Summary Report on Loadings, Sediment Inventory, and Present and Future Outlook for PCB Impacts in Hopedale Harbour

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1.0 INTRODUCTION

On behalf of the Newfoundland and Labrador Department of Environment and Conservation (NLDEC), Aivek Stantec Partnership Limited (Stantec) conducted sampling of environmental media in freshwater and marine environments near the former U.S. Military Site in Hopedale, NL. The purpose of the work was to characterize present and anticipated future distribution of polychlorinated biphenyl (PCB) concentrations in environmental media (particularly in sediment and marine country foods) in the marine environment of Hopedale Harbour and vicinity.

PCBs are man-made chemical mixtures that are persistent and bioaccumulative (CCME, 2001). At elevated levels, PCBs can cause adverse health effects to humans and ecological receptors. From the 1930s to the 1970s, PCBs were widely used around the world as coolants and lubricants for electrical equipment, including transformers and capacitors, and in a number of industrial materials, including sealing and caulking compounds, inks and some paints. The use of PCBs was prohibited in heat transfer and electrical equipment installed after September 1, 1977, and in transformers and capacitors installed after July 1, 1980. The primary source of PCBs in Hopedale Harbour is believed to be related to operations at the former U.S. Military Site.

1.1 Site Description and Background

The Inuit community of Hopedale is located on the Labrador coast, 148 air miles north of Goose Bay, NL and has no outside road access (refer to Figure 01 in Appendix A). Coastal boat service is available to the community of approximately 600 people from mid-summer to late fall. A military base and radar site was constructed in Hopedale in the 1950s, and was operated by the United States (U.S.) government until 1969 as a station on the United States Air Force Pinetree Line and the Mid-Canada Line. The former U.S. Military Site is located north and west of the developed areas of the community of Hopedale (refer to Figure 02 in Appendix A). The former U.S. Military Site consists of three main hilltop sites (i.e., Ballistic Missile Early Warning System (BMEWS), Main Base and Mid-Canada Line) as well as several other associated sites.

In 1969, the base was closed down and the radome and radar antennae were removed. Between 1969 and 1975, portions of the site were operated by Canadian Marconi and ITT as a telecommunications site. Most of the remaining aboveground structures were demolished and buried in several locations around the site in the mid-1980s. At that time, limited clean-up efforts were carried out and included the removal and disposal of PCB-containing transformers. With the exception of infrastructure at the Mid-Canada Line site, only the foundations and floor slabs of buildings and the foundations and bases of antennae currently remain on the site. Bell Aliant is currently operating two antennae and an associated operations building at the Mid-Canada Line site and one antenna and an associated operations building at the BMEWS site.

Several environmental assessment reports have been produced (mainly since 1996) relating to potential and actual contamination at and in the vicinity of the former U.S. Military Site and

Residential Subdivision in Hopedale, Labrador. Previous environmental assessments and a Human Health and Ecological Risk Assessment (HHERA) revealed the presence of total petroleum hydrocarbons (TPH), PCBs and metals in soil at concentrations that may present adverse risks to human and/or ecological receptors (refer to Stantec, 2010 and Stantec, 2011a). Based on this information, a Remedial Action Plan / Risk Management Plan (RAP/RMP) was developed for the terrestrial portion of the site, and soil remediation was recommended in certain areas (Stantec, 2010). In 2009 and 2010, preliminary freshwater and marine sampling revealed elevated concentrations of PCBs in sediments from Hopedale Harbour, and in selected sediment samples collected from freshwater ponds and streams near the site; therefore, a comprehensive marine study, including nearby freshwater sites, was recommended (Stantec, 2010 and Stantec, 2011b).

In the summer of 2011, the Government of Newfoundland and Labrador committed funds over a three year period to support the implementation of the RAP/RMP and the completion of a three year Marine Study. Each year of work was to be conducted in accordance with NLDEC budget allowances and a mutually-agreeable work plan proposed by the Stakeholder Scientific Advisory Working Group (referred to as the “Stakeholder Committee”). The Stakeholder Committee is made up of representatives from the Inuit Community Government of Hopedale, the Nunatsiavut Government, Labrador Grenfell Health, the Department of Labrador and Aboriginal Affairs (now the Labrador and Aboriginal Affairs Office), NLDEC and technical advisors. The scope of work for Years 1 to 3 of the Implementation of the RAP/RMP included the remediation of PCB-impacted soil in terrestrial areas located closest to the residential areas of Hopedale and up-gradient of the community’s water supply (the Old Dump Pond, Residential Subdivision, Wharf and BMEWS sites). The scope of work for the 3-year Marine Study included a characterization of the present and anticipated future distribution of PCBs in sediment and marine country foods in Hopedale Harbour and the investigation of other potential sources of PCB exposure to the residents of Hopedale. It was the intent that data collected as part of the Marine Study would also support a Human Health Risk Assessment based on marine country foods and, if deemed necessary, a remedial action/risk management plan for sediments.

1.2 Scope of this Report

This report represents the culmination of three years of field investigations, lab analysis and modeling of the marine environment of Hopedale Harbour, including work in nearby freshwater environments. The intent is to provide an overview of current and future conditions of PCBs in the marine environment in and around Hopedale Harbour by summarizing some of the pertinent findings in regards to PCB fluxes from streams into the harbour, current PCB inventories in the harbour sediments, PCB concentrations in country foods and other biota, and the hydrodynamics within the marine system.

2.0 PCB FLUXES TO HOPEDALE HARBOUR

2.1 Terrestrial Conditions and Stream Inflow

To gain a full understanding of current and future PCB dynamics in Hopedale Harbour, PCB and sediment flux monitoring was undertaken at terrestrial and freshwater sites with connectivity to the harbour. This consisted mainly of the main watershed, via Old Dump Pond (ODP) and Small Bog Pond, through the Residential Subdivision, to the harbour. To determine whether ODP is a significant source of the PCBs entering the harbour, freshwater monitoring stations were set up just below ODP, and just before entering the harbour, the latter capturing the combined flux from both source areas, thus allowing quantification of the total flux to the harbour. The flux sampling locations are shown in Figure 03 in Appendix A.

2.1.1 Subdivision Source Area

The stream in the Residential Subdivision originates in a small pond and boggy area (the Small Bog Pond), and flows through the east side of the subdivision where it meets the Old Dump Pond outlet and eventually empties into Hopedale Harbour, located approximately 200 m south of the Residential Subdivision (refer to Figure 03 in Appendix A).

Part of the subdivision was built on a former landfill, where steel drums and other military base debris were discovered during previous geophysical surveys and subsurface investigations. Subsequently, sediments with concentrations of PCBs exceeding the site-specific target level of 9 ppm were remediated from an approximately 50 m long reach in the stream in the Residential Subdivision between early July and late September 2012.

2.1.2 Old Dump Pond Source Area

Old Dump Pond is located down gradient of Reservoir Lake on the west side of the main access road. An area of land adjacent to Old Dump Pond was historically used for the storage of various metal waste and debris. Terrain in the immediate vicinity slopes towards the pond which discharges to the southeast into Hopedale Harbour via a small stream. A relatively new area of residential development has been constructed on an elevated gravel pad to the east of the pond.

During previous investigations, elevated concentrations of PCBs (up to 32 parts per million (ppm)) were detected in grab sediment samples collected from the pond. Between 2011 and 2013, soil remediation to remove soil with concentrations of PCBs exceeding of the site-specific target level of 9 ppm was carried out along the eastern shoreline of Old Dump Pond. An approximately 5 m wide strip of soil with a maximum recorded PCB concentration of 290 ppm was left undisturbed between the remedial excavation and the pond to minimize surface water infiltration. This area of impacted soil will be addressed during future remediation of pond sediments (if deemed necessary).

2.1.3 Other Potential Sources

Other potential land-based sources that could be contributing to PCBs in the harbour might include other streams, sewage outflows, coastal erosion, and garbage dumping.

