

Construction of the Steensby Inlet Railway Underwater Noise Modelling Report: Freshwater

JASCO Applied Sciences (Canada) Ltd

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[illegible][illegible]

▷d◁ aΔā^{ᶜᵇ} /L^ᶜ a_c▷C^{ᶜᵇ} C▷/L^ᶜ σΛ^ᶜ ᵇmΠ▷σ^ᶜΓ^a_m^c ◁L^ᶜ ᵇ▷λ▷_▷◁C^{ᶜᵇ}▷C^ᶜ.

- [illegible]

$> 90 \text{ dB re } 20 \mu\text{Pa}$ ($\approx 50 \text{ kPa}$) ($\approx 214 \text{ dB re } 1 \mu\text{Pa PK}$).

- [illegible]

Executive Summary

JASCO Applied Sciences, commissioned by WSP and on behalf of Baffinland Iron Mines Corporation, performed an underwater acoustic modelling study of construction activities associated with building a railway to Steensby Inlet for the Baffinland Mary River Iron Ore Project. Specifically, sound propagation models were applied to assess underwater noise exposure to fish produced by blasting activities at the project site. The models used for this work include ConWep's Shockwave module (Hyde 1988, 1992), to predict source pressures for the charges detonated, and JASCO Applied Science's Full Waveform Range-dependent Acoustic Model (FWRAM) (MacGillivray and Chapman, 2012) to predict in-water pressure levels.

The predicted received levels are evaluated to assess the potential for impacts to fish within the surrounding waters. The results are evaluated against established thresholds based on two metrics - the peak instantaneous sound level (PK), which considers the potential for acute impacts, and the sound exposure level (SEL), which accounts for potential impacts from cumulative sound exposure accumulated over multiple detonations within a day.

The goal of this study is to predict the extent of ensonification from six blasting modelling scenarios (i.e. six blasting locations), to predict the maximum resulting sound levels within the surrounding waters, and to determine whether these levels exceeded currently adopted sound level thresholds for fish injury and mortality. The six selected blasting locations (adjacent to Ravn Camp Lake, Cockburn Lake, and an unnamed lake located near km 137+490 of the Steensby railway) represent locations along the railway alignment that are closest to nearby water bodies containing fish. Since the blasting plan for the project has not yet been determined, the modelling analysis considers a range of possible charge sizes (between 1 and 100 kg TNT equivalent weight). These model estimates are conservative estimates based on the blasting locations selected for modelling and on the modelling parameters used.

Following is a summary of the predicted sound levels and key results:

- None of the considered PK thresholds for mortality, potential mortal injury, and recoverable injury for fish were exceeded at any of the modelled locations, for any of the modelled charge sizes, based on thresholds provided in Popper et al. (2014) and based on thresholds considered by the U.S. National Marine Fisheries Service (NMFS).
- The PK levels from blasting of charges with charge weight as large as 100 kg TNT did not exceed the DFO imposed overpressure threshold of 50 kPa (equivalent to 214 dB re 1 μ Pa PK level).
- The modelled single-detonation SEL values were at least 18 dB below thresholds for mortality, potential mortal injury, recoverable injury, and injury onset as proposed by Popper et al. (2014) and by NMFS. This implies that, at locations 12 m from the water, the total SEL accumulated over multiple detonations would reach levels with the potential to affect fish if more than 63 charges of 100 kg TNT were detonated within a day. For smaller individual charges, the number of charges that could be detonated before threshold exceedance varies between 448 for 1 kg charges to 78 for 50 kg charges. For blasting locations offset from lake shores by 30 m or more exceedance of the SEL thresholds is unlikely, as at least 630 detonations of 100 kg TNT charges could occur within a day before these SEL thresholds would be reached (over 933 detonations of smaller charges could occur).
- The findings of this study are based on the specified offsets of the detonation sites from the nearby lake shores. The closest blast sites are more than 30 m from the shores. These results may not apply if detonation sites occur closer to the lake shores.

1. Introduction

JASCO Applied Sciences (Canada) Ltd. (JASCO) has been commissioned by WSP to perform underwater acoustic modelling of noise from activities associated with construction of the Steensby Port dock and railway for the Baffinland Mary River Iron Ore Project, Canada (Figure 1). This report focusses on underwater noise in the freshwater environment along the railway corridor, to support an assessment of the potential effects to fish, fish eggs and larvae for the project's Fisheries Act Authorization application that will be submitted to Fisheries Oceans Canada (DFO). Modelling for construction activities at Steensby Inlet that may affect the marine environment is being considered in a separate analysis.

The modelling discussed in this report comprises the prediction of sound levels within freshwater lakes (Ravn Camp Lake and Cockburn Lake) and rivers due to blasting activities expected to occur along the southern railway corridor associated with the Baffinland Mary River Iron Ore Project. Six blasting locations were selected (adjacent to Ravn Camp Lake, Cockburn Lake, and an unnamed lake located near km 137+490 of the Steensby railway) to represent locations along railway alignment that are closest to nearby water bodies containing fish. As such, these results provide an assessment of the worst-case conditions in terms of sound levels from blasting activities that would reach freshwater bodies containing fish.

High-intensity sound from rock blasting associated with the proposed construction project will generate underwater sound at levels above existing conditions in the freshwater bodies and has the potential to cause injury or mortality to fish at short distances from the blasting. At longer distances, lower-intensity underwater sound levels have the risk of causing disturbance-related impacts to fish, such as masking, stress response, and avoidance behaviour. Fisheries Act Authorizations (FAA) generally focus on managing activities to avoid injurious effects, but they can also address mitigations to minimize areas over which disturbance may occur.

The modelled noise fields were assessed against acoustic thresholds for fish (see details in Section 2) to determine whether in-water sound levels from blasting at each specified location could reach levels where there would be a potential for injurious effects. The modelling approach considered range-dependent environmental properties to simulate the propagation of sound through the ground and into the surrounding freshwater environment. Acoustic modelling results are presented for relevant peak sound pressure level (PK) and sound exposure level (SEL) metrics described in Section 2. Section 3 describes the methods used to predict blasting source sound levels (representing the noise emissions) and acoustic underwater propagation of the resultant sound. Section 4 presents results as tables of the maximum modelled in-water sound levels (PK and SEL) and as images depicting cross-sections of the sound level contours. Section 5 contains the discussion and concluding remarks.

1.1. Freshwater scenarios

The activities considered in this acoustic modelling exercise for the freshwater scenarios consist of blasting at 6 locations along the Steensby railway (see Figure 1 and Table 1). The blasting plan for the project has not yet been determined, therefore several different charge sizes were considered up to a client-defined maximum of 100 kg. Seven charge sizes (1, 10, 20, 30, 40, 50, and 100 kg TNT) were modelled. The specific charge type that is to be used for blasting has also not yet been defined. The modelled charge sizes are the TNT equivalent weight (denoted throughout this report in units of “kg TNT”), such that the results are broadly applicable to different types of charges (charge weights for other charge types, e.g., ANFO, can be easily converted to a TNT equivalent weight). To assess the potential for effects resulting from the cumulative sound exposure from multiple detonations, model results were

also interpreted to obtain the total SEL for up to 100 detonations within a day for charges as large as 100 kg TNT.

Figures 2 to 6 show the relative locations of the blasting sites to the nearby water bodies. The 6th location is located about 12 m from a known lake (shown in Figure 7), however, the actual bathymetry of the lake was not available. JASCO modeled a representative location (Table 1, F6) using environmental parameters of the F3 modelling area, which generated the most conservative sound levels.

The blast sites are in-land, buried 3 m below the surface topography. The topography at each location of the blasting sites is given in Table 1. The blast charges at Ravn Camp Lake are blasted in land nearly 80 m from the water and at 150 m above sea level, while the Cockburn Lake and River locations are between approximately 30 and 80 m from the water and approximately 50 m above sea level.

In general, the estimated sound levels depend on the water depth, bathymetric variation, sound speed in the water, and geoacoustic characteristics of the land and the lakebed sediment; all of which affect noise propagation. In addition, noise production depends on the size of the charges being detonated and their locations relative to the water.

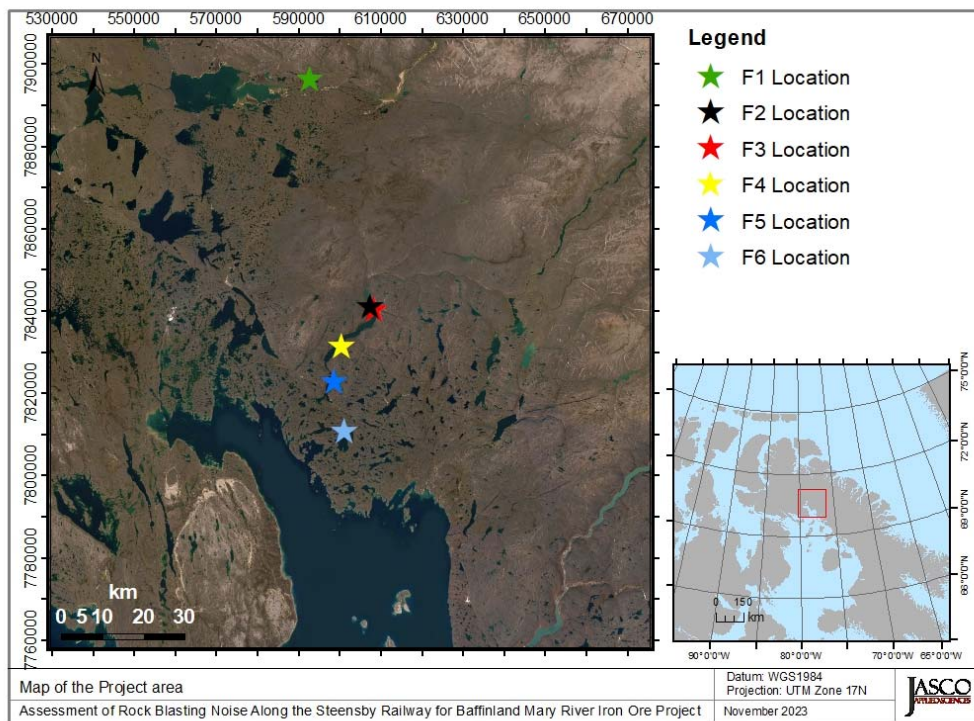


Figure 1. Map of the Project area showing the modelled locations (stars) for freshwater scenarios along the Steensby Railway alignment.

Table 1. Location and description of modelled scenarios considered.

Scenario	Location	Latitude	Longitude	Source Topography (m)	Horizontal distance to water (m)	Slant range to water (m)	UTM Coordinates Zone 17N		Burial depth (m)
							Easting (m)	Northing (m)	
F1	Ravn Camp Lake	71.155° N	78.425° W	154.7	77.5	173.0	592790	7896630	3
F2	Cockburn River ¹	70.653° N	78.094° W	51.1	82.5	97.1	607407	7841220	
F3	Cockburn Lake	70.646° N	78.071° W	47.8	28.1	55.4	608287	7840520	
F4	Cockburn Lake	70.570° N	78.293° W	53.0	56.5	77.5	600481	7831670	
F5	Cockburn Lake	70.493° N	78.352° W	51.0	68.0	85.0	598639	7823010	
F6 ²		70.385° N	78.302° W	10.6	12.0	16.0	601040	7811014	

¹ Near mouth of Cockburn Lake

² Due to a lack of environmental inputs for the Scenario F6 location, results for Scenario F6 were derived from a model run for a representative location 16 m (slant range) from Cockburn Lake at 70.646 N 78.302 W (608260 E 781014 N, UTM 17N).

