TGS: South Africa Orange Basin 3D Seismic Survey

Sound Transmission Loss Modelling

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September 28, 2022

Revision Record

Revision No.	Revision Date	Revision Description
1.0	27 September 2022	Technical review of draft report
1.1	28 September 2022	Seismic Survey area updated
1.2	7 October 2022	Recommended management measures section added and revised

Executive Summary

Environmental Impact Management Services Pty Ltd. (EIMS) is proposing to undertake a 3D seismic survey within the Orange Basin off the West and South-West Coast of South Africa. The proposed survey areas are adjacent to a few Ecologically or Biologically Significant Marine Areas (EBSAs), and Marine Protected Areas (MPAs) including Childs Bank and Shelf Edge, and Cape Canyon and Associated Islands, Bays and Lagoon.

SLR Consulting Australia Pty Ltd. (SLR) has been appointed by EIMS as the independent underwater acoustic specialist to undertake a Sound Transmission Loss Modelling (STLM) study for the proposed exploration activities, in order to assist with the assessment of potential noise impact on marine fauna species of interest.

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 pulses, as well as the 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 2.0 of this report, and the identified relevant zones of impact are summarised in Section 5.4 and Section 5.5 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 a permanent auditory threshold shift (PTS) at close proximity to the source arrays 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 50 metres from the 3D source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 325 metres from the 3D 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 100 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 650 m from the array source.

Behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 3.8 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 PTS and TTS impact. The zones of PTS impact are predicted to range up to 340 metres for the 3D survey, from the adjacent survey lines for the relevant typical 24-hour survey operation scenarios considered, and the maximum zone of TTS impact is predicted to be around 5 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

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 180 m from the array source. However, fish species without swim bladders have higher injury impact thresholds, and therefore have smaller zones of potential injuries within 90 m from the airgun array source.

Impact from cumulative exposure to multiple airgun array pulses

The zones of potential mortal injuries for fish species with a swim bladder, fish eggs, and fish larvae are predicted to be within 30 m from the adjacent survey lines for all the 24-hour survey operation scenarios considered. For recoverable injury, the zones of impact are predicted to be within 80 m from the adjacent survey lines for fish with a swim bladder for all the operation scenarios considered. Fish without swim bladder are not expected to suffer or any potential injury.

The zones of TTS effect for fish species with and without swim bladders are predicted to be within 2.9 km from the adjacent survey lines for the relevant 24-hour survey operation scenarios considered.

Existing experimental data regarding recoverable injury and TTS impacts for fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach, noise 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.

Sea Turtles

Impact from immediate exposure to individual airgun array pulses

The maximum zones of PTS effect for sea turtles are predicted to be within 19 m from the source location. On the other hand, the maximum zones of TTS effect for sea turtles are predicted to be within 24 m of the source array.

The behavioural disturbance for sea turtles caused by the immediate exposure to individual pulses are predicted to be within 1.3 km of the source array.

Impact from cumulative exposure to multiple airgun array pulses

Noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location. The maximum zones of PTS impact are predicted to range within 10 m of the source array. The maximum zones of TTS effect for sea turtles are predicted to be within 500 m of the source array.

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Acronyms and Abbreviations

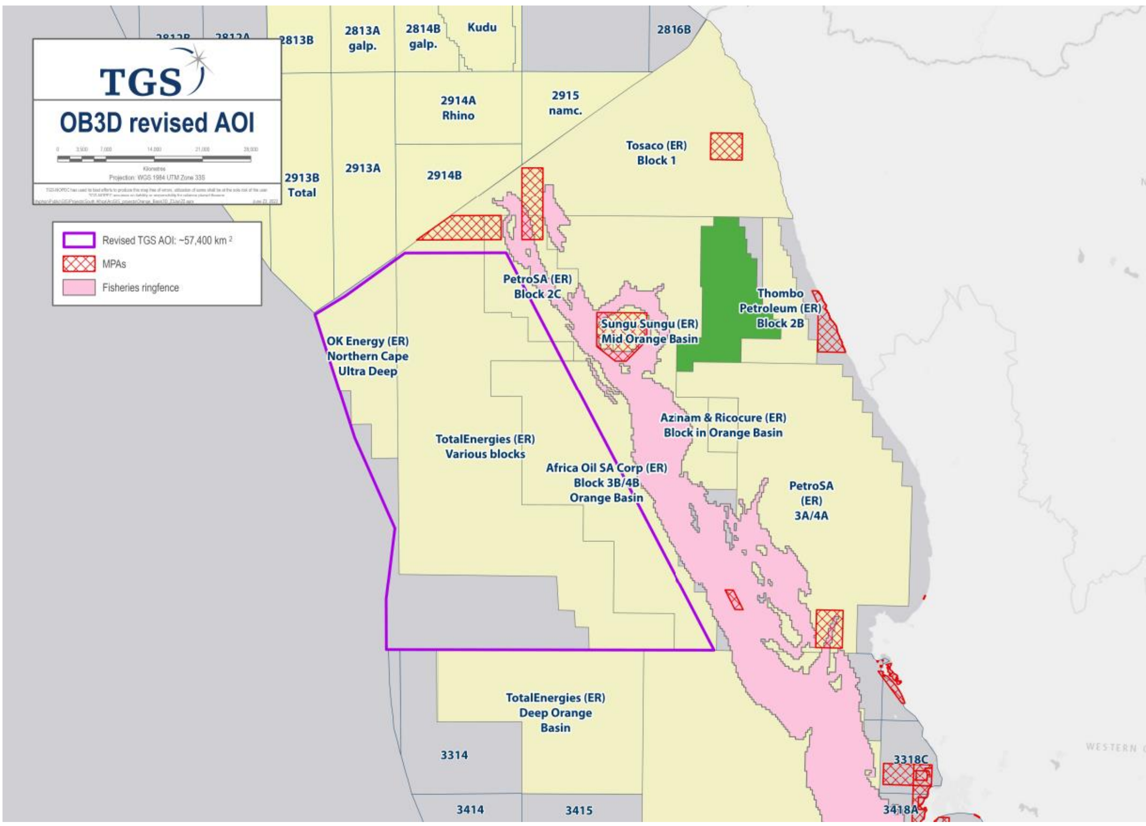
CUI	Cubic Inch
dB	Decibel
EBSA	Ecologically or Biologically Significant Marine Area
GEBCO	General Bathymetric Chart of the Oceans
G-Gun	Gundalf-Gun
MPA	Marine Protected Area
NMFS	National Marine Fisheries Services
NOAA	National Oceanic and Atmospheric Administration
PE	Parabolic Equation
Pk	Peak
PSD	Power Spectral Density
psi	Pounds (force) per square inch
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SEL	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SOFAR	Sound Fixing and Ranging
SPL	Sound Pressure Level
STLM	Sound Transmission Loss Modelling
TTS	Temporary Threshold Shift
UTM	Universal Transverse Mercator
WOA09	World Ocean Atlas 2009
WP	Working Group