No other streams enter the harbour, although there is a sewage outflow east of the DFO dock on the north side of Hopedale Harbour. No measurements were taken at this location, but some minor PCB contribution to the harbour through this outflow is possible. The region around the harbour, however, is mostly exposed bedrock, so that any influx of potentially contaminated soil through coastal erosion is unlikely. Finally, garbage deposition on the ice in the harbour has been observed by local residents, and when the ice melts, some of this material can end up at the bottom of the harbour. Although this has not been quantified, some PCB hotspots in the harbour sediments suggest this may be a possible mechanism by which PCBs historically entered the marine environment.

Despite some of these other minor potential land-based sources, we conclude that the stream characterized above presently constitutes the main pathway for land and freshwater PCBs to enter Hopedale Harbour, recognizing that the historical source or mechanism of PCB contamination remains unclear.

2.2 Total Freshwater PCB Flux

Flux monitoring included measurements of flow, total suspended solids, turbidity, and PCB concentrations. Measurements were taken on a bi-weekly basis from late August to mid November 2011, including after two storm events (August 30 and September 16), as well as between early July and early November 2012.

Flow rates across both years at the harbour site averaged 0.020 m^3/s (SD 0.016), with storm events averaging 0.090 and peaking at 0.16 m^3/s. Total suspended solids averaged 4.85 ppm (SD 5.38). PCBs in stream flow were either not detected (15 of 22, 68.2% of samples), or low (< 0.061 parts per billion (ppb)) in the other 31.8% of samples. In 2011, only one sample had detectable PCBs (0.06 ppb), and that was taken during a storm event. Assuming values of half the detection limit when none could be measured, the average PCB concentration could have been 0.031 ppb (SD 0.011). In 2012, the range of above detection limit samples (6 out of 13) was 0.034 to 0.061 ppb, but taking into account all values, and again assuming values of half the detection limit when none could be measured, PCB concentrations averaged 0.037 ppb (SD 0.014). Based on the assumptions made, these should be considered high estimates.

We cannot directly determine whether the PCBs measured at the entrance of the harbour originate predominantly from ODP or the Residential Area, but it should be noted that only on one occasion during the two years (November 2012) were PCBs detected at the station right below ODP. PCBs were detected at a concentration of 0.064 ppb on that occasion (for more details see Stantec, 2012 and Stantec, 2014a). In addition, data collected in the stream below the silt curtain during the remediation efforts in the stream at the residential site during 2012, showed elevated levels of total suspended solids (up to 430 ppm, as per Table C.6 in Stantec, 2014b), and the timing of remediation efforts shortly preceded times where PCB measurements downstream increased to above detection limits. Thus, detected PCB concentrations during that time should be considered maxima, noting that during non-storm events and times outside remediation efforts, most samples had no detectable concentrations of PCB entering the harbour (<5 ppm). Since some remediation has already taken place at both source areas, the potential PCB input has further been reduced.

Based on available data, the total amount of PCBs entering the harbour can be calculated in several ways:

1. *Catchment area precipitation with ODP sediment PCB concentrations*: Climate data indicate an average annual precipitation of 950 mm in the form of snow and rain for the nearby coastal communities of Makkovik and Nain, NL (Environment Canada, 2014). Taking into consideration evaporation and transpiration, the annual runoff in this area is estimated at 750 mm (Fisheries and Environment Canada, 1978). Applying this to the stream catchment area funnelling inflow into the harbour of approximately 1.3 km^2 (refer to Main Watershed on Figure 03 in Appendix A), the theoretical average annual freshwater flow from this stream into the harbour is about 975 million litres. Assuming an average PCB concentration in the stream that is in equilibrium with the median surface sediment concentrations of ODP (approximately 4 ppm) and taking the average measured TSS in the stream above (4.85 ppm), the total annual sediment flux from the stream to the harbour should not exceed 4,728 kg, carrying no more than 18.9 g of PCBs.
2. *Catchment area precipitation with stream PCB concentrations:* As above but applying the conservatively estimated PCB concentration in the stream water samples (0.037 ppb as discussed above), the total estimate is 36.1 g per year. If alternatively we assume that non-detect limits are more representative of stream conditions and thus apply half of the detection limit (0.025 ppb) to this approach then we estimate that 24.4 g of PCBs are entering Hopedale Harbour via the stream per year.
3. *Stream flow rates and stream PCB concentrations:* Combining the average flow rate across all years (0.020 m^3/s) with the average PCB concentrations of 0.037 ppb (including half detection values for non-detect samples), and assuming a seven month flow season (May-November – Environment Canada, 2014), we estimate that a maximum of 13.4 g of PCBs are entering Hopedale harbour via the stream per year. If alternatively we assume that non-detect limits are more representative of stream conditions and thus apply half of the detection limit (0.025 ppb) to this approach then we estimate that 9.1 g of PCBs are entering Hopedale Harbour via the stream per year.

We conclude that less than 36.1 g, and most likely no more than 24.4 g of PCBs are entering Hopedale Harbour via the stream per year.

3.0 PCB INVENTORY OF HOPEDALE HARBOUR SEDIMENTS

Hopedale Harbour covers an area of approximately 1.5 km^2 and can be split into the inner harbour (inside the main sill including the embayments located south of the main wharf), outer harbour (between the sill and the head of the harbour) and the outer coast (everything east of the head of the bay); refer to Figure 04 in Appendix A. Between 2009 and 2013, field staff collected a total of 84 surface sediment samples to delineate PCB and total organic carbon (TOC) concentrations, 10 grab samples to characterize grain size distribution, and five core samples to determine vertical PCB distribution (two duplicates of which were submitted for radiometric lead-210 dating (see Figure 04 in Appendix A for sampling locations, and Stantec, 2012 and Stantec, 2014a for further details).

3.1 Inner Harbour

The eastern limit of the inner harbour is a sill located roughly along the N-S 5 m isobath, approximately 400 m east of the main wharf, and covers an area of 0.71 km^2. Within this area are two shallow (<10m) embayments that are mostly cut off from the main harbour circulation. Also included in this area are two deeper basins with a depth of up to 20 m (see NATECH, 2013 for details). The areas of highest surface sediment PCB concentrations (2.6 ppm) in all of Hopedale Harbour are located immediately north and south the main wharf, but not extending into the stream outlet area, with values within the rest of the inner harbour ranging from non-detect to 2.3 ppm and a median of 0.27 ppm (see Stantec, 2014a for details). Taking into account all values, PCB concentrations averaged 0.48 ppm (SD 0.53), with a median of 0.31. The observed spatial distribution suggests that the main source of PCBs entering the harbour was located on or at the wharf, and was not due to transport of PCBs from land to sea via the stream. Beyond the main areas of contamination near the wharf, the higher PCB concentrations are found in deeper sections of the harbour, and are lower over the sill.

The five core samples taken in the inner harbour showed PCB concentrations in the sediment up to 23 cm deep, with peaks at three of the stations of 3.4 ppm, 4.4 ppm and 3.5 ppm at approximately 10 cm depth. The PCB profiles for sediment cores collected by Stantec in 2011 are shown in Figure 3-1 (refer to Stantec, 2012 for additional core sampling details). The average maximum depth at which PCBs were detected at these five stations was 15 cm. Despite the variance of PCB concentrations at different sediment depths, the surface sediment PCB concentrations were found to be reflective of the average depth integrated values and are thus used for extrapolation throughout the harbour in this report.

