APPENDIX 8C-2

UNDERWATER NOISE MODELLING FOR MILNE INLET AND ECLIPSE SOUND

JASCO APPLIED SCIENCES

Assessment of Underwater Noise for the Mary River Iron Mine

Construction and Operation of the Milne Inlet Port Facility.

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2.0	2010 Nov 15	M. Zykov	Addressed comments by C. Greene. Updated Ore carriers classes. Added bubble curtain effect section. Added results for mitigated pile driving. Added adjustment tables for vessel length and velocity
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1. Introduction

JASCO Applied Sciences has performed an acoustic modelling study of the underwater noise expected from construction and operation of the Milne Inlet Port Facility for the Mary River Iron Mine.

The Mary River Iron Mine is located on North Baffin Island, Nunavut. A dock facility will be built to the north of the mine in Milne Inlet for seasonal shipping operations of the iron ore with large ore-carriers. The proposed shipping route is from Milne Inlet, through the Eclipse sound, Pond Inlet, and into the Baffin Bay. The operating period of the port will be limited by the open water season, which occurs from mid-August to mid-October in this region.

The construction of the freight dock will require deepening of the sea bottom. The bottom of Milne Inlet is represented by granitic gneiss with thin cover of coarse sediments. The sediment dredging will be performed using cutter-suction. For the construction of ore-loading dock facility pile driving will be needed. The piles will be installed near the shore in 2–3 meters of water.

The operation of the port facility will involve tug maneuvers in the vicinity of the port (ore-carriers assisted docking) and ore-carriers passing along the shipping route. Tugs with 50 tonne bollard pull are expected to be used. The ore carriers of two classes will be involved in shipping: Panamax-class with 70,000 DWT and Post-Panamax carrier with 90,000 DWT. The ore carriers were modelled at four locations along the shipping route. The tug was modelled at two locations: one in the vicinity of the port, the other at one of the locations along the shipping route (Pond Inlet) at which the ore carriers were also modelled.

The modelling of the construction and shipping operations was performed for one season. The sound speed profile for the month of August was used in the environment model.

The modelling was performed for an extended frequency range — 10–20,000 Hz. The source levels for each of the modelled noise sources were estimated based on an extensive literature review as well as JASCO's own source level database.

The results of the modelling are presented in different forms suitable for further noise impact assessment. For each modelling scenario the following output produced:

- Areal map of Sound Pressure Level (SPL) field distribution contoured with 10 dB step (based on 10 Hz – 2000 Hz frequency range)
- Tables of threshold distances to the broadband levels, calculated based on flat-weighted as well as M-weighted (4 different curves) result (based on 10 Hz – 2000 Hz frequency range)
- Tables of estimated maximum sound levels at specified distances for 1/3 octave band central frequency from 10 Hz to 20,000 Hz. The tables are presented in a separate Excel spread sheet document.

2. Source Levels

2.1. Pile driving

2.1.1. Source levels

The pile driving operation for the Milne Inlet port construction is to take place at the ore dock site. Standard sheet piles 7–8 m long are expected to be used for creating a perimeter that will be filled with rocks. The water depth at the pile driving location is approximately 2–3 m. The details of the pile driving technique (vibratory or impact) have not been determined and hence were not available for this evaluation.

With the increase of interest in the noise effects during construction operations, a number of datasets for received levels measurements became available in recent years (ex. Illingworth & Rodkin, 2010, Racca et al., 2007, MacGillivray et al., 2006, Washington State Department of Transportation (WSDT), 2004). The measurements were conducted for various types of piles (steel sheet, steel pipe, concrete, etc.) and sizes using different machinery (vibratory or impact pile drivers).

Table 1 presents broad band received levels for the impact pile driving operation as measured at different constructions sites. Most of the data for the table were taken from ICF Jones & Stokes and Illingworth & Rodkin (2009). The report summarizes data from many technical reports. The data were provided in form of broadband received levels with indication of the distance from the source. The source levels were calculated by back-propagating to 1 m assuming spherical spreading law ($20 \cdot \log R$). The received level from Blackwell (2005) were back-propagated assuming spherical spreading law ($20 \cdot \log R$) for the first 20 m from the source and cylindrical spreading law ($10 \cdot \log R$) for the rest of the distance.

The table shows distinct correlation of the broadband source levels with the size of the pile. The received levels at the same distance are higher for a larger pile as higher impact energy is required to drive the pile into the ground.

Spectrum composition of a typical pulse (Figure 1) from Blackwell (2005, Figure 12a) was used as the starting point for the estimation of the pile driving source levels for the Milne Inlet construction project. The broadband received level of the pulse reported by Blackwell (2005) was 189.3 dB re µPa and after back-propagation, the source level was estimated at 220.2 dB re µPa @ 1 m. It was assumed that the source level for the pile driving operation at Milne inlet construction site would be similar to the source level of a 24 in AZ steel sheet pile (209 dB re µPa @ 1 m) (Table 1). The spectrum by Blackwell was adjusted accordingly to provide the assumed spectrum for the pile driving operation (Figure 1). Furthermore, it was assumed that lower frequencies (less than 63 Hz) were attenuated at higher rates. In order to account for this fact, all 1/3 octave bands below 63 Hz were assumed to have constant level equal to the one for the 63 Hz band (182.0 dB re µPa @ 1 m).

The assumed spectrum should be considered as a worst case scenario. There are several ways to reduce the acoustic energy emission into the water during the pile driving operation.

First, the use of a vibratory pile driver can lead to reduction of up to 25 dB in broad band source level for the same pile. Examination of the data provided in ICF Jones & Stokes and Illingworth & Rodkin (2009) reveals that typical reduction of the source levels with the substitution of the impact driver by a vibratory driver is 10–20 dB.

Second, various mitigation techniques can be used such as air bubble curtains, isolation casings, and cushion blocks. Air bubble curtains can provide an attenuation factor as high as 30 dB, however in general the reduction is about 5 dB for piles less than 14 inch in size (ICF Jones & Stokes and Illingworth & Rodkin, 2009). The air bubble curtains are most effective in reducing the acoustic energy in the frequency range between 100 Hz and 8000 Hz.

Table 1. Broad band received levels from various measurements of impact pile driving operation.

pile type	size	water depth [m]	energy [kJ]	receiver distance [m]	received level [dB re µPa]	source level [dB re µPa @ 1 m]
Steel H pile[1]	10 in	2		10	175 (rms)	195
Steel pipe[1]	12 in	1–2		10	177 (rms)	197
Steel H pile[1]	15 in	2–3		10	180 (rms)	200
Steel pipe[1]	20 in	3–4		10	187 (rms)	207
AZ steel sheet[1]	24 in	15		5	195 (rms)	209
Steel pipe[2]	36 in	10–17	223	62	189.3 (rms)	220.2
CISS steel pipe[1]	156 in	15	358	10	206 (rms)	226

[1] ICF Jones & Stokes and Illingworth & Rodkin (2009)
[2] Blackwell (2005)

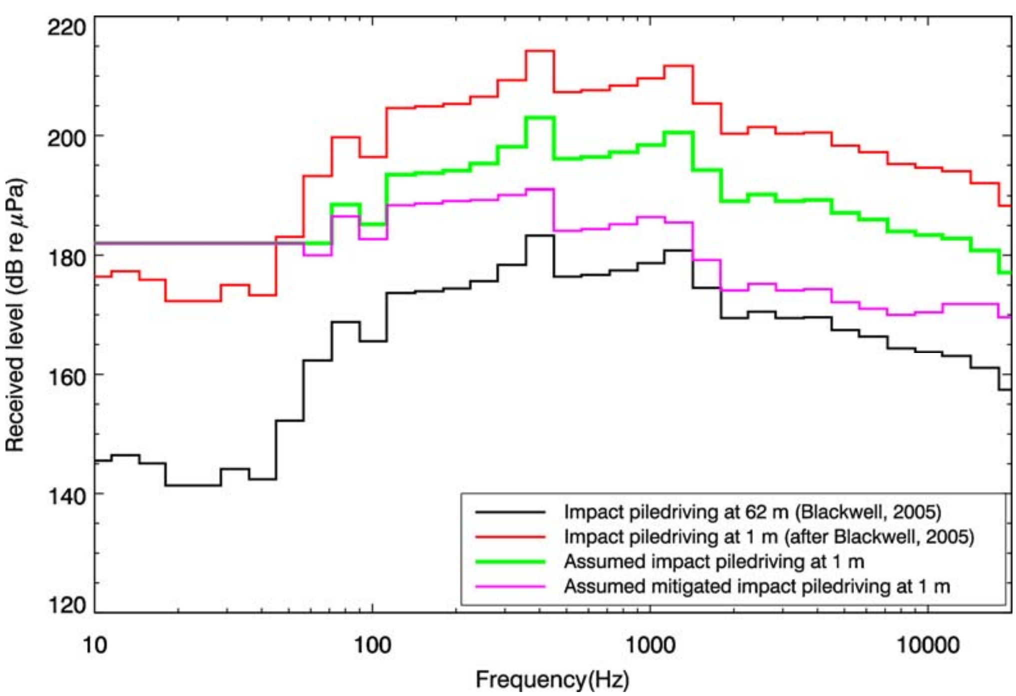

Figure 1. Received levels of measured pile driving pulse and assumed source levels for Milne Inlet construction project.

2.1.2. Effect of mitigations techniques

As it was mentioned in the previous section, various mitigation techniques can be utilized in order to reduce the acoustic energy emitted from the pile driving site. An air bubble curtain and isolation casing are examples of practical noise suppression measures.

In recent years a great number of controlled and uncontrolled experiments had been conducted in order to quantify the effectiveness of bubble curtains. During a controlled experiment acoustic energy was measured with the bubble curtain on and off while all other variables, such as the pile, the driving energy, the distance to the receiver, and the like, were kept as steady as possible (ex. Matuschek & Betke, 2009). The reported numbers for the acoustic energy reduction from several papers are presented in Figure 2.

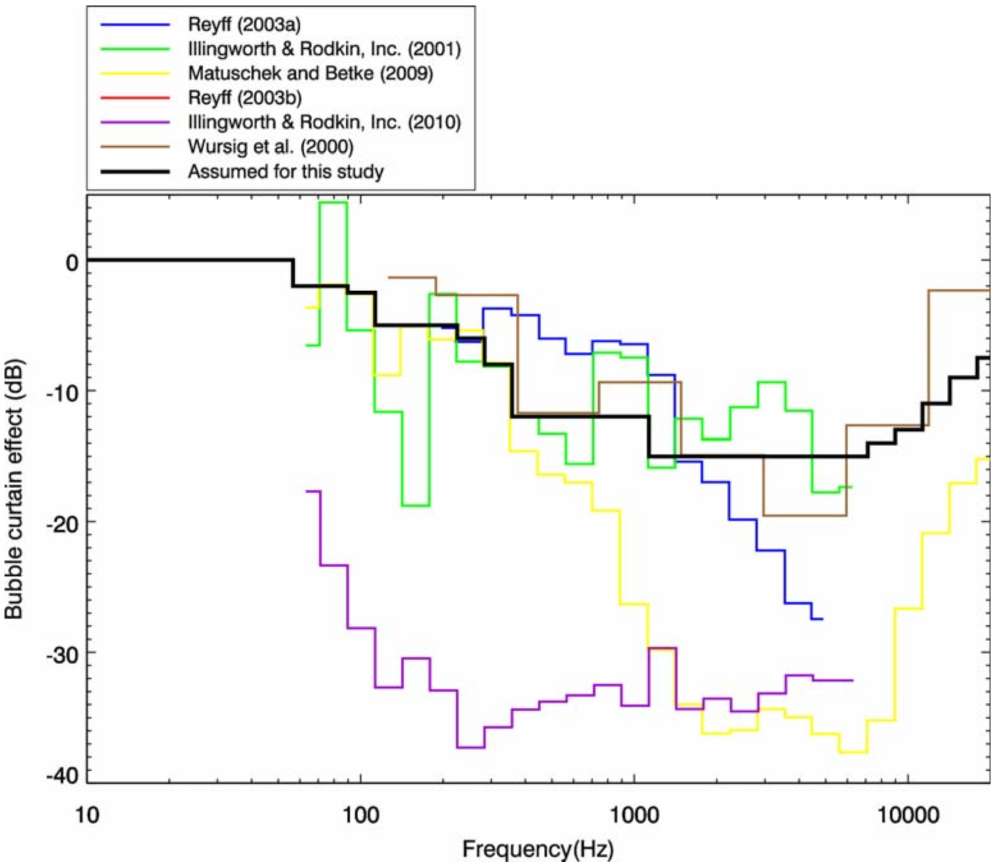

Figure 2. Bubble curtain effect in 1/3 octave bands observed during various studies and assumed effect for this study.

As shown on the graph (Figure 2) the apparent effect of a bubble curtain can vary drastically from 0 dB to -38 dB. Such spread in the numbers may be explained by the differences in the pile driving specifications, measurement techniques, and the environment, e.g. pile driving energy, air blow rate, bubble curtain type, distance to the source, water depth, ambient noise. Despite these differences, it is clear that a bubble curtain is very effective in reducing the energy over the frequency range from 100 Hz to 8000 Hz.

The presented bubble curtain effect curves were analyzed and an assumed curve was created by applying subjective averaging to the data. The conservative approach was utilized by giving the lower values greater weight. The assumed curve is presented in thick black line in Figure 2.

In order to model the acoustic impact of mitigated pile driving operation, the assumed reduction values were subtracted from the levels of unmitigated pile driving source (Figure 1).

2.2. Dredging

The dredging phase is scheduled to occur during the open water season, using suction dredges with cutter head.

Suction dredges utilize a wide pipe (up to 1 m in diameter) and a high power pump to suck water and loose material from the bottom into a hopper or directly to a discharge location. Often a cutter head is used to help with loosing up the sediments. The intake pipe with the cutter head can be steered by winches or thrusters. The dredge vessel itself can be moved by main thrusters or winches. Cutter-suction dredges operate in more or less continuous mode. The noise sources for the cutter suction dredge include the power plant, the suction pump, the cutter head, and the cutter head thrusters. The noisiest suction dredges are those which use thrusters to steer the intake pipe (Figure 3).

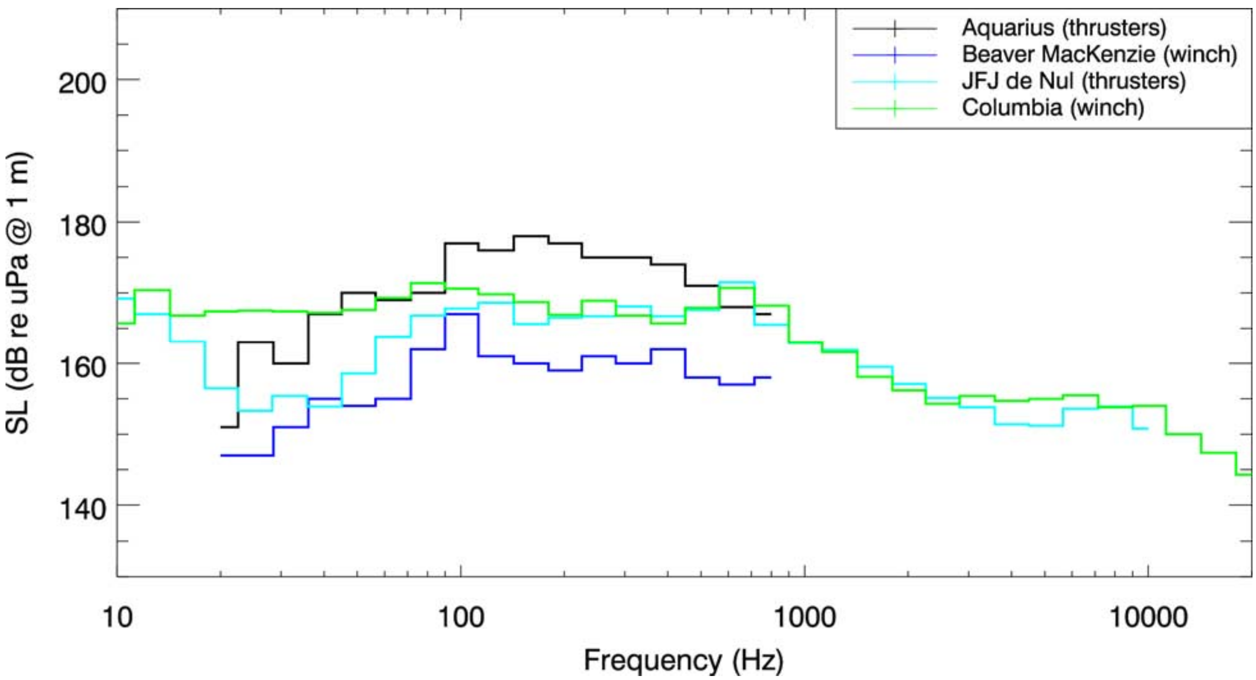

Figure 3. Estimated source levels for cutter-suctions dredges with winch and thruster steering mechanisms. *Aquarius* – thrusters, *Beaver Mackenzie* – winch (Malme et al., 1989); *JFJ de Nul* – thrusters (Hannay et al., 2007); *Columbia* – winch (Zykov et al., 2007).

In order to produce conservative estimates of the source levels produced by dredging operations in Milne Inlet, the maximum levels were extracted from the four spectra presented on Figure 3. The vertical position of the source is assumed to be 1 m above the sea floor.

Where the available data did not provide the source levels for higher frequencies, extrapolation was used by taking the level for the highest available band and reducing the value by 10 dB per decade (or 1 dB per 1/3 octave band) as suggested by Ross (1976). The assumed source levels to be used for modelling of the dredging operation are presented in Figure 4.

