AREVA

Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 7B
Underwater Acoustic Modelling

September 2014

History of Revisions

Revision Number	Date	Details of Revisions
01	December 2011	Initial release Draft Environmental Impact Statement (DEIS)
03	September 2014	FINAL Environmental Impact Statement

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Abbreviations

µPa .... Micropascal

dB .... Decibel

BHP .... Brake Horsepower

Hz .... Hertz

kHz .... Kilohertz

SPL .... Sound Pressure Level

ATB .... Articulated Tug and Barge

PE .... Parabolic Equation

RAM .... Range-dependent Acoustic Model

MONM .... Marine Operations Noise Model

SL .... Source Level

TL .... Transmission Loss

VEC .... Valued Ecosystem Component

UTM .... Universal Transverse Mercator

ppt .... parts per thousand

GDEM .... Generalized Digital Environmental Model

GINA .... Geographic Information Network of Alaska

ha .... hectare

HT .... Hearing Threshold

rms .... root mean square

1 Introduction

The Kiggavik Project is a proposed uranium ore mining and milling operation by AREVA Resources Canada, to be located in the Kivalliq region of Nunavut. A number of segments of marine transport are being considered to support the Kiggavik Project. This report focuses on the Churchill to Baker Lake segment, where supplies for the project would be transported by articulated tug and barge (ATB) north from Churchill to Baker Lake via Chesterfield Inlet during the open-water operating season from August to September (AREVA, 2008). The communities of Chesterfield Inlet, Rankin Inlet, Whale Cove and Arviat have substantial annual subsistence harvests of seal, arctic char and beluga whale, and noise impacts on subsistence animals will be a source of concern to the communities. Valued ecosystem components (VECs) that could be impacted by marine transportation noise include arctic char, belugas, harp seals, ringed seals, and bearded seals.

This report presents results from an acoustic modelling study, performed by JASCO Applied Sciences, to estimate the footprint of underwater sound levels emitted by tug and barge operations along the proposed marine transportation route. Advanced numerical modelling software was used to predict broadband underwater sound level distributions resulting from transiting ATBs. Sound pressure level (SPL) distributions were modelled for four scenarios, each at a unique location of interest along proposed tug transit route. The model results for each scenario are presented as unweighted and audiogram-weighted SPL contour maps. Tables of distances and areas to specified SPL thresholds are also presented. This report also includes a discussion of potential impacts and noise mitigation strategies, as well as a brief summary.

2 Methods

2.1 Scenarios and Locations

In this study, acoustic modelling of tug and barge traffic has been carried out at four locations along the planned tug and barge transportation route. The four modelling locations were selected based on proximity of the planned transportation route to each community. The four acoustic modelling scenarios considered in the current study are as follows:

- Scenario 1: ATB transiting in Chesterfield Inlet;
- Scenario 2: ATB transiting off Rankin Inlet;
- Scenario 3: ATB transiting off Whale Cove; and
- Scenario 4: ATB transiting off Arviat.

The locations of the four modelling scenarios in Hudson Bay and Chesterfield Inlet are shown in Figure 2.1-1. Coordinates and descriptions of the model scenarios are listed in Table 2.1-1.

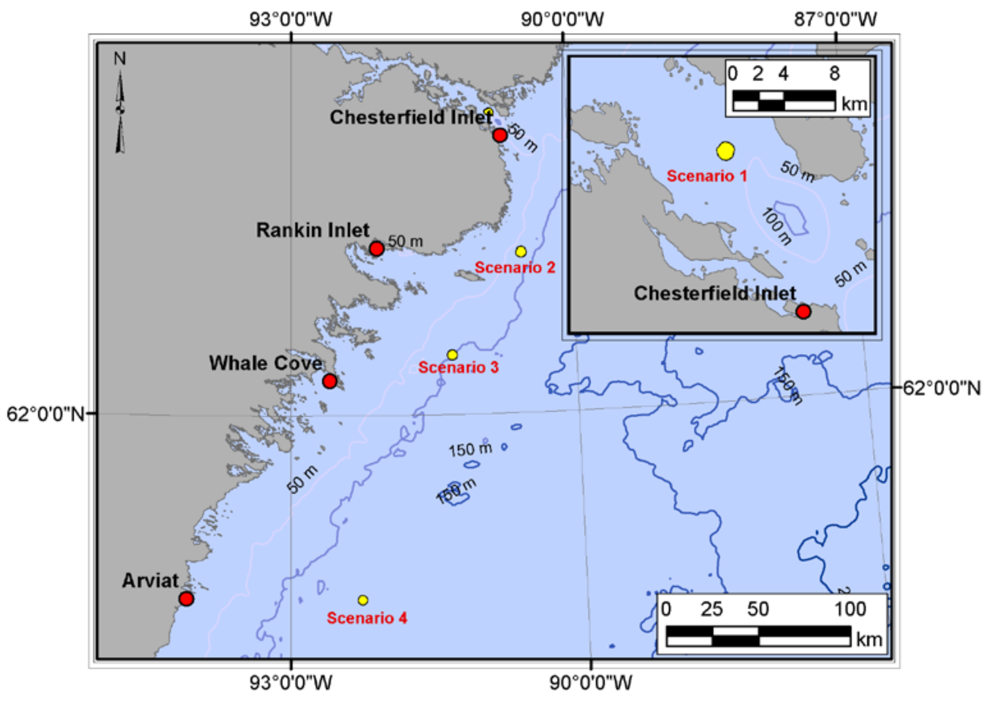

Figure 2.1-1 Locations of the four acoustic modelling scenarios along the proposed tug and barge route

Table 2.1-1 Locations of the four acoustic modelling scenarios. UTM coordinates are Zone 15N

Scenario	Description	Latitude	Longitude	UTM Northing (m)	UTM Easting (m)
1	ATB Transiting in Chesterfield Inlet	63.468° N	90.843° W	7039544	607493
2	ATB Transiting off Rankin Inlet	62.782° N	90.550° W	6963702	624997
3	ATB Transiting off Whale Cove	62.290° N	91.308° W	6907665	587745
4	ATB Transiting off Arviat	61.102° N	92.275° W	6774337	539086

2.2 Acoustic Source Levels

AREVA has proposed to use 4500 BHP, twin-screw, ice-class tugs for transporting barges to the Baker Lake dock site. This study modelled noise emitted from tugs only. Barges are not expected to contribute substantially to underwater noise because barge thrusters are not expected to be used while transiting, only during berthing and close-in manoeuvring. A review of the available literature found no measurements of this specific class of tug. The most representative available measurements were for a 6600 BHP ocean-going anchor handling tug (Britoil 51, Hannay et al, 2004). The 1/3-octave band source levels of the 4500 BHP tugs were estimated from the 6600 BHP tug measurements by applying corrections according to an empirical model relating ship noise emissions to speed, length, and engine power (Ross, 1976):

$$S(f,V,L,P) = S_0(f) + c_v 10\log\left(\frac{V}{V_0}\right) + c_L 10\log\left(\frac{L}{L_0}\right) + 10\log\left(\frac{P}{P_0}\right) \quad (1)$$

where S and f are the source level spectra and frequency, S_0, V_0, L_0 and P_0 are the reference source level spectra, speed, length and power. The constants, c_V and c_L, are taken to be 6 and 2, respectively (Wales and Heitmeyer, 2002). This empirical relationship was derived from an ensemble average of measurements from a large number of vessels. The general specifications for the modelled and reference tugs are shown in Table 2.2-1. The length, draft, propeller diameter, and speed of modelled tugs were estimated based on other 4500 BHP tugs of similar rated engine power.

