APPENDIX 8C-4

Ammendment – Underwater Noise at Steensby Inlet

Assessment of Underwater Noise for the Mary River Iron Mine

Amendment: Vibratory Pile Driving at the Steensby Inlet Port Facility

Submitted to:
Val Moulton
LGL Ltd.

Author:
Mikhail Zykov

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JASCO Applied Sciences
Suite 202, 32 Troop Ave.
Dartmouth, NS, Canada
Phone: +1.902.405.3336
Fax: +1.902.405.3337
www.jasco.com

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1. Introduction

This document is an amendment to the report *Assessment of Underwater Noise for the Mary River Iron Mine: Construction and Operation of the Steensby Inlet Port Facility* Version 1.1 (Matthews *et al.* 2010). JASCO Applied Sciences performed an additional acoustic modelling study of the underwater noise expected from vibratory pile driving planned at the Freight Dock, a part of the Steensby Inlet Port Facility for the Mary River Iron Mine on North Baffin Island, NU.

The modelling of vibratory pile driving was performed for the open water period (August). Modelling was performed for an extended frequency range of 10–20,000 Hz. The source levels for the vibratory pile driving activity were derived from field measurements of the same activity in a similar environment.

The model results are presented in several formats suitable for noise impact assessment. For each modelling scenario the following results are provided:

- Map of the sound field as sound pressure level (SPL) contours (isobels) in 10 dB steps.
- Tables of distances to broadband sound level thresholds, with and without marine mammal frequency weighting (M-weighting).
- Tables of estimated maximum sound levels at specified distances for 1/3-octave bands with central frequencies from 10 to 20,000 Hz. The tables are provided in a separate *MS Excel* spreadsheet file.

2. Source Levels: Pile Driving

The pile driving operation for the Steensby Inlet Port Facility is planned for the freight dock site. Sheet piles 500 mm wide and 22 m long will be driven about 1.5 m into the bottom. The water depth at the pile is expected to be about 15 m. A vibratory pile driver will be used at 2500 rpm (41.7 Hz).

With the increasing interest in noise impacts of construction operations, several measurements of received sound levels from pile driving became available in recent years (*e.g.*, Washington State Department of Transportation 2004; MacGillivray *et al.* 2006; Racca *et al.* 2007; Illingworth and Rodkin 2010). The measurements were conducted for various types (steel sheet, steel pipe, concrete, *etc.*) and sizes of piles using different machinery (vibratory or impact pile drivers).

Table 1 shows received sound levels for impact pile driving operations at various constructions sites, mostly from ICF Jones and Stokes and Illingworth and Rodkin (2009), which summarizes data from many technical reports. The data were provided as broadband received levels at a specified distance from the source. For comparison, the source levels were calculated by back-propagating the received SPL to 1 m reference distance assuming spherical spreading loss ($20\log_{10}R$). The larger pile produced higher received SPLs (and SLs) than the smaller pile, since more impact energy is required to drive the larger pile into the ground.

Table 1: Broadband received sound pressure levels (SPLs) from various impact pile driving operations. For comparison, the source levels (SLs) were calculated by back-propagating the received SPL to 1 m reference distance assuming spherical spreading loss ($20\log_{10}R$).

Pile type	Size (in)	Size (mm)	Water depth (m)	Receiver distance (m)	Received SPL (dB re 1 µPa)	SL (dB re 1 µPa @ 1 m)
Steel H-type[1]	12	300	<5	10	150	170
Steel pipe[1]	12	300	<5	10	155	175
AZ steel sheet[1]	24	600	~15	10	160	180
AZ steel sheet[1]	24	600	~15	10	165	185
Steel H-type[2]	?		~5	14	160	183

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

The relative frequency spectrum of a typical acoustic signal (Figure 1, blue line) from ICF Jones and Stokes and Illingworth and Rodkin (2009, Fig. I.6-3) was used to estimate the source spectrum for the Steensby Inlet pile driver. The broadband received SPL at 10 m was 160–164 dB re 1 µPa. The reported frequency range for the spectrum was 1–5000 Hz. The spectrum was extended to 20 kHz assuming a decrease in sound level of 2 dB per 1/3-octave band. This assumption was based on data provided by Blackwell (2005).