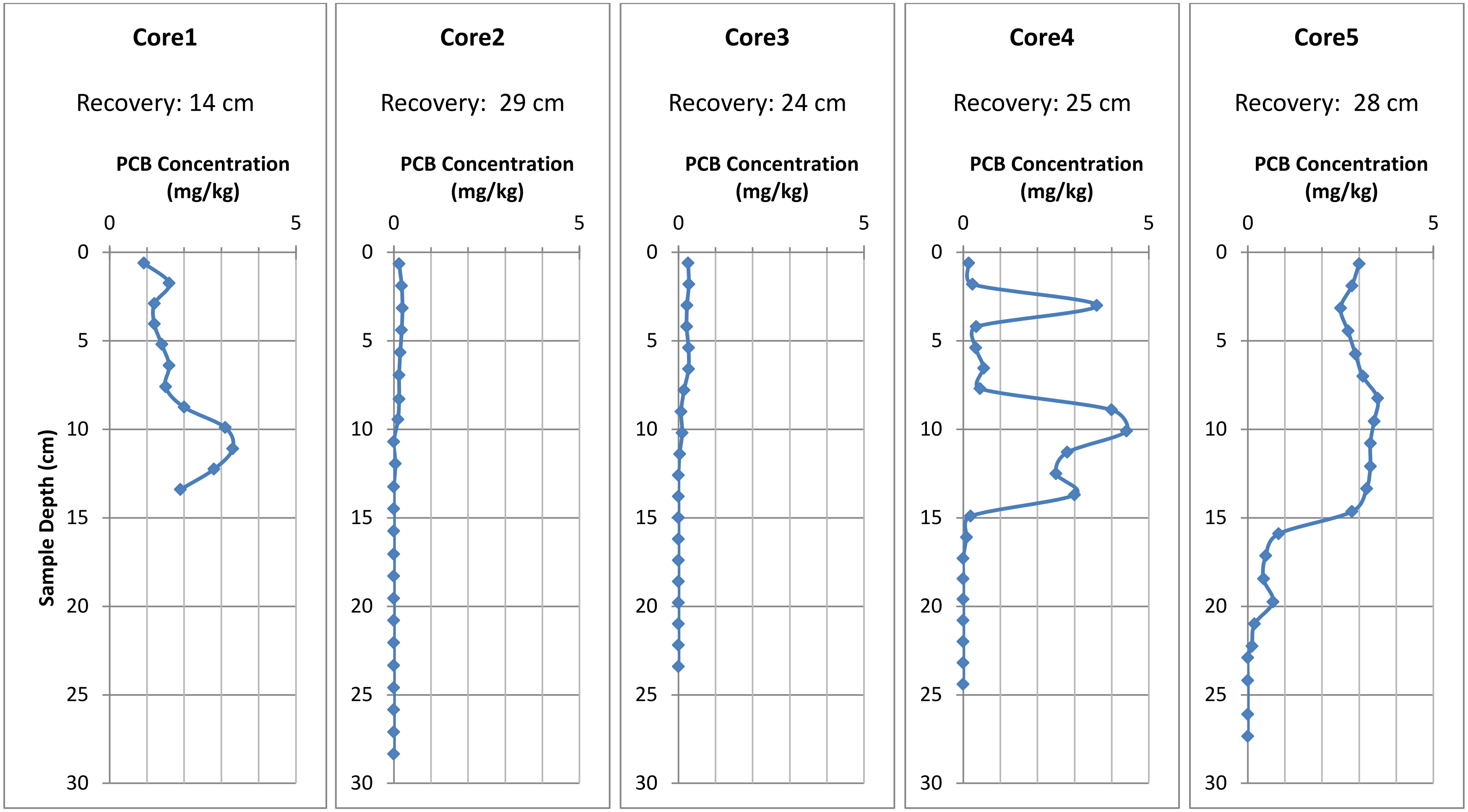

Figure 3-1 PCB Profiles for Hopedale Harbour Sediment Core Samples

To determine the overall PCB inventory in the inner harbour, the surface sediment concentrations shown in Figures 05 and 06 in Appendix A were used, assuming an average penetration depth of 15 cm (from data shown in Fig. 3-1), an 80% moisture content (lab values ranged between 65 and 95%), and a sediment density of 1100 kg/m^3. GIS was used to determine surface area of different concentration areas based on all samples taken across the years. Concentration areas were binned, and total PCB loadings calculated in two different ways:

1. Assuming equal sized bins of 0.5 ppm with a detection limit 0.05, using the average concentration in each bin (Figure 05), and assuming half the values for non-detect areas.
2. Assuming smaller bins at low concentrations to reflect the frequency of observations, with larger ranges at the higher levels, a detection limit of 0.0215 (some samples were run with higher sensitivity), using the geometric mean in each bin (Figure 06 in Appendix A), and assuming half the values for non-detect areas.

Using the first approach, the total inner harbour inventory of PCBs in the sediments is estimated at 6.8 kg. Using the second approach the inventory estimate is 6.7 kg.

To account for different organic carbon concentrations in each of the samples and to facilitate a comparison to PCB concentrations in biological samples, the PCB sediment values were carbon normalized. Carbon normalized values are regularly used to compare sediment values to those found in fish and other organisms because PCB concentrations are related to the carbon content within the tissue/substrate in which they are being measured. Carbon normalized values can be directly compared against one another. Total organic carbon (TOC) in the inner harbour sediment ranged from 0.8 to 25.0 g/kg, resulting in a carbon normalized average estimate of 45.0 mg PCBs per kg TOC (SD 66.8; range 4.8-487.5).

3.2 Outer Harbour

The outer harbour is the area between the sill and the line just beyond the northern head of the bay, and covers an area of 0.82 km^2. This area can be divided into a shallower coastal area (<15 m) and deeper central zone with a maximum depression of 40 m at the western edge (see NATECH, 2013 for details). There is only one small hotspot of surface sediment PCB concentrations (1 ppm) in the middle where the bathymetry drops off south of the town of Hopedale, but the rest of the outer harbour ranges from non-detect to 0.4 ppm and a median concentration of 0.06 ppm (see Stantec, 2014a for details).

Making the same assumptions about surface concentrations and PCB penetration as above, and applying the same calculations, the total outer harbour inventory of PCBs in the sediments is estimated at 2.4 and 2.1 kg, respectively.

As above, the PCB sediment values from the outer harbour were carbon normalized. Total organic carbon in the outer harbour sediment ranged from 1.1 to 21.0 g/kg, resulting in a carbon normalized average estimate of 13.1 mg PCBs per kg TOC (SD 26.9; range 0.2 – 123.3).

3.3 Outer Coast

The "outer coast" is here defined as spanning the area beyond the outer harbour to the edge of the sampling grid halfway past Ellen Island, covering an area of 0.78 km^2. This area is shallow around Ellen Island, but otherwise has depths between 20 and 70 m (see NATECH, 2013 for details). Sediment samples taken within this area showed no PCB concentrations above the detection limit (see Stantec, 2014a for details).

Making the same assumptions about surface concentrations and PCB penetration as above, and applying the same calculations, the total "outer coast" inventory of Hopedale Harbour originated PCBs in the sediments is estimated at 0.6 and 0.3 kg, respectively.

As above, the PCB sediment values from the outer coast were carbon normalized. Total organic carbon in the outer coast sediment ranged from 4.1 to 26.0 g/kg, resulting in a carbon normalized average estimate of 0.7 mg PCBs per kg TOC (SD 0.3; range 0.2 to 1.2).

3.4 Reference Areas

To determine the geographic extent of PCB contamination in the marine environment and for comparison with surrounding areas, three different marine reference areas (Uvidluk Bay, Tooktoosner Bay, and Black Head Tickle) were selected (see Figure 02 in Appendix A and Stantec, 2012 for details). In 2011, one sediment sample was collected and analyzed from each location. No PCBs were detected in any of these samples. These results indicate the absence of PCB sources outside of Hopedale Harbour and speak to the health of the regional marine environment. The problem of PCB contamination is local in nature, and should be treated as such going forward.

4.0 PCB CONCENTRATIONS IN FISH AND SHELLFISH TISSUE

Samples of various finfish including shorthorn sculpin, rock cod, flatfish, Atlantic salmon, Arctic char, and Atlantic cod were collected from Hopedale Harbour (the inner and the outer harbour), Black Head Tickle, Uvidluk Cove, Tooktoosner Bay and an unnamed reference site located 17 km southwest of Hopedale Harbour, in August 2010 and 2011. In 2011, shellfish (mussels and clams) were collected in the southern embayments of inner Hopedale Harbour, as well as in Black Head Tickle and Tooktoosner Bay (refer to Figures 01 and 02 in Appendix A for sampling locations, and Stantec, 2010b and Stantec, 2012 for further details)

Fishing locations were selected based on guidance from local residents as well as information provided by the Environmental Sciences Group (ESG) of the Royal Military College (RMC) in Kingston, Ontario (ON) based on the preliminary results of the Food Basket Survey (Stantec, 2013).