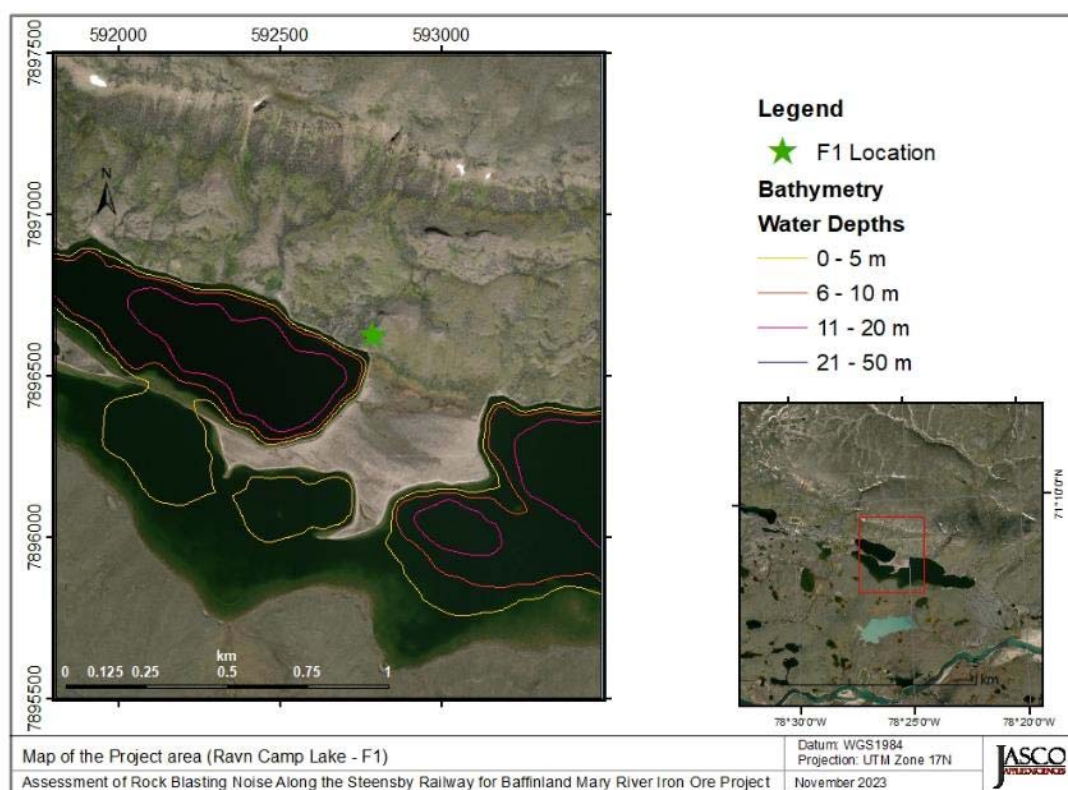


Figure 2. Scenario F1: Project area around Ravn Camp Lake showing the blast location (green star) and water depths.

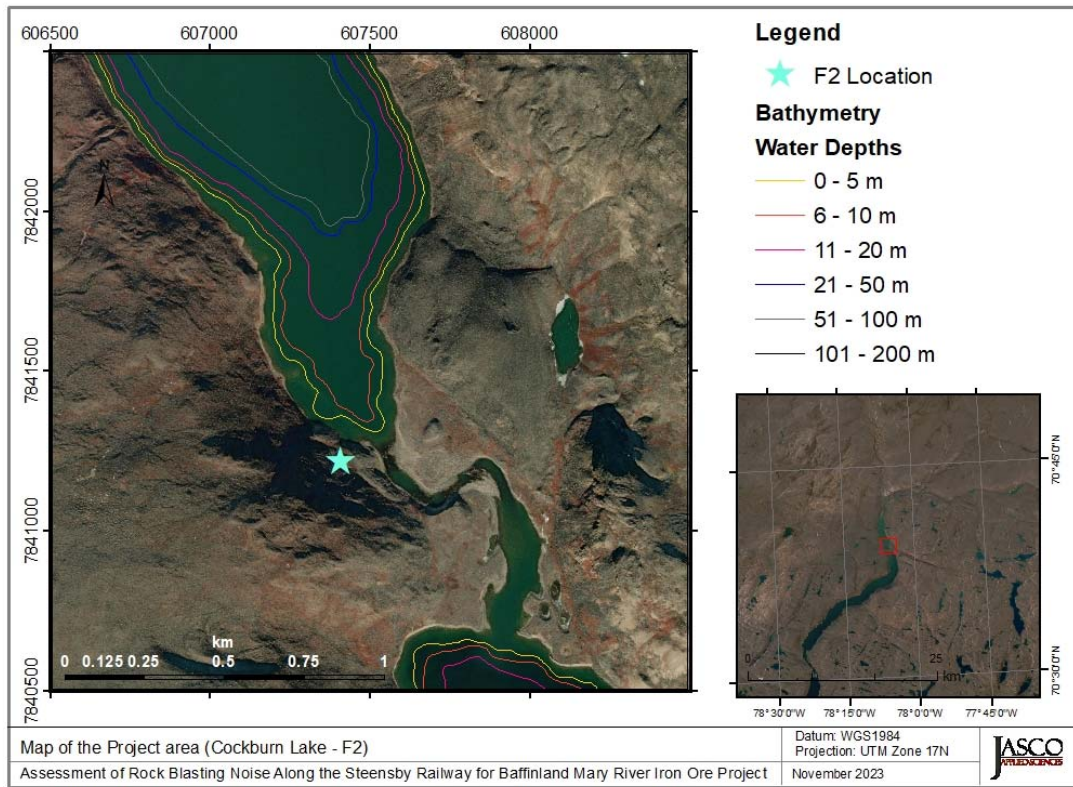


Figure 3. Scenario F2: Project area around Cockburn Lake showing the blast location (cyan star) and water depths.

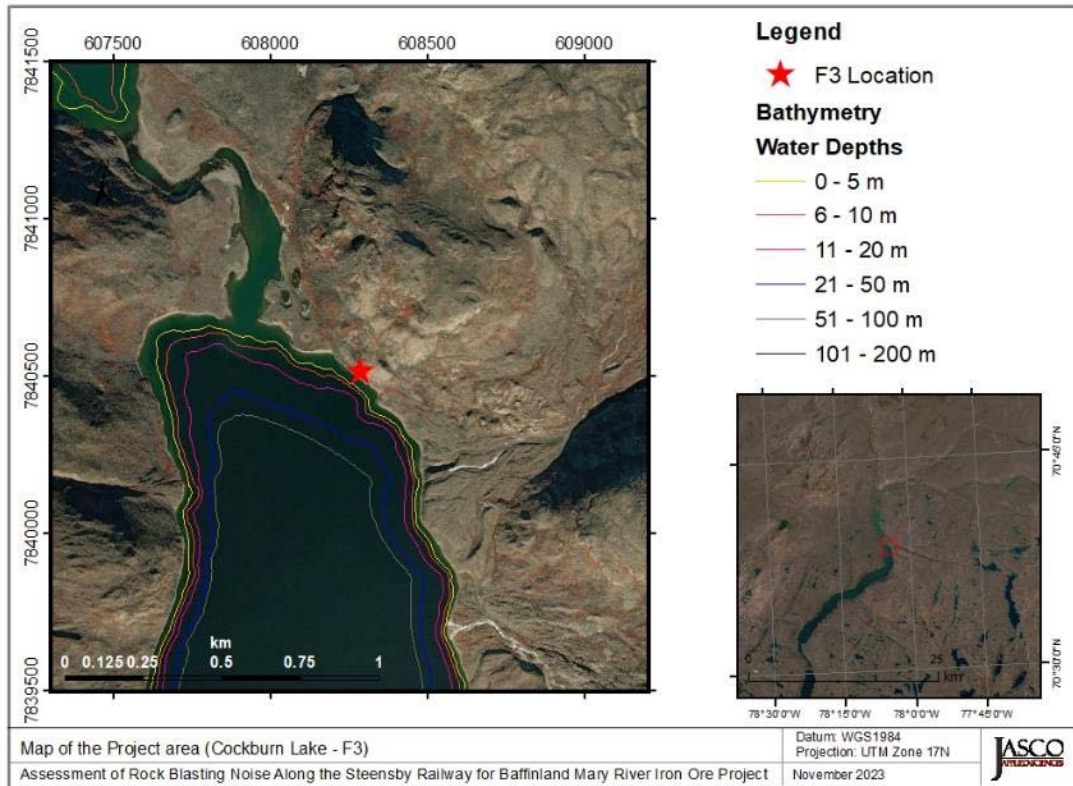


Figure 4. Scenario F3: Project area around Cockburn Lake showing the blast location (red star) and water depths.

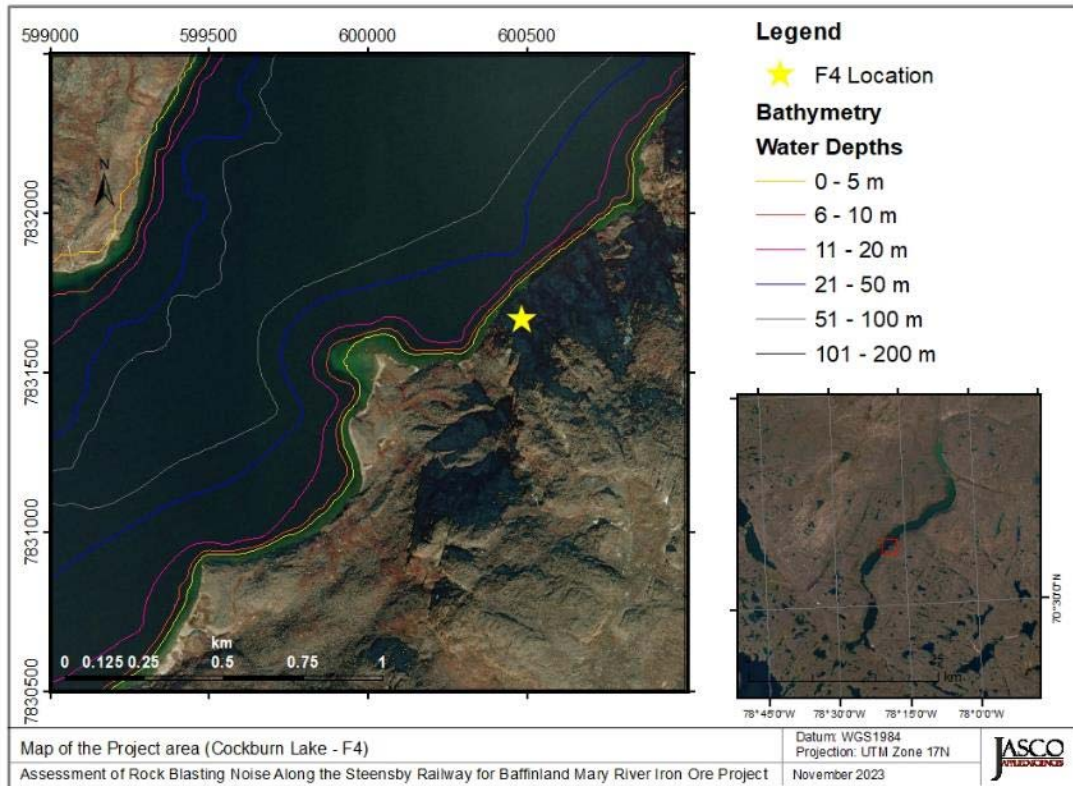


Figure 5. Scenario F4: Project area around Cockburn Lake showing the blast location (yellow star) and water depths.