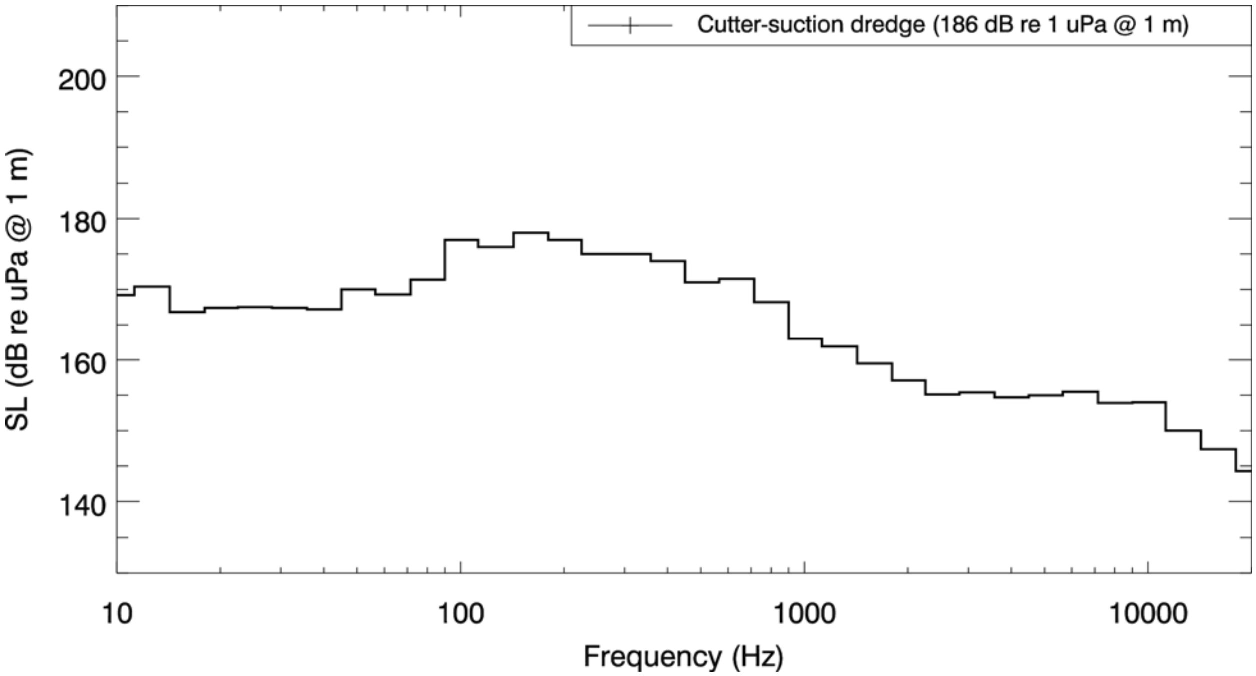

Figure 4. Assumed 1/3-octave band source levels for modelling of the dredging operation.

2.3. Tug

2010 SVITZER Canada Ltd. is expected to provide two Azimuth Stern Drive (ASD) harbour tugs with bollard pull (BP) of 50 t and two 50 t BP ASD ice class tugs in support of the Milne Inlet project.

Source level measurements from previous JASCO experiments were used to estimate the spectrum of a 50 t BP ASD tug. Table 2 presents the known specifications of the pertinent tugs recorded by JASCO, and Figure 5 presents the calculated spectra.

Table 2. Specifications comparison for the proposed Milne Inlet tug and two tugs for which source levels have been calculated from JASCO recordings (Zykov, *et al.*, 2008).

	Milne Inlet Tug	*Kuparuk River*	*Britoil 51*
Tonnage		104 DWT	605 DWT
Length		19.5 m	45 m
Beam		8.2 m	11.8 m
Draft	~ 4.15 m	1.7 m	5.5 m (max)
Main engine	2 x 4 stroke diesel engines	1095 hp diesel	2 x 3300 hp MAK diesel
Propulsion	2 x 2.1 m D, 4 bladed propeller in nozzles	3 x 1.0 m D, 5 bladed propeller on screw	- 2 x 3.2 m D, 4 bladed propeller in nozzles
Bollard pull	50 t	~ 13 t	90 t
NCR rating	2 x 3600 hp at 1500 rpm, for a vessel speed of 12 knots		
MCR rating	2 x 4900 kW at 1800 rpm, for a vessel speed of 12 knots		
Propeller rpm @ speed	280 rpm @ 12 knots		190 rpm @ 13 knots
Recorded activity		Pushing a barge	In transit / Pulling anchor
Reference		Zykov et al., 2008	Hannay et al., 2007

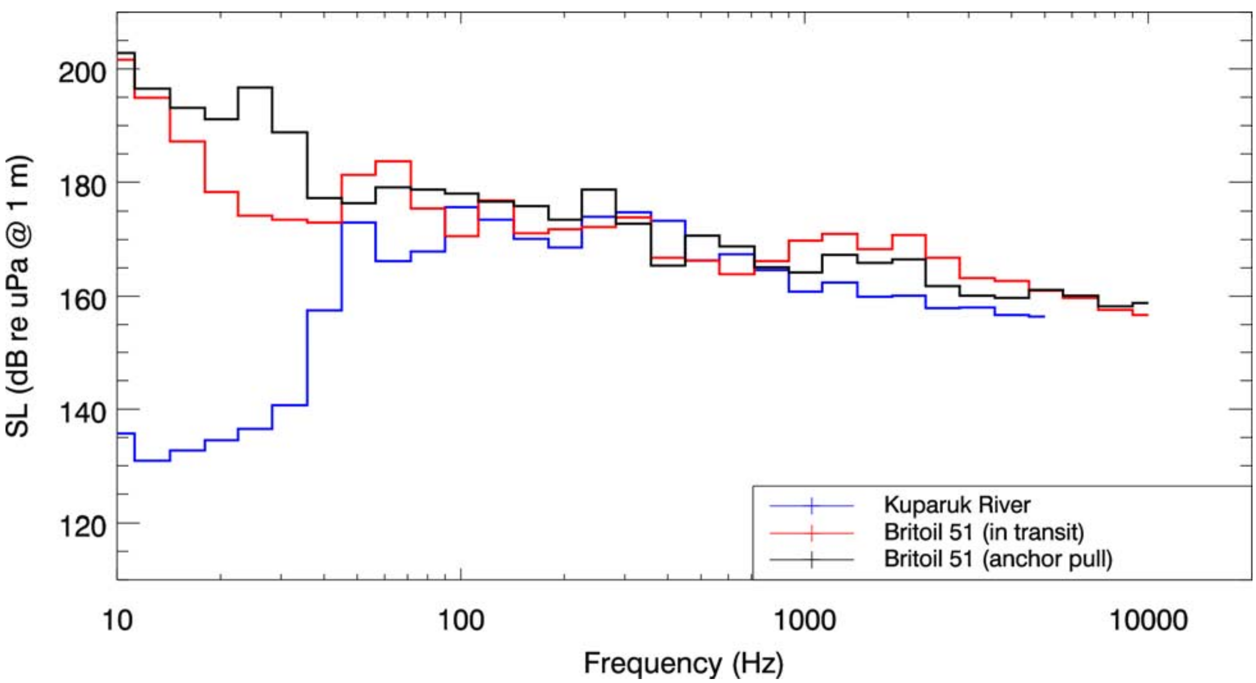

Figure 5. Third-octave band source levels for the tug *Kuparuk River* and the *Britoil 51*, calculated from JASCO recordings (Zykov et al., 2008).

Since the *Kuparuk River* was monitored in very shallow waters (8.5 m depth) the source levels at low frequencies (< 50 Hz) may be underestimated (Zykov et al., 2008). The size and the bollard pull of the *Kuparuk River* and the *Britoil 51* are different. However, the two tugs produce similar source levels (at frequencies > 50 Hz). According to the specifications, the tugs proposed for usage at the Milne Inlet port fit in between the *Kuparuk River* and the *Britoil 51* by the size and power output. Considering the facts mentioned above and in order to exercise conservative approach, the maximum values out of three presented spectra were selected in each 1/3-octave band to construct the assumed spectrum of the Milne Inlet 50 t BP ASD tug (Figure 6). The broad band source level for the tug is 203.7 dB re µPa @ 1 m.

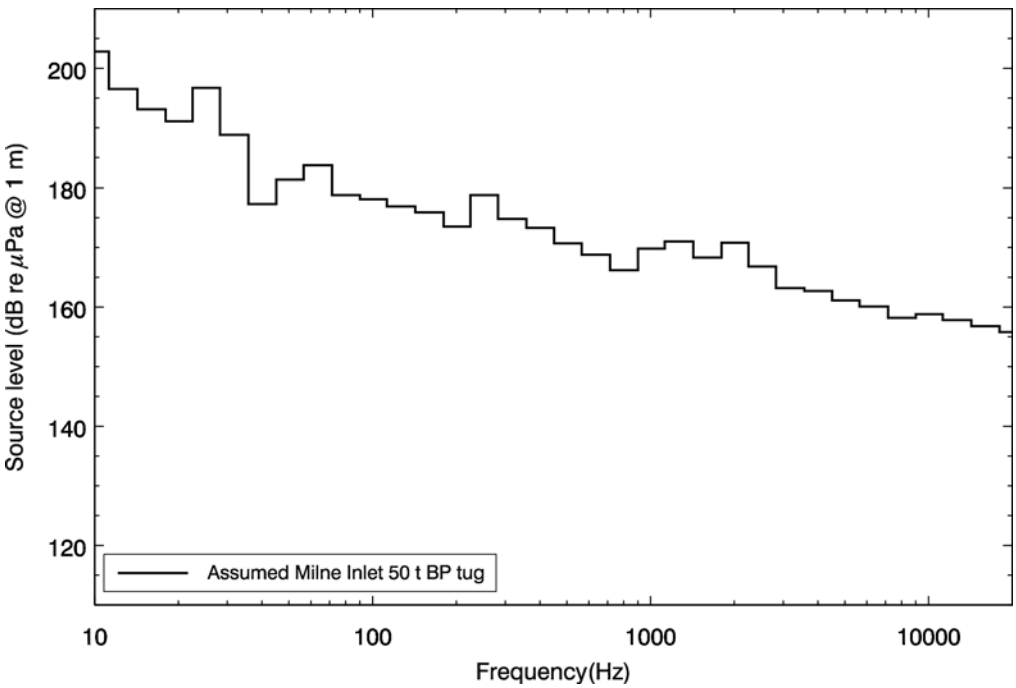

Figure 6. Assumed source level for 50 t BP tug proposed to be used at Milne Inlet port facility (broad band source level is 203.7 dB re µPa @ 1 m).

2.4. Ore Carriers

While in transit, ships emit underwater noise from their various components, including onboard machinery and propellers underwater. Noise spectra from large ships are generally dominated by propeller cavitation noise. Ross (1976) has shown that the intensity of propeller cavitation noise depends on the total number of blades, the propeller diameter, and the propeller tip speed. Based on multiple recordings of large merchant ships, he developed an equation to estimate the overall (broadband and omnidirectional) noise level of ships over 100 m in length, operating in calm open waters:

$$L = 175 + 60\log(u/25) + 10\log(B/4), \qquad (1)$$

where L is the broadband source level, u is the propeller tip speed (m/s), and B is the number of propeller blades. This equation gives the total energy produced by the propeller cavitation at frequencies between 100 Hz and 10 kHz. This equation is valid for propeller tip speed between 15 and 50 m/s (Ross, 1976).

Based on Ross' equation and the examination of recorded spectra, Scrimger and Heitmeyer (1991) and Hamson (1997) developed the following equation to provide an estimate source level spectrum for very large merchant ships:

$$SL = SV(f) + 60\log(V/12) + 20\log(Le/300), \quad (2)$$

where *V* is the vessel speed (knots), *Le* is the vessel length overall (feet), and *SV(f)* is the reference level for a merchant ship noise spectrum. The reference spectrum was estimated based on 50 recorded spectra of merchant ships (Hamson, 1997).

In the present study, source levels from two generic panama- and Post-Panamax-size carriers were estimated as follows. First, the reference spectrum from Hamson (1997) was adjusted to provide the broadband level as calculated with Equation (1) using specified propeller diameter and propeller tip speed. The spectrum was used as the reference spectrum (*SV(f)* in Equation (2) and the assumed spectra were obtained based on the speed and length of the vessels. Table 3 presents the specific values used in the equations (1) and (2). The assumed spectra for the ore carriers are presented in Figure 7. The assumed spectrum for the 50 t BP harbour tug is also presented on the same. The broad band level of each spectrum is provided in the legend of the graph.

Since at the time of modeling the exact specifications were not known, most common values were selected based on the vessel class.

Table 3. Vessels specifications.

	Carrier 1 (Panamax)	*Carrier 2 (Post-Panamax)*
DWT (thousands)	70	90
Length overall (*Le*)	190 m	300 m
Draft	13 m	15 m
Transit speed (*V*)	14 knots	14 knots
Number of propellers	1 x fixed-pitch	1 x fixed-pitch
Propeller diameter	7.6 m	8.0 m
Propeller speed	95 rpm	85 rpm
Number of blades (*B*)	4	5

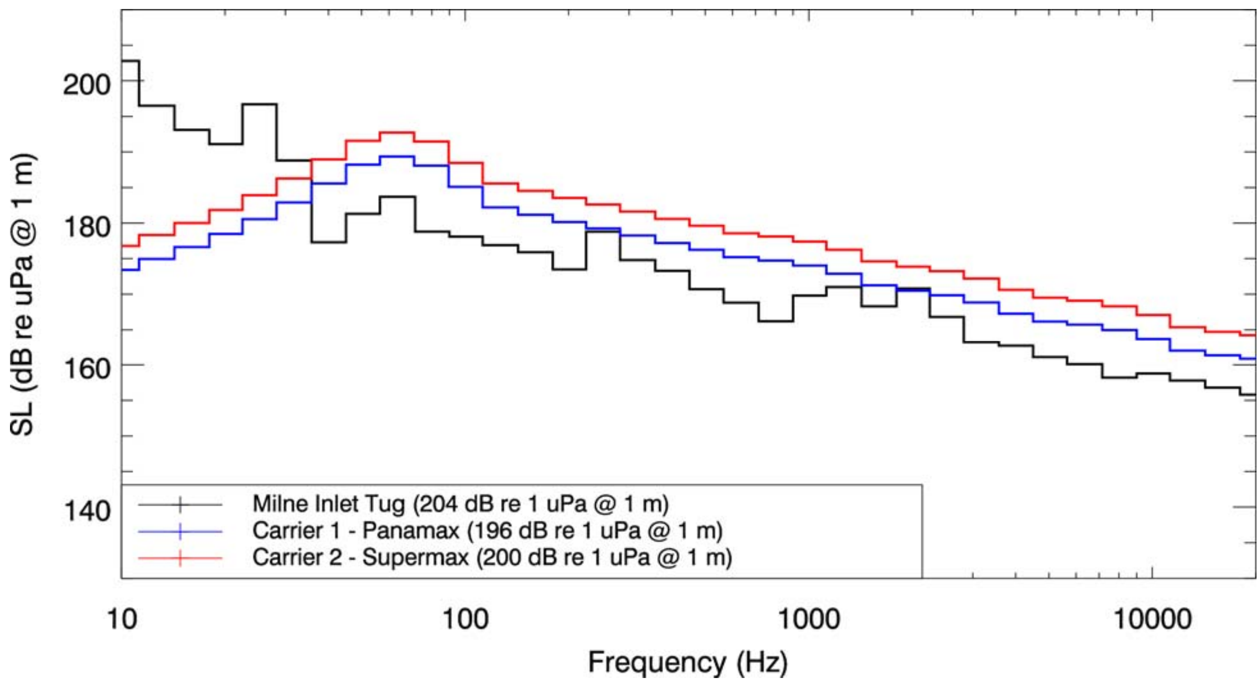

Figure 7. Assumed third-octave band source levels for Carrier 1, Carrier 2, and the Milne Inlet tug used in the modelling.

3. Modelling Sound Propagation

3.1. Modeling Locations

Underwater sound resulting from operations related to the Milne Inlet Project was modeled at four locations along the nominal shipping route and three locations in the vicinity of the Port.

According to the construction plan the dredging is planned to be used at the freight dock site, while the pile driving is scheduled to occur at the ore dock construction site, hence these sites were modelled for each source respectively.

Four modeling locations for the ore carriers were chosen along the shipping route in Koluktoo Bay area, Milne Inlet, Eclipse Sound, and Pond Inlet. The exact coordinates for the sources were obtained from LGL. The locations were chosen with consideration of having a direct line of sight into multiple smaller inlets and investigation of sound field penetration into those small areas.

The sound field modeling from the tug was performed at two locations: at the Assomption Harbour (in the vicinity of the port) and in Pond Inlet (same location as for the ore carrier).

Table 4 and Figures 8 and 7 provide information about the different modeling locations.

Table 4. Modeling locations.

Activities	Locations			Water depth
Ore Carrier in transit	Koluktoo Bay area (1)	72° 02.879' N	80° 40.246' W	285 m
	Milne Inlet (2)	72° 15.725' N	80° 33.919' W	410 m
	Eclipse Sound (3)	72° 39.431' N	79° 38.381' W	410 m
	Pond Inlet (4)	72° 50.406' N	77° 58.906' W	950 m
Tug operations	Pond Inlet (4)	72° 50.406' N	77° 58.906' W	950 m
	Assomption Harbour (5)	71° 53.502' N	80° 52.806' W	53 m
Dredging operations	Assomption Harbour, Freight Dock (6)	71° 53.436' N	80° 53.601' W	19.5 m
Pile driving operations	Assomption Harbour, Ore Dock (7)	71°53.334' N	80°55.045' W	4 m

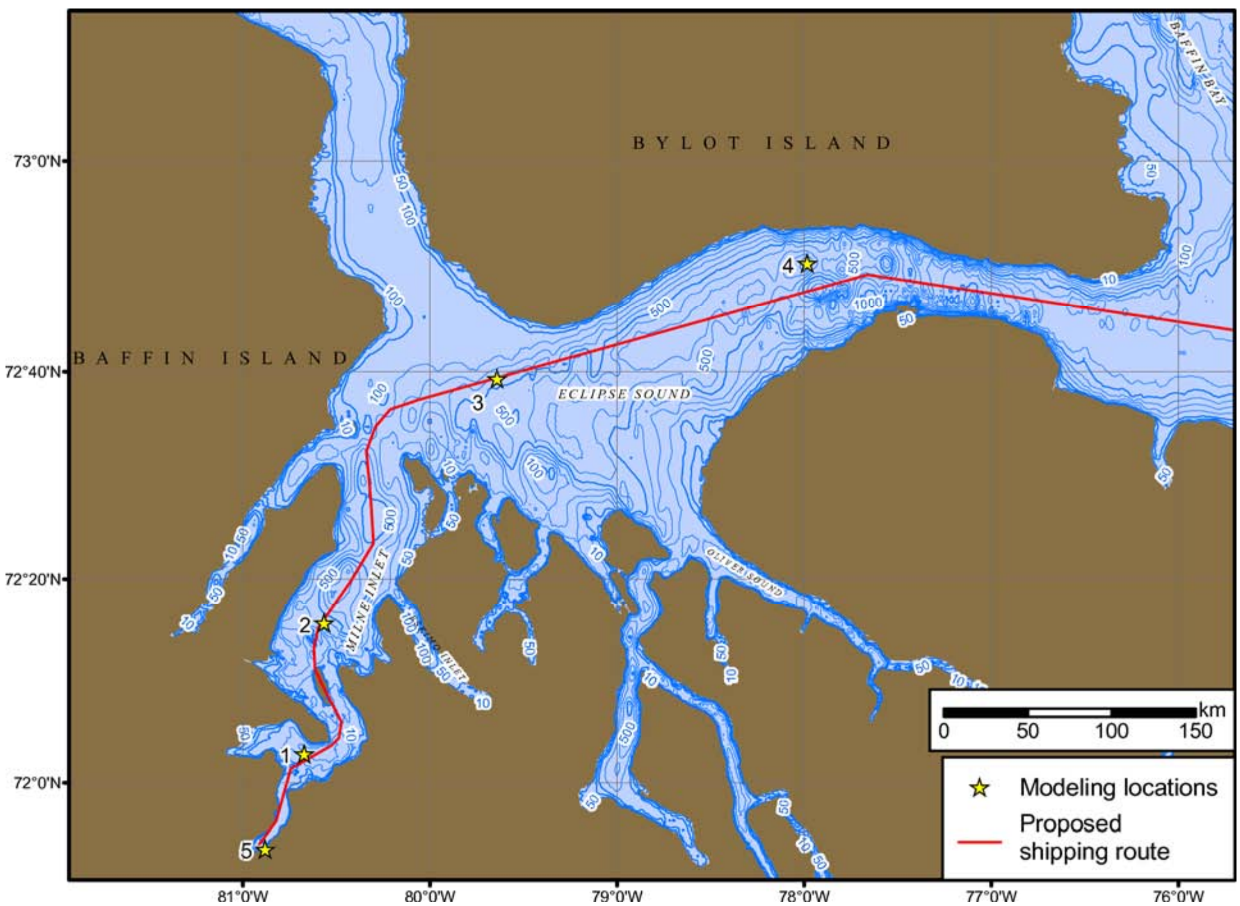

Figure 8. Modelling locations for the shipping and tug operations.