Table 2.2-1 General specifications for the modelled tugs and reference tug

Tug	Type	Power (BHP)	Length (m)	Draft (m)	Propeller diameter (m)	Speed
Modelled Tug	Ocean-going Ice-class	4500	44	4.6	2.7	Assumed 13 knots
Reference Tug	Ocean-going Anchor Handling	6600	45	4.5	3.2	Transiting 13 knots

The modelled tug was assumed to be transiting at the same speed as the reference tug. Because source levels for the reference tug were not available above 10 kHz, modelled source levels were extrapolated to 31.5 kHz based on another empirical relationship that describes the typical high-frequency trend of source spectral levels for surface vessels (Ross, 1976):

$$L_s(f) \propto -20\log f \qquad f > 10\,\text{kHz}$$

where L_S is the source spectrum level (dB re 1 μPa/√Hz @ 1 m) at frequencies above 10 kHz. These levels then were integrated into 1/3-octave band source levels (Figure 2.2-1). The source depth *Zs* of the modelled tug was estimated to be 2.6 m based on the draft *D* and propeller diameter *Dp* using the following equation (Wright and Cybulski, 1983):

$$Z_s = D - \frac{3}{4} D_p$$

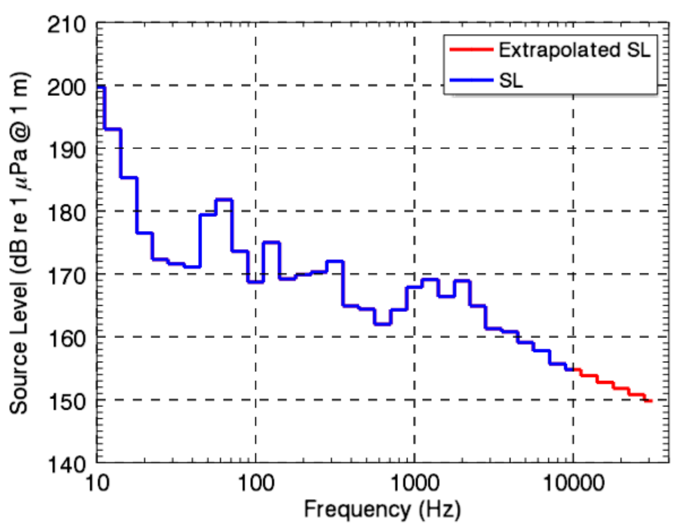

Figure 2.2-1 Estimated 1/3-octave band source levels versus frequency for modelled 4500 BHP tugs

The blue solid line represents the source level up to 10 kHz estimated based on the measurement of Britoil 51. The red solid line represents the extrapolated source level up to 31.5 kHz.

2.3 Sound Propagation Model

The acoustic propagation model used to predict underwater sound levels was JASCO's Marine Operations Noise Model (MONM). MONM treats sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation. The PE 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 shear wave losses from elastic seabeds. The PE 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 sea floor. It also accounts for the additional reflection loss 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. 1/3-octave band received levels are computed by subtracting band transmission loss values from the corresponding source levels. Broadband received levels are then computed by summing the received band levels. MONM's sound level predictions have been validated against other models and experimental data (Hannay and Racca, 2005).

The numerical estimation from MONM was further corrected to account for the absorption of some of the acoustic energy as sound waves interact at a molecular level with the constituents of sea water through a range of mechanisms. The volumetric sound absorption is quantified by an attenuation coefficient, expressed in units of decibels per kilometer (dB/km). This coefficient for seawater can be computed according to the formulation of Francois and Garrison (1982 a, b) which takes into account the contribution of pure seawater, magnesium sulfate and boric acid. It applies to all oceanic conditions and frequencies from 200 Hz to 1 MHz. In this study the water temperature (in degree Celsius) and salinity (in parts per thousand, ppt) in Hudson Bay were estimated from Beaudoin et al., (2006) to obtain the absorption coefficients, which were applied to the transmission loss computed by MONM at frequencies from 1 to 31.5 kHz.

2.4 Acoustic Environment

2.4.1 Water sound speed profile

MONM samples the vertical sound speed profile of the water column along each radial traverse extending from the sound source. Sound speed profiles were derived from ocean temperature and salinity data obtained from the Generalized Digital Environmental Model -GDEM 3.0 database (Teague *et al*., 1990), and measurements from Beaudoin et al. (2006). GDEM is published by the U.S. Naval Oceanographic Office and contains globally gridded ocean temperature and salinity data for each month of the year. The database has specialized extraction routines that use this information to compute sound speeds at various depths for user-specified months and geographic locations. The modelled sound speed as a function of water depth for August and September in west Hudson Bay is shown in Figure 2.4-1).

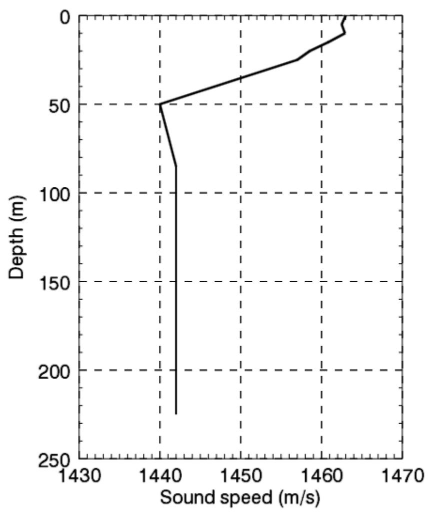

Figure 2.4-1 Estimated mean water sound speed profile in west Hudson Bay, as derived from GDEM and Beaudoin et al. (2006)

2.4.2 Geoacoustics

Sound propagation in shallow water is strongly influenced by the geoacoustic properties of the sea floor. These include the density (ρ), the compressional wave speed (V_P), the shear wave speed (V_s), the compressional wave attenuation (α_P), and the shear-wave attenuation (α_s) of the seabed sediments. MONM takes all of these parameters into account when calculating transmission loss. A review of the available literature found that very limited information was available regarding the seabed geology of west Hudson Bay. Martini (1986) indicated that the major sediment types on seafloor of eastern Hudson Bay are silt and silty sand. Armstrong (2010) and Haberzettl (2010) reported core samples in Hudson Bay showing that sediments were comprised of silt, shale, and limestone.

In this study, geoacoustic properties for the silt layer were computed based on Buckingham's grain-shearing model (Buckingham, 2005). The grain-shearing model computes geoacoustic properties of seabed sediments (sand, silt, clay) from porosity and grain size. The geoacoustic properties for the layers of shale and limestone were estimated from a compendium of historical measurements by Hamilton (1980). Table 2.4-1 presents modelled geoacoustic parameters for west Hudson Bay.

Table 2.4-1 Modelled profiles of seabed geoacoustic properties for west Hudson Bay: ρ (density), V_P (compressional wave speed), α_P (compressional wave attenuation coefficient), V_s (shear wave speed), and α_s (shear wave attenuation coefficient). Shear wave properties are specified for the topmost layer only in MONM.