A series of tones were present in the measured spectrum with frequencies corresponding to the pile driver vibration frequency and its multiples. The field measurements of vibratory pile driving suggest that the level of these tones can be as high as 15 dB above the levels for the adjacent 1/3-octave bands (Blackwell 2005). The existing tones, specific to the measured pile driver, were removed and replaced with tones specific to the pile driver to be used at Steensby

Inlet. The tones were introduced into the assumed spectrum for the 40, 79, and 126 Hz 1/3-octave bands by adding 15 dB to the levels in those bands.

The planned pile driving operation at Steensby Inlet Freight Dock was assumed to have a broadband source level similar to that of a 24 in (600 mm) AZ steel sheet pile (180–185 dB re 1 µPa @ 1 m, see Table 1). To be conservative, the maximum broadband SPL of 185 dB re 1 µPa @ 1 m was assumed. The source spectrum was adjusted accordingly to have this broadband source level. The resulting source level spectrum assumed for the Steensby Inlet pile driving operation is shown in Figure 1 (red line). The source level spectrum for pile driving with mitigation in place (a bubble curtain) was derived as described in Section 2.1.2 of Zykov and Matthews (2010) and is shown in Figure 1 (purple line). The 1/3-octave band source levels assumed for the unmitigated and mitigated vibratory pile driving operations and the effect of bubble curtain mitigation are given in Table 2.

