

# Airborne Noise Modelling

## Construction of Steensby Port Facility

JASCO Applied Sciences (Canada) Ltd

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- $\exists x(A(x) \wedge \neg B(x)) \rightarrow \neg \forall x(A(x) \rightarrow B(x))$
- $\neg \forall x(A(x) \rightarrow B(x)) \rightarrow \exists x(A(x) \wedge \neg B(x))$

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## Plain Language Summary

Baffinland Iron Mines Corporation (Baffinland) is the owner and operator of the Mary River Project, an operating open pit iron ore mine located in the Qikiqtani Region of Baffin Island in Nunavut (the Project). The Nunavut Impact Review Board (NIRB) issued Project Certificate No. 005 on 28 December 2012, authorizing Baffinland to mine and transport iron ore from Deposit No. 1 by rail to a port site in Steensby Inlet (Steensby Port) for year-round shipping along the Southern Shipping Route (via Foxe Basin and Hudson Strait). Baffinland is now proceeding with construction of the approved Steensby Railway and Steensby Port.

During construction, airborne noise from activities such as blasting and pile driving could potentially harm marine mammals or disrupt their behavior if unmitigated. To address this, JASCO Applied Sciences (JASCO) was commissioned by WSP, on behalf of Baffinland Iron Mines Corporation, to study how construction noise at Steensby Port travels in the air and where the noise could affect marine animals, including seals, walruses, and polar bears. The study estimated how far noise might exceed safe levels for:

- Hearing loss (temporary or permanent)
- Behavioural disturbance

## Key Findings

- Noise from impact pile driving could disturb animals up to 465 meters away but is unlikely to cause hearing loss.
- Small blasting charges (1–20 kg) might cause disturbances up to 1.4 kilometers away, while larger charges (30–100 kg) could affect animals up to 2.4 kilometers away. In certain wind conditions, animals located within a small region 15 kilometers down-wind from larger charges could be disturbed.

The study results will guide noise reduction strategies and monitoring plans, which Baffinland will implement as part of a Marine Mammal Management Plan (MMMP) in the Construction Environmental Management Plan (CEMP). These measures will evolve as more data is collected and engagement continues with regulators and Inuit.



## Executive Summary

Baffinland Iron Mines Corporation (Baffinland) is the owner and operator of the Mary River Project, an operating open pit iron ore mine located in the Qikiqtani Region of Baffin Island in Nunavut (the Project). The Nunavut Impact Review Board (NIRB) issued Project Certificate No. 005 on 28 December 2012, authorizing Baffinland to mine and transport iron ore from Deposit No. 1 by rail to a port site in Steensby Inlet (Steensby Port) for year-round shipping along the Southern Shipping Route (via Foxe Basin and Hudson Strait). Baffinland is now proceeding with construction of the approved Steensby Railway and Steensby Port with the earliest anticipated start of construction in late 2025.

Airborne noise generated during construction of the Steensby Port facility has the potential to change the behaviour of marine mammals in the local environment and, if unmitigated, airborne noise from blasting and impact pile driving during construction may cause auditory injuries to marine mammals. JASCO Applied Sciences (JASCO) was commissioned by WSP, on behalf of Baffinland Iron Mines Corporation, to perform an acoustic modelling study of noise associated with the Steensby Port construction activities. Specifically, sound propagation models were applied to assess the propagation of airborne noise produced by impact pile driving and blasting activities at the project site.

Modelling results were interpreted to estimate distances over which airborne sound levels would exceed established acoustic injury and disturbance thresholds for marine mammals. For acoustic injury, the relevant thresholds pertain to the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) of marine mammal hearing. Separate thresholds were considered for phocid carnivores (e.g. ringed seal and bearded seal) and for non-phocid carnivores (e.g. walrus and polar bear). In both cases, thresholds were expressed using two different sound metrics, the peak instantaneous sound level (PK) and the frequency-weighted sound exposure level (SEL). The distances to potential acoustic effects correspond to the metric with the longest exceedance distance.

The modelling results will be used to inform mitigation and monitoring requirements that will be implemented during construction of the Steensby Port facility, which will be outlined in a Marine Mammal Management Plan (MMMP) within Baffinland's Construction Environmental Management Plan (CEMP). The purpose of these management plans is to outline commitments, mitigation measures and monitoring programs that Baffinland will implement during port construction to reduce potential Project-related adverse impacts on marine mammals resulting from airborne noise caused by impact pile driving and onshore rock blasting. The MMMP will address all marine mammal species that could be directly or indirectly affected by airborne noise within the Regional Study Area (RSA) boundaries, including walrus, ringed seal, bearded seal, and polar bear, and their related habitats. Mitigation measures may be refined over the course of the construction project, as the result of information learned through ongoing noise and wildlife monitoring undertaken as part of the MMMP and CEMP, and through discussions with regulators and Inuit organizations.

To carry out the modelling, JASCO obtained frequency-dependent sound levels for each activity of concern, either from publicly available measurements in the case of piling, or from a combination of measurements and the model ConWep's Shockwave module (Hyde 1988, 1992) in the case of blasting. JASCO's Impulse Noise Propagation Model (INPM) was used to estimate how the sound propagates in the atmosphere.

The modelling study included a preliminary step in which monthly atmospheric profiles were generated and calculation of sound propagation was carried out along a single radial to determine which atmospheric profile yielded the most conservative propagation conditions (i.e., those leading to the largest ensonification). Once the most conservative month (September) was determined, the predicted received levels were evaluated in all directions to assess the potential for impacts to marine mammals on land or

those with their head above the water level in the surrounding waters. The results were evaluated against dual criteria that considers both the peak instantaneous sound level (PK) and the sound exposure level (SEL) thresholds.

The goal of the present study was to predict the extent of ensonification from three piling and two blasting modelling scenarios. In the case of blasting scenarios, TNT charges of 1, 10, 20, 30, 40, 50, and 100 kg were modelled at two anticipated blasting locations. Three impact pile driving scenarios were modelled one location representative of noise during installation of sheet piles and cylindrical piles at the ore dock combi-wall and one location representative of installation of mooring point piles. All scenarios were modelled assuming zero wind conditions and the average elevation-dependent wind profile for the month of September.

Modelling results demonstrated that the presence of wind does not influence the acoustic impact distance (i.e., range from the source where sound levels would exceed established acoustic injury or disturbance thresholds), as long as those distances are less than ~2 km, which was the case for all piling activities and blasting activities with charges 1–20 kg TNT. For blasting using larger charges, downward refraction of sound in the atmosphere due to the wind causes ensonification of small annular areas at longer ranges compared to the no-wind conditions.

For impact driving of cylindrical pipe piles, sheet piles, and mooring piles, the PTS threshold was not exceeded for any scenario, and only the TTS threshold for phocid carnivores was exceeded at distances up to 29 m from the source for the IA2 scenario (impact driving of combi-wall sheet piles). Airborne noise generated during impact pile driving exceeded the behavioural disturbance threshold at distances up to 463 m from the source in zero wind conditions, and up to 465 m from the source in average wind conditions. These distances correspond to the 109 dB re 20  $\mu$ Pa PK threshold for behavioural disturbance; exceedance of the SEL behavioural disturbance threshold occurred at shorter distances for these scenarios.

For onshore blasting, threshold exceedance distances were as follows:

- The PTS thresholds were either not exceeded, or were only exceeded at distances <5 m. The presence of wind did not change the threshold exceedance distances.
- The TTS thresholds were exceeded at distances up to 73 m from the source for the SEL metric in both zero wind and average wind conditions.
- In zero wind conditions, the 109 dB re 20  $\mu$ Pa PK disturbance threshold was exceeded at distances up to 235 m from the source for a 1 kg TNT charge, and up to 2,341 m from the source for a 100 kg TNT charge.
- In the presence of wind, the distance to the 109 dB re 20  $\mu$ Pa PK disturbance threshold remained unchanged compared to no-wind conditions for charges comprised of between 1 kg and 20 kg TNT. For charges ranging from 30 kg to 100 kg TNT, the effect of wind became apparent with the disturbance threshold being exceeded in a narrow annular region at distances up to 8,102 m and 15,328 m from the source, respectively.

# 1. Introduction

Baffinland Iron Mines Corporation (Baffinland) is the owner and operator of the Mary River Project, an operating open pit iron ore mine located in the Qikiqtani Region of Baffin Island in Nunavut (the Project). The Nunavut Impact Review Board (NIRB) issued Project Certificate No. 005 on 28 December 2012, authorizing Baffinland to mine and transport iron ore from Deposit No. 1 by rail to a port site in Steensby Inlet (Steensby Port) for year-round shipping along the Southern Shipping Route (via Foxe Basin and Hudson Strait). Baffinland is now proceeding with construction of the approved Steensby Railway and Steensby Port with the earliest anticipated start of construction in late 2025.

Port construction activities such as pile driving and rock blasting will produce airborne noise that can alter the behaviour of nearby marine mammals and that, without mitigation, could result in acoustic injury in the form of permanent or temporary shifts of marine mammal hearing thresholds. JASCO Applied Sciences (Canada) Ltd. (JASCO) was commissioned by WSP, on behalf of Baffinland, to perform an airborne noise modelling study to predict in-air sound propagation and calculate noise footprints associated with impact pile driving of cylindrical piles and sheet piles, and from onshore rock blasting. This report focuses on airborne noise above the land and water surface and within Steensby Inlet; a modelling study of underwater noise produced by the construction activities was also carried out and those results can be found in a separate acoustic modelling report (Austin and Zykov 2025). Model results were interpreted to estimate the maximum distances over which in-air sound levels would exceed established acoustic injury and disturbance thresholds for marine fauna.

In general, sound propagation in air depends on seasonal variability of local atmospheric properties and on local terrain coverage and topographic features. JASCO's specialized airborne sound propagation model takes each of these factors into account. In addition, noise production depends on the type of construction activity. For pile driving, noise production depends on the hammer and pile characteristics. For blasting, noise production depends on the size of the charges being detonated. JASCO determined source noise levels for these activities using empirical data and models.

Table 1 summarizes the main parameters of the five airborne noise scenarios considered in this report. Scenarios IA1 to IA3 represent impact pile driving activities, with Scenario IA1 focusing on cylindrical combi-wall pipe piles, Scenario IA2 on combi-wall sheet piles, and Scenario IA3 on cylindrical mooring piles. Scenarios IA4 to IA5 represent blasting activities, with Scenario IA4 focusing on nearshore blasting and Scenario IA5 on in-land blasting. For each of the blasting scenarios, charges of 1, 10, 20, 30, 40, 50, and 100 kg TNT were considered. Figure 1 shows the location of each of the modelled scenarios.

Table 1. Location and description of acoustic modelling scenarios.

Scenario	Construction Activity	Latitude	Longitude	UTM Zone 17N		Source Elevation above ground (m)	Maximum # of events per day, N <sub>24</sub>
				x (m)	y (m)		
IA1	Impact piling of combi-wall cylindrical pipe piles	70.275560 N	78.535607 W	592804	7798482	8	8 (1.5 piles per day, 5 strikes per pile)
IA2	Impact piling of combi-wall sheet piles					5	300 (6 piles per day, 50 strikes per pile)
IA3	Impact piling of cylindrical mooring piles	70.276546 N	78.533810 W	592867	7798595	10	8 (1.5 piles per day, 5 strikes per pile)
IA4	On-land blasting near shore	70.276230 N	78.533250 W	592889	7798561	-3	100
IA5	On-land blasting far from shore	70.277590 N	78.530910 W	592971	7798716	-3	100

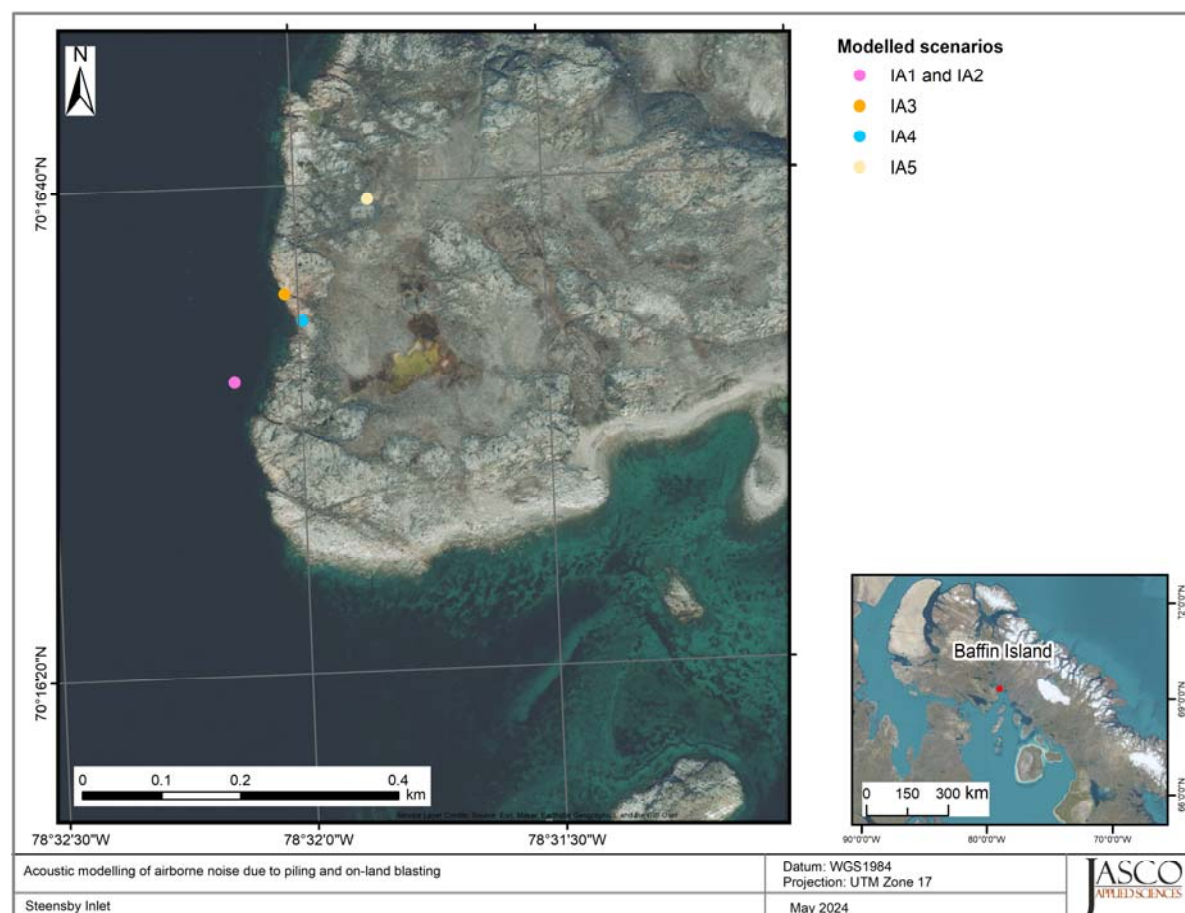


Figure 1. Map of the Project area, showing the locations for modelling airborne noise for impact pile driving (Scenarios IA1–IA3) and onshore blasting activities (Scenarios IA4–IA5).

In this report, we follow the definitions and conventions of ISO (2017) except where stated otherwise in Table 2. The structure of the report is organized as follows: Section 2 describes the noise impact criteria for airborne noise, Section 3 describes the methods used to predict source levels and acoustic propagation, Section 4 presents modelling results (presented as tables and maps showing threshold exceedance distances). Section 5 provides a discussion of the results and presents concluding remarks.

Table 2. Summary of relevant acoustic terminology.

Metric	Main text <sup>a</sup>	Equations/tables <sup>a</sup>
Sound pressure level	SPL	$L_{p,w}$ <sup>b</sup>
Peak pressure level	PK	$L_{pk}$
Cumulative sound exposure level	SEL	$L_{E,w,T}$ <sup>c</sup>

<sup>a</sup> Following (ISO 2017) with modifications described in the footnotes.

<sup>b</sup>  $w$  in  $L_{p,w}$  and  $L_{E,w,T}$  describes frequency-weighting function, if used.

<sup>c</sup>  $T$  in  $L_{E,w,T}$  describes the time window used to calculate SEL.

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## 2. Noise Impact Criteria

Sound level metrics such as peak pressure level (PK) and sound exposure level (SEL) are commonly used to evaluate noise and its effects on animals and humans, although the choice of metrics and thresholds continues to evolve as associated research remains active. The distances to established acoustic thresholds for impacts on marine mammals were predicted based on available sets of criteria for the onset of noise-induced injuries including permanent threshold shift (PTS) and temporary threshold shift (TTS), and for behavioural disturbance. These criteria are listed below and are discussed in more detail in Appendix B. These thresholds are commonly accepted by regulatory agencies and represent current best-available science.