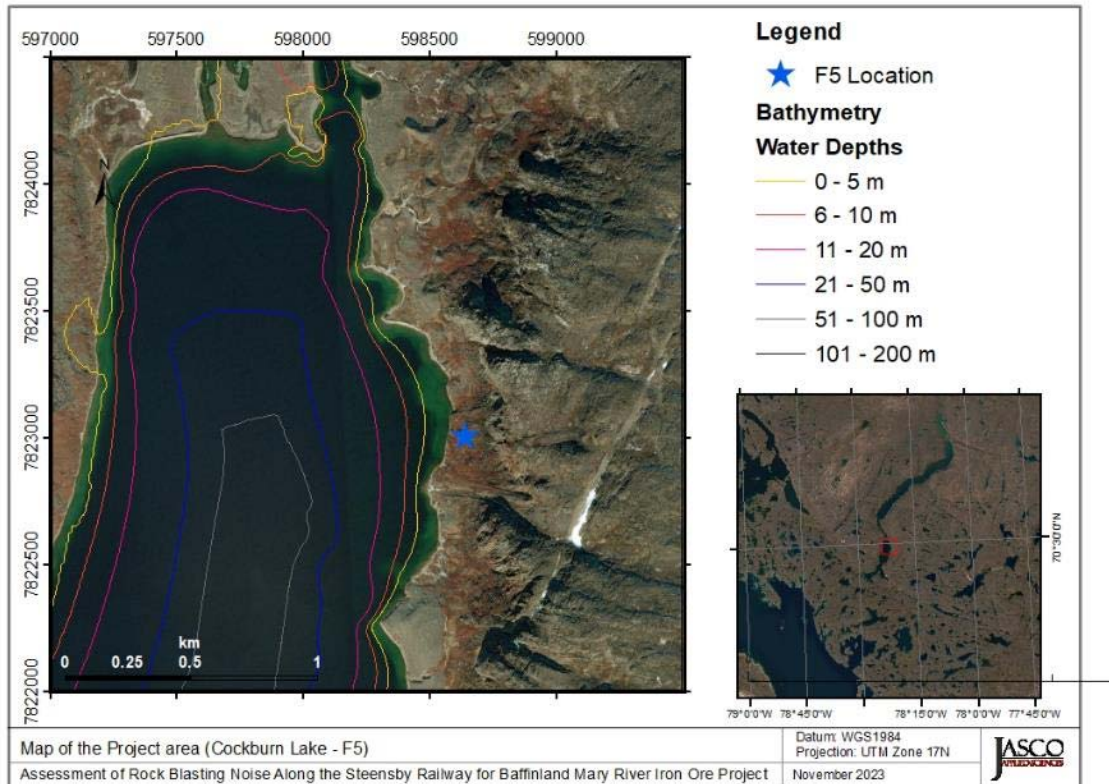


Figure 6. Scenario F5: Project area around Cockburn Lake showing the blast location (blue star) and water depths.

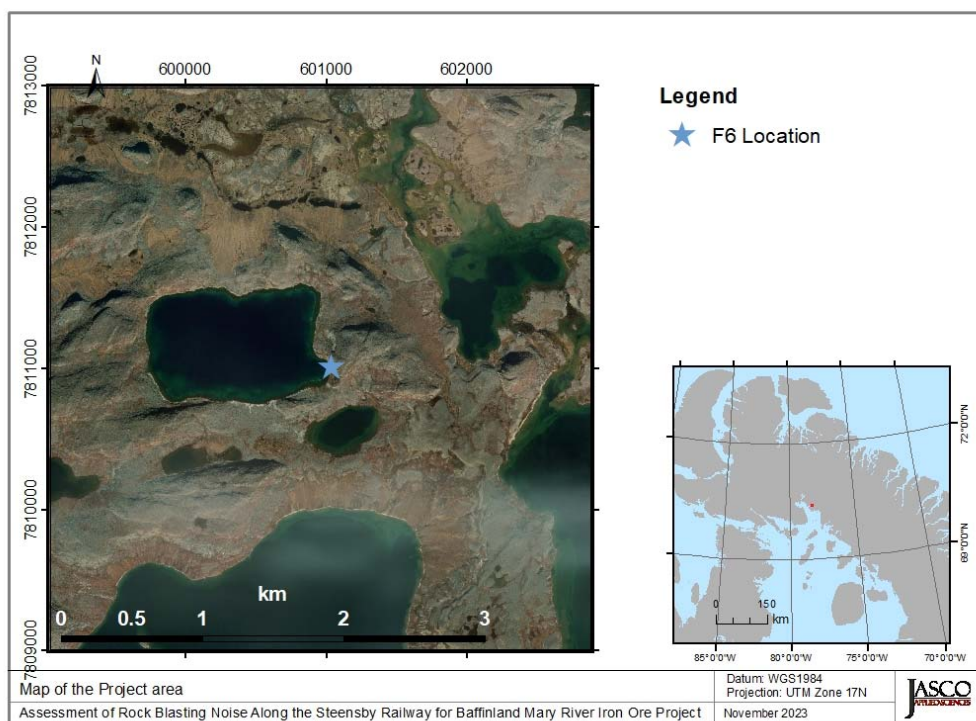


Figure 7. Scenario F6: Project area around an unnamed lake showing the true blast location (light blue star).

2. Noise Effects Criteria

Noise can affect fish in several ways, including eliciting behavioural response, masking detection of acoustic signals, causing hearing threshold shifts, or causing injury that may be recoverable or could be mortal. JASCO has evaluated sound levels for impacts to fish, fish eggs and larvae, based on available sets of criteria for onset of noise-induced injuries, temporary threshold shift, and for behavioural disturbance based on Popper et al. (2014) as well as criteria defined by DFO and by the U.S. National Marine Fisheries Service (NMFS).

The Popper et al. (2014) criteria are listed in Table 2 and discussed in Appendix B. The selected criteria are defined for impulsive sound sources such as impact pile driving and seismic airguns. While Popper et al. (2014) do provide thresholds specifically for explosives, those thresholds are intended for the assessment of single explosive detonations and, as such, do not include SEL thresholds that take into account the accumulated exposure from multiple detonations within a day. In anticipation that the railway construction will require multiple explosive detonations, the more conservative thresholds for impulsive sound sources have been applied here in order to also assess the effects of cumulative exposure. Further, because the blasting sounds will propagate through the ground before reaching the water, the resulting in-water sound waveforms will not exhibit the shockwave features characteristic of explosives (Section 3.1.1); they will be more similar to sounds from an impulsive source. As such, it is appropriate to assess these sounds using the Popper et al. (2014) thresholds for impulsive sources rather than those for explosives. While these are the most up-to-date criteria available in the literature, the U.S. NMFS often refers back to historical thresholds for potential impacts to fish that were defined by a 2008 working group considering effects to fish from impact pile driving. Those criteria define a slightly more conservative PK threshold of 206 dB re 1 μ Pa for the onset of physical injury along with SEL thresholds for the onset of physical injury of 187 dB re 1 μ Pa²s for fish > 2 g or 183 dB re 1 μ Pa²s for fish < 2 g. DFO has requested that this project implement a threshold of $L_{pk,flat} = 50$ kPa (equivalent to 214 dB re 1 μ Pa) for assessing impacts to fish from blasting noise. Therefore, results of this modelling will be compared to this threshold as well as to the more conservative Popper et al. (2014) and NMFS thresholds.

Table 2. Criteria for blasting noise exposure for fish, adapted from Popper et al. (2014)

Type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	Temporary Threshold Shift	Masking	
Fish: No swim bladder (particle motion detection)	> 219 dB SEL _{24h} or > 213 dB PK	> 216 dB SEL _{24h} or > 213 dB PK	>> 186 dB SEL _{24h}	(N) Moderate (I, F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	210 dB SEL _{24h} or > 207 dB PK	203 dB SEL _{24h} or > 207 dB PK	>> 186 dB SEL _{24h}	(N) Moderate (I, F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL _{24h} or > 207 dB PK	203 dB SEL _{24h} or > 207 dB PK	186 dB SEL _{24h}	(N, I) High (F) Moderate	(N, I) High (F) Moderate
Fish eggs and fish larvae	> 210 dB SEL _{24h} or > 207 dB PK	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I, F) Low	(N) Moderate (I, F) Low

Peak sound pressure level dB re 1 μ Pa; SEL_{24h} dB re 1 μ Pa²s.

All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist.

3. Methods

Construction activities that involve rock blasting at locations approximately 50 m from the railway have the potential to generate underwater sound. The blasting activities are on land, buried 3 m from the ground surface. The nearby water body depths vary from 0 to 50 m at Ravn Camp Lake and from 0 to 180 m at Cockburn Lake. Properties of the water and environment (i.e., water temperature, salinity, sound speed, and water depth) were selected to provide conditions for the most conservative sound field (i.e., the parameters leading to the farthest acoustic propagation) during the planned construction period. The water depth modelled considers the water levels at geodetic level. Based on a review of information provide by Knight Piesold on the geologic composition in the project area, the frozen sediment consists of a grey sand and granular fills layer (5 to 25 m thickness) followed by a Granitoid/Gnesis bedrock. Appendix C.3 provides more details on the assumed environmental parameters.

The modelling procedure consists of the following three general steps.

1. The central activity (blasting) is characterized as a sound-radiating source. This involves defining the detonation depths and the TNT-equivalent explosive weight of each source. The ConWep model's Shockwave model was used to calculate the sound pressure function emitted by the charge, close to the detonation location. This pressure function consists simply of absolute pressure versus time, and it is referred to as a source function.
2. Computational modelling was applied to the area to compute sound level losses as the sound source function propagates outwards through the land to the water column, and through the water, as a function of range, depth, and azimuthal direction from the detonation location. The calculation is done as a function of sound frequency.
3. The resulting modelled propagation loss for sound radiating from the source was combined with the source sound levels, summed over frequency, and the maximum-over-depth taken to produce a uniform grid of sound levels across the modelled area. The maximum-over-depth value, which is the maximum over-depth at each lateral location (x, y coordinate), is the most conservative estimate.

The output of these steps produces PK and SEL levels per detonation for blasting at each considered location. Since the SEL criteria mentioned in Section 2 are cumulative (denoted SEL_{24h}), the accumulation of number of charges blasted within a 24 h period is accounted for by adding a factor of $10 \log(N_{24h})$ to the single-event SEL, where N_{24h} represents the maximum number of single charge events for each charge size.

3.1. Noise Sources

3.1.1. Blasting

Underground detonation of explosives generates a series of very high amplitude, but brief, acoustic events. There is a zone in the immediate vicinity of the blast (typically within a few tens of meters) that is dominated by non-elastic strain, fracture, and bulk material transport within the medium (the shock wave zone). Outside this zone, the vibrational energy quickly transforms to linear acoustic signals that can be modelled using conventional in-air and underwater sound propagation models.

In this study, the noise generated by detonation of explosives placed within boreholes drilled in rock was modelled using ConWep's Shockwave module (Hyde 1988, 1992). ConWep generates time-dependent waveforms of the detonation and accounts for scenario-specific input parameters, such as the type and

size of explosive, the charge depth below ground and the characteristics of backfill material. Blasting was modelled assuming a range of charge sizes from 1 to 100 kg of TNT (Table 3).