In 2012, the collection of additional marine life and country foods in and around the town of Hopedale, including fish and shellfish in and outside Hopedale Harbour, was conducted by the

ESG in conjunction with individuals of the Community of Hopedale. ESG also completed a dietary survey amongst the residents of Hopedale in 2011. The results of these sampling events were provided to Stantec and were incorporated into a Human Health Risk Assessment for the Consumption of Country Foods (refer to Stantec, 2013 for details).

PCB and Lipid content was determined for muscle and liver tissues, as well as for whole fish and two specific subsistence foods, *Pitsik* (dried fish), and *Siva* (fried rock cod liver pâté). PCB measurements normalized to lipid contents are summarized by sampling area in Table 4.1 below.

Table 4.1 Average Lipid Normalized PCB Concentrations in Fish and Shellfish Collected from Hopedale Harbour and Reference Sites Between 2010 and 2012.

Species	Tissue	Sample Size*	Average (SD) (µg PCB / g lipid)
Inner Hopedale Harbour			
Rock Cod	Whole	19	70.224 (56.126)
Rock Cod	Muscle	10	48.335 (36.504)
Rock Cod	Liver	3	70.896 (22.879)
Rock Cod	Pitsik	8	153.148 (117.074)
Rock Cod	Siva	2	75.917 (28.166)
Sculpin	Whole	7	15.820 (26.998)
Sculpin	Muscle	10	34.534 (27.646)
Sculpin	Liver	2	46.083 (30.288)
Flatfish	Muscle	5	26.442 (16.315)
Flatfish	Liver	1	54.000 (NA)
Clams	Soft tissue	11	10.655 (13.273)
Winkles	Soft tissue	3	49.765 (72.398)
Sea Urchin	Soft tissue	3	3.745 (3.042)
Mussels	Soft tissue	6	0.117 (0.054)
Outer Hopedale Harbour			
Rock Cod	Muscle	10	50.686 (56.775)
Rock Cod	Liver	3	50.284 (28.568)
Rock Cod	Pitsik	5	1.508 (1.270)
Sculpin	Muscle	7	10.337 (10.070)
Sculpin	Liver	3	5.118 (1.464)
Reference Sites			
Rock Cod	Muscle	19	8.649 (2.523)
Rock Cod	Liver	6	0.363 (0.108)

Species	Tissue	Sample Size*	Average (SD) (µg PCB / g lipid)
Rock Cod	Siva	2	0.578 (0.217)
Sculpin	Whole	6	11.505 (20.081)
Sculpin	Muscle	19	4.806 (1.935)
Sculpin	Liver	6	1.194 (0.243)
Flatfish	Muscle	2	18.182 (24.427)
Clams	Soft tissue	1	0.004 (NA)
Salmon	Liver	8	0.531 (0.223)
Salmon	Muscle	8	0.531 (0.492)
Mussels	Soft tissue	2	0.009 (0.009)
Note: * Sample size refers to the number of individual organisms			

Several things are of note regarding these results:

1. Rock Cod are the most affected species by the PCB contamination.
2. The liver and its food derivatives show the highest concentrations due to their high lipid content.
3. PCB concentrations in species collected decreases with distance from the inner Hopedale Harbour and reference sites are much lower than the inner harbour values.
4. Filter-feeding mussels and clams show lower concentrations than the other species pointing to the sediment as the PCB source, and pointing to little sediment re-suspension.

Human health implications in reference to the PCB concentrations will be evaluated by Stantec and reported under separate cover

4.1 Relationships with Sediment PCB Concentrations

As noted in sections 3.1 to 3.3, PCB in sediment concentrations, like the ones in the tissues of the species collected, decrease between the inner harbour, outer harbour and coastal area. Indeed, the muscle and liver tissues of rock cod, sculpin, flatfish and winkles appear to be at equilibrium with the measured surface sediment concentrations around 50 ppm, indicating that these species appear to be resident in the harbour. Based on equilibrium partitioning theory and using lipid and organic carbon normalized values, the biota-sediment accumulation factors (BSAF) for PCBs should be in the range of 1 to 2 (Iannuzzi et al. 2011). The measured values for biota collected in the inner harbour ranged from 0.003 (mussels) to 3.4 (rock cod *Pitsik*) and had a mean value of 1.05 when compared to the average carbon normalized sediment PCB concentration. For the outer harbour, the BSAF values ranged from 0.08 (rock cod *Pitsik*) to 3.87 (rock cod muscle) with an average value of 1.79.

5.0 STABILITY OF PCB IN HARBOUR SEDIMENTS

5.1 Oceanography of Hopedale Harbour

Field measurements to provide a detailed bathymetric description and water circulation information for Hopedale Harbour were carried out by NATECH between August 29 and September 2, 2012. In addition, a literature survey was carried out to review the changing oceanographic conditions that can occur in the fall, winter and spring along the Labrador coast (see NATECH, 2013 for details).

The observed currents in the inner harbour were variable and did not correlate with tidal stages, mostly likely due to the variable winds, but also because of the presence of eddies created by the irregular shape of the shoreline. Strong steady winds (30-40 km/h), like those recorded during part of the sampling period, seemed sufficient to set up corresponding down-welling and up-welling conditions along the coast. In general, stronger, but not necessarily directionally consistent bottom currents were noted in the inner harbour with the initiation of the flood tide.

During the rising tide, the incoming tidal waters flow from the north into the harbour, with faster currents near the surface. The major portion of this coastal tidal flow, however, passes by the mouth of the harbour inside of Ellen Island, and continues toward the south, with the stronger currents tending to be close to the bottom, possibly as a result of down-welling due to the winds. Stronger currents around the inshore edge of Ellen Island were very noticeable, particularly around low tide.

During the falling tide, the water from the harbour drains toward the north-east, and merges with a larger current coming from the south. Some eddy formation was observed as both flood and ebb tides cross the outer sill of the harbour.

Observed current velocities ranged between 2 and 4 cm/s in the inner harbour, and between 6 and 8 cm/s over the sill between the inner and the outer harbour. Velocities over 30 cm/s were observed in the large channel between the harbour and Ellen Island during the rising tide. Flow at 2 and 5 m depths were usually in the same general direction throughout the area. The stronger currents, up-welling and down-welling patterns over the sill in the outer harbour and close to Ellen Island, prevented strong stratification in those areas, even in summer. Given the slow current in the inner harbour, tidal mixing seemed limited, setting up a somewhat stratified water column, with water temperatures ranging from 5 to 12 °C. Dense cold water seemed to be trapped at the bottom of the two deep (20 m) basins in the inner harbour during this observation period, creating stagnant or semi-stagnant conditions inside the sill, a condition that would limit sediment transport.

It should be noted that the data described herein came from a one week period in late August/ early September of 2012. As such, some of the water characteristics and dynamics may neither be typical for this time a year, nor representative of other seasons. The literature review carried out by NATECH to address this issue indicated that in coastal embayments such as Hopedale Harbour, warmer surface waters as seen in 2012 may be encountered during summer months, but that, most of the time, surface waters (to 10 m depth) are typically around 0°C during the summer and fall. In addition, seasonal and long-term data suggest that, at certain times of the year, colder, denser water may enter the inner harbour over the sill via internal waves or densimetric flushing during large amplitude tides, and sink to the bottom of the deeper inner harbour basins (even though neither of these phenomena were observed in September of 2012). Depending on the strength and frequency of such events, they could potentially disturb the sediments in the inner harbour, or further isolate them from the rest of the water mass.

5.2 Indications from Sediment Cores

As noted in Section 3, the main areas of contamination beyond the hotspots near the wharf were found in deeper (net depositional) sections of the harbour. These locations are all more likely to accumulate sediments and contaminants due to slower currents and/or less mixing due to depth. As a result, and in part also due to the history of human waste disposal in the area, sediments in the inner harbour appeared darker and more organic in nature compared to sediments in the outer harbour (see NATECH, 2013 for details), confirming a generally depositional character of the deeper portions of the inner harbour.

PCB concentrations were lower at the sill and along the edge of the outer harbour and coast because fine or organic sediments are less likely to settle or accumulate there due to erosion from the faster current velocities. Indeed, very little or no sediment could be obtained from some of the sill locations, where the bottom appeared to be rocky.