1.0 Introduction

1.1 Project Background

TGS is proposing to undertake a 3D seismic survey within the Orange Basin off the West Coast of South Africa. Water depths in the proposed survey area range from 1,500 m to beyond 3,600 m. The proposed 3D survey acquisition area is within the entire Reconnaissance area of approximately 30,000 km^2 as shown in **Figure 1**.

Figure 1 Proposed 3D Seismic Survey area off the West Coast of South Africa (purple polygon)



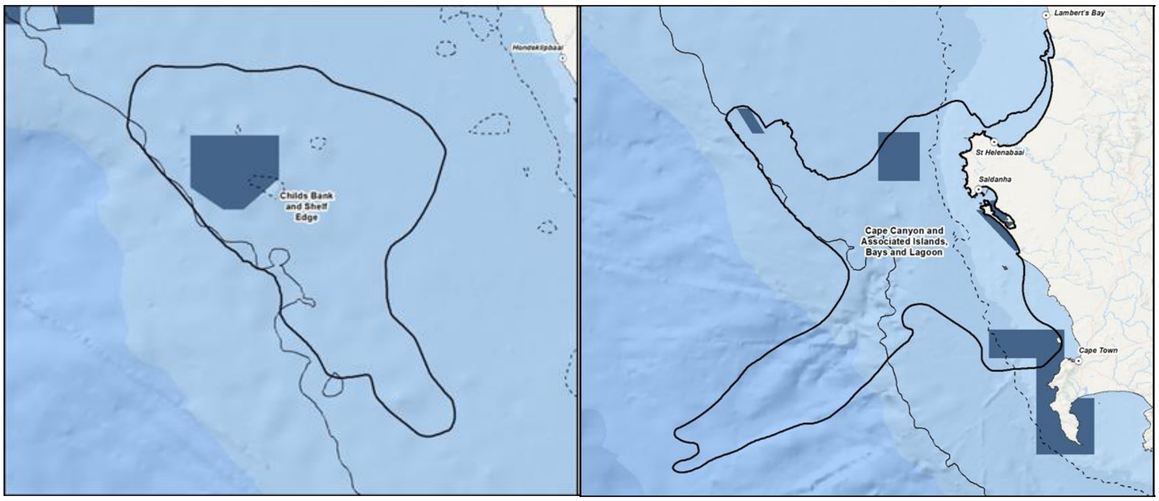
There are a few Ecologically or Biologically Significant Marine Areas (EBSAs) and Marine Protected Areas (MPAs)[1] adjacent to the proposed survey area, particularly the Child Bank and Shelf Edge, as well as Cape Canyon and Associated Islands, Bays and Lagoon, as shown in **Figure 2** below:

- **Childs Bank and Shelf Edge (Childs Bank)** which is a unique submarine bank feature occurring within South Africa's Exclusive Economic Zone (EEZ), rising from ~180 m to ~400 m in water depth on the western continental margin on South Africa; This area includes seven ecosystem types, including those comprising the bank itself, the outer shelf and the shelf edge, supporting hard and unconsolidated ecosystem types. Two of these ecosystem types are Vulnerable and five are Least Concern.

[1] https://cmr.mandela.ac.za/Research-Projects/EBSA-Portal/South-Africa accessed on May 20th, 2021.

- Cape Canyon and Associated Islands, Bays and Lagoon which comprises a collection of special features, ecosystems and species that support a rich diversity and high productivity. The area supports numerous threatened species and ecosystems, and many fragile, sensitive species.

Figure 2 EBSA boundaries (black polygons) for 'Childs Bank and Shelf Edge' (left) and 'Cape Canyon and Associated Islands, Bays and Lagoon' (right). Dark blue areas represent Marine Protected Areas (MPAs).



SLR Consulting Australia Pty Ltd. (SLR) has been appointed by Environmental Impact Management Services Pty Ltd (EIMS) as the independent underwater acoustic specialist to undertake a Sound Transmission Loss Modelling (STLM) study for the proposed exploration activities, 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 concern detailed as above.

1.2 Structure of the Report

This modelling study for the proposed 3D seismic surveys within the Orange Basin off the west coast of South Africa includes the following modelling components:

- Airgun source modelling, i.e., modelling of sound energy emissions from the source array proposed to be used in the 3D seismic 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 location 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 surveys 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 1.0 of the report provides relevant noise impact assessment criteria for marine fauna species of interest. Section 3.0 details the modelling methodology, procedure and results for the seismic survey array source modelling. Section 4.0 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 0 presents the major modelling results and the estimated zones of impact for marine fauna species of interest. Section 6.0 provides a discussion of the acoustic modelling study and some recommendation management measures. Relevant references cited throughout the report are listed in Section 9.0.

Relevant acoustic terminologies used throughout the report are presented in Appendix A. An explanation of marine mammal and sea turtle auditory weighting functions are presented in Appendix B. Classifications of various marine mammal hearing groups are presented in Appendix C. Supplementary noise modelling figures are presented in Appendix D.

2.0 Underwater Noise Impact 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[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, 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. 2013; Erbe et al. 2018; Popper and Hawkins 2019a).

