APPENDIX 5: SOUND TRANSMISSION LOSS MODELLING STUDY (based on previous larger area of interest)

CGG SOUTH AFRICA ALGOA 3D SEISMIC SURVEY

Underwater Acoustics Modelling

Prepared for:

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This report has been prepared by SLR Consulting Australia Pty Ltd with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with SLR Consulting (Cape Town office) (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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EXECUTIVE SUMMARY

CGG is proposing to undertake a speculative 3D seismic survey to investigate for oil and gas reserves off the Southeast Coast of South Africa. The proposed survey area would be in the order of 4 000 km^2, within a 10 000 km^2 identified Area of Interest (AOI) covering a number of petroleum licence blocks. The AOI stretches roughly between Port Elizabeth and Plettenberg Bay and ranges between 35 and 120 km from the coast. Water depths in the AOI range from 200 m to 4 000 m.

SLR Consulting Australia Pty Ltd (SLR) has been engaged by SLR Consulting (South Africa) (Pty) Ltd on behalf of CGG to undertake an underwater acoustic modelling study for the proposed 3D survey, in order to forecast sound levels of various metrics, including peak sound pressure levels (Pk SPLs), root-mean-square sound pressure levels (RMS SPLs), and single-pulse and cumulative sound exposure levels (SELs) at some representative receiving locations within the survey area.

This report details the underwater acoustic modelling study that has been carried out for the proposed survey. For the proposed 3D seismic survey, the following modelling components are included:

- Array source modelling – modelling of the sound energy emissions from the 2 965 cubic inch (CUI) 1500LL/1900LLXT Source Array to be used in the survey, including its far-field signature and power spectral density (PDS);
- Short-range modelling – prediction of the received SELs at distances up to four kilometres from the source array. Short range modelling is used to assess the potential high-risk immediate noise impact to marine fauna species of interest.
- Long-range modelling – prediction of the received SELs over a range of tens to hundreds of kilometres. This modelling assesses the noise impacts to more distant sensitive marine areas; and
- Cumulative modelling – prediction of the received cumulative SELs within 24-hour period (SEL_{24hr}) for a representative survey operation scenario.

The noise modelling results are further analysed to identify zones of impact for marine fauna species of concern based on relevant noise impact assessment criteria. The marine fauna species of concern include marine mammals, fish and turtle species. The noise effects assessed include physiological effects (physical injury/permanent threshold shift (PTS) and temporary threshold shift (TTS)) and behavioural disturbance due to either immediate impact from single airgun pulses or cumulative effects of exposure to multiple airgun pulses over a period of 24 hours.

The noise impact assessment criteria for the marine fauna species of concerns are detailed in **Section 2** of this report, and the identified relevant zones of impact are summarised in **Section 5.4** of the report. The identified relevant zones of impact for marine mammals, fish and sea turtle species are summarised as follows:

Marine mammals

Impact from immediate exposure to individual airgun array pulses

Due to the high level of impulsive signal emissions from the array source, marine mammals are predicted to experience PTS effects at close proximity to the source array due to the immediate exposure to individual pulses. Marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 60 m from the source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 480 m from the array source. The zones of TTS effects due to a single pulse exposure for marine mammals of all hearing groups except very-

EXECUTIVE SUMMARY

high-frequency cetaceans are predicted to be within approximately 135 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 850 m from the array source. Behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 4.4 km from the array source for marine mammals of all hearing groups.

Impact from cumulative exposure to multiple airgun array pulses

The zones of cumulative impact (i.e. the maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels) are estimated based on the modelling results and relevant assessment criteria. Among marine mammals of all six hearing groups, low-frequency cetaceans have the highest zones of cumulative PTS and TTS impact. The zones of PTS impact are predicted to range up to 800 m from the adjacent survey lines for the 24-hour survey operation scenario considered, and the zones of TTS impact are predicted to be up to 12.0 km from the adjacent survey lines. Much lower zones of cumulative PTS and TTS impact are predicted for marine mammals of other hearing groups.

Fish and sea turtles

Impact from immediate exposure to individual airgun array pulses

The zones of potential injuries for fish species with a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 240 m from the array for both PTS and TTS. However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 120 m from the array source.

The behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be 3.1 km from the array source for sea turtles.

Impact from cumulative exposure to multiple airgun array pulses

The zones of potential mortal injuries for fish species with and without a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 20 m from the adjacent survey lines for the 24-hour survey operation scenarios considered. For recoverable injury, the zones of impact are predicted to be within 10 m for fish with no swim bladder, and within 50 m for fish with a swim bladder. The zones of TTS effect for fish species with and without swim bladders are predicted to be up to 2 000 m from the adjacent survey lines for the 24-hour survey operation scenario considered.

Existing experimental data regarding recoverable injury and TTS impacts for sea turtles and fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach, noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field (tens of meters) from the source location while impacts are expected to be moderate for fish eggs and larvae. Impact is expected to be low for all of them at intermediate field (hundreds of meters) and far field (thousands of meters) from the source location.

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1 Introduction

1.1 Project description

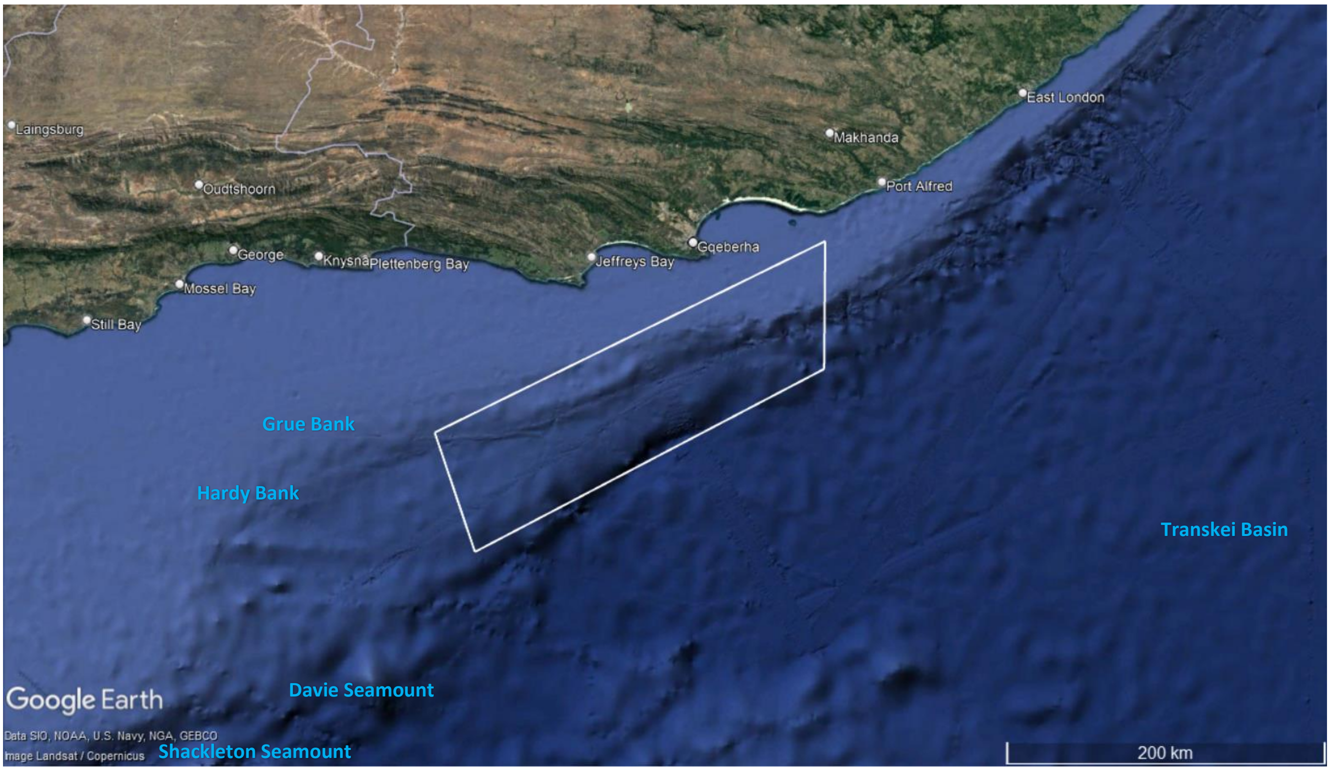
CGG is proposing to undertake a speculative 3D seismic survey to investigate for oil and gas reserves off the Southeast Coast of South Africa.

The reconnaissance permit application area is approximately 19 060 km^2. It stretches from the western border of the Eastern Cape province along the south coast up to a point approximately 80 km east of Port Elizabeth (Gqeberha) and ranges between 20 and 180 km from the coast. Water depths within the permit area range from 100 m to up to 4 500 m.

The proposed survey area would be in the order of 3 500 km^2, within a 15 000 km^2 identified Area of Interest (AOI) covering a number of petroleum licence blocks. The AOI stretches roughly between Port Elizabeth and Plettenberg Bay and ranges between 30 and 120 km from the coast. Water depths in the AOI range from 200 m to 4 000 m.

The locality of the reconnaissance permit application area and proposed survey area is shown in **Figure 1**.

Figure 1 The locality of the reconnaissance permit application area in white.



SLR Consulting Australia Pty Ltd (SLR) has been engaged by SLR Consulting (South Africa) (Pty) Ltd on behalf of CGG to undertake a detailed underwater acoustics modelling study for the proposed survey, in order to assist with the assessment of potential noise impact on marine fauna species of interest, particularly for these major marine sensitive areas of concerns above.

This underwater acoustic modelling study predicts received noise levels of various metrics (i.e. sound exposure levels (SELs) from single pulses, cumulative SELs from multiple pulses over 24 hours (SEL_{24hr}), peak sound pressure levels (Pk SPLs) and root-mean-square sound pressure levels (RMS SPLs)) at noise sensitive locations within and adjacent to the proposed survey area. These noise levels are used to estimate the threshold distances to potential sound effects on marine fauna species of interest, including marine mammals, fish and sea turtle species.

1.2 Structure of the report

This modelling study for the extensive 2D seismic acquisition campaign proposed for the west coast of South Africa includes the following modelling components:

- Airgun source modelling, i.e. modelling of sound energy emissions from the 2 965 cubic inch (CUI) 1500LL/1900LLXT Source Array proposed to be used in the survey, including the far-field signature and its power spectral density (PSD), as well as the beam pattern of the source array.
- Short range modelling, i.e. prediction of the received noise levels over a range of up to four kilometres from the selected array source locations of various depths, in order to investigate sound field variations due to the water depth changes, as well as to assess the potential high-risk immediate noise impact to marine fauna species of interest.
- Long range modelling, i.e. prediction of the received noise levels over a range of up to two hundred kilometres from the selected array source locations, in order to assess the potential noise impact from the survey on relevant far-field marine sensitive areas.
- Cumulative noise exposure modelling, i.e. prediction of the cumulative SELs over a 24-hour period for selected representative survey scenarios adjacent to marine sensitive areas, to assess the potential cumulative noise impact to marine fauna species of interest.

Section 2 of the report provides relevant noise impact assessment criteria for marine fauna species of interest. **Section 3** details the modelling methodology, procedure and results for the seismic survey array source modelling. **Section 4** outlines the methodologies and procedures for the seismic survey acoustic modelling components (including short range and long range transmission loss modelling and the cumulative noise exposure modelling). **Section 5** presents the major modelling results and the estimated zones of impact for marine fauna species of interest. **Section 6** provides discussions and summaries of the acoustic modelling study. Relevant references cited throughout the report are listed in **Section 7**.

Relevant acoustic terminologies used throughout the report are presented in **Appendix A**. Classifications of various marine mammal hearing groups are presented in **Appendix B**.

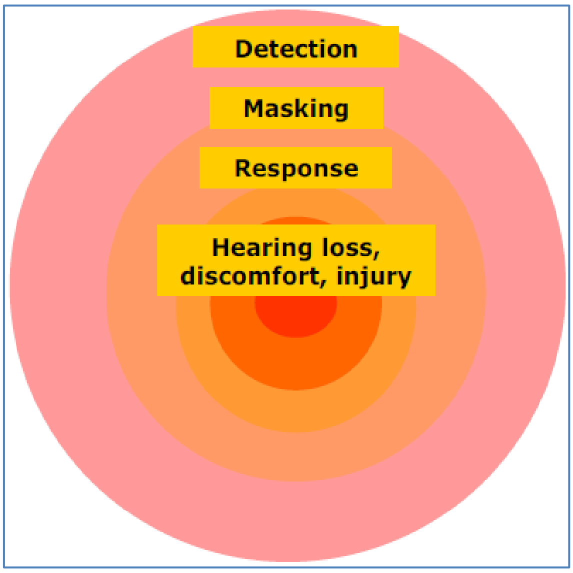
2 Noise Assessment Criteria

2.1 Impact of noise on marine fauna species

The effects of noise and the range over which these effects take place depend on the acoustic characteristics of the noise (e.g. source level, spectral content, temporal characteristics (e.g. impulsive [1] or non-impulsive/continuous[2]), directionality, etc.), the sound propagation environment as well as the hearing ability and physical reaction of individual marine fauna species. The potential impacts of noise on marine fauna species include audibility, detection and masking of communication and other biological important sounds, behavioural responses and physiological impacts which generally include discomfort, hearing loss, physical injury and mortality (Richardson et al, 1995; Hastings and Popper, 2005).

The theoretical zones of noise influence based on the severity of noise impact is illustrated in Error! Reference source not found. below.

Figure 2 Theoretical zones of noise influence (Richardson et al. 1995)



Audibility/detection

A sound is audible when the receiver is able to perceive it over background noise. The audibility is also determined by the threshold of hearing that varies with frequency. The frequency dependant hearing sensitivity is expressed in the form of a hearing curve (i.e. audiogram). In general, marine mammals and fish species usually have U-shaped audiograms, meaning that within their respective hearing ranges, they are more sensitive to the sound energy component in the mid frequency range, and less sensitive to the energy components in the lower and upper frequency ranges (Whitlow et al, 2008; Southall et al, 2007; Popper et al, 2014).

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[1] Impulsive noise is typically very short (with seconds) and intermittent with rapid time and decay back to ambient levels. E.g. noise from pile driving, seismic airguns and seabed survey sonar signals.

[2] Non-impulsive or continuous noise refers to a noise event with pressure level remains above ambient levels during an extended period of time (minutes to hours), but varies in intensity with time. E.g. noise from marine vessels.

For fish species, their sound detection is based on the response of the auditory portion of their ears (i.e. the otolithic organs) to particle motion of the surrounding fluid (Popper et al, 2014). Some fish species have the ability to detect sound pressure via gas-filled structures near the ear and/or extensions of the swim bladder that functionally affect the ear, in addition to purely the fluid particle motion, which as a result increase hearing sensitivity and broaden the hearing bandwidth (Popper et al, 2014).

Masking

Masking occurs when the noise is high enough to impair detection of biologically relevant sound signals such as communication signals, echolocation clicks and passive detection cues that are used for navigation and finding prey. The zone of masking is defined by the range at which sound levels from the noise source are received above threshold within the 'critical band'[3] centred on the signal (Richardson et al. 1995; NRC 2003), and therefore strongly dependent on background noise environment.

The potential for masking can be reduced due to an animal's frequency and temporal discrimination ability, directional hearing, co-modulation masking release (if noise is amplitude modulated over a number of frequency bands) and multiple looks (if the noise has gaps or the signal is repetitive), as well as anti-masking strategies (increasing call level, shifting frequency, repetition, etc.) (Erbe, 2008).

Behavioural Responses

Behavioural responses to noise include changes in vocalisation, resting, diving and breathing patterns, changes in mother-infant relationships, and avoidance of the noise sources. For behavioural responses to occur, a sound would mostly have to be significantly above ambient levels and the animal's audiogram.

The behavioural response effects can be very difficult to measure and depend on a wide variety of factors such as the physical characteristics of the signal, the behavioural and motivational state of the receiver, its age, sex and social status and many others. Therefore, the extent of behavioural disturbance for any given signal can vary both within a population as well as within the same individual. Behavioural reactions can vary significantly, ranging from very subtle changes in behaviour to strong avoidance reactions (Richardson et al, 1995).

Physiological impacts / hearing loss and physical injury

Physiological effects of underwater noise are primarily associated with the auditory system which is likely to be most sensitive to noise. The exposure of the auditory system to a high level of noise for a specific duration can cause a reduction in the animal's hearing sensitivity, or an increase in hearing threshold. If the noise exposure is below some critical sound energy level, the hearing loss is generally only temporary, and this effect is called temporary hearing threshold shift (TTS). If the noise exposure exceeds the critical sound energy level, the hearing loss can be permanent, and this effect is called permanent hearing threshold shift (PTS).

In a broader sense, physiological impacts also include non-auditory physiological effects. Other physiological systems of marine animals potentially affected by noise include the vestibular system, reproductive system, nervous system, liver or organs with high levels of dissolved gas concentrations and gas filled spaces. Noise at high levels may cause concussive effects, physical damage to tissues and organs, cavitation or result in rapid formation of bubbles in venous system due to massive oscillations of pressure.

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[3] In biological hearing systems, noise is integrated over several frequency filters, called the critical bands.