Table 3. Specifications of the charge used for rock blasting.

Explosive type	Explosive TNT mass (kg)	Deployment depth (m)	Backfill material
Bare High Explosive	1, 10, 20, 30, 40, 50, 100	3	Sediment

ConWep's Shockwave module was used to calculate the pressure wave that would be measured in-ground at distances specified by the Gaspin distance from the detonation point for each modelled charge size. These distances, as listed in Table 4, were chosen as sufficient for the blast pressure wave to have decayed to linear propagation. At very close distances, the pressure wave shape evolves with distance due to non-linear effects that are not treated properly by linear propagation models. The ConWep pressure wave was then backpropagated assuming linear spherical spreading to obtain an equivalent point source, suitable for linear propagation modelling. The linear propagation model addresses underground propagation from rock to water and accounts for the rock-to-water transmission (Appendix C.2.2). ConWep considers physical properties of the rock and/or sediment that surrounds the charge. This material is described in the model by its density, compressional sound speed, and absorption (or attenuation) coefficient. The model was calibrated by means of adjusting the attenuation factor to match received peak pressure levels at less than 500 m to lie along the empirical regression lines provided by measurements from Eagle River Flats, AK from the literature (Bowman et al. 2019). The Eagle River Flats measurements regression lines are derived from monitoring measurements of bedrock bottom blasting activity at distance of about 130 m from the Eagle River, with blasting buried at depths 3–6 m. Therefore, these measurements provide a suitable comparison for calibration. The value for the attenuation parameter in ConWep that provided the best match was 4.0 (see Figure 8). This approach maintains the pressure wave shape predicted by ConWep and simultaneously ensures the peak pressures are consistent with the empirical blasting peak pressure models.

Table 4. Gaspin distance for modelled charge size.

Charge size (kg TNT)	Gaspin distance (m)
1	5
10	11
20	13
30	15
40	17
50	18
100	23

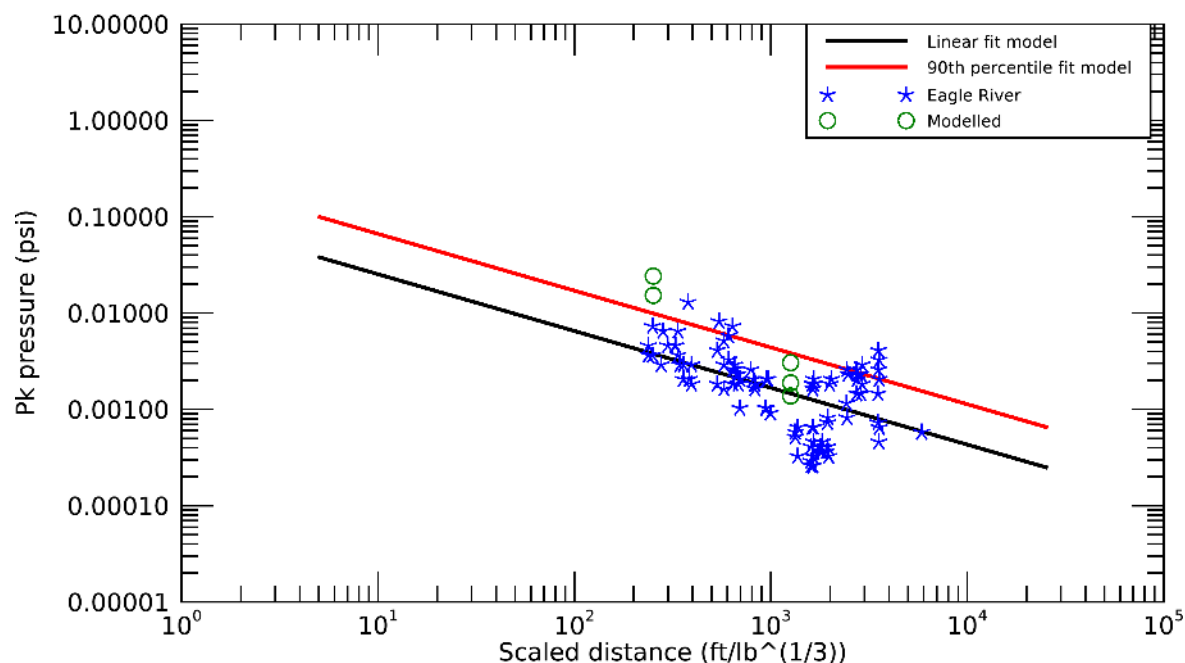


Figure 8. *ConWep* attenuation factor tuning: Modelled peak sound pressure level (maximum-over-depth) for the 1 kg TNT charge, compared to regression functions provided by Eagle River Flats measurements. The attenuation factor value is 4.0.

The source pressure waveforms for blasts of 1.0 kg and 100 kg TNT charges are shown in Figure 9.

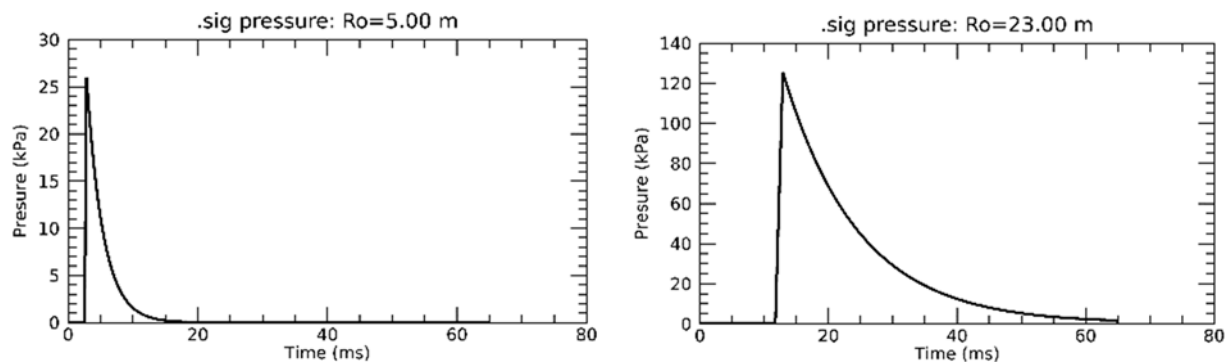


Figure 9. Time-dependent pressure wave for underground detonations: (Left) 1.0 kg TNT charge and (right) 100 kg TNT charge.

3.2. Propagation Models

3.2.1. Modelling Blasting

The blast charges at both Ravn Camp and Cockburn Lake locations are blasted in land at about 80 m from the lake shore in Ravn Camp Lake and at 150 m above sea level, while for Cockburn Lake locations the blast locations are roughly between 30 and 80 m from the lake shore and 50 m above sea level. The 6th source is modelled at 16 m slant range from the lake shore. Appendix C.3.1 and Table 1, respectively, present the water depths in both Ravn Camp and Cockburn Lake locations and the relative locations of

the blast sources. The in-land blast sound propagates mostly through Granitoid/Gneiss bedrock which significantly reduces the received in-water sound levels.

Propagation of the sound for the rock blasting activity was modelled using FWRAM (Appendix C.2.2). The model was run along multiple vertical planes leading radially away from and extending up to 5 km from the blast site or terminating at shorelines. The sound levels are evaluated on the planes at which the sound propagated farthest. The horizontal (radial) modelling step was 2 m and receiver (sampling) depths spanned the entire water column observed along modelled radials, with step size increasing with depth. Modelling frequency range was from 9 to 2239 Hz (low limit of 10 Hz band and high limit of the 2000 Hz band). SEL source levels from 2000 to 140,000 Hz were obtained by adjusting the level of the 2000 Hz decade frequency band by -2 dB per decade. For extrapolated high frequencies, propagation loss due to volumetric absorption was accounted for via range dependent functions derived for each frequency.

4. Results

The largest modelled maximum-over-depth sound levels in water are presented here. Table 5 presents the maximum SEL levels for a single charge size at each modelled location. Figures 10 to 14 contain sound level contour cross-sections of the single-charge SEL sound levels. The blacked-out sections of the figures indicate land.

The maximum PK levels were also calculated from the modelled per-detonation field corresponding to the modelled charge sizes. Consequently, none of the considered PK thresholds (those considered by DFO, NMFS, nor those of Popper et al. 2014) were reached. Table 6 presents the maximum PK levels for each charge size and at each modelled location.

A conservative estimate of the maximum in-water SEL resulting from multiple detonations within a day is obtained by scaling the single-detonation SEL values by $10 \log(N_{24h})$, where N_{24h} is the number of detonations within 24 hours. For example, for 100 detonations at location F3 (30m distance from the lake shores) the maximum SEL would be 174.6 dB (154.6dB + $10 \log 100$) for the 100 kg TNT charge size. As the blast location gets closer to the lake shores, the SEL thresholds for affects to fish can be exceeded after a reasonable number of detonations within 24hr. At location F6, which is 12 m from the lake shore, the 183 dB re 1 $\mu\text{Pa}^2\text{s}$ SEL threshold would be exceeded after 63 detonations of 100 kg TNT charges (this is the threshold that NMFS considers for the onset of injury to fish < 2 g, and is the most conservative of the considered thresholds). Table 7 provides the maximum number of detonations that could occur within a day for the other considered charge sizes before exceeding this threshold at this distance. For the remaining scenarios, which are at least 28 m from adjacent water bodies, the SEL thresholds are unlikely to be exceeded in the water as those levels would not be reached unless 630 detonations or more occurred within one day (not tabulated).

Table 5. Maximum sound exposure level (SEL) for single detonations at each location and for modelled charge sizes between 1 kg and 100 kg TNT equivalent mass.

Scenario	Single Charge SEL (dB re 1 $\mu\text{Pa}^2\text{s}$)						
	1 kg	10 kg	20 kg	30 kg	40 kg	50 kg	100 kg
F1	131.7	137.2	141.1	142.1	142.3	143.4	145.1
F2	137.7	142.6	146.3	147.3	147.3	148.4	149.9
F3	143.5	147.8	151.4	152.3	152.2	153.3	154.6
F4	140.1	144.7	148.4	149.3	149.3	150.4	151.8
F5	139.1	143.8	147.5	148.5	148.5	149.6	151.0
F6	156.5	159.4	162.7	163.3	163.5	164.1	165.0

Table 6. Maximum peak sound pressure level (PK) at each location and for modelled charge sizes between 1 kg and 100 kg TNT equivalent mass.

Scenario	PK (dB re 1 μPa)						
	1 kg	10 kg	20 kg	30 kg	40 kg	50 kg	100 kg
F1	151.2	158.9	162.7	163.8	163.9	165.1	166.6
F2	160.6	167.4	171.0	171.9	171.9	173.0	174.3
F3	169.8	175.7	178.9	179.7	179.5	180.6	181.7
F4	164.3	170.7	174.2	175.0	175.0	176.0	177.3
F5	162.8	169.3	172.9	173.7	173.7	174.8	176.1
F6	190.1	194.0	196.6	197.0	196.6	197.5	198.2

Table 7. Number of detonations after which the 183 dB re 1 $\mu\text{Pa}^2\text{s}$ threshold (per the NMFS criteria) would be exceeded in water located 12 m from the blast location F6 for modelled charge sizes between 1 kg and 100 kg TNT equivalent mass.