When the animal is in close proximity to the acoustic source, physical injuries can occur. As the animal is further away from the source, the impacts are expected to gradually decrease, up to a distance where the impacts are negligible. The theoretical zones of noise influence according to Richardson et al. (2013) based on the severity of the noise impact are illustrated in **Figure 3**.

Figure 3 Theoretical zones of noise influence (adapted from Richardson et al. 2013)

2.1.1 Audibility

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

[2] 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).

energy components in the lower and upper frequency ranges (Finneran 2016, Southall et al. 2019; Popper et al. 2019b).

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 and Hawkins 2018). 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 (Nedelec et al. 2016; Popper and Hawkins 2018).

2.1.2 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. 2013), 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 2016).

2.1.3 Response

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 (Ellison et al. 2012; Richardson et al. 2013).

2.1.4 Hearing Loss / Discomfort

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 (Finneran 2016, Popper and Hawkins 2019a; Southall et al. 2019).

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).

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

2.1.5 Physical Injury

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 (Groton 1998).

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, Fish and Sea Turtles

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine mammal species, fish, and sea turtles. For example, Southall et al (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, sirenians and carnivores), based on review of expanding literature on marine mammal hearing and on physiological and behavioural responses to anthropogenic sounds. Popper *et al*. (2014) proposed sound exposure guidelines for fishes considering the diversity of fish, the different ways they detect sound, as well as various sound sources and their acoustic characteristics. Finneran et al (2017) presented a revision of the thresholds for sea turtle injury and hearing impairment (TTS and PTS).

The following subsection provides the noise exposure levels above which adverse effects on various groups of marine mammals, fish, and sea turtles. The latter is based on all available relevant data and published literature (i.e., the state of current knowledge). For more details, see Appendix B.

2.2.1 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 1, 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}).
- 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 1 µPa for impulsive noise, as shown in Table 2.

Table 1 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

Table 2 The behavioural disruption threshold level for individual marine mammals – impulsive noise (NOAA 2019)

Marine mammal hearing group	Behavioural disruption threshold levels, RMS SPL, dB re 1µPa
	Impulsive noise
All hearing groups	160

2.2.2 Noise Criteria for Fish, Fish Eggs, and Fish Larvae

In general, limited scientific data are available regarding the effects of sound for fishes. 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 fish, fish eggs and fish larvae (Popper et al. 2014), considering the diversity of fish and the different ways they detect sound, as well as various sound sources and their acoustic characteristics. The sound exposure criteria for sound sources relevant to the project including impulsive noise from seismic airguns is presented in Table 3.

Within the two tables, where data exist that can be used to suggest provisional guidelines, received signal levels are reported in appropriate forms (e.g., peak SPL, 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 seismic survey or for the duration of an activity), 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. 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 species.

Table 3 Noise exposure criteria for seismic airguns – fish, fish eggs and fish larvae (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
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 (F) 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).

2.2.3 Noise Criteria for Sea Turtles

Popper et al. (2014) suggested threshold levels for the occurrence of mortality and potential mortal injuries (PTS) of sea turtles. However, these adopted levels were extrapolated from other animal groups such as fish, based on the logic that the hearing range of turtles is much closer to that of poorly hearing fish.

More recently, Finneran et al (2017) revised the sea turtle thresholds (PTS) by reviewing individual references from at least five different species (see **Appendix C**) to construct their composite audiograms and provide thresholds for onset of temporary hearing impairment (TTS). Finneran et al (2017) agreed that sea turtles, even within their best hearing range, have low sensitivity with audiograms more similar to those of fish without specialized hearing adaptations for high frequency like some marine mammals. The revised thresholds for sea turtles are presented in **Table 4.**

Table 4 PTS and TTS threshold levels for sea turtles exposed to impulsive noise events (Finneran et al. 2017)

Type of animal	PTS and TTS threshold levels – impulsive noise events			
	Injury (PTS) onset		TTS onset	
	Pk SPL, dB re 1μPa	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Pk SPL, dB re 1μPa	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$
Sea turtles	232	204	226	189

The behavioural threshold for sea turtles was initially established by McCauley *et al.* (2000) at 166 dB re 1 μPa SPL rms and then it was adopted by the National Marine Fisheries Services (NMFS) to identify the distances at which behavioural response may occur. However, the received sound level at which sea turtles are expected to actively avoid repeated air gun exposures is 175 dB re 1 μPa SPL rms (McCauley et al. 2000) as shown in **Table 5**. Therefore, this threshold has been applied by NMFS to estimate sea turtle behaviour reactions to repeated air gun activities such as survey seismic events (Finneran et al. 2017).

Table 5 The behavioural threshold level for sea turtles – air guns events (McCauley et al. 2000; Finneran et al. 2017)

Type of animal	Behavioural disturbance threshold levels – air guns events
	RMS SPL, dB re 1μPa
Sea turtles	175

2.3 Zones of Bioacoustics 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 1 μPa 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, either behaviourally or physiologically. 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; and
- 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.

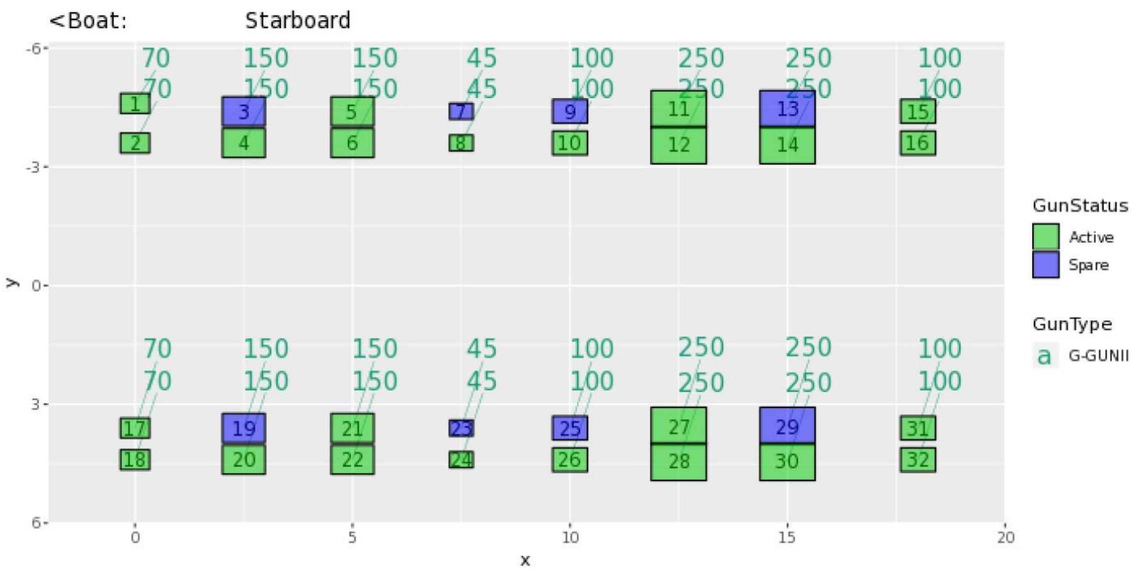
In all cases, zones of impact are conservatively determined by using the maximum predicted noise level across the water column to determine the zone of impact. Since noise levels vary with depth at any location, there will be areas in the water column within the identified zone of impact that are exposed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