From an adverse impact assessment perspective, among the potential noise impacts above, physiological impacts are deemed as the primary adverse impact, and behavioural responses as the secondary adverse impact. The following sub-sections outline the corresponding impact assessment criteria for marine mammals and fish and sea turtle species, as well as human divers and swimmers, based on a review of relevant guidelines and/or literature published.

2.2 Marine mammals

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine mammal species. For example, Southall et al (2007 & 2019) have proposed noise exposure criteria associated with various sound types, including impulsive noise (e.g. piling noise and seismic airgun noise) and non-impulsive noise (e.g. vessel and drilling noise)) for certain marine mammal species (i.e. cetaceans and sirenians and carnivores), based on review of expanding literature on marine mammal hearing and on physiological and behavioural responses to anthropogenic sounds.

The following two subsections provide the recommended frequency-weighting functions for use in assessing the effects of relatively intense sounds on hearing, as well as the noise exposure levels above which adverse effects on various groups of marine mammals, and they are derived based on all available relevant data and published literature (i.e. the state of current knowledge).

2.2.1 Marine mammal auditory weighting functions

Marine animals do not hear equally well at all frequencies within their functional hearing range. Based on the hearing range and sensitivities, Southall et al (2019) have categorised marine mammal species (i.e. cetaceans and pinnipeds) into six underwater hearing groups: low-frequency (LF), high-frequency (HF), very high-frequency (VHF) cetaceans, Sirenians (SI), Phocid carnivores in water (PCW) and Other marine carnivores in water (OCW). For each specific marine mammal species, refer to Appendix I – 6 within the reference document (Southall et al, 2019) for their corresponding hearing groups. A summary of these appendices is presented as **Appendix B** in this report.

The potential noise effects on animals depend on how well the animals can hear the noise. Frequency weighting is a method of quantitatively compensating for the differential frequency response of sensory systems (Southall *et al.*, 2007 & 2019).

When developing updated scientific recommendations in marine mammal noise exposure criteria, Southall *et al.* (2019) adopted the auditory weighting functions as expressed in the equation below, which are based on the quantitative method by Finneran (2015 & 2016) and are consistent with the U.S. National Oceanic and Atmospheric Administration (NOAA) technical guidance (NMFS, 2016 & 2018).

$$W(f) = C + 10log10\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+ (f/f_2)^2]^b}\right\} \tag{2.1}$$

Where:

- ***W(f)*** is the weighting function amplitude (in dB) at frequency f (in kHz).
- f_1 represents LF transition value (in kHz), i.e. the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- f_2 represents HF transition value (in kHz), i.e. the upper frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- **a** represents the LF exponent value (dimensionless) which defines the rate of decline of the weighting function amplitude at low frequencies. The change in weighting function amplitude with frequency at low

frequencies (the LF slope) is 20a dB/decade.

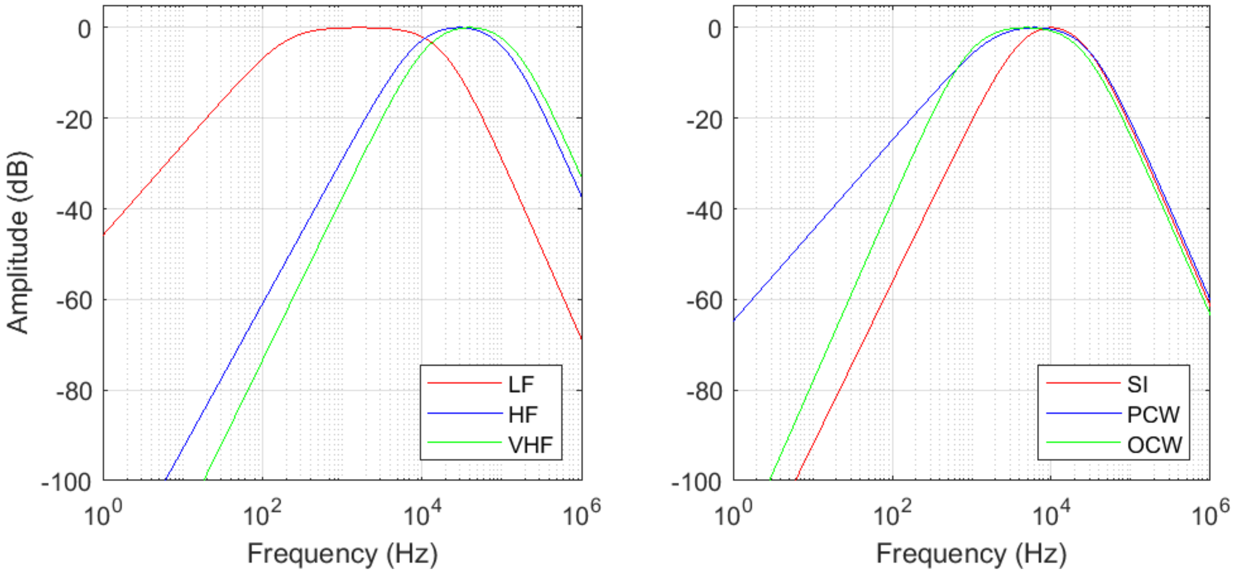
- **b** represents the HF exponent value (dimensionless) which defines the rate of decline of weighting function amplitude at high frequencies, becoming linear with the logarithm of frequency. The change in weighting function amplitude with frequency at high frequencies (the HF slope) is -20b dB/decade.
- **C** is the constant that defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Table 1 lists the auditory weighting parameters as defined above for the six hearing groups. The corresponding auditory weighting functions for all hearing groups are presented in Error! Reference source not found.**.**

Table 1 Parameters for the auditory weighting functions (Southall *et al.*, 2019)

Marine mammal hearing group	*a*	*b*	*f_1 (kHz)*	*f_2 (kHz)*	*C (dB)*
Low-frequency cetaceans (LF)	1.0	2	0.20	19	0.13
High-frequency cetaceans (HF)	1.6	2	8.8	110	1.20
Very-high-frequency cetaceans (VHF)	1.8	2	12	140	1.36
Sirenians (SI)	1.8	2	4.3	25	2.62
Phocid carnivores in water (PCW)	1.0	2	1.9	30	0.75
Other marine carnivores in water (OCW)	2.0	2	0.94	25	0.64

Figure 3 Auditory weighting functions - LF, HF, VHF, SI, PCW and OCW (Southall *et al.*, 2019)



2.2.2 Noise impact criteria for marine mammals

The newly updated scientific recommendations in marine mammal noise exposure criteria (Southall et al, 2019) propose PTS-onset and TTS-onset criteria for impulsive noise events. The PTS-onset and TTS-onset criteria for impulsive noise are outlined in **Table 2**, which incorporate a dual-criteria approach based on both peak sound pressure level (SPL) and cumulative sound exposure level (SEL) within a 24-hour period (SEL_{24hr}).

Table 2 The PTS and TTS threshold levels for individual marine mammals exposed to impulsive noise events (Southall *et al.*, 2019)

Marine mammal hearing group	PTS and TTS threshold levels – impulsive noise events			
	Injury (PTS) onset		**TTS onset**	
	Pk SPL, dB re 1µPa	Weighted SEL$_{24hr}$, dB re 1µPa^2·S	Pk SPL, dB re 1µPa	Weighted SEL$_{24hr}$, dB re 1µPa^2·S
Low-frequency cetaceans (LF)	219	183	213	168
High-frequency cetaceans (HF)	230	185	224	170
Very-high-frequency cetaceans (VHF)	202	155	196	140
Sirenians (SI)	226	203	220	175
Phocid carnivores in water (PCW)	218	185	212	170
Other marine carnivores in water (OCW)	232	203	226	188

For behavioural changes, the widely used assessment criterion for the onset of possible behavioural disruption in marine mammals is root-mean-square (RMS) SPL of 160 dB re 1µPa for impulsive noise, as shown in **Table 3.**

Table 3 The behavioural disruption threshold level for individual marine mammals – impulsive noise events (NMFS, 2013)

Marine mammal hearing group	**Behavioural disruption threshold levels – impulsive noise events**
	RMS SPL, dB re 1µPa
All hearing groups	160

2.3 Fish and sea turtles

In general, limited scientific data are available regarding the effects of sound for fishes and sea turtles. As such, assessment procedures and subsequent regulatory and mitigation measures are often severely limited in their relevance and efficacy. To reduce regulatory uncertainty for all stakeholders by replacing precaution with scientific facts, the U.S. National Oceanic and Atmospheric Administration (NOAA) convened an international panel of experts to develop noise exposure criteria for fishes and sea turtles in 2004, primarily based on published scientific data in the peer-reviewed literature. The panel was organized as a Working Group (WG) under the ANSI-Accredited Standards Committee S3/SC 1, Animal Bioacoustics, which is sponsored by the Acoustical Society of America.

The outcomes of the WG are broadly applicable sound exposure guidelines for fishes and sea turtles (Popper *et al.*, 2014), considering the diversity of fish and sea turtle species, the different ways they detect sound, as well as various sound sources and their acoustic characteristics. The sound exposure criteria for seismic airgun sources are presented in **Table 4.**

Within the table, where data exist that can be used to suggest provisional guidelines, received signal levels are reported in appropriate forms (e.g., peak, SEL). Where insufficient data exist to make a recommendation for guidelines, a subjective approach is adopted in which the relative risk of an effect is placed in order of rank at three distances from the source – near (N), intermediate (I), and far (F) (top to bottom within each cell of the table, respectively). In general, “near” might be considered to be in the tens of meters from the source, “intermediate” in the hundreds of meters, and “far” in the thousands of meters. The relative risk of an effect is then rated as being “high,” “moderate,” and “low” with respect to source distance and animal type. The rating for effects in these tables is highly subjective and represents general consensus within the WG.

It should be noted that the period over which the cumulative sound exposure level (SEL$_{cum}$) is calculated must be carefully specified. For example, SEL$_{cum}$ may be defined over a standard period (e.g., 12 hours of pile driving) or for the duration of an activity (e.g., the full period of construction), or over the total period that the animal will be exposed. Whether an animal would be exposed to a full period of sound activity will depend on its behaviour, as well as the source movements. To be in line with assessment criteria for marine mammals, an exposure period of 24 hours is specified for fish and sea turtle species. The receiving exposure levels over this period are expected to reflect the total exposure at near field where the major adverse impacts are expected to occur for fish and sea turtle species.

Table 4 Noise exposure criteria for seismic airguns – fish and sea turtles (Popper *et al.*, 2014)

Type of animal	Mortality and potential mortal injury	Impairment			Behaviour
		Recovery injury	**TTS**	**Masking**	
Fish: no swim bladder (particle motion detection)	>219 dB SEL$_{cum}$, or >213 dB Pk SPL	>216 dB SEL$_{cum}$ or >213 dB Pk SPL	>>186 dB SEL$_{cum}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL$_{cum}$ or >207 dB Pk SPL	203 dB SEL$_{cum}$ or >207 dB Pk SPL	>>186 dB SEL$_{cum}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL$_{cum}$ or >207 dB Pk SPL	203 dB SEL$_{cum}$ or >207 dB Pk SPL	186 dB SEL$_{cum}$	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	210 dB SEL$_{cum}$ or >207 dB Pk SPL	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate	(N) High (I) Moderate (F) Low
Fish eggs and fish larvae	>210 dB SEL$_{cum}$ or >207 dB Pk SPL	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low	(N) Moderate (I) Low (F) Low

Notes: peak sound pressure levels (Pk SPL) dB re 1 µPa; Cumulative sound exposure level (SEL$_{cum}$) dB re 1 µPa^2·s. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

The behavioural threshold for sea turtles has been established by McCauley *et al.* (2000) as in **Table 5,** and it has been adopted by NMFS and applied in the Arctic Programmatic Environment Impact Statement (PEIS) (NSF, 2011).

Table 5 The behavioural disturbance threshold level for turtles – impulsive noise events (McCauley *et al.*, 2000; NSF, 2011)

Type of animal	**Behavioural disturbance threshold levels – impulsive noise events**
	RMS SPL, dB re 1µPa
Sea turtles	166

2.4 Zones of impact

Received noise levels can be predicted using known source levels in combination with models of sound propagation transmission loss between the source and the receiver locations. Zones of impact can then be determined by comparison of the predicted received levels to the noise exposure criteria for the marine fauna species of concern.

It should be noted that the proposed noise exposure assessment criteria for impulsive noise events are all significantly higher than typical natural ambient noise levels, which have overall RMS SPLs in the range of 80 – 120 dB re 1µPa in the case of calm to strong sea state conditions, respectively. Therefore, the natural ambient noise is not given consideration in the assessment of the zones of impact.

Predicted zones of impact define the environmental footprint of the noise generating activities and indicate the locations within which the activities may have an adverse impact on marine fauna species of interest. In this report, zones of impact are defined as follows:

- For immediate impact from single pulses – the zone of impact represents the maximum horizontal distance from the sound source,
- For cumulative impact from a typical survey operation scenario – the zone of impact represents the maximum perpendicular horizontal distance from an active seismic survey line.

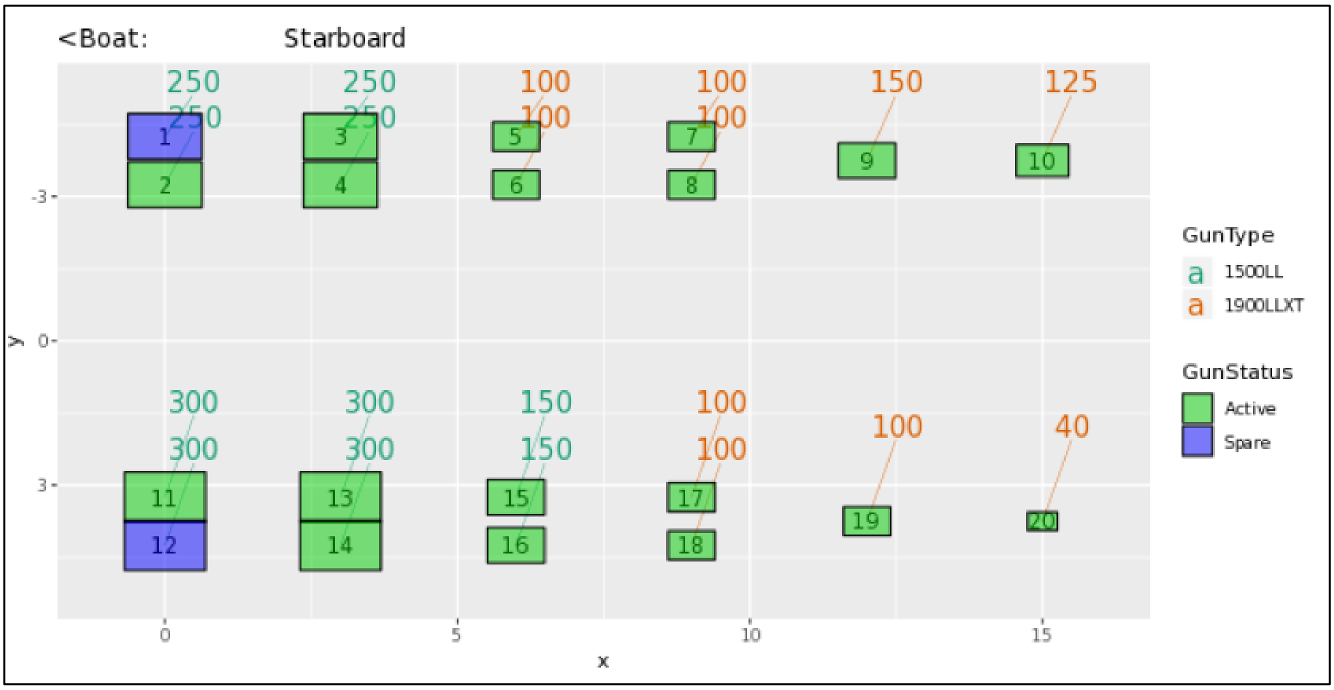
In all cases, zones of impact are conservatively determined by using the maximum predicted noise level across the water column to determine the zone of impact. Since noise levels vary with depth at any location, there will be areas in the water column within the identified zone of impact that are exposed to lower noise levels than implied by the identified zones of impact, which represent the worst case.

3 Seismic Airgun Array Source Modelling

3.1 Airgun array configuration

The airgun array for the 3D seismic survey is proposed to be the 1500LL/1900LLXT 2 965 CUI Source Array with configuration shown in Error! Reference source not found.. The array consists of 18 active airgun units, has a towing depth of 7.0 m and an operating pressure of 2 000 pounds per square inch (PSI).

Figure 4 The configuration of the 2 965 CUI 1500LL/1900LLXT Source Array (green – active, blue - spare)



3.2 Modelling methodology

The outputs of the 1500LL/1900LLXT 2 965 CUI Source Array source modelling include:

- A set of “notional” signatures for each of the array elements; and
- The far-field signature of the array source, including its directivity/beam patterns.

3.2.1 Notional signature

The notional signatures are the pressure waveforms of individual source elements at a standard reference distance of 1 m.

Notional signatures are modelled using the Gundalf Designer software package (2021). The Gundalf source model is developed based on the fundamental physics of the oscillation and radiation of source bubbles as described by Ziolkowski (1970), and for an array source case, taking into account non-linear pressure interactions between source elements (Ziolkowski *et al.*, 1982; Dragoset, 1984; Parkes *et al.*, 1984; Vaage *et al.*, 1984; Laws *et al.*, 1988 & 1990).

