportation

- Ship;
- Road; and
- Rail.

Storage/Destruction

- High temperature Incineration.

6.0 THRESHOLD CRITERIA EVALUATION

The details of three viable options were identified in Section 5. Each option is evaluated in this section against the following mandatory Threshold Criteria:

- Protective of Human Health and Environment; and
- Compliant with Applicable Regulations and Requirements;

6.1 Protective of Human Health and the Environment

To meet this criterion, an option must be both:

- protective of human health; and
- protective of "ecological health" at the population level.

Section 4 provided a summary of the baseline human health and ecological risks posed by the site. Subject to verification of the uncertainties, no adverse human health effects are expected. Adverse ecological effects are likely limited to the benthic community within the 1 mg/kg contour and possibly female snow crab individuals. All three options provide either a reduction in risks or maintain the status quo, as such all three options pass the threshold criteria of being protective of human health and the environment. Table 6.1 provides a rationale for carrying forward each of the options for further evaluation, based on the ability of the option to protect human health and the environment.

Table 6.1 Summary of Risk Protection Threshold Criteria

Option	Meets Threshold Criteria of Protection of Human Health and Environment?	Rationale
Option 1 – No Further Remediation Action	Yes	Existing situation is protective of human health and ecological populations (see Section 4). Will require acceptance of some residual risk to sedentary benthic community in and around the footprint area.
Option 2 – Capping	Yes	Will provide some reduction in risks to local benthic organisms from existing situation Capping will only destroy a very small habitat area of benthic organisms.
Option 3 – Removal	Yes	Will provide some reduction in risks to local benthic organisms from existing situation Removal will only destroy a very small habitat area of benthic organisms

6.2 Applicable Regulations and Requirements

This section considers how the federal government policies and federal and provincial environmental legislation would apply to the three remedial options under consideration. Compliance with applicable legislation and policy is a mandatory threshold criterion.

As the proponent of the project, the Government of Canada must give overriding and due consideration to its *Toxic Substances Management Policy* (1995). Federal legislation that may be applicable to one or more of the options includes:

- *Canadian Environmental Assessment Act*;
- *Canadian Environmental Protection Act*;
- *Fisheries Act*; and
- *Transportation of Dangerous Goods Act*.

Provincial legislation that may be applicable to one or more of the options include:

- New Brunswick *Clean Environment Act*.

6.2.1 Toxic Substances Management Policy

The *Toxic Substances Management Policy* is an overriding impetus for the proposed remediation project under evaluation in this report. The policy puts forward a preventive and precautionary approach to deal with substances that enter the environment and could harm the environment or human health. The policy provides decision-makers with direction and sets out a science-based management framework to ensure that federal programs are consistent with its objectives. The key objective of the policy relevant to the proposed project is:

- virtual elimination from the environment of toxic substances that result predominantly from human activity and that are persistent and bioaccumulative (referred to in the policy as Track 1 substances).

PCBs are Track 1 substances, and thus it is the Government of Canada's policy that PCBs be virtually eliminated from the environment. The policy involving virtual elimination of Track 1 substances from the environment will be based on strategies to prevent the measurable release of the substances into the environment. The original project, the raising of the *Irving Whale*, sought to prevent the release of PCB and other contaminants from the sunken vessel.

The current project considers a range of options targeted at satisfying this objective. However, as noted in the policy, while socio-economic factors have no bearing in setting the ultimate objective for Track 1 substances (virtual elimination from the environment), such factors will be taken into account when determining interim targets, appropriate management strategies and time lines for implementation. The policy suggests that the objective will be achieved by addressing sources of release to the environment or by removing or managing the substance if it is already in the environment (the latter being the case for the current project).

The policy states that remediation may be undertaken when a Track 1 substance is already in the environment. For sites under federal jurisdiction that are contaminated by a Track 1 substance, the policy states that management plans will consider the elimination of that substance, based on an analysis of risks, costs and benefits. Where benefits to the ecosystem or to human health of removing the substance outweigh clean-up costs, including the possibility of further environmental degradation, remediation will be considered. Otherwise, management strategies will focus on minimizing exposure and the site's potential risks. For all three remedial options under consideration in this report, this risk-based cost-benefit approach is being applied in a manner that is consistent with the policy.

In implementing its policy, the Government of Canada has committed to, among other things, public participation (such as the involvement of the Steering Group), openness and transparency in decision making. As such, in addition to the risk-based, cost-benefit analyses contained in this report, public involvement in this project was also implemented by the establishment of a steering group. In addition to independently initiated involvement, the environmental assessment of the project under the *Canadian Environmental Assessment Act* will provide an opportunity for public participation (see Section 4.1.1.6). As such, this aspect of the policy will be appropriately addressed.

6.2.2 Canadian Environmental Protection Act

Section 36 of the *Canadian Environmental Protection Act (CEPA) 1988* applies to the release of toxic substances, including PCB as defined in *CEPA*, into the environment. As such, the person who releases the toxic substance must take all reasonable emergency measures consistent with public safety to prevent the release. If it cannot be prevented, any dangerous condition must be remedied or any danger to the environment and/or to human health must be mitigated or reduced.. In the case of the raising of the *Irving Whale*, the current remedial options under consideration of this report, to be considered for implementation by EC, are intended to address these requirements.

Option 1, no further remediation work, would appear to have no further application of *CEPA* beyond that noted above. If it is found that Option 1 remedies any dangerous condition, then *CEPA* would not apply.

Under Option 2, the proposed actions could potentially further disperse PCB in the environment, and must be considered to be, in spite of this, effective in the remedy of any dangerous condition as described in Section 36 of *CEPA*. Also, the deposit of a capping, stabilising or habitat-enhancing material would be considered to be ocean dumping under *CEPA*. As such, EC would be required to issue a permit pursuant to Section 71 of *CEPA*. In granting of this permit, the Minister must consider the factors specified in Section 72. The mitigative measures proposed for Option 2 would likely be considered appropriate and a permit could reasonably expected to be granted.

Under Option 3, any processing of the PCB-contaminated sediment that would see the re-deposit of non- or decontaminated sediment to the ocean floor would be considered as ocean dumping under Section 71. The remedial measures proposed under Option 3 can reasonably be expected to be acceptable and a permit would likely be granted.

Legal advice raised some concerns on the applicability of the Storage of PCB Waste Regulations, pursuant to CEPA. However, EC does not consider these regulations applicable to in-place contaminated sediments.

The Government of Canada is currently in the process of revising the *Canadian Environmental Protection Act* to, among other things, assist in the implementation of the policy within a legislative framework. Currently under consideration by Parliament, should the *Act* be revised before the selected remedial option is implemented, it may have some bearing on the ultimate action.

6.2.3 Fisheries Act

Under Sections 36 of the *Fisheries Act*, no person can deposit deleterious substances in water frequented by fish. Under Section 35, no person can carry out any work that results in harmful alteration, disruption or destruction of fish habitat. These sections apply variably to two options under consideration.

For Option 2, DFO may consider the placement of a capping material as habitat destruction under Section 35, requiring authorisation. In view of its intended purpose of containing a toxic substance, DFO should consider this reasonable and could be expected to issue an authorisation. Further, if the material selected for capping is selected to support colonisation by aquatic life similar to that present at the site previously, or as an enhancement to support fish of commercial value (as compensation), then the project may be more favourably considered by DFO in issuance of the authorisation.

Under Option 3, removal of the PCB-contaminated sediment would likely be considered habitat destruction. Some enhancement may be required as compensation through the selection of backfill that would support an enhancement of fish habitat. In view of the mitigative purpose of the project, DFO could be expected to issue the authorisation required.

6.2.4 Canadian Food Consumption Guidelines

It is concluded in the risk assessment (Section 3.0), all remedial options are anticipated to ensure that PCB levels in commercially-harvested receptors (e.g., snow crab) will not exceed the Canadian Food Consumption Guidelines.

6.2.5 Transportation of Dangerous Goods Act

The federal *Transportation of Dangerous Goods Act* and the companion provincial legislation will apply to Option 3 respecting the transport of PCB from the *Irving Whale* site to landfall, and again when transported through New Brunswick to Quebec.

6.2.6 Canadian Environmental Assessment Act

Under the *Canadian Environmental Assessment Act* (CEAA) an environmental assessment of a project is required if a federal authority exercises one or more of the following duties, powers or functions (triggers) in relation to a project:

- proposes the project;
- gives up an interest in land to enable the project to proceed;
- provides financial assistance to the project; or
- issues a permit, authorisation or license as described in the Law List Regulations.

Under (CEAA), a project is defined as either:

- an undertaking (e.g., construction, operation, modification) in relation to a physical work (in practice considered to be a tangible thing at a fixed location constructed with human labour); or
- a physical activity not related to a physical work which is specifically named on the Inclusion List Regulations.

In terms of the Inclusion List Regulations, it should be recognised that additional items, as well as changes to the existing list, have been proposed. One of the additional items proposed is "physical activities related to the remediation of contaminated land" with "land" presumably being defined broadly. It is anticipated that the earliest that changes and additions on the Inclusion List will come into effect in the fall of 1998.

With regard to Option 1 where there is no further remediation, there is no physical work and therefore no undertaking (e.g., abandonment) in relation to a physical work. Thus, although there is a trigger under CEAA, in that EC is a responsible authority, it is unlikely that this option would constitute a project under CEAA and since an assessment would not have to be carried out.

For Option 2 where there is in-situ containment of PCB contaminated sediments, there is an undertaking (construction) of a physical work (cap) and therefore a project under CEAA. As EC is proposing the project, it will be the lead Responsible Authority. Placement of material (capping) would trigger the need for an ocean dumping permit. An authorisation is needed under section 35(2) of the *Fisheries Act* for the harmful alteration, disruption or destruction of fish habitat.

Although the removal of PCB contaminated sediments in Option 3 by dredging/excavation is a physical activity, it does not appear to be captured by the Inclusion List as it is not for the purpose of ensuring the navigability of navigable water. On this basis alone this option, in all likelihood, would not constitute a project.

However, if DFO decides that an authorisation under section 35(2) of the *Fisheries Act* is required as discussed above, then Option 3 would be considered as a project as this activity is found on the Inclusion List. In this case, Environment Canada, a proponent, would be the lead RA and DFO would be a RA. If a decision is made that an authorisation under section 35(2) is not required, then Option 3 would not appear to be a project under CEAA and therefore would not require an assessment. It does not appear that for Option 3 there is a requirement for an ocean dumping permit.

Although it appears that only Option 2 clearly meets the definition of a project under CEAA, it would be prudent to carry out an environmental assessment at the screening level for whatever option is selected.

Because it is unlikely that a PCB treatment system would be constructed for treatment of the contaminants as the contaminated material would probably be disposed of at an existing licensed facility. Therefore, there would be no requirement for a comprehensive study under Part X, section 32 of CEAA.

Summary

In all instances, Environment Canada is a responsible authority under CEAA and would probably act as the lead RA as defined in the *Federal Coordination Regulations*. DFO would be an RA if it issues authorisation under Section 35(2) of the *Fisheries Act*.

Option 1 does not appear to meet the definition of a project under CEAA. An environmental assessment is required for Option 2, where it is clear there is a project. It is uncertain if Option 3 constitutes a project, as determination must be made by DFO. In all cases, it would be prudent to carry out an assessment at the screening level and to involve the public.

6.2.7 Provincial Legislation

In New Brunswick, the treatment of PCB at a landing site under Option 3 would require registration under the *Clean Environment Act, Environmental Impact Assessment Regulation*. It is likely, based on previous experiences, that a full environmental assessment would not be required and that the project would be screened out of the process on the basis of the federal environmental assessment under *CEAA*. A certificate of authorisation to operate the PCB treatment facility would be required under the *Clean Environment Act*.

6.2.8 Summary

Tables 6.2 through 6.4 present significant aspects or issues which were considered and identified for further clarification for Option 1 through Option 3 respectively.

Table 6.2 Option 1: Regulations and Requirements Summary

Threshold Criteria	Details	Comments
Meets with applicable regulations and requirements	Meets requirements of *Toxic Substances Management Policy*	If selected as preferred option on the basis of scientific risk assessment and cost-benefit analysis
	Under Section 36 of *CEPA*, person who releases the toxic substance must remedy any dangerous condition or reduce or mitigate any danger to the environment or to human life or health that results from the release of the substance	Meets requirements if selected as the preferred option on the basis of scientific risk assessment and cost-benefit analysis
	Meets Canadian Food Consumption Guidelines	For commercially harvested species

Table 6.3 Option 2: Regulations and Requirements Summary

Threshold Criteria	Details	Comments
Meets with applicable regulations and requirements	Meets requirements of *Toxic Substances Management Policy*	If selected as preferred option on the basis or scientific risk assessment and cost-benefit analysis
	Under Section 36 of CEPA, person who releases the toxic substance must remedy any dangerous condition or reduce or mitigate any danger to the environment or to human life or health that results from the release of the substance	Meeting requirements if selected as the preferred option on the basis of scientific risk assessment and cost-benefit analysis
	Fisheries Act authorisation required pursuant to S. 35(2) and 37(2) for harmful alteration, destruction and disruption of habitat. Ocean Dumping permit required under Part IV of CEPA.	Addressed the issue of habitat destruction by placement of cap
	Meets Canadian Food Consumption Guidelines	For commercially harvested species
	Screening under CEAA	The need for an Ocean Dumping permit will trigger CEAA screening.

Table 6.4 Option 3: Regulations and Requirements

Threshold Criteria	Details	Comments
Meets with applicable regulations and requirements	Meets requirements of *Toxic Substances Management Policy*	If selected as preferred option on the basis of scientific risk assessment and cost-benefit analysis
	Under Section 36 of *CEPA*, person who releases the toxic substance must remedy any dangerous condition or reduce or mitigate any danger to the environment or to human life or health that results from the release of the substance	Meets requirements if selected as the preferred option on the basis of scientific risk assessment and cost-benefit analysis
	Fisheries Act authorisation required pursuant to S. 35(2) and 37(2) for harmful alteration, destruction and disruption of habitat	Addresses the issue of habitat destruction by removal of PCB-contaminated material.
	Meets Canadian Food Consumption Guidelines	For commercially harvested species
	Screening under CEAA	Determination for screening to be made by DFO

7.0 EVALUATION BALANCING CRITERIA FOR EACH OPTION

All three options have now been described in detail and pass the mandatory threshold criteria. Step 5 of the study process is the detailed evaluation of options that pass this screening. The detailed evaluation consists of methodically identifying the pros and cons of the following Balancing Criteria:

1. Effectiveness (short, mid and long term)

2. Risk Reduction (short, mid and long term)

3. Other considerations (socio-economic, community perception, stakeholder acceptance)

As outlined in the evaluation methodology (Section 2), several aspects are considered for each criterion.

Cost is also considered a balancing criterion. This is considered by identifying a range of capital costs and estimated annual monitoring and/or maintenance costs.

The pros and cons of each aspect of the balancing criteria are presented in tabular format. Table 7.1 provides the summary for Option 1, Table 7.2 provides the summary for Option 2 and the summary for Option 3 is presented in Table 7.3.

The following sections outline the important aspects of each of the criteria.

7.1 Effectiveness

The effectiveness of each technique was evaluated in the short, medium and long terms by looking at the following:

- how quickly the option can achieve the remediation objective;
- whether it maintains the objective;
- how well the option is able to contain PCB sediments during implementation and in the longer term;
- whether or not a reduction in contaminant mass is achieved; and
- how much monitoring or maintenance is required.

In summary, the "no further remediation" option does not immobilize or remove any contaminants and may require monitoring programs to confirm that the current PCB concentrations remain stable or decrease.

For both Options 2 and 3, the technologies are demonstrated and would be completed in one construction season, but would likely require pre-booking of equipment one year in advance. Adverse weather conditions would affect performance significantly. Use of local equipment for Option 2 also incurs a higher risk of extending across several construction seasons due to capacity limitations of the barges. Only Option 3 provides a reduction in contaminant volume, but both capping and dredging will leave diffuse contaminants in place at concentrations less than 1 mg/kg. As well, for both Option 2 and 3, there will still remain a PCB impacted area beyond the 1 mg/kg isopleth which will not be remediated.

Tables 7.1, 7.2 and 7.3 provide more detail on the effectiveness of each option.

Table 7.1 Summary of Balancing Criteria for Option 1 - No Further Remediation Action

Balancing Criterion	Aspects Considered	Pros	Cons	Important Issues/Comments
Effectiveness of Technique (Short Term: During implementation)	**Timely achievement of remediation objective**	Assessment program to address uncertainties could be implemented readily.	Some uncertainties need to be addressed.	With source removed (barge), PCB concentrations may decline in the immediate area over time due to currents spreading and diluting contaminants.
	Containment of contaminant mass during implementation	No implementation: not applicable (N/A)	N/A	
	Reduction of contaminant volume	No contaminant volume reduction necessary to meet remediation objectives for humans or snow crabs.	No reduction in contaminant volume	
Effectiveness of Technique (Mid Term: 1-5 years)	**Maintains remediation objective in mid term**	Remedial objective for humans and male snow crab would continue to be met		Ongoing monitoring would provide clearer indication of changes to PCB in sediment and biota.
	Containment of contaminant mass	No containment of contaminant mass necessary to meet remediation objectives for human or snow crabs.	Unlimited spreading of contaminants due to currents	Currents could mobilize sediments away from site. However, the net load is insignificant in comparison with the total annual load calculated to enter the Gulf each year.
	Maintenance/monitoring requirements	Monitoring could be undertaken using readily available, existing methods and techniques.	Ongoing monitoring of sediment quality and biota required.	
Effectiveness of Technique (Long Term: 5-25 years)	**Maintains remediation objective in long term**	Objective would continue to be met		
	Containment of contaminant mass	No containment of contaminant mass necessary to meet remediation objectives for human or snow crabs.	Unlimited spreading of contaminants due to storm action	Currents could mobilize sediments away from site. However, the net load is insignificant in comparison with the total annual load calculated to enter the Gulf each year.
	Maintenance/monitoring requirements	Monitoring may be able to be curtailed after system dynamics understood	Ongoing monitoring of sediment quality and biota required.	
Human Health and Environmental Risk Reduction (Short Term: During implementation)	**Avoidance of short term physical impacts to the local habitat**	No physical disruption of existing habitat from sampling and evaluation study. No increase in risks during sampling and evaluation study.	No reduction of risks to sedentary benthic species within the 1 mg/kg isopleth contour.	
Human Health and Environmental Risk Reduction (Mid Term: 1-5 years)	**Reduction in adverse ecological effects compared to existing (1997) post-lift conditions.**	Current (1997) risk conditions are low. Option maintains low risk state.	No reduction to existing low-risk conditions. Adverse effects possible for benthic biota within the 1 mg/kg isopleth if sediment is found not to move with time.	No adverse effects on humans No adverse effects on male snow crab individuals. No adverse effects on snow crab population. Adverse effects expected only on infauna benthic community within 1 mg/kg concentration contour. However, sediment concentrations, and therefore adverse effects, may decrease with time if sediments are lost due to local currents. Further sediment and biota sampling may be required to confirm assumptions made in the risk assessment (see text). Updated PCB sediment and body burden information could be used to re-evaluate the fishing exclusion zones in the area.
	Reduction in adverse human health effects compared to existing (1997) post-lift conditions.	Current (1997) risk conditions are low. Option maintains low risk state.	No reduction to existing low-risk conditions	
Human Health and Environmental Risk Reduction (Long Term: 5-25 years)	**Reduction in adverse ecological effects compared to existing (1997) post-lift conditions.**	Current (1997) risk conditions are low. Option maintains low risk state.	No reduction to existing low-risk conditions. Adverse effects possible for benthic biota within the 1 mg/kg isopleth if sediment is found not to move with time.	
	Reduction in adverse human health effects compared to existing (1997) post-lift conditions.	Current (1997) risk conditions are low. Option maintains low risk state.	No reduction to existing low-risk conditions	
Other Considerations	**Stakeholder Acceptance**	Acceptance by some PAC members on condition that this option would not result in human health risk or the environment.	Option not universally accepted by PAC members as the optimal mitigation method.	Point of consensus is that the PAC members want the fishery closure to be justified as is or adjusted or removed based on scientific fact.
	Socio-Economic Advantages and Disadvantages	Continued monitoring generate potential jobs and revenue (see text for cost breakdown). Some PAC members consider this option will not cause negative effects to their livelihood or community if closure is removed.	If snow crab closure zone remains some amount of crab stock not available to fishery. Perceived potential economic disadvantage from the aspect of crab quality caused as long as closure in place.	Any jobs or revenue from monitoring would be funded from taxpayer revenue.
	Community perception and the environment	If there was an assurance that snow crab on the site would not pose a health hazard, this option would be acceptable to some PAC members.	Other PAC members feel that as long as contaminated sediments are in place that there is doubt within the community as to the fate of the PCBs.	The point of consensus among PAC members is that they want a decision made on which option will be taken as soon as possible.
Capital Costs		$96,000		Canadian Content: 100% of capital cost, 100% annual costs
Annual Costs[1] (monitoring of biota/sediment)		~$60,000/yr		

1) Frequency of annual costs will be dependent upon the results of each sample session.