Depth (mbsf)	Sediment type	P (g/cm^3)	V_P (m/s)	α_P (dB/λ)	V_s (m/s)	α_s (dB/λ)
0-62	Silt	1.52	1508-1627	0.18-0.67	110	0.04
62-82	Shale	2.00	1867	0.383		
>82	Limestone	2.50	4305	0.086		

2.4.3 Bathymetry

MONM samples the depth of the ocean bottom from a gridded bathymetry file for the model area. For this study, gridded bathymetry information for Hudson Bay was obtained from the University of Alaska's Geographic Information Network of Alaska (GINA) dataset. GINA data consist of a combination of topography and bathymetry information from three publicly available gridded datasets, re-sampled and merged into uniformly registered latitude/longitude grids at 30 arcsecond resolution (Lindquist *et al.,* 2004). The GINA data were found to be too coarse for modelling sound propagation in Chesterfield Inlet; a high-resolution bathymetry dataset for this region (derived from multibeam sonar surveys) was therefore procured from TCarta Global Geospatial Data.

Point bathymetry soundings from both datasets were projected into UTM Zone 15N coordinates and interpolated onto a cartesian grid at 50 meters resolution. GINA bathymetry data were used for Scenarios 2-4 (off Rankin Inlet, Whale Cove, and Arviat). The high-resolution bathymetry dataset for Chesterfield Inlet was used for Scenario 1. Image plots of both bathymetry grids are shown in Figure 2.4-2.

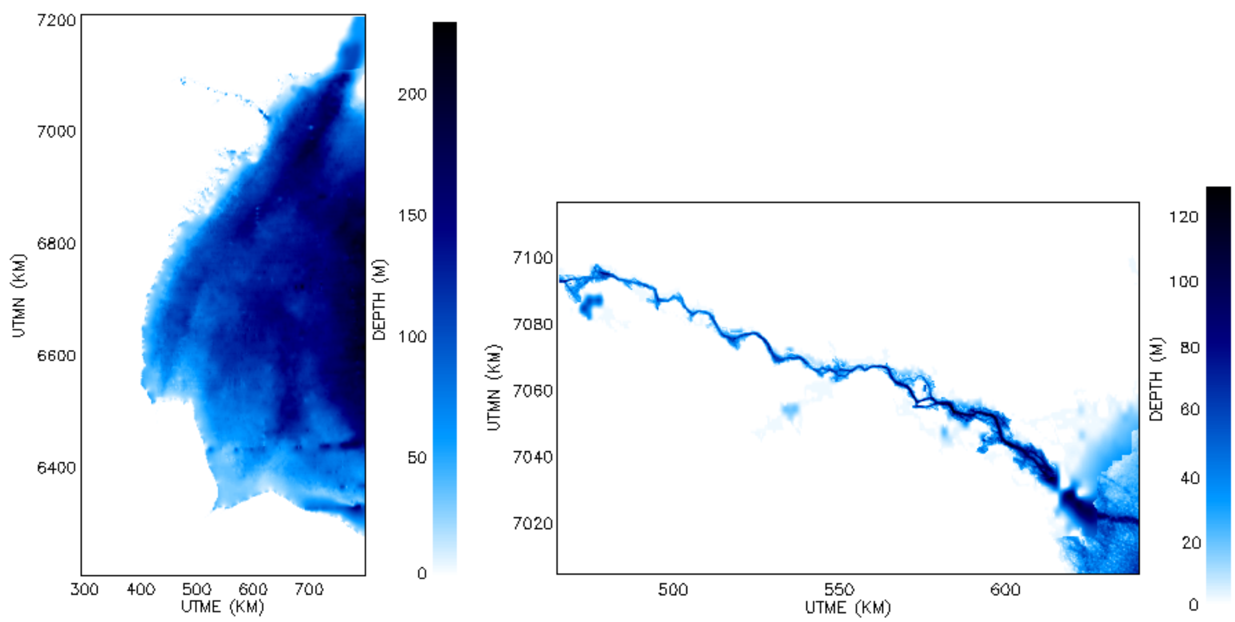

Figure 2.4-2 Plot of Hudson Bay (left) and in Chesterfield Inlet (right) bathymetry grids used for acoustic modelling. Coordinates are UTM Zone 15N.

2.4.4 Ambient Noise

Underwater ambient noise levels directly influence the zone of audibility of industrial noise for marine mammals. A review of the published literature found no publicly available information on underwater ambient noise in Hudson Bay. In lieu of direct measurements, underwater ambient noise levels for this geographic region were estimated based on empirical models of ocean noise. Surface agitation (i.e., wind and waves) is the dominant source of underwater ambient noise when shipping, precipitation, and marine life are absent. Baseline ambient noise levels were therefore estimated from the modelled surface agitation component for sea state 1 conditions (Figure 2.4-3, adapted from NRC 2003). Zones of audibility were taken to be the region where audiogram-weighted noise levels (see Section 2.5) exceeded ambient noise levels.

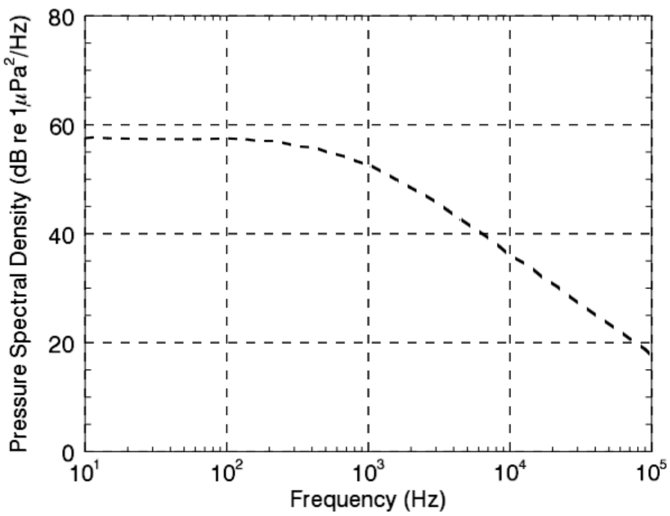

Figure 2.4-3 Modelled pressure spectral density contribution of surface agitation for sea state 1 conditions (adapted from NRC 2003, Fig 4-2)

2.5 Marine Mammal Audiograms

The potential for vessel operation noise to impact marine wildlife depends on how well the wildlife can hear the sounds produced. An animal's hearing sensitivity varies with frequency; the curve describing an animal's hearing threshold versus frequency is called an audiogram. With the exception of cases where the sound pressure is so high as to cause physical discomfort or injury, noises are less likely to disturb animals if they are at frequencies that the animals cannot hear well (i.e., where the hearing threshold is high). In this study, species-specific audiogram weighting was applied to the modelled noise levels. Figure 2.5-1 presents measured audiograms for the five VECs identified in the current study (adapted from Nedwell et. al., 2004 and Richardson et. al., 2007): arctic char, beluga whale, bearded seal, harp seal, and ringed seal. An audiogram for salmon was used as a surrogate for arctic char, since arctic char is a member of the Salmonidae family and is expected to have similar hearing sensitivity. Because ringed seal and harp seal audiograms only extended down to 1 kHz, they were extrapolated down to 100 Hz based on the trend of the harbor seal audiogram (Blackwell, 2004). The tabulated hearing thresholds of these species, at 1/3-octave band centre frequencies, are listed in Appendix B. In order to compute audiogram-weighted SPLs for each species, the 1/3-octave band hearing thresholds were subtracted from the corresponding modelled 1/3-octave band noise levels (maximized over depth in the water column), and the resulting weighted 1/3-octave band levels were summed to yield broadband noise levels above the hearing threshold.