The model solves a complex set of differential equations combining both heat transfer and dynamics and has been calibrated against multiple measurements of both non-interacting source elements and interacting clusters for all common source types at a wide range of deployment depths.

The model has the capability to predict noise spectra with frequency range up to tens of kHz. For frequencies above 1 kHz, the modelled spectra generally follow a close to *1/f* attenuation (Landrø *et al.*, 2011). As the noise emissions from an airgun array are predominantly below hundreds of Hz, the following result section only demonstrates modelling results within frequency range below 1 kHz.

3.2.2 Far-field signatures

The notional signatures from all airguns in the array are combined using appropriate phase delays in three dimensions to obtain the far-field source signature of the array. This procedure to combine the notional signatures to generate the far-field source signature is summarised as follows:

- The distances from each individual acoustic source to nominal far-field receiving location are calculated. A 9 km receiver set is used for the current study;
- The time delays between the individual acoustic sources and the receiving locations are calculated from these distances with reference to the speed of sound in water;
- The signal at each receiver location from each individual acoustic source is calculated with the appropriate time delay. These received signals are summed to obtain the overall array far-field signature for the direction of interest; and
- The far-field signature also accounts for ocean surface reflection effects by inclusion of the “surface ghost”. An additional ghost source is added for each acoustic source element using a sea surface reflection coefficient of -1.

3.2.3 Beam patterns

The beam patterns of the acoustic source array are obtained as follows:

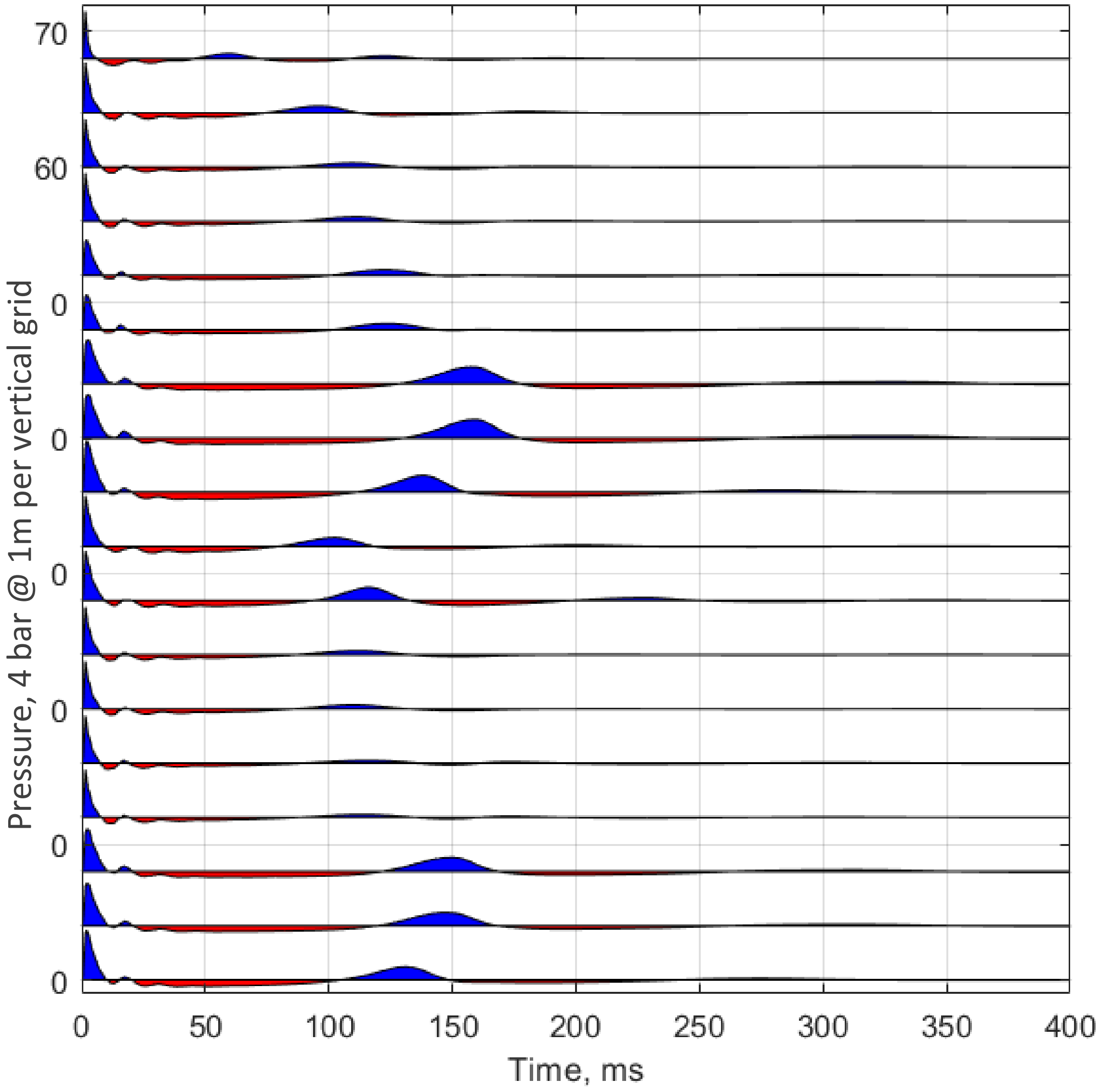
- The far-field signatures are calculated for all directions from the source using azimuthal and dip angle increments of 1-degree;
- The PSD (dB re 1 µPa^{2}s/Hz @ 1m) for each pressure signature waveform is calculated using a Fourier transform technique; and
- The PSDs of all resulting signature waveforms are combined to form the frequency-dependent beam pattern for the array.

3.3 Modelling results

3.3.1 Notional signatures

Figure 5 shows the notional source signatures for the 30 active airgun array elements. Each line within the figure represents the notional source signature of the corresponding array element as shown in Error! Reference source not found..

Figure 5 Notional source signatures for the 1500LL/1900LLXT 2 965 CUI Source Array

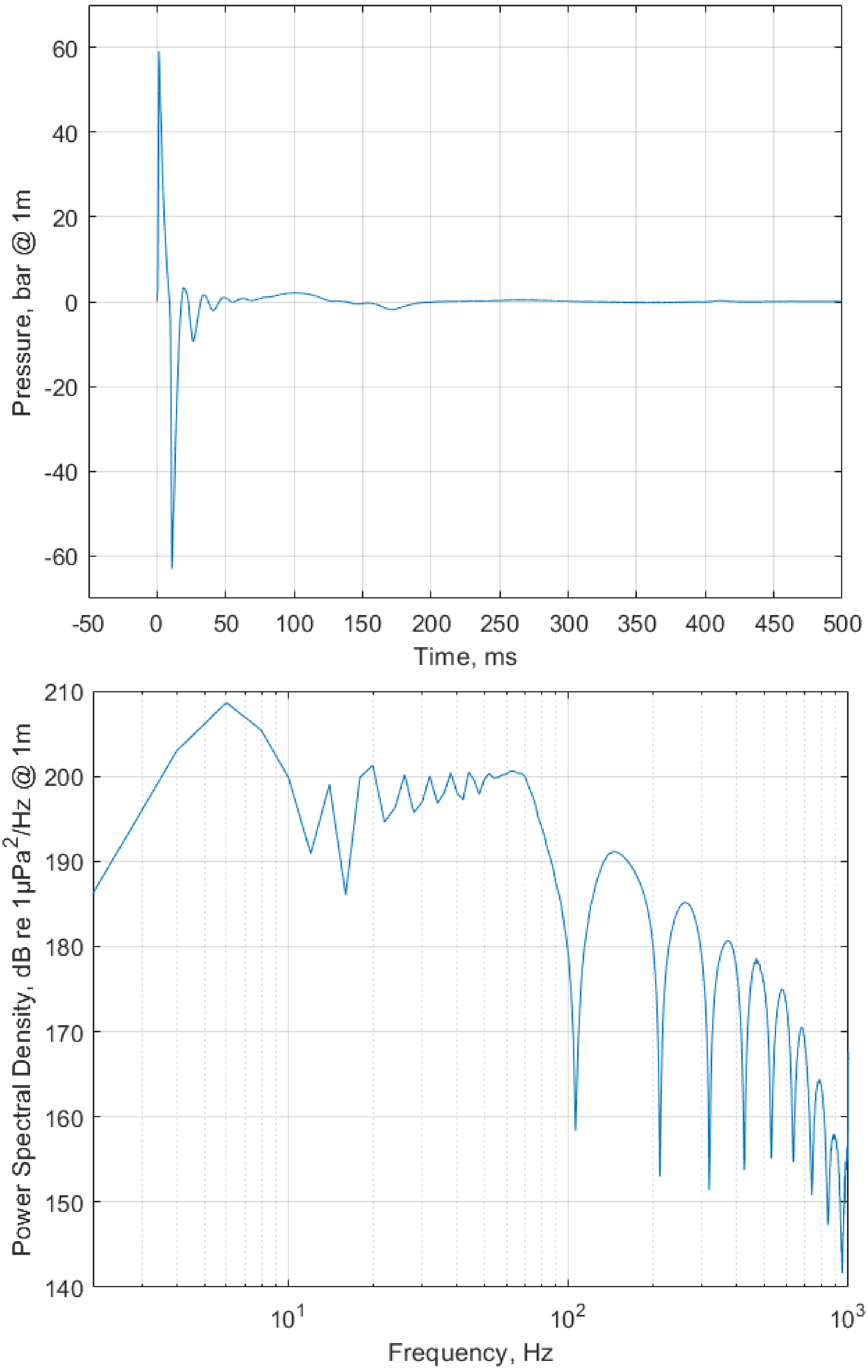


3.3.2 Far-field signature and its power spectral density

Error! Reference source not found. shows the far-field signature waveform and its power spectral density simulated by the Gundalf Designer software. The signatures are for the vertically downward direction with surface ghost included.

The source modelling result shows that the peak sound pressure level (Pk SPL) is 256.0 dB re 1 µPa @ 1m, the root-mean-square sound pressure level (RMS SPL) 250.3 dB re 1 µPa @ 1m with a 90%-energy pulse duration of 12.5 milliseconds, and the sound exposure level (SEL) 232.5 dB re µPa^2·s @ 1m.

Figure 6 **The far-field signature in vertically downward direction (top) and its power spectral density (bottom) for the 1500LL/1900LLXT 2 965 CUI Source Array**



3.3.3 Beam patterns

Array far-field beam patterns of the following three cross sections are presented in Error! Reference source not found.:

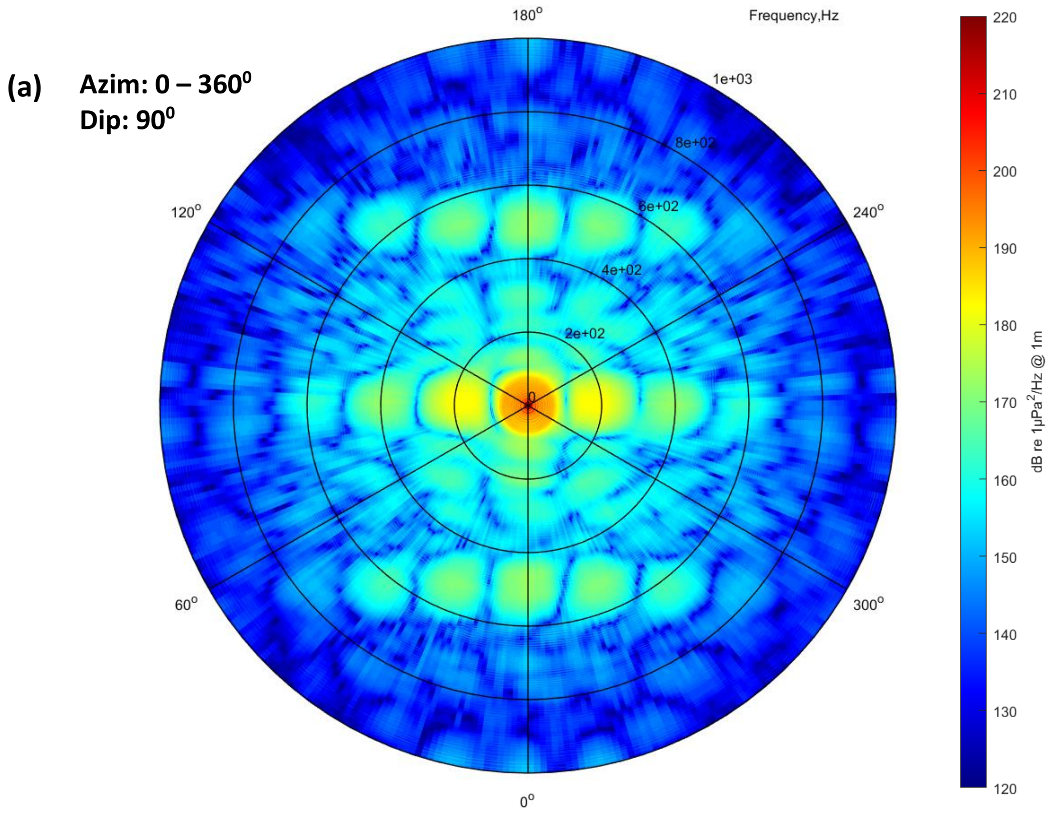
a) The horizontal plane (i.e. dip angle of 90 degrees) with azimuthal angle of 0 degree corresponding to the in-line direction;

b) The vertical plane for the in-line direction (i.e. azimuthal angle of 0 degree) with dip angle of 0 degree corresponding to the vertically downward direction; and

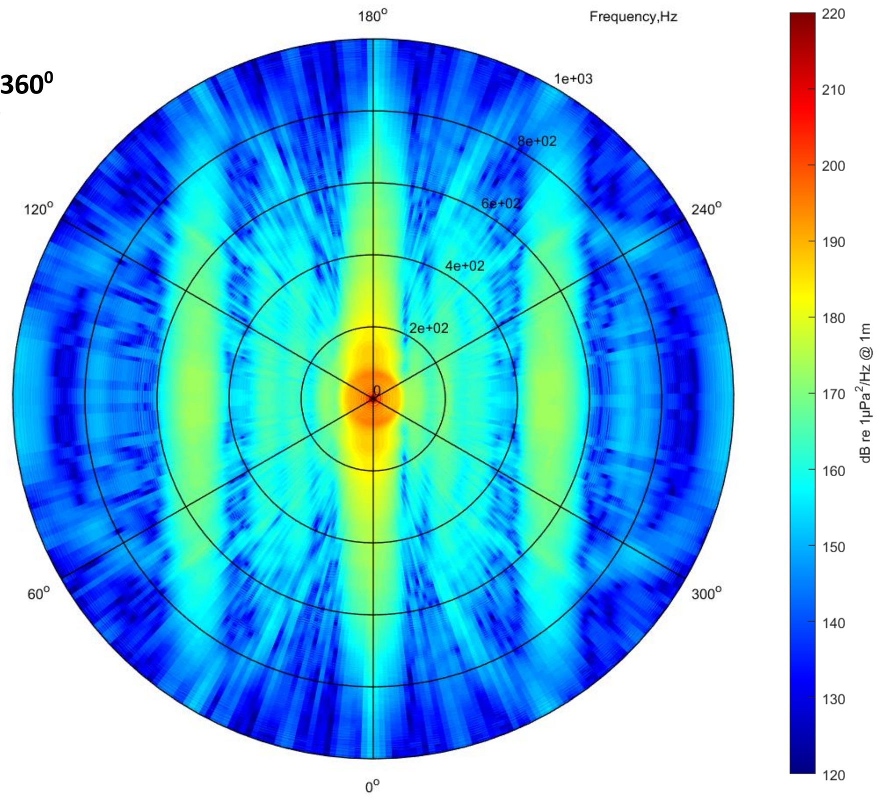
c) The vertical plane for the cross-line direction (i.e. azimuthal angle of 90 degrees) with dip angle of 0 degree corresponding to the vertically downward direction.

The beam patterns in Error! Reference source not found. illustrate strong angle and frequency dependence of the energy radiation from the array. The beam pattern of the horizontal plane shows relatively stronger energy radiation in the cross-line direction than in the in-line direction. The beam patterns of the in-line and cross-line vertical planes have the strongest radiation in the vertical direction.