Table 7.2 Summary of Balancing Criteria for Option 2 – Capping

Balancing Criterion	Aspects Considered	Pros	Cons	Important Issues/Comments
Effectiveness of Technique (Short Term: During implementation)	**Timely achievement of remediation objective**	Equipment readily available. Precision capping -international supply Bottom dumping -local supply Placement of cap could be completed in one construction season depending on technology used and weather conditions. Use of larger vessels would potentially increase cost but decrease risk of non-performance due to weather.	Current market demand for large size ships (with drop tubes) appears to be high; high likelihood that large ships will require a one year pre-booking. Adverse weather conditions may cause unexpected delays resulting in costly downtime and possibly necessitating 2nd construction season Using locally available small size barges increase duration of cap placement time and increase possibilities of entering into 2nd construction season. Loss of fine sediment during aggregate placement using bottom-dump poses significant risk of non-performance.	Special equipment will be required to position barges and control placement. Local barges have a maximum capacity of 750 m^3 Larger ships have capacity up to 5000 m^3 but require more lead time to book vessels. Large ships could complete work in eight to 10 trips, verses fifty or more trips for smaller vessels.
	Containment of contaminant mass during implementation	Capping has been demonstrated on other deep ocean (over 80 metres) sites. Low likelihood of cap disturbance by local fisheries, ships or currents.	Any activity near contaminated sediments will result in some limited re-suspension (e.g. placement of geotextile), aggregate impact. Surface dumping of aggregate will lead to greater chance of sediment re-suspension and further spread of PCBs as well as aggregate misplacement. PCB impacted sediment less than 1 mg/kg will remain uncapped.	Use of geotextile may minimize spreading of contaminated sediments in the >1 mg/kg zone. Using drop-tube techniques will reduce aggregate mis-placement and sediment re-suspension during placement. Limited existing engineering design information. Detailed engineering analysis of placement techniques will be required prior to final design. This will include modelling maximum surface drop rates, detailed bathymetry, PCB distribution within sediment matrix (on fine/coarse grain materials), currents etc.
	Reduction of contaminant volume	No contaminant volume reduction necessary to meet remediation objectives for human or male snow crabs.	No reduction in contaminant volume.	Once capped, PCBs will likely degrade at a very slow rate.
Effectiveness of Technique (Mid Term: 1-5 years)	**Maintains remediation objective in mid term**	Objective of containing sediments in area with concentrations >1 mg/kg achieved	Complete removal of benthic biota community in capped area Requires long term monitoring and possible maintenance.	Extent of cap limited to area with concentrations greater than 1 mg/kg. Not designed for full containment of contaminants. Potential for loss of remaining PCB sediment to off-site areas over the longer term.
	Containment of contaminant mass	Containment of sediments with concentrations > 1mg/kg	Unlimited spreading of sediments with concentrations < 1 mg/kg Bottom-dump barge has a high potential to re-suspend sediment	
	Maintenance/monitoring requirements	Monitoring could be undertaken using readily available, existing methods and techniques. Available monitoring techniques include echo-sounders or SWATH.	Monitoring will be required to verify cap integrity.	
Effectiveness of Technique (Long Term: 5-25 years)	**Maintains remediation objective in long term**	Objective of containing sediments in area with concentrations >1 mg/kg would continue to be met. No significant forces present to significantly disturb cap. Once placed, long term performance will be good although periodic monitoring will be necessary.	Some maintenance may be required to maintain objective. Requires long term monitoring and possible maintenance. Will require the Fisheries exclusion zone to remain, but potentially on a much reduced area.	
	Containment of contaminant mass	Containment of sediments with concentrations >1 mg/kg	Unlimited spreading of sediments with concentrations < 1 mg/kg	
	Maintenance/monitoring requirements	Monitoring could be undertaken using readily available, existing methods and techniques.	Ongoing monitoring of cap performance and integrity would be required. Some monitoring of biota would likely be continued.	

Table 7.2 Summary of Balancing Criteria for Option 2 – Capping - *Continued*

Human Health and Environmental Risk Reduction (Short Term: During implementation)	**Avoidance of short term physical impacts to the local habitat**	Current (1997) risk conditions are low. Option reduces low risk state by burial of "contaminated" benthic community, allowing establishment of new community.	Complete removal of benthic biota community in capped area. Other species (e.g. groundfish, snow crab) may be affected at the individual level	
Human Health and Environmental Risk Reduction (Mid Term: 1-5 years)	**Reduction in adverse ecological effects compared to existing (1997) post-lift conditions.**	Some reduction in snow crab PCB body burden expected as compared to Option 1 on a very localized level. Current (1997) risk conditions are low. Option reduces low risk state. Area will be disrupted, but benthic community expected to re-establish in capped area after time	Sediment PCB concentrations <1 mg/kg will remain surrounding cap which will continue to enter ecosystem. Adverse effects possible for benthic biota within the 1 mg/kg isopleth (total habitat destruction). Although very limited in area, capping may make existing snow crab habitat unsuitable. Area will be disrupted- benthic community that establishes on cap will be different to prior community	PCB body burden of male snow crab population may not be statistically lower than those expected from existing (1997) conditions due to other PCB sources in Gulf.
	Reduction in adverse human health effects compared to existing (1997) post-lift conditions.	Some reduction in snow crab PCB body burden in local area expected therefore slight reduction in exposure to humans Current (1997) risk conditions are low. Option reduces low risk state.	Sediment PCB concentrations <1 mg/kg will remain surrounding cap which will continue to enter ecosystem.	
Human Health and Environmental Risk Reduction (Long Term: 5-25 years)	**Reduction in adverse ecological effects compared to existing (1997) post-lift conditions.**	Some reduction in snow crab PCB body burden expected as compared to current conditions Current (1997) risk conditions are low. Option reduces low risk state. Area will be disrupted, but benthic community expected to re-establish in capped area after time	Sediment PCB concentrations <1 mg/kg will remain surrounding cap which will continue to enter ecosystem. Adverse effects possible for benthic biota within the 1 mg/kg isopleth. Area will be disrupted- benthic community that establishes on cap will be different to prior community	
	Reduction in adverse human health effects compared to existing (1997) post-lift conditions.	Some reduction in snow crab PCB body burden expected therefore minor reduction in exposure to humans Current (1997) risk conditions are low. Option reduces low risk state.	Sediment PCB concentrations <1 mg/kg will remain surrounding cap which will continue to enter ecosystem.	
Other Considerations	**Stakeholder Acceptance**	Acceptance by some PAC members as an acceptable containment method for contaminated sediments.	Option not universally accepted by all PAC members because in some cases it would not be optimal (only removal would be) and others because it might exceed what is needed if the existing condition poses low risk.	
	Socio-Economic Advantages and Disadvantages	One time economic benefit for services, materials, and jobs. Continued monitoring generates jobs and revenue (see cost break down in text).	If snow crab closure zone remains some amount of crab stock is not available to fishery (see text) Local area lost as crab production zone due to habitat destruction for some period of time. Cost to the taxpayers to conduct in-situ mitigation.	Any jobs or revenue created from this would be funded by taxpayers.
	Community perception and the environment	Some PAC members believe this would be an action that would show the governments resolve to contain the contaminated sediments.	Other PAC members believe that to conduct any further action, whether it be capping or removal would be the same as admitting there is a problem when the risk analysis show low risk.	The point of consensus amongst PAC members is that they want a decision made on which option will be taken as soon as possible.
Capital Costs		Bottom Dump Barge: $5.5 to $8 million Drop Tube Placement: $7.6 to $12.3 million		Canadian Content: Bottom Dump: 100 % Canadian Drop Tube: 15 % of capital cost, 100% annual costs
Annual Costs[1] (monitoring of biota/sediment and cap integrity only)		~$134,000/yr (does not included maintenance costs; maintenance may be required if cap damaged)		

1) Frequency of annual costs will be dependent upon the results of each sample session

Table 7.3 Summary of Balancing Criteria For Option 3 – Dredging And Disposal

Balancing Criterion	Aspects Considered	Pros	Cons	Important Issues/Comments
Effectiveness of Technique (Short Term: During implementation)	**Timely achievement of remediation objective**	Equipment readily available. Dredging equipment - international supply Other equipment - local supply Dredging expected to be completed in one construction season Destruction facility (Bennett Environmental) is now operating in Quebec and is permitted to receive PCB sediments for destruction. Land-based dewatering proven and has low risk of non-performance	There is a high likelihood that dredge ships would need to be booked at least one year in advance. Adverse weather conditions may cause unexpected delays resulting in costly downtime and possibly necessitating 2nd construction season. Shore-based infrastructure (processing yards, containment cells etc) would be required to receive and treat contaminated sediment/water in order to be assured of timely achievement of project Ocean-based dewatering schemes are not proven Efficiency of dewatering and volume reduction will depend on a number of factors and may require bench scale testing.	There are only a few ships internationally which can effectively dredge at these depths and control sediment re-suspension during recovery. To limit potential for non-performance, larger ships, shuttle barges and related equipment could be utilized.
	Containment of contaminant mass during implementation	Use of precision dredging will minimize suspension of contaminated sediments.	Any activity near contaminated sediments will result in some limited re-suspension, however it is expected to be limited if carried out properly Some risk of sediment loss during transfer operations	Further investigations into placement techniques will be required prior to final design
	Reduction of contaminant volume	Dredging to 1 mg/kg contour will reduce contaminant mass.	Not all contaminant mass will be removed. PCB impacted sediment <1 mg/kg will remain.	A large area of residual PCB impacted material will remain beyond the dredge zone (1 mg/kg isopleth)
Effectiveness of Technique (Mid Term: 1-5 years)	**Maintains remediation objective in mid term**	Objective of removing sediments in area with concentrations >1 mg/kg achieved	Complete removal of benthic biota community in dredged area	Option only addresses area with concentrations >1 mg/kg. Not designed for removal of all PCB material.
	Containment of contaminant mass	Removal and disposal of sediments with concentrations > 1 mg/kg	Unlimited spreading of sediments with concentrations < 1 mg/kg	
	Maintenance/monitoring requirements	No residual structures (e.g. cap) need to be maintained after completion.	Confirmatory sampling of sediment and biota may be required over a longer period.	
Effectiveness of Technique (Long Term: 5-25 years)	**Maintains remediation objective in long term**	Objective of removing sediments in area with concentrations >1 mg/kg achieved	Complete removal of benthic biota community in dredged area	
	Containment of contaminant mass	Removal and disposal of sediments with concentrations > 1mg/kg	Unlimited spreading of sediments with concentrations < 1 mg/kg	
	Maintenance/monitoring requirements	No maintenance required.	Confirmatory sampling of sediment and biota may be required over a longer period.	
Human Health and Environmental Risk Reduction (Short Term: During implementation)	**Avoidance of short term physical impacts to the local habitat**	Current (1997) risk conditions are low. Option reduces low risk state by removal of "contaminated" benthic community, allowing establishment of new community.	Complete removal of benthic biota community in dredged area. Other species (e.g. groundfish, snow crab) may be affected at the individual level	
Human Health and Environmental Risk Reduction (Mid Term: 1-5 years)	**Reduction in adverse ecological effects compared to current site conditions (1997).**	Some reduction in snow crab PCB body burden expected as compared to current (1997) site conditions. Current (1997) risk conditions are low. Option reduces low risk state. Area will be disrupted but a benthic community is expected to re-establish in dredged area after time	Sediment PCB concentrations < 1mg/kg will remain surrounding dredged area which will continue to enter ecosystem. Adverse effects possible for benthic biota within the 1 mg/kg isopleth.	PCB body burden may not be statistically lower than those expected from existing (1997) conditions due to other PCB sources in Gulf
	Reduction in adverse human health effects compared to current site conditions (1997).	Some reduction in snow crab PCB body burden expected therefore reduction in exposure to humans.	Sediment PCB concentrations < 1mg/kg will remain surrounding dredged area which will continue to enter ecosystem.	
Human Health and Environmental Risk Reduction (Long Term: 5-25 years)	**Reduction in adverse ecological effects compared to current site conditions (1997).**	Some reduction in snow crab PCB body burden expected as compared to Option 1 Area will be disrupted but benthic community expected to re-establish in dredged area after time	Sediment PCB concentrations < 1mg/kg will remain surrounding dredged area which will continue to enter ecosystem. Adverse effects possible for benthic biota within the 1 mg/kg isopleth.	
	Reduction in adverse human health effects compared to current site conditions (1997).	Some reduction in snow crab PCB body burden expected therefore reduction in exposure to humans	Sediment PCB concentrations < 1mg/kg will remain surrounding dredged area which will continue to enter ecosystem.	
Other Considerations	**Stakeholder Acceptance**	Some PAC members feel that this is the optimal mitigation method for contaminated sediments.	Some PAC members believe this option would exceed what is required if the risk is low at the site.	
	Socio-Economic Advantages and Disadvantages	One time economic benefit for services material and job. Follow up monitoring to confirm removal generates jobs and revenue (see text for cost break down).	If snow crab closure zone remains some amount of crab stock is not available to fishery (see text).	Any jobs or revenue created from this would be funded by taxpayers.
	Community perception and the environment	Some PAC members believe that removal of contaminated sediments would show government resolve to mitigate the former Irving Whale site.	Other PAC members believe that to conduct further action such as sediment removal or capping when the risk to the environment is low would be in exceedence of what is necessary.	The point of consensus amongst all PAC members is that they want a decision made on the option which will be taken as soon as possible.
Capital Costs		$20 to $24.5 million		Canadian Content: 35 % of capital cost, 100% annual costs
Annual Costs[1] (monitoring of biota/sediment)		$60,000/yr		

1) Frequency of annual costs will be dependent upon the results of each sample session

7.2 Risk Reduction

The risk reduction of each technique was evaluated by comparing the ability of the option to reduce human health risks from the current (1997 data) condition in the short, medium and long terms.

In summary, the no further remedial option does not provide any incremental risk reduction, however, the current risks are relatively low-- no adverse human health effects are expected and the only adverse effects on benthic biota are expected in a zone bounded by the 1 mg/kg contour. Some individual effects on female snow crabs may be possible but there is a lack of data.

For both Options 2 and 3, the technologies will completely destroy the benthic community within the 1 mg/kg contour, and so in effect do not reduce the risks to these biota. Nevertheless, some PCB body burden reductions would be expected by the reduction in exposure. However, this reduction in body burden may be difficult to measure due to inputs from other PCB sources in the Gulf.

Refer to Tables 7.1, 7.2 and 7.3 for more detail on the risk reduction provided by each option.

7.3 Other Considerations

The "other considerations" category of the Balancing Criteria involves identifying the pros and cons of a) socio-economic issues, b) community perception and c) the environment and stakeholder acceptance. This is an extension of the work conducted in 1996 (Sawyer *et. al*)to quantify potential economic impacts of an accidental release of PCBs during the salvage of the Irving Whale. The 1996 study was an in depth analysis of the potential releases of PCB's resulting in large scale fisheries closures and other resulting economic effects.

7.3.1 Quantitative Assessment

A potential economic disadvantage is the possibility that snow crab fishing closure area of approximately 85 km^2 will remain in place, but this may occur for all three options. In addition, the economic benefits of reopening the area was limited and difficult to estimate. A simplistic first order calculation of the percent of surface area of the potential crab grounds in Area 12 compared to the closure area (0.26% of Area 12) and the extrapolation of the 1997 landings (DFO, 1998) shows that conservatively the landings of snow crabs in the closure area represents 40 metric tonnes. In 1997, the maximum catch of snow crab in Area 12 is regulated by a set landing of 15,400 metric tonnes. This means that, even if the area was opened, the impact would be limited to some increase in efficiency of vessels and fishers. It would not result in an increase of revenue. It is also important to note that, since the removal of the barge, no devaluation of fisheries has been observed. At the present time, DFO's primary concern is that, if the area is opened for fishing, the PCB contaminated sediments may be re-suspended by fishing gear, e.g. trawling. Since the area supports up to six commercial species, one of the possible options is to open the area for snow crab fishing only to prevent disturbance of sediments by other fishing gear. Before opening any part of the closure area, the fishing industry should be consulted and informed.

Potential advantages of the no further remediation option would be the potential jobs and third party revenue generated by monitoring the environment at the former Irving Whale site. A potential economic advantage of the capping option would be the sales of material used for capping and the potential short term jobs and revenue of the capping process and follow-up. The third option of removal of sediments would have potential direct economic advantages of the short term jobs and revenue generated by equipment charter, contaminated material transportation and disposal and site follow-up. The method used to estimate monetary expenditures assumes:

1) Advantages for Atlantic Canada Region only are considered;
2) Total free market agreements, with no regional benefits clause; and
3) Advantages would be direct line only in 1997 dollars.

Based on the consideration of Canadian content of the overall costs to implement each option, the amount of money which would remain in Canada through federal expenditures on the project have been estimated in Table 7.4

Table 7.4 Summary of Monetary Expenditures Remaining in Canadian Economy

	Capital Amounts	**Yearly Amounts**
Option 1	$96,000	$60,000
Option 2	$3.7 - 5.5 million	$134,000
Option 3	$5.3 - 13.6 million	$60,000

It should be noted that all stakeholders recognized that the money would be derived from the Crown, and therefore generated from the tax base.

7.3.2 Qualitative Assessment

The qualitative considerations cannot be allocated a specific dollar value. As part of the study methods, to record a representative view of the stakeholders on the PAC, a series of five questions were formulated and the questions posed to the PAC members on the Steering Group. The questions, as presented in Appendix D, formulate the basis upon which these aspects considered are summarized.