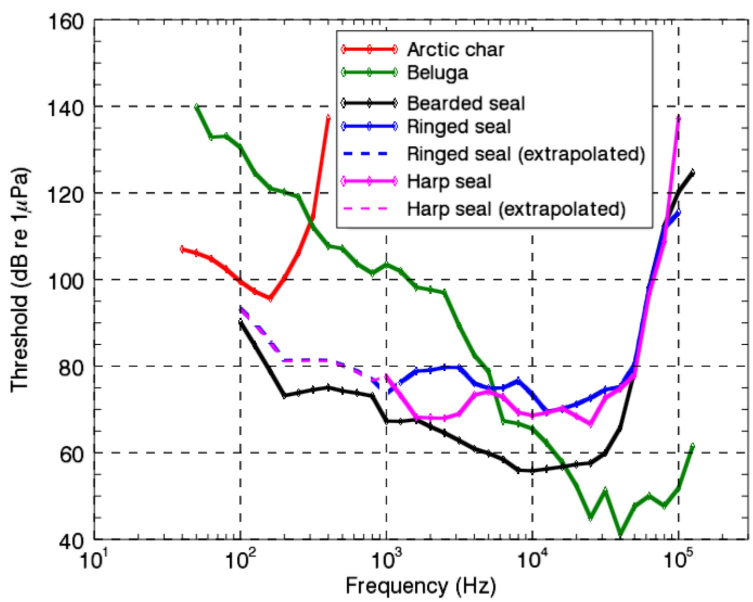

Figure 2.5-1 Modelled audiograms for arctic char, beluga, bearded seal, ringed seal, and harp seal in 1/3-octave bands.

3 Results

For each scenario, sound propagation was modelled inside a 100 km × 100 km computation area centered on each of the four modelling locations. The propagation model used a 50 m radial step size, providing high-resolution estimates of the sound field. SPL values were computed at 22 receiver depths ranging from 5 m below the water surface to the seabed. Post-processing of the model output involved gridding of all the data points in each horizontal plane separately at each depth. The resulting stack of grids was collapsed into a single grid using a maximum-over-depth rule, meaning that the sound level at each planar point was taken to be the maximum value that occurred over all modelled depths for that point.

Received SPLs (in dB re 1 μPa) were converted to noise contour maps showing the estimated acoustic footprint for each scenario. The maximum radius (R_{max}), 95th percentile radius ($R_{95\%}$), and total area were tabulated for each SPL contour. The maximum radius is defined as the greatest distance from the source to the specified threshold value, while the 95th percentile radius is defined as the radius of a circle that encompasses 95% of the grid points whose value is equal to or greater than the threshold value. For a given threshold level, the latter radius provides a range beyond which no more than 5% of a uniformly distributed population would be exposed to sound at or above that level, regardless of the geometrical shape of the noise footprint. The contour area represents the total geographic area ensonified above the specified threshold value. Contour areas are given in units of hectares (1 ha = 1×10^4 m^2).

3.1 Unweighted Sound Pressure Levels

Figure 3.1-1 shows unweighted, broadband (10 Hz to 31.5 kHz) SPL contours in dB re 1 μPa for all four ATB model scenarios. The map inset shows SPL contours for Scenario 1 (Chesterfield Inlet) at increased scale for greater detail.

Table 3.1-1 presents the contour radii and contour areas for each scenario. The distance to the 150 dB re 1 µPa SPL threshold was less than 100 m from the source in all cases. The shape of the SPL contours is strongly influenced by the underlying bathymetry. Seabed absorption of sound energy is generally greater in shallow water, hence the apparent truncation of the contours in the onshore direction for the Whale Cove and Rankin Inlet scenarios. Similarly, in the the relatively shallow water of Chesterfield Inlet, the close proximity of the river banks severely limits the distance that sound can travel, in comparison to the open-water scenarios, and leads to strongly anisotropic contours.

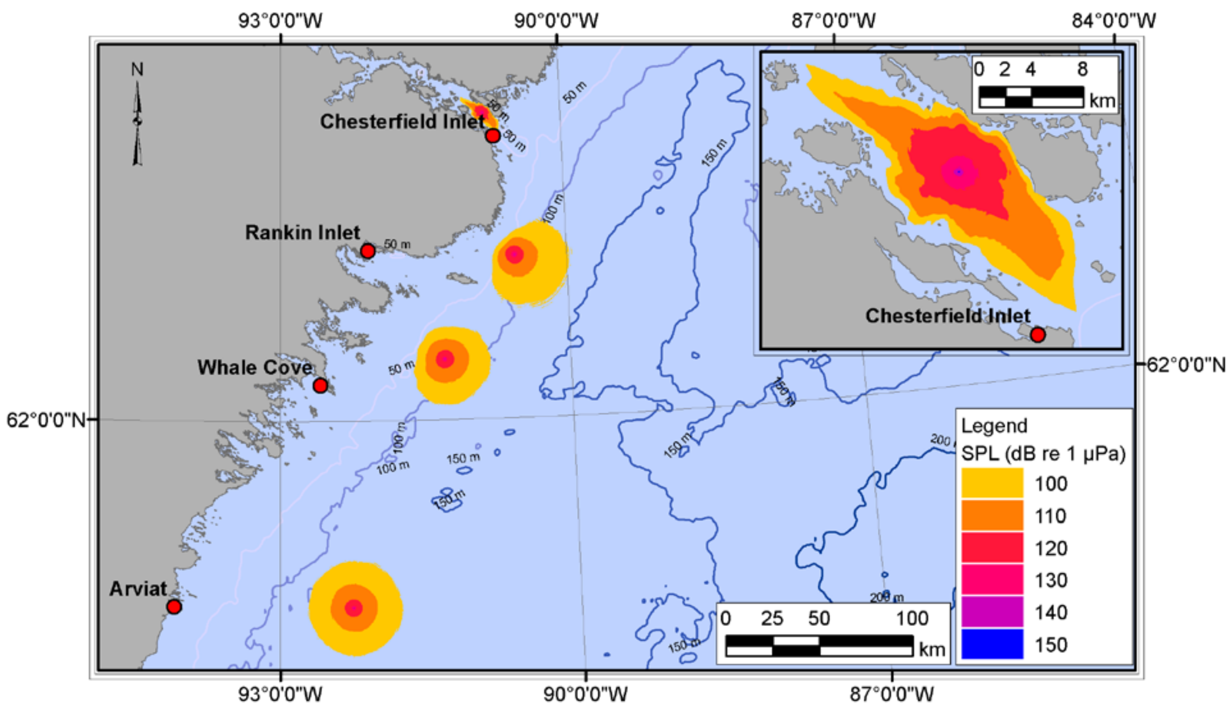

Figure 3.1-1 **Maps of unweighted SPL contours for tug and barge scenarios (10 Hz – 31.5 kHz)**

Table 3.1-1 Radii and areas of unweighted SPL contours

SPL (dB re 1 µPa)	*Scenario 1 (Chesterfield Inlet)*			*Scenario 2 (off Rankin Inlet)*			*Scenario 3 (off Whale Cove)*			*Scenario 4 (off Arviat)*		
	Rmax (km)	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rma (km)**	**R95% (km)**	**Area (ha)**
100	14.398	11.748	14535.3	33.524	27.974	144451.1	25.785	23.103	135487.0	27.536	24.654	167137.5
110	11.443	9.340	9687.4	13.207	11.809	35013.1	13.187	12.223	44264.1	13.358	12.366	50368.0
120	5.374	4.031	3842.1	5.168	4.808	7517.6	5.14	4.805	7520.7	4.876	4.617	7034.0
130	1.629	1.350	549.6	1.638	1.557	790.8	1.383	1.329	585.1	1.238	1.202	475.1
140	0.364	0.354	32.8	0.461	0.447	54.6	0.403	0.403	42.1	0.292	0.292	27.3
≥150	< 0.1	< 0.1	<3	< 0.1	<0.1	<3	< 0.1	<0.1	<3	< 0.1	<0.1	<3