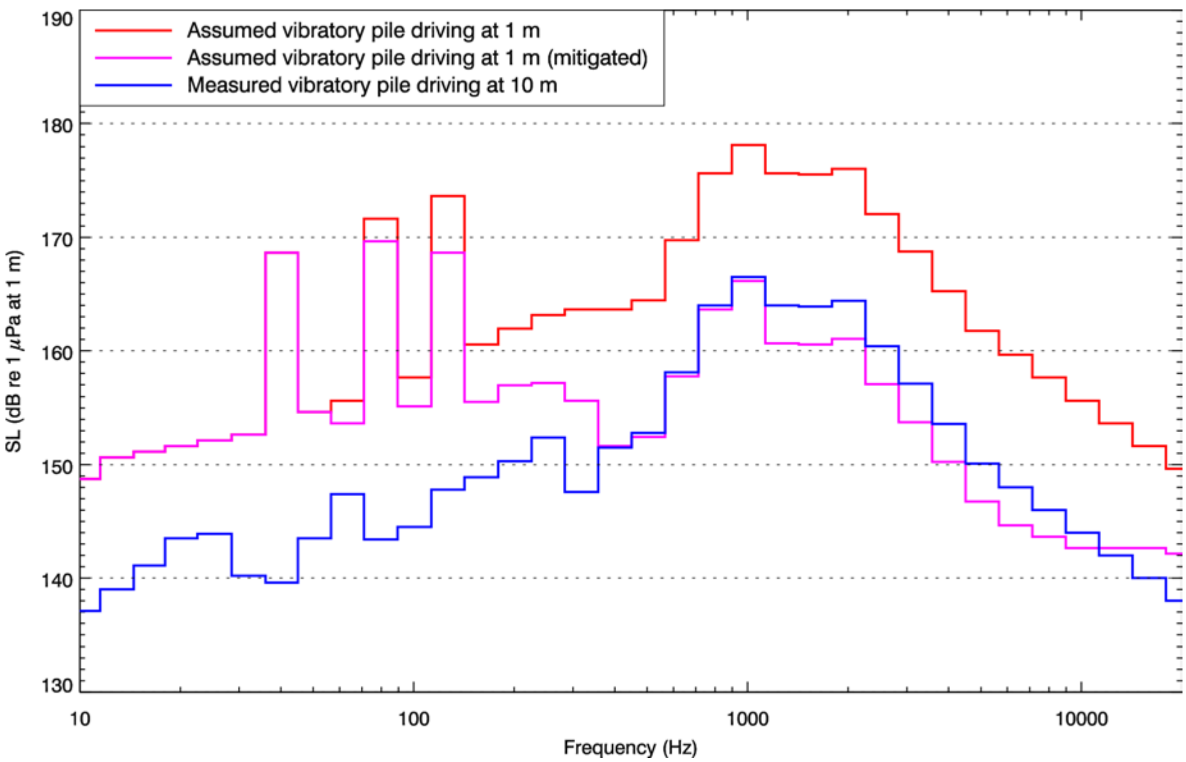

Figure 1: Assumed source levels for unmitigated and mitigated vibratory pile driving at Steensby Inlet based on the measured received spectrum at 10 m from a 24 in (600 mm) AZ steel sheet pile (ICF Jones and Stokes and Illingworth and Rodkin, 2009, Figure I.6-3), assuming a broadband source level of 185 dB re 1 µPa @ 1 m.

Table 2: Third-octave band source levels assumed for the unmitigated and mitigated vibratory pile driving from 10 to 20,000 Hz.

1/3-octave band (Hz)	Unmitigated SL (dB re 1 μPa @ 1 m)	Mitigated SL (dB re 1 μPa @ 1 m)	Bubble curtain effect (dB)
10	148.8	148.8	0
12.5	150.7	150.7	0
16	151.2	151.2	0
20	151.7	151.7	0
25	152.2	152.2	0
31.5	152.7	152.7	0
40	168.7	168.7	0
50	154.7	154.7	0
63	155.7	153.7	-2
80	171.7	169.7	-2
100	157.7	155.2	-2.5
125	173.7	168.7	-5
160	160.6	155.6	-5
200	162.0	157.0	-5
250	163.2	157.2	-6
315	163.7	155.7	-8
400	163.7	151.7	-12
500	164.5	152.5	-12
630	169.8	157.8	-12
800	175.7	163.7	-12
1000	178.2	166.2	-12
1250	175.7	160.7	-15
1600	175.6	160.6	-15
2000	176.1	161.1	-15
2500	172.1	157.1	-15
3150	168.8	153.8	-15
4000	165.3	150.3	-15
5000	161.8	146.8	-15
6300	159.7	144.7	-15
8000	157.7	143.7	-14
10,000	155.7	142.7	-13
12,500	153.7	142.7	-11
16,000	151.7	142.7	-9
20,000	149.7	142.2	-7.5
Broadband	*185.0*	*175.9*	*-9.1*

3. Modelling Sound Propagation

3.1. Modelling Location

Underwater sound propagation from vibratory pile driving related to the Mary River Iron Mine was modelled at the freight dock of the Steensby Inlet Port Facility. The water depth at the piles is expected to be 15 m. The modelling site coordinates were selected accordingly based on the available bathymetry (Table 3, Figure 2).

Table 3: Modelling Location.

Activity	Location		Water depth
Vibratory pile driving	Freight Dock:	70°16'43.60" N, 78°27'47.29" W	15 m