For in-air noise due to impulsive sounds such as detonating buried (i.e., capped) explosives or impact pile driving, results are presented for the following criteria:

- Injury thresholds (onset of PTS and TTS; Table 3) for phocid carnivores in air (PCA) and other marine carnivores in air (OCA), based on Southall et al. (2019).
- Behavioural thresholds for pinnipeds in air (Table 3), based on Southall et al. (2007).

The PK criteria threshold is applied to the maximum instantaneous value over the course of the construction operation. The SEL metric is an integral metric, and the criteria threshold is applied to the combined exposure over a specific period, namely a 24-hour period, which is indicated as SEL<sub>24h</sub>. The criteria thresholds are defined for each marine mammal functional hearing group individually and applied to frequency-weighted sound exposure level field (SEL<sub>w,24h</sub>) using group-specific auditory weighting curves.

Table 3. Injury and behavioural disturbance thresholds for phocid carnivores in air and other marine carnivores in air for impulsive sounds from Southall et al. (2007, 2019). SEL<sub>24h</sub>: sound exposure level accumulated over 24 h; PK: peak sound pressure level; SEL<sub>w,event</sub>: sound exposure level for a single event.

Functional hearing group or species	PTS		TTS		Behavioural disturbance	
	SEL <sub>w,24h</sub> (dB re 20 µPa <sup>2</sup> ·s)	PK (dB re 20 µPa)	SEL <sub>w,24h</sub> (dB re 20 µPa <sup>2</sup> ·s)	PK (dB re 20 µPa)	SEL <sub>w,event</sub> (dB re 20 µPa <sup>2</sup> ·s)	PK (dB re 20 µPa)
Phocid carnivores in air	138 <sup>1</sup>	161	123 <sup>1</sup>	155	100 <sup>3</sup>	109
Other marine carnivores in air	161 <sup>2</sup>	176	146 <sup>2</sup>	170		

Threshold values are:

<sup>1</sup> Frequency-weighted according to the curve for phocid carnivores in-air provided by Southall et al. (2019).

<sup>2</sup> Frequency-weighted according to the curve for other carnivores in-air provided by Southall et al. (2019).

<sup>3</sup> Non-cumulative and frequency-weighted according to the curve for pinnipeds in-air (PA) provided by Southall et al. (2007).

### 3. Methods

The construction activities considered in this modelling report will generate airborne sound that can reach marine fauna at the surrounding water surface, or on land. For modelling, sound will be considered as generated from a point source at the top of the pile (impact piling activities) or at the ground surface (blasting). Properties of the atmosphere and environment (i.e., sound speed in the air, sound reflectivity of the ground and the water, topographic features) were considered in this modelling to provide conditions for the most conservative sound field (i.e., the parameters leading to the farthest acoustic propagation) during the entire year.

The following steps describe this study's general approach to modelling sounds and estimating distances to the relevant noise thresholds (as listed in Section 2):

1. The modelled operations are characterized as sound-radiating sources, and the source pressure functions are predicted in the nearfield, typically within a few tens of metres. This characterization is done using a proxy (source level spectra derived from measurement of similar operations) or by using theoretical models (see details in Section 3.1).
2. Computational propagation modelling is applied to predict how sound propagates from the sound sources through the air, as a function of range, elevation/depth, and azimuthal direction.
3. The propagated sound field is used to compute received sound levels over a large regular grid from which distances to effect criteria thresholds are calculated and contour maps are generated. Two distances for each threshold are presented in this work: the maximum distance from the source at which given sound level is predicted to occur ( $R_{\max}$ ) and the distance to a given sound level after the 5 % farthest points were excluded ( $R_{95\%}$ ; see Appendix C.2).

The output of the above steps produces PK and SEL levels per detonation or per piling strike (for blasting and impact pile driving, respectively) at each considered location. Since the SEL criteria mentioned in Section 2 are cumulative (denoted  $SEL_{24h}$ ), the accumulation of sound energy from a number of events (i.e. number of charges blasted or number of impact hammer strikes) within a 24 h period is accounted for by adding a factor of  $10 \log(N_{24h})$  to the single-event SEL, where  $N_{24h}$  provided in Table 1 represents the maximum anticipated number of events per day.



## 3.1. Acoustic Sources

### 3.1.1. Impact Driving of Sheet Piles - Source Spectra

Pile driving of 1.4 m wide sheet piles for scenario IA2 will be carried out with an IHC S-280 impact hammer (280 kJ energy). Source levels for this operation were obtained as an average from five decidecade-band spectra in a report by The Greenbusch Group (2017) corresponding to airborne noise measurements during a similar piling operation using an APE D50-52 (167 kJ energy) to drive sheet piles. The average decidecade-band spectra used for modelling in this work (see Figure 2) was adjusted by a  $10 \log_{10} (280 \text{ kJ}/167 \text{ kJ})$  dB correction factor, to account for the higher energy of the IHC S-280 compared to the APE D50-52.

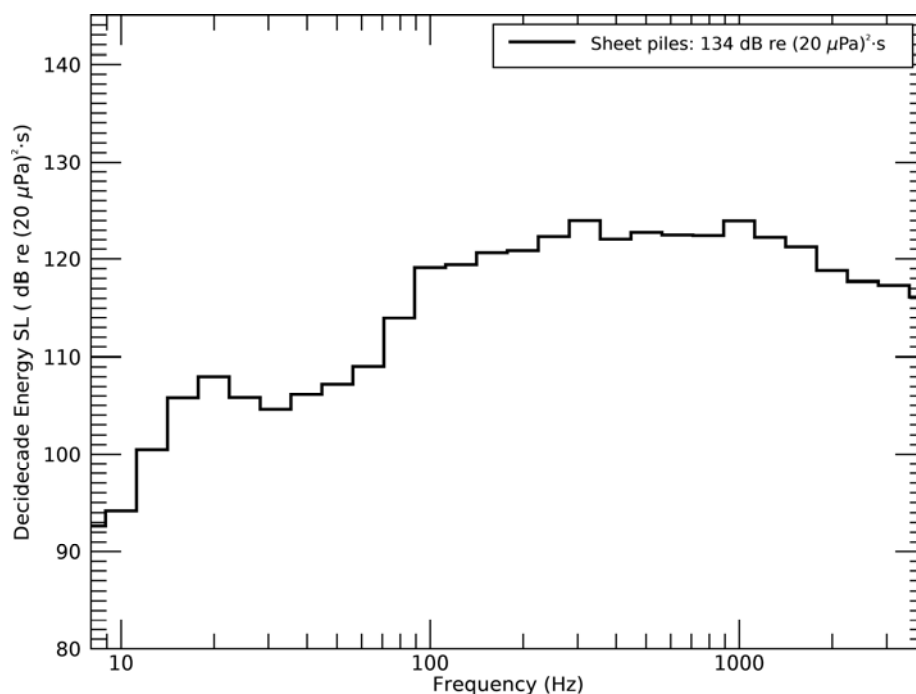


Figure 2. Decidecade-band spectra for acoustic modelling of airborne noise due to impact pile driving of sheet piles. The broadband sound exposure level (SEL) source level for a single strike is shown in the legend.

Modelling of PK levels for cylindrical piles was done by applying a 25 dB SEL-to-PK conversion factor to the unweighted (single detonation) SEL results. This factor was obtained based on the difference between SEL and PK measurements from (Blackwell et al. 2004) for cylindrical piles, since no airborne measurements of PK levels specific for sheet piles were available.



### 3.1.2. Impact Driving of Cylindrical Piles - Source Spectra

Source levels for modelling in-air propagation during impact piling of the 1.2 m diameter cylindrical pipe piles (Scenario IA1) are derived from A-weighted source levels available in the literature (JASCO 2009), corresponding to impact piling modelled for the NaiKun offshore wind farm project using a hammer with 550 kJ ram energy. These levels were originally derived from measurements in a published study of pile driving noise measured during the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project (Thorson and Reyff 2004).

To account for the lower ram energy of the IHC S-280 hammer used in the present study (280 kJ), the source level is adjusted by a  $10 \log_{10} (280 \text{ kJ}/550 \text{ kJ})$  correction factor. In addition, the A-weighting of the source levels in JASCO (2009) has been removed by normalizing by the frequency response of the A-weighting filter, which yields the unweighted source levels shown in Figure 3. In-air acoustic propagation modelling represents the hammer strike as a point source on top of the pipe pile, 8 m above the ground (which is the height of the pile at the beginning of the impact piling operation).

For the 0.9 m diameter mooring piles (Scenario IA3), it is assumed here that the shape of the decade band spectra is the same as for the 1.2 m piles from Scenario IA1, since the impact hammer is the same for both operations. However, to account for the small difference in diameter, the spectra for the 0.9 m piles was offset by  $-3.96 \text{ dB}$ , a correction determined based on the dependence of the impact piling noise on pile diameter according to measurements in Illingworth & Rodkin (2017).

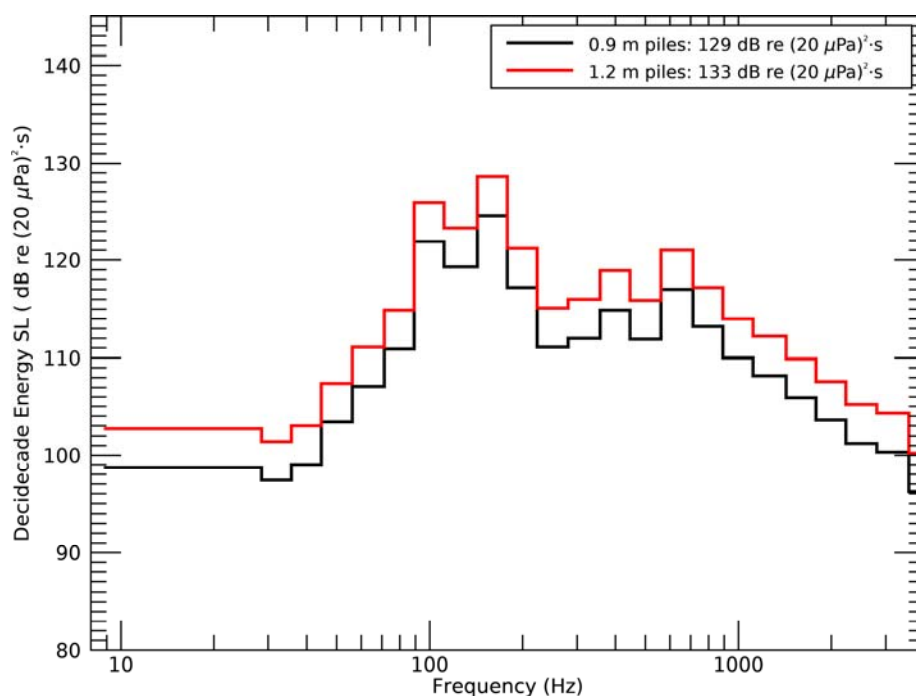


Figure 3. Decade-band spectra for acoustic modelling of airborne noise due to impact driving of cylindrical piles. The broadband sound exposure level (SEL) source level for a single strike is shown in the legend.

Modelling of PK levels for cylindrical piles was done by applying a 25 dB SEL-to-PK conversion factor to the unweighted (single detonation) SEL results. This factor was obtained based on the difference between SEL and PK measurements from (Blackwell et al. 2004).

### 3.1.3. Blasting Source Spectra

In this study, the noise generated by detonation of explosives placed within boreholes drilled 3 m into rock was modelled using ConWep (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. Based on the work by Gaspin (1983), it is expected that the detonation shockwave would not contribute significantly to airborne noise for ranges beyond  $R_0$ , defined as

$$R_0 = 4.76 \times W^{1/3} \quad (1)$$

where  $W$  is the charge weight in kg, and  $R_0$  is in meters. For the charges considered in this work,  $R_0$  varies from 5 m (1 kg TNT) to 22 m (100 kg TNT).

Blasting was modelled at nearshore and inland locations as outlined in Scenarios IA4 and IA5 for TNT charges of 1, 10, 20, 30, 40, 50, and 100 kg. We use ConWep's Shockwave module to estimate the pressure wave that would be measured in the bedrock at a distance of 3 m from the detonation point (i.e., the distance from the burial depth of the charges to the bedrock-air interface). This pressure wave represents blast energy in the bedrock, and therefore it requires application of a bedrock-to-air coupling factor for in-air modelling. Mathematical description of this factor is complex, requiring accurate knowledge of the media surrounding the explosive and its dynamic behaviour during the explosion. To overcome this complexity, this study applies a coupling (scaling) factor based on field measurements of rock blasting in quarries (Siskind et al. 1980), leading to the source levels shown in Figure 4 for in-air SEL modelling. Details of the fine-tuning of the blast source levels to match available measurements are provided in Appendix D.

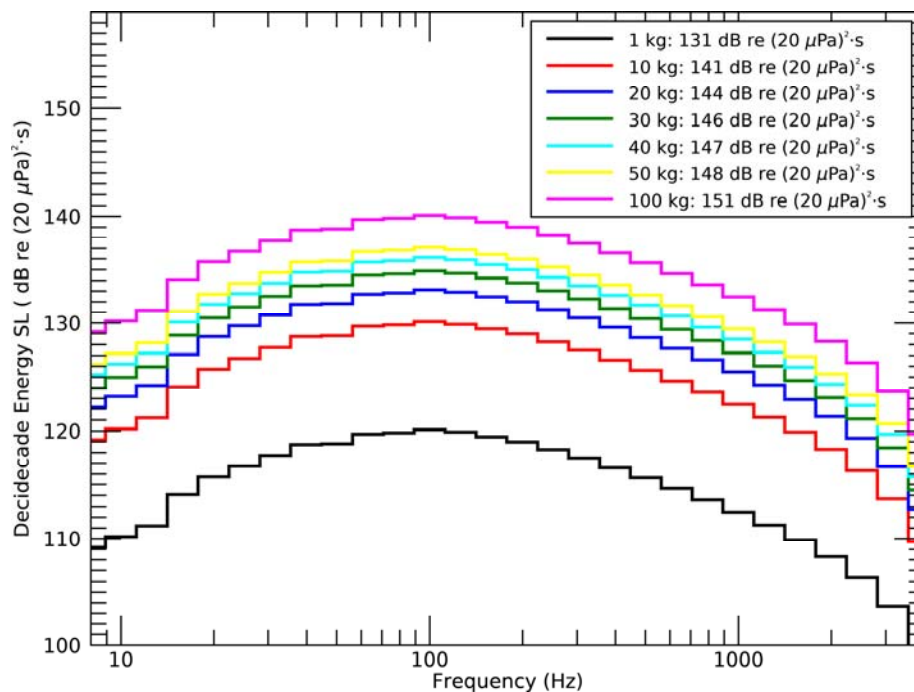


Figure 4. Decade-band spectra for acoustic modelling of airborne noise due to detonation of TNT charges 1, 10, 20, 30, 40, 50, and 100 kg. The broadband sound exposure level (SEL) source level for a single strike is shown in the legend.

Modelling of PK levels was done by applying a 25 dB SEL-to-PK conversion factor to the unweighted (single detonation) SEL results. This factor was obtained based on the difference between measured SEL and PK data from Siskind et al. 1980 (Appendix D).

## 3.2. Sound Propagation Model

For in-air sound propagation, the loss in acoustic level depends on the sound speed as a function of elevation above the ground and the water, which is determined by atmospheric conditions. Sound ducts forming in the atmosphere can trap sound, leading to propagation over long distances from the source. To estimate distances to SEL and PK thresholds, JASCO's Impulse Noise Propagation Model (INPM; Appendix C.1) is used with the source levels described in Section 3.1 to determine the sound levels that would be received by marine mammals with their head above the water or the land's surface.

Conservative modelling is implemented by selecting the seasonal input parameters (i.e., atmospheric profiles) that yielded the longest in-air sound propagation. In addition, results were estimated assuming zero wind speed, as well as assuming the average wind speed along azimuth 270°, which is the direction with the least ground obstruction from the sources, as a precautionary assessment of the sound propagation. Modelling was performed in the 10 Hz to 4 kHz frequency range.