Overall, the finest sediments were located near the shoreline in the inner harbour and within the most southerly embayment south of the airstrip (silt with sand). Sediments in the outer harbour were slightly coarser (silty sand) and sediments in the channel west of Ellen Island contained the highest percentage of coarse material (silty sand with gravel; see Stantec, 2014a for details)

Concerning the origin and longevity of PCBs found in the sediments and biota, laboratory analysis confirmed that PCBs were generally characterized as Aroclor 1260, the type typically used in transformers in North America between the 1950s and 1970s. The two duplicate core samples collected in 2011 and submitted to LANSET at the University of Ottawa for radiometric lead-210 dating confirmed that the PCBs in the harbour date back to approximately 1950 (although sediment mixing and bioturbation could push PCBs into 'older' sediments), with peak deposition in marine sediments between the 1950 and the mid-1980s, the latter coinciding with the time when most of the remaining aboveground structures were demolished and buried in several locations around Hopedale. Figure 5.2 below shows PCB concentration profile and lead-210 dating results for sampling conducted by LANSET (see Stantec, 2012 for details). The core profiles suggest that bioturbation and other processes will continue to mix PCBs in the sediments so that burial of the contaminated sediments by new clean sediment will take a long time (decades or longer).

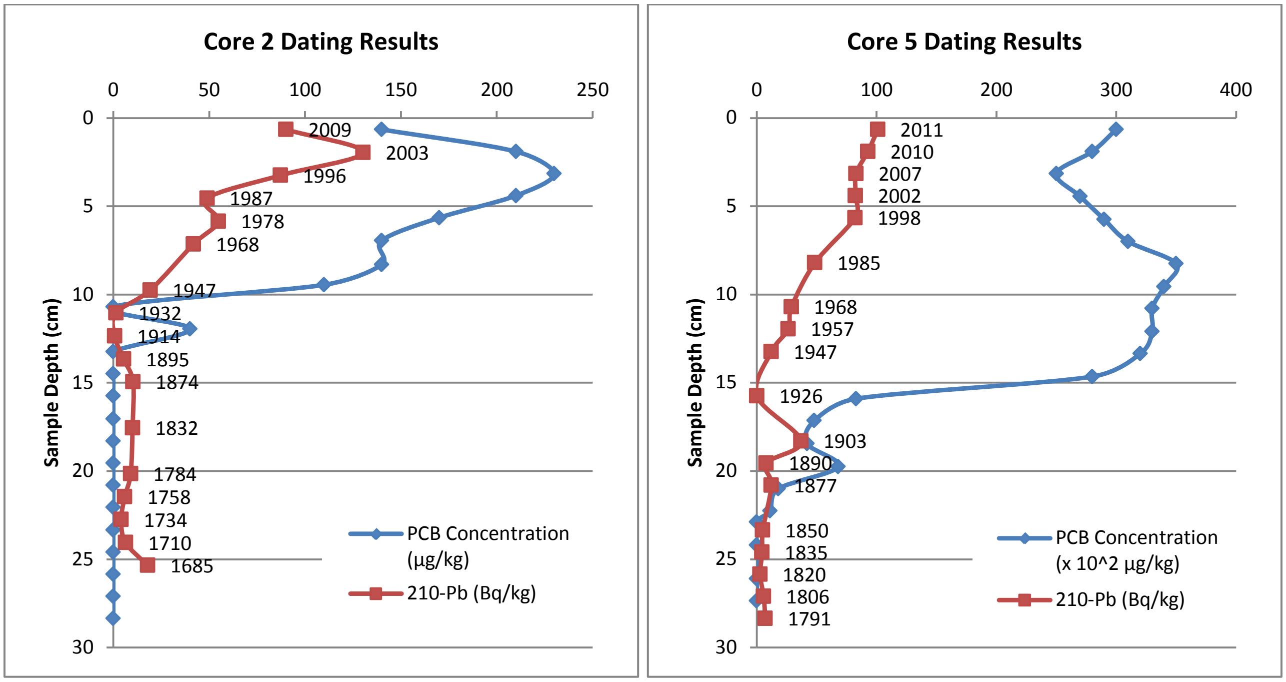

Figure 5-1 Core Dating Results

5.3 PCB Transport Measurements at the Sill

Fifty water column samples were collected in September 2013 along the sill separating the inner from the outer harbour during rising and falling tides to measure total suspended solids (TSS), and volatile suspended solids (VSS). The five samples containing the highest TSS concentrations were also submitted for PCB analysis (see Stantec, 2014a for details).

TSS concentrations ranged from 1 to 13 ppm, and non-detect to 13 ppm during rising and falling tide, respectively, but averaged 3.2 (SD 2.6) ppm, and did not correlate with depth. VSS concentrations ranged from non-detect to 5.2 ppm, averaged 1.8 (SD 1.1) ppm, and also showed no correlation with depth.

All samples submitted for PCB analysis were below the 0.05 ppb detection limit.

Based on these data, we conclude that, during the observation period, there was very little net transport of sediment or PCBs from the inner harbour across the sill to the outer harbour.

5.4 Sediment Transport Model Results

To assess the sediment transport dynamics in Hopedale Harbour using tidal and wind conditions, and provide an estimate of the annual sediment transport out of Hopedale Harbour, a hydrodynamic and sediment transport model was built and parameterized with the appropriate and available field data collected between 2011 and 2013 (see Stantec, 2014c for details). The model simulation covered the period of July 12, 2012 to July 20, 2012, selected to represent typical neap tide, average tide and spring tide conditions. The annual sediment load leaving from Hopedale Harbour was estimated by extrapolating the sediment load for spring, neap and average tidal conditions from this period to the rest of the year.

Modeled currents showed the same confused flow in the inner harbour as the field measurements, increased current speeds over the sill, and the majority of the water masses and strongest currents passing along the outer coast, on both sides of Ellen Island.

Taking into account the spatial distribution of sediment types across the inner and outer harbour, (refer to Figure 3.3 in Stantec, 2014c), and assuming three different particle size scenarios (fine, medium, and coarse), the model estimated an annual sediment transport across the sill out of the inner harbour between 44,057 and 72,317 kg, with a middle estimate of 69,430 kg. Across the boundary between the outer harbour and the outer coast, the model estimated a sediment flux between 700,482 and 1,811,260 kg, with a middle estimate of 1,566,356 kg. According to the model, most of this transport across both boundaries is composed of silt, and occurs during spring tide conditions.

It should be noted that the model tended to over-estimate total suspended sediment concentrations across most of the model domain, and makes a series of other assumptions that would tend to overestimate transport. As a result the above estimates should be considered maxima.

Taking the median (0.31 ppm) and maximum (2.6 ppm) PCB concentrations from inner harbour sediments, and applying the middle annual sediment transport estimate over the sill (69,430 kg), we estimate that between 22 and 181 g of PCBs would be leaving the Inner harbour via tidal flow. Between the outer harbour and the outer coast, applying the middle annual sediment transport estimate between these regions (1,566,356 kg), the equivalent PCB flux (using median and maximum outer harbour sediment concentrations of 0.06 and 1 ppm, respectively) is estimated to be between 94 and 1,566 g.

In conclusion, only small amounts of PCBs are leaving the harbour each year (probably less than 100 g/year), suggesting that PCB concentrations in the sediment are likely stable and should not be expected to change as a result of natural processes.

6.0 OUTLOOK FOR FUTURE CONDITIONS IN HOPEDALE HARBOUR

6.1 Geographic Scope

The problem of PCB contamination in the marine environment around the community of Hopedale is restricted to sediments, fish and deposit feeding invertebrates in the inner harbour and to some fish in the outer harbour. Deposit feeders are animals that live on the ocean floor and feed on the thin layer of organic matter that sits right at the surface of the ocean floor. This layer of organic matter is sometimes also called detritus, and consists of bacteria, and remnants of algae and decaying animals. Based upon the measured BSAF values, fish in the outer harbour may have acquired most of their contamination while resident in the inner harbour. The sediment PCB hotspots are close to the main wharf in the inner harbour, and at one deep water location in the outer harbour.