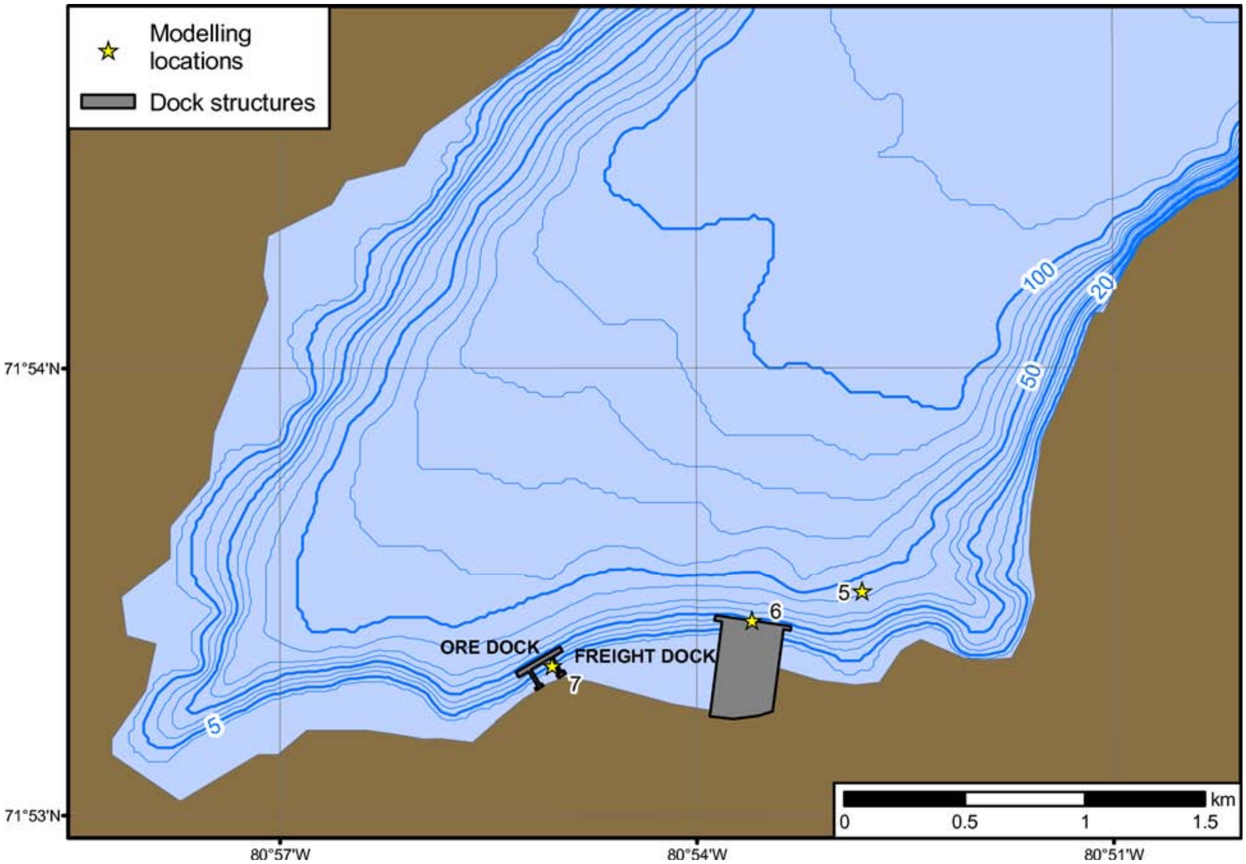

Figure 9. Modeling locations in the vicinity of the port (tug operation, dredging, and pile driving).

3.2. Environment

3.2.1. Bathymetry

The accuracy of sound propagation model results depends on the quality of bathymetry data used. Several sources were used to create the bathymetry grid for the environment model.

Table 5. Bathymetry datasets used in preparation of the environment model.

dataset name	coverage	resolution	reference
SRTM 30+	global	0.5'x0.5' (300 x 900 m)	Becker et al., 2009
Global self-consistent hierarchical high-resolution shorelines v2.0, 2009	global	1:75,000	Wessel and Smith, 1996
Canadian Hydrographic Survey 3477	Milne Inlet south of 72° 15'	200 x 200 m	
Terra Remote Sensing Inc. echosounding data (2008)	Port shore area to 40-50 m isobath	10 x 10 m	

The SRTM 30+ in conjunction with the shoreline data provided the global coverage for the area, while CHS 3477 and Terra Remote datasets provided higher resolution insight for the southern part of Milne Inlet.

In order to prepare the bathymetry grid, all available datasets were combined and gridded using Minimum curvature gridding method. Note, the data points from the lower resolution datasets were excluded for the areas where higher resolution data were available.

Two bathymetry grids were created: one covering the whole area of Milne Inlet, Eclipse Sound, and Pond inlet, with 125 x 125 m cell size; and the other covering only the southern part of the Milne Inlet, with 20 x 20 m resolution. The first grid was used for modelling the shipping and tug operations. The second grid was used in the modelling of dredging operation at the port.

3.2.2. Geoacoustics

Drillhole logs from the ore and freight dock areas were provided by LGL Ltd. The logs indicate that the surficial sediments in the nearshore area are composed of a layer of compact, grey sand with traces of silt, 20-m thick, followed by a layer of cobbles size rocks.

Little is known about the sediment type at depth greater than 24 m below the seafloor, in the studied area. Generally, permafrost soils carried in river pack ice tend to be coarser in the nearshore areas. As the sediment is carried farther away, the material is re-worked and the grain size reduced. Consequently, offshore Arctic glacial sediments tend to be silts and clays. Dewing et al. (2007) describe the geological history of the area, explaining the presence of a pre-Cambrian basement around Baffin Island and Foxe Basin. No references to the depth of the basement layer or the thickness of surficial sediment were available.

To produce generic geoacoustic profiles representing the different modelling areas, silt content in the surficial layer of compact sand was assumed to increase with increasing water depth and distance from Assomption Harbour. The thickness of the surficial and semi-consolidated sediments was estimated based on previous literature review for the area of Steensby Inlet and Foxe Basin (Matthews and Zykov, 2010). P-wave velocity and attenuation were estimated using Hamilton (1980), Ellis and Hughes (1989), Buckingham (2005), and Barton (2007); S-wave velocity and attenuation were estimated based on the sediment type and grain size values through the grain-shearing model (Buckingham, 2005). Tables 6 to 8 present the generic geoacoustic profiles used in the present study.

Table 6. Geoacoustic parameters – Assomption Harbour, Koluktoo Bay area, and Milne Inlet.

Layers	Depth [m bsf]	Density [g/cm^3]	P-wave velocity [m/s]	P-Attenuation [dB/λ]	S-wave velocity [m/s]	S-Attenuation [dB/λ]
compact sand	0 – 20	2.07 – 2.10	1700 – 2050	0.24 – 1.3	300 – 580	0.024 – 0.76
cobbles to granitic gneiss	20 – 350	2.1 – 2.4	2050 – 3500	1.3 – 0.35	580 – 3300	0.76 – 0.54
pre-Cambrian basement	350 - ∞	2.6	5500	0.275	3000	0.3

Table 7. Geoacoustic parameters – Eclipse Sound.

Layers	Depth [m bsf]	Density [g/cm^3]	P-wave velocity [m/s]	P-Attenuation [dB/λ]	S-wave velocity [m/s]	S-Attenuation [dB/λ]
silty sand to compact sand	0 – 20	2.04 – 2.10	1670 – 2050	0.19 – 1.3	300	0.024
cobbles to granitic gneiss	20 – 350	2.1 – 2.4	2050 – 3500	1.3 – 0.35	-	-
pre-Cambrian basement	350 - ∞	2.6	5500	0.275	-	-

Table 8. Geoacoustic parameters – Pond Inlet.

Layers	Depth [m bsf]	Density [g/cm^3]	P-wave velocity [m/s]	P-Attenuation [dB/λ]	S-wave velocity [m/s]	S-Attenuation [dB/λ]
silty sand to compact sand	0 – 20	1.80 – 2.10	1550 – 2050	0.11 – 1.3	150 – 580	0.004 – 0.76
cobbles to granitic gneiss	20 – 350	2.1 – 2.4	2050 – 3500	1.3 – 0.35	-	-
pre-Cambrian basement	350 - ∞	2.6	5500	0.275	-	-

3.2.3. Sound Speed Profiles

Sound speed profiles for the different modeling locations were obtained from the U.S. Naval Oceanographic Office Generalized Digital Environmental Model (GDEM) database (Teague et al., 1990). The latest release of the GDEM database (version 3.0, October 2003) (Naval Oceanographic Office, 2003) provides average monthly profiles of temperature and salinity for the World's oceans on a latitude/longitude grid with 0.25° resolution. Profiles in GDEM are provided at 78 fixed depth points up to a maximum depth of 6800 m. The profiles in GDEM are based on historical observations of global temperature and salinity from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS).

Temperature and salinity data were extracted from the GDEM database for the months of August, September, and October. Based on the data the sound speed profiles were calculated using the equations of Coppens (1981):

$$\begin{aligned} c(z,T,S) &= 1449.05 + 45.7T - 5.21t^2 - 0.23t^3 \\ &\quad + (1.333 - 0.126t + 0.009t^2)(S - 35) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2 \\ Z &= (z/1000)(1 - 0.0026\cos(2\phi)) \\ t &= T/10 \end{aligned} , \qquad (3)$$

Here z is depth in meters, T is temperature in degrees Celsius, S is salinity in psu, and ϕ is latitude (in radians). Resulting profiles for four locations along the shipping route are presented in Figure 10. Only months of open water season, when the shipping activity is expected to occur, were selected. These months include August, September, and October.

The profiles present little variation along the expected shipping route (maximum variation of 2 m/s between Koluktoo Bay and Milne Inlet during the month of August). The difference between sound speed profiles for August and September is virtually nil. These two observations, most likely, reflect the lack of data for the area.

The sound speed profile for October changes significantly compared to August and September profiles. The changes are in both the sound speed values and its shape. August and September sound speed profiles feature well pronounced sound channel with axis depth of 50 m. During the month of October the mid-water column sound channel goes deeper (the axis depth gets to 100–120 m) and widens. In addition to the deeper sound channel, October's sound speed profiles feature surface duct with 2 m/s velocity variation between the maximum and minimum.

In most of the places around the area of interest the water depth quickly becomes deeper than 100 m. At such depths the resulting sound channel for August and September profiles favours sound propagation. Consequently the sound speed profile for the month of August was chosen to be incorporated into the acoustic propagation model as a conservative approach.

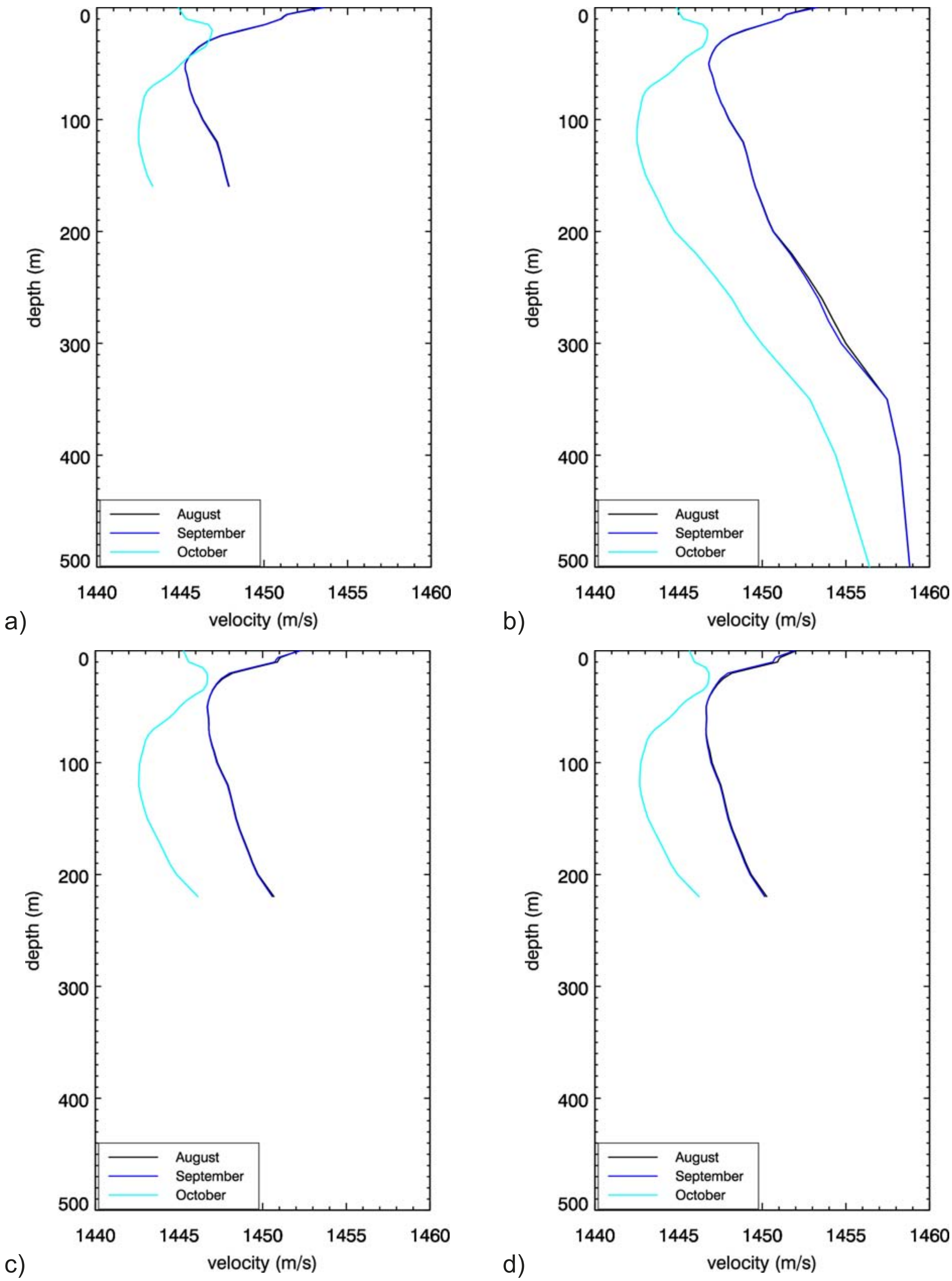

Figure 10: Sound speed profiles at different sites of area of interest for the months of open water season: (a) Koluktoo Bay; (b) Milne Inlet; (c) Eclipse Sound; (d) Pond Inlet.

3.3. Propagation Modelling Approach

The acoustic propagation model used to model the acoustic sources at frequencies below 10 kHz is JASCO's Marine Operations Noise Model (MONM). MONM computes received Sound Exposure Levels (SEL) for impulsive sources if SEL source levels are input. For a continuous source, such as a vessel, dredge or drill rig, MONM outputs RMS levels.

MONM treats sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation. The parabolic equation code used by MONM is based on a version of the Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed. The Parabolic Equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins, 1993).

MONM computes acoustic fields in three dimensions by modelling transmission loss along evenly spaced 2-D radial traverses covering a 360° swath from the source, an approach commonly referred to as N×2-D. The model fully accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles in the water column and the sub-bottom. It also accounts for the additional reflection loss at the seabed that is due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces. It includes wave attenuations in all layers. The acoustic environment is sampled at a fixed range step along radial traverses.

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave bands between 10 Hz and 10 kHz. This frequency range includes the important bandwidth of noise emissions for the operating vessel or construction activity. The 1/3-octave band received levels are computed by subtracting band transmission loss values from the corresponding directional source levels. Broadband received levels are then computed by summing the received band levels. MONM's sound level predictions have been extensively validated against experimental data (Hannay & Racca, 2005). The modelling of the sources at frequencies from 10 kHz to 20 kHz was done using the BELLHOP acoustic raytrace model (Porter and Liu, 1994). BELLHOP also computes received Sound Exposure Levels (SEL).

BELLHOP models transmission loss in the ocean using the Gaussian beam tracing technique. In addition to other types of attenuation, BELLHOP accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water (Fisher and Simmons, 1977). This type of attenuation is large for frequencies higher than 5 kHz and cannot be neglected without noticeable effect on the modelling results at increasing distances from the source.

Similar to MONM, BELLHOP computes sound propagation along a single 2-D radial profile in range and depth. In order to obtain the 3-D spatial distribution of the sound field around the source, a series of 2-D profiles is projected from the source covering a 360° swath in azimuth.

The acoustic models take into account the variability of the sound levels emitted in different directions from the source. This variability is referred to as source directivity. Source directivity is specified to the model as a function of both azimuthal and depression angle where azimuthal angle is the sideways direction relative to north, and depression angle is the vertical angle relative to horizontal. The BELLHOP modelling code estimates sound pressure levels at various horizontal distances from the source as well as at different depths.

3.4. M-Weighting

The potential for noise to affect marine species depends on how well the species can hear the sounds produced (Martin et al., 2010). Noises are less likely to disturb animals if they are at frequencies that the animal cannot hear well. An exception is when the sound pressure is so high that it can cause physical injury. For non-injurious sound levels, frequency weighting curves based on audiograms may be applied to weight the importance of sound levels at particular frequencies in a manner reflective of the receiver's sensitivity to those frequencies (Nedwell and Turnpenny, 1998).