Scenario	Number of charges						
	1 kg	10 kg	20 kg	30 kg	40 kg	50 kg	100 kg
F6	448	231	107	92	88	78	63

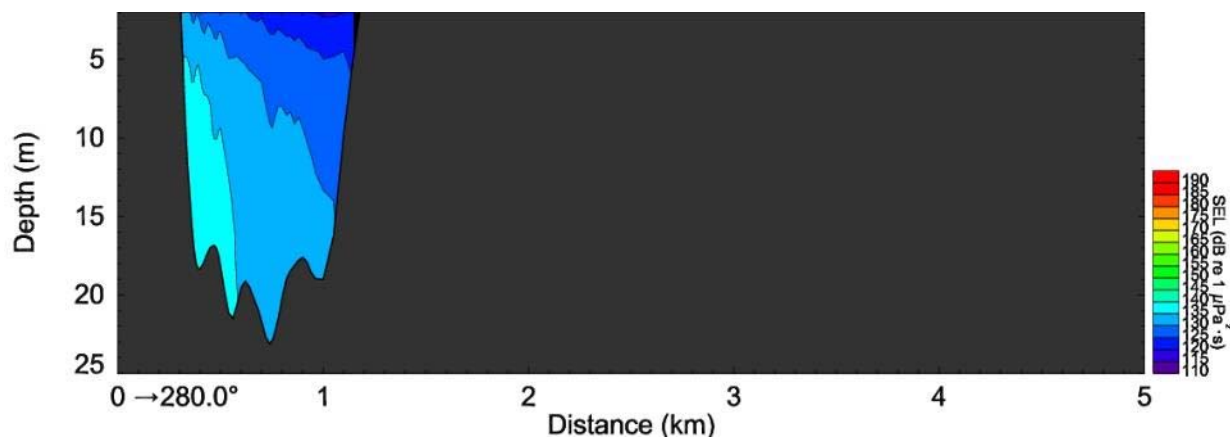


Figure 10. *Scenario F1 blasting*: Single shot sound exposure level (SEL) cross section for a 100 kg TNT charge.

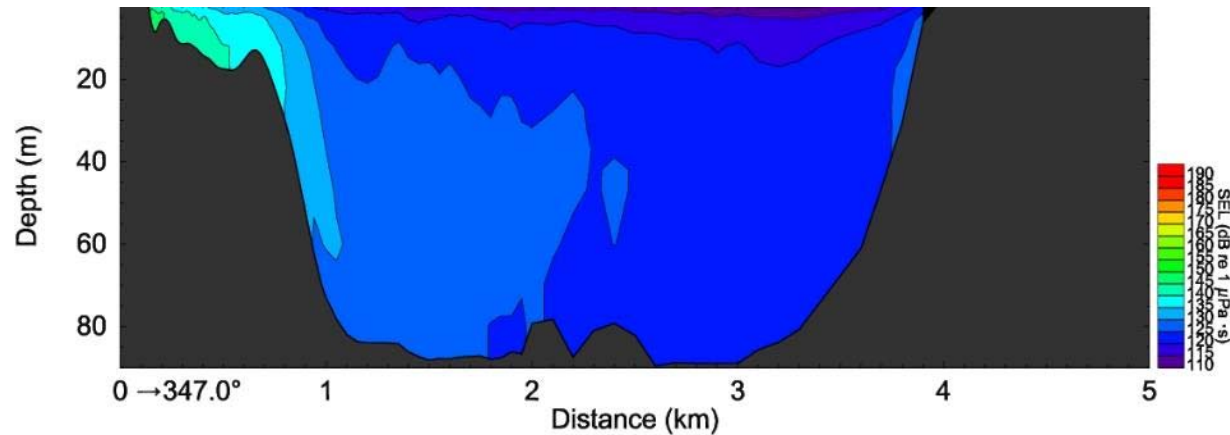


Figure 11. *Scenario F2 blasting*: Single shot sound exposure level (SEL) cross section for a 100 kg TNT charge.

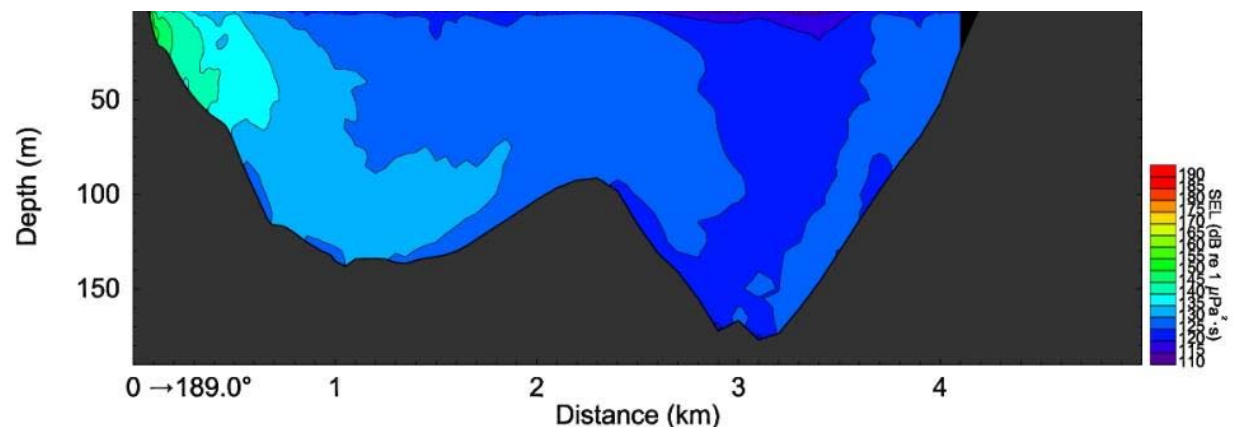


Figure 12. *Scenario F3 blasting*: Single shot sound exposure level (SEL) cross section for a 100 kg TNT charge.

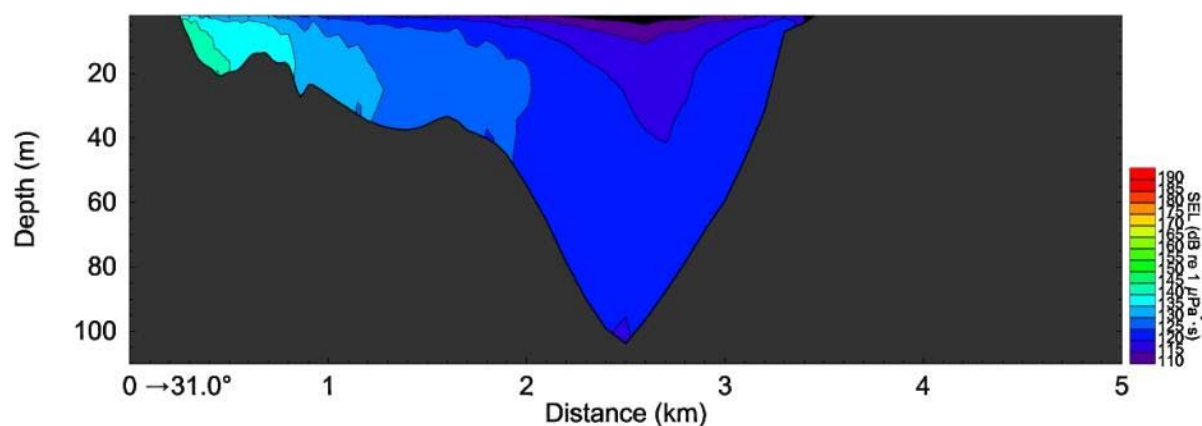


Figure 13. *Scenario F4 blasting*: Single shot sound exposure level (SEL) cross section for a 100 kg TNT charge.

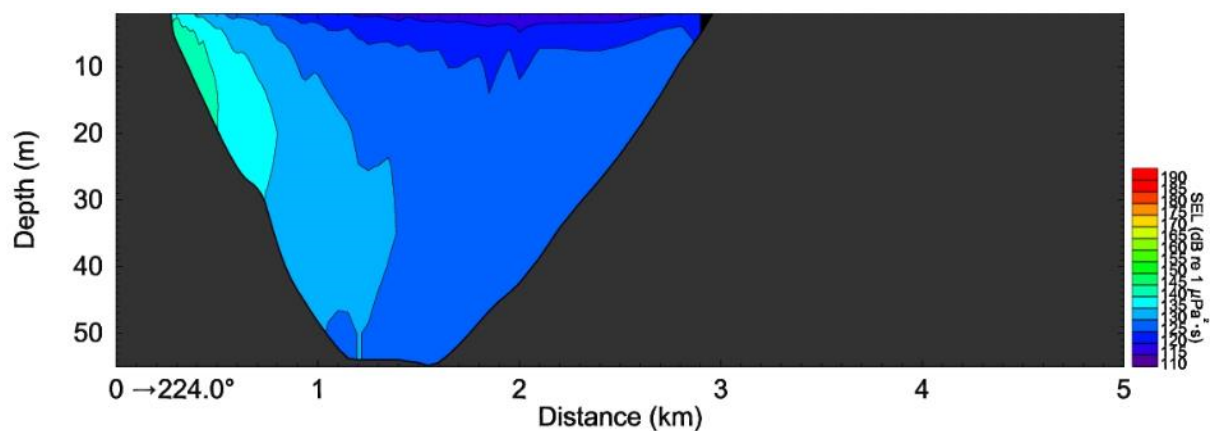


Figure 14. *Scenario F5 blasting*: Single shot sound exposure level (SEL) cross section for a 100 kg TNT charge.

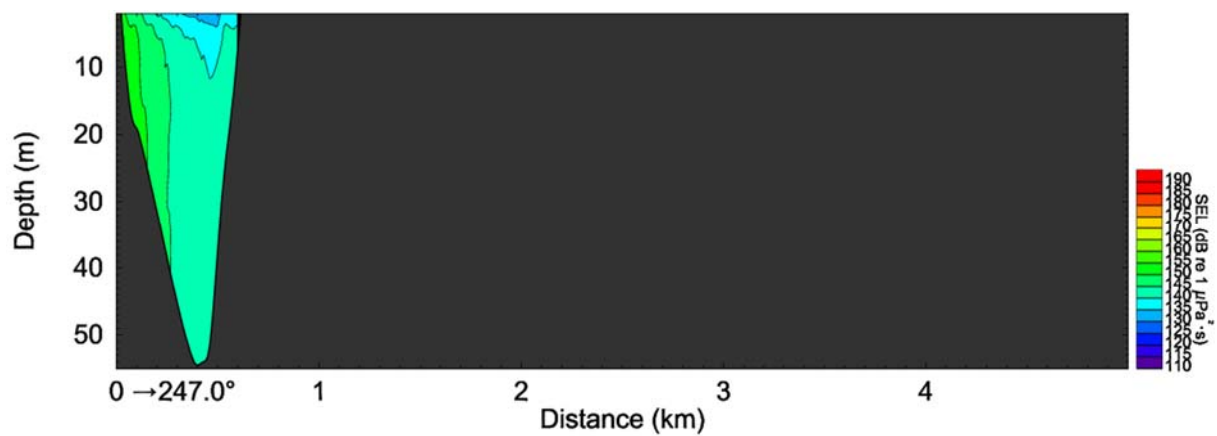


Figure 15. *Scenario F6 blasting*: Single shot sound exposure level (SEL) cross section for a 100 kg TNT charge.