## 4. Results

Results are presented in a series of tables showing the threshold exceedance distances (as per noise criteria listed in Section 2). Results are presented separately for zero wind conditions of (0 m/s wind speed, Section 4.1) and for September average wind conditions in the east-to-west direction (Section 4.2). Section 4.3 provides contour maps showing the behavioural disturbance threshold distances (thresholds for acoustic injury were either not exceeded or were exceeded at distances too small to show meaningfully on contour maps).

### 4.1. No Wind Conditions

Table 4. *Impact pile driving*: Distances (m) to  $SEL_{w, 24h}$  thresholds (dB re 20  $\mu Pa^2 \cdot s$ ) for permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds, and to  $SEL_{w, single}$  threshold for behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{E, w, 24h}$ or $L_{E, w, single}$ threshold	Scenario IA1		Scenario IA2		Scenario IA3	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	138	-	-	-	-	-	-
	OCA	161	-	-	-	-	-	-
TTS	PCA	123	-	-	29	29	-	-
	OCA	146	-	-	-	-	-	-
Disturbance	PA	100	56	56	56	56	<5	<5

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA1: Combi-wall pipe pile

Scenario IA2: Combi-wall sheet pile

Scenario IA3: Mooring pile

Table 5. *Impact pile driving*: Distances (m) to PK thresholds (dB re 20  $\mu Pa$ ) for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{pk}$ threshold	Scenario IA1		Scenario IA2		Scenario IA3	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	161	-	-	-	-	-	-
	OCA	176	-	-	-	-	-	-
TTS	PCA	155	-	-	-	-	-	-
	OCA	170	-	-	-	-	-	-
Disturbance	PA	109	463	441	363	343	292	269

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA1: Combi-wall pipe pile

Scenario IA2: Combi-wall sheet pile

Scenario IA3: Mooring pile

Table 6. *Onshore blasting (nearshore)*: Distances (m) to  $SEL_{w, 24h}$  thresholds (dB re 20  $\mu Pa^2 \cdot s$ ) for permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds, and to  $SEL_{w, single}$  threshold for behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{E,w, 24h}$ or $L_{E,w, single}$ threshold	Scenario IA4													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS*	PCA	138	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	161	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	123	<5	<5	22	22	30	30	40	40	47	47	55	47	73	65
	OCA	146	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance	PCA	100	40	40	118	107	172	142	198	162	216	173	216	181	263	242

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA4: On land blasting near the shore

Table 7. *Onshore blasting (nearshore)*: Distances (m) to PK thresholds (dB re 20  $\mu Pa$ ) for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{pk}$ threshold	Scenario IA4													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	161	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	176	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	155	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	170	-	-	-	-	-	-	-	-	-	-	-	-	<5	<5
Disturbance	PA	109	235	201	838	798	1170	1121	1416	1355	1617	1548	1792	1716	2444	2341

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA4: On land blasting near the shore

Table 8. *Onshore blasting (inland)*: Distances (m) to  $SEL_{w, 24h}$  thresholds (dB re 20  $\mu Pa^2 \cdot s$ ) for permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds, and to  $SEL_{w, single}$  threshold for behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{E,w, 24h}$ or $L_{E,w, single}$ threshold	Scenario IA5													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	138	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	OCA	161	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	123	-	-	20	20	30	30	30	30	46	44	58	55	73	71
	OCA	146	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance	PCA and OCA	100	30	30	108	101	129	122	164	140	184	152	189	161	241	204

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA5: On land blasting far from the shore

Table 9. *Onshore blasting (inland)*: Distances (m) to PK thresholds (dB re 20  $\mu$ Pa) for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{pk}$ threshold	Scenario IA5													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	161	-	-	-	-	-	-	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	176	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	155	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance	PCA and OCA	109	221	189	791	737	1106	1045	1342	1270	1535	1456	1701	1615	2328	2218

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA5: On land blasting far from the shore

## 4.2. East-to-west Wind Conditions

Table 10. *Impact pile driving*: Distances (m) to  $SEL_{w, 24h}$  thresholds (dB re 20  $\mu$ Pa<sup>2</sup>-s) for permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds, and to  $SEL_{w, single}$  threshold for behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{E,w, 24h}$ or $L_{E,w, single}$ threshold	Scenario IA1		Scenario IA2		Scenario IA3	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	138	-	-	-	-	-	-
	OCA	161	-	-	-	-	-	-
TTS	PCA	123	-	-	29	29	-	-
	OCA	146	-	-	-	-	-	-
Disturbance	PA	100	56	56	56	56	<5	<5

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA1: Combi-wall pipe pile

Scenario IA2: Combi-wall sheet pile

Scenario IA3: Mooring pile

Table 11. *Impact pile driving*: Distances (m) to PK thresholds (dB re 20  $\mu$ Pa) for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{pk}$ threshold	Scenario IA1		Scenario IA2		Scenario IA3	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	161	-	-	-	-	-	-
	OCA	176	-	-	-	-	-	-
TTS	PCA	155	-	-	-	-	-	-
	OCA	170	-	-	-	-	-	-
Disturbance	PA	109	465	441	366	345	292	270

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA1: Combi-wall pipe pile

Scenario IA2: Combi-wall sheet pile

Scenario IA3: Mooring pile

Table 12. *Onshore blasting (nearshore)*: Distances (m) to  $SEL_{w, 24h}$  thresholds (dB re 20  $\mu Pa^2 \cdot s$ ) for permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds (NMFS 2018), and to  $SEL_{w, single}$  threshold for behavioural disturbance (Southall et al. 2007).

Criteria	Hearing group	$L_{E, w, 24h}$ or $L_{E, w, single}$ threshold	Scenario IA4													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	138	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	161	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	123	<5	<5	22	22	30	30	42	42	47	47	55	47	73	65
	OCA	146	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance	PA	100	40	40	118	107	172	142	198	162	216	173	216	181	265	243

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA4: On land blasting near the shore

Table 13. *Onshore blasting (nearshore)*: Distances (m) to PK thresholds (dB re 20  $\mu Pa$ ) for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{pk}$ threshold	Scenario IA4													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	161	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	176	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	155	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	170	-	-	-	-	-	-	-	-	-	-	-	-	<5	<5
Disturbance	PA	109	235	203	843	802	1179	1126	8102	7359	9194	7894	9785	8359	15328	11123

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA4: On land blasting near the shore

Table 14. *Onshore blasting (inland)*: Distances (m) to  $SEL_{w, 24h}$  thresholds (dB re 20  $\mu Pa^2 \cdot s$ ) for permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds, and to  $SEL_{w, single}$  threshold for behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{E, w, 24h}$ or $L_{E, w, single}$ threshold	Scenario IA5													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	138	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	OCA	161	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	123	-	-	20	20	30	30	30	30	46	44	58	55	73	71
	OCA	146	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance	PA	100	30	30	108	101	129	122	164	135	184	152	189	161	241	204

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA5: On land blasting far from the shore

Table 15. *Onshore blasting (inland)*: Distances (m) to PK thresholds (dB re 20  $\mu$ Pa) for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance (Southall et al. 2007, 2019).

Criteria	Hearing group	$L_{pk}$ threshold	Scenario IA5													
			1 kg		10 kg		20 kg		30 kg		40 kg		50 kg		100 kg	
			$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$	$R_{max}$	$R_{95\%}$
PTS	PCA	161	-	-	-	-	-	-	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	176	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TTS	PCA	155	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	OCA	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disturbance	PA	109	221	189	795	742	1113	1050	7679	1280	8746	7541	9768	8013	12459	9645

PCA: phocid carnivores in air; OCA: other marine carnivores in air; PA: pinnipeds in-air

Scenario IA5: On land blasting far from the shore

### 4.3. Contour Maps

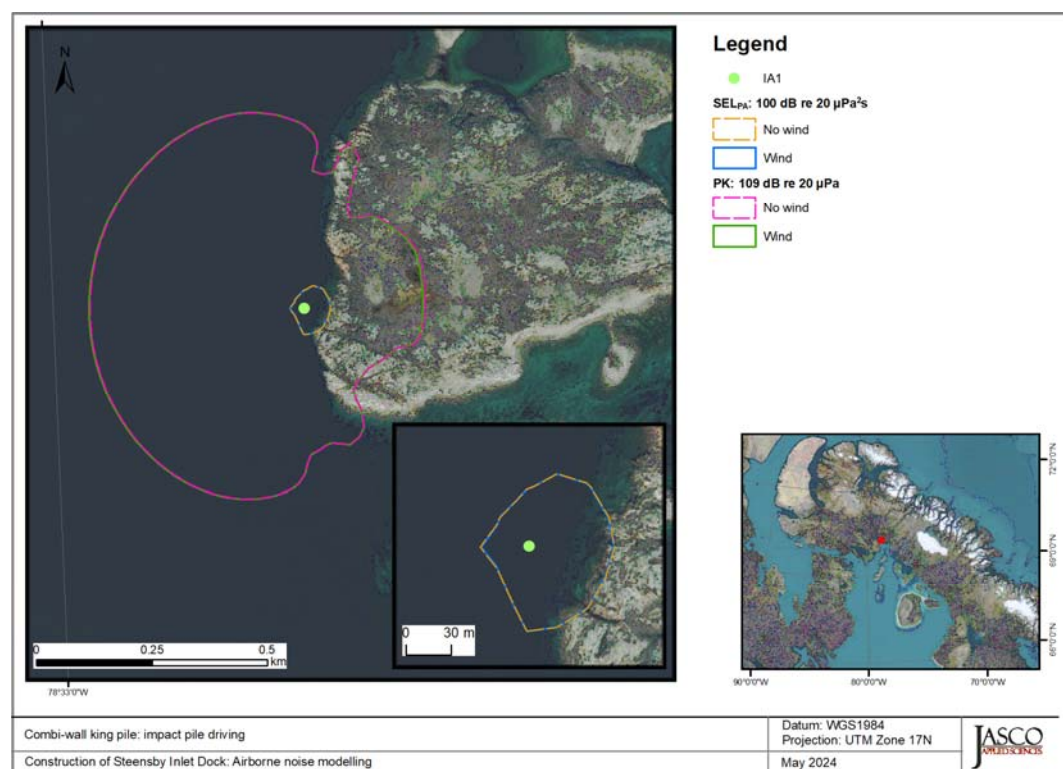


Figure 5. *Scenario IA1, impact pile driving of combi-wall pipe piles*: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.



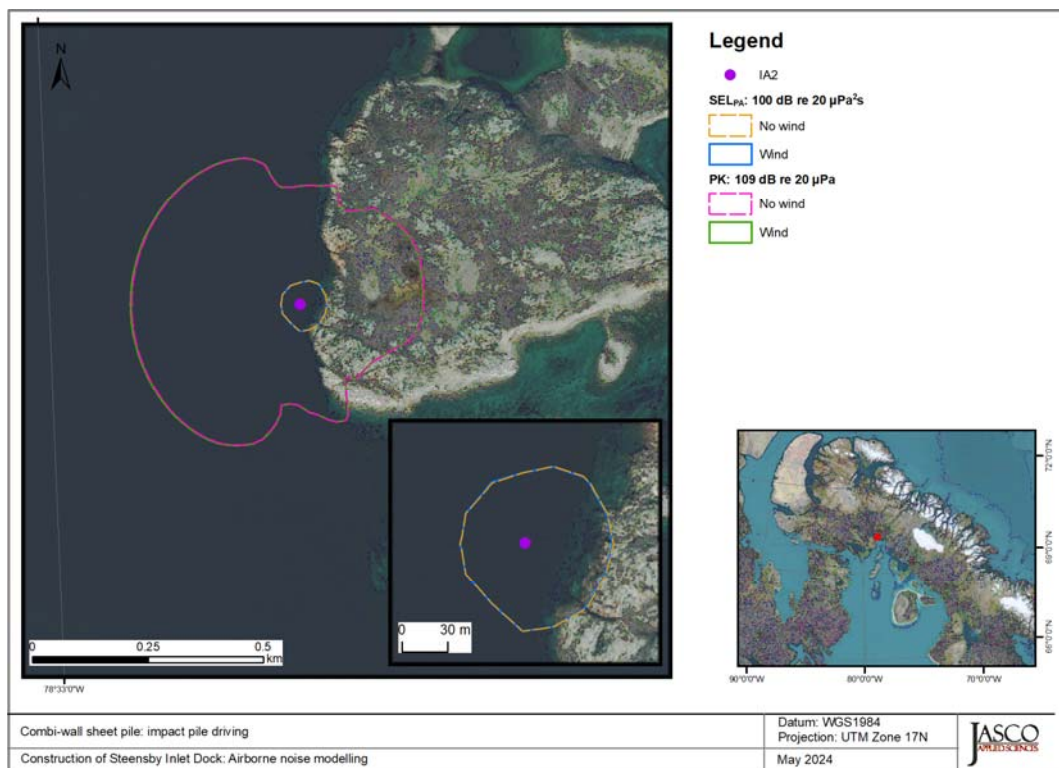


Figure 6. Scenario IA2, impact pile driving of combi-wall sheet piles: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

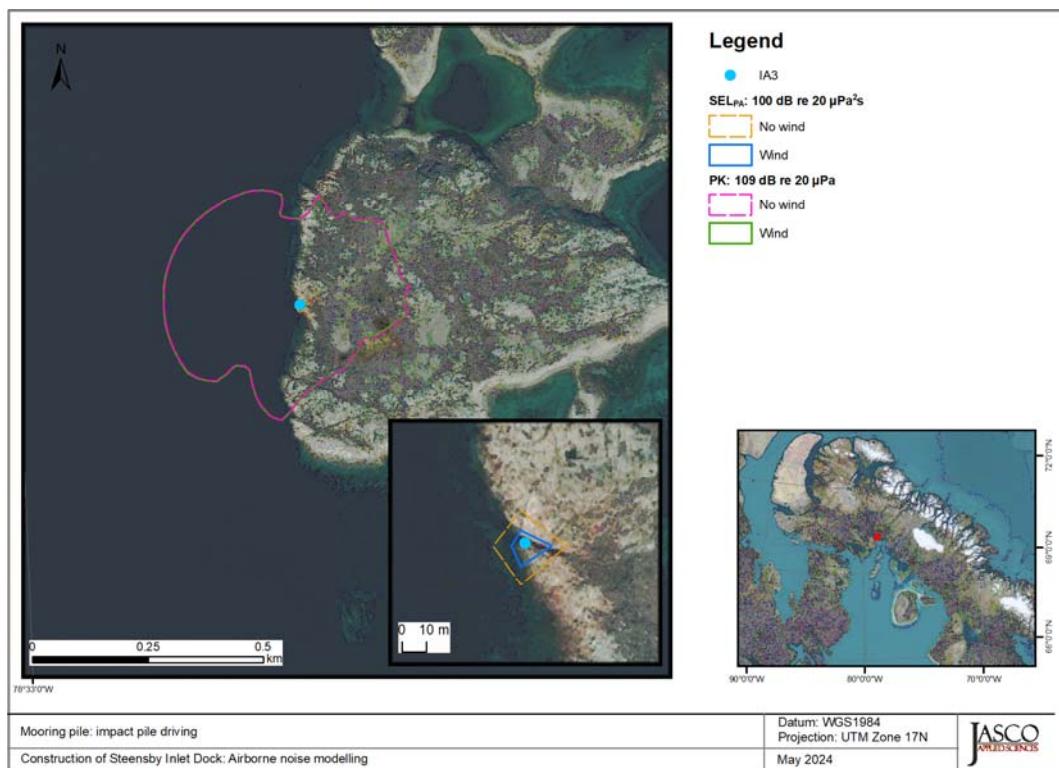


Figure 7. Scenario IA3, impact pile driving of mooring piles: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