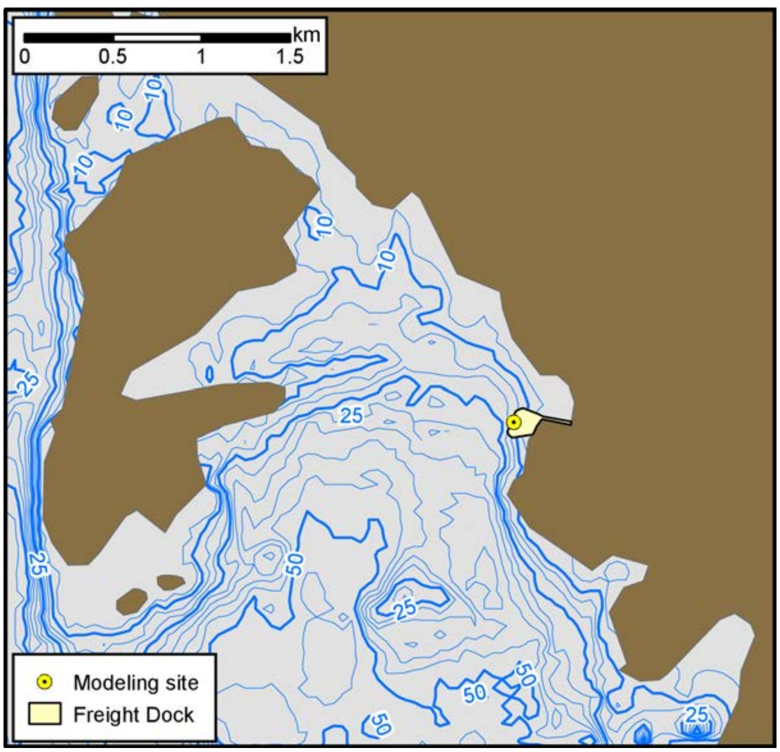

Figure 2: Modelling site for vibratory pile driving at the Steensby Inlet Port Facility. The bathymetry data are in meters.

3.1.1. Geoacoustics

The geoacoustic profile of the seabed for the Steensby Port Area is that described in Section 3.2.1 of Matthews *et al.* (2010) and is provided in Table 4.

Table 4: Geoacoustic parameters–Steensby Port Area.

Layers	Depth (mbsf)	P-wave velocity (m/s)	Density (g/cm^3)	P-wave attenuation (dB/λ)	S-wave velocity (m/s)	S-wave attenuation (dB/λ)
silty sand to gravel to cobles	0–5	1650–2000	1.8–2.1	0.85–1.00	150	1.5
granitic gneiss	5–330	3500–5000	2.4–2.6	0.35		
pre-Cambrian basement	>330	5500	2.6	0.275		

3.1.2. Sound Speed Profile

The sound speed profile for the open water period (August) at Steensby Inlet is that described in Section 3.2.2 of Matthews *et al*. (2010).

3.2. Sound Propagation Modelling

Underwater sound propagation was modelled with JASCO's Marine Operations Noise Model (MONM) as described in Section 3.3.1 of Matthews *et al.* (2010). The applicable volumetric attenuation of the acoustic wave at high frequencies is described in Section 3.4 of Matthews *et al.* (2010). The M-weighting technique is described in Section 3.5 of Matthews *et al.* (2010).

4. Results

Sound propagation modelling was performed at the Steensby Inlet Port site using JASCO's Marine Operations Noise Model (MONM) for 1/3-octave bands from 10 Hz to 20 kHz. The modelling radials were constructed with a 3° angular step. In the sector between 156° and 195° (east of UTM north), where the propagation was not limited by the inlet shoreline, the density of the radials was increased by using a 1° angular step size, for a total of 146 modelled radials. Sampling points were placed horizontally every 10 m along the radials. At each sampling point, modelled receivers were placed at various depths within the water column. The received sound level at a given sampling point was taken as the highest sound level that occurred over all modelled receiver depths at that location (*i.e.*, the maximum over depth).

M-weighting filters for four marine mammal functional hearing groups (Matthews *et al.* 2010, Table 11, Southall *et al*. 2007, Table 2) were applied to the modelled sound fields by weighting the modelled sound levels according to Equation (7) in Matthews *et al.* (2010). M-weighting was applied separately to each 1/3-octave band. After the filter was applied the individual values in each band were summed to compute the broadband sound levels.

The calculations of maximum distances to specific broadband sound levels were performed based on the broadband (10–20,000 Hz) maximum-over-depth sound levels. For each specified sound level, two distances are reported: (1) R_{max}–the furthest distance from the source at which the specific sound level was registered in the modelled maximum-over-depth sound field; and (2) $R_{95\%}$–the radius of the circle that contains 95% of the grid points with maximum-over-depth sound levels that exceed the specified level.

4.1. Vibratory Pile Driving

Vibratory pile driving sound levels were modelled at 20 depths between 1 and 150 m below the sea surface. The acoustic source was modelled at 7.5 m water depth, *i.e.*, mid-water column at the pile driving site. The associated source levels for unmitigated pile driving and pile driving mitigated with a bubble curtain are shown in Figure 1 and Table 2.