A NMFS-sponsored Noise Criteria Committee has proposed standard frequency weighting curves — referred to as M-weighting filters — for use with marine mammal species (Gentry et al., 2004). M-weighting filters are band-pass filter networks that are designed to reduce the importance of inaudible or less-audible frequencies for four broad classes of marine mammals:

1. Low-frequency cetaceans,
2. Mid-frequency cetaceans,
3. High-frequency cetaceans, and
4. Pinnipeds.

The amount of discount applied by M-weighting filters for less-audible frequencies is not as great as would be indicated by the corresponding audiograms for these groups of species. The rationale for applying a smaller discount than would be suggested by the audiogram is in part due to an observed characteristic of mammalian hearing that perceived equal loudness curves increasingly have less rapid roll-off outside the most sensitive hearing frequency range as sound levels increase. This is the reason that C-weighting curves for humans, used for assessing very loud sounds such as blasts, are flatter than A-weighting curves used for quiet to mid-level sounds. Additionally, out-of-band frequencies, although less audible, can still cause physical injury if pressure levels are very high. The M-weighting filters therefore are primarily intended to be applied at high sound levels where effects such as temporary or permanent hearing threshold shifts may occur. The use of M-weighting should be considered precautionary (in the sense of overestimating the potential for an effect) when applied to lower level interactions such as onset of behavioural response. Figure 11 shows the decibel frequency weighting of the four standard underwater M-weighting filters.

These filters have unity gain (0 dB) through the pass band and their high and low frequency roll-off is approximately –12 dB per octave. The amplitude response of the M-weighting filters is defined in the frequency domain by the following function:

$$G(f) = -20\log_{10}\left[\left(1+\frac{f_{lo}^2}{f^2}\right)\left(1+\frac{f^2}{f_{hi}^2}\right)\right] \quad , \qquad (4)$$

The roll-off and pass band of these filters are controlled by the two parameters f_{lo} and f_{hi}; the parameter values that are used for the four different standard M-weighing curves are given in Table 9.

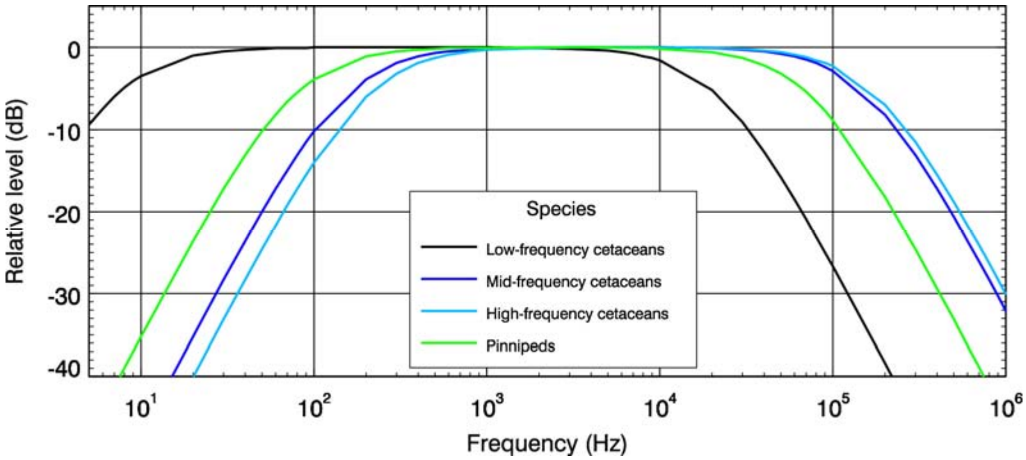

Figure 11. Plot of standard M-weighting curves for low-frequency, mid-frequency, and high-frequency cetaceans and for pinnipeds in water.

Table 9. Low frequency and high frequency cut off parameters for standard marine mammal M-weighting curves.

M-weighting filter	f_{lo} (Hz)	f_{hi} (Hz)
Low frequency cetaceans	7	22 000
Mid-frequency cetaceans	150	160 000
High-frequency cetaceans	200	180 000
Pinnipeds underwater	75	75 000

4. Results

Sound propagation modelling was performed using two geographic coverage methods:

(a) areal coverage up to a 200 km x 200 km zone centered on each modelling location, using a 20 m modelling step size in horizontal range, for frequencies between 10 Hz and 2 kHz, and

(b) along three individual profiles in the direction of the maximum sound field extension (as determined with the results from the areal modelling) up to the distance where the broad band levels drop below 100 dB re µPa, using a 5 m modelling step size in horizontal range, for frequencies between 10 Hz and 20 kHz.

Regime (a) provides high resolution area map of the sound field around each source, while regime (b) provides a full-band, high resolution assessment of the sound field in the directions of maximum sound propagation. The extent of the frequency range used in regime (b) would make the modelling at all azimuths around the source too computationally intensive for approach (a).

Processing of the output data from the modelling code involved gridding of the data points in horizontal planes corresponding to multiple receiver depths. The resulting stack of grids was collapsed to a single grid using a maximum-over-depth rule; that is, the sound level at each geographic location was taken to be the maximum value that occurred over all modelled depths for that location.

Four M-weighting filters (Table 9) were applied to the modelled sound fields by weighting the modelled sound levels according to Equation (4). M-weighting is applied to each third-octave band separately. After the filter is applied the individual values in each band are summed to compute the broadband sound levels.

The presented maps of ensonification levels were calculated using the results from the geographic approach (a). Consequently, these maps represent the maximum-over-depth levels in the 10 to 2000 Hz band.

The calculations of maximum distances to specific broadband sound levels were performed based on the grids of the broadband (10 – 2000 Hz) levels from areal modelling results complemented with modelling along three profiles if the threshold level extended beyond the modelling area. Since the source levels for frequencies higher than 2000 Hz are appreciably lower than the ones for lower frequencies, the usage of reduced band (only up to 2000 Hz, rather than 20,000 Hz) for calculation of the broadband levels did not affect the results.

For each level, two distances are reported: (1) R_{max} – the maximum distance at which the specific sound level was registered in the modelled field; and (2) $R_{95\%}$ – the maximum distance to a grid point at which the specific sound level was registered after exclusion of the 5% farthest points.

The calculations of maximum-over-depth sound levels in each third-octave band at specific distances were performed using the results of the modelling along three extended profiles exclusively for the full frequency range (from 10 Hz to 20,000 Hz). These threshold levels are reported in Appendix B (separate document).

4.1. Pile Driving

Two source level scenarios were modelled: unmitigated and mitigated pile driving operations.

Sound levels were modelled at 18 receiver depths between 1 m to 200 m below the surface. This modelling was performed using a source depth of 2 m below the sea surface, representing an acoustic energy wave emitted from the centre of a vibrating pile (water depth is 4 m at the location).

The maximum distances to specific sound levels produced by pile driving operations are presented in Table 10. The resulting ensonification field maps are presented in Figure A-1 (unmitigated pile driving) and Figure A-2 (mitigated). The black lines in this figure indicate the direction of the geographic method (b) extended frequency band modelling profiles. Table 17 presents the R_{max} and $R_{95\%}$ distances calculated with and without M-weighting filters applied. The longest range from the source to a shore along a line of sight was 11.5 km.

Table 10. Threshold distances from pile driving operations at the Ore Dock, calculated from broadband (10 – 2000 Hz) sound fields.

RMS SPL (dB re 1 μPa)	Threshold distances (m)			
	Unmitigated		mitigated	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	< 5	< 5	–	–
190	25	25	< 5	< 5
180	165	125	25	20
170	1,700	600	130	115
160	5,500	2,600	1,600	600
150	*shore limited*		5,020	2,580
140			*shore limited*	

4.2. Dredging

Sound levels from dredging were modelled at 18 receiver depths between 1 m to 200 m below the surface. This modelling was performed using a source depth of 17 m below the surface, representing cutter-suction dredging with thrusters.

The maximum distances to specific sound levels produced by dredging operations are presented in Table 11. The resulting ensonification field map is presented in Figure A-3. The black lines in this figure indicate the direction of the geographic method (b) extended frequency band modelling profiles. Table 19 presents the R_{max} and $R_{95\%}$ distances calculated with and without M-weighting filters applied. The longest range from the source to a shore along a line of sight was 21.8 km.

Table 11. Threshold distances from dredging operations at the Freight Dock, calculated from broadband (10 – 2000 Hz) sound fields.

RMS SPL (dB re 1 μPa)	Threshold distances (m)	
	R_{max}	$R_{95\%}$
180	< 5	< 5
170	10	10
160	45	40
150	350	250
140	2,750	2,250
130	11,125	8,775
120	*shore limited*	

4.3. Port Operations – Tug

The tug’s propeller depth is estimated at 3.1 m below the surface (at its centre). Assuming the effective source depth to be located below the top of the propeller blade arc by an amount between 15 and 25% of the propeller diameter (Gray and Greeley, 1980; Wales and Heitmeyer, 2002), the source depth was modeled at 2.0 m below the sea surface. The sound levels produced by tug operations were modelled at 17 depths between 1 m and 200 m below the sea surface in Assomption Harbour, and 26 depths between 1 m and 1100 m below the sea surface in Pond Inlet.

The maximum distances to specific sound levels are presented in Table 12. The resulting ensonification field maps are presented in Figures A-4 and A-5. The black lines in these figures indicate the directions of the geographic method (b) extended bandwidth modelling profiles. Tables A-20 and A-21 present the R_{max} and $R_{95\%}$ distances calculated with and without M-weighting filters applied for each source. The longest range from the source to a shore along a line of sight was 21.8 km at the Assomption Harbour modeling location. There were no shore limits at the Pond Inlet site.

Table 12. Comparison between predicted unweighted threshold distances from tug operations at 2 locations along the shipping route, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (m)	
	Assomption Harbour	Pond Inlet
	Tug	Tug
170	< 20	<20
160	50	< 20
150	200	100
140	2,500	350
130	10,200	2,300
120	*shore limited*	12,700
110		40,000
100		150,500

4.4. Shipping Operations and Ore Carriers

Assuming the effective source depth to be located below the top of the propeller blade arc by an amount between 15 and 25% of the propeller diameter (Gray and Greeley, 1980; Wales and Heitmeyer, 2002), the source depth for the Panamax-size ore carrier was modelled at 7.0 m, and the source depth for the Post-Panamax-size ore carrier was modelled at 9.0 m below the sea surface. The sound levels produced by tug operations were modelled at varying depths, depending on the modelling location. These numbers are detailed in Table 13.

Table 13. Modeling details for Ore Carriers modeling locations.

Locations	Number of receivers	Depth of receivers	Shore limit (km)
Koluktoo Bay area (1)	18	between 1 m and 300 m	19.5
Milne Inlet (2)	24	between 1 m and 900 m	77.5
Eclipse Sound (3)	26	between 1 m and 1100 m	104
Pond Inlet (4)	26	between 1 m and 1100 m	no shore limit

The maximum distances to specific sound levels are presented in Table 14. The resulting ensonification field maps are presented in Figures A-6 to A-13. The black lines in these figures indicate the directions of the geographic method (b) extended bandwidth modelling profiles. Tables A-22 to A-29 present the R_{max} and $R_{95\%}$ distances calculated with and without M-weighting filters applied for each source.

The longest ranges from the source to a shore along a line of sight for each modelled location are presented in Table 13

Table 14. Comparison between predicted unweighted threshold distances from ore carriers, at four locations along the shipping route, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field

RMS SPL (dB re 1 µPa)	Threshold distances (meters)							
	Koluktoo Bay area		Milne Inlet		Eclipse Sound		Pond Inlet	
	Panamax Carrier	Post-Panamax Carrier	Panamax Carrier	Post-Panamax Carrier	Panamax Carrier	Post-Panamax Carrier	Panamax Carrier	Post-Panamax Carrier
180		< 20	< 20	< 20	< 20	< 20	< 20	< 20
170	< 20	40	30	40	30	40	30	40
160	80	125	80	125	85	125	80	125
150	500	1,100	280	875	280	900	260	450
140	4,150	8,150	3,650	10,600	3,180	8,350	2,300	5,000
130	9,200	12,000	16,600	30,800	19,750	38,000	10,000	20,700
120	14,000	*shore limited*	39,750	67,250	59,500	79,500	41,200	71,200
110	*shore limited*		70,000	72,700	102,800	102,800	137,700	167,000
100			*shore limited*		*shore limited*		>170,000	>170,000

5. Discussion

Pile driving is expected to be the loudest sound source of all source discussed in the report. However, due to the configuration of the Milne Inlet and the position of the pile driving location most of the sound will not propagate farther than 11.5 km from the site. At that distance the received broadband level is expected to be about 158–160 dB re µPa. As discussed in Section 4.1, the acoustic effect from pile driving operation can be measurably reduced by using mitigation methods such as bubble curtains or a non-impact method of pile driving.

A notable feature of the received acoustic field can be observed on the maps for pile driving and dredging operations. The sound field tends to amplify when the acoustic wave reaches the opposite shore. This amplification phenomenon can be explained by the fact that the water depth decreases towards the shoreline thereby reducing the height of the waveguide (water column). With the reduction of the wave-guide cross-section and constant acoustic energy flux (attenuation due to interaction with the hard bottom is minimal) the acoustic energy density increases.

The effect of M-weighting on broadband threshold distances depends directly on the long-range propagating frequencies. Thus, the effect of M-weighting depends on the locations of the source and the water conditions.

Because of the higher attenuation coefficient at higher frequencies, acoustic energy propagating at frequencies above 5000 Hz has limited contribution to the broadband level and, therefore, to the threshold distances. This is especially true for the distances more than 10 km.

In most studied cases, the difference between the low-frequency cutoff parameters for M-weighting filters and the frequency of maximum source level influences the reduction of the broadband threshold distances. For example, the sound field from tug operations is affected by all M-weighting filters. However, because of a 63-Hz peak in the source level spectrum, the ore carrier's broadband threshold distances are not affected by the low-frequency cetaceans filter (cutoff at 7 Hz). This is also true in the case of the dredging operations, however, the percentage of reduction from the M-weighting filters is less because most of the source energy is propagated at higher frequencies (source spectrum maximum is at approximately 200 Hz).

Estimated source level adjustments for the ore carriers

If the specifications of the ore carrier vessels to be used for shipping at the Milne Inlet port facility are different from the specifications assumed in this report it is possible to apply adjustments to the provided results. For the purpose of the modeling two classes of the ore carriers were chosen — Panamax and Post-Panamax — with the length of 190 m and 300 m respectively. The normal velocity for both classes was assumed to be 14 knots.

The adjustments can be calculated using the Equation (2), where the second term of the equation reflects the variation of the source level with the vessel velocity and the third term reflects the variation of the source level with the vessel length. The estimated adjustments for variations in vessel length and velocity are presented in Table 15 and Table 16 respectively. It should be noted that in case the actual vessel velocity differs from the normal velocity by more than 5 knots the adjustment value would lose accuracy.

Table 15. Estimated adjustments to the source levels of ore carriers due to vessel length change.

Length (m)	160	180	200	220	240	260	280	**300**	320
Correction (dB)	-5.5	-4.4	-3.5	-2.7	-1.9	-1.2	-0.6	**0.0**	0.6

Table 16. Estimated adjustments to the source levels of ore carriers due to vessel length change.

Velocity (knots)	5	6	7	8	9	10	11	12	13	**14**	15	16
Correction (dB)	-26.8	-22.1	-18.1	-14.6	-11.5	-8.8	-6.3	-4.0	-1.9	**0.0**	1.8	3.5

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Appendix A.

A.1. Unweighted Sound Field – Pile Driving Operations

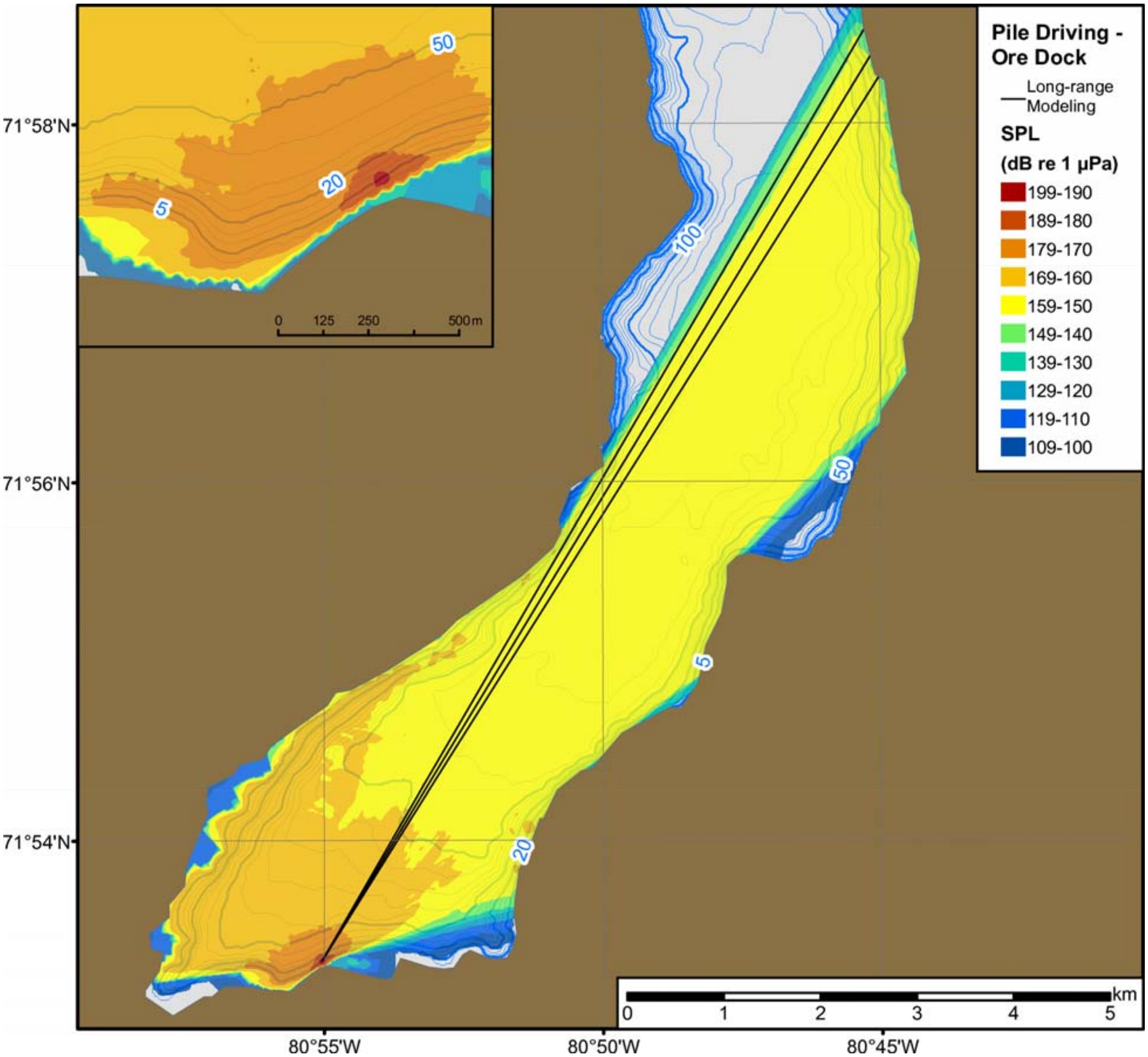

Figure A-1. Estimated broadband (10 – 2000 Hz) sound pressure levels around unmitigated pile driving operations at the Ore Dock (Assomption Harbour).