3.0 Seismic Airgun Array Source Modelling

3.1 Airgun Array Configuration

The seismic airgun array proposed is a 3 370 cubic inch (CUI) G-GunII array (32 total airguns, 24 active) with its configuration shown in **Figure 4** as below. The array consists of 24 active G-Gun airgun units and has an average towing depth of 7.0 m and an operating pressure of 2,000 pounds per square inch (psi).

Figure 4 The configuration of the 3 370 CUI G-GunII array



3.2 Modelling Methodology

For each source array configuration, the outputs of the 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 metre.

Notional signatures are modelled using the Gundalf Designer software package (2018). 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.

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:

a) The far-field signatures are calculated for all directions from the source using azimuthal and dip angle increments of 1-degree;

b) The power spectral density (PSD) (dB re 1 $\mu Pa^2 s/Hz$ @ 1 m) for each pressure signature waveform is calculated using a Fourier transform technique; and

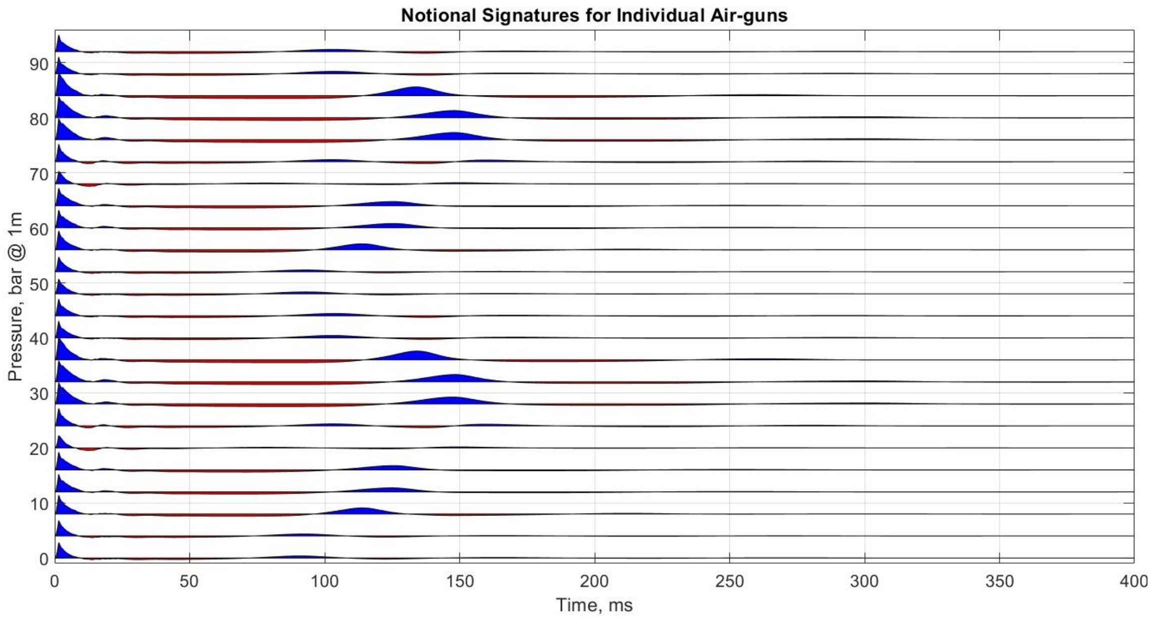
c) The PSDs of all resulting signature waveforms are combined to form the frequency-dependent beam pattern for the array.

3.3 Modelling Results

3.3.1 Notional Signatures

Figure 5 shows the notional source signatures for the four airgun array elements. Each line within the figure represents the notional source signature of the corresponding array element as shown in Figure 4.

Figure 5 Notional source signatures for the 3 370 CUI G-GunII array



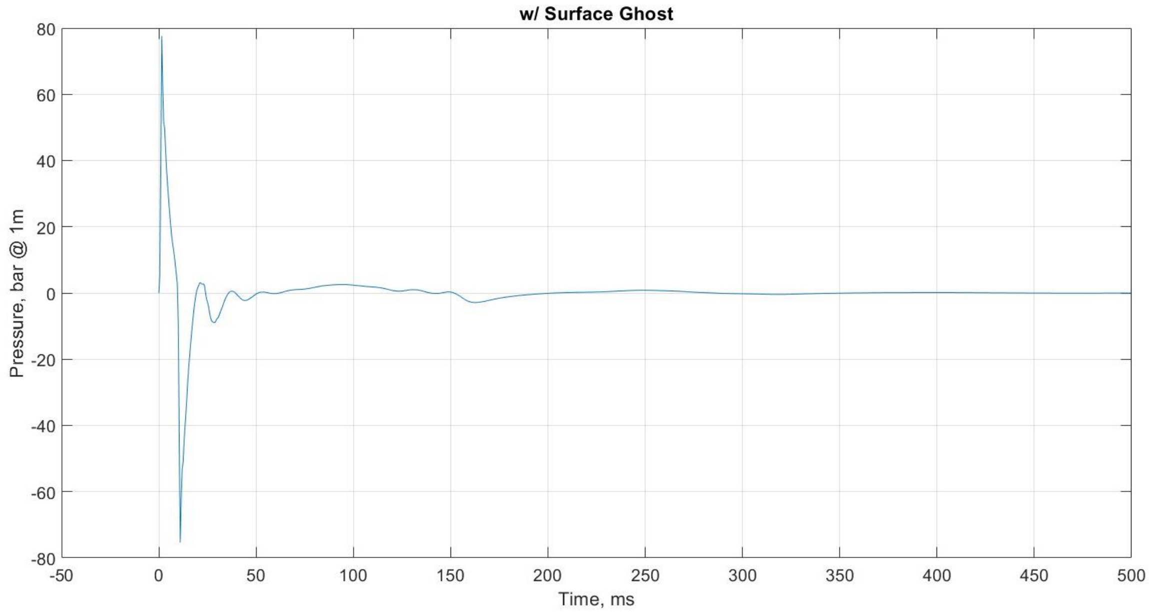
3.3.2 Far-field Signature and Its Power Spectral Density