There is little physical export of PCBs from the harbour, and if PCBs do leave, they are expected to be swept away from this system by the strong currents that flow along shore around Ellen Island. In this regard, the fate and consequence of PCBs exported from Hopedale Harbour appears to be similar to the fate of PCBs eroded with near-shore sediments at Saglek (Brown et al. 2009), although the rate of removal of PCB contaminated sediments at Hopedale is not sufficient to effect natural remediation within a short period of time, as was the case at Saglek.

Selected reference sites located within easy reach of the community indicate clean sediments and biota with no evidence for meaningful physical or biological export of PCBs to surrounding areas. The impact and remediation problem is thus local to the inner part of Hopedale Harbour.

6.1.1 PCB Input from Land

The only documented influx of PCBs from land is through the stream, and is estimated to be below 36 g/year, with the mostly likely values below 24 g. Given the remediation efforts to date, these flux estimates are likely decreasing. Due to the spatial pattern of PCB concentrations in the sediments, and a low influx rate of under 36 g per year, there is no indication that the stream is currently a significant source of PCBs to the marine environment. Although of potential significance to the freshwater systems, further remediation on land will not significantly change the distribution or concentrations of PCBs currently present in the harbour.

6.1.2 PCB Concentrations in Marine Sediment

The transport of sediment out of the inner harbour through tidal flushing appears small (22-181 g/year). With a PCB inventory of 6.8 kg in the inner harbour, it would take 37-311 years for this amount to be removed through tidal currents. Considering the likely stream input of 24 g/year or less, the system is close to a steady state. In addition, bioturbation of sediments as inferred from the sediment core PCB and lead-210 profiles will continue to refresh the PCB concentration of surface sediments and retard net burial of contaminated sediments. As a result, little to no anticipated change in sediment PCB concentrations in the inner harbour is expected due to natural processes on a time scale of decades.

6.1.3 PCB Concentrations in Fish and Shellfish

PCB concentrations in fish and deposit feeding shellfish in the inner harbour are elevated, and for several of the main country food species (e.g., rock cod, winkles) appear to be in equilibrium with sediment concentrations. Given that no short-term increase and little or no long-term decrease in sediment PCB concentrations is anticipated, no meaningful changes in tissue PCB concentrations of resident species are expected.

7.0 CONCLUSIONS

PCB concentrations in sediment and biota in the inner harbour are currently high but stable, and natural processes such as burial or erosion of contaminated sediments are not likely to cause this to change substantially in the foreseeable future.

As communicated to the public in 2012, fish and deposit feeding invertebrates from the inner harbour should not be consumed by humans.

8.0 CLOSURE

This report documents work that was performed in accordance with generally accepted professional standards at the time and location in which the services were provided. No other representations, warranties or guarantees are made concerning the accuracy or completeness of the data or conclusions contained within this report, including no assurance that this work has uncovered all potential liabilities associated with the identified property.

This report provides an evaluation of selected environmental conditions associated with the identified portion of the property that was assessed at the time the work was conducted and is based on information obtained by and/or provided to Stantec at that time. There are no assurances regarding the accuracy and completeness of this information. All information received from the client or third parties in the preparation of this report has been assumed by Stantec to be correct. Stantec assumes no responsibility for any deficiency or inaccuracy in information received from others.

The opinions in this report can only be relied upon as they relate to the condition of the portion of the identified property that was assessed at the time the work was conducted. Activities at the property subsequent to Stantec's assessment may have significantly altered the property's condition. Stantec cannot comment on other areas of the property that were not assessed.

Conclusions made within this report consist of Stantec's professional opinion as of the time of the writing of this report, and are based solely on the scope of work described in the report, the limited data available and the results of the work. They are not a certification of the property's environmental condition. This report should not be construed as legal advice.

This report has been prepared for the exclusive use of the client identified herein and any use by any third party is prohibited. Stantec assumes no responsibility for losses, damages, liabilities or claims, howsoever arising, from third party use of this report.

The locations of any utilities, buildings and structures, and property boundaries illustrated in or described within this report, if any, including pole lines, conduits, water mains, sewers and other surface or sub-surface utilities and structures are not guaranteed. Before starting work, the exact location of all such utilities and structures should be confirmed and Stantec assumes no liability for damage to them.

The conclusions are based on the site conditions encountered by Stantec at the time the work was performed at the specific testing and/or sampling locations, and conditions may vary among sampling locations. Factors such as areas of potential concern identified in previous studies, site conditions (e.g., utilities) and cost may have constrained the sampling locations used in this assessment. In addition, analysis has been carried out for only a limited number of chemical parameters, and it should not be inferred that other chemical species are not present. Due to the nature of the investigation and the limited data available, Stantec does not warrant against undiscovered environmental liabilities nor that the sampling results are indicative of the condition of the entire site. As the purpose of this report is to identify site conditions which may pose an environmental risk; the identification of non-environmental risks to structures or people on the site is beyond the scope of this assessment.

Should additional information become available which differs significantly from our understanding of conditions presented in this report, Stantec specifically disclaims any responsibility to update the conclusions in this report.

This report was prepared by Francis Weise and reviewed by Jim Slade, P.Eng., P.Geo.

Respectfully Submitted

STANTEC CONSULTING LTD

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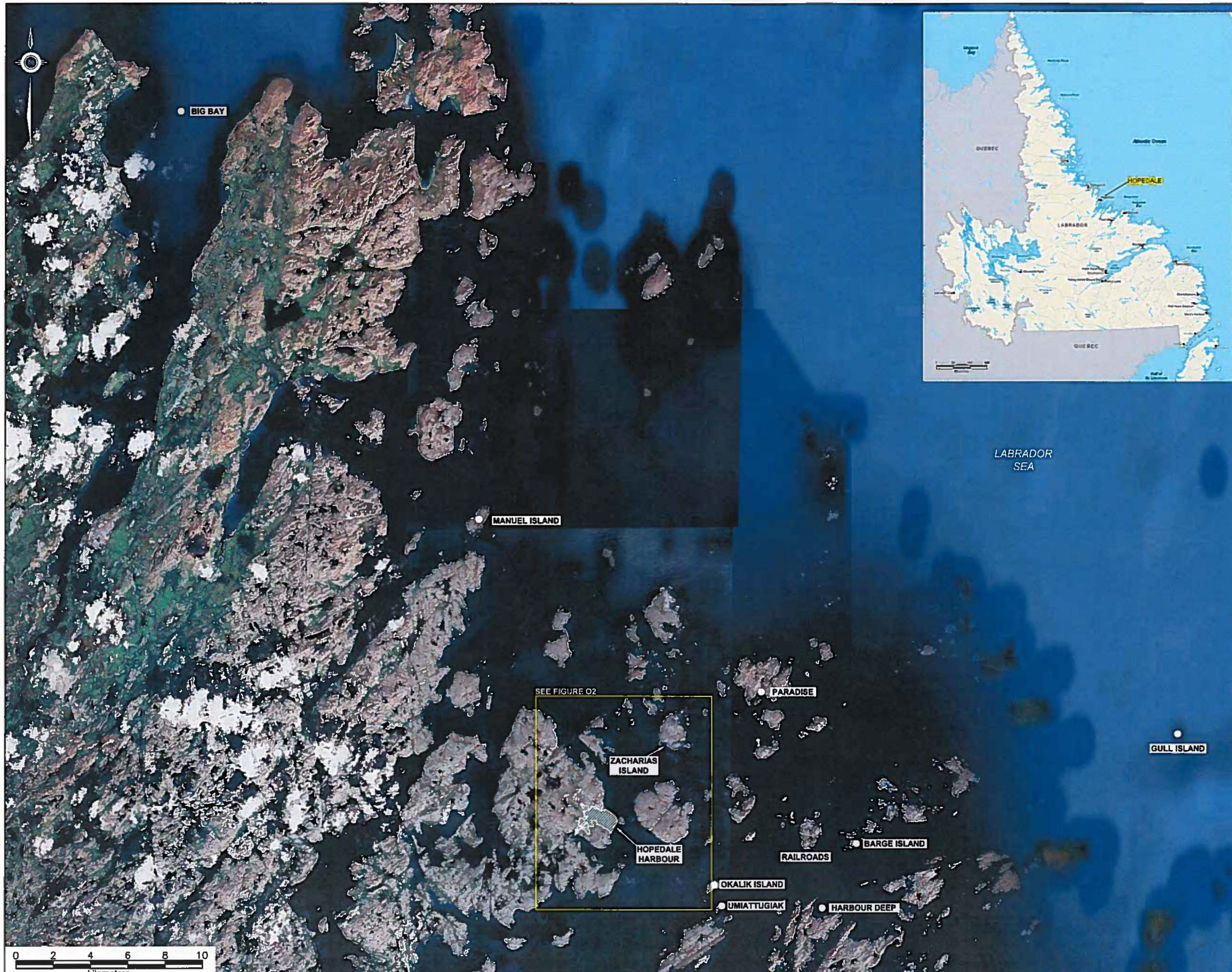
APPENDIX A