Summary of Socio-Economic Concerns and Issues

The elimination of the snow crab fishing closure area would return 85 km^2 of fishing grounds to the fishery. This would not necessarily mean that direct revenue would be returned to the fishers, rather that further fishing grounds would be available enabling them to attain their quota more efficiently. All three options would allow for the re-consideration of the snow crab closure area over some period of time. Any of the other potential economic advantages that could be realized from direct remedial actions (options two and three) would be the one time purchase of materials and services and the generation of short term jobs in the area.

With all options, the perceived economic advantage or disadvantage of the remedial option by the PAC members had one point of consensus. It was viewed that as long as there was a public perception of doubt that the PCB contaminated sediment was not a risk to the environment and /or human health, that economic disadvantages such as potential for diminished value of snow crab on the market would be a possibility. It is not possible to allocate a value to this perception but it should be recognized as a consensus point of concern of the PAC. However, there have not been any such market impacts on the snow crab fishery documented to date.

7.4 Summary of Costs

The budget estimates for each option are presented in detail in Appendix E. Tables 7.1, 7.2 and 7.2 provide the approximate capital cost to implement and annual maintenance or monitoring costs. The annual costs typically represent the monitoring budget to undertake the work.

Figure 7.1 provides a graphical illustration of the capital cost range of each option.

As there was only one basic set of techniques for Option 1, no effort was made to calculate a range of cost estimates. For Option 2 several variations were considered, one utilizing a split-hulled ship for placing aggregate, and the other using a ship equipped with a drop tube. The drop tube method estimate was prepared for simple straight fall methods as well as more sophisticated and accurate systems using diffuser nozzle technologies.

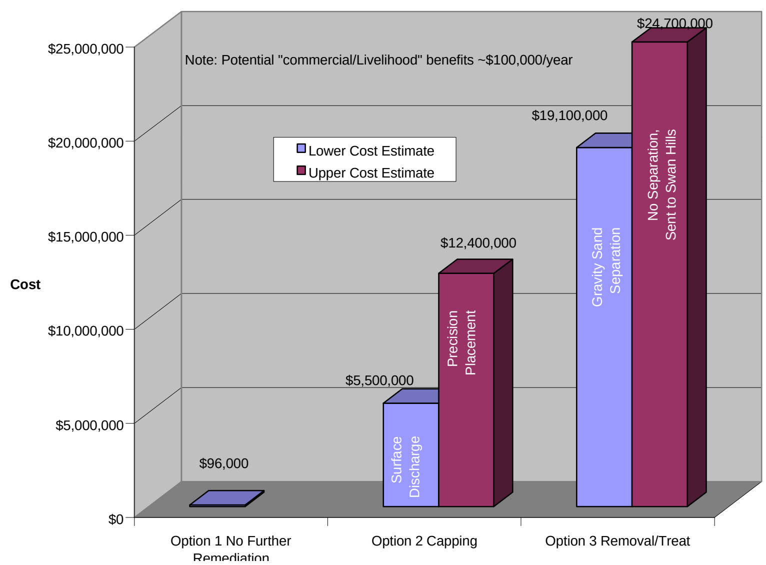

Figure 7.1 Summary of Costs

For Option 3, the budget to implement the remediation program ranges from approximately $20 million to $24.5 million depending on the disposal strategy. This range did not include a concept to dewater at sea, which could save approximately $2 million if pilot tests demonstrated positive results. The financial analysis for demonstrated technologies indicates the least expensive alternative within Option 3 is to dewater sediments and reduce the volume using particle size separation and transfer the contaminated residue to Quebec for destruction. The most expensive alternative under Option 3 is to not use any volume reduction methods and transfer the material to Alberta for destruction.

8.0 STUDY SUMMARY

This report has used a step-by-step methodology to:

- Identify sediment remediation options and associated techniques for the former *Irving Whale* site, including no further remedial action; and
- For each of the options, evaluate the technical merits, limitations, costs, environmental and health risk/benefits, availability of resources and other considerations.

The methodology involved the determination of an appropriate remedial objective. It was determined that under present conditions, no adverse effects are expected for humans and the snow crab population. Adverse effects are likely for the benthic community within a limited area and may be possible for individual female snow crabs, but there is a lack of conclusive data.

It was determined that should remediation be required to mitigate adverse effects on the benthic community, an objective of 1 mg/kg would be protective of the sedentary benthic community in this area.

Three viable remedial options were identified:

1. Option 1: No further remedial action

2. Option 2: In-situ containment, consisting of the placement of an aggregate "cap" over sediments with PCB concentrations greater than 1 mg/kg.

3. Option 3: Removal and disposal, consisting of the dredging of sediments with PCB concentrations greater than 1 mg/kg, the separation of the water from the solids, volume reduction and ultimately disposal in an out-of-province licensed facility.

These three options satisfy the mandatory pass/fail "screening" or threshold criteria in that they are technically feasible, provide overall protection of human health and the environment and are compliant with applicable regulations and requirements.

The study methodology used four additional "balancing criteria", including effectiveness, risk reduction, other considerations ie. socio-economic, community perception, stakeholder acceptance, and ultimately, cost. The options were contrasted against each other by the identification of pros and cons of each option under several aspects of each criterion.
The terms of reference of the study did not involve the identification of a preferred option. Instead, a summary of the most important aspects for each option consideration, is presented in Table 8.1.

Table 8.1 Summary Table of Various Options

	Option 1 No Further Remediation Action	Option 2 Capping	Option 3 Dredging and Disposal
Summary of Technique	• No active remediation • Mid- or long-term monitoring and study	• Containment of sediments with concentrations greater than 1 mg/kg with aggregate blanket; post-construction monitoring	• Removal of sediments with concentrations greater than 1 mg/kg. Destruction of PCBs; post-construction monitoring
Protection of human health and environment, Implementability, Compliance with policies and regulations	• All options are protective of human health and snow crab populations • "No further remediation action" option requires acceptance of some residual risk to sedentary benthic community in and around the footprint area. • Capping and dredging will cause total removal of existing benthic community within the 1 mg/kg isopleth, but a new benthic community will be reestablished over time. • All options are technically feasible, proven and practical. • All options comply with applicable policies and regulations.		
Effectiveness of Technique	• No reduction in contaminant volume. Further studies reduce the uncertainty regarding effects on female snow crab and benthic organisms. • Contaminants will continue to be spread in Gulf • Monitoring required	• Capping is demonstrated technology that could be completed in one construction season, but adverse weather conditions will result in costly downtime. • Placement of geotextile is a complex technology • Use of local surface dump barges could result in project extending over several seasons. • No reduction in contaminant volume • May result in spread of PCB during construction • Not designed for full containment of contaminants, some spreading will continue to occur • Monitoring and possible maintenance required	• Dredging is a demonstrated technology that can be completed in one construction season, but adverse weather conditions will result in costly downtime. • Transportation of contaminated water volumes of this magnitude and subsequent dewatering has not been well demonstrated on similar projects of this nature. • Significant reduction in contaminant volume, although not designed for removal of all PCB material; some spreading will continue to occur • Only short-term monitoring required, no maintenance required
Reduction in Risk to Human Health and Environment Compared to Existing Conditions	• No adverse human health effects • No adverse effects on male snow crab or snow crab population. • Only current adverse effects are to benthic biota and possibly female snow crabs within area of concern. • Option maintains existing localized low-risk state	• No adverse human health effects • No adverse effects on male snow crab, or snow crab population • Objective of containing sediments that cause adverse effects to benthic biota met, however complete removal of biota is caused by construction, with new benthic community reestablished over time. • Some reduction of risk expected to local benthic organisms, however, PCBs outside of cap will continue to migrate	• No adverse human health effects • No adverse effects on male snow crab or snow crab population • Objective of removing sediments that may cause adverse effects to benthic biota met, however complete removal of biota is caused by construction, with new benthic community reestablished over time. • Some reduction of risk expected to local benthic biota, however, PCBs outside of dredged area will continue to migrate • Some very small increased risk to humans from exposure to PCB material during the dewatering and transportation work.
Other Considerations (stakeholder acceptance, perception and socio-economic issues)	• Option not universally accepted by PAC members, but is accepted by certain individuals as long as option is protective of human health and the environment • PAC members want fishery closure to be justified or adjusted based on science	• Option not universally accepted by PAC members a) since it is not optimal solution, or b) since it exceeds what needs to be done	• Some PAC members feel that this is the optimal method, while others consider that it exceeds what needs to be done
	• All PAC members want a decision made on the option immediately		
Capital Costs	$96,000	Bottom Dump Barge: $5.5 to $8 million Drop Tube Placement: $7.6 to $12.4 million	$19 to $24.5 million
Annual Costs	~$60,000/yr (monitoring)	~$134,000/yr (monitoring only, maintenance may be required if cap damaged)	~$60,000/yr (monitoring)

Note: Tables 7.1, 7.2 and 7.3 provide more detail on the effectiveness of each option.

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APPENDIX A

PROJECT TERMS OF REFERENCE

APPENDIX B

CANTOX RISK ASSESSMENT

1.0 INTRODUCTION

A detailed ecological risk assessment was conducted in 1996 by CanTox to evaluate the potential risks from PCB-contaminated sediment to critical aquatic receptors and to develop site-specific sediment remediation criteria for indigenous biota at the *Irving Whale* site. This site-specific approach was considered appropriate to ensure protection of the highly valued commercial fishery species in the area and to ensure that remediation options, priorities and costs would be based on site-specific environmental conditions. The site-specific ecological risk assessment (ERA) was conducted using existing sediment and snow crab digestive gland PCB concentrations (Government of Canada, 1996) to determine the potential risks to snow crab at the *Irving Whale* site. The snow crab was selected as an important ecological receptor in the 1996 assessment due to its abundance, its exposure to contaminated sediments at the site and its social and economic value. This ERA was conducted according to the Environment Canada Framework for Ecological Risk Assessment at Contaminated Sites (Gaudet *et al.*, 1994).

The 1996 assessment was conducted prior to the lift of the Irving Whale (the barge was removed from the sea floor on July 30th, 1996); thus it does not reflect current conditions and does not consider more recent data which has been collected since the lifting of the barge. Based on a review of the available post-lift data, current conditions are quite different from those which existed in 1996 when the original risk assessment was conducted. Some of the major differences include the following:

- Removal of the Irving Whale barge, which has resulted in a change in biological habitat, current flow and sediment contamination in the area;

- An altered study boundary (with respect to sediment contamination), compared to that assessed in 1996. The most recent available data (Gilbert *et al.*, 1998) shows a wider dispersal pattern of PCB sediment contamination; and

- Differing concentrations of PCBs within sediments, compared to those reported in 1995 and 1996. The most recent data indicates that former hot spots have decreased in concentration since 1996 (Gilbert *et al.*,1998).

Therefore, in order to determine whether or not remedial action is required (based on current conditions), update the boundaries of the remedial effort, and appropriately evaluate potential remedial options for this site, it was necessary to confirm whether or not the post-lift data would change the conclusions of the 1996 risk assessment study. The available post-lift data which were considered included: Fisheries and Oceans Canada and Environment Canada (1997) and Gilbert *et al.*, (1998).

To evaluate the potential impact of the post-lift data on the 1996 risk assessment conclusions, recent sediment and biological data (Fisheries and Oceans Canada and Environment Canada (1997), Gilbert *et al.*, (1998) were examined with respect to possible changes to the approach that was applied in the 1996 assessment, study boundary issues, and the derivation of appropriate remedial objectives. The current assessment focuses on potential risks to the marine aquatic receptor, snow crab *(Chionoecetes opilio)*, as this species was identified as a critical receptor in the 1996 ecological risk assessment. In addition, the current assessment separately addresses the risk to sedentary benthic invertebrates, as this group of organisms would likely incur higher exposures than the snow crab.

2.0 THE ECOLOGICAL RISK ASSESSMENT FRAMEWORK

In Canada, a tiered framework for ecological risk assessment exists (Gaudet *et al.*, 1994; CCME, 1996), which includes:

I. Screening Assessment
II. Preliminary Quantitative Ecological Risk Assessment
III. Detailed Quantitative Ecological Risk Assessment

Each tier is successively more detailed, with assessment characteristics ranging from relatively simple qualitative and literature-based approaches in Screening Assessments, to more complex, quantitative and predictive approaches for the Detailed Quantitative Ecological Risk Assessment (CCME, 1996). While each tier differs in terms of level of effort, detail and complexity, all have five main components:

- Planning Stage
- Receptor Characterization
- Exposure Assessment
- Hazard Assessment
- Risk Characterization

Each of these stages of ecological risk assessment are discussed with respect to the Irving Whale site in the sections which follow.

3.0 PLANNING STAGE

The planning stage is one of the most critical stages of an ERA, as this is the stage that determines what information will be used, what issues will be addressed, and what direction the ERA will take. The Planning Stage is typically comprised of the following steps: i. site characterization; ii. problem identification; iii. identification of Valued Ecosystem Components (VECs); iv. establishment of ERA objectives; v. selection of assessment and measurement endpoints; vi. establishment of level of effort; vii. selection of background (reference) sites; and viii. development of a conceptual model. Most of these aspects have been addressed in previous studies (*i.e.*, CanTox, 1996; Fisheries and Oceans Canada and Environment Canada, 1997; Gilbert *et al.*, 1998). This report only presents those aspects of the Planning Stage that are critical to the current assessment. The level of effort of the current assessment lies between the Screening and Preliminary Quantitative tiers of the ERA framework.

3.1 Purpose and Objectives of Baseline Risk Assessment

The objectives of the ecological risk assessment portion of the current project are to:

- Review the baseline risk for the study area, using recent post-lift sediment and biological data;

- Determine whether or not the conclusions of the 1996 Ecological Risk Assessment change in light of this review; and

- Update the boundaries of the remedial effort and remediation criteria, if necessary.

3.2 Extent of PCB Contamination in Sediments and Biota at the Former Site of the *Irving Whale*

Based on a review of the available post-lift data from Fisheries and Oceans Canada and Environment Canada (1997), and Gilbert *et al.,* (1998), only the sediment and biota data from Gilbert *et al.,* (1998) were used in the review of the baseline risk at the former Irving Whale site. The following section provides a rationale for the selection of the Gilbert *et al.,* (1998) data set in the current assessment:

- Sediment and biological data in Gilbert *et al.,* (1998) is the most recent data available; thus it best reflects current conditions.

- The 1997 sampling program reported in Gilbert *et al.,* (1998) was well-conducted (*i.e.*, sampling locations were based on hotspots identified in the 1996 sampling program and modelling of bottom residual currents around the site (Gilbert and Walsh, 1996)); and an adequate number of data points were available.

- Both phases of the 1996 sampling program reported in Fisheries and Oceans Canada and Environment Canada (1997) were conducted within 3 months of the barge lift; thus equilibration of PCB contamination with sediments and biota may not have occurred by the time samples were taken.

- All 1997 sediment samples were taken within 10 cm depth whereas some 1996 sediment samples were taken at depths >10 cm; thus they are less biologically relevant.

- A number of significant changes were observed in both sediment and crab contamination profiles from the 1996 to 1997 sampling programs (*e.g.*, hotspots decreased, overall PCB load decreased in study area, all crabs caught in 1997 had tissue concentrations less than Canadian guideline of 2 mg/kg; while 20% of crabs in 1996 exceeded this value).

3.3 PCB Concentrations in Sediment

Table 3.1 presents sediment PCB concentrations and sample locations from the Spring, 1997 sampling program (*i.e.*, Gilbert *et al.*, 1998). Figure 3.1 shows the PCB sediment concentrations in relation to distance and direction from the barge footprint.

Table 3.1 PCB Sediment Concentrations (Aroclor 1242) Collected Around the Former Irving Whale Site in the Spring of 1997[a]

Sample Code	Distance from the barge footprint (m)[b]	PCB Sediment Concentration[c] (mg/kg dry weight)
A5	-95 / -30	0.72
B5	-75 / -30	8.8
D0	-45 / -130	19
D1	-45 / -110	6.7
D2	-45 / -90	10
D3	-45 / -70	1.4
D4	-45 / -50	14
D5	-45 / -30	250
D7	-45 / -5	13
D10	-45 / 20	71
F2	-25 / -90	24
F5	-25 / -30	70
H(-2)	-5 / -170	43
H(-1)	-5 / -150	13
H0	-5 / -130	2
H1	-5 / -110	53
H2	-5 / -90	34
H3	-5 / -70	320
H4	-5 / -50	140
H5	-5 / -30	70
J2	15 / -90	130
J4	15 / -50	5.5
J5	15 / -30	4000

Table 3.1 PCB Sediment Concentrations (Aroclor 1242) Collected Around the Former Irving Whale Site in the Spring of 1997[a]

Sample Code	Distance from the barge footprint (m)[b]	PCB Sediment Concentration[c] (mg/kg dry weight)
K0	35 / -130	3.3
K1	35 / -110	2.9
K2	35 / -90	42
K3	35 / -70	40
K4	35 / -50	330
K5	35 / -30	1500
K7	35 / -5	120
L4	55 / -50	2.4
L10	55 / 20	3.8
M4	75 / -50	8.9
M10	75 / 20	57
N4	95 / -50	3.5

a Source: Gilbert *et al.*, 1998.

b South West - North East / South East - North West; negative values are South of the barge footprint while positive values are North.

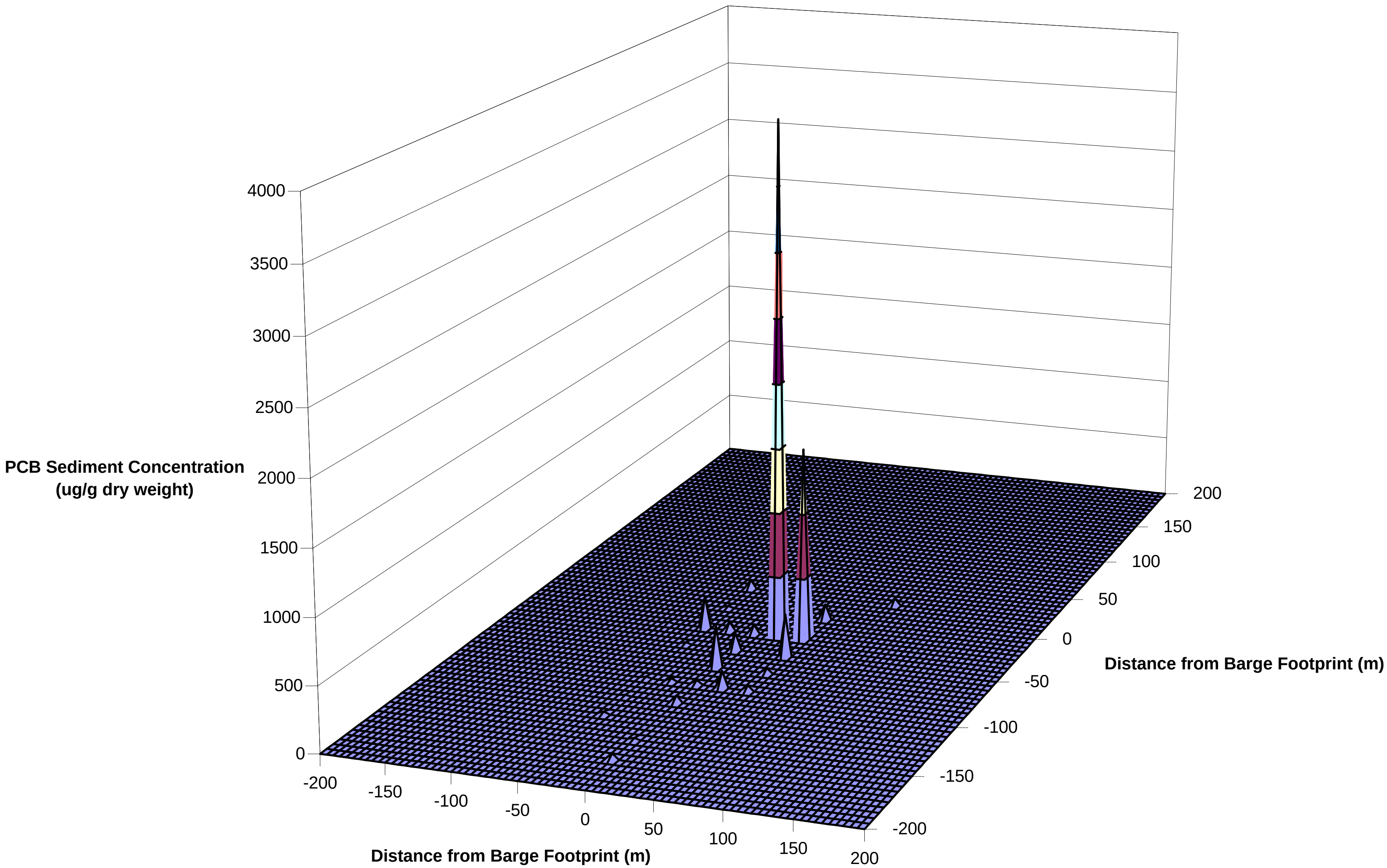
c Although PCB sediment concentrations were obtained from three different laboratories (*i.e.*, Environment Canada, Moncton; Phillips Analytical Services, Halifax; and New Brunswick Research and Productivity Council, Fredericton - RPC), only results from Phillips Analytical Services are reported as they were generally higher, and therefore more conservative than the results reported by the other two laboratories. In addition, this laboratory conducted the analyses in the 1996 sampling program; therefore the analytical methods and equipment used were consistent with previous sediment analyses. PAS also had the best PCB matrix spike recoveries of the three labs (Gilbert *et al.*, 1998).