5. Discussion and Conclusion

Underwater sound levels resulting from rock blasting along the Steensby railway were calculated for six locations along the rail alignment that are nearest to water bodies, and for charge sizes from 1 kg TNT to 100 kg TNT. None of the PK and 24h SEL thresholds for effects to fish (see Section 2) were exceeded at any of the modelled locations near the Ravn Camp and Cockburn lakes. The maximum PK level modelled among the 6 blasting sites was 198.2 dB re 1 μ Pa which is below the DFO overpressure requirement of 50 kPa (equivalent to a PK level of 214 dB re 1 μ Pa) and is below both the 207 dB re 1 μ Pa threshold recommended by Popper et al. (2014) and the 206 dB re 1 μ Pa threshold considered by NMFS.

The maximum SEL level modelled for a single 100 kg TNT charge was 165.0 dB re 1 μ Pa²s for scenario F6. This is 18 dB below the most conservative SEL threshold considered (183 dB re 1 μ Pa²s, denoting the onset of injury for fish < 2 g as considered by NMFS), indicating that 63 charges of 100 kg TNT could be detonated within 12 m of nearby freshwater waterbodies (the shortest considered horizontal distance to fish-bearing water) without exceeding any of the Popper et al. (2014) SEL thresholds for mortality, potential mortal injury, and recoverable injury or exceeding the NMFS SEL thresholds for onset of injury for fish of any size. For smaller individual charge weights at this distance, an increased number of detonations could occur before these thresholds would be reached in the water (448, 231, 107, 92, 88, and 78 detonations for charges 1, 10, 20, 30, 40, and 50 kg TNT, respectively). For the blasting locations offset from lake shores by around 30 m or more (Scenarios F1 through F5), these SEL thresholds are unlikely to be exceeded. They would only be reached after more than at least 630 detonations of 100 kg TNT charges in a day or more than 930 detonations or more for the smaller charge sizes.

The findings of this study are based on the specified offsets of the modelled detonation sites from the nearby lake shores. These closest blast sites are more than 12 m from the shores. These results may not apply if detonation sites occur closer to the lake shores.

Glossary of Acoustics Terms

Unless otherwise stated in an entry, these definitions are consistent with ISO 18405 (2017).

Light blue text indicates related terms that might be in this glossary. Dark blue text indicates clickable links to related terms in this glossary

absorption

The conversion of [sound](#) energy to heat energy. Specifically, the reduction of [sound pressure](#) amplitude due to particle motion energy converting to heat in the propagation medium.

acoustic noise

[Sound](#) that interferes with an acoustic process.

ambient sound

[Sound](#) that would be present in the absence of a specified activity (ISO 18405:2017). It is usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

attenuation

The gradual loss of acoustic energy from [absorption](#) and scattering as [sound](#) propagates through a medium. Attenuation depends on [frequency](#)—higher frequency sounds are attenuated faster than lower frequency sounds.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

bandwidth

A range within a continuous band of frequencies. Unit: [hertz \(Hz\)](#).

broadband level

The total [level](#) measured over a specified [frequency](#) range. If the frequency range is unspecified, the term refers to the entire measured frequency range.

compressional wave

A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called a longitudinal wave. In seismology/geophysics, it's called a primary wave or P-wave. [Shear waves](#) in the seabed can be converted to compressional waves in water at the water-seabed interface.

decade

Logarithmic [frequency](#) interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006). For example, one decade up from 1000 Hz is 10,000 Hz, and one decade down is 100 Hz.

decibel (dB)

Unit of **level** used to express the ratio of one value of a power quantity to another on a logarithmic scale. Especially suited to quantify variables with a large dynamic range.

decidecade

One tenth of a **decade**. Approximately equal to one third of an octave ($1 \text{ ddec} \approx 0.3322 \text{ oct}$), and for this reason sometimes referred to as a **1/3 octave**.

decidecade band

Frequency band whose **bandwidth** is one **decidecade**. The bandwidth of a decidecade band increases with increasing centre frequency.

DFO

Fisheries and Oceans Canada.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: **hertz (Hz)**. Symbol: f . 1 Hz is equal to 1 cycle per second.

FWRAM

JASCO's Full Waveform Range-dependent Acoustic Model.

GDEM

Generalized Digital Environmental Model V 3.0.

geoacoustic

Relating to the acoustic properties of the seabed.

GI

Gastrointestinal

hertz (Hz)

Unit of **frequency** defined as one cycle per second. Often expressed in multiples such as kilohertz (1 kHz = 1000 Hz).

hydrostatic pressure

The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified **reference value** of that quantity. For example, a value of **sound pressure level** with reference to $1 \mu\text{Pa}^2$ can be written in the form $x \text{ dB re } 1 \mu\text{Pa}^2$.

Masking

Obscuring of **sounds** of interest by other sounds at similar frequencies.

NMFS

National Marine Fisheries Service.

NOAA

National Oceanic and Atmospheric Administration.

NONNA

NON-Navigational. Name use to define bathymetric data offered by Canadian Hydrographic Service (CHS).

octave

The interval between a [sound](#) and another sound with double or half the [frequency](#). For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

ONR

Office of Naval Research.

parabolic equation method

A computationally efficient solution to the acoustic wave equation that is used to model [propagation loss](#). The parabolic equation approximation omits effects of backscattered [sound](#) (which are negligible for most ocean-acoustic propagation problems), simplifying the computation of propagation loss.

particle acceleration, particle displacement, particle motion, particle velocity

See sound particle acceleration, sound particle displacement, [sound particle motion](#), and [sound particle velocity](#).

PSDM

JASCO's Pile Driving Source Model, a physical model of pile vibration and near-field sound radiation.

peak sound pressure level (PK), zero-to-peak sound pressure level

The [level](#) (L_{pk}) of the squared maximum magnitude of the [sound pressure](#) (p_{pk}^2) in a stated [frequency](#) band and time window. Defined as $L_{pk} = 10\log_{10}(p_{pk}^2/p_0^2) = 20\log_{10}(p_{pk}/p_0)$. Unit: [decibel \(dB\)](#). [Reference value](#) (p_0^2) for [sound](#) in water: 1 μPa^2 .

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. Considered auditory injury. Compare to [temporary threshold shift](#).

point source

A source that radiates [sound](#) as if from a single point.

power spectral density

Generic term, formally defined as power in a unit [frequency](#) band. Unit: watt per hertz (W/Hz). The term is sometimes loosely used to refer to the spectral density of other parameters such as squared [sound pressure](#). Ratio of [energy spectral density](#), E_f , to time duration, Δt , in a specified temporal observation

window. In equation form, the power spectral density P_f is given by $P_f = E_f/\Delta t$. Power spectral density can be expressed in terms of various field variables (e.g., sound pressure, [sound particle displacement](#)).

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called [sound pressure](#).

Unit: pascal (Pa).

propagation loss (PL)

Difference between a [source level](#) (SL) and the level at a specified location, $PL(x) = SL - L(x)$.

Unit: [decibel \(dB\)](#). See also [transmission loss](#).

received level

The [level](#) of a given field variable measured (or that would be measured) at a given location.

reference value

Standard value of a quantity used for calculating underwater [sound level](#). The reference value depends on the quantity for which the level is being calculated:

Quantity	Reference value
Sound pressure	$p_0^2 = 1 \mu\text{Pa}^2$ or $p_0 = 1 \mu\text{Pa}$
Sound exposure	$E_0 = 1 \mu\text{Pa}^2 \text{ s}$
Sound particle displacement	$\delta_0^2 = 1 \text{ pm}^2$
Sound particle velocity	$u_0^2 = 1 \text{ nm}^2/\text{s}^2$
Sound particle acceleration	$a_0^2 = 1 \mu\text{m}^2/\text{s}^4$

$R_{95\%}$ distance

The distance to a given sound level after the 5% farthest points were excluded.

R_{max} distance

The maximum distance to a given sound level over all azimuths.

shear wave

A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called a secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to [compressional waves](#) in water at the water-seabed interface.

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium. In common meaning, a form of energy that propagates through media (e.g., water, air, ground) as pressure waves.

sound exposure

Time integral of squared [sound pressure](#) over a stated time interval in a stated [frequency](#) band. The time interval can be a specified time duration (e.g., 24 h) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: pascal squared second ($\text{Pa}^2 \text{ s}$). Symbol: E .

sound exposure level (SEL)

The **level** (L_E) of the **sound exposure** (E) in a stated **frequency** band and time window: $L_E = 10\log_{10}(E/E_0)$ (ISO 18405:2017). Unit: **decibel (dB)**. **Reference value** (E_0) for **sound** in water: $1 \mu\text{Pa}^2 \text{ s}$.

sound field

Region containing **sound** waves.

sound intensity

Product of the **sound pressure** and the **sound particle velocity** (ISO 18405:2017). The magnitude of the sound intensity is the **sound** energy flowing through a unit area perpendicular to the direction of propagation per unit time. Unit: watt per meter squared (W/m^2). Symbol: I .

sound particle acceleration

The rate of change of **sound particle velocity**. Unit: meter per second squared (m/s^2). Symbol: a .

sound particle motion

Movement caused by the action of **sound** of the smallest volume of a medium that represents its mean physical properties. Important for determining effects of underwater noise on fishes and invertebrates because their hearing organs sense particle motion rather than **sound pressure**.

sound particle displacement

Displacement of a material element caused by the action of **sound**, where a material element is the smallest element of the medium that represents the medium's mean density (ISO 18405:2017). Unit: meter (m). Symbol: δ .

sound particle velocity

The velocity of a particle in a material moving back and forth in the direction of the pressure wave. Unit: metre per second (m/s). Symbol: u .

sound pressure

The contribution to total pressure caused by the action of **sound** (ISO 18405:2017). Unit: pascal (Pa). Symbol: p .

sound pressure level (SPL), rms sound pressure level

The **level** (L_p) of the time-mean-square **sound pressure** (p_{rms}^2) in a stated **frequency** band and time window: $L_p = 10\log_{10}(p_{\text{rms}}^2/p_0^2) = 20\log_{10}(p_{\text{rms}}/p_0)$, where rms is the abbreviation for root-mean-square. Unit: **decibel (dB)**. **Reference value** (p_0^2) for **sound** in water: $1 \mu\text{Pa}^2$. SPL can also be expressed in terms of the root-mean-square (rms) with a **reference value** of $p_0 = 1 \mu\text{Pa}$. The two definitions are equivalent.

sound speed profile

The speed of **sound** in the water column as a function of depth below the water surface.

source level (SL)

A property of a **sound** source equal to the **sound pressure level** measured in the **far field** plus the **propagation loss** from the acoustic centre of the source to the receiver position. Unit: **decibel (dB)**. **Reference value**: $1 \mu\text{Pa}^2 \text{ m}^2$.

spectrum

Distribution of acoustic signal content over [frequency](#), where the signal's content is represented by its power, energy, mean-square [sound pressure](#), or [sound exposure](#).

Net Explosive Weight (NEW)

The total mass of explosive substances excluding packaging or casings.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity caused by noise exposure. Compare with [permanent threshold shift](#).

transmission loss (TL)

The difference between a specified level at one location and that at a different location: $TL(x_1, x_2) = L(x_1) - L(x_2)$ (ISO 18405:2017). Unit: [decibel \(dB\)](#). See also [propagation loss](#)

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Appendix A. Acoustic Metrics

This section describes in detail the acoustic metrics, impact criteria, and frequency weighting relevant to the modelling study. The technical details of the modelling methodology are described thereafter.

A.1. Pressure Related Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of $p_0 = 1 \mu\text{Pa}$. Because the perceived loudness of sound, especially pulsed sound such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 2017, ANSI S1.1-2013).