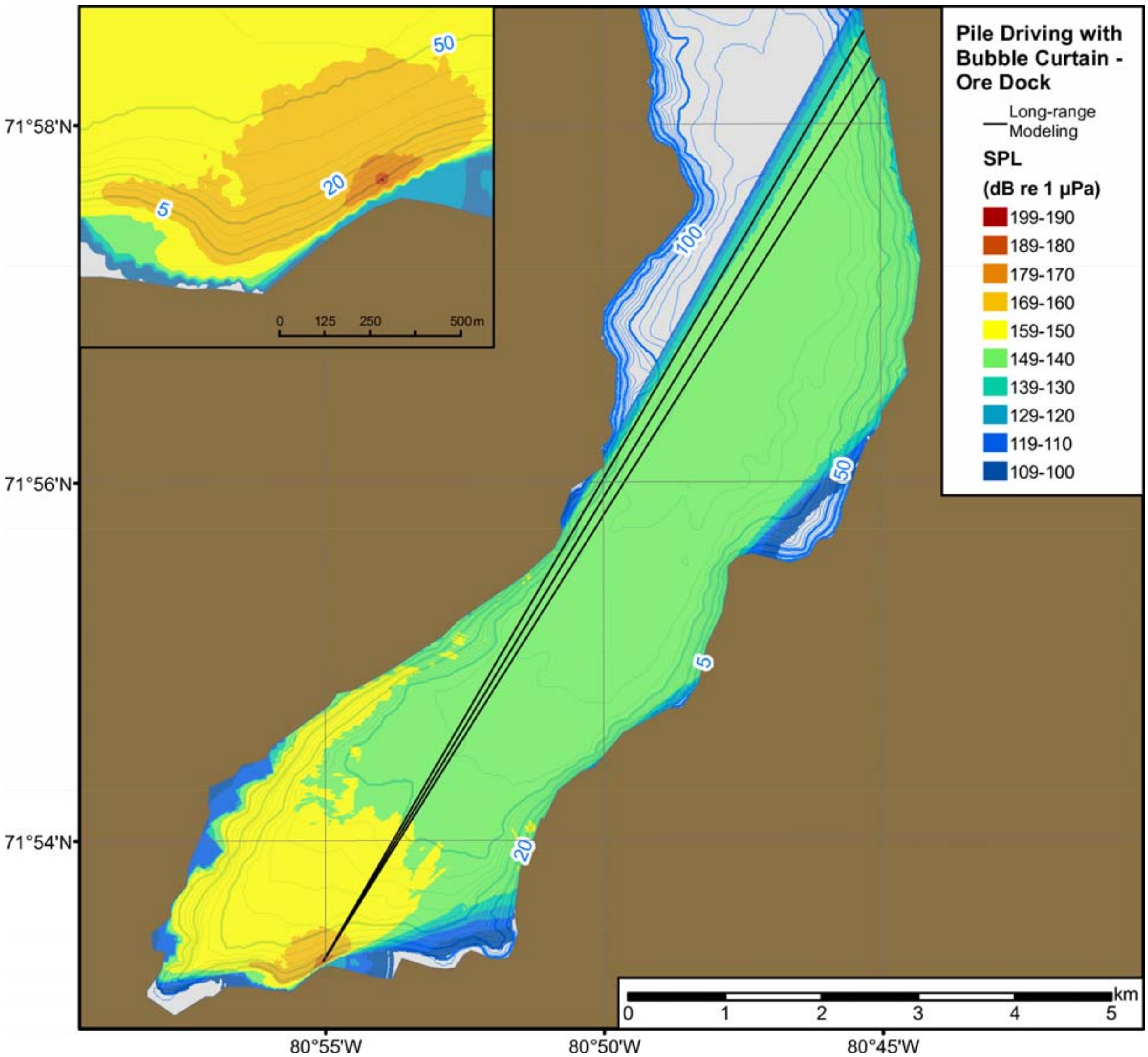

Figure A-2. Estimated broadband (10 – 2000 Hz) sound pressure levels around mitigated pile driving operations at the Ore Dock (Assomption Harbour).

A.2. Threshold Distances – Pile Driving Operations

Table 17. Comparison between predicted m-weighted and unweighted threshold distances from unmitigated pile driving operations at the Ore Dock (Assomption Harbour). Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
200	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
190	25	25	25	20	25	20	20	20	25	25
180	165	125	165	125	145	115	140	110	150	120
170	1,700	600	1,700	600	795	560	755	555	1,700	600
160	5,500	2,600	5,500	2,600	5,000	2,500	5,000	2,400	5,150	2,575
150	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400	11,400

Table 18. Comparison between predicted m-weighted and unweighted threshold distances from mitigated pile driving operations at the Ore Dock (Assomption Harbour). Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
190	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
180	25	20	25	20	15	15	15	15	20	20
170	130	115	130	115	120	90	100	80	125	100
160	1,600	600	1,600	600	750	550	700	500	750	560
150	5,020	2,580	5,020	2,580	5,000	2,350	4,500	2,050	5,000	2,550
140	11,400	11,400	11,400	11,400	11,400	11,400	10,950	8,800	11,400	11,400
130							11,400	11,400		

A.3. Unweighted Sound Fields – Dredging Operations

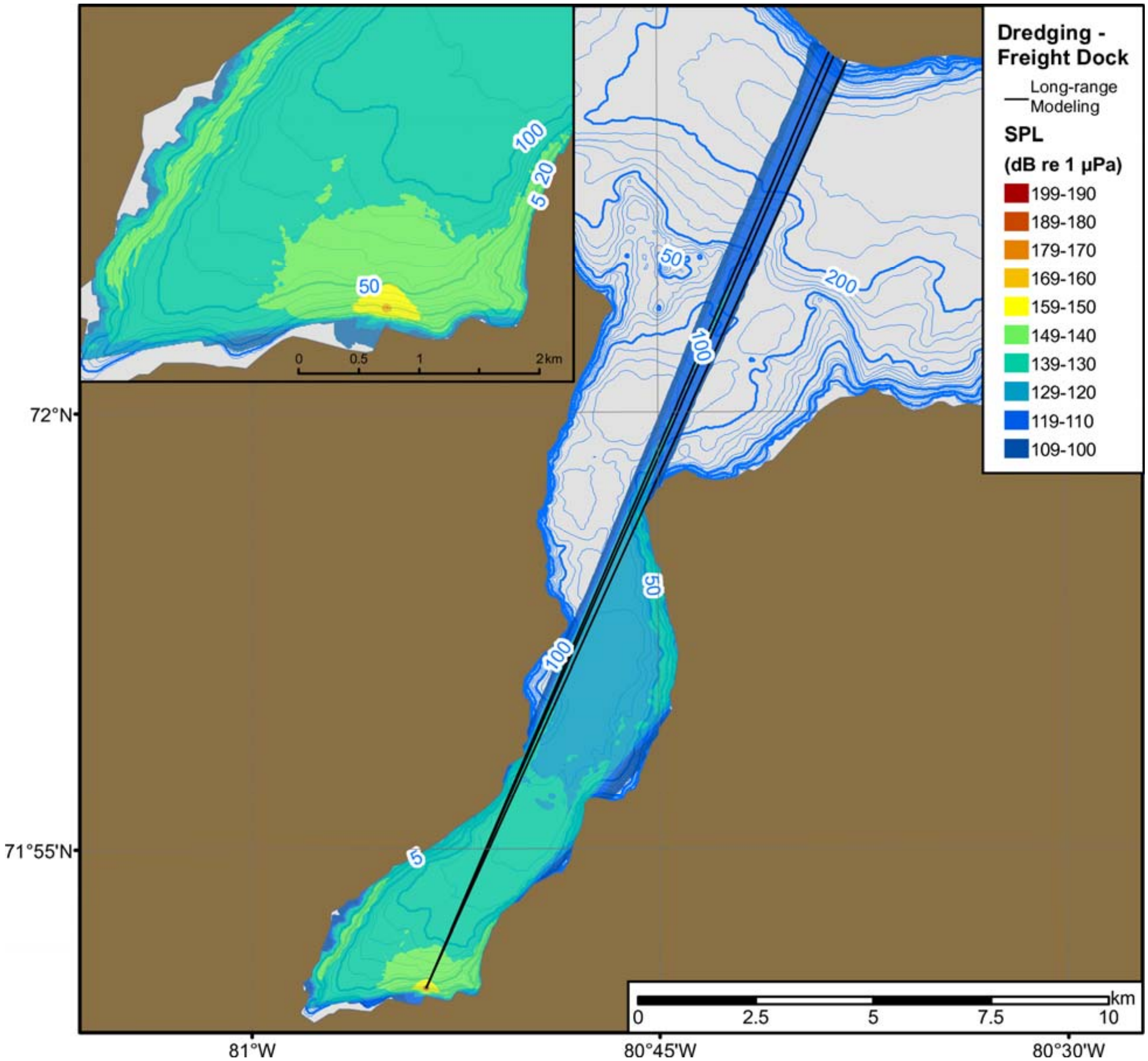

Figure A-3. Estimated broadband (10 – 2000 Hz) sound pressure levels around dredging operations at the Freight Dock (Assomption Harbour), in open water conditions.

A.4. Threshold Distances – Dredging Operations

Table 19. Comparison between predicted m-weighted and unweighted threshold distances from dredging operations at the Freight Dock (Assomption Harbour), in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 5	< 5	< 5	< 5					< 5	< 5
170	10	10	10	10	< 5	< 5	< 5	< 5	10	10
160	45	40	45	40	25	25	20	20	30	30
150	350	250	345	250	150	125	115	100	250	175
140	2,750	2,250	2,750	2,250	1,350	1,050	1,200	600	2,500	1,200
130	11,125	8,775	11,125	8,775	10,350	3,000	10,275	2,700	11,000	5,000
120	*shore limited*		*shore limited*		12,000	9,750	11,800	9,675	15,700	10,000
110					*shore limited*		*shore limited*		*shore limited*	

A.5. Unweighted Sound Fields – Tug Operations

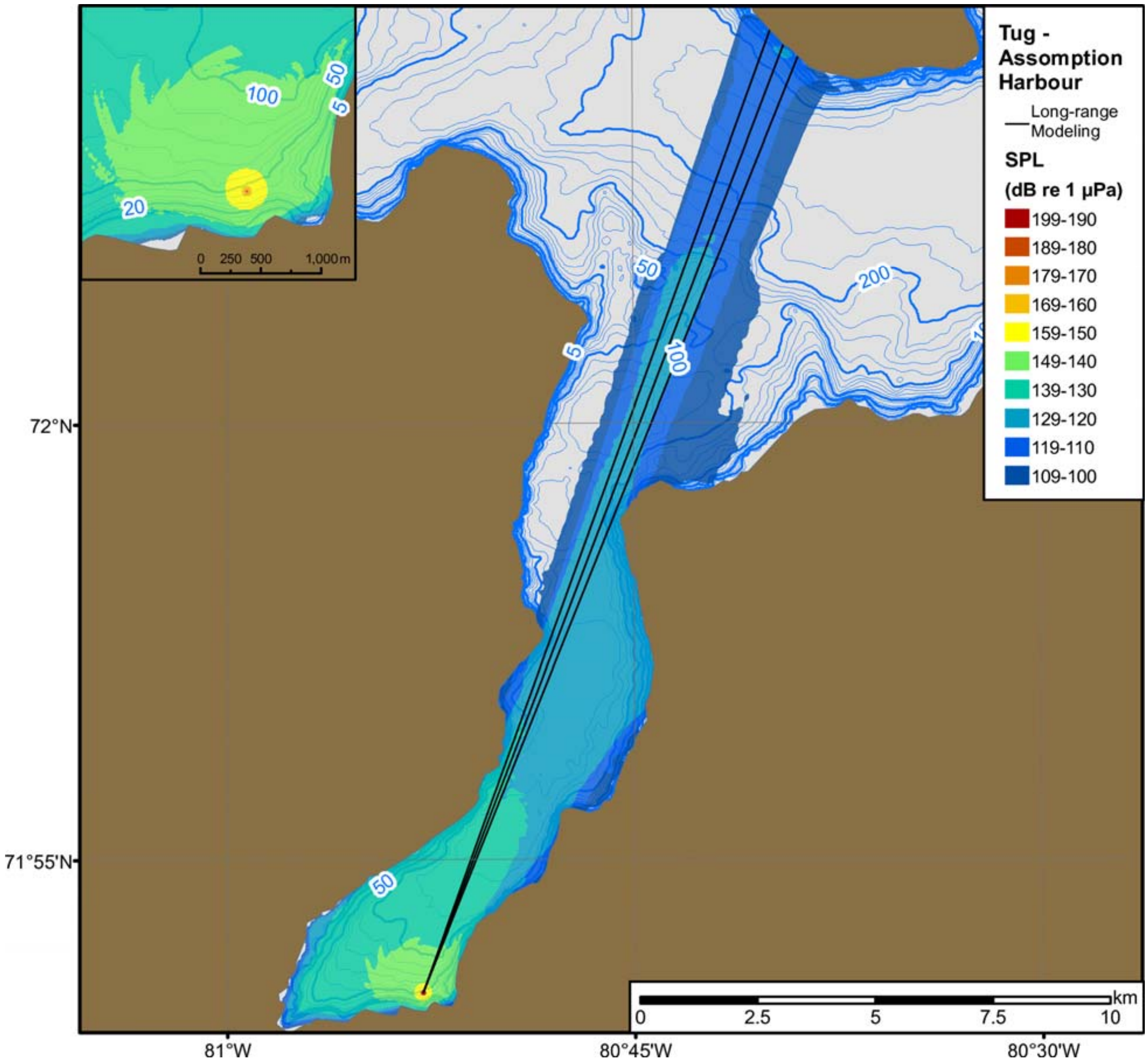

Figure A-4. Estimated broadband (10 – 2000 Hz) sound pressure levels around tug operations close to the Ore Loading Dock (Assomption Harbour), in open water conditions.

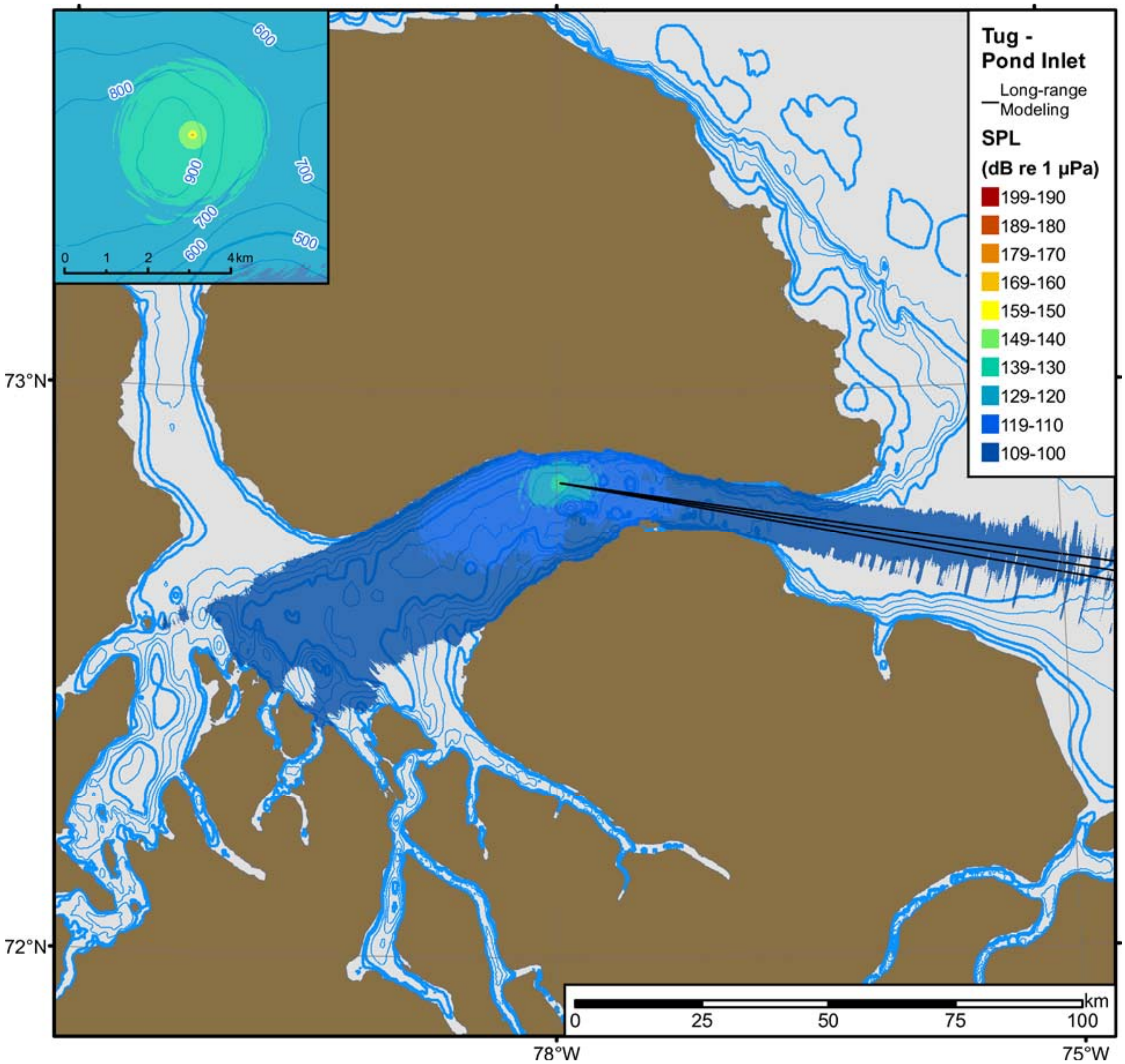

Figure A-5. Estimated broadband (10 – 2000 Hz) sound pressure levels around tug operations in Pond Inlet, in open water conditions.