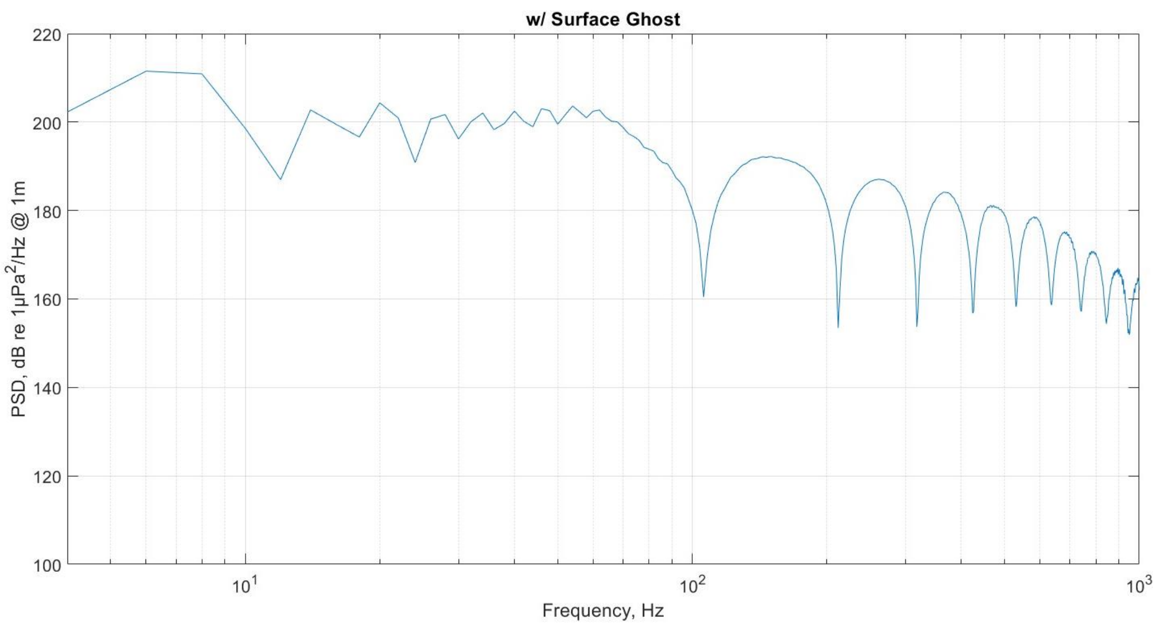
Figure 6 shows the far-field signature waveform and the proposed airgun array's power spectral density (simulated by the Gundalf Designer software, 2018). The signatures are for the vertically downward direction with surface ghost included. The source modelling result shows the parameters presented in Table 6.

Table 6 Source levels of the array source

Source Levels	3D source array
Peak sound pressure level (Pk SPL) (dB re 1 µPa @ 1 m)	257.9
Root-mean-square sound pressure level (RMS SPL) (dB re 1 µPa @ 1 m with a 90%-energy pulse duration of 12.5 milliseconds)	244.9
Sound exposure level (SEL) (dB re µPa^2·s @ 1 m)	233.9

Figure 6 The far-field signature in vertically downward direction (top) and its power spectral density (bottom) for the 3 370 CUI G-Gun array