Figures



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CLIENT:

NEWFOUNDLAND AND LABRADOR
DEPARTMENT OF
ENVIRONMENT AND CONSERVATION

PROJECT TITLE:

SUMMARY REPORT ON LOADINGS, SEDIMENT INVENTORY, AND PRESENT AND FUTURE OUTLOOK FOR PCB IMPACTS IN HOPEDALE HARBOUR

DRAWING TITLE:

SITE LOCATION PLAN

Stantec Consulting Ltd.

SCALE: 1:200,000	DATE: MAY 7, 2014	REV. No. 0
DRAWN BY: N.M.	EDITED BY: -	CHECKED BY: AR
DRAWING No: FIGURE 01	CAD FILE: 121411777_610-EE-01.DWG	

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PROJECT TITLE:

SUMMARY REPORT ON LOADINGS, SEDIMENT INVENTORY, AND PRESENT AND FUTURE OUTLOOK FOR PCB IMPACTS IN HOPEDALE HARBOUR

DRAWING TITLE:

COUNTRY FOOD SAMPLE LOCATIONS

Stantec Consulting Ltd.

SCALE: 1:40,000	DATE: MAY 7, 2014	REV. No. 0
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DRAWING No: FIGURE 02	CAD FILE: 121411777_610-EE-02.DWG	

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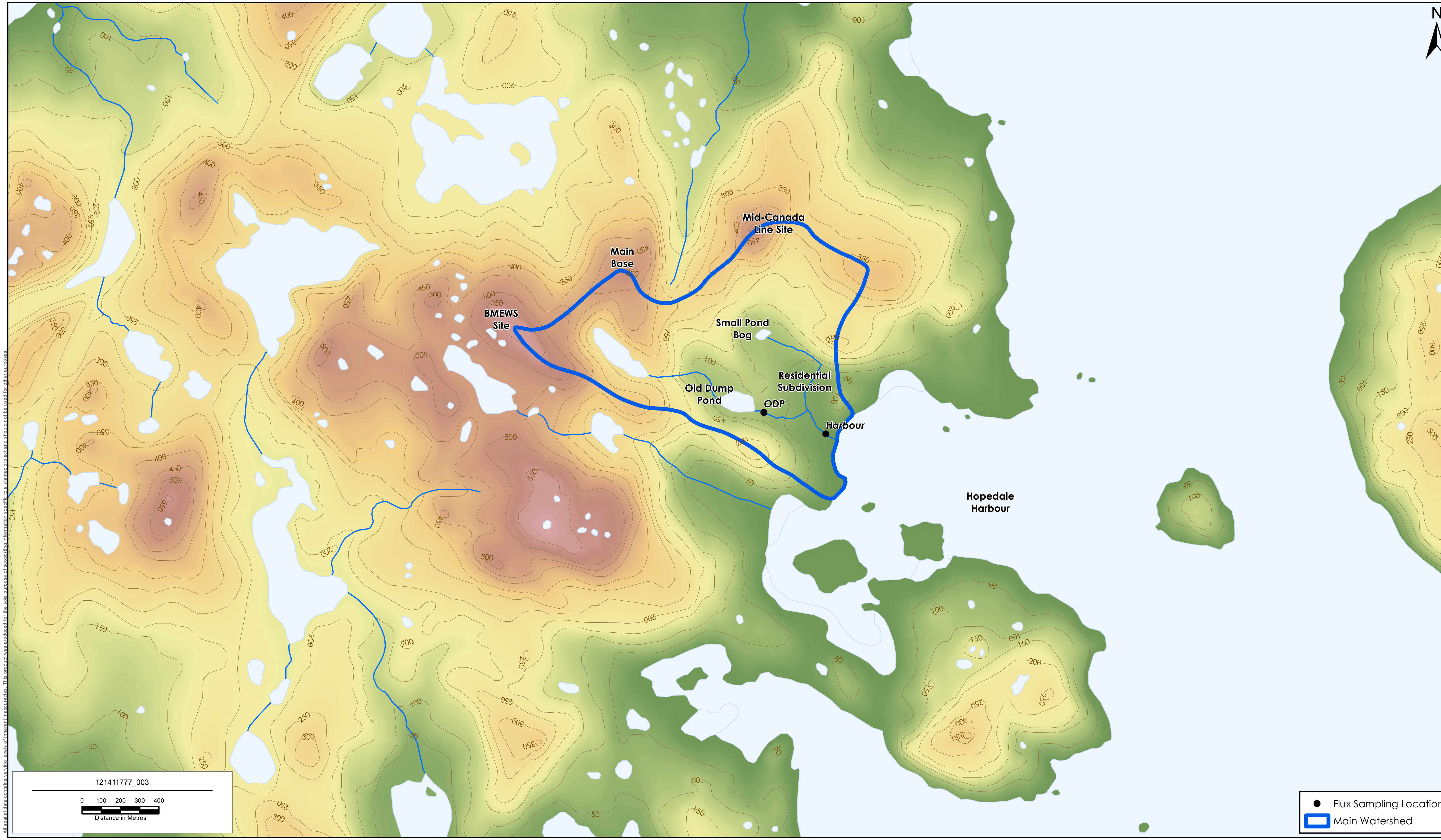

PREPARED BY: Z. Bartlett	Summary Report on Loadings, Sediment Inventory, and Present and Future Outlook for PCB Impacts in Hopedale Harbour	FIGURE NO.: 03
REVIEWED BY: H. Ward	Hopedale, NL	DATE: May 05, 2014
CLIENT: Newfoundland and Labrador Department of Environment and Conservation	**Topographic Plan Showing Main Watershed**	Stantec

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LEGEND

- GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2013)
- UNSUCCESSFUL GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2013)
- WATER SAMPLING LOCATION (STANTEC, 2013)
- GRAB SEDIMENT SAMPLE LOCATION (NATECH, 2012)
- UNSUCCESSFUL GRAB SEDIMENT SAMPLE LOCATION (NATECH, 2012)
- GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2012)
- UNSUCCESSFUL GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2012)
- GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2011)
- UNSUCCESSFUL GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2011)
- GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2010)
- GRAB SEDIMENT SAMPLE LOCATION (STANTEC, 2009)
- CORE SEDIMENT SAMPLE LOCATION (STANTEC, 2011)
- FLUX SAMPLING LOCATION (STANTEC, 2011-2012)

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PROJECT TITLE:

SUMMARY REPORT ON LOADINGS, SEDIMENT INVENTORY, AND PRESENT AND FUTURE OUTLOOK FOR PCB IMPACTS IN HOPEDALE HARBOUR

DRAWING TITLE:

HARBOUR BATHYMETRY AND SEDIMENT SAMPLE LOCATIONS

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SCALE: 1:8000	DATE: MAY 7, 2014	REV. No. 0
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DRAWING No: FIGURE 04	CAD FILE: 121411777_610-EE-04.DWG	