A.6. Threshold Distances – Tug operations

Table 20. Comparison between predicted m-weighted and unweighted threshold distances from tug operations close to the Ore Loading Dock (Assomption Harbour), in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
170	< 20	< 20	< 20	< 20						
160	50	50	35	35	< 20	< 20	< 20	< 20	< 20	< 20
150	200	175	180	165	125	125	100	100	140	130
140	2,500	1,200	1,500	1,100	700	500	625	400	1,100	650
130	10,200	4,400	10,000	4,100	4,750	2,700	4,000	2,500	5,250	3,000
120	*shore limited*	15,000	*shore limited*	14,850	16,800	9,900	16,600	9,700	21,400	11,300
110		*shore limited*		*shore limited*	*shore limited*	*shore limited*	*shore limited*	*shore limited*	*shore limited*	*shore limited*

Table 21. Comparison between predicted m-weighted and unweighted threshold distances from tug operations in Pond Inlet, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
160	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
150	100	100	100	100	60	60	45	45	60	60
140	350	325	320	300	175	175	160	160	220	220
130	2,300	1,850	2,300	1,650	550	550	450	450	700	675
120	12,700	7,350	10,500	6,700	9,150	3,750	6,800	2,900	9,200	4,000
110	40,000	25,500	38,700	24,000	29,200	18,500	19,200	17,750	31,000	19,400
100	150,500	123,250	144,500	119,750	144,500	115,750	144,500	115,750	145,000	116,000

A.7. Unweighted Sound Fields – Ore Carriers

A.7.1. Panamax-size Ore Carrier

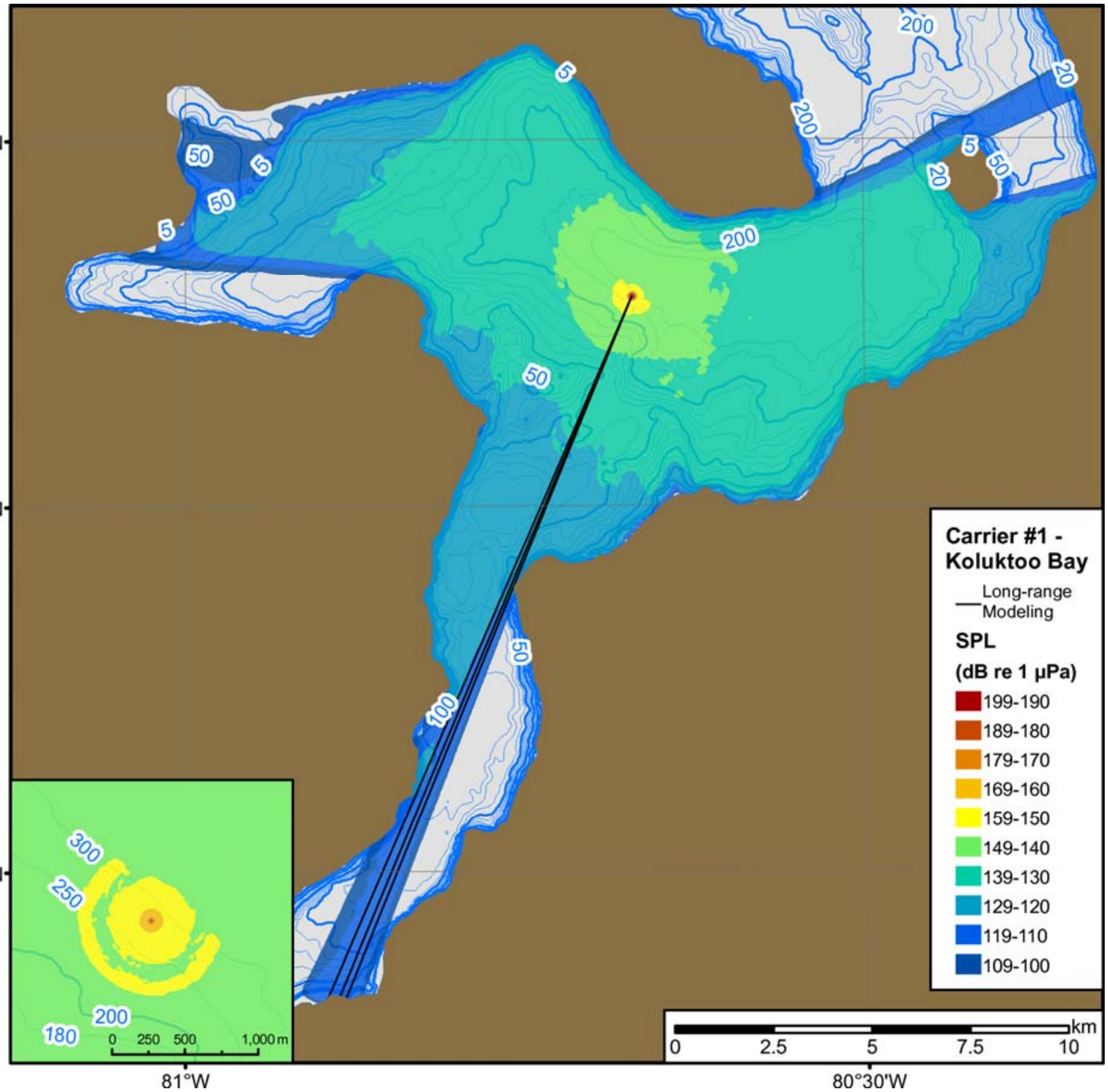

Figure A-6. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Panamax-size ore carrier in transit in the Koluktoo Bay area, in open water conditions.

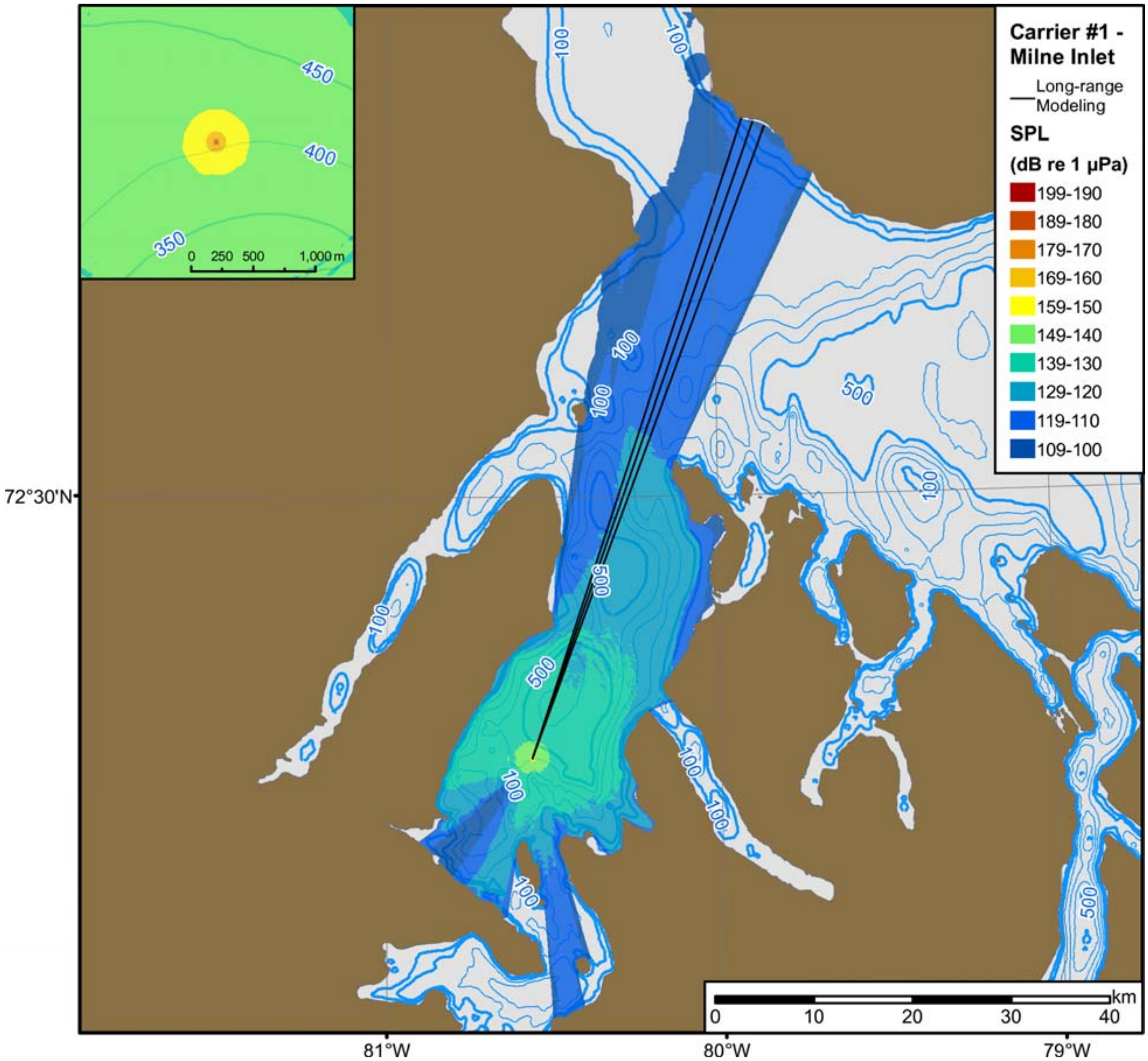

Figure A-7. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Panamax-size ore carrier in transit in Milne Inlet, in open water conditions.

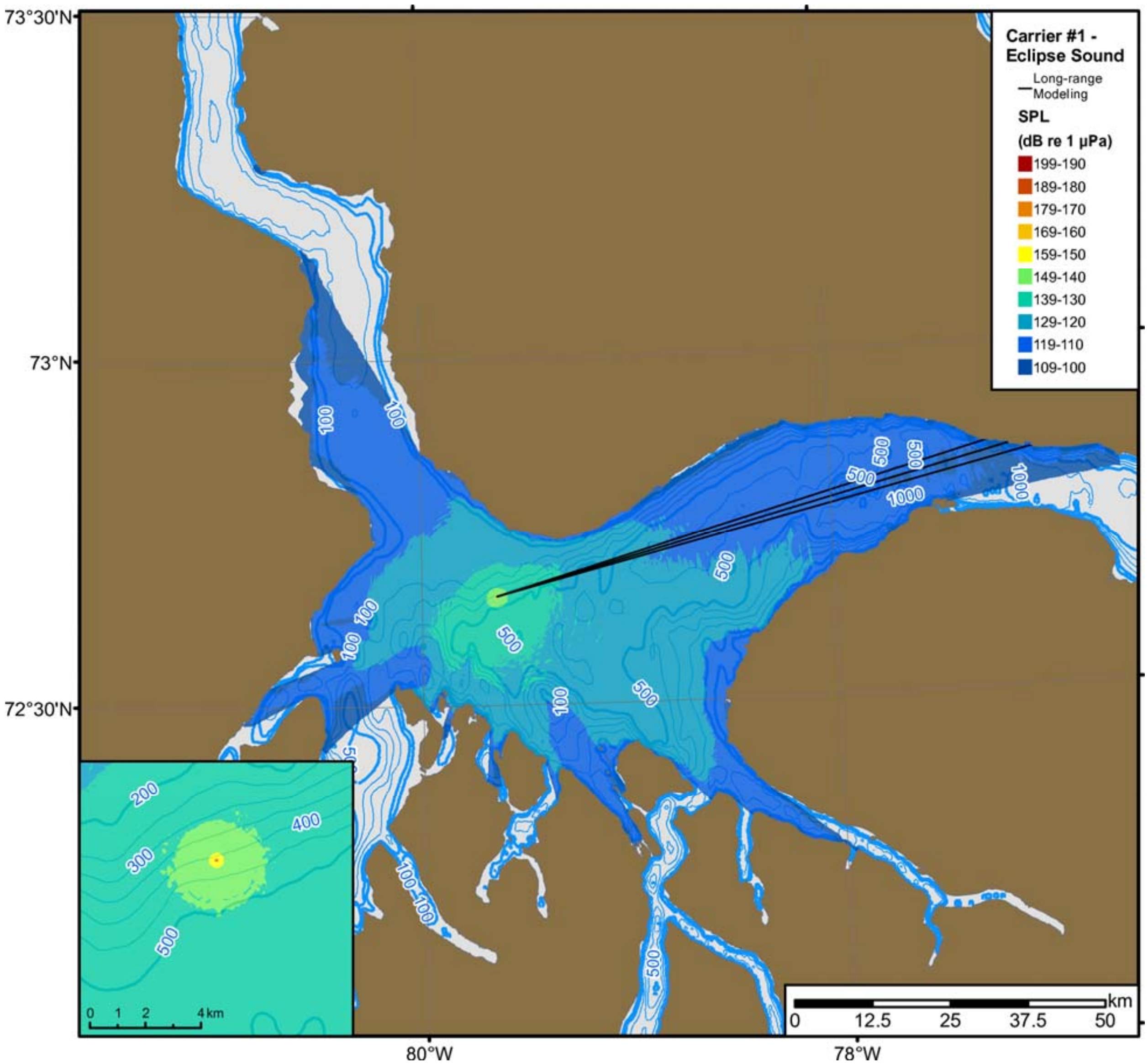

Figure A-8. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Panamax-size ore carrier in transit in Eclipse Sound, in open water conditions.

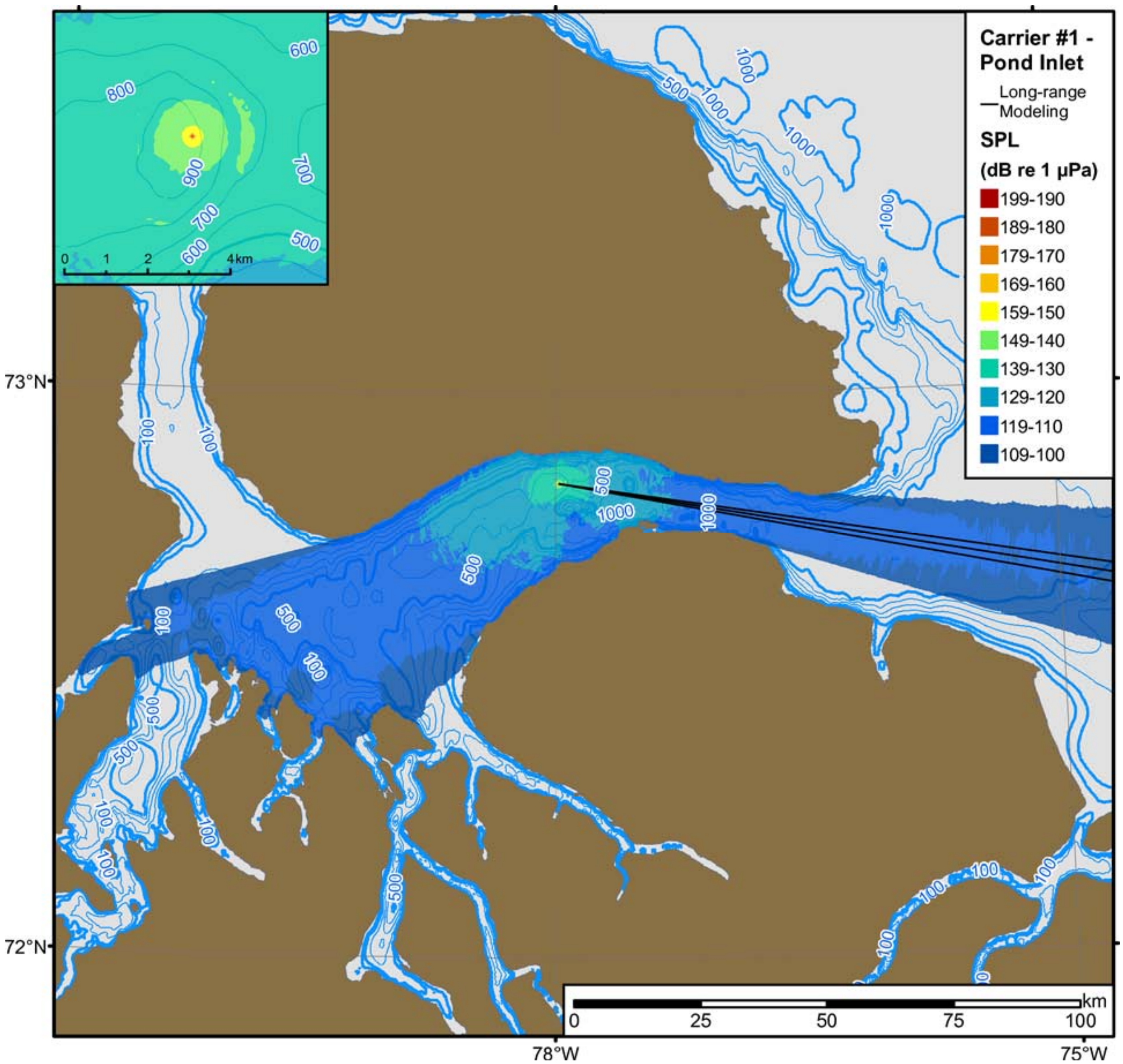

Figure A-9. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Panamax-size ore carrier in transit in Pond Inlet, in open water conditions.

A.7.2. Post-Panamax-size Ore Carrier

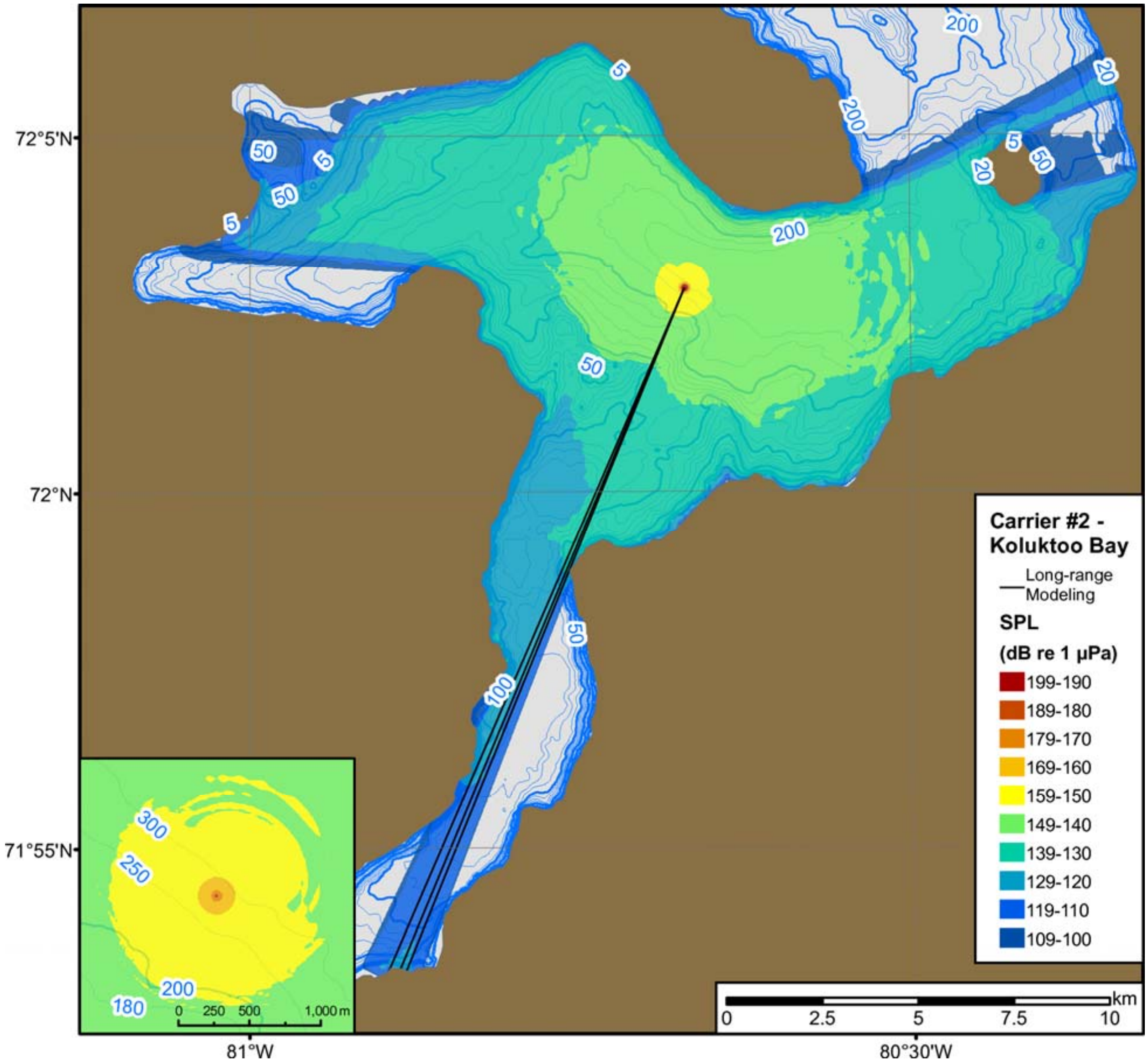

Figure A-10. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Post-Panamax-size ore carrier in transit in the Koluktoo Bay area, in open water conditions.