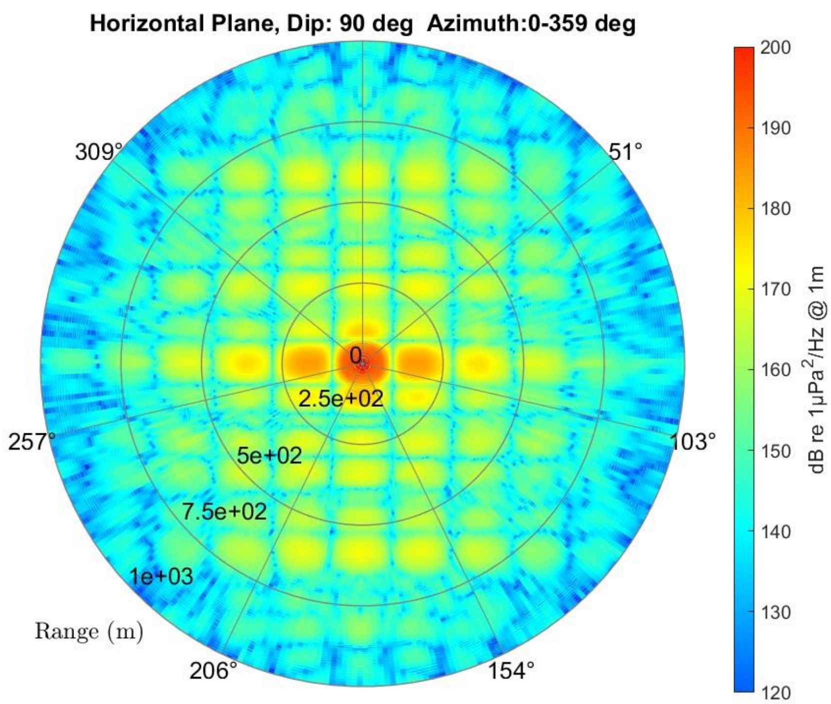
3.3.3 Beam Patterns

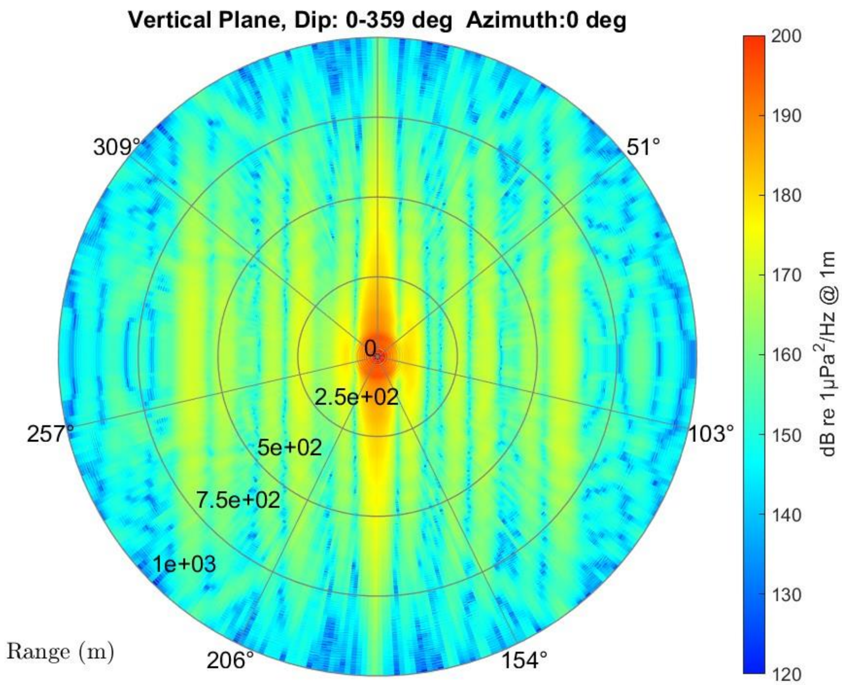
Array far-field beam patterns of the following three cross sections are presented in **Figure 7**:

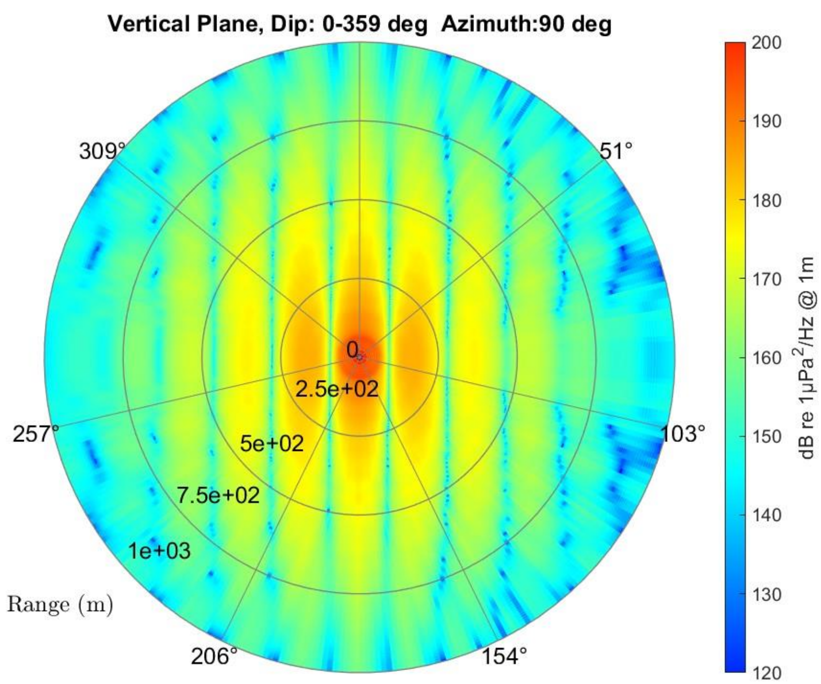
1. The horizontal plane (i.e., dip angle of 90 degrees) with azimuthal angle of 0 degree corresponding to the in-line direction;
2. The vertical plane for the in-line direction (i.e., azimuthal angle of 0 degree) with dip angle of 0 degree corresponding to the vertically downward direction; and
3. The 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 **Figure 7** 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 3 370 CUI G-GunII 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 crossline direction. The 0-degree dip angle corresponds to vertically downward direction




Vertical Plane, Dip: 0-359 deg Azimuth:0 deg
309°
51°
257°
103°
206°
154°
0
2.5e+02
5e+02
7.5e+02
1e+03
Range (m)
dB re 1μPa²/Hz @ 1m
200
190
180
170
160
150
140
130
120


Vertical Plane, Dip: 0-359 deg Azimuth:90 deg
309°
51°
257°
103°
206°
154°
0
2.5e+02
5e+02
7.5e+02
1e+03
Range (m)
dB re 1μPa²/Hz @ 1m
200
190
180
170
160
150
140
130
120