The maximum distances (R_{max}) to specific maximum-over-depth sound levels produced by the pile driving operations are presented in Table 5. The resultant sound field maps are presented in Figures A-1 and A-2. Tables A-1 and A-2 present the R_{max} and $R_{95\%}$ distances calculated with and without M-weighting applied for unmitigated and mitigated pile driving, respectively.

Table 5: Maximum distances (R_{max}) to broadband (10–20,000 Hz) maximum-over-depth RMS SPL thresholds from unmitigated and mitigated (with a bubble curtain) vibratory pile driving at the Steensby Inlet Freight Dock.

RMS SPL (dB re 1 μPa)	Vibratory pile driving maximum distance (m)	
	Unmitigated	Mitigated
180	<30	–
170	<30	<30
160	41	<30
150	318	54
140	1,430	394
130	4,370	2,610
120	29,000	4,710
110	79,000	26,400
100	85,600	66,200

5. Discussion

Most of the acoustic energy from vibratory pile driving was in the frequency range from 500 to 3000 Hz. Only mid- and high-frequency cetacean M-weighting had noticeable effects on the distances to sound level thresholds as they reduced the contribution from low frequency tones. The decrease in distances to sound level thresholds was about 10–20% for distances less than 5 km. M-weighting had no noticeable effect on distances to sound level thresholds larger than 10 km.

The results show that bubble curtain sound mitigation of pile driving can provide significant reductions in distances to sound level thresholds, as the sound attenuation was most effective in the frequency band of highest acoustic energy emission. The reduction in distances to RMS SPL thresholds varied from 85% to 75% for 150 and 110 dB re 1 µPa, respectively.

6. References

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Appendix A. Sound Field Maps and Distances to Sound Level Thresholds