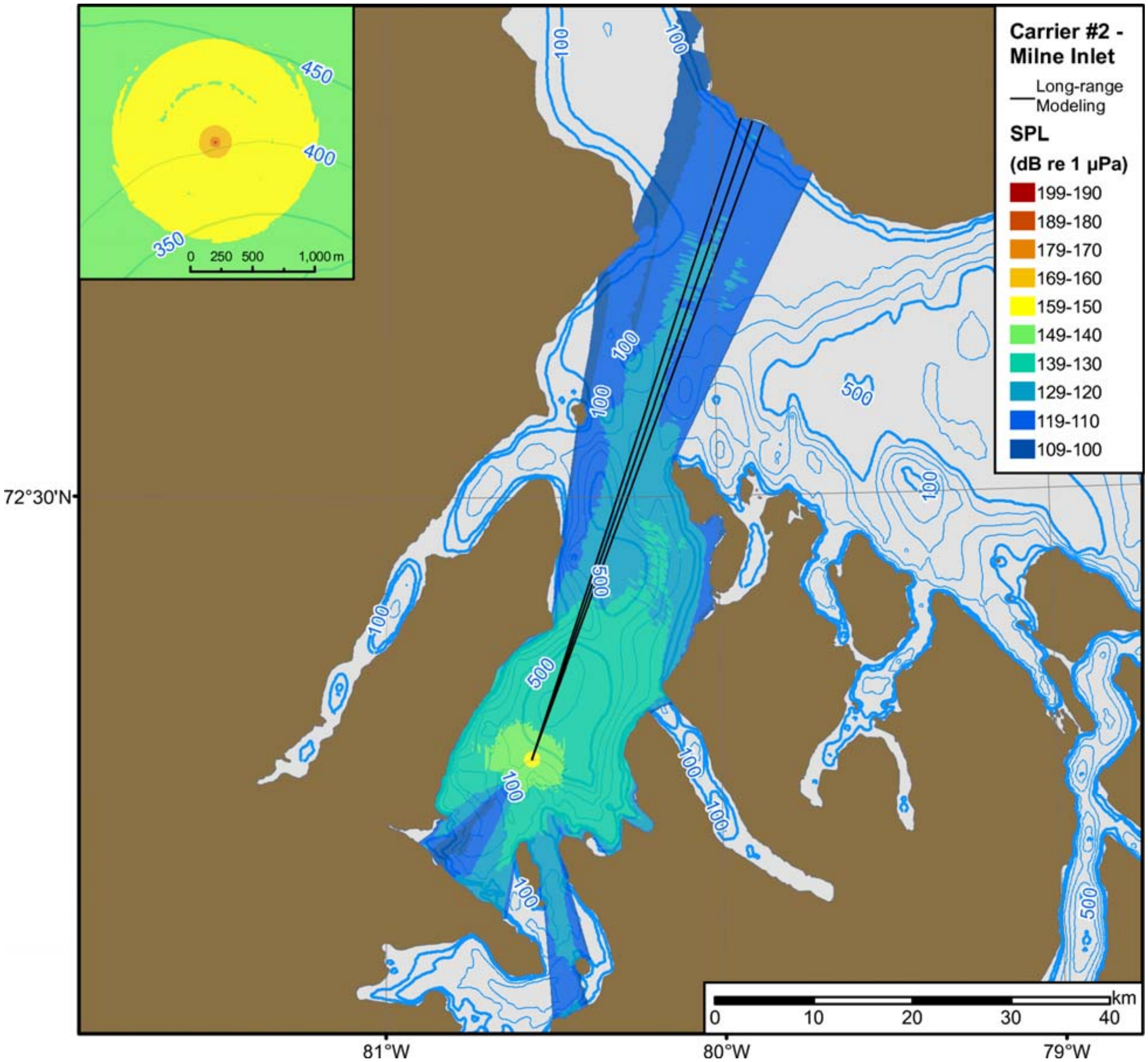

Figure A-11. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Post-Panamax-size ore carrier in transit in Milne Inlet, in open water conditions.

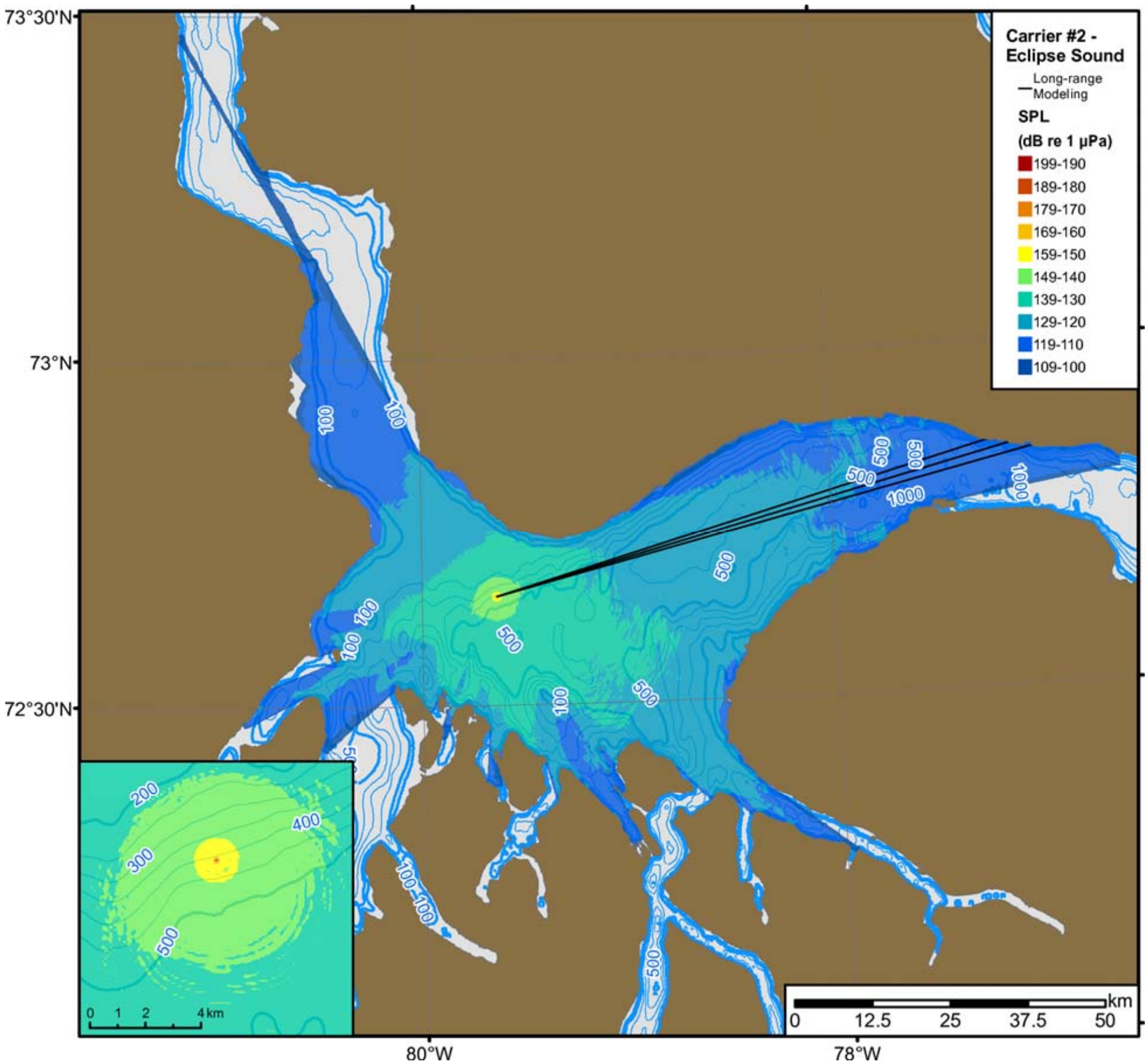

Figure A-12. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Post-Panamax-size ore carrier in transit in Eclipse Sound, in open water conditions.

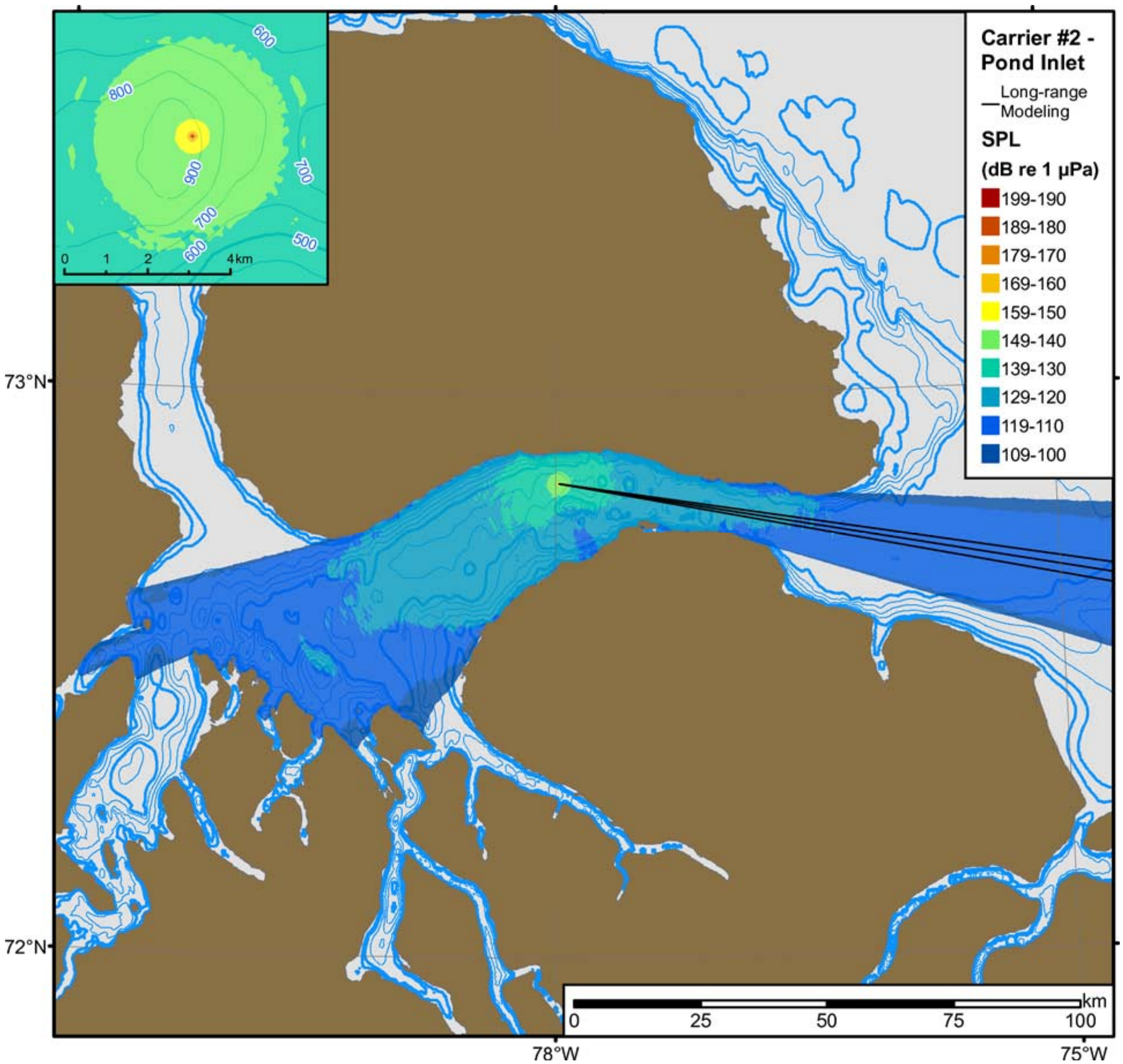

Figure A-13. Estimated broadband (10 – 2000 Hz) sound pressure levels around a Post-Panamax-size ore carrier in transit in Pond Inlet, in open water conditions.

A.8. Threshold Distances – Ore Carriers

A.8.1. Panamax-size Ore Carrier

Table 22. Comparison between predicted m-weighted and unweighted threshold distances from a Panamax-size ore carrier in transit in the Koluktoo Bay area, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
170	< 20	< 20	< 20	< 20	< 20	< 20			< 20	< 20
160	80	80	80	80	30	30	< 20	< 20	50	50
150	500	500	500	500	100	100	100	100	150	150
140	4,150	2,550	4,150	2,500	600	550	500	500	2,200	850
130	9,200	7,550	9,000	7,550	6,750	3,550	6,000	3,000	8,850	5,950
120	14,000	9,700	14,000	9,650	13,600	9,275	1,300	9,100	13,800	9,500
110	*shore limited*	11,600	*shore limited*	11,600	*shore limited*	10,900	*shore limited*	10,650	*shore limited*	11,300
100		*shore limited*		*shore limited*		*shore limited*		*shore limited*		*shore limited*

Table 23. Comparison between predicted m-weighted and unweighted threshold distances from a Panamax-size ore carrier in transit in Milne Inlet, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	30	30	30	30	< 20	< 20	< 20	< 20	< 20	< 20
160	80	80	80	80	30	30	30	30	45	45
150	280	260	280	260	100	100	85	85	150	150
140	3,650	2,150	3,650	2,050	330	320	275	265	980	900
130	16,600	12,500	16,600	12,300	6,450	3,150	4,200	2,500	11,500	5,800
120	39,750	29,500	39,750	29,500	29,000	15,150	29,100	12,000	31,900	25,900
110	70,000	61,500	70,000	61,500	67,000	35,700	66,100	32,100	69,400	54,800
100	*shore limited*		*shore limited*		*shore limited*		*shore limited*		*shore limited*	

Table 24. Comparison between predicted m-weighted and unweighted threshold distances from a Panamax-size ore carrier in transit in Eclipse Sound, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	30	30	30	30	< 20	< 20	< 20	< 20	< 20	< 20
160	85	85	80	80	30	30	30	30	45	45
150	280	260	270	260	100	100	85	85	150	150
140	3,180	1,850	3,170	1,800	330	315	275	265	980	900
130	19,750	13,200	19,200	13,000	4,000	2,200	2,500	1,550	8,600	5,000
120	59,500	41,300	58,800	41,100	29,100	17,200	23,000	12,700	40,900	28,700
110	102,800	64,500	102,800	67,200	102,800	50,200	102,800	46,500	102,800	60,200
100	*shore limited*		*shore limited*		*shore limited*		*shore limited*		*shore limited*	

Table 25. Comparison between predicted m-weighted and unweighted threshold distances from a Panamax-size ore carrier in transit in Pond Inlet, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 µPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	30	30	30	30	< 20	< 20	< 20	< 20	< 20	< 20
160	80	80	80	80	30	30	30	30	45	45
150	260	250	260	250	100	100	85	85	150	150
140	2,300	1,450	2,300	1,400	325	300	275	270	500	470
130	10,000	6,550	10,000	3,400	2,200	1,900	950	900	5,100	2,900
120	41,200	24,300	41,200	24,000	21,000	12,000	21,000	10,800	26,200	19,500
110	137,700	116,300	137,700	116,000	106,700	70,800	106,600	62,700	116,400	80,300
100	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000

A.8.2. Post-Panamax-size Ore Carrier

Table 26. Comparison between predicted m-weighted and unweighted threshold distances from a Post-Panamax-size ore carrier in transit in the Koluktoo Bay area, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 μPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	40	40	40	40	< 20	< 20	< 20	< 20	< 20	< 20
160	125	125	125	125	45	45	25	25	75	75
150	1,100	770	1,100	770	150	150	125	125	480	450
140	8,150	5,300	8,150	5,300	2,500	850	1,750	680	3,750	2,200
130	12,000	8,600	12,000	8,600	11,900	6,150	10,300	5,300	11,900	7,900
120	*shore limited*	10,300	*shore limited*	10,300	19,300	9,800	13,900	9,750	19,300	10,000
110		*shore limited*		*shore limited*	*shore limited*	11,700	*shore limited*	11,600	*shore limited*	12,000
100						*shore limited*		*shore limited*		*shore limited*

Table 27. Comparison between predicted m-weighted and unweighted threshold distances from a Post-Panamax-size ore carrier in transit in Milne Inlet, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 μPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	40	40	40	40	< 20	< 20	< 20	< 20	< 20	< 20
160	125	125	125	125	45	45	25	25	75	75
150	875	800	875	800	150	150	125	125	250	225
140	10,600	4,500	10,600	4,400	900	850	725	680	3,400	1,400
130	30,800	19,200	30,800	18,700	9,500	5,350	9,500	3,850	16,500	10,200
120	67,250	43,500	67,250	42,500	34,200	26,600	32,000	23,200	41,600	29,800
110	72,700	63,500	72,300	63,500	69,900	58,800	69,200	56,000	70,000	62,600
100	*shore limited*		*shore limited*		*shore limited*		*shore limited*		*shore limited*	

Table 28. Comparison between predicted m-weighted and unweighted threshold distances from a Post-Panamax-size ore carrier in transit in Eclipse Sound, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 μPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	40	40	40	40	< 20	< 20	< 20	< 20	< 20	< 20
160	125	125	125	125	45	45	30	30	70	70
150	900	800	900	800	150	150	125	125	250	225
140	8,350	4,400	8,350	4,300	900	825	750	675	1,750	1,350
130	38,000	26,000	38,000	25,600	8,950	4,600	6,000	3,400	18,000	11,200
120	79,500	52,500	79,500	52,000	43,800	29,500	36,000	23,000	58,500	40,500
110	102,800	73,800	102,800	73,700	102,800	66,900	102,800	63,400	102,800	71,600
100	*shore limited*		*shore limited*		*shore limited*		*shore limited*		*shore limited*	

Table 29. Comparison between predicted m-weighted and unweighted threshold distances from a Post-Panamax-size ore carrier in transit in Pond Inlet, in open water conditions. Distances calculated from broadband (10 – 2000 Hz) sound field.