All sediment samples were taken at depths ranging from 0.5 to 10 cm.

Water content of sediment samples ranged from 21 to 70%.

All PCB concentrations were measured as Aroclor 1242.

Figure 3.1 - Sediment PCB Concentrations in Relation to Distance and Direction from the Barge Footprint



3.3.1 PCB Concentrations in Biota

Table 3.2 presents snow crab digestive gland and muscle PCB concentrations and sample locations from the Spring, 1997 sampling program (*i.e.*, Gilbert *et al.*, 1998). For comparison purposes, the 1996 data (Fisheries and Oceans Canada and Environment Canada, 1997) are also presented, but are not considered in the current assessment, as previously discussed in Section 3.2. Figure 3.2 shows the 1997 snow crab digestive gland PCB concentrations in relation to distance and direction from the barge footprint.

Table 3.2 Concentration of PCBs[a] in Snow Crab Samples Collected in the Former Vicinity of the Irving Whale

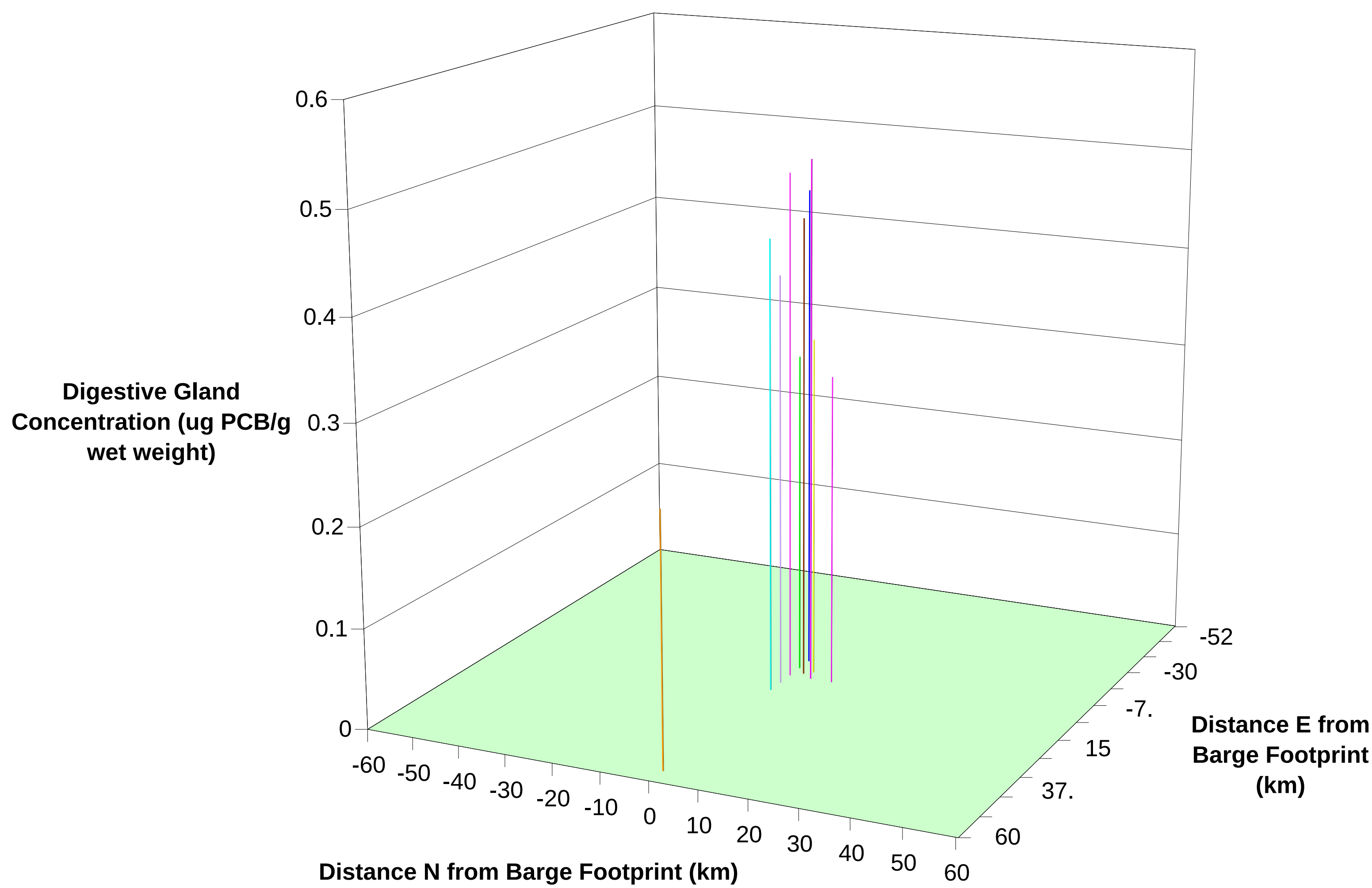
Sample Location[b]	Digestive Gland Concentration (μg/g wet weight)		Muscle Tissue Concentration (μg/g wet weight)	
	October, 1996[d]	May, 1997[e]	October, 1996[d]	May, 1997[e]
Barge Footprint				
0-N-1	2.5	0.9	0.56	0.009
0-N-2	27.2	0.63 / 0.65[f]	2.2	0.007 / 0.006[f]
0-N-1[c]	0.68	0.410	-	-
0-N-2[c]	0.32	0.450	-	-
0-N-3[c]	1.1	0.420	-	-
0-N-4[c]	0.54	0.250	-	-
0-N-5[c]	0.72	0.330	-	-
North				
0.54-N-1	0.31	-	0.034	-
1-N-1	2.1	-	0.044	-
2.5-N-1	-	0.410	-	0.001
5-N-1	-	0.450	-	0.003
30-N-1	0.2	0.250 / 0.250[f]	0.008	0.004 / 0.002[f]
East				
0.54-E-1	2.00	-	0.035	-
1-E-1	0.47	-	0.022	-
2.5-E-1	0.16	0.520	0.002	0.008
5-E-1	-	0.310	-	0.001

Table 3.2 Concentration of PCBs[a] in Snow Crab Samples Collected in the Former Vicinity of the Irving Whale

Sample Location[b]	Digestive Gland Concentration (μg/g wet weight)		Muscle Tissue Concentration (μg/g wet weight)	
	October, 1996[d]	May, 1997[e]	October, 1996[d]	May, 1997[e]
Southeast				
0.13-SE-1	0.76	-	0.027	-
0.27-SE-1	0.55	-	0.014	-
0.54-SE-1	0.96	-	0.013	-
1-SE-1	0.46	-	0.006	-
1.35-SE-1	0.27	0.460	0.001	0.003
2.7-SE-1	0.55	0.340	0.004	0.004
5.4-SE-1	0.96	-	0.088	-
South				
0.54-S-1	0.29	-	0.015	-
1-S-1	3.3	-	0.100	-
2.5-S-1	0.25	0.320	0.021	0.003
5-S-1	-	0.230	-	0.013
West				
0.54-W-1	0.25	-	0.030	-
1-W-1	0.43	-	0.013	-
2.5-W-1	-	0.32	-	0.002
5-W-1	-	0.48	-	0.002

[a] PCBs were measured as total PCBs. The analytical method used is capable of detecting 159 PCB congeners.
[b] Sample locations are coded as: distance from barge footprint (nautical miles) - orientation from barge footprint - laboratory number. (One nautical mile = 1.85 km = 1850 m).
[c] Individual samples.
[d] From Fisheries and Oceans Canada and Environment Canada, 1997.
[e] From Gilbert *et al.*, 1998.
[f] Laboratory duplicate samples.
- represents locations for which samples were not taken at.
The shaded row is the reference site, 30 nautical miles (56 km) north of the barge footprint.

Figure 3.2 - Snow Crab PCB Concentrations in Relation to Distance and Direction From the Barge Footprint



4.0 SELECTION OF VALUED ECOSYSTEM COMPONENTS AND RECEPTOR CHARACTERIZATION

A wide variety of aquatic species, many of which are valued fisheries resources, are found in the Gulf of St. Lawrence ecosystem. Included among the commercially important species are: crustaceans (*e.g.*, northern shrimp, snow crab, American lobster); molluscs (*e.g.*, several species of clam, oyster, mussel, and scallops). There is also a diversity of benthic invertebrates, (including polychaetes, echinoderms, crustaceans), numerous species of pelagic and demersal fish, various seabirds and marine mammals (*e.g.*, several species of seal and whale). In order to evaluate potential risk at the former *Irving Whale* site, it was considered appropriate to select aquatic receptors that would be exposed both through consumption of contaminated prey or food, and also be exposed to PCB-contaminated sediments directly, through consumption of sediment and/or behavioural activities which involve direct contact with surficial sediments.

It is also important that the selected receptors meet the criteria for valued ecosystem components (VECs). As described in Beanlands and Duinker (1983), VECs are resources or environmental features that are:

- Important to human populations;
- Have economic and/or social value;
- Have intrinsic ecological significance; and/or
- Serve as a baseline to evaluate impacts of a particular development.

Selection of the receptors for the current assessment were based on a careful consideration of the above criteria.

4.1 Rationale for Selection of Snow Crab as an Aquatic Receptor in the 1996 Ecological Risk Assessment

In the 1996 ecological risk assessment, snow crab were selected as the main receptor species and were considered to be representative of the indigenous ecological populations in the vicinity of the *Irving Whale*. This species was selected as the most appropriate aquatic receptor for the following key reasons:

(i) The snow crab fishery is a highly valued economic resource in the area;

(ii) Snow crabs are continually in direct contact with sediments and feed on organisms within the sediment bed, thereby increasing their exposure potential;

(iii) Snow crabs are higher trophic level organisms which are somewhat mobile, but have periods of time when they are relatively sedentary and therefore could spend periods of time in the immediate vicinity of the barge;

(iv) Site-specific data were available for snow crab digestive glands (Government of Canada, 1996);

(v) Snow crab are abundant in the area.

It was recognized in the 1996 assessment that sedentary benthic invertebrates would potentially incur higher exposure levels than snow crab, and could therefore be an additional receptor group. However, limited data on these organisms were available in 1996; thus sedentary benthic invertebrates were not selected as aquatic receptors, but possible effects on this group of organisms were discussed.

In order to further evaluate the possible use of the snow crab as a receptor in the current ERA, additional information on snow crab biology was obtained through conducting recent detailed literature searches, as well as discussions with a snow crab biologist (*i.e.*, D. Maynard, personal communication). Thus, the following section (Section 4.2) is an updated and more detailed version of snow crab biology than that which appeared in the 1996 Receptor Characterization section of CanTox (1996).

4.2 Snow Crab Biology

The snow crab fishery in the Gulf of St. Lawrence is a highly valued economic resource. Only male crabs with a carapace width of at least 95 mm (the minimum legal size) are allowed to be harvested. Snow crabs (*Chionoecetes opilio*) are benthic crustaceans which are directly exposed to sediment contamination as they crawl along the surface or dig into the sediments searching for food. The feeding behaviour of the snow crab is not well characterized, but its claws are designed for sifting and sieving of sediments, rather than pincing and crushing hard-shelled prey (Maynard, 1998, personal communication). Snow crabs are omnivorous and have a broad diet which includes dead fish, other crabs (cannibalism), polychaetes, benthic crustaceans, algae, anemones, tube worms, small benthic fish species, bivalves, gastropods, and echinoderms (Wieczorek and Hooper, 1995; Barnes, 1980; Maynard, 1998, personal communication). Dietary (or food chain) exposure is likely the more significant exposure route to chemicals than direct sediment contact. Snow crabs appear to be mainly opportunistic feeders with no detectable differences in feeding patterns between sexes, among size groups, or between individuals with old and new carapaces (Wieczorek and Hooper, 1995). However, Lefebvre and Brethes (1991) observed different feeding behaviour between large and small crabs, and suggested that different size classes may associate with different benthic communities. Prey such as sponges, small crustaceans, and polychaetes appear to be preferred food choices, depending on their availability. Snow crabs may also ingest substantial amounts of sediment particles, and small pieces of rubber, plastic and metal garbage (Wieczorek and Hooper, 1995).

The most important predators of snow crab in the Gulf of St. Lawrence appear to be cod, hake, sculpin and thorny skates, as well as hard-shelled adult male snow crabs which may cannibalize softer-shelled males (Robichaud *et al.,* 1991; Watson, 1971). This cannibalistic behaviour is most evident during breeding seasons and likely reflects aggressive competition for females. Birds and marine mammals may also be important occasional predators of snow crab. It is mainly the male snow crab that is preyed upon due to its larger size and greater mobility than females. Males are especially vulnerable to predation during moulting periods. The smaller female crabs tend to bury in sediments and remain sedentary for extended periods of time (Dufour, 1988; Maynard, 1998, personal communication).

The spatial distribution of snow crabs in the Gulf of St. Lawrence is patchy and appears to be related to temperature, bottom substrate, and seasonally to reproduction and growth (Comeau *et al.,* 1998). The preferred habitat of adult snow crabs is mud or sandy-mud sediments at depths of 70 to 160 m and temperatures of between -1 and 2^{o} C (Powles, 1968). Juveniles tend to inhabit shallower areas with gravel bottoms (Lovrich *et al.,*1995).

Crab reproduction is generally not well understood (Elner and Benninger, 1992). However, recent research indicates a biennial reproductive cycle in female snow crabs in the Gulf of St. Lawrence, with at least two or three egg clutches being produced in a female s lifespan (Sainte-Marie, 1997; 1993). There is much uncertainty over the relationship between moulting (especially the terminal moult) and mating in snow crab. However, the terminal moult in males (sometimes called the moult to maturity) has been linked to reproductive success. In males, the terminal moult may be triggered by both the success and failure of juveniles to copulate (Elner and Beninger, 1995). For example, juvenile males that are not successful at mating may greatly increase their success by undergoing their terminal moult and achieving mature male status. Conversely, juvenile males that are already successful will quickly molt to maturity to maintain their success, and reduce the risk of mortality (predation and cannibalism) by continuing to moult (Elner and Beninger, 1995). During mating, podding behaviour has been observed where large piles of female crabs are found in the presence of mature male crabs (Comeau *et al.,* 1998). Such behaviour is common to many crab species. Field studies have suggested that a distinct mating hierarchy exists for mature male snow crabs. This hierarchy is based on the developmental stage and size of males, where adults may outcompete adolescents and larger adults may outcompete smaller adults (Elner and Beninger, 1995; Sainte-Marie and Hazel, 1992). Female snow crabs, once they have matured, may engage in repeat and multiple matings (Sainte-Marie *et al.,* 1997). Gulf of St. Lawrence females typically mate in March and April and eggs hatch mainly from April to June (Sainte-Marie, 1993). The number of broods produced by females depends on the life expectancy following their terminal moult (Sainte-Marie, 1993).

The average lifespan of this species is 5 to 10 years (Jamieson *et al.,* 1988), although higher life expectancy has been reported in some populations (*e.g.,* 13 and 19 years for males and females, respectively in Bonne Bay, Newfoundland) (Comeau *et al.,* 1998). The life expectancy of males following terminal moulting may reach 5 to 6 years (Sainte-Marie and Dufour, 1994). However, within approximately 4 years after the terminal moult, male crabs decline in their market value and are less likely to survive due to increasing numbers of missing limbs, decreased hardiness, and reduced exoskeleton rigidity (Sainte-Marie, 1997). Females also tend to live for 4 years after their terminal moult (Comeau *et al.*, 1991). However, it should be noted that male and female snow crabs may be several years old before they terminally moult.

Snow crabs are a relatively mobile benthic species; however, mobility of the crabs appears to be quite variable. Mature male snow crabs which were tagged and released in Bonavista Bay, Newfoundland from 1979 to 1982 were found to have travelled distances ranging from 0.6 to 74.1 km (mean of 10.7 km), based on where crabs were recaptured (Taylor, 1992). Lefebvre and Brethes (1991) found that male snow crabs moved a distance of 14 km on average, during a 1 to 2 year period, with approximately two thirds of the crabs moving less than 15 km. Snow crabs in Eastern Canada are known to migrate in the early spring (April-May) towards shallower waters for mating. Early spring migration towards shallower waters also appears to occur in an effort to avoid predation and/or cannibalism during moulting stages, when the crabs are most vulnerable (Comeau *et al.*, 1998). Following the breeding season, snow crabs return to deeper waters. Another major movement of snow crabs involves the migration of juveniles into deeper waters preferred by adult snow crabs at a certain stage in their life cycle (Dufour, 1988). Movements at other times of the year appear to be random, with increased activity at night. Maynard and Webber (1987), in a study which employed the use of ultrasonic transmitters attached to crabs, found that diurnal movements of male and female snow crabs differed, suggesting that there are different strategies of movement for male and female crabs at particular life stages. No clear pattern of diurnal movement was apparent for male snow crabs. Short-term movements appear to be related to food, shelter and the distribution of predators and competitors. The majority of snow crabs in eastern Canada cover less than 25 km during long-term movements (Dufour, 1988) and females and terminally moulting males may be relatively sedentary for extended periods (as much as 2 or 3 years in females), with movements of less than 1 km. When not mating, female snow crabs are especially immobile and may bury in sediments and remain motionless for extended periods of time (Dufour, 1988).