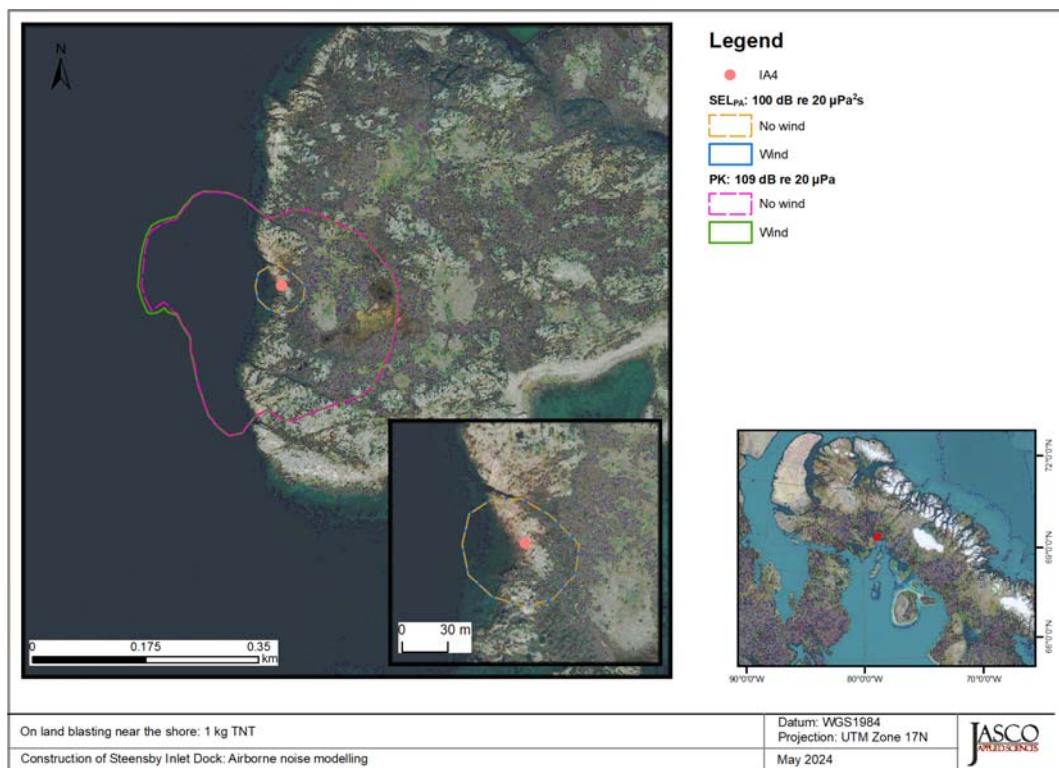


Figure 8. Scenario IA4, onshore blasting (nearshore), 1 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

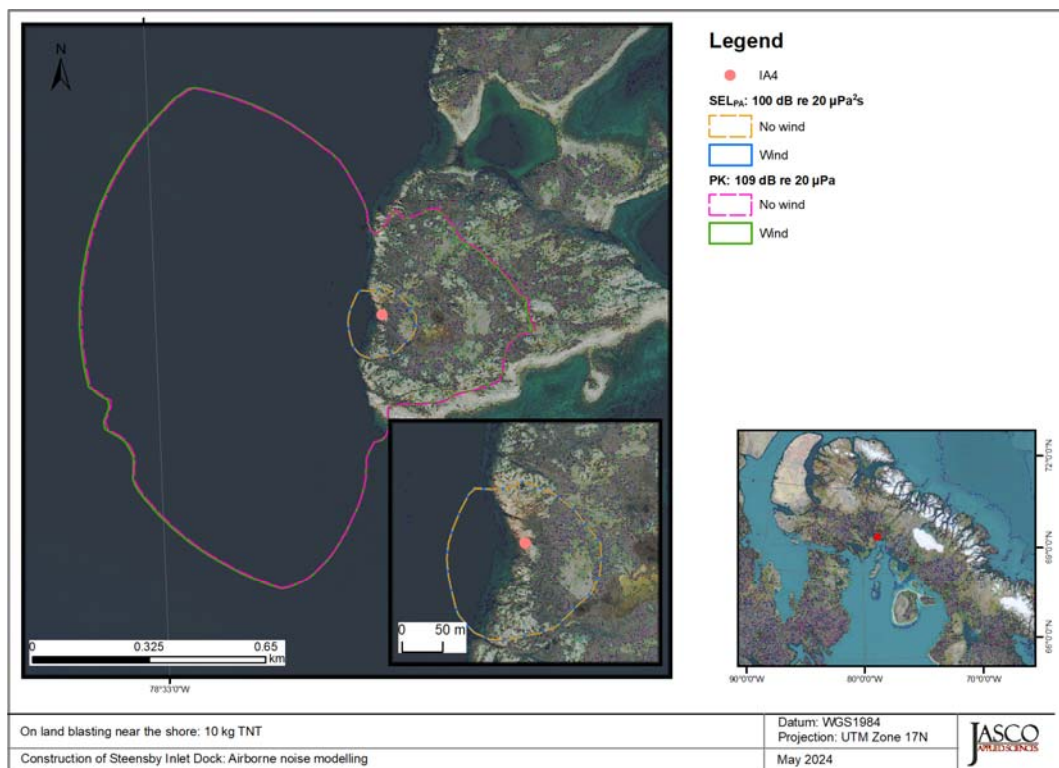


Figure 9. Scenario IA4, onshore blasting (nearshore), 10 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

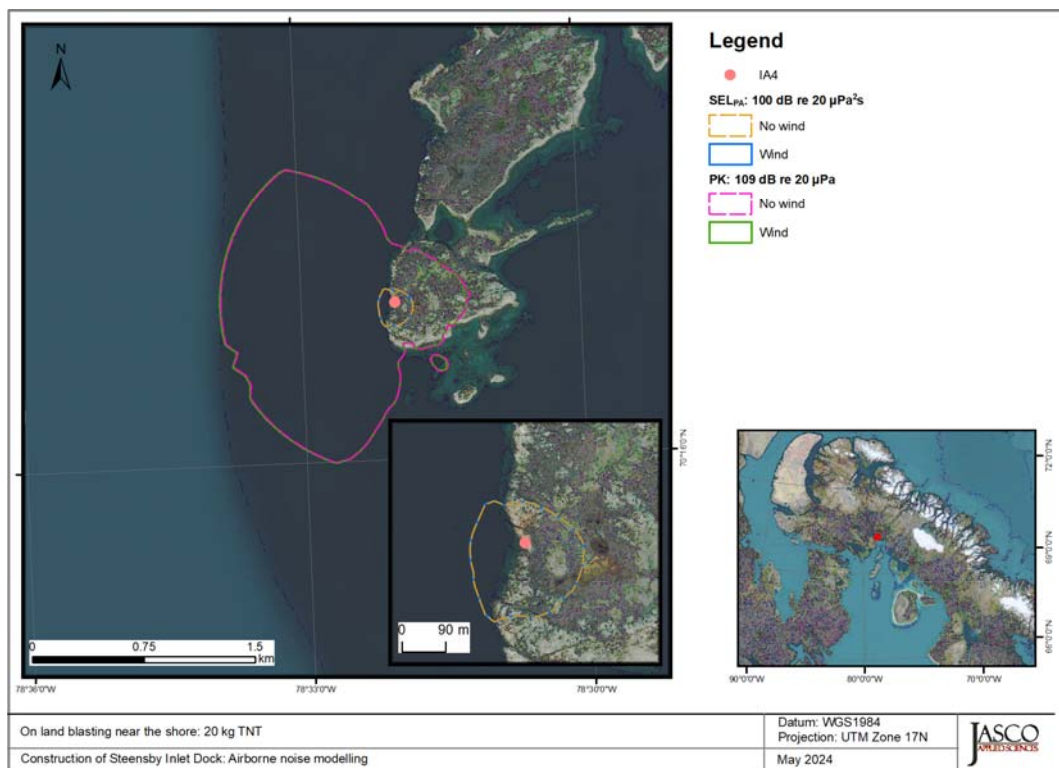


Figure 10. Scenario IA4, onshore blasting (nearshore), 20 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

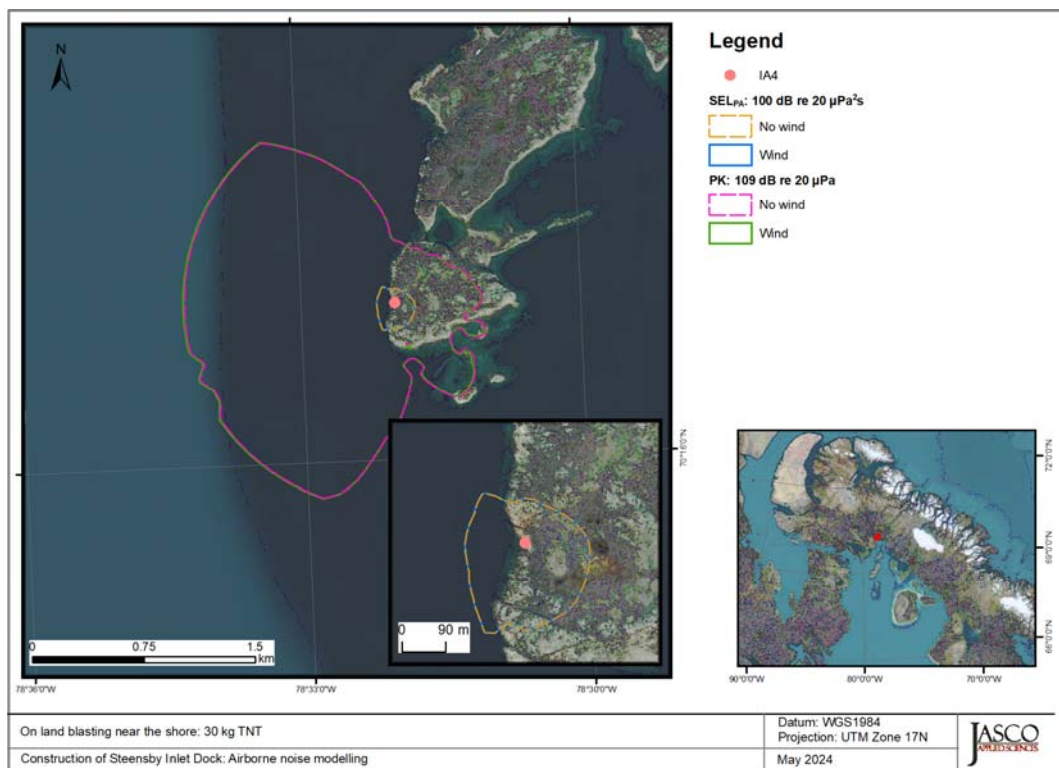


Figure 11. Scenario IA4, onshore blasting (nearshore), 30 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.



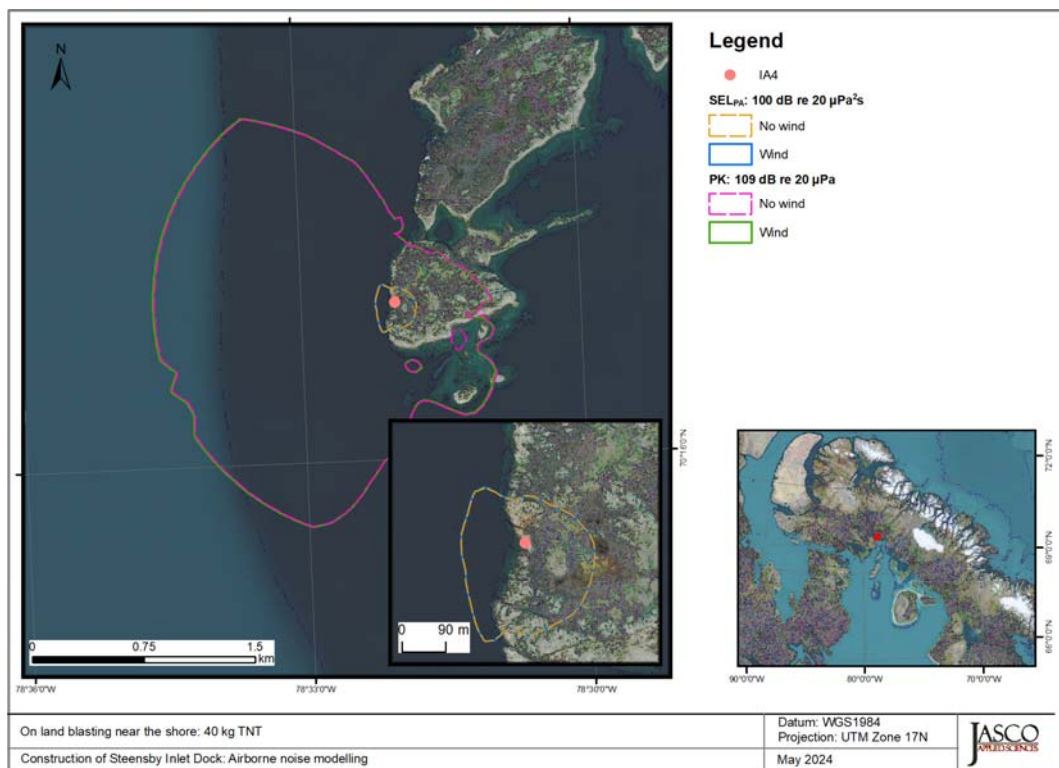


Figure 12. Scenario IA4, onshore blasting (nearshore), 40 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

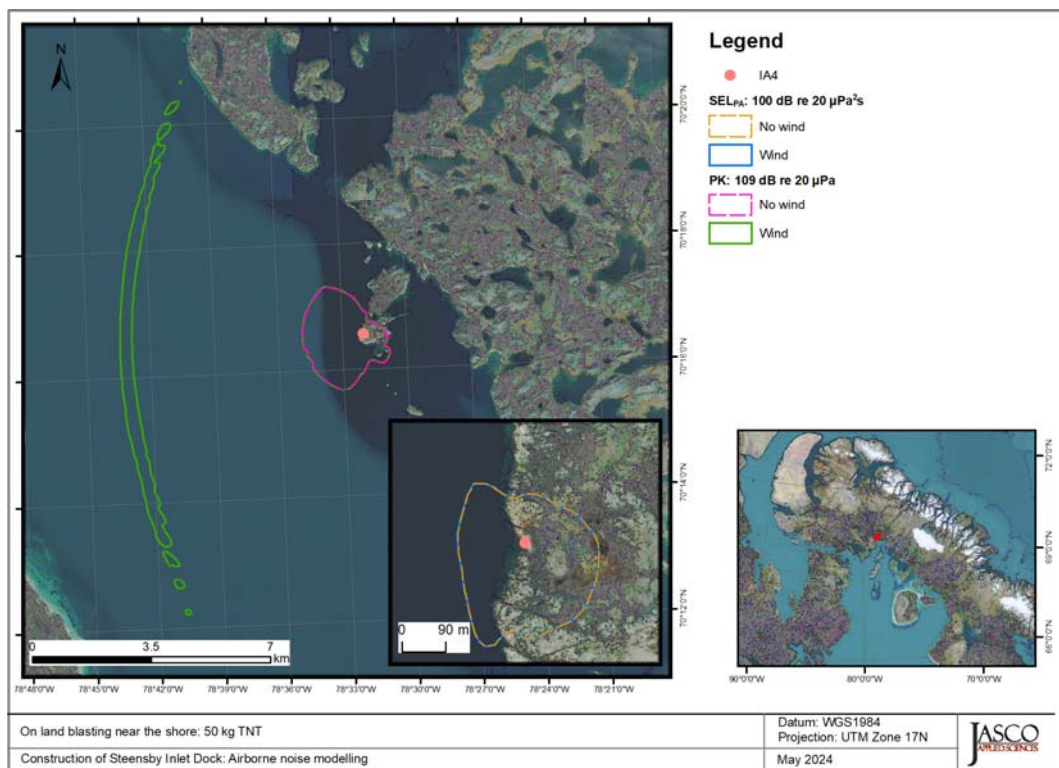


Figure 13. Scenario IA4, Onshore blasting (nearshore), 50 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