A.1. Unweighted Sound Fields–Vibratory Pile Driving

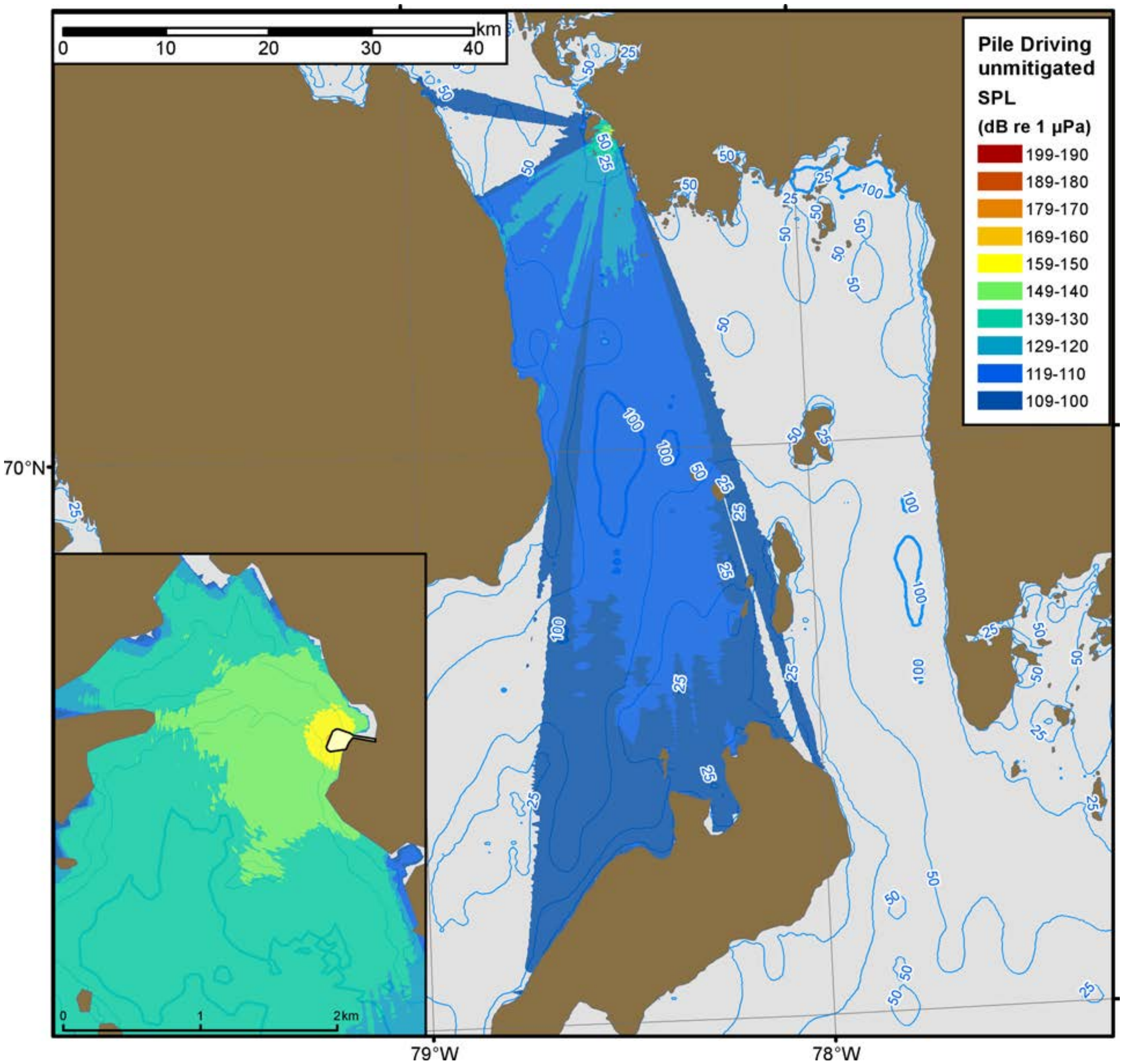

Figure A-1: Modelled broadband (10–20,000 Hz) maximum-over-depth RMS sound pressure levels around *unmitigated* vibratory pile driving at the Steensby Inlet Freight Dock.