4.3 Selection of Aquatic Receptors

Based on the above discussion of snow crab biology in the Gulf of St. Lawrence (Section 4.2), its use as an aquatic receptor in the 1996 (pre-lift) and current (post-lift) ecological risk assessment of the Irving Whale site is considered appropriate. However, there are a number of difficulties and uncertainties associated with the use of the snow crab as a receptor species which stem from its life history and patterns of behaviour. The major problem with the snow crab is that is a relatively mobile species with complex patterns of movement. Mobile or migratory species are generally not as suitable as more sedentary species due to the inherent difficulties in estimating their exposure. For example, mobile species can not be assumed to spend 100% of their time in a contaminated area. Furthermore, when there are uncertainties surrounding the pattern of movement for a species, as is the case with snow crab, estimates of exposure become even more difficult.

The problem of utilizing a mobile receptor species was illustrated in the 1996 assessment (CanTox, 1996). Review of the sediment and biota data and consideration of several approaches for correlating the two data sets led to the conclusion that the crab PCB exposure was not directly related to the sediment concentration at the location where the crabs were captured. While PCB concentrations measured in crab digestive glands are clearly a consequence of exposure to contaminated sediments, the magnitude of the tissue residue is a function of both the dietary and/or sediment concentration (exposure concentration) and the exposure duration. Exposure duration is a function of the time snow crabs may spend at a given location, which in turn, is a function of crab mobility.

The 1996 and 1997 post-lift sampling programs (Fisheries and Oceans Canada and Environment Canada, 1997; Gilbert *et al.,* 1998) also revealed a number of uncertainties associated with the use of snow crab as an aquatic receptor. First, the mobility of the snow crab suggests that they would likely not remain in the vicinity of hot spots for an appreciable time. In addition, the Irving Whale, prior to its recovery, was covered with a variety of marine organisms, many of which are prey for the snow crab. Removal of the barge has removed this local food source, thus crabs may have dispersed in search of better foraging areas. The activity on the sea floor surrounding the barge removal (*i.e.*, presence of divers and equipment; sediment disturbance) may have induced the migration of a significant portion of crabs that were resident within or around the sunken barge. There are also uncertainties with respect to the developmental stages of the crabs that were sampled in both the 1996 and 1997 sampling programs. While all crabs caught were males of legal commercial size (*i.e.*, >95 mm carapace width), it was not clear if the crabs represented different year classes. As mentioned in Section 4.2, there is considerable variation with respect to the age at which snow crabs undergo their terminal moult, as well as the life expectancy following the terminal moult. This makes it difficult to assess exposures to different crab cohorts. Additionally, the post-lift snow crab sampling to date has been unable to account for seasonal changes in snow crab physiology (*i.e.*, reproduction, moulting), which could affect contaminant dynamics in their tissues (Gilbert *et al.,* 1998). The uncertainties surrounding snow crab mobility and physiology have made it difficult to predict the future intensity and spatial extent of snow crab PCB contamination (Fisheries and Oceans Canada and Environment Canada, 1997).

Although such uncertainties create difficulties in estimating snow crab exposure, the selection of snow crab as a receptor in the current assessment was considered to be appropriate as this species is a highly valued fishery resource, it is clearly in direct contact with sediments, its diet is comprised of sediment dwelling organisms, and it is abundant within the study area.

In addition to the snow crab, sedentary benthic invertebrates are also assessed in the current ERA. As previously indicated, this group of organisms would likely incur greater PCB exposures than snow crab due to their limited mobility. As a result, risk estimates for sedentary benthos could be higher than those for the snow crab, as indicated in CanTox (1996). As the exposure potential for snow crab and sedentary benthos likely differ substantially, risks identified for snow crabs may not be representative of risks to non-mobile benthic species which do not have the option of moving away from contaminated sediments. Therefore, snow crab and sedentary benthic invertebrates are assessed separately in the current assessment.

5.0 EXPOSURE ASSESSMENT

5.1 The 1996 Exposure Assessment

In the 1996 assessment, small sample sizes for sediment and biota data necessitated the derivation of site-specific bioaccumulation factors (BAFs) from the available sediment and male snow crab digestive gland concentrations. BAFs for female snow crab could not be derived due to a lack of tissue residue data. PCBs are well known to bioaccumulate due to their persistence and lipophilic nature. A BAF quantifies the magnitude of PCBs propensity to bioaccumulate, and is determined by dividing the tissue concentration within an organism by the concentration of chemical in an environmental medium (*i.e.*, the exposure concentration). However, a review of the sediment and biota data and consideration of several approaches for correlating the two data sets led to the conclusion that the crab PCB concentrations were not directly related to the sediment concentrations at the locations where the crabs were captured (see Section 4.3). To allow for BAF values to be derived, a more detailed analysis of the data, involving ANOVA, statistical tests of comparison, and stochastic modelling were conducted. The result was a range of possible BAF values (*i.e.*, 12-100) within which the true site-specific BAF was believed to lie. The range of BAF values could not be narrowed any further using the 1996 sediment and crab digestive gland concentrations. This BAF range of 12 to 100 was considered reasonable for the Irving Whale site. In addition, this range was not considered to be substantially different from BAF values reported in the literature, when species differences, tissue differences, and different routes of exposure were considered.

The application of this derived BAF range in the 1996 risk characterization step produced site-specific sediment remediation criteria that were within 10% of existing sediment quality guidelines (*i.e.*, Environment Canada (1995) TEL and PEL). Therefore, for the current assessment it was considered unnecessary to apply a similar BAF approach.

5.2 The 1998 Exposure Assessment

PCBs are the only chemicals considered to be of concern for the current assessment of the former site of the Irving Whale. As mentioned in Section 4.3, snow crabs and sedentary benthic invertebrates are assessed separately. The exposure assessment of sedentary benthic species is based on the most recent sediment PCB concentrations available, while the exposure assessment of snow crabs is based on the most recent snow crab digestive gland and muscle tissue PCB concentrations (*i.e.*, Gilbert *et al.*, 1998).

5.2.1 PCB Concentrations in Sediment

The 1997 sediment sampling program was based on previously observed contamination hotspots (from the 1996 sampling program) as well as the modelling of bottom residual currents around the site (*i.e.*, Gilbert and Walsh, 1996). This modelling and the 1996 sampling results showed that the highest sediment contamination was located southeast of the barge footprint. Therefore, 30 sediment samples were collected at sites that ranged from the vicinity of the barge footprint to 170 m southeast of the barge footprint. Table 3.1 presents sediment PCB concentrations and sample locations from the Spring, 1997 sampling program (*i.e.*, Gilbert *et al.*, 1998).

PCB concentrations within the area sampled range from 0.72 to 4000 μg PCB/g dry weight of sediment, and decrease with distance from the barge footprint (see Figure 3.1). Gilbert *et al.*, (1998) compared the 1997 sediment concentrations to those obtained in the 1996 post-lift sampling program (Fisheries and Oceans Canada and Environment Canada, 1997; data not shown). A summary of their key findings follows:

- Elevated PCB concentrations occurred in the same general area as in the 1996 sampling program.
- Contamination hotspots (areas where sediment PCB concentrations exceeded 100 mg/kg) were found to be located mainly southeast of the barge footprint, as was the case in 1996.
- The area of >100 mg/kg PCB sediment concentrations increased by 1.5-fold between 1996 and 1997.
- The area delimited by PCB sediment concentrations >10 mg/kg was found to be more spread out towards the south direction in 1997 than in 1996.
- Contrary to 1996 data, no areas with sediment PCB concentrations of <1 mg/kg were found within 100 m southeast of the barge footprint.
- Comparison of sites at which samples were collected in both years showed that PCB concentrations decreased significantly within contamination hotspots identified in 1996.
- A 6-fold decrease in mean PCB concentrations was observed for all sites that were sampled in both years.

5.2.2 PCB Concentrations in Biota

Snow crab samples were collected at 12 locations around the former site of the Irving Whale, six of which had been sampled in the second phase (October) of the 1996 sampling program. These locations included two sites at the barge footprint, sites that were 2.5 and 5 nautical miles N, W, S, and E, and 1.35 and 2.7 nautical miles southeast of the barge footprint, as well as a reference site 30 nautical miles to the north of the site. Only male crabs with carapace widths ranging from 85 to 135 mm were dissected and analyzed for PCB concentrations in digestive gland and muscle tissue. Snow crab digestive gland and muscle tissue PCB concentrations from both the 1997 and 2nd phase of the 1996 sampling program are presented in Table 3.2, along with sample locations. All digestive gland and muscle tissue concentrations represent composite samples (five crabs per sample), unless indicated otherwise.

Total 1997 PCB concentrations ranged from 0.23 to 0.9 mg/kg in the digestive gland, with the highest concentrations in samples collected at the barge footprint. Muscle tissue concentrations ranged from 0.001 to 0.013 mg/kg, 17.7 to 900-fold lower than the more lipid-rich digestive gland concentrations. The digestive gland and muscle tissue concentrations from the reference site (0.250 and 0.004/0.002 mg/kg, respectively, were within the ranges found at locations around the barge footprint. Digestive gland PCB concentrations around the barge footprint varied from 10% below, to 3.6-fold above the reference site concentration. Muscle tissue concentrations from around the former Irving Whale site varied from 8-fold below, to 10% above the reference site concentration. Digestive gland and muscle concentrations decrease significantly with distance from the barge for both 1996 and 1997 snow crab samples (see Figure 3.2).

A comparison of 1997 snow crab tissue concentrations to those obtained in the 1996 sampling program revealed the following (Gilbert *et al.*, 1998):

- Digestive gland and muscle PCB concentrations that exceeded 2.0 mg/kg decreased from 25% and 5% of pooled snow crab samples in 1996 to 0% (both digestive gland and muscle) in 1997.

- Snow crabs caught close to the barge footprint in 1997 had lower concentrations of low-chlorinated PCBs in digestive glands than in 1996.

- Concentration of high-chlorinated PCBs in digestive glands was relatively unchanged between 1996 and 1997, with the exception of one highly contaminated 1996 sample from the barge footprint.

No other marine biota were analyzed for tissue or whole body PCB concentrations in the Spring, 1997 sampling and analytical programs.

6.0 TOXICITY ASSESSMENT

A review of marine PCB sediment quality guidelines and peer-reviewed literature on the marine sediment toxicology of PCBs was conducted to determine the maximum exposure level which could occur that would result in a low potential for measurable adverse effects on snow crab and sedentary benthic invertebrates.

6.1 Marine Sediment Quality Guidelines

Marine sediment quality guidelines (or concentration limits) for total PCBs are available from three Canadian jurisdictions, and are presented in Table 6.1. These guidelines are intended to protect the most sensitive species, thus they are considered generally protective of marine benthic biota. There are no sediment quality guidelines available for Aroclor 1242 specifically.

Table 6.1 Canadian Marine Sediment Quality Guidelines for Total PCBs

Jurisdiction	Type of Sediment Quality Guideline	Guideline Value (mg/kg dry weight)
Environment Canada (Interim), 1995	Threshold Effect Level (TEL) Probable Effect Level (PEL)	0.0215 0.189
Environment Canada and MEQ, 1992	No Effect Threshold (NET) Minimal Effect Threshold (MET) Toxic Effect Threshold (TET)[a]	0.02 0.2 1[a]
BC MOEE, 1995	No Effect Level (NEL)[a]	0.02[a]

a Sediment Quality Guidelines are derived based on 1% TOC and need to be adjusted for site-specific TOC concentrations (*i.e.*, SQG x %TOC). EC and MEQ, 1992 recommend no SQG adjustment beyond 10% TOC in sediments.

No site specific TOC data was available from either the 1997 or 1996 studies. Thus, the current assessment focuses on the TEL and PEL SQGs (Environment Canada, 1995), as these SQGs do not require adjustment for site-specific TOC, and they are more conservative than EC and MEQ (1992). In addition, the use of these guidelines allows for assessment of the potential for both effects and adverse effects on benthic species. An effect was considered to be any consequence of exposure where a measurable change occurs in some biological parameter, but where this change does not result in significant harm or injury to the organism, or cause significant diminished biological function. This is represented by the TEL. An adverse effect was considered to be any consequence of exposure where a measurable change occurs in some biological parameter, which results in significant harm or injury to the organism, or causes significant diminished biological function. This is represented by the PEL. Adverse effects were assumed to have a high probability of manifesting themselves at the population level while effects were assumed to be measurable mainly at the individual level.

A number of U.S. jurisdictions have also developed sediment quality benchmarks for total PCBs. The National Oceanic and Atmospheric Administration has an Effects Range-Low and an Effects Range-Median of 0.0227 and 0.180 mg/kg, respectively (Long *et al.*, 1995). The Florida Department of Environmental Protection has a TEL and PEL of 0.0216 and 0.189 mg/kg, respectively (MacDonald, 1994). Chapman (1996) derived a sediment effects concentration (SEC) for total PCBs in marine sediments of 0.592 mg/kg dry weight. A SEC is intended to be a sediment benchmark above which adverse effects would be expected to occur. The Environment

Canada (1995) TEL and PEL are equally or more conservative than these American guideline values which further supports their use in the current assessment.

6.2 Summary of the Toxicology of PCBs in Marine Benthic Invertebrates

In the 1996 assessment, CanTox conducted literature searches to identify relevant toxicological studies conducted with crabs and/or other marine invertebrates from which to derive an appropriate concentration limit for snow crabs. This information was presented in the 1996 report as a summary of available toxicological information. For the current assessment, recent literature searches were conducted to identify any relevant literature that has been published since the 1996 assessment. The following section updates the 1996 aquatic toxicology summary and focuses on the marine sediment toxicity of PCBs to benthic invertebrates, which includes the snow crab.

6.2.1 Bioavailability, Bioaccumulation and Biomagnification

PCBs are chemically stable, persistent, lipophilic compounds with a tendency to bioaccumulate in lipid-rich tissues of aquatic biota. There are 209 congeners of PCBs with varying potentials for bioaccumulation, biomagnification and toxicity, depending on the amount of chlorine substitution. Because of their lipophilic nature, PCBs tend to associate with high organic carbon content sediments, with the more highly chlorinated PCBs tending to bind the strongest (Eisler and Belisle, 1996). Most PCB congeners are insoluble in water and preferentially associate with the sediment phase or dissolved particulate matter (Baker *et al.*, 1986). Water solubility of PCBs has been found to decrease as salinity increases (Weise and Griffin, 1978), thus PCBs are particularly insoluble in sea water. Binding coefficients (K_{oc} values) and octanol-water partition coefficients (K_{ow}) can be used to predict the behaviour of PCBs in water and sediments, and their potential to bioaccumulate and exert toxic effects (Eisler and Belisle, 1996). Log K_{ow} values for PCBs are high, with values of 4.5 to 5.8 reported for Aroclor 1242 (the principal congener released from the Irving Whale) (Moore and Walker, 1991).

In general, PCBs bound to organic carbon-rich sediments have been found to have reduced bioavailability to benthic invertebrates (Rubinstein *et al.*,1983; McElroy and Means, 1988), although PCBs are accumulated to a greater extent by sediment-ingesting organisms than filter-feeders (Rubinstein *et al.*, 1983). No specific sediment organic content data was available for the barge footprint area in the current assessment. Some studies have found that uptake of PCBs from sediments is a major exposure pathway for certain benthic species (Stein *et al.*, 1987). Ingestion, respiration, and dermal sorption may be important exposure routes for organisms in direct contact with contaminated sediments. However, bioavailability of PCBs is greatly influenced by sediment organic carbon content, particle size, feeding behaviour of organisms, and lipid content of their tissues.

Bioconcentration factors (BCFs) have been found to vary considerably with the physical-chemical properties of PCBs, sediments, and across aquatic species. For marine benthic invertebrates, BCF ranges of 12,000 to >400,000 have been reported (NAS, 1979; Evans and Landrum, 1989). The rates of uptake for aquatic organisms appear to depend primarily on life stage, reproductive stage, and diet (Eisler, 1986). PCBs have been estimated to be capable of biomagnifying greater than a million times from water concentrations to top trophic levels (Norstrom *et al.*, 1978). The highly chlorinated PCBs tend to show the greatest transfer up to higher trophic levels.

As PCBs are insoluble in water, BCFs (which are tissue concentrations divided by water concentrations) are difficult to interpret and are of questionable value in the aquatic risk assessment of PCBs. Unfortunately, BSAFs (ratio of tissue concentrations to sediment concentrations) have been less studied. However, a recent study by Columbo *et al.,* (1995) estimated a BSAF range of 380-9700 for total PCBs on a lipid weight basis for Asiatic clams (*Corbicula fluminea)* in the Rio de La Plata estuary, Argentina; a sandy environment similar to the Magdelan Shallows in the Gulf of St. Lawrence. On a wet weight basis, assuming 90% water content in clams, the BSAF range was estimated as 3 to 87. Clark *et al.*, (1986) found that fiddler crabs *(Uca pugilator, Uca minax)* did not bioaccumulate PCBs to a substantial degree based on BSAFs of 0.19 to 1.07. In general, sediment BSAFs for PCBs have been reported to range from <1 to several orders of magnitude higher, depending on species, sediment type, and exposure duration, thus hindering efforts to predict PCB concentrations at various trophic levels from sediment concentrations (Dexter and Field, 1989).

6.2.2 Marine Sediment Toxicity Studies

The marine sediment toxicity database for PCBs is weak and there are few studies available where marine test organisms were chronically exposed to PCBs in sediments. No studies on the sediment toxicity of Aroclor 1242, specifically, were identified in the literature reviewed. The bulk of PCB aquatic toxicity studies were conducted in the 1970's and early 1980's and typically involved acute waterborne exposures using carrier solvents. It should be noted that waterborne PCB exposure is not a relevant pathway for benthic organisms, as PCBs are relatively insoluble in water and readily partition into the sediment phase (see Section 6.2.1).

Toxicity of PCBs in sediments varies among the PCB congeners and may be different for sediments with similar total PCB concentrations but differing congener composition. Thus, when congener profiles are unavailable (which is usually the case), it is difficult to compare effects observed in one study (or site) to another where the congener composition may be quite different. For example, non-ortho (or planar) congeners 77, 126, and 169 are considered to be among the most toxic, with toxic potencies similar to 2,3,7,8-TCDD (Ahlborg *et al.*, 1994). The commercial PCB mixture released from the Irving Whale (*i.e.*, Aroclor 1242) does not contain the 126 or 169 congeners and is only 0.45% congener 77 (Schultz *et al.*,1989).

Significant mortality and an impaired ability of surviving test animals to rebury in clean sediments were observed in infaunal marine amphipods *(Rhepoxynius abronius)* exposed to sediments spiked with 1.0 to 5.2 μg PCBs (Aroclor 1254)/g dry weight for a 10 day exposure period (Plesha *et al.*, 1988). Sand worms *(Nereis diversicolor)* displayed 50% mortality when exposed to spiked sediments containing 15 mg/kg dry weight of an Aroclor 1254 formulation for 62.5 days (Polikarpov *et al.*, 1983). A sediment toxicity study using freshwater copepods (Dipinto *et al.*, 1993), found that Aroclor 1254, at a sediment concentration of 4 mg/kg, impaired reproduction. This same study also estimated LC_{50} values of 251 mg/kg for females, and 117 mg/kg for males.

A number of studies have correlated PCB tissue concentrations or body burdens with a variety of effects in both marine and freshwater benthic invertebrates. Several of these studies are summarized in Table 6.2. These data should be interpreted with caution as the exposures were waterborne and PCB uptake may have been facilitated by the use of carrier solvents. Thus, tissue uptake rates may not be indicative of those under field exposure conditions.