4.0 Sound Transmission Loss Modelling

4.1 Modelling Input Parameters

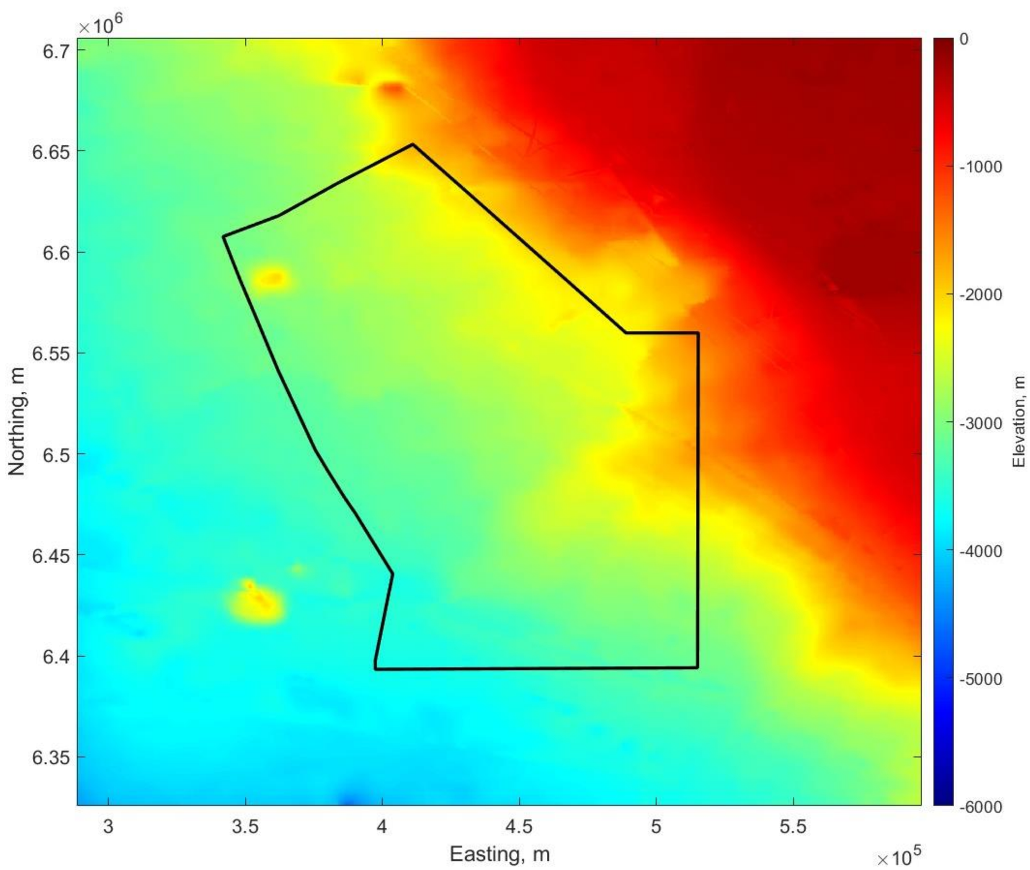
4.1.1 Bathymetry

The bathymetry data used for the sound propagation modelling were obtained from the General Bathymetric Chart of the Oceans (GEBCO) dataset grid (GEBCO 2022). This is the fourth GEBCO grid developed through the Nippon Foundation-GEBCO 'Seabed 2030 Project' (https://seabed2030.org).

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 acquisitions area are presented in **Figure 8**.

Figure 8 Bathymetry data for study area. The proposed 3D seismic area is shown with a black polygon, based on WGS 84/UTM Zone 33S



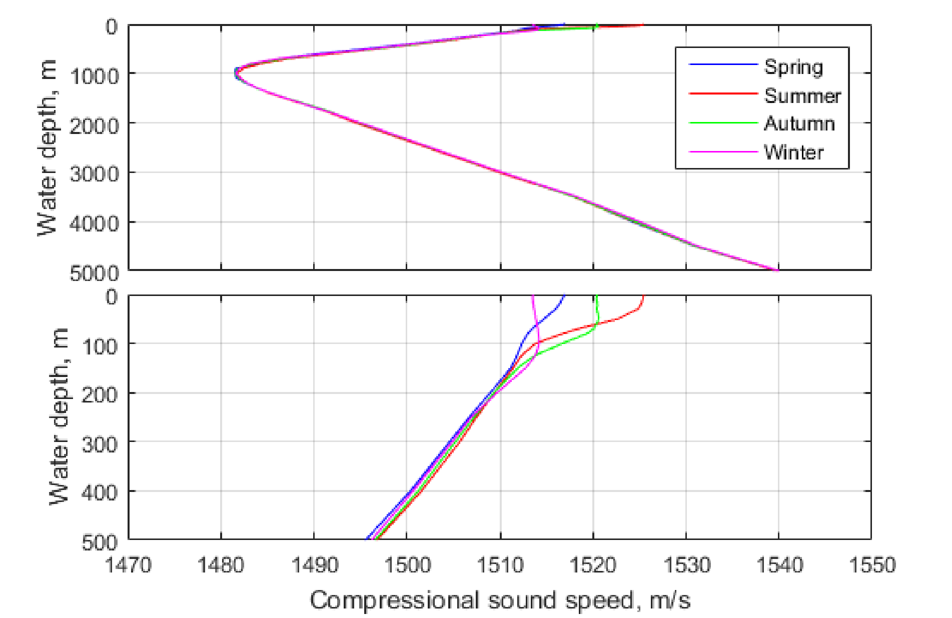
4.1.2 Sound Speed Profiles

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 the typical sound speed profiles for four seasons around 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 source array. Based on a conservative consideration, winter season sound speed profile was selected as the modelling input.

As can be seen in the figure below, the overall speed profiles of different seasons across the water column are quite similar, although in shallower water (less than 200 m) there is slight seasonal variation. As such, the differences in sound fields between different seasons are not expected to be significant.

Figure 9 Typical sound speed profiles within the survey area for different Southern Hemisphere seasons. The top panel shows profiles across the entire 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 in southern Africa, 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 for southern Africa and adjacent ocean regions. The data sample classification reveals that the seafloor of the Western South African and Namibia shelves is primarily composed of mud sediment with a noticeable proportion of sand.

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).

For the stratified layers beneath the superficial sediment layer within the offshore Orange Basin, relevant geological modelling studies (Paton et al. 2007; Campher et al. 2009) show that, for a typical east-west trending transect across the Orange Basin, a dominant layer of leaky shale/mudstone is predicted to be up to 2,000 m – 4,000 m from the seabed depth, followed by layers of sandstone and rock basement.