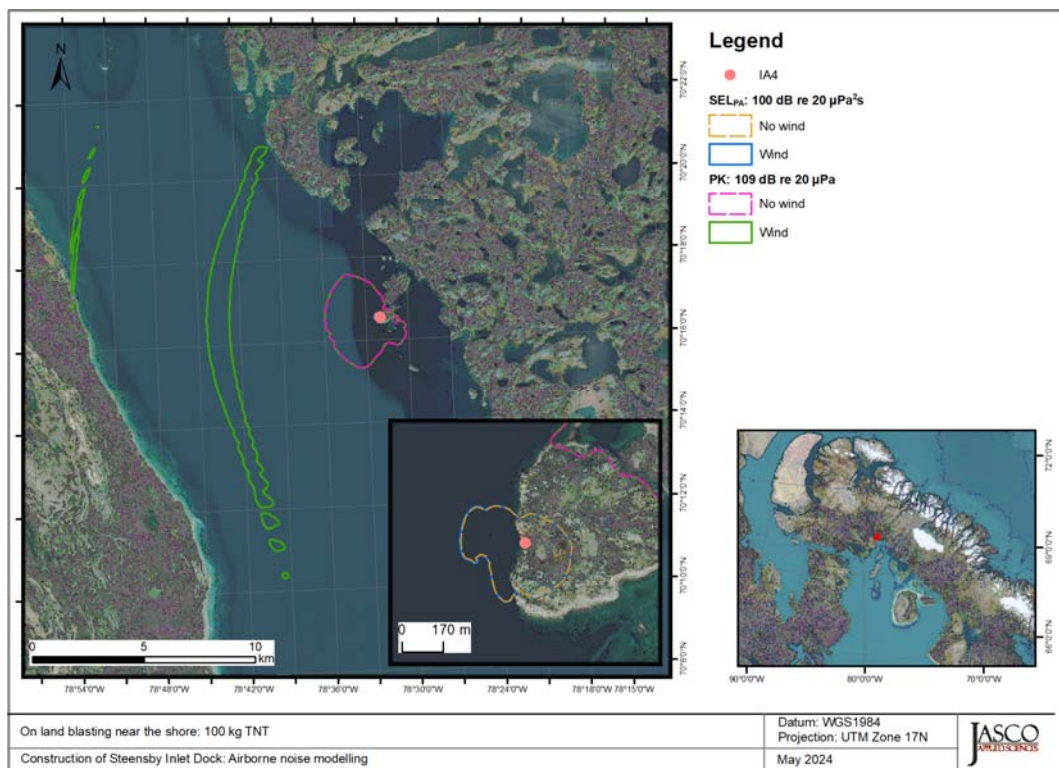


Figure 14. Scenario IA4, onshore blasting (nearshore), 100 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

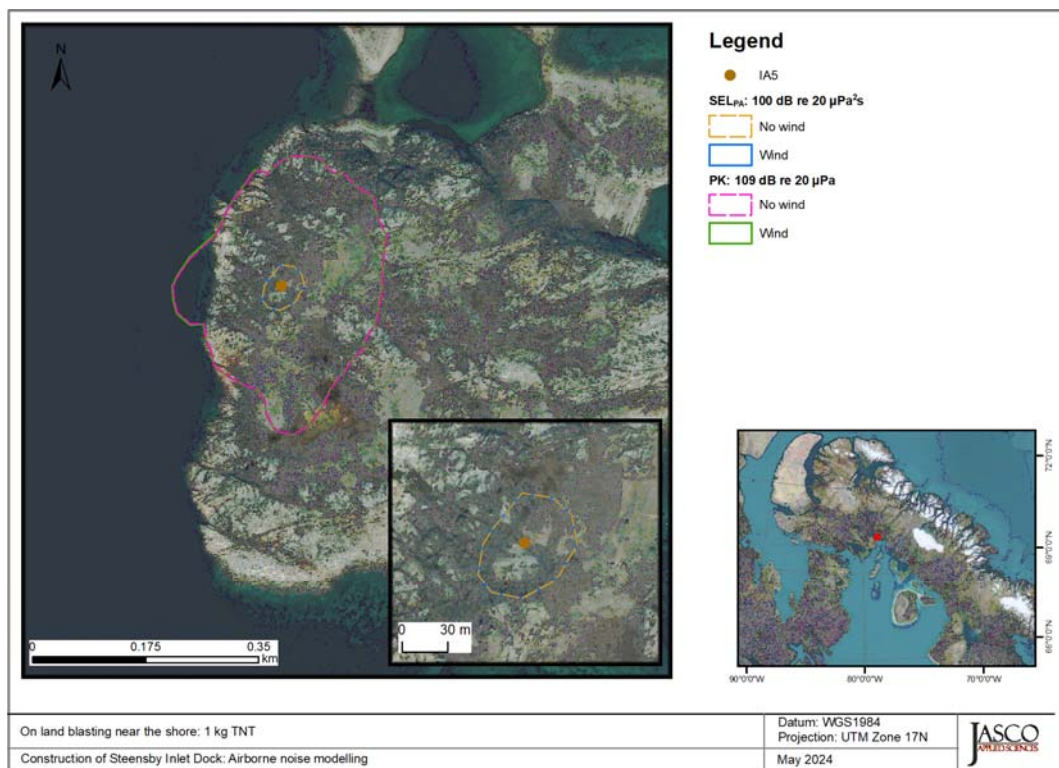


Figure 15. Scenario IA5, onshore blasting (inland), 1 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

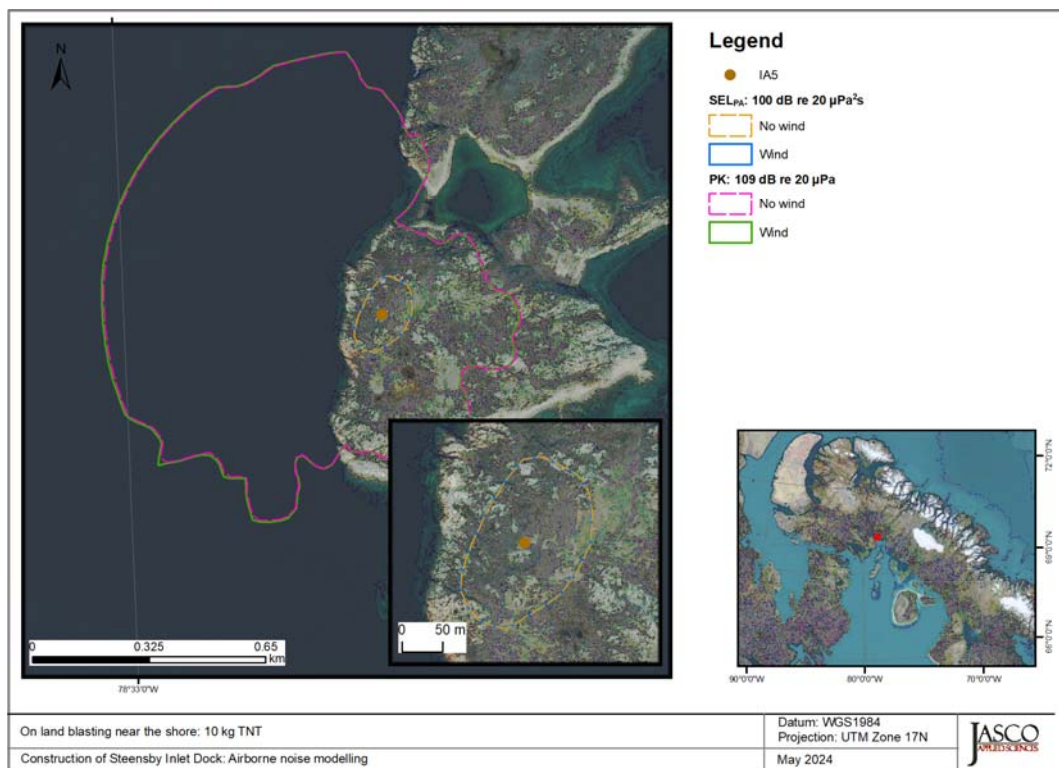


Figure 16. Scenario IA5, onshore blasting (inland), 10 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

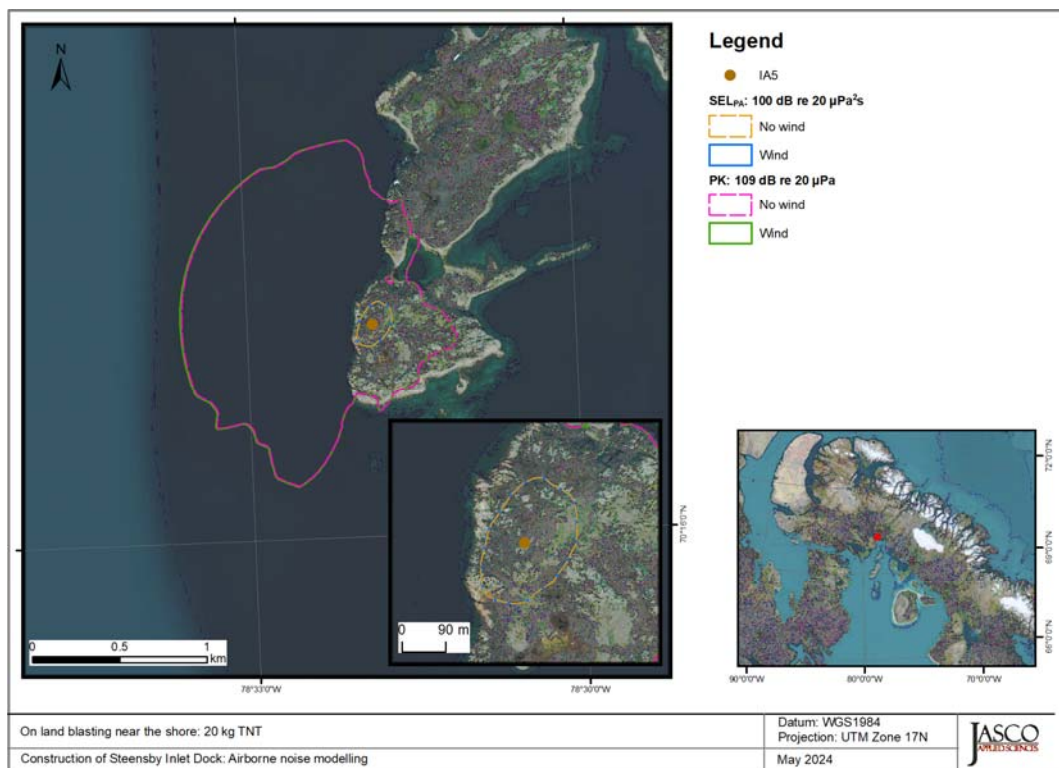


Figure 17. Scenario IA5, onshore blasting (inland), 20 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.



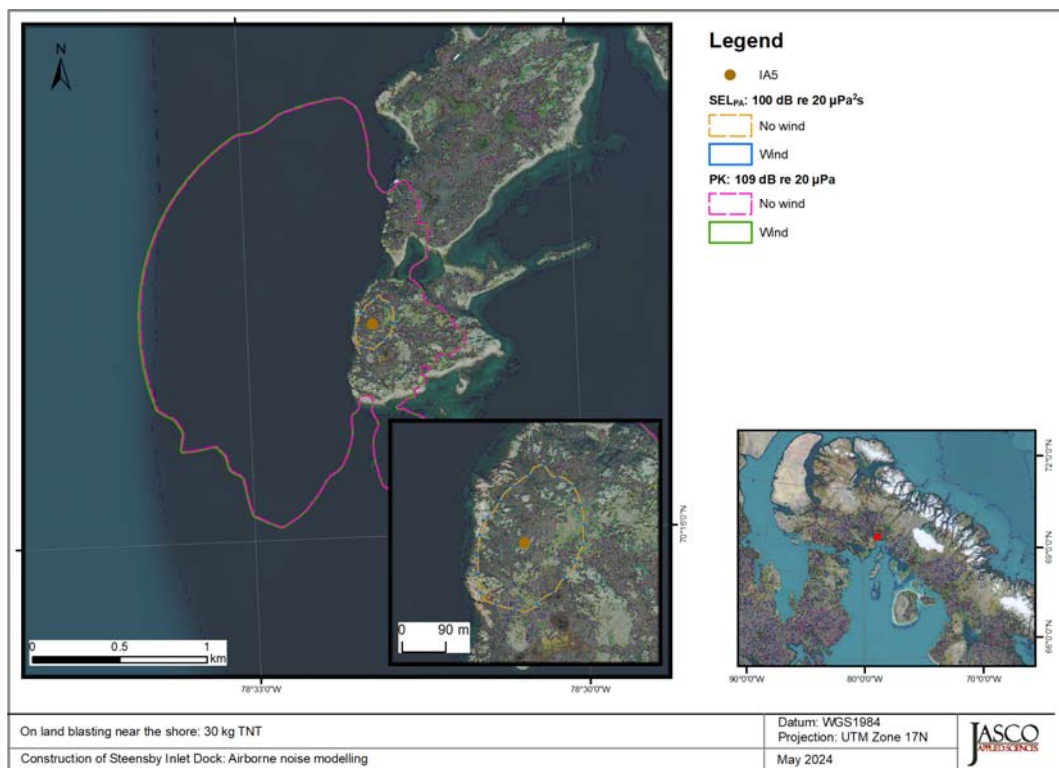


Figure 18. Scenario IA5, onshore blasting (inland), 30 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

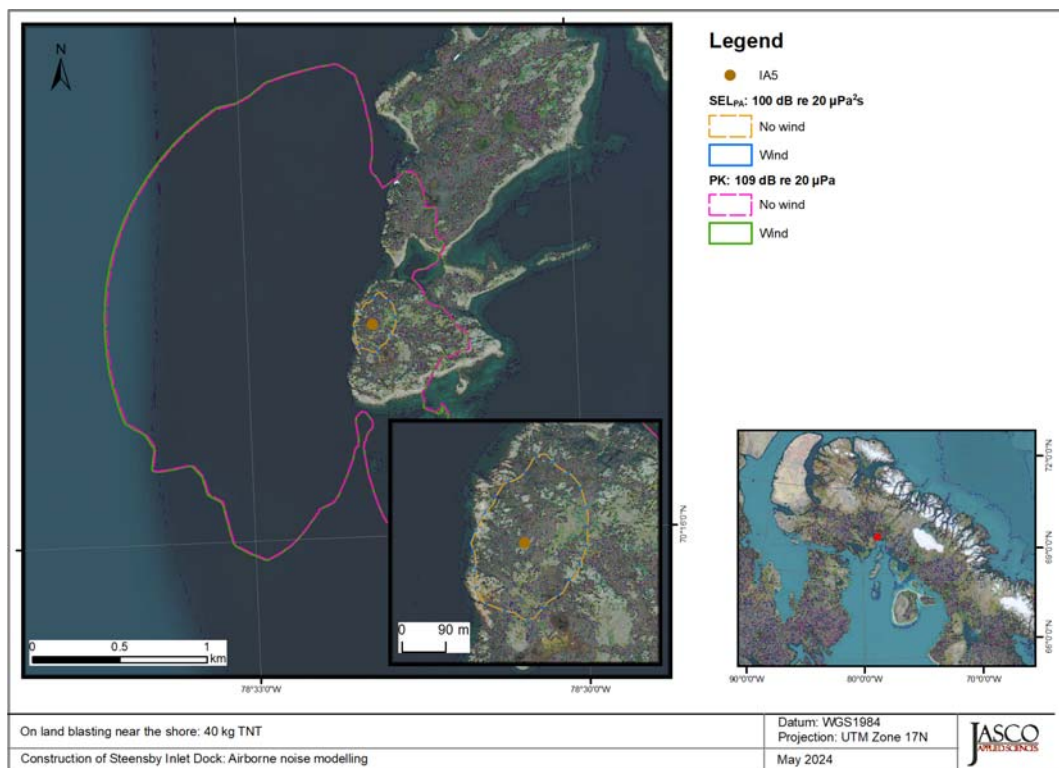


Figure 19. Scenario IA5, onshore blasting (inland), 40 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

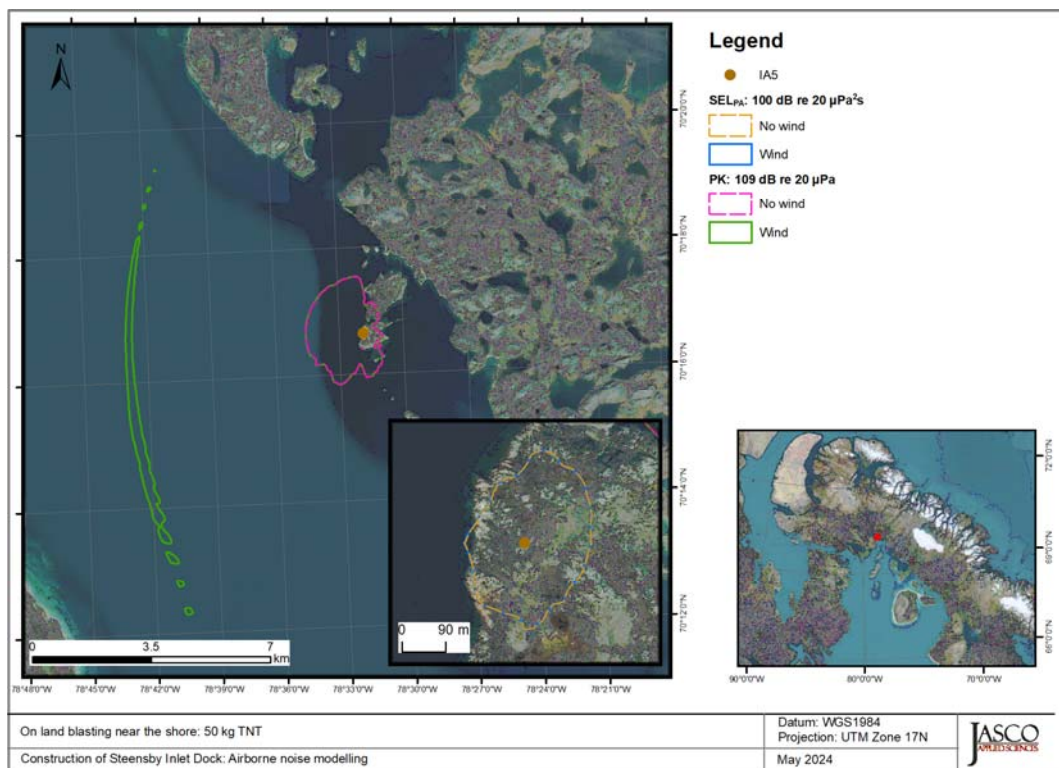


Figure 20. Scenario IA5, onshore blasting (inland), 50 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.