Table 6.2 PCB Tissue Concentrations and Associated Effects in Marine and Freshwater Benthic Invertebrates

Species	**Chemical**	**Exposure Duration and Concentration**	**Observed Effects**	**Tissue Concentration (μg/g wet weight)**	**Reference**
Marine species					
juvenile pink shrimp	Aroclor 1254	20 d; 5 μg/L	72% mortality	dead shrimp - 16 μg/g survivors - 33 μg/g	Duke *et al.*, 1970
juvenile blue crabs	Aroclor 1254	20 d; 5 μg/L	5% mortality	survivors had 18-27 μg/g	Duke *et al.*, 1970
oysters	Aroclor 1254	168 d; 5 μg/L 210 d; 1 μg/L 180 d; 5 μg/L	reduced growth and altered connective tissue structure at 5 μg/L; no observed effects at 1 μg/L	oysters displaying reduced growth and abnormal connective tissue had 50 μg/g	Nimmo *et al.*, 1975
shrimp	Aroclor 1254	30 d; 3 μg/L	altered hepatopancreas structure	3 μg/g	Nimmo *et al.*, 1975
Freshwater Species					
amphipod (*Gammarus)*	Aroclor 1242	60 d; 3-234 μg/L	inhibited reproduction at 9-234 μg/L	>320 μg/g in inhibited animals; those that reproduced had 76 μg/g	Nebeker and Puglisi, 1974

Table 6.2 PCB Tissue Concentrations and Associated Effects in Marine and Freshwater Benthic Invertebrates					
Species	**Chemical**	**Exposure Duration and Concentration**	**Observed Effects**	**Tissue Concentration (µg/g wet weight)**	**Reference**
amphipod *(Hyalella)*	Aroclor 1242	70 d; 3-100 µg/L	adverse effects on survival, growth, and reproduction at >30 µg/L	animals displaying toxic effects had 30-100 µg/g	Borgmann *et al.,* 1990

Niimi (1996) summarized data on PCB concentrations in a variety of macroinvertebrate aquatic organisms at which effects and adverse effects have been reported. Based on the available data, it was concluded that adverse effects on survival, growth, and reproduction may occur at body burden concentrations exceeding 25 µg/g PCBs. Lower concentrations in whole organisms or in tissues may result in cellular and biochemical changes (Niimi, 1996).

6.3 Determination of Protective Concentration Limits for PCBs

At present, there do not appear to be any Canadian tissue residue guidelines for the protection of fish and shellfish, based on the literature reviewed for the current assessment. In the 1996 assessment, 25 µg/g (as reported by Niimi, 1996) was considered to be a conservative and appropriate concentration limit for marine benthic macroinvertebrates. An uncertainty factor of 10 was applied to this value to account for differences in species sensitivity, a lack of sediment exposure data, and the limited data set from which this value was derived, to yield a derived concentration limit of 2.5 µg PCB/g tissue (wet weight).

In order to protect human consumers of snow crab, any recommended PCB tissue residue limit for the protection of snow crab and other shellfish should not be greater than the Canadian tissue residue guideline of 2.0 µg PCB/g tissue intended for human consumption of fish and fish products. (There are presently no Canadian PCB tissue residue guidelines for the human consumption of shellfish and shellfish products, specifically). Since the derived concentration limit of 2.5 µg/g (based on Niimi, 1996) approximates the Canadian human consumption guideline of 2.0 µg/g, this Canadian guideline was considered to be an appropriate and conservative concentration limit for the protection of snow crab in the 1996 assessment.

For the current assessment, the use of 2 µg/g as a concentration limit that is protective of snow crab was again considered appropriate and conservative.

As there were no post-lift tissue or whole body PCB concentrations available for any sedentary benthic invertebrates, sediment quality guidelines recommended by Environment Canada

(1995)(*i.e.*, TEL and PEL), were considered to be appropriate concentration limits for this group of organisms in the current assessment.

7.0 RISK CHARACTERIZATION

In the 1996 assessment, the site-specific BAF range of 12-100 was applied to the concentration limit of 2.0 μg/g to derive an acceptable sediment concentration range. In turn, measured PCB sediment concentrations were divided by this range to obtain CR values. This BAF-based approach was not considered appropriate for the current assessment (see Section 5.1). In the current assessment, the risk potential for snow crabs and sedentary benthic invertebrates from exposure to PCB-contaminated sediments at the former site of the Irving Whale are characterized separately for reasons previously outlined in Sections 4.3 and 5.2.

7.1 Risk to Snow Crab

Concentration ratios (CR s) for PCBs in snow crab digestive gland and muscle tissue were calculated to determine if the measured exposure levels (*i.e.*, tissue concentrations) posed a risk of adverse health effects to snow crabs. CR values were calculated as follows:

$$CR = \frac{\text{exposure concentration (measured tissue concentration)}}{\text{concentration limit}}$$

The concentration limit of 2.0 μg/g was used in the CR calculation. A CR value less than one indicates that the exposure is less than the concentration limit, and therefore no risk of adverse health effects is expected. However, there may still be effects at concentrations less than the concentration limit. Such effects would be expected to be confined to individual organisms and would likely occur at the cellular or biochemical level, rather than manifesting themselves at the individual level. A CR value greater than one indicates that the exposure concentration exceeds the recommended concentration limit, and may pose a high risk of adverse health effects. CR values that are marginally less than, or greater than one require re-evaluation of the assumptions of the assessment before the potential risks to aquatic organisms can be characterized.

The concentration limit of 2.0 μg/g, which is considered protective of snow crab in the current assessment, is equivalent to the Canadian human consumption limit for marine and freshwater fish recommended by Health Canada. This concentration criterion is employed as the action level by Fisheries and Oceans Canada Inspection Services for all fish and shellfish products. It is intended for edible portions of fish and fish products and is expressed on a wet weight basis. This edible fish tissue criterion was based on attributing 100% of the tolerable daily intake (1 μg/kg body weight/day) to dietary exposure and assuming 100% bioavailability via ingestion. This criterion is considered to be protective of humans under average exposure situations (*e.g.*, consumption of fish and fish products). It should be noted however, that exceedance of the 2.0 μg/g tissue residue level would not necessarily result in fishing and harvesting bans. If this guideline were to be exceeded, the information would be provided to Health Canada, who would assess the situation and determine if action is required. Such action could likely take the form of a consumption advisory that limits consumption to certain protective levels which would vary for different consumer groups.

Concentration ratios for PCBs in both the digestive gland and muscle tissue of snow crabs captured during the 1997 sampling program are presented in Table 7.1.

Table 7.1 Concentration Ratios for PCBs[a] in Digestive Gland and Muscle Tissue of Snow Crabs

Sample Location[b]	Digestive Gland Concentration Ratio	Muscle Tissue Concentration Ratio
Barge Footprint		
0-N-1	0.45	0.0045
0-N-2	0.32 / 0.33[f]	0.0035 / 0.003[f]
0-N-1[c]	0.21	ND
0-N-2[c]	0.23	ND
0-N-3[c]	0.21	ND
0-N-4[c]	0.13	ND
0-N-5[c]	0.17	ND
North		
0.54-N-1	ND	ND
1-N-1	ND	ND
2.5-N-1	0.21	0.0005
5-N-1	0.23	0.0015
30-N-1	0.13 / 0.13[f]	0.002 / 0.001[f]
East		
0.54-E-1	ND	ND
1-E-1	ND	ND
2.5-E-1	0.26	0.004
5-E-1	0.16	0.0005
Southeast		
0.13-SE-1	ND	ND

Table 7.1 Concentration Ratios for PCBs[a] in Digestive Gland and Muscle Tissue of Snow Crabs

Sample Location[b]	**Digestive Gland Concentration Ratio**	**Muscle Tissue Concentration Ratio**
0.27-SE-1	ND	ND
0.54-SE-1	ND	ND
1-SE-1	ND	ND
1.35-SE-1	0.23	0.0015
2.7-SE-1	0.17	0.002
5.4-SE-1	ND	ND
South		
0.54-S-1	ND	ND
1-S-1	ND	ND
2.5-S-1	0.16	0.0015
5-S-1	0.12	0.007
West		
0.54-W-1	ND	ND
1-W-1	ND	ND
2.5-W-1	0.16	0.001
5-W-1	0.24	0.001

a PCBs were measured as total PCBs. The analytical method used is capable of detecting 159 PCB congeners.
b Sample locations are coded as: distance from barge footprint (nautical miles) - orientation from barge footprint - laboratory number. (One nautical mile = 1.85 km = 1850 m).
c Based on individual samples.
d Based on Fisheries and Oceans Canada and Environment Canada, 1997.
e Based on Gilbert *et al.*, 1998.
f Laboratory duplicate samples.
ND CR values could not be calculated as samples were not taken at these locations in the 1997 program.
The shaded row is the reference site, 30 nautical miles (56 km) north of the barge footprint.

All CR values are <0.5, which suggests that adverse health effects on the snow crab would not be expected. The 1997 digestive gland PCB concentrations were 2.2 to 8.3-fold below the concentration limit of 2.0 µg/g (as indicated by CR s of 0.12 to 0.45), while muscle tissue PCB concentrations were 154 to 2000-fold below this value (as indicated by CR s of 0.0005 to 0.007. Digestive gland PCB concentrations are the most relevant for assessing potential risk to the snow crab as this gland is lipid rich relative to muscle tissue, and PCBs preferentially partition into lipid-rich tissues. However, it should be noted that whole body concentrations for snow crab would be less than digestive gland concentrations as PCBs accumulate to a greater degree in this lipid-rich tissue, than in the rest of the crab body. Thus, basing risk estimates on digestive gland concentrations is a highly conservative approach that likely overestimates risk.

As previously described in Section 4.2, digestive gland and muscle tissue concentrations from the reference location (0.250 and 0.004/0.002 µg/g, respectively), were within the ranges found at locations around the barge footprint. Digestive gland PCB concentrations around the barge footprint varied from 10% below, to 3.6-fold above the reference site concentration. Muscle tissue concentrations from around the footprint varied from 8-fold below, to 10% above the reference site concentration. Based on these data, digestive gland and muscle tissue PCB concentrations from snow crabs captured around the barge footprint do not appear to be substantially elevated above background. The reference location (30-N-1) is considered to be outside the range of influence of the Irving Whale site as it is 30 nautical miles (56 km) north of the barge footprint.

Other reference site snow crab samples collected near Cheticamp, Nova Scotia in August of 1995 found an average digestive gland PCB concentrations of 0.11 (±0.001) µg/g, based on two analyses that were comprised of digestive gland tissue from 5 crabs (Gilbert and Walsh, 1996). All digestive gland PCB concentrations measured in the 1997 program exceed this background concentration by factors of 2.1 to 8.2. Thus, it appears as though digestive gland PCB concentrations from snow crabs captured around the barge footprint are elevated above background. By comparison, St. Lawrence estuary snow crabs were found to have maximum digestive gland concentrations of 0.75 µg/g (Gilbert and Walsh, 1996). All but one of the measured digestive gland concentrations (*i.e.*, 0.9 µg/g at 0-N-1) from crabs collected in the 1997 sampling program are below this concentration.

In addition to all 1997 snow crab digestive gland concentrations being below the concentration limit of 2.0 µg/g, all digestive gland PCB concentrations are also considerably lower than tissue or whole body concentrations reported in toxicity studies where the residues were associated with effects or adverse effects. For example, the highest digestive gland PCB concentration (0.9 µg/g) reported in Gilbert *et al.*, (1998) is 2.7-fold less than the most conservative (*i.e.*, lowest) tissue concentration reported in Section 6.2.2, Table 6.2 (*i.e.*, shrimp with body burden of 3.0 µg/g displayed altered hepatopancreas structure (Nimmo *et al.*, 1975)). Taken together, these data suggest a limited exposure of snow crab to PCB-contaminated sediments in the area around the barge footprint. This is likely a function of snow crab mobility (see Section 4.2). The hypothesis of increased crab mobility following barge removal is supported by the presence of several 1997 crab samples collected away from the barge footprint with higher PCB digestive gland concentrations than in the 1996 sampling program (Gilbert *et al.*, 1998).

It is also noteworthy that some of the snow crab samples collected around the barge footprint are believed to have been contaminated by PCBs originating from a source other than the Irving Whale (Gilbert *et al.*, 1998). This belief is based on the results of a Principle Components Analysis which revealed that a number of snow crab samples had a lower prevalence of PCB congeners typical of Aroclor 1242, and also contained some congeners which are not usually components of this particular Aroclor formulation.

Based on the above information, and the conservative nature of the assessment, adverse health effects on snow crabs around the area of concern are not expected. However, there may be biochemical and histological effects in individual organisms, especially those that are sensitive or exposed to the highest PCB sediment concentrations. Crab digestive gland PCB concentrations do not appear to differ substantially from available background data, and all concentrations are below the conservative concentration limit of 2.0 μg/g. Therefore, snow crab exposure to sediment PCB contamination appears to be low, likely due to their relatively high mobility. Thus, PCB contamination in the digestive glands of snow crabs appears to pose a low risk potential to this species.

It should be noted however, that all available snow crab PCB concentrations were measured in male crabs of legal commercial size; thus this assessment only characterizes exposure and risk for males. Exposures and potential risks to female snow crabs have not been quantified in this, or any previous assessment conducted on the Irving Whale site. In addition, there is a lack of data in the literature which would enable a prediction of female snow crab PCB exposure. Despite this lack of data, the low risk potential determined for male snow crabs combined with the relatively small spatial extent of PCB sediment contamination in the barge footprint area suggests that the risk potential for females is likely low, when considered on a population basis.

7.2 Risk to Sedentary Benthic Invertebrates

Concentration ratios (CR s) for PCBs in sediments were calculated to determine if the measured exposure levels (*i.e.*, sediment concentrations) posed a risk of adverse health effects to sedentary benthic invertebrates. CR values were calculated as follows:

$$CR = \frac{\text{exposure concentration (measured sediment concentration)}}{\text{concentration limit}}$$

The concentration limit used in the CR calculation was the probable effects level (PEL) of 0.189 mg/kg recommended by Environment Canada, 1995. The rationale for the use of EC (1995) sediment quality guidelines has been previously discussed in Section 6.1. The PEL was chosen over the TEL (threshold effect level) for the CR calculation as it is more indicative of potential population level effects which are considered to be a more relevant and measurable indicator of aquatic ecosystem health.

A sediment concentration divided by the PEL is considered to represent an adverse-effects concentration ratio (AECR) (ARG, 1998), as sediment concentrations which exceed the PEL are considered to be within the probable effects range , where adverse effects are predicted to occur frequently (Environment Canada, 1995). An AECR value less than one indicates that the exposure is less than the concentration limit, and therefore adverse health effects are not expected. However, there may still be effects at concentrations less than the concentration limit; with such effects expected to be confined to individual organisms and mainly occurring at the cellular or biochemical level. An AECR value greater than one indicates that the exposure concentration exceeds the recommended concentration limit, and that adverse effects are expected. However, an AECR >1.0 does not necessarily imply a high risk potential to benthic species. To refine the potential for adverse effects to benthic biota, the following criteria (ARG, 1998) were used to interpret AECR values.

- AECR<1.0 - low potential for adverse effects.
- AECR>1.0 and <1.5 - marginal potential for adverse effects.
- AECR>1.5 and <6 - moderate potential for adverse effects.
- AECR>6 - high potential for adverse effects.

Concentration ratios for PCBs in sediment samples collected in the 1997 sampling program are presented in Table 7.2.

Table 7.2	**PCB (Aroclor 1242) Sediment Adverse Effect (AECR) Concentration Ratios**	
Sample Code	**Distance from the barge footprint (m)[a]**	**Sediment AECR[b]**
A5	-95 / -30	4
B5	-75 / -30	47
D0	-45 / -130	101
D1	-45 / -110	35
D2	-45 / -90	53
D3	-45 / -70	7
D4	-45 / -50	74
D5	-45 / -30	1323
D7	-45 / -5	69
D10	-45 / 20	376
F2	-25 / -90	127
F5	-25 / -30	370
H(-2)	-5 / -170	228
H(-1)	-5 / -150	69
H0	-5 / -130	11
H1	-5 / -110	280
H2	-5 / -90	180
H3	-5 / -70	1693
H4	-5 / -50	741
H5	-5 / -30	370
J2	15 / -90	688
J4	15 / -50	29
J5	15 / -30	21,164
K0	35 / -130	17
K1	35 / -110	15
K2	35 / -90	222
K3	35 / -70	212

Table 7.2 PCB (Aroclor 1242) Sediment Adverse Effect (AECR) Concentration Ratios		
Sample Code	**Distance from the barge footprint (m)[a]**	**Sediment AECR[b]**
K4	35 / -50	1746
K5	35 / -30	7937
K7	35 / -5	635
L4	55 / -50	13
L10	55 / 20	20
M4	75 / -50	47
M10	75 / 20	302
N4	95 / -50	19

a South West - North East / South East - North West; negative values are South of the barge footprint while positive values are North

b AECR values are rounded to the nearest significant figure.

With the exception of sample A-5 (0.72 mg/kg), which indicates a moderate potential for adverse effects, all AECR values suggest a high potential for adverse effects on benthic biota. AECR values in Table 7.2 range from 4 to 21,164.

No background PCB sediment data was collected in the 1997 sampling program. In fact, few measurements of PCBs exist for sediments in offshore regions of the Gulf of St. Lawrence that could be considered as ambient background PCB concentrations (Gilbert and Walsh, 1996). However, limited sediment sampling that occurred from 1988 to 1992 in the Gulf of St. Lawrence, the St. Lawrence Trough, and the St. Lawrence estuary, at varying depths, found PCB sediment concentrations to range from 1 x 10^{-4} to 0.1 mg/kg (Gilbert and Walsh, 1996). PCB sediment concentrations from the 1997 sampling program around the barge footprint are 7.2 to 40,000-fold greater than the highest background concentration (0.1 mg/kg). Halifax Harbour, although inappropriate as a background location, had a mean sediment PCB concentration of 0.60 (±0.41) mg/kg, based on samples collected around the Irving Nova Dock (where the recovered barge was decommissioned) in October, 1997 (Gilbert *et al.,* 1998). PCB sediment concentrations from around the barge footprint exceed this mean concentration by 1.2 to 6667-fold. Thus, PCB concentrations in the sediments within the barge footprint area are substantially elevated compared to other locations in the Gulf of St. Lawrence - St. Lawrence Estuary and Atlantic Region.

No post-lift body-burden or tissue-residue data were available for benthic species other than the snow crab. While some tissue residue data for benthic species were collected in 1995, these data could not be used to derive benthic invertebrate tissue-residue concentration ratios in the current assessment for the following reasons:

- These data represent pre-lift conditions; the tissue burdens in benthic species could be considerably different since the barge was lifted (*e.g.*, Gilbert *et al.*, 1998).

- Small sample sizes; thus statistical confidence is low.

- Hazard information from which to interpret benthic tissue residue data is extremely limited.

Attempts to derive post-lift estimates of PCB residues in benthic species were unsuccessful due to a lack of appropriate BSAF values (from the Irving Whale site and other sites, based on available literature), and a lack of site-specific data on sediment organic carbon content.