3.2 Audiogram-weighted Sound Pressure Levels and Zones of Audibility

Audiogram-weighted SPL contours, or isopleth maps, were generated for each model scenario for arctic char (Figure 3.2-1), beluga (Figure 3.2-2), bearded seal (Figure 3.2-3), harp seal (Figure 3.2-4) and ringed seal (Figure 3.2-5). Representative radii and areas for a range of levels above marine animal hearing threshold were also tabulated for each scenario (Tables 3.2-1 to 3.2-5). Audiogram-weighted SPLs are given in dB units relative to the species-specific hearing threshold (dB re HT, by species). Zones of audibility, denoted as ZoA in the isopleth maps, were also estimated based on the comparisons of modelled noise levels with audiograms and ambient noise. Note that audiogram-weighted SPL for seals are only presented down to 20 dB re HT, since the contours at this level already reached the boundary of the modelling area. The estimated zone of audibility for seals also exceeded the modelling bounds; the maps show therefore the contour corresponding to 15 dB above the threshold of audibility. It is important to note that, because frequencies below1 kHz dominated vessel sound levels, calculation of the audiogram weighted levels for harp seals and ringed seals depended strongly on the extrapolated segments of their audiograms. The contours for these two species therefore appear quite similar because their extrapolated low-frequency hearing thresholds were nearly identical (see Section 2.5). Low frequencies are predominant at long ranges because they experience less absorption loss in seawater than high frequencies.

3.2.1 Arctic Char

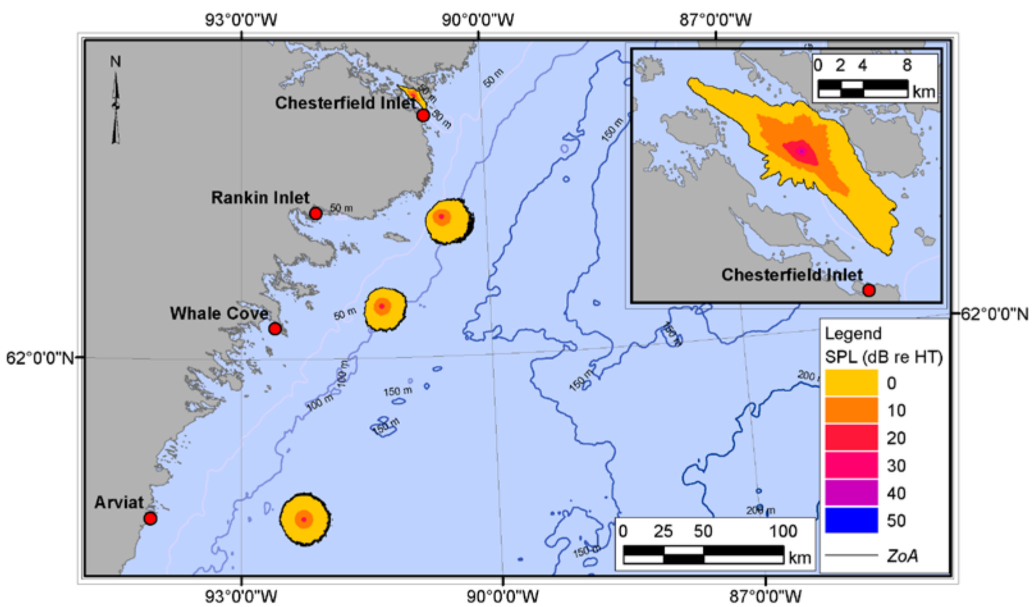

Figure 3.2-1 Maps of arctic char audiogram-weighted SPL (computed frequency band: 31.5 Hz – 400 Hz) contours for tug and barge scenarios. SPL unit is dB re HT (Arctic char).

Table 3.2-1 Radii and areas of arctic char audiogram-weighted SPL contours

SPL (dB re HT)	***Scenario 1 (Chesterfield Inlet)***			***Scenario 2 (off Rankin Inlet)***			***Scenario 3 (off Whale Cove)***			***Scenario 4 (off Arviat)***		
	Rmax (km)	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**
0	12.208	10.328	9197.0	21.133	18.089	62789.9	16.585	14.562	55543.5	17.891	15.290	74710.2
10	6.081	4.552	2745.6	6.863	5.692	9602.4	6.364	5.552	9543.5	5.985	5.680	10577.5
20	1.953	1.598	444.7	1.897	1.677	922.5	1.834	1.677	866.3	1.598	1.550	788.8
30	0.522	0.500	67.0	0.532	0.500	81.0	0.532	0.474	74.2	0.502	0.492	77.2
40	0.158	0.158	8.2	0.180	0.180	10.5	0.150	0.150	7.3	0.158	0.158	9.3
≥50	0	0	<1	0	0	<1	0	0	<1	0	0	<1

3.2.2 Beluga

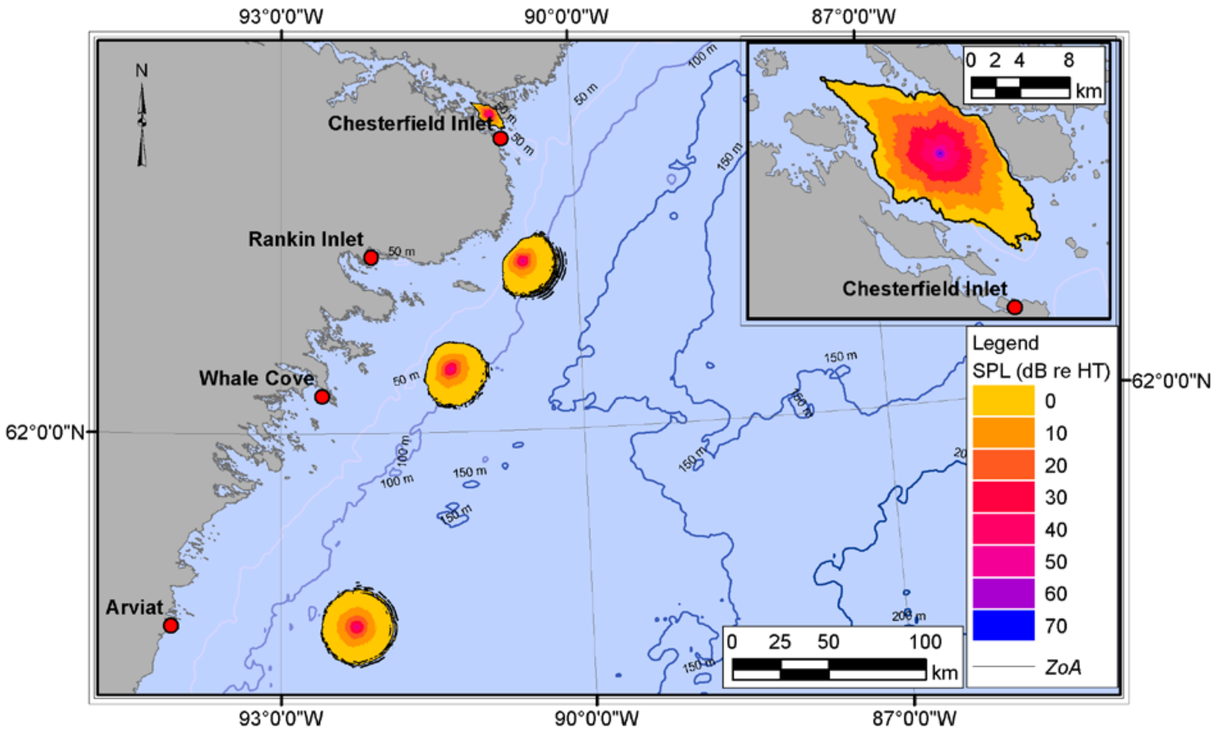

Figure 3.2-2 Maps of beluga audiogram-weighted SPL (computed frequency band: 40 Hz – 31.5 kHz) contours for tug and barge scenarios. SPL unit is dB re HT (Beluga).