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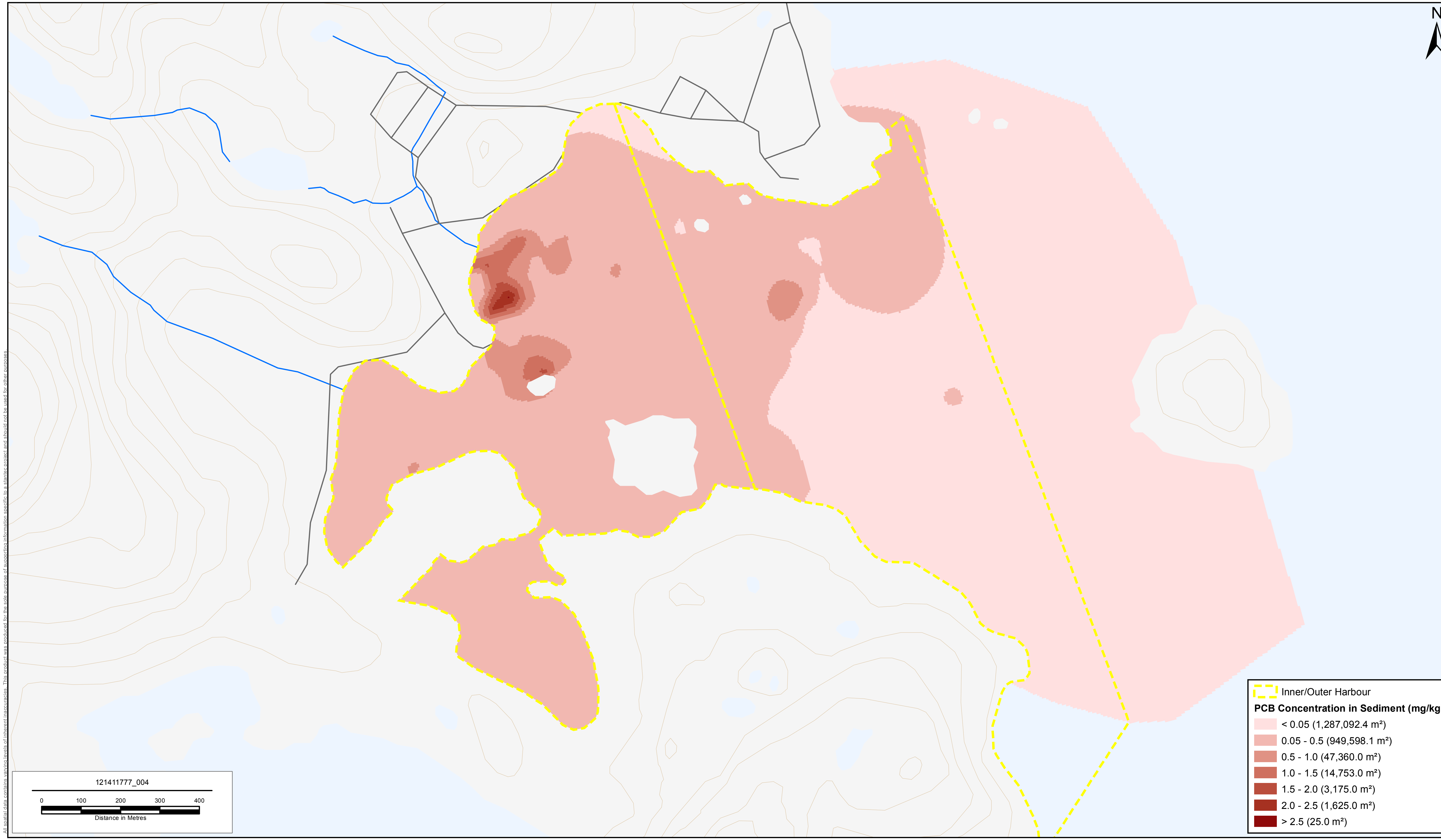
07MAY14 9:00AM



PREPARED BY: Z. Bartlett

REVIEWED BY: H. Ward

CLIENT: Newfoundland and Labrador Department of Environment and Conservation

Summary Report on Loadings, Sediment Inventory, and Present and Future Outlook for PCB Impacts in Hopedale Harbour

Hopedale, NL

PCB Concentrations - Bin Scenario 1

FIGURE NO.: 05

DATE: May 05, 2014

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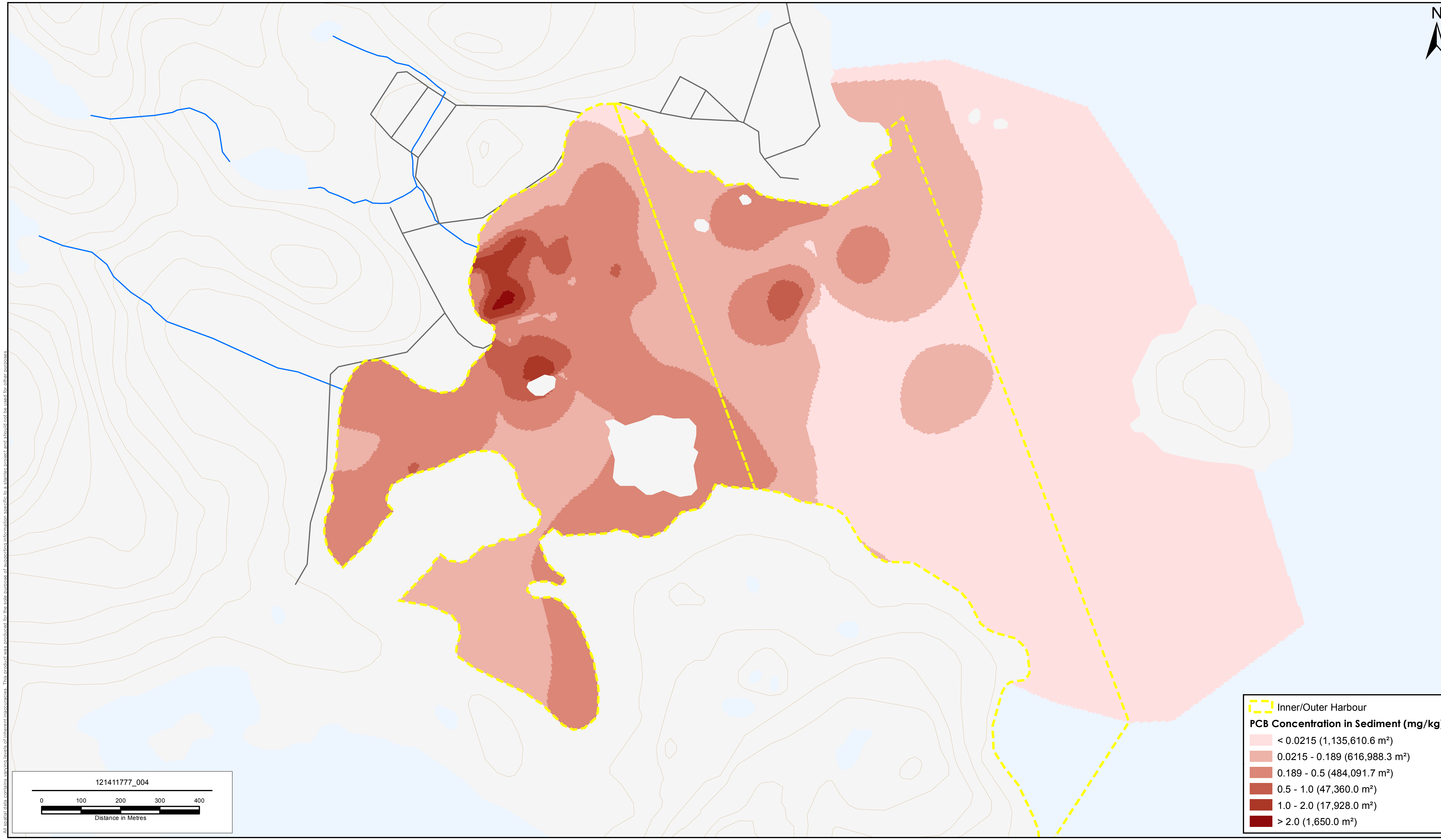

PREPARED BY: Z. Bartlett

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Summary Report on Loadings, Sediment Inventory, and Present and Future Outlook for PCB Impacts in Hopedale Harbour

Hopedale, NL

PCB Contours - Bin Scenario 2

FIGURE NO.: 06

DATE: May 05, 2014

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