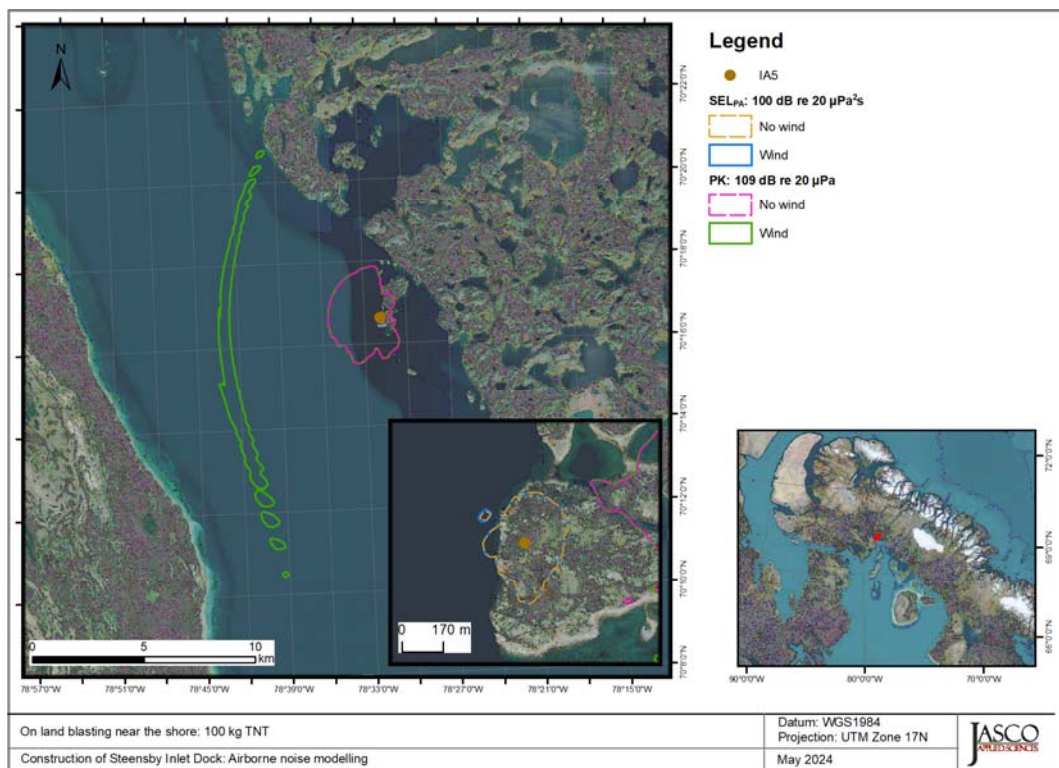


Figure 21. Scenario IA5, onshore blasting (inland), 100 kg TNT: Maps of PK and SEL contours corresponding to behavioural disturbance thresholds.



## 5. Discussion and Conclusions

Acoustic propagation modelling was conducted to estimate airborne sound levels at Steensby Inlet produced by impact pile driving of cylindrical piles and sheet piles, and by onshore charge detonations for rock blasting associated with construction of the Steensby Port facility. Where uncertainties in operating conditions existed, the models were parametrized to yield realistic conservative noise levels. The following conservative assumptions were applied to the methods used in this study so that the results would not underestimate potential effects on marine life:

- Airborne sound propagation was modelled for the most conservative season (September) to determine maximum possible distances to the relevant acoustic thresholds.
- Modelling was conducted assuming zero wind to represent typical conditions, as well with wind blowing toward the ocean to represent the most conservative propagation conditions.
- Impact pile driving noise levels consistent with field measurements were adjusted to account for the impact pile driver energy anticipated to be used in this Project.
- Airborne noise levels due to underground detonations were consistent with field measurements.
- For acoustic criteria that require cumulative SEL, the modelled  $R_{\max}$  accounts for accumulation of the largest number of events (hammer strikes for impact piling and detonations for blasting) expected to occur in a single day.

At ranges near to the modelled sound sources, the wind does not have strong effect on causing downward refraction of the airborne noise. The downward refracting effect of the wind only becomes apparent after a few kilometers of propagation. This downward refracting of sound is clearly noted in the arrivals impinging the ground at 8 and 14 km in Figure C-1 (right) and in the narrow edge-shaped contours in Figures 13, 14, 20, and 21. The relatively short exceedance distances for impact pile driving were, therefore, not changed in the presence of wind compared to the zero wind conditions. This is also true for blasting of TNT charges up to 20 kg. For larger charges, the wind effect can lead to narrow bands of noise at levels exceeding the behavioural disturbance threshold at long distances from the source.

We note that the model predictions for blasting noise may not accurately predict levels very close to the charge where the shock wave can affect the field (i.e. within 5 m for 1 kg charges of TNT and within 22 m for 100 kg charges of TNT). However, at these short ranges the main potential risk to marine mammals would be exposure to detonation debris. The agreement between the model and available empirical data confirms validity of the model predictions at longer ranges.

The threshold exceedance distances are summarized as follows:

- For impact pile driving, the PTS threshold was not exceeded for any scenario, and only the TTS threshold for phocid carnivores was exceeded at distances up to 29 m from the source for the IA2 scenario (impact pile driving of combi-wall sheet piles). Airborne noise generated during impact pile driving exceeded the behavioural disturbance threshold at distances up to 463 m from the source in zero wind conditions, and up to 465 m from the source in average wind conditions. This distance was dictated by the exceedance distance for the PK metric (109 dB re 20  $\mu$ Pa).
- For onshore blasting, threshold exceedance distances were as follows:
  - The PTS injury thresholds were either not exceeded, or were only exceeded at distances <5 m. The presence of wind did not change the threshold exceedance distances.

- The TTS thresholds were exceeded at distances up to 73 m from the source, based on the SEL metric, in both zero wind and average wind conditions.
- The behavioural disturbance threshold exceedance distances corresponded to the PK metric (109 dB re 20  $\mu$ Pa) and were as follows:
  - In zero wind conditions, the disturbance threshold was exceeded at distances up to 235 m from the source for a 1 kg TNT charge, and up to 2,341 m from the source for a 100 KG TNT charge.
  - In the presence of wind, the distance to the disturbance threshold remained unchanged compared to no-wind conditions for charges comprised of between 1 kg and 20 kg of TNT. For charges ranging from 30 kg to 100 kg of TNT, the effect of wind became apparent with the disturbance threshold being exceeded in a narrow annular region at distances up to 8,102 m and 15,328 m from the source, respectively.

## 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.

### **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.

### **auditory frequency weighting**

The process of applying an [auditory frequency-weighting function](#). An example for marine mammals are the auditory frequency-weighting functions published by Southall et al. (2007).

### **auditory frequency-weighting function**

[Frequency-weighting function](#) describing a compensatory approach accounting for a species' (or [functional hearing group's](#)) [frequency](#)-specific hearing sensitivity.

### **azimuth**

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

### **bandwidth**

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

### **cetacean**

Member of the order Cetacea. Cetaceans are aquatic mammals and include whales, dolphins, and porpoises.

### **confined explosives**

Explosives detonated within a substrate, including ice, as opposed to unconfined explosives that are detonated in open water, or not within a substrate.

### **continuous sound**

A [sound](#) whose [sound pressure level](#) remains above the [background noise](#) during the observation period and may gradually vary in intensity with time, e.g., sound from a marine vessel.

**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.

**delphinid**

Member of the family of oceanic dolphins (Delphinidae), composed of approximately 35 extant species, including dolphins, porpoises, and killer whales.

**energy source level**

A property of a **sound** source equal to the **sound exposure 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:**  $1 \mu\text{Pa}^2 \text{m}^2 \text{s}$ .

**ensonified**

Exposed to **sound**.

**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.

**frequency weighting**

The process of applying a **frequency-weighting function**.

**frequency-weighting function**

The squared magnitude of the **sound pressure** transfer function (ISO 18405:2017). For **sound** of a given **frequency**, the frequency-weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency-weighting function:* compensatory frequency-weighting function accounting for a species' (or **functional hearing group's**) frequency-specific hearing sensitivity.
- *System frequency-weighting function:* frequency-weighting function describing the sensitivity of an acoustic recording system, which typically consists of a **hydrophone**, one or more amplifiers, and an analog-to-digital converter.

**functional hearing group**

Category of animal species when classified according to their hearing sensitivity, hearing anatomy, and susceptibility to [sound](#). For marine mammals, initial groupings were proposed by Southall et al. (2007), and revised groupings are developed as new research/data becomes available. Revised groupings proposed by Southall et al. (2019) include low-frequency cetaceans, high-frequency cetaceans, very high-frequency cetaceans, phocid carnivores in water, other carnivores in water, and sirenians. Example hearing groups for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014). See also [auditory frequency-weighting functions](#), which are often applied to these groups.

**hertz (Hz)**

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

**high-frequency (HF) cetaceans**

See [functional hearing group](#). The mid- and high-frequency cetaceans groups proposed by Southall et al. (2007) were renamed high- and very-high-frequency cetaceans, respectively, by Southall et al. (2019).

**impulsive sound**

Qualitative term meaning [sounds](#) that are typically transient, brief (less than 1 s), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Sources of impulsive sound include, among others, explosives, seismic airguns, and impact pile drivers.

**isopleth**

A line drawn on a map through all points having the same value of some specified quantity (e.g., sound pressure level isopleth).

**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  $x \text{ dB re } 1 \mu\text{Pa}^2$ .

**low-frequency (LF) cetaceans**

See [functional hearing group](#).

**mid-frequency (MF) cetaceans**

See [functional hearing group](#). The mid-frequency cetaceans group proposed by Southall et al. (2007) was renamed high-frequency cetaceans by Southall et al. (2019).

**M-weighting**

A set of [auditory frequency-weighting functions](#) proposed by Southall et al. (2007).

**otariid**

Member of the family Otariidae, one of the three groupings of [pinnipeds](#) (along with [phocids](#) and walrus). These eared seals, commonly called fur seals and sea lions, are adapted to semi-aquatic life; they use their large fore flippers for propulsion underwater and can walk on all four limbs on land.

**otariid pinnipeds underwater (OW)**

See [functional hearing group](#).

**other marine carnivores in water (OCW)**

See [functional hearing group](#).

**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.

**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:  $1 \mu\text{Pa}^2$ .

**permanent threshold shift (PTS)**

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

**phocid**

Member of the family Phocidae, one of the three groupings of [pinnipeds](#) (along with [otariids](#) and walrus). These true/earless seals are more adapted to in-water life than are [otariids](#), which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves underwater.

**pinniped**

Member of the superfamily Pinnipedia, which is composed of [phocids](#) (true seals or earless seals), [otariids](#) (eared seals or fur seals and sea lions), and walrus.

**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,  $\Delta t$ , 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](#)).

**power spectral density level**

The [level](#) ( $L_{P_f}$ ) of the [power spectral density](#) ( $P_f$ ) in a stated [frequency](#) band and time window. Defined as:  $L_{P_f} = 10\log_{10}(P_f/P_{f0})$ . Unit: [decibel \(dB\)](#).

As with [power spectral density](#), power spectral density level can be expressed in terms of various field variables (e.g., [sound pressure](#), [sound particle displacement](#)). The [reference value](#) ( $P_{f0}$ ) for power spectral density level depends on the nature of the field variable.

**power spectral density source level**

A property of a sound source equal to the **power spectral density level** of the **sound pressure** 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**:  $1 \mu\text{Pa}^2 \text{ m}^2/\text{Hz}$ .

**propagation loss (PL)**

Difference between a **source level** (SL) and the level at a specified location,  $\text{PL}(x) = \text{SL} - L(x)$ .

Unit: **decibel (dB)**.

**received level**

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

**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 exposure spectral density**

Distribution as a function of **frequency** of the time-integrated squared **sound pressure** per unit **bandwidth** of a **sound** having a continuous **spectrum** (ISO 18405:2017). Unit: pascal squared second per hertz ( $\text{Pa}^2 \text{ s}/\text{Hz}$ ).

**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 ( $\text{W}/\text{m}^2$ ). Symbol:  $I$ .

**sound pressure**

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

**sound speed profile**

The speed of [sound](#) in the water column as a function of depth below the water surface. For airborne sound propagation, it is the speed of sound in the atmosphere as a function of elevation above the ground.

**soundscape**

The characterization of the [ambient sound](#) in terms of its spatial, temporal, and [frequency](#) attributes, and the types of sources contributing to the [sound](#) field (ISO 18405:2017).

**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](#).

**temporary threshold shift (TTS)**

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

**unweighted**

Term indicating that no [frequency-weighting function](#) is applied.



## Literature Cited

- [ANSI] American National Standards Institute and [ASA] Acoustical Society of America. S1.1-2013. *American National Standard: Acoustical Terminology*. NY, USA. <https://webstore.ansi.org/Standards/ASA/ANSIASAS12013>.
- [ISO] International Organization for Standardization. 2006. *ISO 80000-3:2006. Quantities and units -- Part 3: Space and time*. <https://www.iso.org/standard/31888.html>.
- [ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater Acoustics – Terminology*. Geneva. <https://www.iso.org/standard/62406.html>.
- [NMFS] National Marine Fisheries Service. 2016. *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts*. U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 pp.
- [NMFS] National Marine Fisheries Service. 2018. *2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts*. U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 pp. <https://www.fisheries.noaa.gov/webdam/download/75962998>.
- [USGS] US Geological Survey. Online. *3D Elevation Program* (webpage). <https://www.usgs.gov/3d-elevation-program>.
- Alduchov, O.A. and R.E. Eskridge. 1996. Improved Magnus form approximation of saturation vapor pressure. *Journal of Applied Meteorology* 35(4): 601-609.
- Au, W.W.L. and M.C. Hastings. 2008. *Principles of Marine Bioacoustics*. Springer. 510. <https://doi.org/10.1007/978-0-387-78365-9>.
- Austin, M. and M. Zykov. 2025. *Underwater Noise Modelling: Construction of Steensby Port Facility–Marine Environment*. Document 03377, Version 1.0. Technical report by JASCO Applied Sciences for WSP Canada.
- Blackwell, S.B., J.W. Lawson, and M.T. Williams. 2004. Tolerance by ringed seals (*Phoca hispida*) to impact pipe-driving and construction sounds at an oil production island. *Journal of the Acoustical Society of America* 115(5): 2346-2357. <http://dx.doi.org/10.1121/1.1701899>.
- Bowden, W. 2016. *Air Quality and Noise Abatement Management Plan*. Document Number BAF-PH1-830-P16-0002, Rev 6. Report by Baffinland Iron Mines Corporation. 42 pp. [https://baffinland.com/resources/document\\_portal/baf-ph1-830-p16-0002-r6---air-quality-and-noise-abatement-management-plan\\_2017-01-09-42.pdf](https://baffinland.com/resources/document_portal/baf-ph1-830-p16-0002-r6---air-quality-and-noise-abatement-management-plan_2017-01-09-42.pdf).
- Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93(4): 1736-1742.
- Delany, M.E. and E.N. Bazley. 1970. Acoustical properties of fibrous absorbent materials. *Applied Acoustics* 3(2): 105-116. [https://doi.org/10.1016/0003-682X\(70\)90031-9](https://doi.org/10.1016/0003-682X(70)90031-9).
- Gaspin, J.B. 1983. *Safe swimmer ranges from bottom explosions*. Document Number NSWC/WOL TR-83-84. Naval Surf. Weap. Cent., White oak Lab., Silver Spring, MS. 51 pp.
- Hyde, D.W. 1988. *User's guide for microcomputer programs ConWep and FunPro applications of TM 5-855-1. "Fundamentals of protective design for conventional weapons"*.
- Hyde, D.W. 1992. *Conventional weapons effect computer program, US Waterways Experiment Station*. Document Number Instructional Report SL-88-1. U.S. Army Corps of Engineers.
- Illingworth & Rodkin, Inc. 2017. *Pile-Driving Noise Measurements at Atlantic Fleet Naval Installations: 28 May 2013-28 April 2016*. Report by Illingworth & Rodkin, Inc. under contract with HDR Environmental for NAVFAC. 152 pp. [https://www.navy-marinespeciesmonitoring.us/files/4814/9089/8563/Pile-driving Noise Measurements Final Report 12Jan2017.pdf](https://www.navy-marinespeciesmonitoring.us/files/4814/9089/8563/Pile-driving%20Noise%20Measurements%20Final%20Report%2012Jan2017.pdf).
- JASCO Applied Sciences. 2009. *NaiKun Offshore Wind Energy Project: Volume 4 - Noise and Vibration (Sections 4 and 5)*. Report by JASCO Applied Sciences for NaiKun. Submitted to the Government of BC. <https://projects.eao.gov.bc.ca/api/document/5886ad82a4acd4014b81fc57/fetch/Volume%204%20Section%204%20and%205%20Airborne%20Noise%20Modelling.pdf>.

- Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, et al. 2014. *Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. ASA S3/SC1.4 TR-2014. SpringerBriefs in Oceanography. ASA Press and Springer. 76 pp.  
<https://doi.org/10.1007/978-3-319-06659-2>.
- Racca, R.G., D.E. Hannay, and S.A. Carr. 2006. An environmental noise impact assessment and forecasting tool for military training activities. *Canadian Acoustics* 34(4): 2. <https://jcaa.caa-aca.ca/index.php/jcaa/article/view/1862>.
- Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, California. 576.
- Salomons, E.M. 2001. *Computational Atmospheric Acoustics*. Kluwer Academic Publishers, Dordrecht, The Netherlands. 335.
- Siskind, D.E., V.J. Stachura, M.S. Stagg, and J.W. Kopp. 1980. *Structure Response and Damage Produced by Airblast From Surface Mining*. Report Number 8485. Report for the US Department of the Interior, Bureau of Mines.  
<https://www.osmre.gov/resources/blasting/docs/USBM/RI8485StructureResponseDamageProducedAirblast1980.pdf>.
- Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521.  
<https://doi.org/10.1080/09524622.2008.9753846>.
- Southall, B.L., J.J. Finneran, C.J. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals* 45(2): 125-232.  
<https://doi.org/10.1578/AM.45.2.2019.125>.
- The Greenbusch Group. 2017. *Elliott Bay Seawall Project Season 4 (2017): Acoustic Monitoring Report*. Document Number NWS-2011-778-WRD and NWR-2013-10650. Report by The Greenbusch Group, Inc. for City of Seattle Department of Transportation.  
<https://www.fisheries.noaa.gov/s3/2023-10/SDOTelliotbay-2014LOA-AcoustMonRepYear4-508-OPR1.pdf>.
- Thorson, P. and J.A. Reyff. 2004. *San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. Marine Mammal and Acoustic Monitoring for the Eastbound Structure*. Report for Caltrans.
- Wartzok, D. and D.E. Ketten. 1999. Marine Mammal Sensory Systems. In Reynolds, J. and S. Rommel (eds.). *Biology of Marine Mammals*. Smithsonian Institution Press, Washington DC. 117-175.

## Appendix A. Acoustics Metrics

This section describes in detail the acoustic metrics relevant to the modelling study.

### A.1. Acoustic Metrics

Underwater sound pressure amplitude is quantified in decibels (dB) relative to a fixed reference pressure of  $p_0 = 20 \mu\text{Pa}$  for airborne noise. 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 18405:2017, ANSI S1.1-2013).

The zero-to-peak sound pressure, or peak sound pressure (PK or  $L_{pk}$ ; dB re  $20 \mu\text{Pa}$ ), is the decibel level of the maximum instantaneous sound pressure in a stated frequency band attained by an acoustic pressure signal,  $p(t)$ :

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

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 sound exposure level (SEL or  $L_E$ ; dB re  $(20 \mu\text{Pa})^2 \text{s}$ ) is the time-integral of the squared acoustic pressure over a duration ( $T$ ):

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

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:

$$L_{E,N} = 10 \log_{10} \left( \sum_{i=1}^N 10^{\frac{L_{E,i}}{10}} \right) . \quad (\text{A-3})$$

#### A.1.1. 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.

Animals perceive exponential increases in frequency rather than linear increases, so 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 decidecade band,  $f_c(i)$ , is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \text{ kHz}, \quad (\text{A-4})$$

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

$$f_{lo,i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{hi,i} = 10^{\frac{1}{20}} f_c(i). \quad (\text{A-5})$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1).

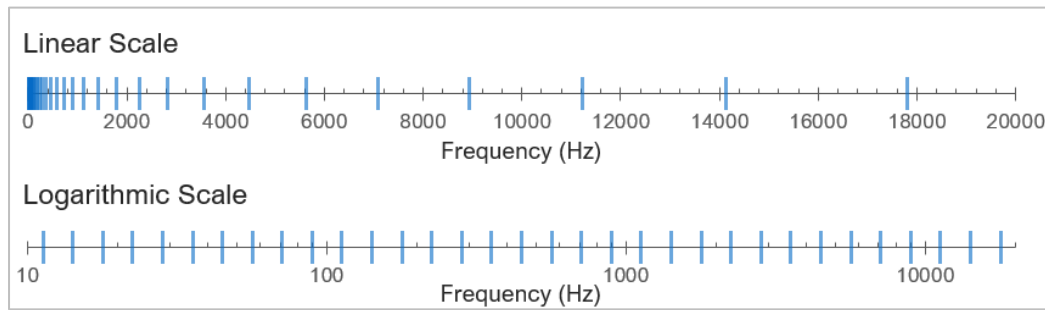


Figure A-1. Decidecade frequency bands (vertical lines) shown on (top) a linear frequency scale and (bottom) a logarithmic scale. On the logarithmic scale, the bands are equally spaced.

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

$$L_{p,i} = 10 \log_{10} \int_{f_{lo,i}}^{f_{hi,i}} S(f) df \text{ dB}. \quad (\text{A-6})$$

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

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \text{ dB}. \quad (\text{A-7})$$

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.

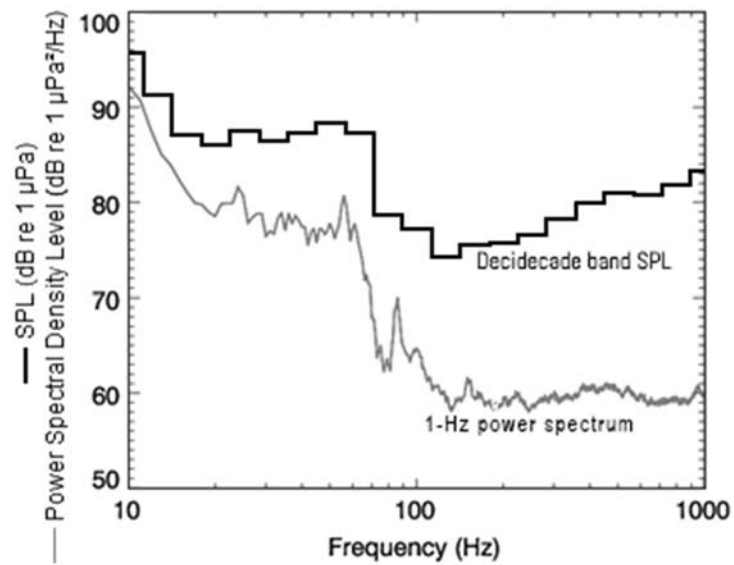


Figure A-2. Sound pressure spectral density levels and the corresponding decade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decade bands are wider with increasing frequency, the decade SPL is higher than the power spectrum, which is based on bands with a constant width of 1 Hz.

## Appendix B. Impact Criteria

Current data and predictions show that marine mammal species differ in their hearing capabilities, in their absolute hearing sensitivity as well as their frequency band of hearing (Richardson et al. 1995, Wartzok and Ketten 1999, Southall et al. 2007, Au and Hastings 2008). While hearing measurements are available for a small number of species based on captive animal studies, direct measurements of many species do not exist. Southall et al. (2007) proposed dividing marine mammals into hearing groups, each with separate criteria for onset of TTS and PTS. This division was updated in 2016 and 2018 by NOAA Fisheries using more recent best available science (NMFS 2016, 2018).

Southall et al. (2019) published an updated set of criteria for onset of TTS and PTS in marine mammals. While the authors propose a new nomenclature and classification for the marine mammal functional hearing groups, the proposed thresholds and weighting functions for exposure to underwater sound do not differ in effect from those proposed by NOAA (2018). Hearing groups from Southall et al. (2019) for in-air TTS and PTS thresholds used in this analysis are Phocid carnivores in air (PCA) and Other carnivores in air (OCA). For behavioural response, this report uses the PK and SEL thresholds for pinnipeds in air (PA) from Southall et al. (2007). Figure B-1 shows the marine mammal auditory weighting curves for these hearing groups.

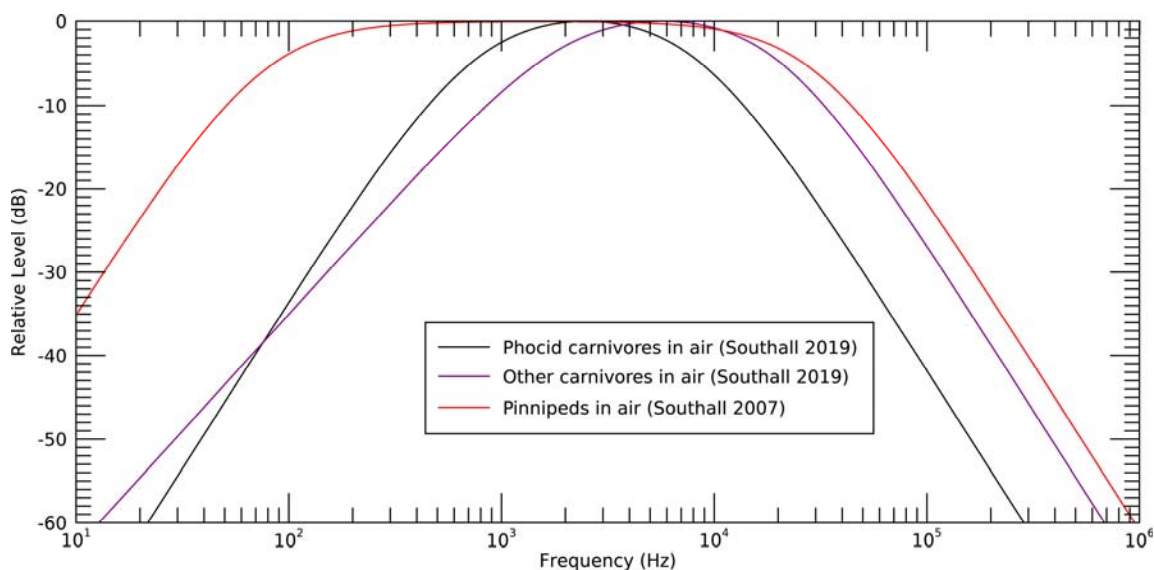


Figure B-1. Auditory weighting functions for in-air hearing sensitivity for pinnipeds hearing groups as recommended by Southall et al. (2019) for Phocid carnivores in air (PCA) and Other carnivores in air (OCA), and by Southall et al. (2007) for pinnipeds in air (PA).

## Appendix C. Modelling Methodology and Parameters

This section contains a detailed description of the methodology and parameters used for this modelling study.

### C.1. In-air Noise Propagation with Impulse Noise Propagation Model (INPM)

INPM uses a split-step Padé solution (Collins 1993) for the parabolic form of the wave equation to determine frequency-dependent transmission losses as a function of range away from a point source. The split-step Padé solution is computationally faster than the finite-difference solution of the Parabolic Equation (PE) by approximately two orders of magnitude and is more accurate than the split-step Fourier solution for wide angle propagation. This approach is also superior to standard ray tracing models that can yield unrealistically large received sound level values due to caustics, which are computationally intensive to remove (Salomons 2001). The model uses a two-dimensional (2-D) implementation of the PE method that accounts for diffraction, air turbulence, and sound interaction with the terrain. INPM has been verified by comparing model outputs against a set of benchmarks available in the open literature. The model shows nearly perfect agreement to the published results (Racca et al. 2006).

INPM can output the complete sound level field in range and height along a radial from the source. This can be rendered as an image plot (Figure C-1), which shows noise propagation for a single piling strike using the September atmospheric profile, selected as the most conservative.

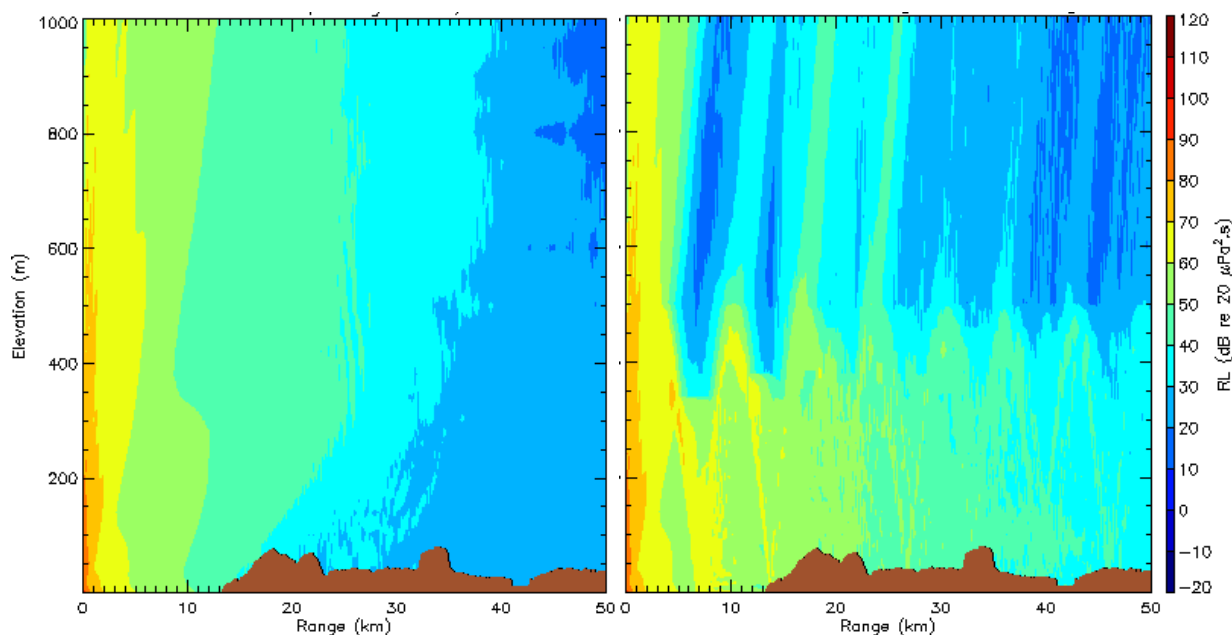


Figure C-1. Example of in-air unweighted broadband received sound level vertical radial plot from Impulse Noise Propagation Model (INPM), corresponding to a single impact piling strike for scenario IA1, using the most conservative atmospheric profile corresponding to September: (left) Wind speed 0 m/s; (right) Wind speed corresponds to the average September speed and constant east-to-west direction.



## C.2. Estimating Ranges to Threshold Levels

Sound level isopleths were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the seafloor for each location in the modelled region. The predicted distances to specific levels were computed from these isopleths. Two distances relative to the source are reported for each sound level: (1)  $R_{\max}$ , the maximum distance to the given sound level over all azimuths, and (2)  $R_{95\%}$ , the range to the given sound level after the 5 % farthest points were excluded (see examples in Figure C-2).

The  $R_{95\%}$  is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in the image in Figure C-2a. In cases such as this, where relatively few points are excluded in any given direction,  $R_{\max}$  can misrepresent the area of the region exposed to such effects, and  $R_{95\%}$  is considered more representative. In contrast, in strongly radially asymmetric cases such as shown in Figure C-2b,  $R_{95\%}$  neglects to account for substantial protrusions in the footprint. In such cases,  $R_{\max}$  might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features that affect propagation. The difference between  $R_{\max}$  and  $R_{95\%}$  depends on the source directivity and the non-uniformity of the acoustic environment.