As previously indicated in Section 7.1, PCBs appear to be of limited bioavailability to snow crab. Available sediment toxicity data indicates that PCB sediment concentrations around the Irving Whale footprint are elevated enough to cause acute and/or chronic effects on local sediment biota. Similar conclusions were arrived at in the 1996 assessment (pre-lift).

Significant mortality and an impaired ability of surviving test animals to rebury in clean sediments were observed in infaunal marine amphipods *(Rhepoxynius abronius)* exposed to sediments spiked with 1.0 to 5.2 μg PCBs (Aroclor 1254)/g dry weight for a 10 day exposure period (Plesha *et al.*, 1988). All but one sediment sample (*i.e.*, Sample A5; 0.72 mg/kg) collected around the barge footprint exceeded this sediment PCB concentration range. Sediment PCB concentrations from the former barge location were 1.4 to 400-fold above the concentration range reported by Plesha *et al.*, (1988). Thus, based on these data, increased amphipod mortality and impaired burrowing activity would be expected in the majority of locations where sediments were collected in 1997.

Sand worms *(Nereis diversicolor)* displayed 50% mortality when exposed to spiked sediments containing 15 mg/kg dry weight of an Aroclor 1254 formulation for 62.5 days (Polikarpov *et al.*, 1983). Approximately half (*i.e.*, 54%) of the sediment samples collected from various locations around the barge footprint exceeded this PCB sediment concentration range by factors of 1.3 to 267. Therefore, based on these data, sandworm mortality would be expected to be elevated within the study area.

A sediment toxicity study using freshwater copepods (DiPinto *et al.*, 1993), found that Aroclor 1254, at a sediment concentration of 4 mg/kg impaired reproduction. This same study also estimated LC_{50} values of 251 mg/kg for females, and 117 mg/kg for males. Twenty seven of the thirty five (77%) sediment PCB concentrations measured from the study area samples exceeded the concentration at which impaired reproduction was observed by 1.4 to 1000-fold. Thus, based on these data, reduced reproductive success in copepods would be expected around the area of concern. Only four of the 1997 sediment concentrations (*i.e.*, samples H3, J5, K4, and K5) exceeded the LC_{50} value reported for female copepods (251 mg/kg), while eight sediment concentrations (*i.e.*, samples D3, H3, H4, J2, J5, K4, K5, and K7) exceeded the male LC_{50} of 117 mg/kg. Thus, acute lethal effects on male and female copepods would be expected at these sampling locations, assuming that these organisms remain there. However, as the test animals used by DiPinto *et al.,* (1993) are freshwater pelagic organisms, it is difficult to estimate potential effects on marine benthos.

It should be noted that there may be differences in sediment toxicity between Aroclor 1254, which was used as the test chemical in the above toxicity studies, and Aroclor 1242, which was the PCB formulation released from the Irving Whale. The congener composition of these two Aroclors are not the same. For example, non-ortho (or planar) congeners 77, 126, and 169 are considered to be among the most toxic, with toxic potencies similar to 2,3,7,8-TCDD (Ahlborg *et al.,* 1994). Neither the commercial PCB mixture released from the Irving Whale (*i.e.*, Aroclor 1242) nor Aroclor 1254 contains the 126 or 169 congeners (Schultz *et al.,*1989; Smith *et al.,* 1990; Safe *et al.,* 1985; Bush *et al.,* 1985). Aroclor 1242 is 0.45% congener 77, which is not present at all in Aroclor 1254 (Smith *et al.,* 1990; Safe *et al.*, 1985; Bush *et al.*, 1985; Schultz *et al.,*1989). However, when the mono-ortho congeners are also considered, Aroclor 1254 is approximately 3.5 times more toxic than Aroclor 1242, as it contains congeners 105, 118, and 156 in greater abundance.

Based on the above information, and the conservativeness of the assessment, sediment PCB concentrations around the area of concern suggest a high potential for adverse effects on sedentary benthic organisms. These PCB concentrations appear to be substantially elevated compared to other locations in the Gulf of St. Lawrence - St. Lawrence Estuary and Atlantic Region. Available sediment toxicity data indicates that the PCB sediment concentrations are elevated enough to cause acute and/or chronic effects on sedentary sediment biota, such as mortality, altered behaviour, and impaired reproduction. Therefore, sediment PCB concentrations within and around the barge footprint area are considered to pose a high risk potential to sedentary benthic species.

8.0 SUMMARY AND CONCLUSIONS

8.1 1996 Findings

In the 1996 assessment, the following conclusions were made:

- The presence of PCBs in sediments immediately adjacent to the *Irving Whale* poses an elevated risk to the ecological health of snow crabs, especially relatively sedentary females. PCB concentrations in sediment up to 0.1 km east and 0.45 km southeast of the *Irving Whale* also pose a potential risk to snow crab populations.

- The level of PCB contamination in sediments immediately adjacent to the *Irving Whale* is likely to result in acute toxicity to sedentary benthic invertebrate species.

- The site-specific BAF range for the *Irving Whale* site of 12 to 100 results in acceptable sediment concentrations of 0.02 to 0.17 mg/kg for the protection of snow crab and human consumption of snow crab.

<u>1996 Remediation Criterion</u>

In the 1996 assessment, the upper limit of the derived site-specific remediation criteria range (0.17 mg/kg) was recommended to be used as the sediment remediation criterion for the Irving Whale site. This recommendation was based on:

- The low probability of snow crab spending the majority of their lifespan within PCB-contaminated sediments around the Irving Whale (due to their mobility).

- Relative confinement of the highest PCB sediment contamination to the vicinity of the barge.

- 1996 pre-lift sediment and biota PCB concentrations.

If the barge was successfully removed and the sediments beneath it were remediated to 0.17 mg/kg, currents and natural dispersion processes were estimated to be likely to re-distribute the remaining contamination such that PCB concentrations would be relatively low throughout the study area. However, if a spill occurred during the lift, the lower site-specific remediation criterion of 0.02 mg/kg was recommended.

These recommended remediation criteria were based on the protection of individual snow crabs, rather than the snow crab population in the vicinity of the barge. At the time of the 1996 assessment, focusing remedial criteria towards the protection of individuals was considered an acceptable practice. Presently however, it is considered more appropriate to focus remedial criteria towards the protection of populations, as population-level effects are a more measurable and relevant indicator of ecosystem health.

8.2 Present Study

This assessment concluded that:

- No adverse effects from exposure to PCBs in the study area are expected for individual male snow crabs

- As female snow crabs tend to be more sedentary than males, and are more likely to remain in a given area than males, they would be expected to incur higher exposures to chemicals in sediment. Therefore, if females were to spend a significant amount of time in the vicinity of the barge footprint, their risk would be expected to be higher than that of males. However, as no female snow crab tissue concentrations are available, there is insufficient data with which to make conclusions regarding potential risk to female snow crabs. Despite this uncertainty, the lack of significant risk for male snow crab suggests that even adverse effects on individual females would not be expected to cause adverse effects at the population level. It should be noted however, that the risk potential to female crabs should be quantified in future monitoring programs.

- All snow crab tissue concentrations were below the 2.0 μg PCB/g tissue Canadian human consumption guidelines; thus no adverse effects from human consumption of snow crab are expected.

- Adverse effects are expected for sedentary benthic species within and around the barge footprint area only.

While it is difficult to extrapolate the risk estimates to a larger boundary than the study area (such as the Gulf of St. Lawrence), based on a qualitative consideration of the results of the current risk assessment, the findings of the most recent monitoring program (Gilbert *et al.*, 1998), and other key issues, no population level adverse effects would be anticipated for male and female snow crabs or for benthos in the Gulf of St. Lawrence, as a result of the PCB sediment contamination within and around the barge footprint area. It should be noted however, that this statement is based on a limited amount of data.

Remediation Criterion

The evaluation has determined the following:

- no remedial action is required to protect human health, therefore no sediment remediation criterion is required for this purpose;

- no remedial action is required to protect the snow crab population, therefore no sediment remediation criterion is required for this purpose, subject to the continued monitoring of effects at the site; and

- the potential exists for adverse effects to the benthic community if sediment concentrations exceed 1 mg/kg. This concentration has been identified in some sediment in and around the barge footprint.

If remediation is necessary, an appropriate remedial objective for the site would therefore be either to remediate sediement in and immediately around the barge footprint to less than a remediation criterion of 1 mg/kg or to otherwise isolate any sediment exceeding this 1 mg/kg level from the benthic community, in order to protect the benthic community from adverse effects.

Some individual and possibly population level effects may occur at concentrations lower than 1 mg/kg, however, this concentration appears to be protective of sedentary benthic organisms based on available sediment toxicity data. The value of 1 mg/kg is more relevant to the protection of populations than 0.17 mg/kg (the TEL), which was recommended in the 1996 assessment. As previously stated, the 1996 0.17 mg/kg value was set to ensure protection of individual snow crabs; not populations of sedentary benthic invertebrates.

The decision to remediate at a contaminated site and final remedial objectives should involve considerations other than the application of sediment quality criteria alone (Fisheries and Oceans Canada and Environment Canada, 1997). PCB sediment quality criteria are conservative values that are generally based on toxicity to sensitive species that may comprise a small portion of a given community or ecosystem. Other environmental impacts associated with remediation may be of greater ecological importance than PCB contamination (Dexter and Field, 1989). Key considerations in establishing remedial objectives include background concentrations and the nature and size of the affected area within the ecosystem.

9.0 LIMITATIONS AND SOURCES OF UNCERTAINTY

As in any risk assessment study, the findings of the assessment are based on field data, in conjunction with a number of assumptions. Every effort is made to ensure these assumptions and data adequately represent field conditions, however, data are often limited, resulting in uncertainty in the assessment. Where uncertainty exists, assumptions are made and data are selected so as to err on the conservative side. The major limitations and sources of uncertainty associated with the ecological risk assessment of the Irving Whale footprint and surrounding area were:

- The most recent data available may not reflect current conditions.
- There is a lack of adequate reference or background data available for both sediment and snow crab PCB concentrations.
- The snow crab poorly represents potential exposures and risks to sedentary benthic species.
- The numerous uncertainties associated with snow crab behaviour and physiology makes it difficult to predict the future intensity and spatial extent of PCB contamination in this species.
- There is a weak database on the marine sediment toxicity of PCBs.
- The potential risk to female snow crabs can not be estimated as there are no PCB tissue residue data collected for females.

- There is presently no data on benthic community structure, diversity or abundance of benthos in the area around the area of concern.

10.0 REQUIREMENTS FOR ADDITIONAL DATA

The conclusions provided in Section 8 are conservative with respect to the uncertainties identified above. To reduce the uncertainty, the following actions are recommended:

- Review of the most recent sediment and biota sampling program. These data will be available by August, 1998. The data presented in Gilbert *et al.*, (1998) showed that PCB profiles in sediments and biota are clearly changing based on a comparison to the previous year s sampling results. If this trend has continued over the winter of 1997, estimates of risk, as reported in the current assessment may change. In addition, this would allow for the current spatial distribution of PCB sediment contamination to be established.

- Further sampling and monitoring of snow crabs including the collection of digestive gland and muscle tissue data from female snow crabs to quantitatively assess the risk potential to females that might incur greater exposures than males, due to less mobility (Dufour, 1988).

- Future snow crab monitoring should account for different age classes and seasonal changes in the physiological condition of crabs, as these may affect contaminant dynamics within snow crab tissues.

- Collection of ambient background data from reference sites, to better assess whether sediment and snow crab concentrations in the area of concern are elevated over background.

- Collection of more snow crab samples from beyond the 5 km x 5 km fishing exclusion zone

- The exclusion zone should remain in place until further monitoring is conducted to ensure the trend of decreasing PCB concentrations in the sediments continues.

- Additional information regarding benthic invertebrate populations (*i.e.*, species diversity; abundance; PCB body burdens etc.) for the area around the barge footprint and a suitable reference location are required to evaluate the costs and benefits of remedial efforts to protect this group of organisms.
- Further sediment monitoring should analyze samples for particle size, and Total Organic Carbon, as these factors can have a major influence on PCB bioavailability to benthic organisms.

- Tissue residue data, coupled with Principle Components Analysis data should be collected for organisms at various trophic levels to determine the extent of PCB entry into the Gulf of St. Lawrence ecosystem.

It should be noted that some of these recommendations may not be necessary should further remediation of the site be carried out.

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Appendix C
Detailed Information on Option 3 - Recovery

This Appendix contains additional details on Option 3, sediment removal. Option 3 has several operational components including recovery (dredging), dewatering, volume reduction, destruction and disposal. Details are provided herein on the techniques available for dredging and PCB destruction. A summary of all techniques within each operational component is provided at the end of this Appendix, along with a summary of whether each technique passes the mandatory threshold criteria.

DREDGING SYSTEMS

Commercial Dredge Type	Ability to handle slurries with low sediment content,	Ability to operate in deep waters (approx. 67 m),	Ability to excavate thin layers of sediment,	Accuracy in positioning dredge head and in removal of contaminated sediment layer,	Ability to efficiently operate in moderate seas (waves under 4 meters),	Potential for sediment resuspension,	Technology is proven and commercially available.	Ability to recover various grain size sediment, including rocks and cobbles
Bucket Dredger	N	Y	N	L	L	H	Y	SD
Grab Dredger	N	N	N	M	L	H	Y	ND
Dipper Dredger	N	N	N	M	L	H	Y	ND
Trailing Suction Hopper	Y	Y	Y	L	M	M	Y	FD
Dustpan Dredger	N	Y	Y	M	M	M	Y	FD
Disc Bottom Cutter	Y	N	Y	H	M	M	Y	FD
Auger Dredger	Y	N	Y	M	M	H	Y	FD
Suction Dredger with Otter Hea	Y	N	Y	H	M	M	Y	FD
Bucket Wheel Dredger	N	Y	N	M	L	M	Y	FD
Dipper Dredger with Pump	Y	N	N	H	M	M	Y	FD
Plough with Pump	N	N	N	L	M	M	Y	FD
Air Lift Technology	Y	Y	Y	M	H	L	Y	ND
Pneuma/Oozer	Y	Y	Y	H	H	L	Y	SD

Notes
Y = Yes
N = No
H = High
M = Moderate
L = Low
FD = Frequent Difficulty
SD = Some Difficulty
ND = No Difficulty

Several commercially available technologies were considered within the scope of this work. The ability of these technologies to function in deep ocean conditions was reviewed and summarized in Table C.1.

Specific information on those technologies which passed the threshold criteria is presented below.

Dustpan Dredger

The dustpan dredger is a stationary suction dredger which is typically moved longitudinally using anchor wires. This dredger has a wide flat suction mouth to remove thin layers of sediment in water greater than 1 to 2 m. When removing sand or consolidated silt, water jets are used to break any cohesion. When working in silt or clay-rich sediments, the system is prone to blockage around the suction mouth. If water jets are used to break up cohesive sediment, the suction mouth must be fitted with a shield to restrict loss of contaminated sediment and create potential turbidity problems. It is possible to accurately dredge both horizontally and vertically. However, the vertical accuracy is limited by the heave compensation ability of the surface vessel. Spillage and turbidity occur during the breaking of the sediment cohesion in the water and when the water jets are in use. However, it is unlikely this will be an issue with the silty sands found around the former Irving Whale site.

Pneuma/Oozer Dredging System

The Pneuma and Oozer systems are dredge pumps which make use of changing air pressure to cause the mixture of contaminants and sediment to flow into a suction mouth. Both systems use the different pressure that occurs when air is introduced at specific depths under water. The Oozer system is also equipped with a vacuum pump. Most dredging systems make use of a centrifugal pump which produces a specific vacuum. The advantage of the Pnuema and Oozer pump is that they function at great depths (i.e. 30 to 100 m) and with high mixture concentrations. If these pumps are installed on a stationary dredger and a special shaped suction mouth is used, dredging can be as accurate as with stationary dredgers using centrifugal pumps. As with the dustpan dredge systems, spillage and turbidity are a problem when attempting to break up cohesive sediments.

Suction Air Lift Technology

Air lift systems are an old and well proven technique which use air to create a suction vacuum system. Typically, air is pumped down to the ocean floor and released back into a flexible shaft pipe connected to a recovery barge at surface. As the air rises inside the pipe, strong suction pressures are developed creating an effective vacuum to lift sediments to surface. The technique is capable of mobilizing large volumes of material in a relatively short period of time. However, when used in conditions with limited sediment thicknesses, such as the Irving Whale site, there is a tendency to return large volumes of water along with the sediment. Under ideal conditions, air lift systems operating in areas with thin sediment thicknesses (such as the former Irving Whale Site) will tend to recover 100 m^3 water for every 1 m^3 of sediment (i.e. one percent slurry rate). A one percent slurry rate would translate to 30,000,000 litres of water recovered for every 300 cubic metres of impacted sediment. In the event of a system shut-down, there is a risk of sediment spillage and elevated turbidity in the vicinity of the lift unless careful precautions are taken. The suction air lift can operate efficiently at depths over 10 metres and can recover a broad range of silts, sands, and cobbles. More sophisticated systems use inflow nozzles directed by cables or remote power-heads equipped with lateral and vertical thrusters.

PCB REMEDIATION TECHNOLOGIES

Table C.2 presents a summary of the PCB remediation technologies reviewed for Option 3.

Table 3.6 PCB Remedial Technologies Reviewed For Option 3

Thermal - Infrared Units $ OHM Corporation $ Westinghouse Haztech
Thermal - Circulating Bed Combustor $ Cintec Environmental Inc.
Thermal - Other $ Eco Logic Process $ Plasma Arc
Chemical $ Ontario Hydro $ Myers - BCD Process $ OHM/Rust - DeChlor/KGME Process $ Galson Remediation Corp - APEG PLUS J Technology $ Green Earth Technology
Biological $ Ensite Environmental - SafeSoil Process $ DeTox Industries $ Myco Tech Corp.

THRESHOLD EVALUATION SUMMARY

Table C.3 contains a summary of each available technique within each of the five technical components. The table indicates which of the techniques pass the threshold criteria.

Option 3 Sediment Removal		Meets ARAR's	Protective of Human Health and Environment	Implementable	Comment/Notes
Recovery	Air Lift	Y	Y	Y	Most efficient, least cost method
	Dustpan	Y	Y	Y	May have some difficulty with boulders
	Oozer/Pneuma	Y	Y	Y	Requires special vessels to operate
	Bucket Dredge Systems	Y	N	N	Cannot operate in 65 m depth
	Positive Pressure Pump Systems	Y	N	N	Cannot operate in 65 m depth
	Divers	Y	N	N	Cannot control suspended sediments
Dewatering	Natural Settling	Y	Y	N	Only sand will settle, not contaminated silt
	Centrifuge	Y	Y	Y	Effective if used with chemical flocculants
	Plate Press	Y	Y	Y	Effective if used with chemical flocculants
	Diaphram Press	Y	Y	Y	Effective if used with chemical flocculants
Volume Reduction	Sand Separation	Y	Y	Y	May provide up to 90% volume reduction
	Thermal Desorption	Y	Y	Y	Will require transport of material to Quebec
	Solvent Extraction	Y	Y	N	No systems permitted in Canada
Destruction	Thermal - Infrared Units	N	Y	N	No systems permitted in Canada
	Thermal - Circulating Bed Combustor	N	Y	N	No systems permitted in Canada
	Thermal - Chemical	N	Y	N	No systems permitted in Canada
	Incineration	Y	Y	Y	Swan Hills is only licenced facility in Canada
	Chemical	N	N	N	No systems permitted in Canada
	Biological	N	N	N	No proven, commercial systems
Disposal	Landfill	N	Y	Y	Cannot receive >50 ppm material
	Registered Storage Site	Y	Y	Y	Does not satisfy federal Toxic Management Policy well

Table C.3 Comparison of Threshold Criteria by Technique

Appendix D
PAC Questionnaire

As part of the study methods, to record a representative view of the stakeholders on the PAC, a series of five questions were formulated and the questions posed to the PAC members on the Steering Committee. The responses to these questions formulate the basis on which these aspects considered are recorded.