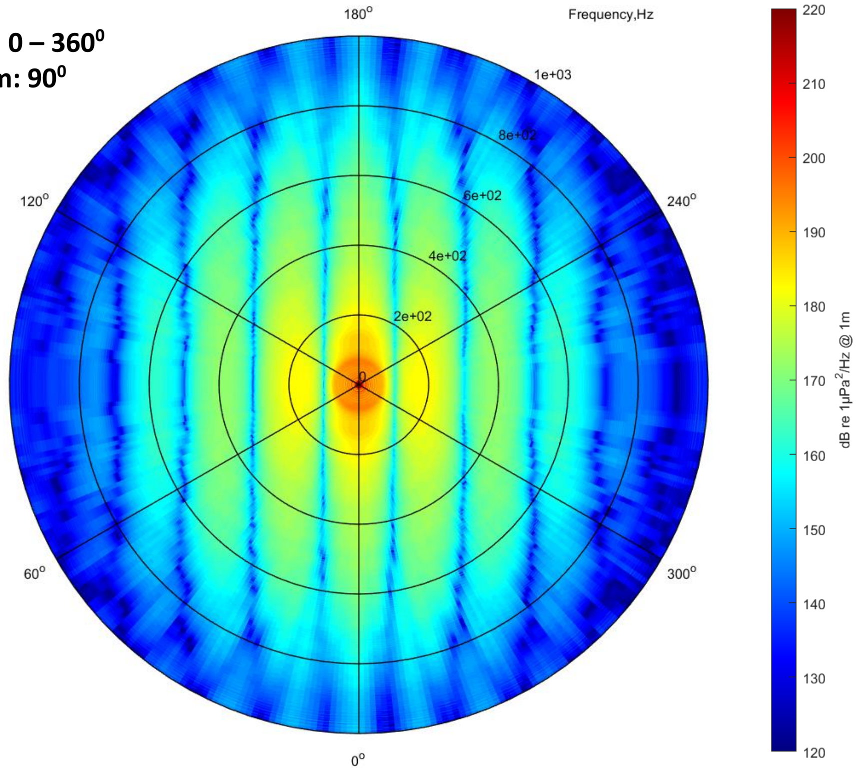
Figure 7 Array far-field beam patterns for the 1500LL/1900LLXT 2 965 CUI Source Array, as a function of orientation and frequency. (a) - The horizontal plane with 0 degree corresponding to the in-line direction; (b) – The vertical plane for the in-line direction; (c) – The vertical plane for the cross-line direction. 0 degree dip angle corresponds to vertically downward direction.



(b) **Dip: 0 – 360^0**
Azim: 0^0



(c) **Dip: 0 – 360^0**
Azim: 90^0



4 TRANSMISSION LOSS MODELLING

4.1 Modelling input parameters

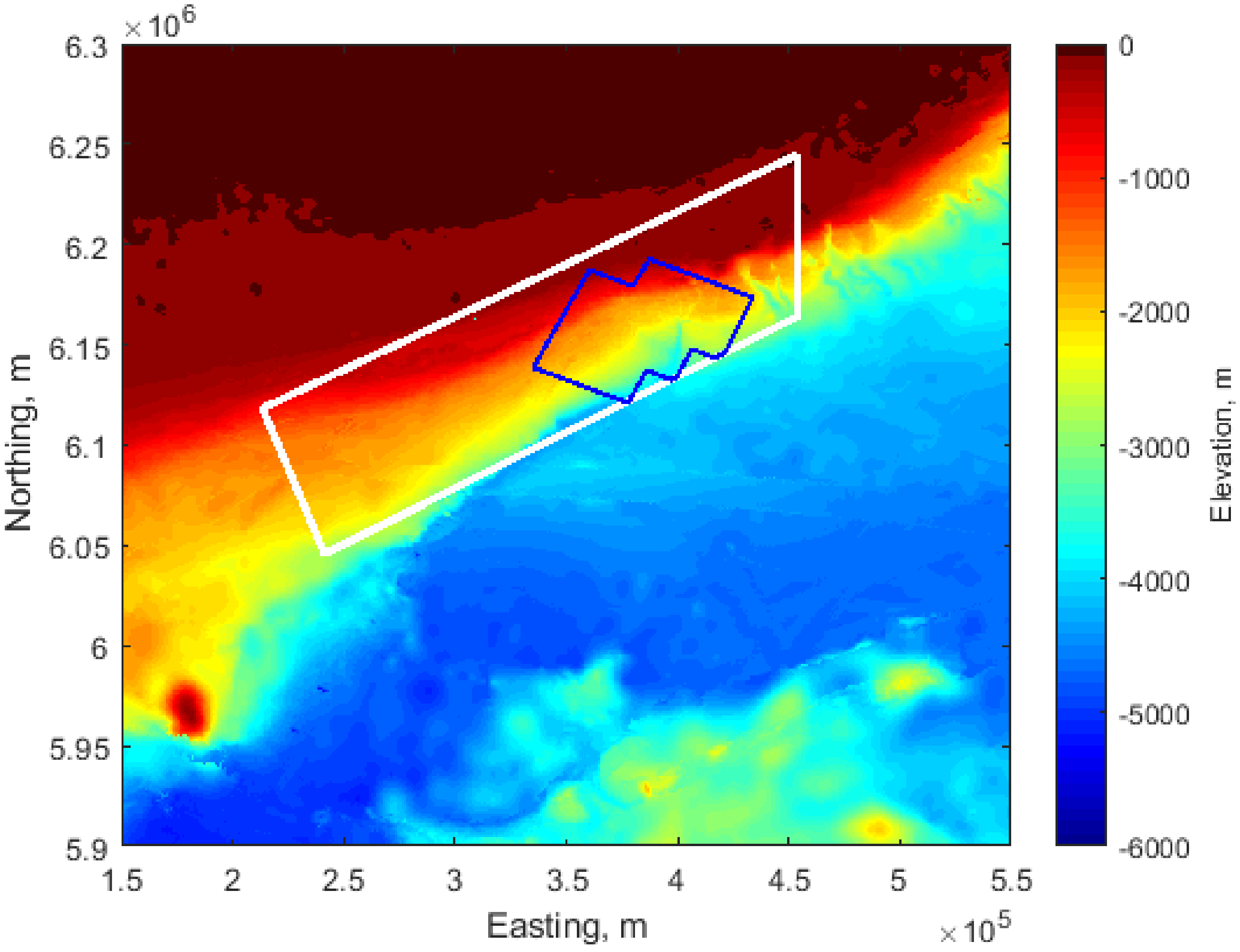
4.1.1 Bathymetry

The bathymetry data used for the sound propagation modelling was obtained from the 15 arc seconds bathymetric dataset GEBCO_2020 Grid (GEBCO, 2020). The GEBCO_2020 Grid is the latest global bathymetric product released by the General Bathymetric Chart of the Oceans (GEBCO) and has been developed through the Nippon Foundation-GEBCO 'Seabed 2030 Project' (https://seabed2030.gebco.net/), which is a collaborative project between the Nippon Foundation of Japan and GEBCO.

The ocean currents within the survey area are not expected to have significant effects on sound propagation, due to limited current heights compared with overall water depths and low current speed compared with sound speed within typical sea water.

The bathymetric imagery within and surrounding the permit area and proposed survey area are presented in **Figure 8**.

Figure 8 The bathymetric imagery within and surrounding the permit area. The coordinate system is based on WGS 84/UTM Zone 35S.



4.1.2 Sound speed profiles

Temperature and salinity data required to derive the sound speed profiles were obtained from the World Ocean Atlas 2009 (WOA09) (Locarnini *et al.*, 2010; Antonov *et al.*, 2010). The hydrostatic pressure needed for calculation of the sound speed based on depth and latitude of each particular sample was obtained using Sanders and Fofonoff's formula (Sanders and Fofonoff, 1976). The sound speed profiles were derived based on Del Grosso's equation (Del Grosso, 1974).

Figure 9 presents typical sound speed profiles for four seasons within the survey area. The figure demonstrates that the most significant distinctions for the profiles of four seasons occur within the mixed layer near the surface. The summer season has the strongest downwardly refracting feature among the four seasons, and the winter season exhibits a deeper surface duct than the other three seasons. Due to the stronger surface duct within the profile, it is expected that the winter season will favour the propagation of sound from a near surface acoustic array source.

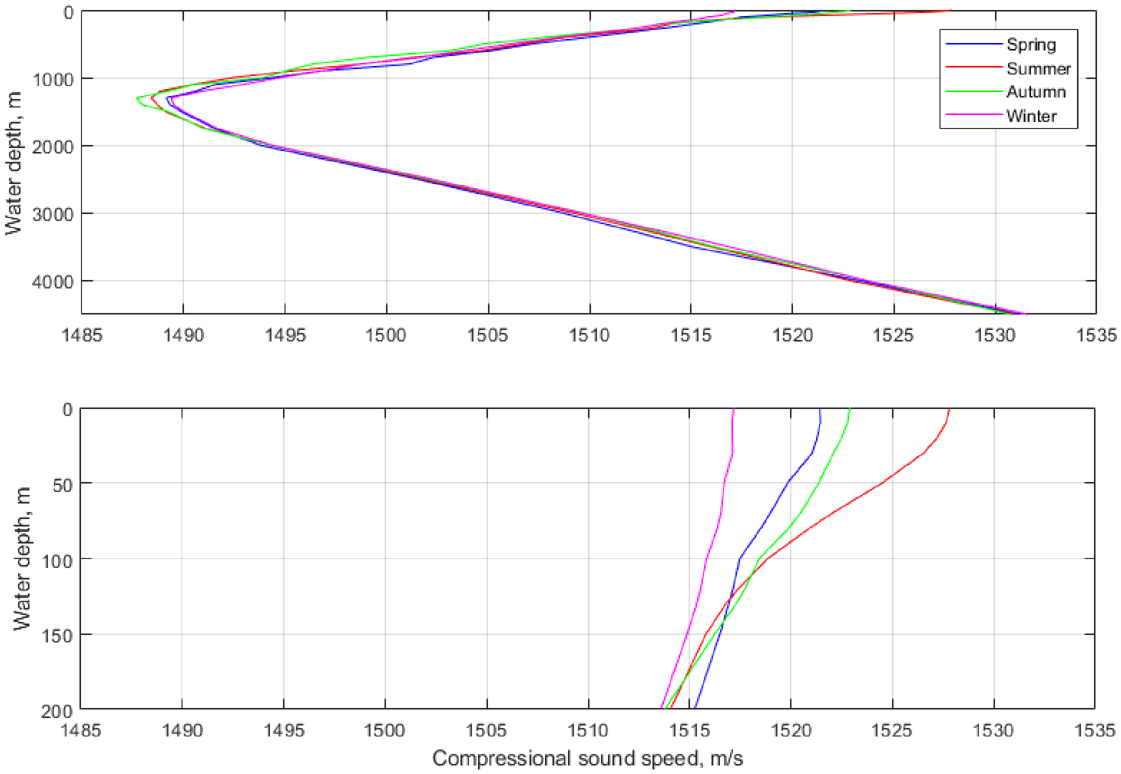


Figure 9 Typical sound speed profiles within the survey area for different seasons. The top panel shows profiles across the entire deep-water column, and the bottom panel shows profiles across the water column section near the surface.

4.1.3 Seafloor geoacoustic model

To inform the 2018 national marine ecosystem classification and mapping efforts, Sink et al, (2019) collated sediment data from numerous samples acquired by grab or core under 13 different projects to produce a national layer of sediment types. The data sample classification reveals that the seafloor of the South African shelf is primarily composed of sand with a noticeable proportion of mud.

Relevant literature also shows that from continental shelf to deep sea basin, the sediment spatial distribution has general transition from sand/mud to deep sea ooze sediment, as a result of the regional oceanography and terrigenous sediment supply, as well as the deep sea sedimentary processes (Dingle et al, 1987; Dutkiewicz et al, 2015).

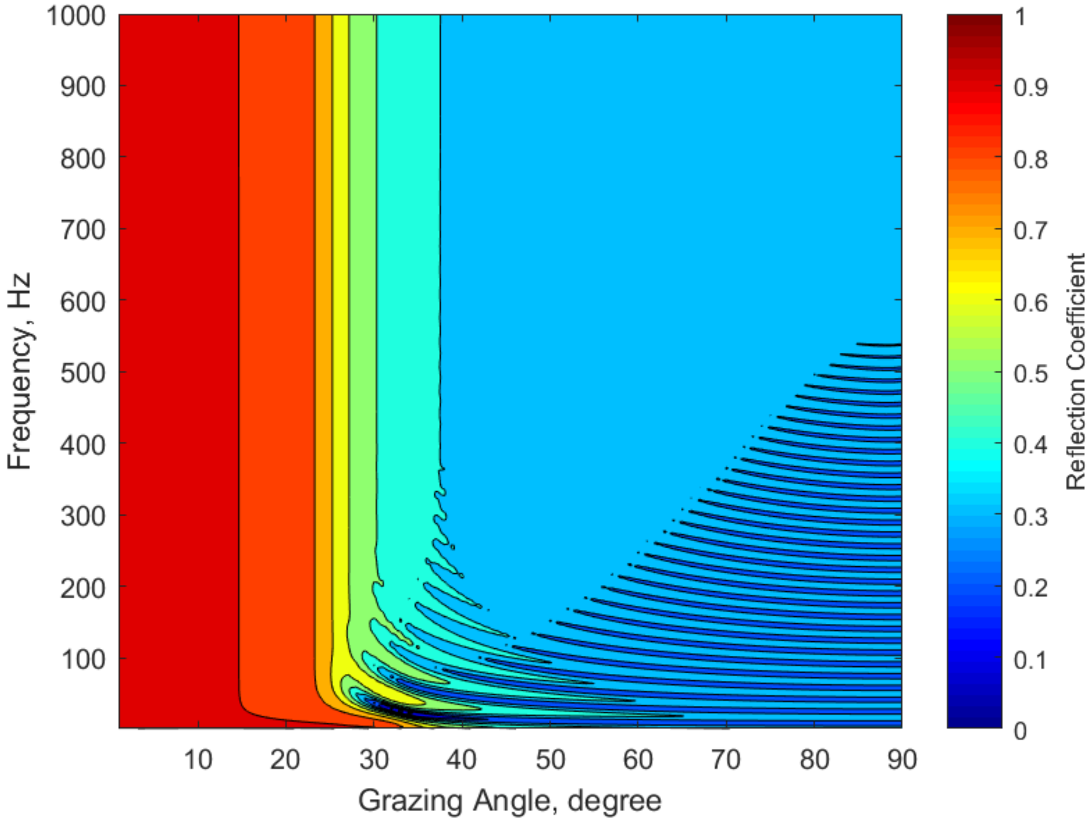
Based on above as well as a conservative consideration, it is proposed that for the entire modelling area, the seafloor geoacoustic model comprises of a 50-m fine and silty sand sediment layer, followed by a sandy half space/substrate as detailed in Error! Reference source not found.. The geoacoustic properties for sandy sediments are as described in Hamilton (1980), with attenuations referred to Jensen et al (2011). The elastic properties of sands are treated as negligible.

Table 6 Geoacoustic parameters for the proposed seafloor model

Seafloor Materials	Thickness, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, c_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Silty sand	50	1700	1650	0.8
Sand half-space	∞	1900	1800	1.0

Figure 10 below shows the reflection coefficient variation with grazing angle and frequency for the proposed seafloor geoacoustic model, calculated using the plane-wave reflection coefficient program Bounce (Porter, 2007). As shown in the figure, the seafloor acoustic reflection is dominated by the top sediment layer across the frequency range, with high reflection at low grazing angles and low reflection (high refraction) at higher grazing angles.

Figure 10 Reflection coefficient vs grazing angle and frequency for the proposed geoacoustic model



4.2 Detailed modelling methodologies and procedures

The sub-sections below describe the modelling methodologies and procedures for predicting received noise levels of relevant metrics associated with seismic survey activities.

The modelling components as detailed in **Section 4.2.1** to **Section 4.2.5** involve SELs and noise levels in relevant acoustic metrics (i.e. Peak SPLs and RMS SPLs) for single shots from the 1500LL/1900LLXT 2 965 CUI Source Array, as well as for the cumulative SELs within a 24-hour period for representative survey scenarios.

4.2.1 Short range modelling

4.2.1.1 Modelling methodology and procedure

Short range modelling has been used to model received SELs in relatively close proximity to the airgun source, with consideration of the near-field effect of the sound field. As such, the predictions for the short range case are modelled by reconstructing the received signal waveforms from individual airgun source units within the array.

The wavenumber integration modelling algorithm SCOOTER (Porter, 2020) is used to calculate the transfer functions (both amplitudes and phases) between sources and receivers. SCOOTER is a finite element code for computing acoustic fields in range-independent environments. The method is based on direct computation of the spectral integral and is capable of dealing with an arbitrary layered seabed with both fluid and elastic characteristics.

The following procedures have been followed to calculate received SELs for short range cases:

1. The modelling algorithm SCOOTER is executed for frequencies from 1 Hz to 1 kHz, in 1 Hz increments. The source depth is taken to be the array depth of 7.0 m. A receiver grid of 1 m in range (maximum range 4.0 km) and 1 m in depth is applied for the selected receivers. For each gridded receiver, the received SEL is calculated by following steps 2) – 5);
2. The range from the source to each receiver is calculated, and the transfer function between the source and the receiver is obtained by interpolation of the results produced by modelling algorithm SCOOTER in Step 1). This interpolation involves both amplitude and phase of the signal waveform in frequency domain;
3. The complex frequency domain signal of the notional signature waveform for each source element is calculated via Fourier Transform, and multiplied by the corresponding transfer function from Step 2) to obtain the frequency domain representation of the received signal from the source element;
4. The waveform of received signal from the array source is reconstructed via Inverse Fourier Transform. The received signal waveforms from all airgun sources in the array are summed to obtain the overall received signal waveform; and
5. The signal waveform is squared and integrated over time to obtain the received SEL value. Alternatively, the SEL value can also be calculated via integration of the energy power density (ESD) over frequency in Step 3).

4.2.1.2 Modelling scenarios

The modelling inputs for the short range modelling case, such as sound speed profile and seabed geoacoustic models, has been detailed in **Section 4.1**. To analyse the received SEL variations with water depth changes, modelling has been undertaken for six water column input cases covering the large depth range over the entire permit area (i.e. 100 m, 400 m, 1 000 m, 1 800 m, 3 000 m and 4 500 m).