Table 3.2-2 Radii and areas of beluga audiogram-weighted SPL contours

SPL (dB re HT)	***Scenario 1 (Chesterfield Inlet)***			***Scenario 2 (off Rankin Inlet)***			***Scenario 3 (off Whale Cove)***			***Scenario 4 (off Arviat)***		
	Rmax (km)	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**
0	11.485	8.972	11262.6	22.651	18.690	71623.6	21.338	18.057	83918.7	23.174	19.222	116308.3
10	7.213	5.685	7051.9	8.832	7.562	17446.5	10.791	9.018	24233.3	11.115	9.902	31658.0
20	4.860	3.835	4080.8	5.434	4.706	6772.0	6.255	5.348	8533.1	6.667	5.814	10911.8
30	3.124	2.566	1907.9	3.465	2.958	2777.2	3.733	3.314	3269.8	3.750	3.400	3754.7
40	1.768	1.521	684.1	1.844	1.657	885.2	1.972	1.767	961.6	1.916	1.751	1014.0
50	0.890	0.743	140.5	0.814	0.776	180.4	0.863	0.738	157.0	0.680	0.667	145.6
60	0.381	0.364	41.4	0.335	0.320	35.2	0.43	0.424	54.9	0.461	0.461	61.3
≥70	< 0.1	<0.1	<3	< 0.1	< 0.1	<3	< 0.1	< 0.1	<3	< 0.1	< 0.1	<3

3.2.3 Bearded Seal

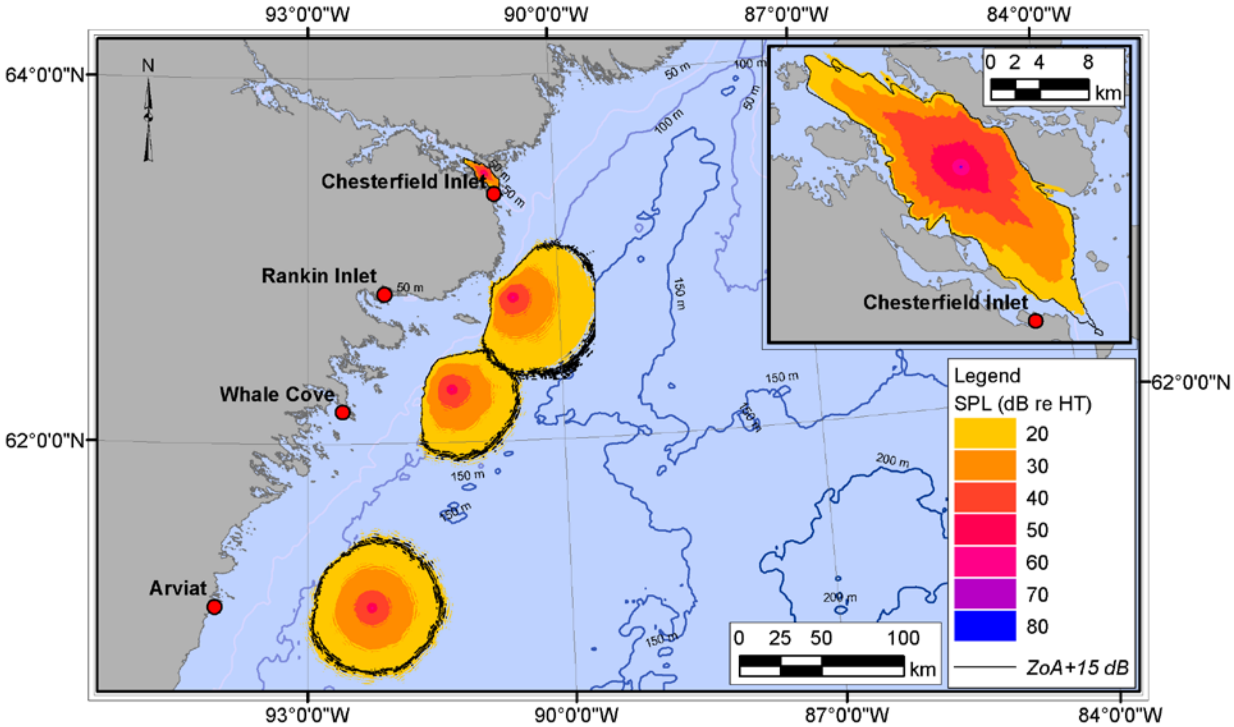

Figure 3.2-3 Maps of bearded seal audiogram-weighted SPL (computed frequency band: 80 Hz – 31.5 kHz) contours for tug and barge scenarios. SPL unit is dB re HT (Bearded seal).

Table 3.2-3 Radii and areas of bearded seal audiogram-weighted SPL contours

SPL (dB re HT)	***Scenario 1 (Chesterfield Inlet)***			***Scenario 2 (off Rankin Inlet)***			***Scenario 3 (off Whale Cove)***			***Scenario 4 (off Arviat)***		
	Rmax (km)	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**
20	15.627	12.943	18003.3	59.402	46.494	399898.5	48.976	41.598	337834.4	51.220	42.851	559236.8
30	12.592	10.480	13111.8	32.539	25.794	126657.3	29.683	23.724	127858.3	29.862	24.843	189125.3
40	8.184	5.942	6333.1	13.277	10.326	27727.3	13.507	11.050	31847.5	12.734	10.769	37169.6
50	3.227	2.421	1442.0	3.779	3.293	3530.2	3.905	3.247	3386.4	3.447	3.132	3233.5
60	0.716	0.671	146.5	0.820	0.750	183.3	0.743	0.711	167.3	0.743	0.721	174.3
70	0.316	0.292	11.2	0.304	0.304	22.2	0.158	0.158	9.3	0.158	0.158	9.3
≥80	< 0.1	<0.1	<3	< 0.1	< 0.1	<3	< 0.1	<0.1	<3	< 0.1	< 0.1	<3