The zero-to-peak sound pressure, or peak sound pressure (PK or L_{pk} ; dB re $1 \mu\text{Pa}$), is the decibel level of the maximum instantaneous acoustic pressure in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{pk} = 10 \log_{10} \frac{\max|p^2(t)|}{p_0^2} = 20 \log_{10} \frac{\max|p(t)|}{p_0} \quad (\text{A-1})$$

PK is often included as a criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of an acoustic event, it is generally a poor indicator of perceived loudness.

The impulse is the time integral of pressure through the largest positive phase of a pressure waveform (CSA 2004):

$$J_p = \int_0^T p(t) dt. \quad (\text{A-2})$$

In this formula, T is the end time of the largest positive phase of the pressure waveform. The impulse has SI units of pascal seconds (Pa·s).

The sound exposure level (SEL or L_E ; dB re $1 \mu\text{Pa}^2 \text{ s}$) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10 \log_{10} \left(\int_T p^2(t) dt / T_0 p_0^2 \right) \text{ dB} \quad (\text{A-3})$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10 \log_{10} \left(\sum_{i=1}^N 10^{\frac{L_{E,i}}{10}} \right) \text{ dB} \quad (\text{A-4})$$

A.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3-octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor of 10 in sound frequency. Each octave represents a factor of 2 in sound frequency. The centre frequency of the i th band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \text{ kHz} \quad (\text{A-5})$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the i th decade band are defined as:

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i) \quad (\text{A-6})$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1). The acoustic modelling spans from band 7 ($f_c(7) = 5 \text{ Hz}$) to band 44 ($f_c(44) = 25 \text{ kHz}$).

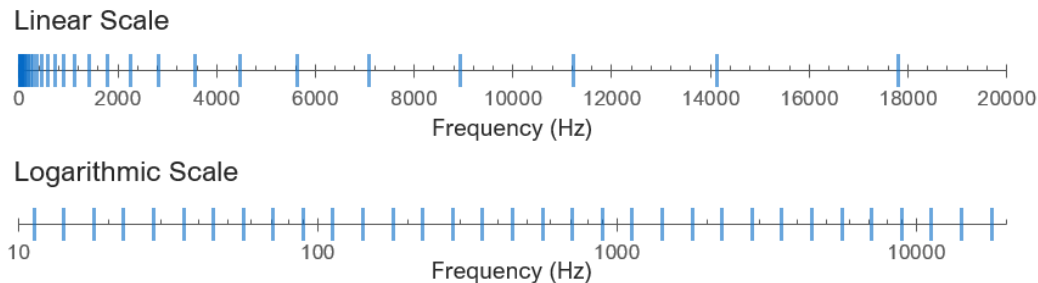


Figure A-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the i th band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{lo,i}$ and $f_{hi,i}$:

$$L_{p,i} = 10 \log_{10} \int_{f_{lo,i}}^{f_{hi,i}} S(f) df \text{ dB} \quad (\text{A-7})$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \text{ dB} \quad (\text{A-8})$$

Figure A-2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the decidecade bands are wider than 1 Hz, the decidecade band SPL is higher than the spectral levels at higher frequencies. Acoustic modelling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

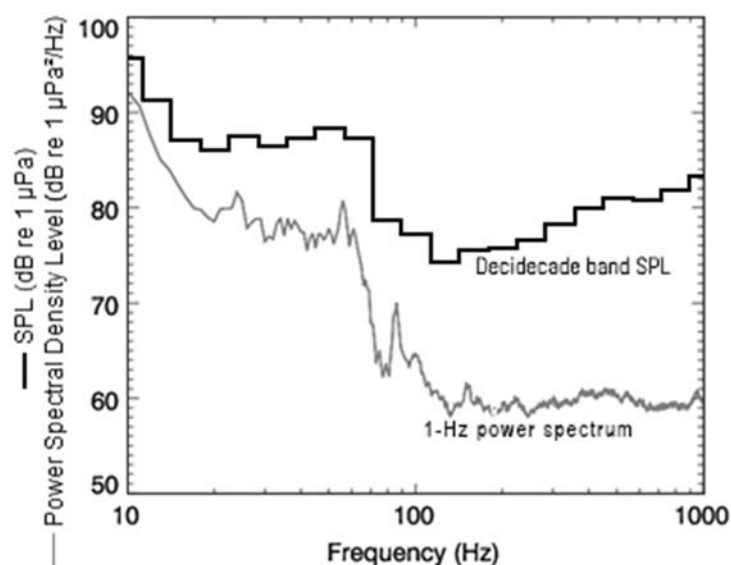


Figure A-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the decidecade SPL is higher than the power spectrum.

Appendix B. Impact Criteria

Fish have all of the basic acoustic processing capabilities of other vertebrates (see review by Popper et al. 2003, Ladich and Popper 2004). Fish can discriminate between sounds of different magnitudes or frequencies, detect specific sounds when other signals are present, and determine the direction of a sound source. Their auditory systems differ, however, from those of marine mammals.

The pressure component of sound is represented by sound waves, which are characterized by the medium compressing and expanding as sound energy moves through it. At the same time, the particles that form the medium move back and forth (particle motion). All fish directly sense the particle motion component of sound (Fay 1984), although relatively few fish sense both the particle and pressure components (Popper et al. 2003). The ears of all fish consist of otolith- (or otoconia-) containing end organs that function as inertial accelerometers. Fish that sense pressure have additional morphological adaptations that allow them to detect acoustic pressure (e.g., Popper et al. 2003). In these fish, gas-filled bladders such as the swim bladder, which is near the ear, or mechanical connections such as Weberian ossicles, which are between the gas-filled bladder and the ear, convey sound pressure from the water to the ear when pressure deforms the bladder.

Most fish detect only particle motion, not pressure, and their hearing frequency range is typically limited to frequencies below 1 kHz. Pressure-sensing fish tend to have extended hearing bandwidth and lower detection thresholds. They are often capable of detecting signals up to 3–4 kHz, with thresholds that may be 20 dB or more lower than for fish that are not sensitive to pressure (Hastings and Popper 2005). Several fish taxonomic groups contain fish that can sense pressure, but this feature is not used to allocate fish into groups. Hearing abilities have been determined for relatively few (~100) of the more than 27,000 extant fish species (see Fay 1988, Popper et al. 2003). Hearing capabilities between different species, especially those that are taxonomically or geographically distant, must be extrapolated with caution.

B.1. Injury Criteria

In 2008, the Fisheries Hydroacoustic Working Group (FHWG), sponsored by NOAA, developed interim (dual) criteria for onset of injury to fish from impact hammering noise (FHWG 2008, Buehler et al. 2015). These dual criteria specify a peak pressure level threshold of 206 dB re 1 μ Pa and a size-dependent SEL_{24h} threshold. For fish weighing 2 g or more, the threshold is 187 dB re 1 μ Pa² s, whereas for fish under 2 g it is 183 dB re 1 μ Pa² s. The FHWG did not establish criteria for fish injury caused by vibratory pile driving or other types of sources. NOAA considers these FHWG thresholds when assessing noise from blasting near water.

An ANSI-accredited standards committee on the effects of sound on fish and turtles, sponsored by the Acoustical Society of America (Popper et al. 2014), was formed in 2006 to develop noise exposure criteria for fish and sea turtles based on work started by the FHWG (a NOAA panel). Similar to the FHWG interim criteria, the ANSI guidelines also recommend peak pressure level and SEL thresholds, both without frequency weighting. They specify that SEL be integrated over 24 h or the duration of the activity, whichever is less.

Popper et al. (2014) categorized fish into three groups based on their hearing capabilities¹, which are determined by whether a swim bladder is present and is directly involved in hearing. The categories are: (i) fish without a swim bladder, (ii) fish with a swim bladder not involved in hearing, and (iii) fish with a swim bladder involved in hearing. Their report provides received sound levels based on the best available science that are suitable as provisional guidelines for assessing onset of injury to fish from various sources (Table B-1 provides the recommended thresholds for impulsive sound sources).

Table B-1. Peak sound pressure level (PK) and sound exposure level (SEL) dual thresholds for acoustic effects from impulsive noise sources on fish, fish eggs, and fish larvae as proposed by Popper et al. (2014). Relative risk (high, moderate, or low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

Type of animal	Mortality and Potential mortal injury		Recoverable injury		TTS	Masking	Behaviour
	SEL (dB re 1 μPa^2 s)	PK (dB re 1 μPa)	SEL (dB re 1 μPa^2 s)	PK (dB re 1 μPa)	SEL (dB re 1 μPa^2 s)		
Fish: No swim bladder (particle motion detection)	219	213	216	213	186	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	210	207	203	207			(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207					(N) High (I) High (F) Moderate	
Fish eggs and fish larvae	210		(N) Moderate (I) Low (F) Low				

All criteria are presented as sound pressure, even for fish without swim bladders, because no data for particle motion exist.

¹ The classification of fish into 'hearing specialist' or 'hearing generalist' refers to their hearing sensitivity. Thresholds to impact criteria were not developed on this system of classification. Bony fish with specializations that enhance their hearing sensitivity are called 'hearing specialists' whereas those that lack such capabilities are called 'hearing generalists' (non-specialists; Popper 2003, Ladich and Popper 2004). These specializations are not criteria for assigning fish to specific taxa; hearing specialists and generalists are distributed over many taxa.

Appendix C. Modelling Methodology and Parameters

This section provides a detailed description of the modelling methodology.

C.1. Noise Propagation from Blasting

For a blast signature, source level characteristics were modeled under the assumption that the pressure wave generated by detonation of an underground explosive consists of an initial high-amplitude blast that exhibits an exponential decay. The initial blast pressure varies over time, as per the equation of Gaspin (1983) and Richardson et al. (1995):

$$p(t) = P e^{-\frac{t}{\tau}} \text{ Pa}, \quad (\text{C-1})$$

where P is the maximum amplitude and τ is the exponential time constant. Near the charge, the maximum pressure is defined empirically as:

$$P = 5.17107 e^7 (W^{1/3}/R)^{1.13} \text{ Pa}, \quad (\text{C-2})$$

where W is the (TNT-equivalent) mass of explosive in kilograms and R is the distance from the explosive (Richardson et al. 1995) in meters. The leading constant in equation C-1 has been adapted here to reflect the peak amplitude corresponding to a confined detonation (Oriard 2002). The exponential time constant has the form:

$$\tau = 9.25 e^{-5} W^{1/3} (W^{1/3}/R)^{-0.22} \text{ s}. \quad (\text{C-3})$$

These equations are characteristic of a shock wave near the charge. The limiting range of validity, R_0 , can be estimated using the Gaspin (1983) equation:

$$R_0 = 4.76 W^{1/3} \text{ m}. \quad (\text{C-4})$$

Thus, R_0 may be used to estimate the range at which sound from a blast may be modeled using typical sound propagation models (e.g., FWRAM).

C.2. Sound Propagation Models

C.2.1. Transmission Loss

The propagation of sound through the environment was modelled by predicting the acoustic transmission loss—a measure, in decibels, of the decrease in sound level between a source and a receiver some distance away. Geometric spreading of acoustic waves is the predominant way by which transmission loss occurs. Transmission loss also happens when the sound is absorbed and scattered by the water and absorbed, scattered, and reflected at the water surface and within the lake bed. Transmission loss depends on the acoustic properties of the ocean and seabed; its value changes with frequency.