4.2.2 Long range modelling

4.2.2.1 Modelling methodology and procedure

The long range modelling generally involves complex and variable environmental factors (such as sound speed profiles and bathymetric variations) along an extended range of sound propagation environments, and requires an efficient modelling prediction algorithm with reasonable accuracy. Therefore, the modelling prediction for the long range case is carried out using the far-field source levels of octave frequency bands and their corresponding transmission loss calculations.

The fluid parabolic equation (PE) modelling algorithm RAMGeo (Collins, 1993) is used to calculate the transmission loss between the source and the receiver. RAMGeo is an efficient and reliable PE algorithm for solving range-dependent acoustic problems with fluid seabed geo-acoustic properties.

The received sound exposure levels are calculated following the procedure as below:

1) One-third octave source levels for each azimuth to be considered are obtained by integrating the horizontal plane source spectrum over each frequency band, these levels are then corrected to SELs;

2) Transmission loss is calculated using RAMGeo at one-third octave band central frequencies from 8 Hz to 1 kHz, with a maximum range of 200 km and at 5-degree azimuth increments. The bathymetry variation along each modelling track is obtained via interpolation from the bathymetry dataset;

3) The one-third octave source SEL levels and transmission loss are combined to obtain the received SEL levels as a function of range, depth and frequency;

4) The overall received SEL levels are calculated by summing all frequency band SEL levels.

4.2.2.2 Modelling scenarios

Two long range modelling source locations are proposed for the 1500LL/1900LLXT 2 965 CUI Source Array, as detailed as in

Table 7 and shown in

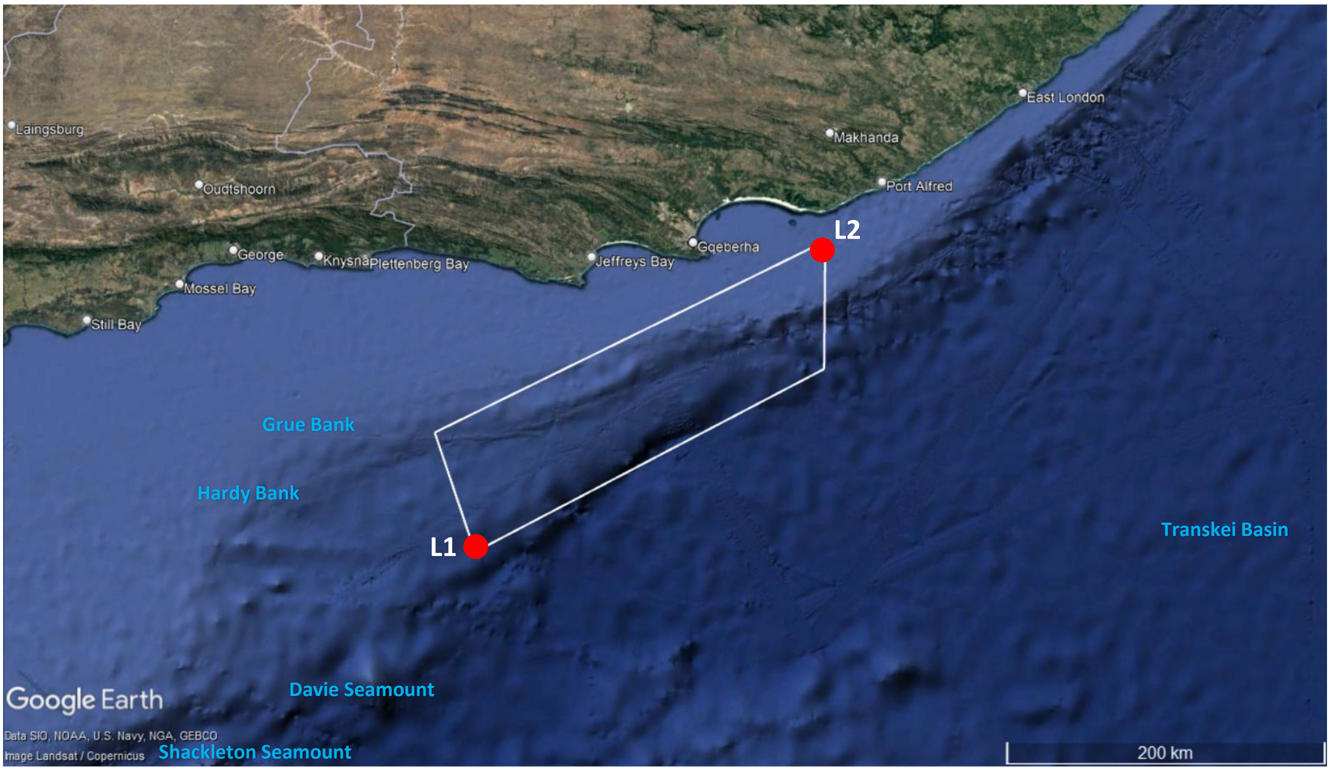
Source Location	Water Depth, m	Coordinates, m [Easting, Northing]	Locality
L1	~2780	[2.413364 x10^5, 6.045892 x10^6]	Southwest boundary of the reconnaissance permit application area, on continental shelf for deep water assessment
L2	~110	[4.537925 x10^5, 6.244712 x10^6]	Shallowest point, approximately 80 km east of Port Elizabeth

Figure 11. The in-line survey directions for the two cases are assumed as a N112.5°/N292.5° direction.

Table 7 Details of the two selected single source locations for the long range modelling

Source Location	Water Depth, m	Coordinates, m [Easting, Northing]	Locality
L1	~2780	[2.413364 x10^5, 6.045892 x10^6]	Southwest boundary of the reconnaissance permit application area, on continental shelf for deep water assessment
L2	~110	[4.537925 x10^5, 6.244712 x10^6]	Shallowest point, approximately 80 km east of Port Elizabeth

Figure 11 The selected two long range modelling source locations (L1 & L2) indicated as red dots. Permit area in white.



4.2.3 Cumulative SEL modelling

4.2.3.1 Modelling methodology and procedure

The cumulative SEL accounts for the total acoustic energy received from all seismic impulses within a specific period of exposure (i.e. 24 hours). There will be thousands of survey shots during a typical survey operation within a 24-hour period, and it is not practical to perform sound modelling for every survey shot in an efficient manner. However, the propagation environments for a set of consecutive survey shots are similar, and therefore one propagation model could be performed as representative for the set group. The sound field for the representative survey shot then could be adjusted to represent the rest of the survey shots within the set group accounting for their source positions.

The cumulative SELs (frequency unweighted and weighted) are modelled based on the steps as below:

1. The received SELs at individual grid locations (a 100-m grid size for this study) from individual representative survey shot considered (one in every ten shots for this study) is modelled based on the long range modelling methodology and procedure as detailed in Section **4.2.2.1**, and then the results are adjusted for the rest of survey shots based on their shot locations;
2. The SEL_{24hr} at individual receiving grid locations are obtained by summing SEL contribution from all survey shots within a 24-hour period for the survey operation scenario considered;
3. For weighted SEL_{24hr} for individual marine mammal hearing groups, the source spectra are adjusted accounting for the frequency weighting functions for individual hearing groups (as in **Table 1**), and the weighted SEL_{24} for individual hearing groups to be obtained by repeating the first two steps as above;
4. For high frequency energy component which is important for marine mammals with high frequency hearing range, the source spectra and propagation modelling are extended up to 10 kHz, with the source spectra being close to $1/f$ attenuation for frequencies above 1 kHz (Landrø *et al.*, 2011), so that the high frequency energy component to be included for the weighted SEL_{24} predictions.

It should be noted that the source level inputs for long range modelling as detailed in Section **4.2.2.1** are based on the array source noise emissions in the horizontal plane, and this approach may underestimate the actual sound field close to the array source (< 4 km). As such, the sound fields close to the array source predicted by the long-range modelling as described in Step (1) above are benchmarked against short range modelling results to account for the near-field effects.

4.2.3.2 Modelling scenarios

Based on relevant project information provided, the following survey schedule is assumed:

- Survey shot spacing of approximately 18.75 m with the vessel speed of approximately 4.0 knots during acquisition;
- N112.5°/N292.5° survey orientation/in-line direction, with two survey lines of up to 70 km each to be acquired within 24 hours for each scenario.

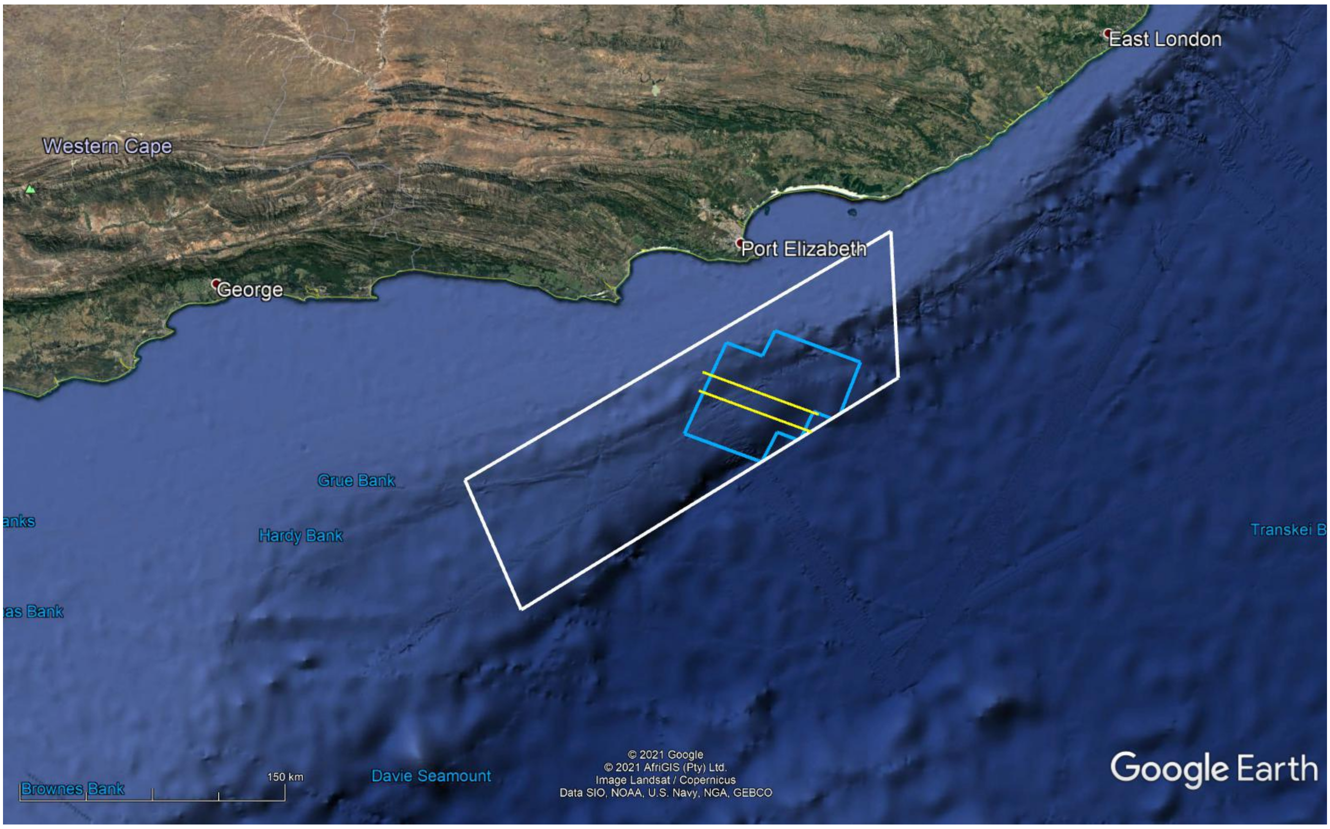
The survey line details for the modelling scenario are detailed in **Table 8** and indicated in **Figure 12**.

Table 8 Details of the selected survey lines for the cumulative SEL modelling

Survey Scenario	Survey Lines	Southern point coordinates, m [Easting, Northing]	Length, km	Locality
S1	1	[4.09415 x 10^5, 6.145899x 10^6]	70	

Survey Scenario	Survey Lines	Southern point coordinates, m [Easting, Northing]	Length, km	Locality
	2	[4.05479 x 10^5, 6.136416 x 10^6]	70	Centre of the 3D survey area and close to the Marine Protected Area

Figure 12 The selected survey lines (yellow) representing a 24-hour survey scenario considered



4.2.4 Pk SPLs and RMS SPLs – estimate methodology from modelled SELs

For received individual signals emitted from impulsive sources such as seismic airguns, the differences between the SEL and other sound parameters, such as the Pk SPL/RMS SPL, are expected to be greatest at the source location, and then gradually decrease with receiving locations further away from the source location. This is due to the following effects:

- Theoretically, the airgun pulse goes through increasing waveguide distortion effects (e.g. dispersion, interference effects, seafloor and surface reflections, differences of time arrivals, etc.) with increasing range from the source, which impact predominantly on temporal characteristics of the pulse (e.g. lower peak level, extended pulse duration, etc.) rather than the energy based metric levels.
- The above statement is reliably supported by numerous theoretical and empirical research studies, e.g. the relevant seismic survey signal modelling and measurement studies (e.g. Austin *et al.*, 2013, Matthews and MacGillivray, 2013, Galindo-Romero *et al.*, 2015, McCauley *et al.*, 2000 & 2016) show that the differences between the three temporal parameters (i.e. Pk SPL, and RMS SPL) and SEL are increasingly higher at the receiver closer to the source location.

SEL vs Pk SPL

As presented in **Section 3.3.2**, the difference between the Pk SPL and SEL of the far-field signature of the 2 965 CUI Source Array (at a reference distance of 1 m from the centre of the array) is 22.2 dB. This value is taken as the conversion factor applied to the SELs for calculating the received Pk SPLs over the receiving range close to the source location. This approach is regarded as conservative for estimating relevant near-field acoustic parameters based on SEL predictions.

SEL vs RMS SPL

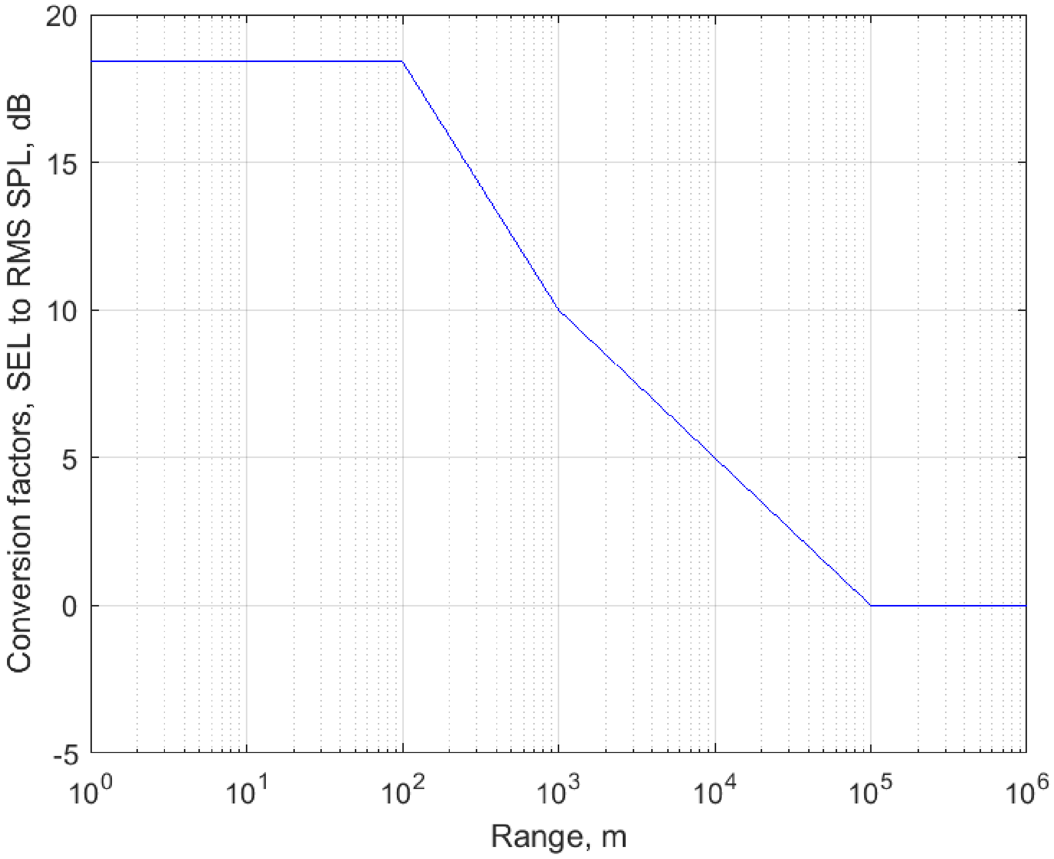
Previous empirical studies demonstrate that at relatively close distances from the airgun sources (within 1.0 km), the difference between SELs and RMS SPLs could be between 10 dB to 15 dB (Austin *et al.*, 2013, McCauley *et al.*, 2000,). The differences could drop to under 5 dB when the distances are close to 10 km (Austin *et al.*, 2013). The differences are expected to drop further with the increasing distances beyond 10 km (Simon *et al.*, 2018).