3.2.4 Harp Seal

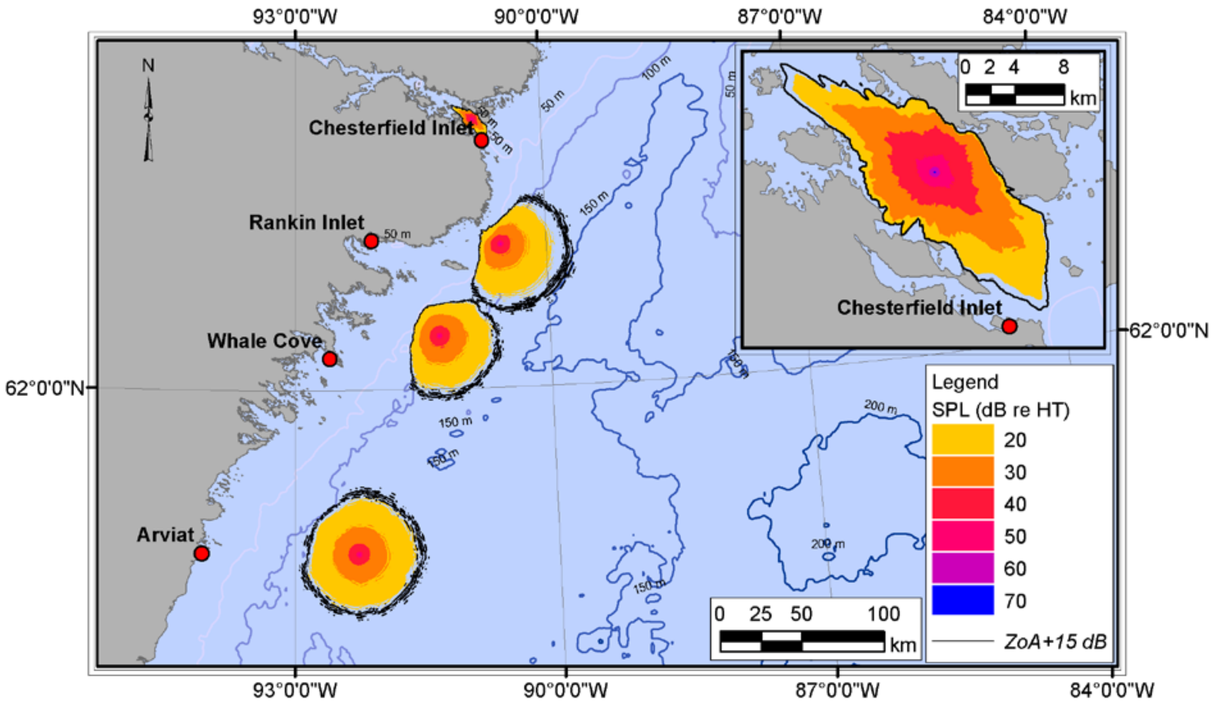

Figure 3.2-4 Maps of harp seal audiogram-weighted SPL (computed frequency band: 80 Hz – 31.5 kHz) contours for tug and barge scenarios. SPL unit is dB re HT (Harp seal).

Table 3.2-4 Radii and areas of harp seal audiogram-weighted SPL contours

SPL (dB re HT)	Scenario 1 (Chesterfield Inlet)			Scenario 2 (off Rankin Inlet)			Scenario 3 (off Whale Cove)			Scenario 4 (off Arviat)		
	Rmax (km)	R95% (km)	Area (ha)	Rmax (km)	R95% (km)	Area (ha)	Rmax (km)	R95% (km)	Area (ha)	Rmax (km)	R95% (km)	Area (ha)
20	14.038	11.363	15271.9	37.551	30.648	186774.5	36.215	30.437	202995.2	38.704	31.866	317669.2
30	10.569	7.864	9633.7	19.149	15.103	54281.2	19.535	16.134	69402.7	21.162	16.909	90639.3
40	5.218	4.031	3625.6	7.718	6.100	11573.1	7.849	6.270	12423.1	8.026	6.500	13686.1
50	1.840	1.524	607.6	2.080	1.851	1085.1	2.081	1.836	1032.1	1.942	1.867	1141.9
60	0.495	0.412	55.4	0.500	0.412	55.4	0.461	0.450	63.6	0.474	0.472	62.7
≥70	< 0.1	<0.1	<3	< 0.1	< 0.1	<3	< 0.1	< 0.1	<3	< 0.1	<0.1	<3

3.2.5 Ringed Seal

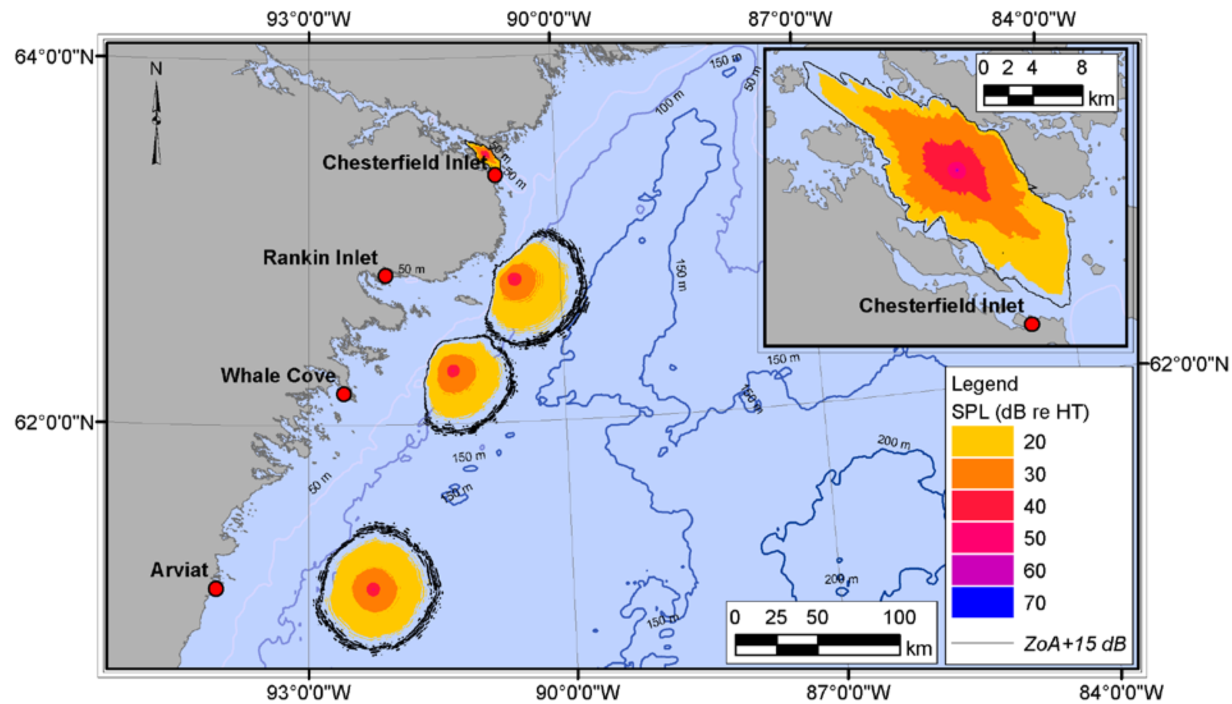

Figure 3.2-5 Maps of ringed seal audiogram-weighted SPL (computed frequency band: 80 Hz – 31.5 kHz) contours for tug and barge scenarios. SPL unit is dB re HT (Ringed seal).