Socio-economic Questions to the Remediation Option Study Steering Committee Members on PAC

1. *What do you feel would be a possible positive socio-economic benefit, including any effects that would be considered from direct action (i.e. vessel charter) or indirect action (i.e. peoples perception of a product), would there be for the option of no further remedial action?, of in-situ stabilization of impacted sediments (capping)? and of removal of impacted sediments?*

2. *What do you feel would be a possible economic disadvantage, including any direct (i.e. vessel charter) or indirect action (i.e. peoples perception of a product), for the option of no further remedial action?, of in-situ stabilization of impacted sediments (capping)? and of removal of impacted sediments?*

3. *What, if anything, do the members of your community presently feel about the PCB impacted sediments at the former Irving Whale site?*

4. *What do you think will happen to the environment and the community if no further remedial action is taken?, of in-situ stabilization of impacted sediments(capping), and of removal of impacted sediments.*

5. *What would your community feel is the best option?*

On June 15, 1998, before the draft report was distributed to the Steering Committee, Prince Edward Island PAC members Barry Murray and Ansel Ferguson were interviewed together at Barry Murray s residence in Seaview. On June 16, 1998 Magdalen Islands PAC member Helene Chevrier was interviewed via telephone conference call with Vincent Jarry and Ernest Bouffard attending the call, Mario Cyr was not available to participate in the interview. On July 4, 1998 at a meeting with all PAC Steering Committee members present the results of the draft report were discussed and further input was received. At this meeting it was agreed by the Steering Committee that there were divergent opinions on the most appropriate remediation option amongst the PAC members but that for the purposes of this report the opinions would be recorded but not accredited to specific PAC members.

Appendix E
DETAILED COST ANALYSIS

Table E.1 Summary of Annual Costs for Option 1, No Further Remediation

Confirming Risk Assessment Assumptions

	Unit Rate	# Units	Subtotal
Adminstration Costs	$2,500	1 unit	$2,500
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Benthic and Species Devers	$300	35 Samples	$10,500
Subtotal Sampling Program			*$50,500*

Data Analysis and Reporting

Proffessional Fees	$700	60 Person Days	$42,000
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$45,500*

Total Capital Cost ***$96,000***

Long Term Monitoring Program

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,250	1 unit	$3,250
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,000*

Data Analysis and Reporting

Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*

Total Annual Costs (Sample Collection and Reporting) ***$60,000***

Table E.2 In-Situ Capping, Precision Placement

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1	$60,000	$60,000
Pre-Construction Survey	1	$50,000	$50,000
Tender Development	1	$15,000	$15,000
Tender Process	1	$15,000	$15,000
Subtotal Engineering			$140,000
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Mobilization/Demobilization DSV	1 unit	$1,000,000	$1,000,000
Pre-Construction Survey	1 unit	$80,000	$80,000
Cap Construction			
Ship Rentals DP Flexible Fall Pipe Vessel	35 days	$150000 /day	$5,250,000
Supply/Place Geotextile	40000 sq.m	$ 10 /sq.m	$400,000
Supply/Place 0.5m lift Stone[1]	22000 cu.m	$30 /cu.m	$660,000
Supply/Place 0.5m lift Armor Stone[1]	22000 cu.m	$30 /cu.m	$660,000
Inspection Services	8%	$8,065,000	$645,200
Contingency	40%		$3,484,080
Subtotal Construction Works			$12,194,280
Total Capital			$12.4 million

Long Term Monitoring Program

Annual Sampling Program			
Administration Costs	$2,750	1 unit	$2,750
SWATH Survey	$100,000	1 unit	$100,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Analytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			$120,500
Data Analysis and Reporting			
Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			$14,000

Total Annual Costs (Sample Collection and Reporting) ***$134,500***

Notes

1 Placement of Aggregate assumes 10% over-placement due to current and positioning equipment

Table E.3 In-Situ Capping, Precision Placement using Local Barges

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1	$60,000	$60,000
Pre-Construction Survey	1	$50,000	$50,000
Tender Development	1	$15,000	$15,000
Tender Process	1	$15,000	$15,000
Subtotal Engineering			$140,000
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Mobilization/Demobilazation DSV	1 unit	$100,000	$100,000
Pre-Construction Survey	1 unit	$80,000	$80,000
Cap Construction			
Ship Rentals DP Flexible Fall Pipe Vessel	60 days	$50000 /day	$3,000,000
Supply/Place Geotextile	40000 sq.m	$ 10 /sq.m	$400,000
Supply/Place 0.5m lift Stone[1]	22000 cu.m	$30 /cu.m	$660,000
Supply/Place 0.5m lift Armour Stone[1]	22000 cu.m	$30 /cu.m	$660,000
Inspection Services	8%	$4,915,000	$393,200
Contingency	40%		$2,123,800
Subtotal Construction Works			$7,432,000
Total Capital			$7.6 million

Long Term Monitoring Program

Annual Sampling Program

Adminstration Costs	$2,750	1 unit	$2,750
SWATH Survey	$100,000	1 unit	$100,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			$120,500

Data Analysis and Reporting

Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			$14,000

Total Annual Costs (Sample Collection and Reporting) ***$134,500***

Notes

1 Placement of Aggregate assumes 10% over-placement due to current and positioning equipment

Table E.4 In-Situ Capping Using Bottom Dump Barges

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1	$60,000	$60,000
Pre-Construction Survey	1	$50,000	$50,000
Tender Development	1	$15,000	$15,000
Tender Process	1	$15,000	$15,000
Subtotal Engineering			$140,000
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Mobilization/Demobilazation DSV	1 unit	$100,000	$100,000
Pre-Construction Survey	1 unit	$80,000	$80,000
Cap Construction			
Barge Rentals (2 - 750 cu.m barges)	70 days	$3000 /day	$210,000
Supply/Place Geotextile	40000 sq.m	$ 10 /sq.m	$400,000
Supply/Place Cap Aggregate Stone[1]	80000 cu.m	$35 /cu.m	$2,800,000
Inspection Services	8%	$3,605,000	$288,400
Contingency	40%		$1,557,360
Subtotal Construction Works			$5,450,760
Total Capital			$5.5 million

Long Term Monitoring Program

Annual Sampling Program

Adminstration Costs	$2,750	1 unit	$2,750
SWATH Survey	$100,000	1 unit	$100,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal			$120,500

Total Annual Costs (Sample Collection and Reporting) ***$220,500***

Notes

1 Placement of Aggregate assumes 100% over-placement due to current and positioning equipment

Table E.5 Removal and Incinerate

All Sediments Sent For Treatment, No Separation of Sand and Gravel

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal		
Pre-Engineering					
Engineering Design	1 unit	$60,000	$60,000		
Pre-Construction Survey	1 unit	$50,000	$50,000		
Tender Development	1 unit	$15,000	$15,000		
Tender Process	1 unit	$15,000	$15,000		
Subtotal Engineering			*$140,000*		
Construction					
Environmental Monitoring	1 unit	$15,000	$15,000		
Recovery					
Vessel Mobilization/Demobilazation	1 unit	$1,300,000	$1,300,000		
Barge Mobilization/Demobilazation	1 unit	$975,000	$975,000		
Recovery Ship Rentals	35 days	$180000 /day	$6,300,000		
Geo-positioning Survey Rental	1 unit	$80,000	$80,000		
Transport to Shore					
Barge #1 Rental	35 days	$35000 /day	$1,225,000		
Dewatering Treatment System					
Temporary Water Storage	1 unit	$500,000	$500,000		
Dewatering					
Equipment Mobilization	1 unit	$200,000	$200,000		
Flocculant (0.01% Solution)	60000 litres	$10 /liter	$600,000		
Centrifuge/Plate Press	60 days	$12500 /day	$750,000		
Transport and Incinerate		Swan Hills Alberta		Bennett Environmental	
Transportation	75 Truckloads	$15000 /truckload	$1,125,000	$1800 /truckload	$135,000
Incineration	600 cu.m	$5400 /cu.m	$3,240,000	$1000 /cu.m	$600,000
Inspection Services	10%	$11,945,000	$1,194,500		
Contingency	40%	$17,504,500	$7,001,800		
Subtotal Construction Works			*$24,506,300*		*$20,876,300*
Total Capital Cost			$24.7 million		$21.1 million

Long Term Monitoring Program

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,250	1 unit	$3,250
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,000*
Data Analysis and Reporting			
Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*
Total Annual Costs (Sample Collection and Reporting)			***$60,000***

Table E.6 Removal and Destroy, With Sand/Gravel Separation

Fine Sediments Treated, Clean Sand and Gravel Mechanically Removed

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1 unit	$60,000	$60,000
Pre-Construction Survey	1 unit	$50,000	$50,000
Tender Development	1 unit	$15,000	$15,000
Tender Process	1 unit	$15,000	$15,000
Subtotal Engineering			*$140,000*
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Recovery			
Vessel Mobilization/Demobilazation	1 unit	$1,300,000	$1,300,000
Barge Mobilization/Demobilazation	1 unit	$975,000	$975,000
Recovery Ship Rentals	35 days	$200000 /day	$7,000,000
Geo-positioning Survey Rental	1 unit	$80,000	$80,000
Transport to Shore			
Barge #1 Rental	35 days	$35000 /day	$1,225,000
Dewatering Treatment System			
Temporary Water Storage	1 unit	$500,000	$500,000
Dewatering			
Equipment Mobilization	1 unit	$200,000	$200,000
Flocculant (0.01% Solution)	60000 litres	$10 /liter	$600,000
Centrifuge/Plate Press	60 days	$12500 /day	$750,000
Volume Reduction			
Equipment Mobilization	1 unit	$50,000	$50,000
Shale Shaker (Residual sand removal)	45 days	$2000 /day	$90,000
Dispose of Clean Sand (Ocean Dumping)			
Transportation	2 Shipload	$100000 /shipload	$200,000
Transport and Incinerate, Bennett Environmental			
Transportation	4 Truckloads	$1800 /truckload	$7,200
Incineration	20 cu.m	$1000 /cu.m	$20,000
Inspection Services	10%	$12,985,000	$1,298,500
Contingency	40%	$14,310,700	$5,724,280
Subtotal Construction Works			$20,034,980

Total Capital Cost $20.2 million

Long Term Monitoring Program

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,250	1 unit	$3,250
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,000*
Data Analysis and Reporting			
Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*

Total Annual Costs (Sample Collection and Reporting) ***$60,000***

Table E.7 Removal and Destroy, With Sand/Gravel Separation

Fine Sediments Treated, Clean Sand and Gravel Gravity Settlement

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1 unit	$60,000	$60,000
Pre-Construction Survey	1 unit	$50,000	$50,000
Tender Development	1 unit	$15,000	$15,000
Tender Process	1 unit	$15,000	$15,000
Subtotal Engineering			*$140,000*
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Recovery			
Vessel Mobilization/Demobilazation	1 unit	$1,300,000	$1,300,000
Barge Mobilization/Demobilazation	1 unit	$975,000	$975,000
Recovery Ship Rentals	35 days	$200000 /day	$7,000,000
Geo-positioning Survey Rental	1 unit	$80,000	$80,000
Transport to Shore			
Barge #1 Rental	35 days	$35000 /day	$1,225,000
Dewatering Treatment System			
Temporary Water Storage	1 unit	$500,000	$500,000
Dewatering			
Equipment Mobilization, setup	1 unit	$200,000	$200,000
Flocculant (0.01% Solution)	60000 litres	$10 /liter	$600,000
Volume Reduction			
Equipment Mobilization	1 unit	$50,000	$50,000
Shale Shaker (Residual sand removal)	45 days	$2000 /day	$90,000
Dispose of Clean Sand (Ocean Dumping)			
Transportation	2 Shipload	$100000 /shipload	$200,000
Transport and Incinerate, Bennett Environmental			
Transportation	4 Truckloads	$1800 /truckload	$7,200
Incineration	20 cu.m	$1000 /cu.m	$20,000
Inspection Services	10%	$12,235,000	$1,223,500
Contingency	40%	$13,485,700	$5,394,280
Subtotal Construction Works			$18,879,980

Total Capital Cost $19.1 million 19100000

Long Term Monitoring Program

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,250	1 unit	$3,250
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,000*
Data Analysis and Reporting			
Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*

Total Annual Costs (Sample Collection and Reporting) ***$60,000***

Table E.8 Removal and Incinerate With Thermal Desorption

All Sedimented Treated, Including Clean Sand and Gravel

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1 unit	$60,000	$60,000
Pre-Construction Survey	1 unit	$50,000	$50,000
Tender Development	1 unit	$15,000	$15,000
Tender Process	1 unit	$15,000	$15,000
Subtotal Engineering			*$140,000*
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Recovery			
Vessel Mobilization/Demobilazation	1 unit	$1,300,000	$1,300,000
Barge Mobilization/Demobilazation	1 unit	$975,000	$975,000
Recovery Ship Rentals	35 days	$200000 /day	$7,000,000
Geo-positioning Survey Rental	1 unit	$80,000	$80,000
Transport to Shore			
Barge #1 Rental	35 days	$35000 /day	$1,225,000
Dewatering Treatment System			
Temporary Water Storage	1 unit	$500,000	$500,000
Dewatering			
Equipment Mobilization	1 unit	$200,000	$200,000
Flocculant (0.01% Solution)	60000 litres	$10 /liter	$600,000
Centrifuge/Plate Press	60 days	$12500 /day	$750,000
Volume Reduction			
Transport To Thermal Unit	75 Truckloads	$5000 /truckload	$375,000
Thermal Desorption	600 cu.m	$450 /cu.m	$270,000
Dispose of Clean Sand (Ocean Dumping)			
Transportation	2 Shipload	$100000 /shipload	$200,000
Transport and Incinerate, Bennett Environmental			
Transportation	1 Truckloads	$1800 /truckload	$1,800
Incineration	30 cu.m	$1000 /cu.m	$30,000
Inspection Services	10%	$13,490,000	$1,349,000
Contingency	40%	$14,870,800	$5,948,320
Subtotal Construction Works			$20,819,120
Total Capital Cost			$21.0 million

Long Term Monitoring Program

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,250	1 unit	$3,250
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,000*
Data Analysis and Reporting			
Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*

Table E.9 Removal and Incinerate With Sand Separation & Thermal Desorption

Fine Sediment Treated, Clean Sand and Gravel Not Processed

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1 unit	$60,000	$60,000
Pre-Construction Survey	1 unit	$50,000	$50,000
Tender Development	1 unit	$15,000	$15,000
Tender Process	1 unit	$15,000	$15,000
Subtotal Engineering			*$140,000*
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Recovery			
Vessel Mobilization/Demobilazation	1 unit	$1,300,000	$1,300,000
Barge Mobilization/Demobilazation	1 unit	$975,000	$975,000
Recovery Ship Rentals	35 days	$200000 /day	$7,000,000
Geo-positioning Survey Rental	1 unit	$80,000	$80,000
Transport to Shore			
Barge #1 Rental	35 days	$35000 /day	$1,225,000
Dewatering Treatment System			
Temporary Water Storage	1 unit	$500,000	$500,000
Dewatering			
Equipment Mobilization	1 unit	$200,000	$200,000
Flocculant (0.01% Solution)	60000 litres	$10 /liter	$600,000
Centrifuge/Plate Press	60 days	$12500 /day	$750,000
Volume Reduction			
Equipment Mobilization	1 unit	$50,000	$50,000
Shale Shaker (Residual sand removal)	45 days	$2000 /day	$90,000
Transport To Thermal Unit	2 Truckloads	$5000 /truckload	$10,000
Thermal Desorption	40 cu.m	$450 /cu.m	$18,000
Dispose of Clean Sand (Ocean Dumping)			
Transportation	2 Shipload	$100000 /shipload	$200,000
Transport and Incinerate, Bennett Environmental			
Transportation	1 Truckloads	$1800 /truckload	$1,800
Incineration	10 cu.m	$1000 /cu.m	$10,000
Inspection Services	10%	$13,013,000	$1,301,300
Contingency	40%	$14,326,100	$5,730,440
Subtotal Construction Works			$20,056,540
Total Capital Cost			$20.2 million

Long Term Monitoring Program

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,250	1 unit	$3,250
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,000*
Data Analysis and Reporting			
Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*
Total Annual Costs (Sample Collection and Reporting)			***$60,000***

Table E.10 Removal and Store In Registered Facility

Construction Program (Capital Cost Analysis)

	Unit Rate	# Units	Subtotal
Pre-Engineering			
Engineering Design	1 unit	$60,000	$60,000
Pre-Construction Survey	1 unit	$80,000	$80,000
Tender Development	1 unit	$15,000	$15,000
Tender Process	1 unit	$15,000	$15,000
Subtotal Engineering			*$170,000*
Construction			
Environmental Monitoring	1 unit	$15,000	$15,000
Recovery			
Vessel Mobilization/Demobilazation	1 unit	$1,300,000	$1,300,000
Barge Mobilization/Demobilazation	1 unit	$975,000	$975,000
Recovery Ship Rentals	35 days	$200000 /day	$7,000,000
Geo-positioning Survey Rental	1 unit	$50,000	$50,000
Transport to Shore			
Barge #1 Rental	35 days	$35000 /day	$1,225,000
Dewatering Treatment System			
Temporary Water Storage	1 unit	$500,000	$500,000
Dewatering			
Equipment Mobilization	1 unit	$200,000	$200,000
Flocculant (0.01% Solution)	60000 litres	$10 /liter	$600,000
Centrifuge/Plate Press	60 days	$12500 /day	$750,000
Storage Facility			
Containers	20 Containers	$15000 /Container	$300,000
Compound Yard Elements (fencing etc)	$3,500	1 unit	$3,500
Inspection Services	10%	$12,615,000	$1,261,500
Contingency	40%	$14,180,000	$5,672,000
Subtotal Construction Works			*$19,852,000*

Total Capital Cost $20.1 million

Long Term Monitoring Program

Annual Maintenance

Storage Yard

	Unit Rate	# Units	Subtotal
Adminstration Costs	$3,600	1 unit	$3,600
General Maintenance (painting, welding etc)	$2,000	1 unit	$2,000
Disbursements	$3,500	1 unit	$3,500
Subtotal For Storage Yard			*$9,100*
Dredging Area After Removal			
Adminstration Costs	$4,150	1 unit	$4,150
Boat Rental	$2,000	5 days	$10,000
Survey/Positioning Systems	$15,000	1 unit	$15,000
Personnel Costs	$700	10 Person Days	$7,000
Misc. Equipment	$2,000	1 unit	$2,000
Anaytical Costs			
Sediment Samples	$100	35 Samples	$3,500
Biological Samples	$150	35 Samples	$5,250
Subtotal Sampling Program			*$46,900*

Data Analysis and Reporting

Personnel Costs	$700	15 Person Days	$10,500
Disbursements	$3,500	1 unit	$3,500
Subtotal			*$14,000*