For this project, the RMS SPLs were estimated using the following conversion factors to be applied to the modelled SELs within different distance ranges. These conversion factors are conservatively estimated based on the source array modelling results and above previous measurement results:

- 0 – 100 m, a conversion factor of 17.8 dB. This is the difference between RMS SPL and SEL of the far-field signature of the 1500LL/1900LLXT 2 965 CUI Source Array as modelled in **Section 3.3.2**.
- 100 – 1 000 m, conversion factors 17.8 dB to 10.0 dB, following a logarithmic trend with distance;
- 1 000 – 10 000 m, conversion factors 10.0 dB to 5.0 dB, following a logarithmic trend with distance;
- 10 000 – 100 000 m, conversion factors 5.0 dB to 0.0 dB, following a logarithmic trend with distance;
- > 100 000 m, a conversion factor of 0.0 dB.

The SEL to RMS SPL conversion factors as a function of horizontal ranges from source array are demonstrated in **Figure 13** as below.

Figure 13 SEL to RMS SPL conversion factors as a function of horizontal range from source array



4.2.5 Model validation – airgun seismic survey noise modelling

The accuracy of airgun array sound field modelling depends on the suitability and accuracy of the airgun array source model and the transmission loss model, as well as the realism of the parameters defining the sound propagation environment, including the bathymetry, seafloor geo-acoustics and sound speed profiles (DOC, 2016).

The following model validation exercises have been undertaken previously in regards to the airgun array source model, short range and long range model approaches that have been used in this modelling study:

- The source modelling software Gundalf has been calibrated against various datasets of near-field recorded signatures, and has been verified against other airgun array source signature models (Ainslie *et al.*, 2016);
- The short range and long range modelling approaches have been validated from a few underwater acoustic measurement programs undertaken by independent third parties, with good agreements between modelled and measured results being reported (e.g. Simon *et al.* (2018) and Li *et al.* (2021)).

5 MODELLING RESULTS

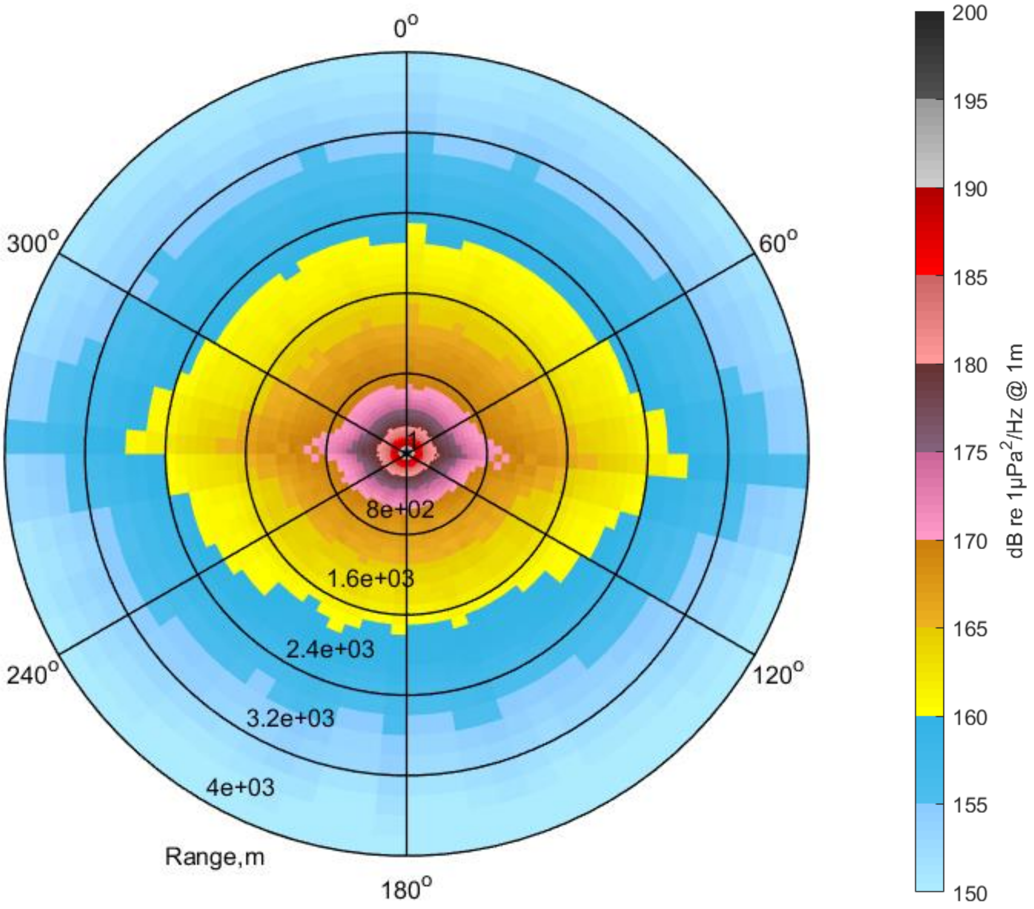
This section presents the modelling results for seismic surveys which include three STLM components (, i.e. short range modelling, long range modelling and cumulative noise exposure modelling).

5.1 Short range modelling

The received SELs from the 1500LL/1900LLXT 2 965 CUI Source Array have been modelled for six water depth cases. The water depths modelled are 100 m, 400 m, 1 000 m, 1 800 m, 3 000 m and 4 500 m.

Taking the 100 m water depth case as an example, **Figure 14** shows the maximum received SELs across the water column for a single survey shot as a function of azimuth (0 – 360°) and near-field horizontal range (0 – 4 km) from the centre of the array. The figure illustrates slightly higher SEL levels in both the in-line direction and the highest SEL levels in the cross-line directions as a result of the directionality of the source array.

Figure 14 The predicted maximum SELs across the water column as a function of azimuth and horizontal range from the centre of the array. 0 degree azimuth corresponds to the in-line direction. The modelling scenario is for the 1500LL/1900LLXT 2 965 CUI Source Array at the survey location with a water depth of 100 m

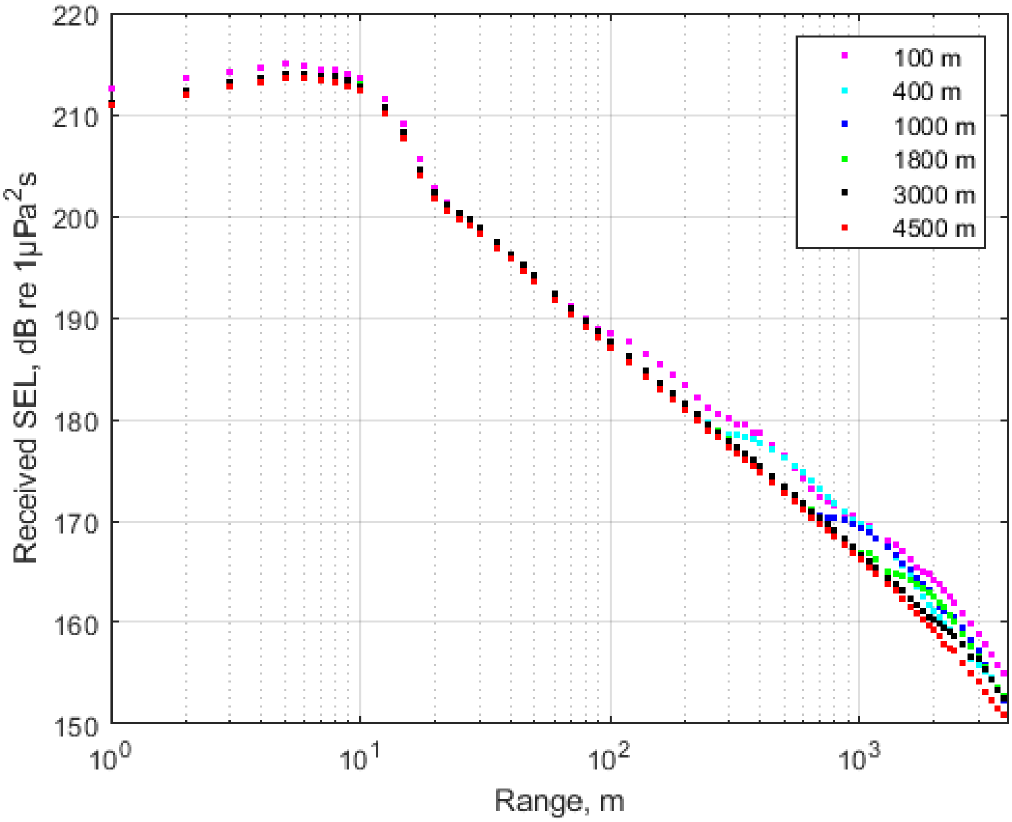


The scatter plot of the predicted maximum SELs across the water column for all azimuths as a function of horizontal range (0 – 4 km) from the source array is displayed in **Figure 15** for all six water depth cases.

It is noted from the figure:

- At horizontal distances close to the array centre (< 100 m), the maximum received SELs are up to 2dB higher for the 100 m water depth case.
- At horizontal distances further away from the array centre (> 100 m), the maximum received SELs are predicted to be up to 5 dB higher for the 100 m water depth. This is because the sound field of a shallower water depth has the highest acoustic energy reflected from the seabed among the water depth cases. With the water depth increases, the acoustic energy reflected from the seabed is becoming weaker and the maximum received SELs across the water column is again increasingly dominated by the direct arrival of acoustic energy from the array source.

Figure 15 The predicted maximum SELs across the water column for all azimuths as a function of range (0 – 4 km) from the source locations with water depths of 100 m, 400 m, 1 000 m, 1 800 m, 3 000m, and 4500 m)



5.2 Long range modelling

Figure 16 shows the contour images of the predicted maximum SELs received at locations up to 200 km from the two long range source locations L1 and L2 respectively, overlaying the local bathymetry contours. **Figure 17** and **Figure 18** show the noise propagation for L1 and L2 respectively to the west, east, north and south of the modelled location.

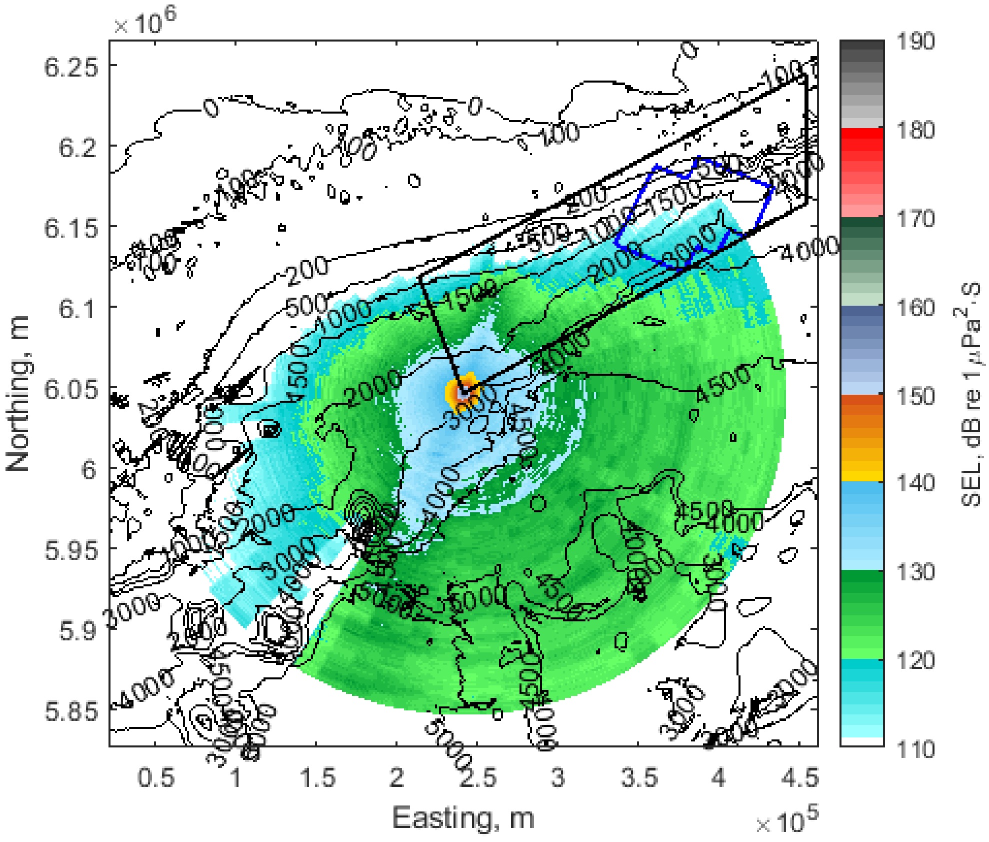
As can be seen from the contour figures, the received noise levels at far-field locations vary at different angles and distances from the source locations. This directionality of received levels is due to a combination of the directivity of the source array, and propagation effects caused by bathymetry and sound speed profile variations.

For the source location L1 which is located within the deep water region, the sound fields are predicted to experience strong attenuation when propagating along upslope sections towards the continental shelf directions as illustrated in **Figure 17**, as a result of the strong intersection between the sound signal and seabed. The sound fields have much less attenuation propagating in parallel with the shorelines as well as towards the deep water regions offshore.

For the source location L2 which is located within the nearshore shallow water region, the sound fields are predicted to experience much stronger acoustic attenuation compared with the deep water environment, as shown in **Figure 18**, which is due to stronger interaction between the sound signal and seabed within a shallow water environment.

Figure 16 **Modelled maximum SEL (maximum level across water column) contours for source location a) L1 and b) L2 to a maximum range of 200 km, overlayed with bathymetry contour lines. Coordinates in WGS 84/UTM Zone 35S.**

a)



b)

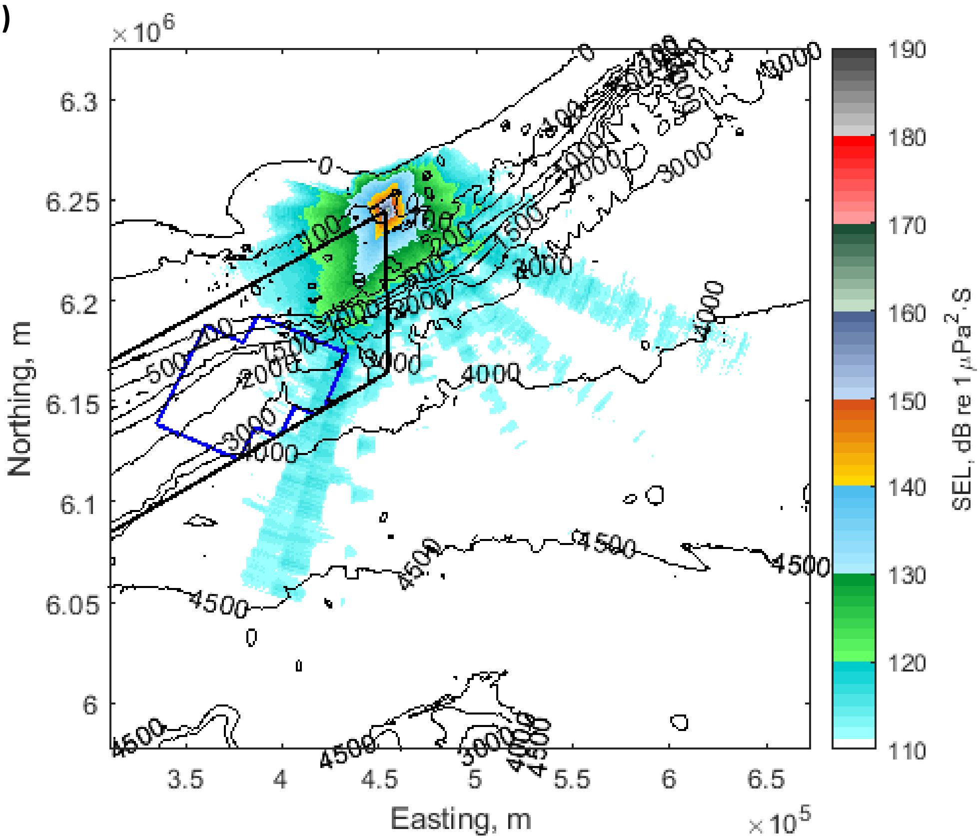

× 10^6
6.3
6.25
6.2
6.15
6.1
6.05
6
Northing, m
3.5
4
4.5
5
5.5
6
6.5
Easting, m
× 10^5
190
180
170
160
150
140
130
120
110
SEL, dB re 1 μPa²·S
0
500
1500
2000
3000
4000
4500

Figure 17 Modelled SELs vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L1. Black line shows the seabed depth.