Table 3.2-5 Radii and areas of ringed seal audiogram-weighted SPL contours

SPL (dB re HT)	***Scenario 1 (Chesterfield Inlet)***			***Scenario 2 (off Rankin Inlet)***			***Scenario 3 (off Whale Cove)***			***Scenario 4 (off Arviat)***		
	Rmax (km)	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**	**Rmax (km)**	**R95% (km)**	**Area (ha)**
20	13.788	11.224	14515.1	39.251	31.541	181210.8	32.202	27.459	162729.0	36.023	28.832	252511.3
30	9.599	7.004	7668.9	19.119	14.413	42091.7	15.871	13.340	44652.6	16.617	13.316	54520.9
40	3.650	2.977	1766.7	4.741	4.220	5418.3	5.408	3.854	4705.2	4.285	4.040	5342.9
50	0.791	0.716	162.8	0.930	0.873	252.1	0.806	0.762	191.5	0.791	0.776	198.0
60	0.200	0.141	6.5	0.141	0.141	6.2	0.141	0.141	6.2	0.141	0.141	6.2
≥70	< 0.1	< 0.1	<3	< 0.1	< 0.1	< 3	< 0.1	< 0.1	< 3	< 0.1	< 0.1	< 3

4 Discussion

4.1 Potential Impacts of Tug and Barge Noise

The dominant noise source from ATB transiting operations is expected to be the propulsion systems of the 4500 BHP tugs. At high propulsion levels, the predominant noise source with most vessels is propeller cavitation. The barges are not under their own power and therefore do not contribute substantially to underwater noise levels. The contours for the scenario off Arviat are the largest among the four locations, because the deeper water permits sound to propagate farther. The smallest estimated noise contours were observed in Chesterfield Inlet, where sound propagation was limited by the proximity of the river bank and islets in the river channel. The modelling results indicate that noise levels down to 120 dB re 1 µPa are estimated to extend 4-6 km from the transiting ATBs (up to 3800-7500 ha total ensonified area). Note that the current study has considered only noise levels originating from a single transiting ATB. Combined noise levels from two ATBs transiting together would be approximately 3 dB higher than the values presented here.

The potential impact of anthropogenic (man-made) noise on marine animals depends on the level of noise exposure. At low to moderate exposure levels, underwater noise may cause a change in the behaviour of a marine animal. At high exposure levels, underwater noise can induce hearing loss or physical injury. Noise levels from the ATBs (< 150 dB at distances > 100 m) are very unlikely to induce hearing loss or physical injury in marine mammals or fish over the brief exposure periods associated with a transiting vessel. Marine mammals may exhibit behavioural response to ATB noise: non-pulsed noise levels in the range 90-150 dB re 1 µPa have been observed to induce overt behavioural responses in free-ranging belugas and seals (Southall et al., 2007). The available data, however, indicate that response thresholds are highly variable and context specific. Behavioural response cannot occur below the threshold of audibility.

The zone of audibility of noise is estimated to be smallest (21 km or less) for arctic char, based on the audiogram for salmon which is a similar, hearing-generalist fish. The zone of audibility is also relatively small for belugas (23 km or less), due to their relatively poor hearing sensitivity at low frequencies where noise from the tugs is concentrated. The audiograms of bearded seals, harp seals, and ringed seals indicate that they have better low frequency hearing sensitivity, resulting in a larger zone of audibility (> 70 km). For these pinnipeds, the zone of audibility contour exceeded the extent of the modelling area. Audiogram-weighted SPLs were up to 70–80 dB above the hearing thresholds for pinnipeds at very short ranges (less than 0.1 km). Audibility of vessel noise along the proposed marine transportation route will also be limited by ambient noise levels. The accuracy of the estimated distances to the boundary of audibility is constrained by the lack of specific ambient noise data for Hudson Bay.

4.2 Noise Mitigation

Propeller cavitation is one of the primary sources of sub-surface acoustic noise from shipping, and is usually the strongest in terms of overall sound pressure (Ross, 1976, p. 272). Operational mitigation is best achieved by minimizing tug propulsion noise. Propeller cavitation is generally the dominant noise source, particularly at higher frequencies audible to many species of marine mammals. All propellers will cavitate if sufficiently loaded; the excessive load may be due to high installed power, rapid increase in revolutions, crash stops or violent manoeuvres. Good practices of propeller design will avoid cavitation under normal operation and raise the cavitation speed as much as possible. Many custom propeller shapes have been developed to combat cavitation; in particular, “high skew” propellers are well suited to minimizing cavitation and are readily available from many manufacturers. It is important, however, that the propeller be kept in good condition through monitoring and maintenance, since damage will increase the propensity to cavitate and generally result in higher noise. Other operational noise mitigation procedures for vessels are speed reduction, engine power reduction, and planning of routes and schedules to avoid areas of high use by VECs. The influence of vessel speed on sound emissions can be estimated using the empirical scaling equation of Wales and Heitmeyer (Section 2.2). For example, according to Equation (1), increasing vessel speed from 13 knots to 15 knots would increase underwater sound levels by approximately 3.7 dB (i.e., $60\times\log_{10}(15/13)$). This estimate is, of course, based on an empirical scaling law and so it should be interpreted as an approximate value.

5 Summary

Underwater sound levels from ATBs transiting from Churchill to Baker Lake have been modelled for the purpose of estimating potential disturbance to marine animals. VECs identified for this study include arctic char, beluga, bearded seal, harp seal, and ringed seal. The modelling results show that ATB noise during transiting is likely to be audible to all of the species of interest within a range of tens of kilometres from the source. Noise levels from ATBs may generate behavioural responses from VECs in close proximity to the vessel, but are not likely to result in hearing loss or injury.

For arctic char and belugas, noise levels from the ATBs are expected to fall below the threshold of audibility at ranges beyond about 20 km, whereas the same noise may be audible to seals at ranges beyond 70 km. The distance estimates to the boundary of audibility, however, are limited in accuracy by the lack of specific ambient noise data for Hudson Bay. The ATB noise level contours are largest offshore where conditions permit sound to propagate father, and much smaller in enclosed coastal zones like Chesterfield Inlet, where sound propagation is limited by the proximity of the river bank and islets in the river channel.

The best operational mitigation strategy for limiting the impact of ATB noise on marine animals is minimization of tug propulsion noise. Noise reduction approaches include optimal propeller selection (including the adoption of low-cavitation types such as “high skew” designs) and regular monitoring and maintenance to keep propellers in good condition. Other mitigation procedures include vessel speed reduction, engine power reduction, schedule management, and route planning to avoid areas of high use by VECs.

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7 Glossary

Audiogram

A curve of hearing threshold (SPL) as a function of frequency that describes the hearing sensitivity of an animal over its normal hearing range.

Audiogram Weighting

The process of applying an animal's audiogram to sound pressure levels to determine the sound level relative to the animal's hearing threshold (units dB re HT).

Broadband Sound Level

The total sound pressure level over a specified frequency range.

Decibel (dB)

A logarithmic unit of sound pressure. Numerically, the dB level is equal to $20 \times \log_{10}(P / P_{ref})$, where P is the sound pressure and P_{ref} is some reference pressure. In ocean acoustics, the standard reference pressure is taken to be 1 μPa.

Ensonified

Exposed to sound.

Geoacoustic

Relating to the acoustic properties of the seabed.

Parabolic Equation (PE) Method

A computationally-efficient solution to the acoustic wave equation that is used for modelling transmission loss (TL). The PE approximation simplifies the computation of TL by neglecting the back-scattered component of the acoustic field. This component is very small for most ocean-acoustic propagation problems.

Sound Pressure Level (SPL)

The decibel ratio of sound pressure to some reference pressure, expressed in units of dB re 1 μPa in ocean acoustics. Unless otherwise stated, SPL refers to the root mean square (rms) sound pressure.

Source Level (SL)

The SPL that would be measured at 1 metre distance from a point-like source that radiates the same total amount of sound power as an actual source. Source levels are expressed in units of dB re 1 μPa at 1 m.

Transmission Loss (TL)

The dB reduction in sound level that results from the spreading of sound away from an acoustic source, subject to the influence of the surrounding environment. Also referred to as propagation loss.

Valued Ecosystem Component (VEC)

Any part of the environment that is considered important by stakeholders in the assessment process. Importance may be determined, among other criteria, on the basis of cultural values or scientific concern.

1/3-Octave Band Levels

Frequency resolved SPLs in non-overlapping pass-bands that are 1/3 of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave bands make up one octave. 1/3-octave bands become wider with increasing frequency.