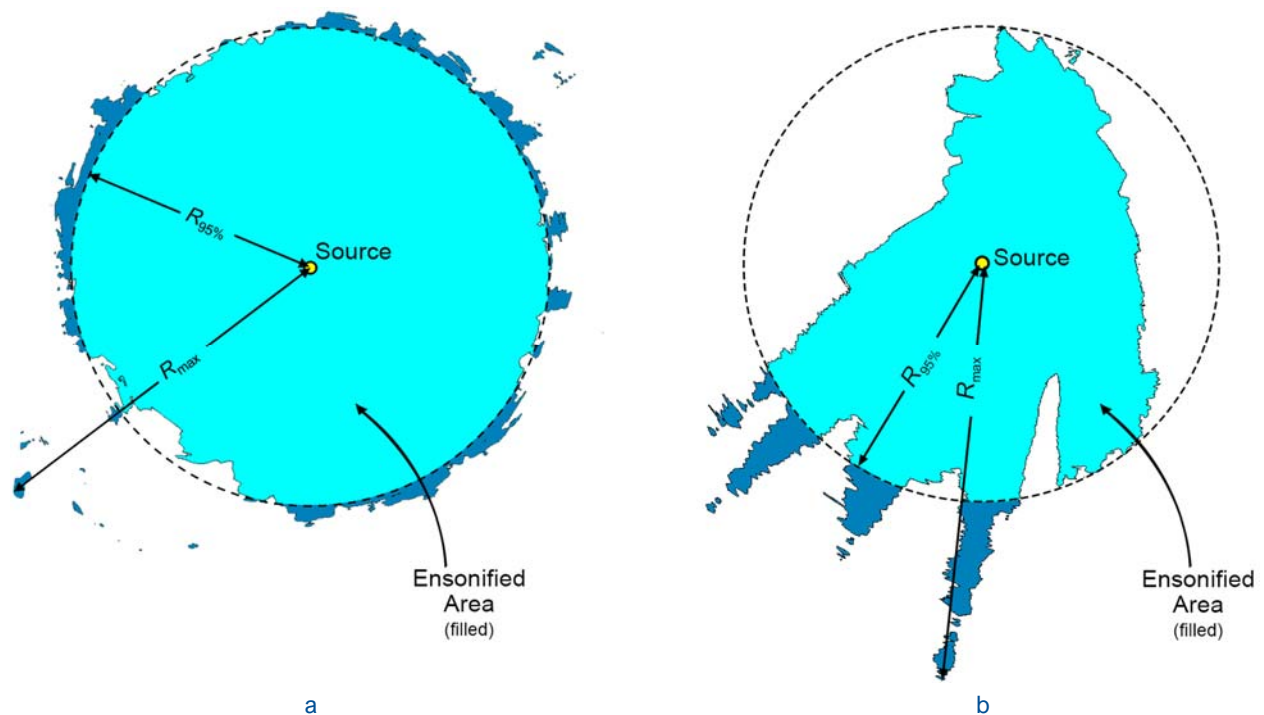


Figure C-2. Sample areas ensonified to an arbitrary sound level with  $R_{\max}$  and  $R_{95\%}$  ranges shown for two contrasting scenarios: (a) a largely radially symmetric sound level contour with small protrusions, for which  $R_{95\%}$  best represents the ensonified area; and (b) a strongly asymmetric sound level contour with long protrusions, for which  $R_{\max}$  best represents the ensonified areas in some directions. Light blue indicates the ensonified areas bounded by  $R_{95\%}$ ; darker blue indicates the ensonified areas beyond  $R_{95\%}$  that determine  $R_{\max}$ .



## C.3. Environmental Parameters

### C.3.1. Terrain Topography

For the terrain topography, two data sets were used to generate an elevation grid of 50 × 50 km centred around the modelled area:

- For the regions surrounding the modelled sites, JASCO used elevation data from the United States Geological Survey (USGS Online), with resolution 100 × 100 m.
- To represent the terrain at the modelled sites, JASCO used higher resolution 5 m elevation contours, provided to JASCO by Baffinland.

The two data sets were combined and grided to 20 × 20 m resolution for INPM acoustic modelling (see Figure C-3).

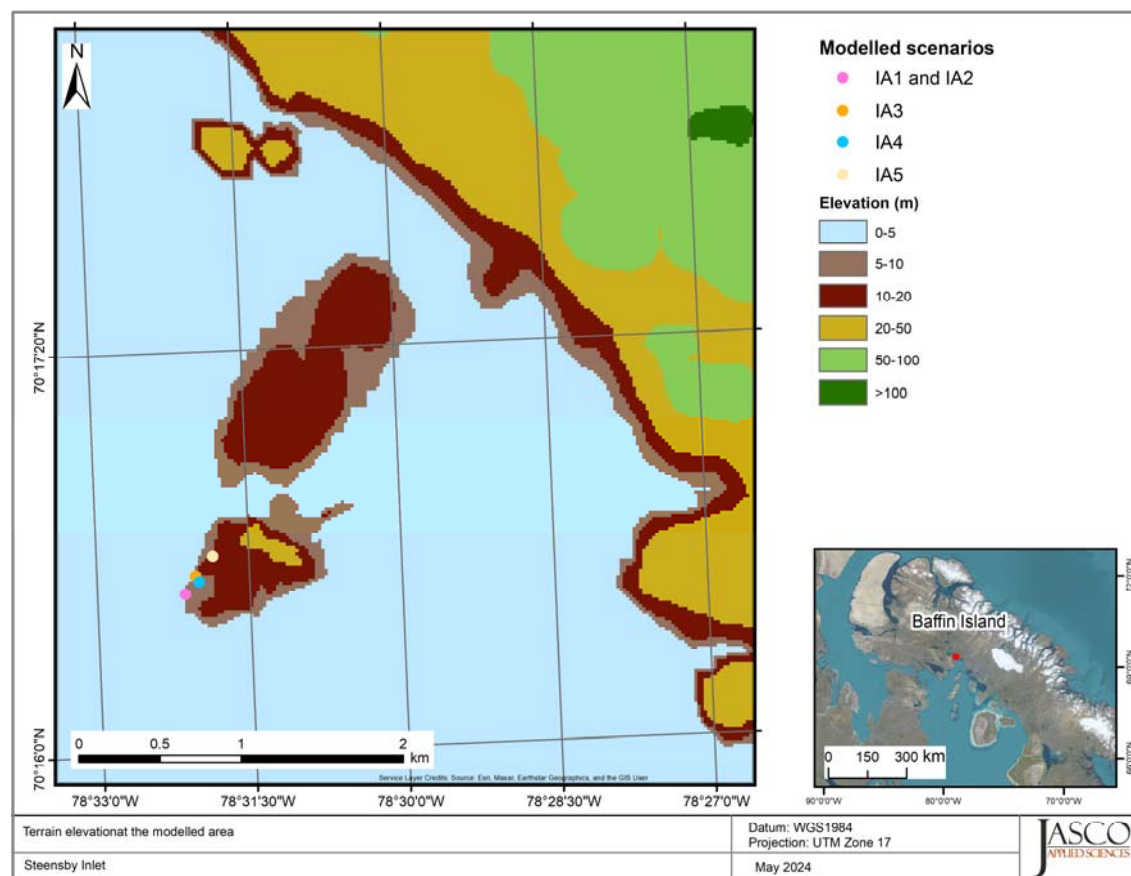


Figure C-3. Terrain elevation within the modelled area.

### C.3.2. Soil Flow Resistivity

Interaction of sound with the terrain is accounted for in INPM by considering the relationship between acoustic impedance of the ground or the water and the air. This relationship dictates a ratio of sound energy that is reflected into the atmosphere and the sound energy that is absorbed into the ground or the water. The parameter that describes this absorption of energy is called the flow resistivity (Delany and Bazley 1970), as shown in Table C-1. The flow resistivity in the modelled area was set to 2000 kNs/m<sup>4</sup>, based on aerial photographs that show that the terrain is mostly water and hard soil, gravel, small stones, and sparse vegetation.

Table C-1. Flow resistivity values associated with differently common types of soil.

Region	Flow resistivity (kNs/m <sup>4</sup> )
Rock/vegetation	100
Urban area	630
Soft packed snow	40
Water with hard soil, gravel, small stones, and sparse vegetation	2000

### C.3.3. Atmospheric Profiles

The atmospheric profiles used in this investigation were calculated from twice-daily weather balloon launches from the nearest and lowest-elevation data station CAM00071081 at Hall Beach, for May 2023 to April 2024. For each month, weather data consists of elevation-dependent profiles of pressure, temperature, and dew point. Relative humidity was then calculated from temperature and dew point using the equation from Alduchov and Eskridge (1996). All the data were averaged in 200 m bins, interpolated from 0 and 10 km elevations, and smoothed using a moving average. Since this station is ~250 km from the modelled Steensby locations, the temperature elevation-dependent profile (which is the one that determines the sound speed profile) was offset to match, for each month, the average temperature collected at the Steensby Meteorological Station (lat/lon 70° 16' 36.4"/78° 31' 37.4"; Bowden 2016).

Preliminary modelling of broadband unweighted SEL was carried out to determine the atmospheric profile that is likely to yield the most precautionary distances to thresholds. The September profile used in this study (Figure C-4) yielded the most conservative results.

A wind velocity of zero was used in JASCO's model so as not to bias the sound propagation in any direction, given that wind conditions may change from hour to hour and therefore would not be representative of the entire operation. In addition, more conservative results with east-to-west wind (i.e., along azimuth 270°) are presented in this study.

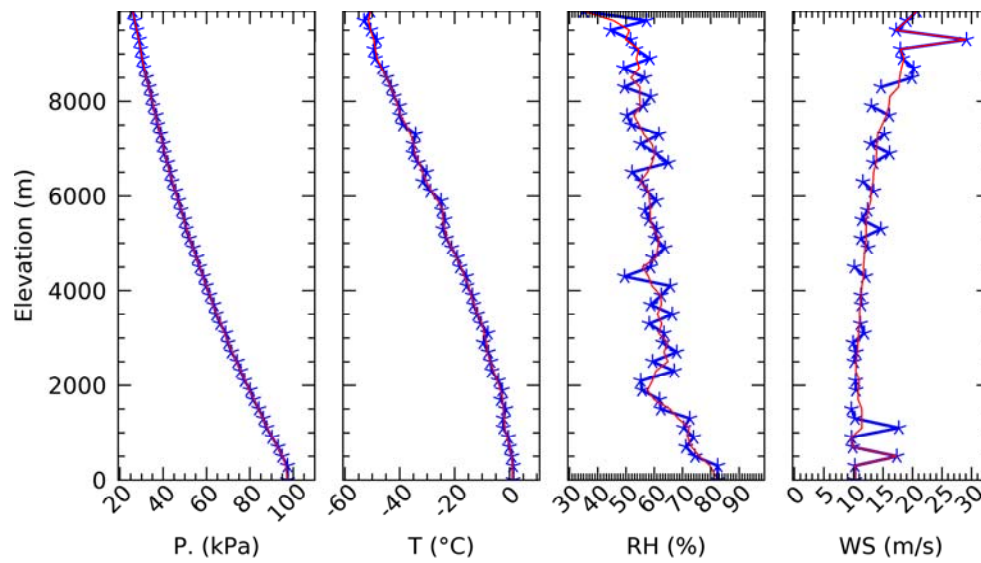


Figure C-4. September: Atmospheric pressure (P), temperature (T), relative humidity (RH), and wind speed (WS) profiles used to model airborne sound propagation. The stars represent binned data from the radiosonde measurements, while the red lines are smoothed curves used for modelling.

## Appendix D. Blasting source levels

This appendix discusses the steps used to fine-tune the source levels for blasting obtained from ConWep's Shockwave module (Section 3.1.3) to achieve PK and SEL modelled results consistent with publicly available field measurements. For this process, JASCO used PK and SEL data from (Siskind et al. 1980), which provides airborne detonation noise measurements obtained at ranges 70 m to 12,000 m for charges of weights between 10 kg and up to 9,500 kg TNT. These charges were detonated as part of the operations in a coal surface mine.

In technical literature on blasting, it is commonplace that measured levels (either PK or SEL) are plotted against the so-called *scaled distance* (SD), which is defined as the range  $R$  (in m) divided by the cube root of the charge weight  $W$  (in kg of TNT),

$$SD = R/(W)^{1/3} \quad (D-1)$$

This scaling reflects the fact that two charges with identical explosive composition and geometry, but different size (weight), in similar ambient conditions, will produce self-similar blast waves at equal scaled distances. It enables the common graphing of measured levels (PK or SEL) against scaled distance for different charge sizes, yielding linear trends on a semilogarithmic plot. Figure D-1 shows a comparison of the PK and unweighted SEL (single detonation) for scenario IA4 with 50 kg charges (\* markers) to measurements from (Siskind et al. 1980) (o markers). Figure D-1 also shows three linear trend models from (Siskind et al. 1980), commonly used to predict PK levels as a function of distance from the charge:

- The “highwall” model represents typically well confined charges.
- The “parting” model corresponds to under-confined charges, thereby yielding the highest PK levels at close range from the charge.
- The “front” model, which was obtained by fitting PK measurements collected in the direction of the front face of highwall blasting operations in a metal mine quarry.

The following observations are highlighted:

- The (Siskind et al. 1980) data exhibit variability up to 20 dB even for detonations at similar scaled distance. This could be due to the fact that these data were obtained for multiple mining operations such as parting blasts (usually smaller but less confined charges) and highwall blasting (typically more confined).
- JASCO's modelled SEL line up well with the (Siskind et al. 1980) SEL data at all scaled ranges. To be conservative, the fine tuning of JASCO's model tends to ignore the lowest SEL measurements, such as the 105 dB re 20  $\mu\text{Pa}^2\text{s}$  at scaled distance of 10 m/kg<sup>1/3</sup>.
- Both (Siskind et al. 1980) and JASCO's modelled PK data are in good agreement to the “front” model.

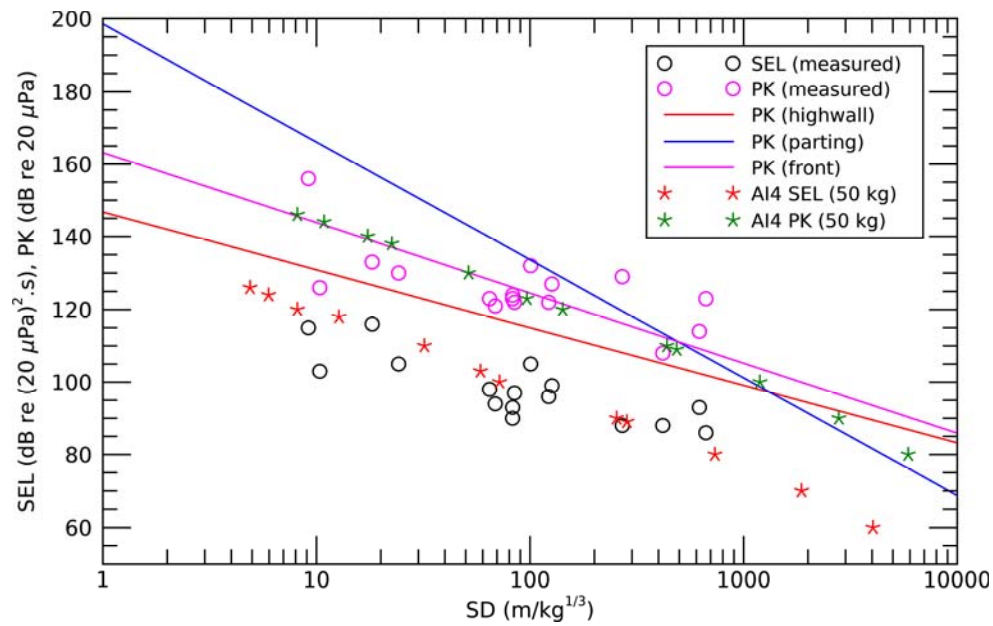


Figure D-1. Comparison of JASCO's modelled peak (PK) and sound exposure levels (SEL) for scenario IA4 (50 kg charge) to measurements from (Siskind et al. 1980), as a function of scaled distance (SD). Solid lines show several trend lines models commonly used to predict PK and SEL airborne noise.