RMS SPL (dB re 1 μPa)	Threshold distances (meters)									
	No weighting applied		Cetaceans						Pinnipeds	
			Low-frequency		Mid-frequency		High-frequency			
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
180	< 20	< 20	< 20	< 20						
170	40	40	40	40	< 20	< 20	< 20	< 20	< 20	< 20
160	125	125	125	125	45	45	30	30	75	75
150	450	400	425	400	150	150	125	125	225	225
140	5,000	2,575	3,850	2,500	500	480	400	400	775	725
130	20,700	13,000	20,700	12,900	6,000	2,700	5,800	2,300	10,000	7,000
120	71,200	45,700	71,200	45,300	35,500	19,700	33,000	19,000	41,200	28,000
110	167,000	148,200	167,000	146,000	138,200	117,000	133,800	115,800	142,800	132,000
100	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000	> 170,000

Table1a. Estimated sound levels at set radii from a tug operating in the port area (Assomption Harbour), during open water conditions.

Range (m)	broad band	Frequency (Hz)																															
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	157	147	142	138	138	150	142	133	138	144	141	141	141	143	141	149	145	144	140	138	135	140	140	137	139	136	132	131	127	126	125	124	123	122	121
300	150	141	136	133	130	143	136	127	132	137	133	134	134	135	136	141	136	137	133	130	132	133	134	133	134	130	126	126	125	122	120	118	117	115	114
1,000	143	135	130	126	128	135	130	120	127	131	128	128	129	129	130	136	131	132	129	126	125	127	128	126	129	127	120	122	119	118	119	112	110	108	106
3,000	136	127	122	119	118	128	122	113	119	124	120	122	122	124	121	129	127	124	122	120	118	121	123	120	124	119	116	115	113	112	109	103	101	97	92
10,000	132	121	117	114	113	123	117	108	115	120	116	118	118	120	118	125	124	122	120	118	114	120	119	118	119	113	109	110	107	105	102	90	83	73	59
20,000	127	112	108	108	108	116	113	102	109	114	109	110	115	114	111	119	117	116	114	111	110	113	112	110	110	105	100	99	96	94	91				

Table1b. Estimated sound levels at set radii from a tug operating in the Pond Inlet area, during open water conditions.

Range (m)	broad band	Frequency (Hz)																															
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	152	143	138	137	136	144	138	128	134	138	135	136	137	138	136	143	140	139	137	135	132	136	137	134	137	133	129	128	127	126	125	122	121	120	119
300	143	133	129	128	128	134	129	119	125	129	126	127	127	128	127	133	130	129	127	125	123	126	128	125	127	123	120	119	118	117	115	113	112	111	109
1,000	134	129	123	123	122	128	121	111	116	120	117	118	120	120	119	125	121	119	117	117	113	117	118	116	118	114	110	110	109	108	106	104	102	100	98
3,000	128	121	117	116	113	122	114	105	111	114	111	113	112	113	112	119	116	116	113	112	110	112	113	112	114	110	107	106	104	103	102	102	99	96	91
10,000	123	113	110	108	107	115	109	99	105	110	105	107	106	107	105	113	110	110	109	109	108	111	111	111	117	113	110	109	105	105	104	89	83	74	60
30,000	115	106	102	100	100	108	102	91	98	103	98	100	100	100	100	106	104	104	102	101	100	104	104	104	109	105	102	101	96	96	97	61	44	16	
100,000	107	97	94	93	93	101	93	85	90	94	91	92	93	92	90	98	95	96	94	93	92	95	97	97	100	99	95	92	92	91	90				
130,000	105	95	92	89	90	98	91	83	89	92	89	88	91	91	88	96	93	93	93	93	90	95	96	96	99	97	94	92	92	91	90				
160,000	104	87	84	86	86	94	86	78	83	87	83	84	85	85	83	90	89	89	87	89	86	91	93	92	96	94	91	90	90	88	90				

Table2a. Estimated sound levels at set radii from panamax-size ore carrier in the vicinity of Koluktoo Bay, during open water conditions.

Range (m)	broad band	Frequency (Hz)																															
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	160	124	128	131	134	139	142	146	150	153	152	150	147	147	146	145	144	143	142	141	141	139	138	136	136	136	135	133	132	132	131	127	126	125	124
300	152	118	121	125	127	132	137	140	144	146	144	142	139	138	138	136	136	135	135	133	132	132	130	128	128	127	126	125	123	122	122	120	119	118	118
1,000	146	108	117	117	122	126	129	133	137	139	139	138	135	134	133	131	134	133	130	129	129	128	128	126	124	124	122	119	119	118	117	115	113	111	110
3,000	137	100	105	107	108	113	117	121	126	129	129	126	125	126	127	127	128	127	125	125	125	125	124	124	122	121	121	117	116	115	115	107	104	100	96
10,000	124	84	85	89	93	97	101	105	109	112	113	113	111	114	114	115	115	114	114	113	113	113	111	111	109	108	107	104	103	99	100	89	82	72	59
18,000	123	78	80	84	89	94	100	103	108	114	114	112	111	113	114	114	116	116	116	115	115	111	110	108	108	108	102	101	96	95	92				

Table2b. Estimated sound levels at set radii from panamax-size ore carrier in the Milne Inlet area, during open water conditions.

Range (m)	broad band	Frequency (Hz)																															
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	160	125	129	132	135	139	142	147	151	153	152	150	148	147	146	145	144	143	142	141	141	140	139	137	136	136	135	134	132	132	131	128	126	125	125
300	151	118	121	125	128	131	136	140	143	146	144	141	139	139	137	136	136	135	134	132	131	131	130	128	127	127	126	125	123	122	122	120	119	118	118
1,000	145	111	115	119	121	126	129	133	136	139	139	136	134	132	130	132	129	129	127	127	126	125	124	123	122	121	120	118	116	116	113	113	111	110	108
3,000	139	107	110	112	117	119	123	127	130	133	133	129	127	126	125	125	124	123	122	120	121	120	119	117	116	115	114	113	110	111	110	102	98	95	90
10,000	134	101	102	107	110	114	119	125	127	129	129	127	123	122	120	121	119	118	120	119	119	117	115	113	115	114	114	112	112	110	110	93	87	77	64
30,000	128	88	90	98	102	105	110	115	118	121	122	120	120	119	117	117	116	115	115	115	114	113	113	111	109	109	107	105	104	103	102	65	47	19	
68,000	121	72	73	85	86	96	95	100	110	109	112	109	111	111	111	108	107	108	108	107	107	105	104	103	101	101	99	97	95	94	91	15			

Table2c. Estimated sound levels at set radii from panamax-size ore carrier in Eclipse Sound, during open water conditions.

Range (m)	broad band	Frequency (Hz)																															
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	160	126	128	132	135	139	142	148	150	153	153	150	148	147	146	145	144	143	142	141	141	140	139	137	136	136	135	134	132	132	131	128	126	125	125
300	151	117	122	125	129	131	136	139	143	144	143	141	138	139	137	136	135	136	134	132	131	131	130	128	127	127	126	125	123	122	122	120	119	118	118
1,000	146	113	116	120	123	127	130	134	137	141	139	137	134	133	131	131	130	129	128	127	125	126	124	122	122	121	120	118	117	116	116	113	111	110	108
3,000	141	108	110	114	118	121	125	129	133	135	136	133	129	128	125	125	125	124	124	122	123	123	121	118	119	117	116	114	113	112	111	103	100	96	92
10,000	136	100	103	108	111	114	120	124	128	132	130	128	126	124	123	122	121	121	121	119	119	118	117	115	114	114	115	112	113	110	111	94	87	77	64
30,000	124	88	91	94	100	103	110	112	116	118	119	117	117	114	114	113	111	112	111	112	112	110	110	108	107	106	107	102	104	103	101	65	47	18	
100,000	117	84	84	89	96	95	100	103	108	110	112	109	107	107	107	108	108	107	108	108	108	107	106	103	104	106	106	105	102	99	98				

Table2d. Estimated sound levels at set radii from panamax-size ore carrier in Pond Inlet, during open water conditions.

Range (m)	broad band	Frequency (Hz)																															
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	160	124	127	131	134	138	143	146	151	153	152	150	148	147	146	145	144	143	142	141	141	140	139	137	136	136	135	134	132	132	131	127	126	125	124
300	150	114	119	122	125	129	133	137	141	143	143	140	138	137	137	136	135	134	133	132	131	131	130	128	127	127	126	125	123	122	122	120	119	118	118
1,000	141	110	112	117	120	123	126	129	133	134	134	131	128	128	127	127	126	125	125	123	123	121	120	118	118	117	115	114	113	113	112	113	111	109	108
3,000	136	103	106	111	111	117	119	123	128	130	130	129	125	125	123	122	120	120	120	119	119	117	116	115	115	114	113	110	109	109	108	101	97	93	89
10,000	131	94	99	103	105	110	114	118	122	125	124	123	120	120	118	119	118	118	118	118	118	117	115	113	113	113	113	112	111	110	110	93	86	77	64
30,000	124	88	91	95	98	102	106	109	115	118	117	116	114	113	112	112	111	112	110	112	112	109	107	107	108	105	107	103	105	104	101	64	47	18	
100,000	116	79	84	87	91	95	98	104	108	109	111	108	107	106	105	104	105	104	104	104	105	103	103	103	103	103	101	100	99	98	96				
130,000	114	76	81	84	89	93	96	102	106	108	107	105	105	104	103	103	103	103	103	103	103	102	101	101	102	102	100	99	99	98	96				
160,000	113	69	73	81	84	88	91	97	100	102	102	100	100	100	99	99	100	99	100	100	100	100	99	99	98	98	96	95	96	94	93				

Table3a. Estimated sound levels at set radii from Post-Panamax-size ore carrier in the vicinity of Koluktoo Bay, during open water conditions.

Range	broad	Frequency (Hz)																																	
(m)	band	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	164	129	133	137	139	144	147	151	155	157	156	153	151	150	149	148	147	146	145	144	144	143	141	140	140	139	138	137	135	135	134	131	129	128	128
300	156	123	127	130	132	138	142	145	148	150	148	144	143	142	140	140	139	138	137	136	135	135	133	131	131	130	129	127	126	126	125	122	120	119	118
1,000	151	113	122	123	127	131	134	138	142	144	144	142	139	137	136	137	137	135	134	134	132	131	131	129	129	128	126	123	123	122	120	118	116	115	113
3,000	141	105	110	112	113	119	122	127	131	135	134	131	130	131	132	132	131	129	127	128	128	127	129	125	126	125	123	122	120	119	117	110	107	103	99
10,000	129	89	90	95	98	102	106	111	115	118	119	118	116	119	119	120	120	119	118	116	116	115	116	113	111	111	109	108	105	105	101	92	85	75	63
18,000	128	83	86	89	95	100	105	108	114	119	120	117	116	118	119	119	121	120	120	118	118	115	114	114	109	110	105	104	102	100	97				

Table3b. Estimated sound levels at set radii from Post-Panamax-size ore carrier in the Milne Inlet area, during open water conditions.

Range	broad	Frequency (Hz)																																	
(m)	band	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	164	130	135	138	140	144	147	151	155	157	156	154	152	150	150	149	148	147	146	145	144	144	142	141	140	139	138	137	136	135	134	131	129	129	128
300	155	123	126	131	134	136	141	144	147	149	147	145	143	141	141	140	139	138	136	135	135	134	133	131	131	130	129	127	126	126	125	122	120	119	118
1,000	150	116	121	124	127	132	134	138	141	144	143	140	137	135	136	133	133	131	131	130	129	128	128	126	125	124	123	121	120	119	117	116	114	113	112
3,000	143	113	115	117	122	124	128	132	135	137	137	132	129	129	129	129	127	126	125	125	122	122	123	120	119	119	117	116	114	115	113	105	101	98	93
10,000	138	107	108	112	115	120	124	130	132	134	133	130	126	125	124	125	123	124	122	122	123	120	119	118	119	117	117	115	115	113	113	98	91	82	69
30,000	133	93	95	103	107	111	115	120	124	126	127	125	124	122	121	120	120	119	119	118	118	117	116	114	112	113	110	109	107	108	105	68	50	22	
68,000	125	78	79	91	92	102	100	106	115	115	118	114	115	115	115	112	112	114	111	111	110	110	107	106	105	106	103	101	98	96	95	18			

Table3c. Estimated sound levels at set radii from Post-Panamax-size ore carrier in Eclipse Sound, during open water conditions.

Range	broad	Frequency (Hz)																																	
(m)	band	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	164	131	134	137	140	144	147	152	155	157	157	154	151	151	150	149	147	147	146	145	144	144	142	141	140	139	138	137	136	135	134	131	129	129	128
300	155	122	127	130	134	137	141	144	147	148	147	144	142	142	141	140	139	139	137	135	135	134	133	131	131	130	129	127	126	126	125	122	120	119	118
1,000	150	119	121	125	128	132	135	139	142	144	143	140	138	135	135	134	133	132	132	130	130	129	128	126	125	124	123	122	120	120	119	116	114	113	112
3,000	145	114	116	120	123	126	130	134	138	140	140	136	131	129	130	130	130	128	126	126	126	125	124	121	122	120	119	117	116	116	115	106	103	100	95
10,000	140	106	109	114	116	120	126	129	133	136	134	132	129	128	127	125	124	126	123	122	122	122	120	119	117	118	116	115	115	114	114	98	91	82	69
30,000	129	94	97	100	105	108	115	117	122	123	124	122	120	117	118	115	116	115	115	115	114	113	112	111	109	111	109	107	107	106	106	67	49	21	
100,000	122	90	90	94	101	100	105	109	113	115	117	113	111	111	112	113	113	112	112	112	111	111	109	107	107	109	111	107	102	103	103				

Table3d. Estimated sound levels at set radii from Post-Panamax-size ore carrier in Pond Inlet, during open water conditions.

Range	broad	Frequency (Hz)																																	
(m)	band	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	164	130	133	137	140	144	148	151	155	157	157	154	151	151	150	149	147	147	146	145	144	144	142	141	140	139	138	137	136	135	134	131	129	128	128
300	154	120	124	127	131	134	138	142	146	148	147	144	142	141	140	139	138	137	136	135	135	134	133	131	131	130	129	127	126	126	125	121	119	119	118
1,000	145	116	118	123	125	128	131	134	137	139	138	134	132	132	131	131	129	128	128	126	126	125	123	122	121	120	119	118	117	116	115	116	114	113	112
3,000	141	108	112	116	117	122	125	129	133	135	134	132	129	126	126	125	125	124	123	123	124	122	120	119	117	117	115	114	113	112	111	104	100	96	92
10,000	135	100	104	108	111	115	120	123	127	130	129	127	124	124	122	122	122	123	123	121	120	118	118	117	116	117	115	115	114	114	113	98	91	82	69
30,000	128	93	97	100	104	108	112	115	121	123	122	120	118	118	115	116	115	116	115	116	113	111	111	111	109	111	108	106	108	106	105	67	49	21	
100,000	121	84	89	92	97	101	104	109	113	115	116	113	112	110	109	108	110	109	108	108	108	106	106	107	105	105	107	102	102	101	99				
130,000	118	82	86	89	94	98	101	107	112	113	112	109	109	108	107	107	108	108	108	107	106	105	105	104	103	106	103	101	101	100	99				
160,000	117	74	78	86	89	94	97	102	106	108	107	105	104	105	103	104	105	104	104	104	104	103	102	102	101	102	101	99	100	100	97				

Table4. Estimated sound levels at set radii from dredging operating at the Freight Dock, during open water conditions.

Range (m)	broad band	Frequency (Hz)																																
		10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	156	124	131	133	136	138	138	137	139	140	141	148	147	149	147	145	145	146	142	143	140	134	134	132	129	125	127	126	126	124	123	123	119	116	113
300	150	117	124	127	130	131	131	131	133	133	135	143	139	141	140	138	140	139	136	136	132	129	128	125	122	122	121	120	119	122	117	116	112	109	106
1,000	141	114	122	120	123	125	123	122	125	125	126	135	132	134	133	131	129	130	128	128	124	119	119	118	115	114	113	112	111	112	111	107	103	99	95
3,000	135	105	111	112	116	117	117	116	119	119	121	127	127	129	127	125	125	124	123	124	120	116	116	112	109	107	108	107	107	107	104	101	95	90	83
10,000	135	96	104	108	111	114	115	116	117	119	121	127	127	127	127	127	125	124	123	124	118	115	112	109	106	103	102	101	99	99	97	87	77	65	49
20,000	125	84	93	97	103	104	107	106	108	106	112	114	113	113	119	112	116	114	112	113	109	101	97	95	91	90	89	86	85	87	84				

Table5a. Estimated sound levels at set radii from sheet pile driving operating at the Ore Dock, during open water conditions.

Range	broad	Frequency (Hz)																																	
(m)	band	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	181	109	110	112	118	120	127	132	137	142	153	152	162	164	165	167	171	175	169	166	169	171	174	165	162	165	163	163	162	159	157	154	153	151	147
300	174	102	108	111	115	118	122	126	130	134	145	145	156	157	158	160	164	170	159	162	162	165	168	160	155	157	156	155	153	153	150	146	146	143	139
1,000	165	101	106	111	111	113	114	118	122	126	137	136	147	149	149	152	153	160	153	152	156	157	158	150	145	148	149	150	143	144	142	139	137	135	130
3,000	159	95	96	100	101	102	106	111	115	120	130	130	140	141	143	146	148	153	148	149	151	151	154	146	141	143	142	143	142	138	137	130	128	123	116
10,000	159	86	88	93	96	99	104	110	114	119	130	131	141	144	145	148	152	156	149	149	149	150	152	145	141	140	139	137	134	134	130	119	112	100	83

Table5b. Estimated sound levels at set radii from sheet pile driving operating with bubble curtains at the Ore Dock, during open water conditions.

Range	broad	Frequency (Hz)																																	
(m)	band	10	13	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
100	170	109	110	113	118	120	127	132	137	140	151	149	157	159	160	161	163	163	157	154	157	159	159	150	147	150	148	147	147	144	143	141	142	142	140
300	163	103	108	111	115	118	122	126	130	132	143	142	151	152	153	154	156	158	147	150	150	153	153	145	140	142	141	140	138	138	136	133	135	134	132
1,000	154	101	106	111	111	113	114	118	122	124	135	133	142	144	144	146	145	148	141	140	143	145	143	135	130	133	134	135	128	129	129	126	126	126	122
3,000	148	95	96	100	101	102	106	111	115	118	128	127	135	136	138	140	140	141	136	137	139	139	139	131	126	128	127	128	127	123	123	117	117	114	108
10,000	149	86	88	93	96	99	104	110	114	117	128	129	136	139	140	142	144	144	137	137	137	138	137	130	126	125	124	122	119	119	116	106	101	91	76