If the acoustic source level (SL), expressed in dB re $1 \mu\text{Pa}^2 \text{m}^2 \text{s}$, and transmission loss (TL), in units of dB, at a given frequency are known, then the received level (RL) at a receiver location can be calculated in dB re $1 \mu\text{Pa}^2 \text{s}$ by:

$$\text{RL} = \text{SL} - \text{TL} \quad (\text{C-5})$$

C.2.2. Sound Propagation with FWRAM

For cylindrical pile driving, time-domain representations of the pressure waves generated in the water are required for calculating peak pressure level. Furthermore, the pile must be represented as a distributed source to accurately characterise vertical directivity effects in the near-field zone. For this study, synthetic pressure waveforms were computed using FWRAM, which is a time-domain acoustic model based on a wide-angle parabolic equation (PE) algorithm. FWRAM computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments and takes as environmental inputs the bathymetry, water sound speed profile, and geoacoustic profile of the ground. FWRAM computes pressure waveforms via Fourier synthesis of the modelled acoustic transfer function in closely spaced frequency bands.

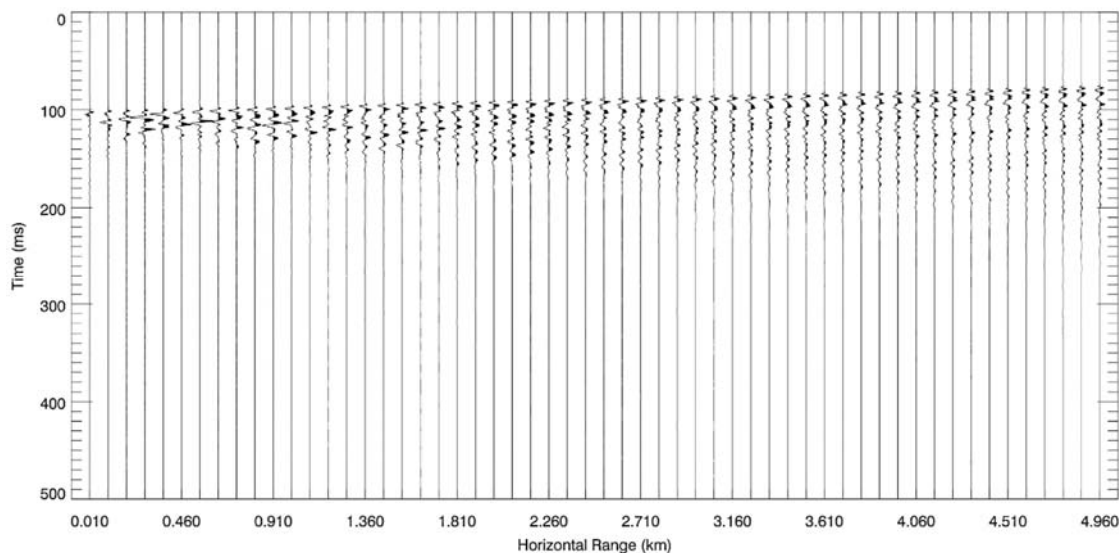


Figure C-1. Example of synthetic pressure waveforms computed by FWRAM for impact pile driving at multiple range offsets. The amplitudes of the pressure traces have been normalized for display purposes.

C.3. Environmental Parameters

C.3.1. Bathymetry

Water depths throughout the project area in freshwater were extracted from client information. The client provided bathymetry and topography data around the project area. The bathymetry water depths describe the lake water depths up to 185 m from the lake shore. The topography data extend up to 175 m high from the lake shore. Figure C-3 and Figure C-3 shows bathymetric contours of the modelled area.

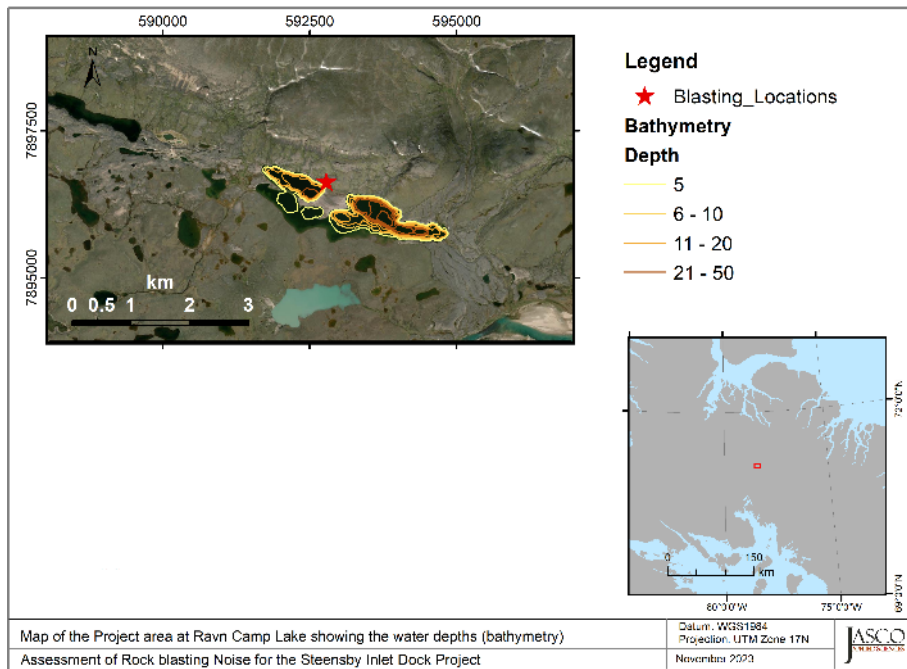


Figure C-2. Bathymetry profile for the project area at the Ravn Camp Lake.

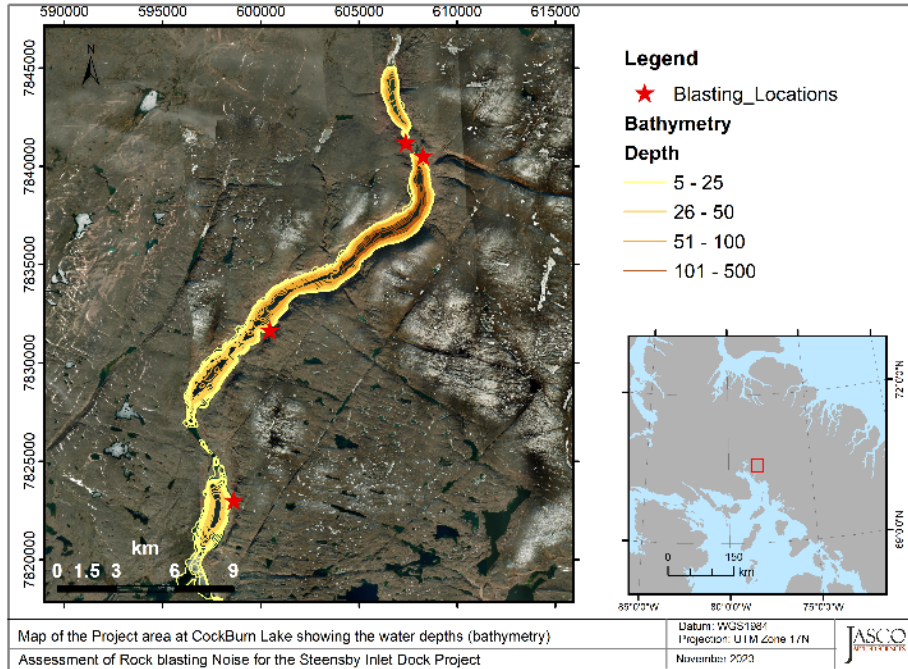


Figure C-3. Bathymetry profile for the project area at the Cockburn Lake.

C.3.2. Sound Speed Profiles

The sound speed profile in the freshwater lakes for project area was derived from temperature and salinity profiles provided by the client using the Coppens Function (Coppens (1981)).

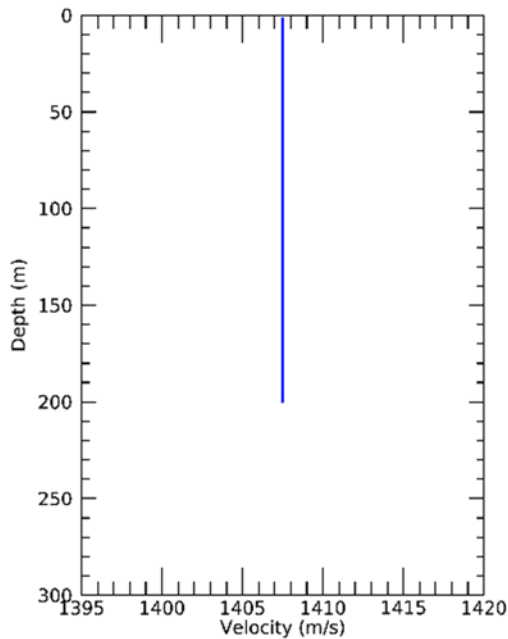


Figure C-4. Sound speed profiles. The constant velocity profile was based on 1 °Celsius temperature and no salinity.

C.3.3. Seabed Geoacoustic Profiles

The geoacoustic profiles for the modelled locations (Ravn Cape Lake and Cockburn Lake) were obtained from nearby well core soil profiles provided by the client. For both locations, the geology profile has a thin layer of glacial till formation composed of soil, ice, and gravel materials, followed by 5–20 m of frozen grey sand materials with some cobbles. Beneath the soil layer is the bedrock made of Granitoid/Gneiss lithology. Tables C-1 and C-2 summarize the geoacoustics properties of the different soil units within the modelled locations.

Table C-1. Seabed geoacoustic properties at Ravn Cape locations. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave.

Depth below seafloor (m)	Material	Density (g/cm ³)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0–6.0	Glacial till/ Soil	2.1	1950.0	0.4	300	3.65
6.0	Soil/Sand	2.1–2.094	1950–1786.5	0.4–0.878		
6.0–13.0		2.094–2.103	1786.5–1795.6	0.878–0.876		
13.0–20.0		2.103–2.113	1795.6–1804.5	0.876–0.874		
20.0		2.113–2.650	1804.5–3000	0.878–0.1		
20.0–50.0	Granitoid	2.650	3000–3500	0.1		
50.0–145.0			3500–4000			
>145.0			4000			

Table C-2. Seabed geoacoustic properties at Cockburn locations. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave.

Depth below seafloor (m)	Material	Density (g/cm³)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0–10	Glacial till/ Soil	2.1–2.113	1950.0–1963.0	0.4–0.396	300	3.65
10.0–20.0		2.113–2.127	1963–1975.8	0.396–0.393		
20.0		2.127–2.65	1975.8–3000	0.393–0.1		
20.0–50.0	Granitoid	2.65	3000–3500	0.1		
50.0–145.0			3500–4000			
>145.0			4000			

C.4. Sound pressure level formula:

The standard unit for sound pressure is Pascal (Pa). However, most of the sound level metrics and threshold in the report are presented as sound pressure levels in units of decibels (dB re 1 μPa). The dB measure is a logarithmic quantity that is commonly used for characterizing underwater sound levels given the wide range of pressure values that can occur in water. In underwater acoustics, the measure is referenced to the sound level (p_0) of 1 μPa. To convert the sound pressure in Pa (in fact, μPa) to sound pressure level in dB re 1 μPa, we use the following equation:

$$p \text{ (dB re 1 } \mu\text{Pa)} = 20 \log_{10} \left(\frac{p \text{ (}\mu\text{Pa)}}{p_0} \right)$$