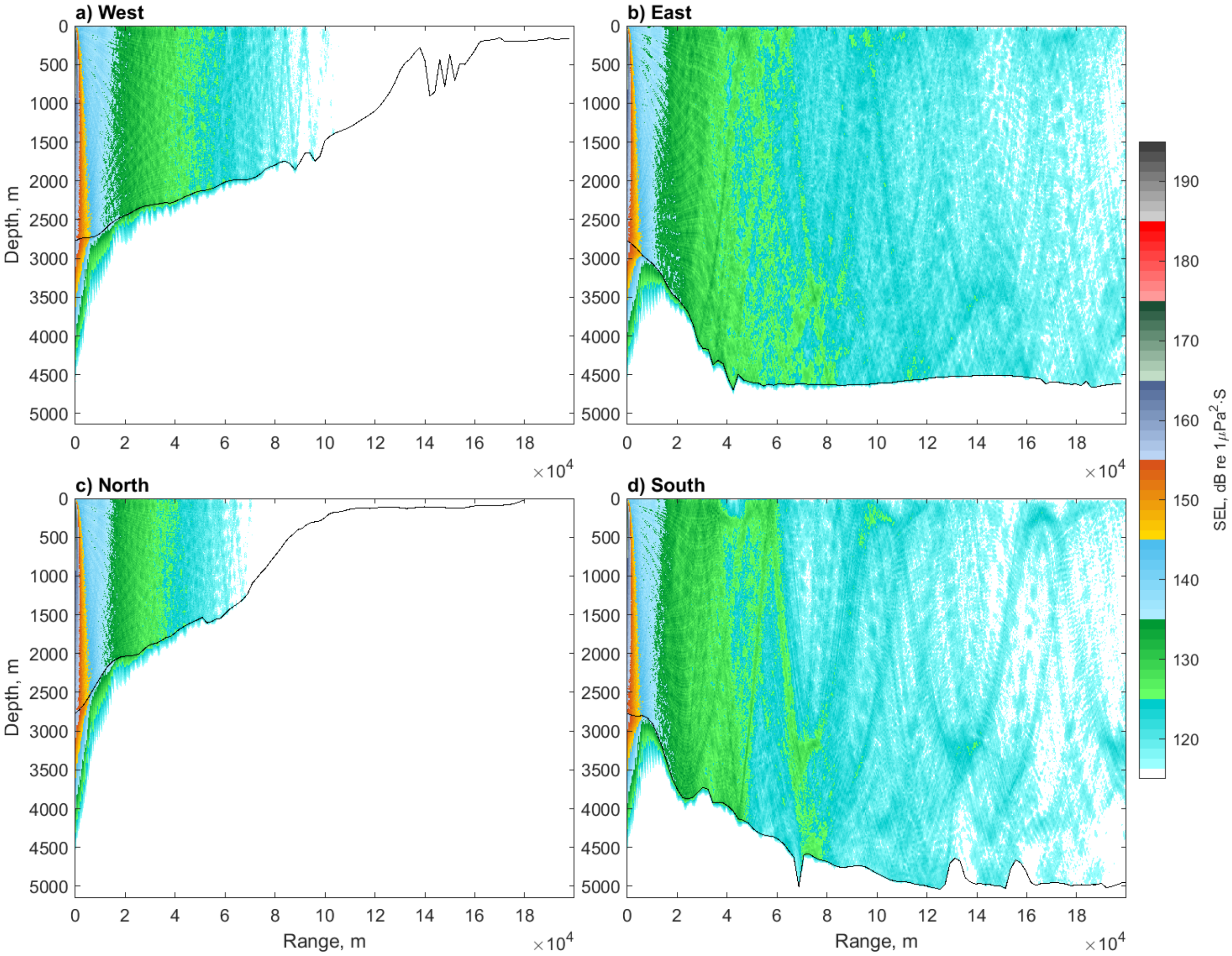
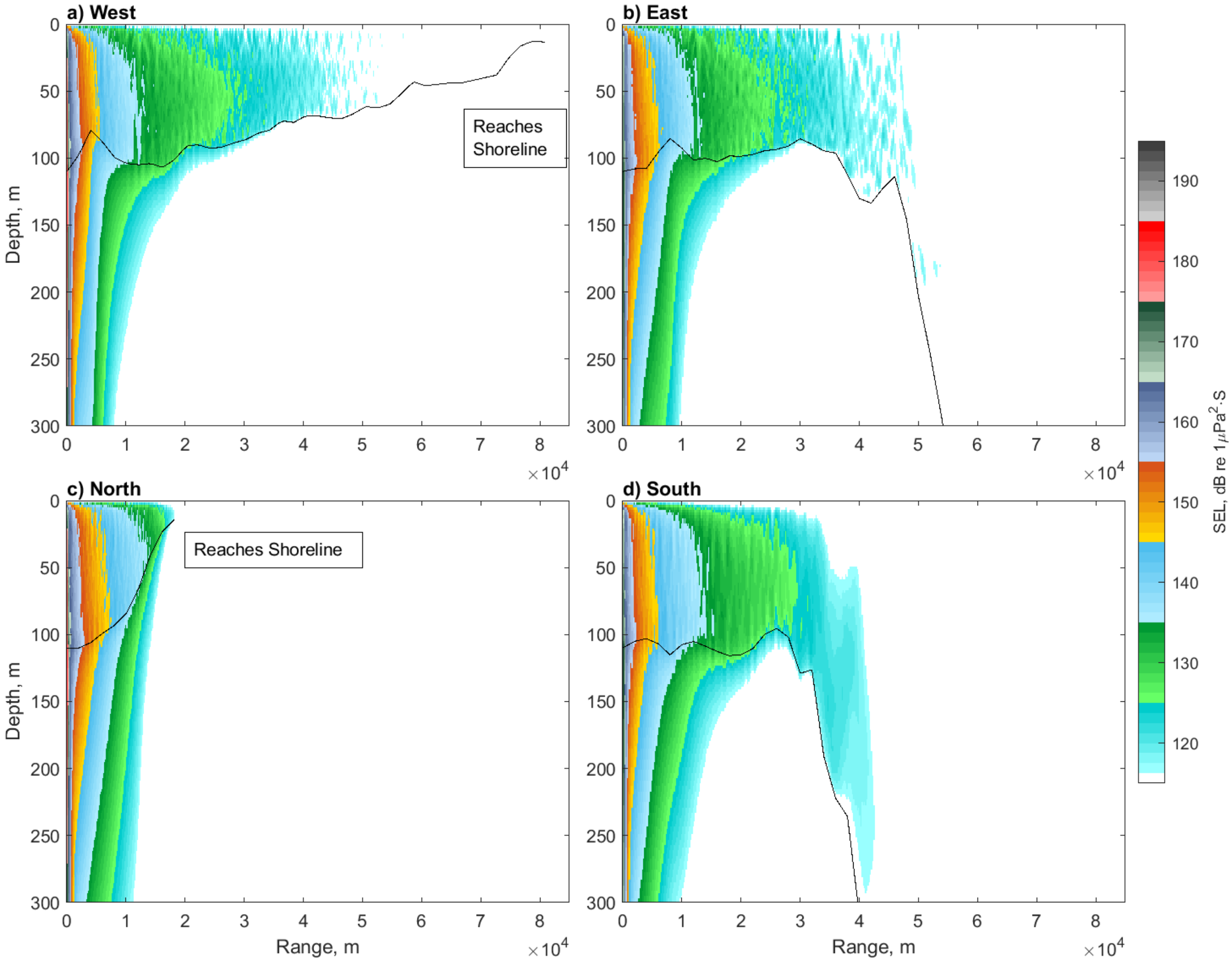


Figure 18 Modelled SELs vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L2. Black line shows the seabed depth variation



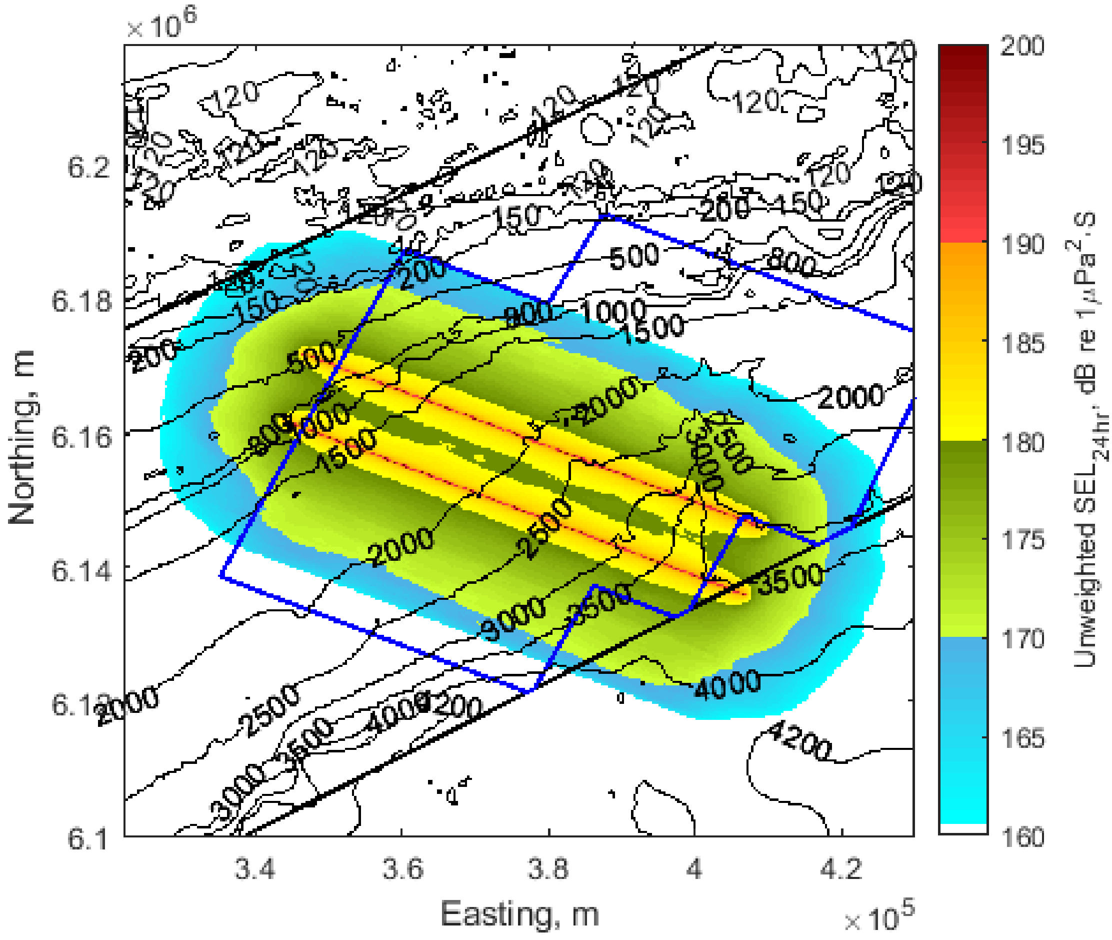
5.3 Cumulative SEL modelling

The sound exposure contributions from adjacent survey shots vary with the distances from the receiving locations to the survey line. From the short range modelling results as presented in **Section 5.1**, sound exposure level from a survey shot received at a receiving location with a distance of 1.0 km is predicted to be up to 30 dB lower than the level from a survey shot at a close distance of 30 m.

With the receiving location perpendicularly further away from the survey lines, the distance differences between the survey location and adjacent survey shots become smaller, and the sound exposure contributions from adjacent multiple shots along the survey lines become more significant proportionally compared with the survey shots closer to the survey lines. Based on this consideration, cumulative modelling is carried out for a modelling area within a 60-km zone around the survey lines and with a 100-m grid size, so that the modelling area is sufficiently large to include all potential zones of impact for assessed marine fauna species.

The cumulative SEL modelling has been carried out for a 24-hour survey operation scenario as described in **Section 4.2.3.2**, based on the modelling methodology and procedure as laid out in **Section 4.2.3.1**, for unweighted SEL$_{24}$ case and weighted SEL$_{24}$ cases with frequency weighting functions of different marine mammal hearing groups applied. The modelled unweighted SEL$_{24hr}$ contour map for the survey operation scenario within a 24-hour period is presented in **Figure 19**.

Figure 19 The predicted maximum unweighted SEL$_{24hr}$ across the water column for the assessed survey scenario



5.4 Zones of impact

Based on the noise modelling prediction results presented above, the zones of impact (i.e. maximum horizontal threshold distance from array source location/survey lines) for marine fauna species of interest are summarized in the following sub sections.

5.4.1 Zones of impact – immediate exposure from single pulses

Table 9 below outlines the predicted maximum SELs and the estimated Pk SPLs and RMS SPL across the water column for all azimuths as a function of horizontal distance from the seismic airgun source array, for water depth range within the survey area, based on the short range SEL modelling results as in **Section 5.1** and relevant estimate approach as in **Section 4.2.4**.

Table 9 The maximum SELs, Pk SPLs and RMS SPL across the water column for all azimuths as a function of distance from the seismic airgun source array for water depth range within survey area

Horizontal distance from the source array, m	The predicted maximum levels across the water column for all azimuths, for water depth range within the survey area		
	SEL, dB re 1 µPa^2·s	Pk SPL, dB re 1µPa	RMS SPL, dB re 1µPa
10	214	239	232
20	203	228	221
50	194	219	213
80	190	215	208
100	188	214	207
200	183	208	200
500	176	202	189
800	171	197	182
1 000	170	195	180
2 000	164	189	173
4 000	158	183	165

The zones of impact from seismic surveys based on per-pulse SEL, Pk SPL and RMS SPL metrics are estimated and presented in **Table 10** for PTS and TTS effects for marine mammals, **Table 11** for fish and sea turtles, and **Table 12** for behavioural disturbance for marine mammals and sea turtles.

5.4.1.1 Marine mammal physiological effects

Due to the high level of impulsive signal emissions from the array source, marine mammals are predicted to experience a permanent auditory threshold shift (PTS) at close proximity to the source array due to the immediate exposure to individual pulses. Based on zones of impact estimated Pk SPL metric criteria as in **Table 10**, marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 60 m from the source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 480 m from the array source.

The zones of a temporary auditory threshold shift (TTS) due to a single pulse exposure for marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to be within approximately 135 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 850 m from the array source as presented in **Table 10**.

It should be noted that the zones of immediate impact assessed are for the airgun array source under the full-power operation condition (with an operating pressure of 2 000 PSI). During the soft start process, the airgun array source is under reduced operating pressure conditions, and consequently has lower noise emissions. As such, the zones of impact during the soft start process are predicted to be less than the full-power operation condition. As an example, under a reduced operating pressure of 1 000 PSI, the noise emissions from the airgun array source is approximately 6 dB lower than from the full-power operation, and the resulted zones of impact are estimated to be approximately half of those zones assessed under the full-power operation condition.

Table 10 Zones of immediate impact from single seismic airgun array pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Injury (PTS) onset		**TTS onset**	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	219	55	213	120
High-frequency cetaceans (HF)	230	20	224	30
Very-high-frequency cetaceans (VHF)	202	480	196	850
Sirenians (SI)	226	25	220	50
Phocid carnivores in water (PCW)	218	60	212	135
Other marine carnivores in water (OCW)	232	20	226	25

5.4.1.2 Fish and sea turtle physiological effects

For seismic surveys, as presented in **Table 11**, the zones of potential injuries for fish species with a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 240 m from the airgun array source. However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 120 m from the airgun array source.

Table 11 Zones of immediate impact from single seismic airgun array pulses for mortality and recovery injury– fish, turtles, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Mortality and potential mortal injury		**Recovery injury**	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	> 213	120	>213	120

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Mortality and potential mortal injury		**Recovery injury**	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Fish: swim bladder is not involved in hearing (particle motion detection)	>207	240	>207	240
Fish: swim bladder involved in hearing (primarily pressure detection)	>207	240	>207	240
Sea turtles	>207	240	-	-
Fish eggs and fish larvae	>207	240	-	-

Note: a dash indicates the threshold is not applicable.

5.4.1.3 Marine mammal and fish and sea turtle behavioural responses

The zones of behavioural disturbance for marine mammals and turtles caused by the immediate exposure to individual seismic airgun array pulses for seismic surveys are presented in **Table 12** below.

The results show that behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 4.4 km from the array source for marine mammals of all hearing groups, and within 3.1 km from the array source for sea turtles.

For general fish species, based on the noise exposure criteria provided by Popper et al. (2014), relatively high to moderate behavioural risks are expected at near to intermediate distances (tens to hundreds of meters) from the source location. Relatively low behavioural risks are expected for fish species at far field distances (thousands of meters) from the source location.

Table 12 Zones of immediate impact from single seismic airgun array for behavioural disturbance – marine mammals and sea turtles

Type of animal	**Zones of impact – maximum horizontal distances from source to impact threshold levels**	
	Behavioural disturbance	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals	160	4 400
Sea turtles	166	3 100

5.4.2 Zones of impact – cumulative exposure from multiple pulses

As described in **Section 5.3**, for seismic surveys, the cumulative sound fields in unweighted SEL_{24hr} and weighted SEL_{24hr} with relevant frequency weighting functions applied are modelled based on one assumed 24-hour survey operation scenario.

The zones of cumulative impact for seismic surveys (i.e. the maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels) are estimated based on the above modelling results. **Table 13** presents the cumulative PTS and TTS effects for marine mammals, and **Table 14** the cumulative mortality, injury and TTS effects for fish and sea turtles.

5.4.2.1 Cumulative impacts for marine mammals

For seismic surveys, among marine mammals of all six hearing groups, low-frequency cetaceans have the highest zones of PTS and TTS impact, as can be seen in **Table 13**. The zones of PTS impact are predicted to range up to 800 m from the adjacent survey lines for the representative 24-hour survey operation scenario considered, and the maximum zone of TTS impact is predicted to be up to 12.0 km from the adjacent survey lines.

The cumulative PTS criteria SEL_{24hr} are predicted not to be exceeded for high-frequency cetaceans, sirenians and other marine carnivores in water, but the cumulative TTS criteria SEL_{24hr} to be slightly exceeded, with zones of impact within 10 m from the adjacent survey lines.