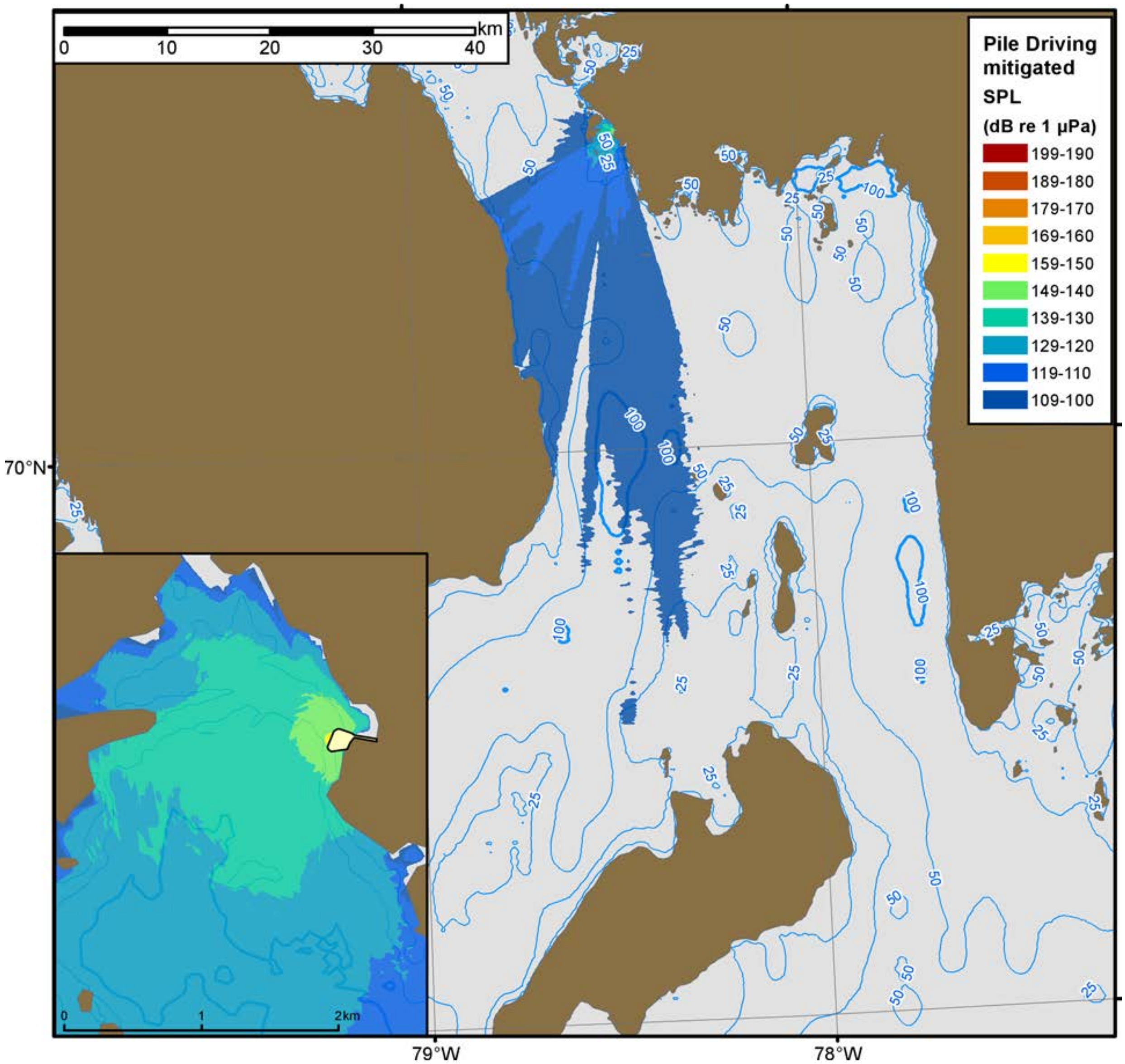

Figure A-2: Modelled broadband (10–20,000 Hz) maximum-over-depth RMS sound pressure levels around *mitigated (with a bubble curtain)* vibratory pile driving at the Steensby Inlet Freight Dock.

A.2. Distances to Sound Level Thresholds–Vibratory Pile Driving

Table A-1: Maximum (R_{max}) and 95% ($R_{95\%}$) distances from *unmitigated* vibratory pile driving at the Steensby Inlet Freight Dock to broadband (10–20,000 Hz) maximum-over-depth sound level thresholds for unweighted and M-weighted sound fields.

RMS SPL (dB re 1 µPa)	Distances (meters)									
	Unweighted		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	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
170	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
160	41	41	41	40	32	32	32	32	41	36
150	318	219	318	218	260	192	260	189	260	204
140	1,430	1,050	1,430	1,040	1,310	867	1,310	830	1,400	951
130	4,370	3,080	4,370	3,070	3,940	2,910	3,860	2,870	4,140	2,990
120	29,000	15,600	29,000	15,600	29,000	15,100	29,000	15,000	29,000	15,300
110	79,000	51,400	79,000	51,300	78,900	49,700	76,800	48,900	79,000	50,900
100	85,600	69,600	85,600	69,600	85,600	69,600	85,600	69,600	85,600	69,600

Table A-2: Maximum (R_{max}) and 95% ($R_{95\%}$) distances from *mitigated (with a bubble curtain)* vibratory pile driving at the Steensby Inlet Freight Dock to broadband (10–20,000 Hz) maximum-over-depth sound level thresholds for unweighted and M-weighted sound fields.

RMS SPL (dB re 1 µPa)	Distances (meters)									
	Unweighted		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	<30	<30	<30	<30	–	–	–	–	–	–
160	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
150	54	51	54	51	<30	<30	<30	<30	32	32
140	394	311	394	303	166	130	139	114	250	180
130	2,610	1,500	2,600	1,490	858	610	833	569	1,240	850
120	4,710	3,410	4,700	3,380	3,210	2,610	3,210	2,560	3,490	2,830
110	26,400	15,000	26,400	15,000	16,300	9,680	15,900	8,390	26,400	14,600
100	66,200	41,000	66,200	40,800	66,200	35,200	66,200	32,900	66,200	38,100