The cumulative PTS criteria SEL_{24hr} are predicted to be slightly exceeded for both very-high-frequency cetaceans and phocid carnivores in water, with zones of impact within 80 m from the adjacent survey lines. For very-high frequency cetaceans the zones of TTS impact are predicted to be up to 4 000 m, and for phocid carnivores in water up to 800 m from the adjacent survey lines for the 24-hour survey operation scenario considered.

It should be noted that the cumulative zones of impact presented above are conservative, and since cetaceans are highly mobile, they are likely to have moved considerable distances away from the source over the cumulative survey period.

Table 13 Zones of cumulative impact from multiple airgun array pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal perpendicular distances **from assessed survey lines to cumulative impact threshold levels**			
	Injury (PTS) onset		**TTS onset**	
	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183	800	168	12 000
High-frequency cetaceans (HF)	185	-	170	< 10
Very-high-frequency cetaceans (VHF)	155	80	140	4 000
Sirenians (SI)	203	-	175	< 10
Phocid carnivores in water (PCW)	185	10	170	800
Other marine carnivores in water (OCW)	203	-	188	< 10

Note: a dash indicates the threshold is not reached.

5.4.2.2 Cumulative impacts for fish and sea turtles

As presented in **Table 14**, the zones of potential mortal injuries for fish species with and without a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 20 m from the adjacent survey lines for the 24-hour survey operation scenario considered. For recoverable injury, the zones of impact are predicted to be within 10 m from the adjacent survey lines for fish without a swim bladder, and within 50 m for fish with a swim bladder. The zones of TTS effect for fish species with and without swim bladders are predicted to be up to 2 000 m from the adjacent survey lines for the 24-hour survey operation scenario considered.

Existing experimental data regarding recoverable injury and TTS impacts for sea turtles and fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach as indicated in **Table 4**, noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location while impacts are expected to be moderate for fish eggs and larvae. Impact is expected to be low for all of them at intermediate and far field from the source location.

Table 14 Zones of cumulative impact from multiple airgun array pulses for mortality and recovery injury– fish, turtles, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal perpendicular distances **from assessed survey lines to cumulative impact threshold levels**					
	Mortality and potential mortal injury		**Recoverable injury**		**TTS**	
	Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	219	< 10	216	< 10	186	2 000
Fish: swim bladder is not involved in hearing (particle motion detection)	210	10	203	50	186	2 000
Fish: swim bladder involved in hearing (primarily pressure detection)	207	20	203	50	186	2 000
Sea turtles	210	10	-	-	-	-
Fish eggs and fish larvae	210	10	-	-	-	-

Note: a dash indicates the threshold is not applicable.

5.4.3 Discussions

5.4.3.1 Combined zones of impact from either immediate or cumulative sound exposure

As detailed in **Section 2**, dual metric criteria (i.e. per-pulse impact criteria Pk SPL and cumulative exposure impact criteria SEL_{24hr}) are applied to assess PTS and TTS impact for marine mammals, and mortality and recovery injury for fish and sea turtles. The combined threshold distance for each impact effect is considered as the maximum threshold distances (i.e. the worst-case scenario) estimated from either metric criteria being applied.

For marine mammals, the combined zones of impact from seismic surveys for all six hearing groups based on estimated results in **Table 10** and **Table 13** are presented in **Table 15**. As can be seen, the cumulative noise exposure results in extended zones of PTS and TTS impact for low-frequency cetaceans, and extended zones of TTS impact for very-high-frequency cetaceans and phocid carnivores in water.

Table 15 Combined zones of impact from airgun array pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Combined zones of impact – maximum horizontal distances to either Pk SPL or cumulative SEL threshold levels			
	Injury (PTS) onset		**TTS onset**	
	Criteria applied - Pk SPL, dB re 1 µPa / Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	Criteria applied - Pk SPL, dB re 1 µPa / Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183 Weighted SEL_{24hr}	800	168 Weighted SEL_{24hr}	12 000
High-frequency cetaceans (HF)	230 Pk SPL	20	224 Pk SPL	30
Very-high-frequency cetaceans (VHF)	202 Pk SPL	480	140 Weighted SEL_{24hr}	4 000
Sirenians (SI)	226 Pk SPL	25	220 Pk SPL	50
Phocid carnivores in water (PCW)	218 Pk SPL	60	170 Weighted SEL_{24hr}	800
Other marine carnivores in water (OCW)	232 Pk SPL	20	226 Pk SPL	25

The combined zones of mortal and recoverable injury impact from seismic surveys for fish species are the zones of impact estimated based on immediate impact criteria Pk SPL as in **Table 11**, and the zones of TTS impact from seismic surveys for fish species based on cumulative impact criteria SEL as in **Table 14**.

For marine seismic surveys, the cumulative exposure level at certain locations is modelled based on the assumption that the animals are constantly exposed to the survey airgun noise at a fixed location over the entire 24-hour period. However, in reality marine fauna species, particularly marine mammals and fish species assessed in this study, would not stay in the same location for the entire period unless individuals are attached to a specific feeding or breeding area or those species that can't move away, e.g. plankton and fish eggs/larvae. Therefore, the zones of impact assessed for marine mammals and fish species represent the worst-case consideration.

6 Summary

CGG is proposing to undertake a speculative 3D seismic survey to investigate for oil and gas reserves off the Southeast Coast of South Africa.

The noise modelling results have been used to identify zones of impact for marine mammals and other species of concern based on relevant noise impact assessment criteria. Zones of impact have been evaluated for physiological effects and behavioural disturbance, due to the immediate impact from single airgun, as well as the cumulative effects of exposure to multiple airgun shots over a typical period of 24 hours for representative operation scenarios.

The identified relevant zones of impact for marine mammals and fish and sea turtle species are summarised as follows:

Marine mammals

Impact from immediate exposure to individual airgun array pulses

Due to the high level of impulsive signal emissions from the array source, marine mammals are predicted to experience PTS effects at close proximity to the source array due to the immediate exposure to individual pulses. Marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 60 m from the source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 480 m from the array source. The zones of TTS effects due to a single pulse exposure for marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to be within approximately 135 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 850 m from the array source. Behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 4.4 km from the array source for marine mammals of all hearing groups.

Impact from cumulative exposure to multiple airgun array pulses

The zones of cumulative impact (i.e. the maximum horizontal perpendicular distances from assessed survey lines to cumulative impact threshold levels) are estimated based on the modelling results and relevant assessment criteria. Among marine mammals of all six hearing groups, low-frequency cetaceans have the highest zones of cumulative PTS and TTS impact. The zones of PTS impact are predicted to range up to 800 m from the adjacent survey lines for the 24-hour survey operation scenario considered, and the zones of TTS impact are predicted to be up to 12.0 km from the adjacent survey lines. Much lower zones of cumulative PTS and TTS impact are predicted for marine mammals of other hearing groups.

Fish and sea turtles

Impact from immediate exposure to individual airgun array pulses

The zones of potential injuries for fish species with a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 240 m from the array for both PTS and TTS. However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 120 m from the array source.

The behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be 3.1 km from the array source for sea turtles.

Impact from cumulative exposure to multiple airgun array pulses

The zones of potential mortal injuries for fish species with and without a swim bladder, turtles and fish eggs and fish larvae are predicted to be within 20 m from the adjacent survey lines for the 24-hour survey operation scenarios considered. For recoverable injury, the zones of impact are predicted to be within 10 m for fish with no swim bladder, and within 50 m for fish with a swim bladder. The zones of TTS effect for fish species with and without swim bladders are predicted to be up to 2 000 m from the adjacent survey lines for the 24-hour survey operation scenario considered.

Existing experimental data regarding recoverable injury and TTS impacts for sea turtles and fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach, noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field (tens of meters) from the source location while impacts are expected to be moderate for fish eggs and larvae. Impact is expected to be low for all of them at intermediate field (hundreds of meters) and far field (thousands of meters) from the source location.

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APPENDIX A

Acoustic Terminology

Sound Pressure	A deviation from the ambient hydrostatic pressure caused by a sound wave
Sound Pressure Level (SPL)	The logarithmic ratio of sound pressure to the reference pressure. The reference pressure underwater is P_{ref} = 1 µPa
Root-Mean-Square Sound Pressure Level (RMS SPL)	The mean-square sound pressure is the average of the squared pressure over the pulse duration. The root-mean-square sound pressure level is the logarithmic ratio of the root of the mean-square pressure to the reference pressure. Pulse duration is taken as the duration between the 5% and the 95% points on the cumulative energy curve
Peak Sound Pressure Level (Peak SPL)	The peak sound pressure level is the logarithmic ratio of the peak pressure over the impulsive signal event to the reference pressure
Peak-to-Peak Sound Pressure Level (Peak-Peak SPL)	The peak-to-peak sound pressure level is the logarithmic ratio of the difference between the maximum and minimum pressure over the impulsive signal event to the reference pressure
Sound Exposure Level (SEL)	SEL is a measure of energy. Specifically, it is the dB level of the time integral of the squared instantaneous sound pressure normalised to a 1-s period
Power Spectral Density (PSD)	PSD describes how the power of a signal is distributed with frequency
Source Level (SL)	The acoustic source level is the level referenced to a distance of 1m from a point source
1/3 Octave Band Levels	The energy of a sound split into a series of adjacent frequency bands, each being 1/3 of an octave wide
Sound Speed Profile	A graph of the speed of sound in the water column as a function of depth

APPENDIX B

Marine Mammal Hearing Group Classification

The following appendix gives a summary of marine mammal hearing group classification. Not all animals listed in **Table B.** are found off the Southeast Coast of South Africa.

Table B.1 Summary of marine mammal classification

Classification	Common Name	Scientific Name
Low frequency cetaceans (extracted from Appendix 1 Southall *et al.* (2019))	Bowhead whale	*Balaena mysticetus*
	Southern right whale	*Eubalaena australias*
	North Atlantic right whale	*Eubalaena glacialis*
	North Pacific right whale	*Eubalaena japonica*
	Common minke whale	*Balaenoptera acutorostrata*
	Antarctic minke whale	*Balaenoptera bonaerensis*
	Sei whale	*Balaenoptera borealis*
	Bryde's whale	*Balaenoptera edeni*
	Omura's whale	*Balaenoptera omurai*
	Fin whale	*Balaenoptera physalus*
	Humpback whale	*Megaptera novaeangliae*
	Pygmy right whale	*Caperea marginate*
	Gray whale	*Eschrichtius robustus*
High frequency cetaceans (extracted from Appendix 2 Southall *et al.* (2019))	Sperm whale	*Physeter macrocephalus*
	Arnoux' beaked whale	*Berardius arnuxii*
	Baird's beaked whale	*Berardius bairdii*
	Northern bottlenose whale	*Hyperoodon ampullatus*
	Southern bottlenose whale	*Hyperoodon planifrons*
	Tropical bottlenose whale	*Indopacetus pacificus*
	Sowerby's beaked whale	*Mesoplodon bidens*
	Andrews' beaked whale	*Mesoplodon bowdoini*
	Hubb's beaked whale	*Mesoplodon carlbubbsi*
	Blainville's beaked whale	*Mesoplodon densirostris*
	Gervais' beaked whale	*Mesoplodon europaeus*
	Ginkgo-toothed beaked whale	*Mesoplodon ginkgodens*
	Gray's beaked whale	*Mesoplodon grayi*
	Hector's beaked whale	*Mesoplodon hectori*
	Deraniyagala's beaked whale	*Mesoplodon hotaula*
	Layard's beaked whale	*Mesoplodon layardii*
	True's beaked whale	*Mesoplodon mirus*

Classification	Common Name	Scientific Name
	Perrin’s beaked whale	*Mesoplodon perrini*
	Pygmy beaked whale	*Mesoplodon peruvianus*
	Stejneger’s beaked whale	*Mesoplodon stejnegeri*
	Spade-toothed whale	*Mesoplodon traversii*
	Tasman beaked whale	*Tasmacetus shepherdi*
	Cuvier’s beaked whale	*Ziphius cavirostris*
	Killer whale	*Orcinus orca*
	Beluga	*Delphinapterus leucas*
	Narwhal	*Monodon monoceros*
	Short- and long-beaked common dolphins	*Delphinus delphis*
	Pygmy killer whale	*Feresa attenuata*
	Short-finned pilot whale	*Globicephala macrorhynchus*
	Long-finned pilot whale	*Globicephala melas*
	Risso’s dolphin	*Grampus griseus*
	Fraser’s dolphin	*Lagenodelphis hosei*
	Atlantic white-sided dolphin	*Lagenorhynchus acutus*
	White-beaked dolphin	*Lagenorhynchus albirostris*
	Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
	Dusky dolphin	*Lagenorhynchus obscurus*
	Northern right whale dolphin	*Lissodelphis borealis*
	Southern right whale dolphin	*Lissodelphis peronii*
	Irrawaddy dolphin	*Orcaella brevirostris*
	Australian snubfin dolphin	*Orcaella heinsohni*
	Melon-headed whale	*Peponocephala electra*
	False killer whale	*Pseudorca crassidens*
	Indo-Pacific humpback dolphin	*Sousa chinensis*
	Indian Ocean humpback dolphin	*Sousa plumbea*
	Australian humpback dolphin	*Sousa sahulensis*
	Atlantic humpback dolphin	*Sousa teuszii*
	Tucuxi	*Sotalia fluviatilis*
	Guiana dolphin	*Sotalia guianensis*
	Pantropical spotted dolphin	*Stenella attenuata*
	Clymene dolphin	*Stenella clymene*
	Striped dolphin	*Stenella coeruleoalba*
	Atlantic spotted dolphin	*Stenella frontalis*
	Spinner dolphin	*Stenella longirostris*
	Rough-toothed dolphin	*Steno bredanensis*
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*

Classification	Common Name	Scientific Name
	Common bottlenose dolphin	*Tursiops truncatus*
	South Asian river dolphin	*Platanista gangetica*
Very high frequency cetaceans (extracted from Appendix 3 Southall *et al.* (2019))	Peale's dolphin	*Lagenorhynchus australis*
	Hourglass dolphin	*Lagenorhynchus cruciger*
	Commerson's dolphin	*Cephalorhynchus commersonii*
	Chilean dolphin	*Cephalorhynchus eutropia*
	Heaviside's dolphin	*Cephalorhynchus heavisidii*
	Hector's dolphin	*Cephalorhynchus hectori*
	Narrow-ridged finless porpoise	*Neophocaena asiaeorientalis*
	Indo-Pacific finless porpoise	*Neophocaena phocaenoides*
	Spectacled porpoise	*Phocoena dioptrica*
	Harbor porpoise	*Phocoena phocoena*
	Vaquita	*Phocoena sinus*
	Burmeister's porpoise	*Phocoena spinipinnis*
	Dall's porpoise	*Phocoenoides dalli*
	Amazon river dolphin	*Inia geoffrensis*
	Yangtze river dolphin	*Lipotes vexillifer*
	Franciscana	*Pontoporia blainvillei*
	Pygmy sperm whale	*Kogia breviceps*
	Dwarf sperm whale	*Kogia sima*
Sirenians (extracted from Appendix 4 Southall *et al.* (2019))	Amazonian manatee	*Trichechus inunguis*
	West Indian manatee	*Trichechus manatus*
	West African manatee	*Trichechus senegalensis*
	Dugong	*Dugong dugon*
Phocid carnivores (extracted from Appendix 5 Southall *et al.* (2019))	Hooded seal	*Cystophora cristata*
	Bearded seal	*Erignathus barbatus*
	Gray seal	*Halichoerus grypus*
	Ribbon seal	*Histriophoca fasciata*
	Leopard seal	*Hydrurga leptonyx*
	Weddell seal	*Leptonychotes weddellii*
	Crabeater seal	*Lobodon carcinophaga*
	Northern elephant seal	*Mirounga angustirostris*
	Southern elephant seal	*Mirounga leonina*
	Mediterranean monk seal	*Monachus monachus*
	Hawaiian monk seal	*Neomonachus schauinslandi*
	Ross seal	*Ommatophoca rossii*
	Harp seal	*Pagophilus groenlandicus*
	Spotted seal	*Phoca largha*

Classification	Common Name	Scientific Name
	Harbor seal	*Phoca vitulina*
	Caspian seal	*Pusa caspica*
	Ringed seal	*Pusa hispida*
	Baikal seal	*Pusa sibirica*
Other marine carnivores (extracted from Appendix 6 Southall *et al.* (2019))	Walrus	*Odobenus rosmarus*
	South American fur seal	*Arctocephalus australis*
	New Zealand fur seal	*Arctocephalus forsteri*
	Galapagos fur seal	*Arctocephalus galapagoensis*
	Antarctic fur seal	*Arctocephalus gazella*
	Juan Fernandez fur seal	*Arctocephalus philippii*
	Cape fur seal	*Arctocephalus pusillus*
	Subantarctic fur seal	*Arctocephalus tropicalis*
	Northern fur seal	*Callorhinus ursinus*
	Steller sea lion	*Eumetopias jubatus*
	Australian sea lion	*Neophoca cinerea*
	South American sea lion	*Otaria byronia*
	Hooker's sea lion	*Phocarctos hookeri*
	California sea lion	*Zalophus californianus*
	Galapagos sea lion	*Zalophus wollebaeki*
	Polar bear	*Ursus maritimus*
	Sea otter	*Enhydra lutris*
	Marine otter	*Lontra feline*

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