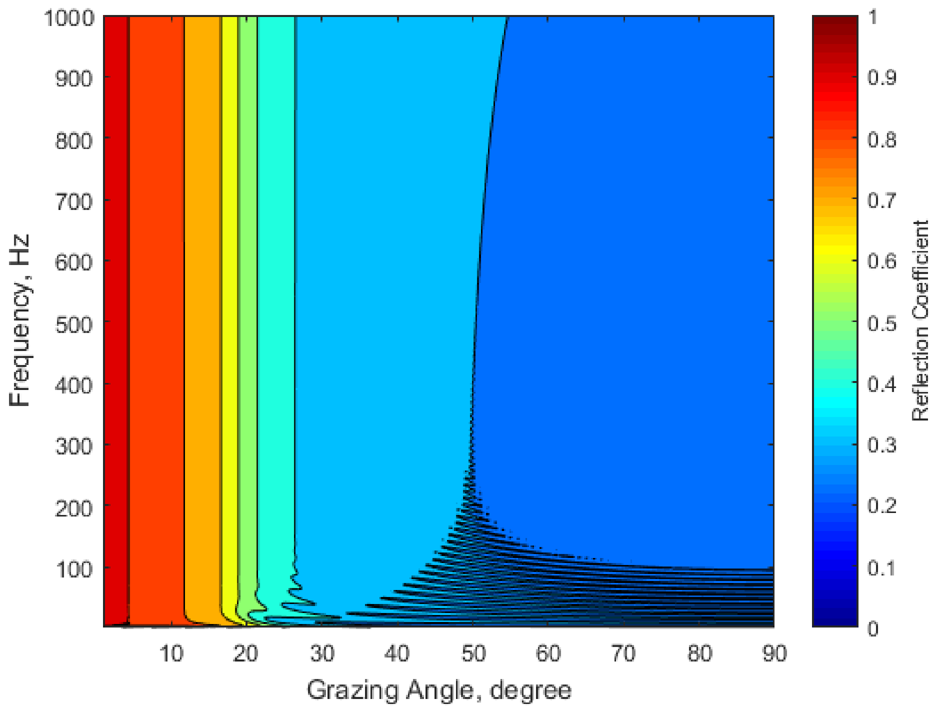
Based on above, as well as a conservative consideration, it was proposed that for the entire modelling area, the seafloor geoacoustic model comprises of a 50 metre thick fine and silty sand sediment layer, followed by a soft to sei-cemented mudstone/shale sediment layer and a semi to full-cemented mudstone /shale substrate as detailed in Table 7. The geoacoustic properties for silty mud and sand are as described in Hamilton (1980), with attenuations referred to Jensen et al (2011). The elastic properties of silt and sand are treated as negligible.

Figure 10 shows the reflection coefficient variation with grazing angle and frequency for the proposed seafloor geoacoustic scenario, calculated using the plane-wave reflection coefficient model (Porter 2001, 2020). 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.

Table 7 Geoacoustic parameters for the proposed seafloor model

Seafloor Materials	Depth Range, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, c_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Fine/silty sand	0 - 50	1,900	1,650	0.8
Soft to semi-cemented mudstone / shale sediment layer	50 - 500	2,000	1,900	1.0
Semi-/full- cemented mudstone /shale half-space	500 - ∞	2,300	2,500	1.0

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



4.2 Methodology and Procedure

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 G-Gun II 3,370 CUI Source Array for the 3D seismic survey, as well as for the cumulative SELs within a 24-hour period for the representative 3D survey scenarios.

4.2.1 Short Range Modelling

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 2001, 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 8.0 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).

4.2.1.1 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 four (4) water depth cases for the 3D survey area (i.e., 1,900 m, 2,500 m, 3,100 m, and 3,700 m).

4.2.2 Long Range Modelling

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.

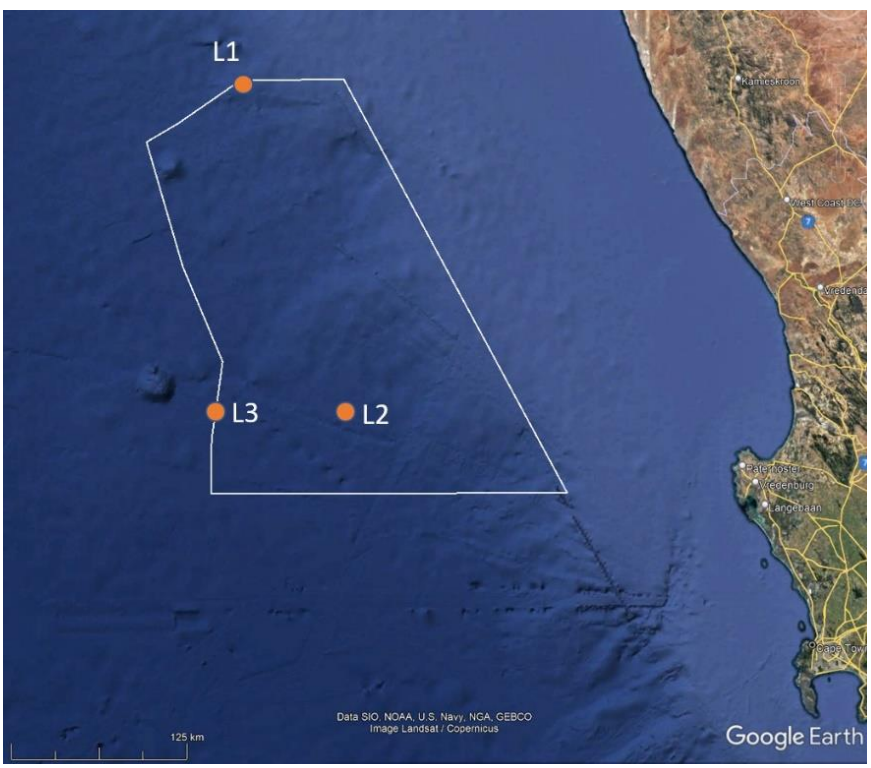
4.2.2.1 Source locations

Three (3) long range modelling source locations are proposed for the 3D seismic survey as detailed in Table 8 and shown in Figure 11. The modelling is representative of the noise propagation within the proposed 3D seismic area. Source location L1 is adjacent to the marine sensitive area, L2 represents the average depth of the south survey area and L3 is located towards the deeper water environment of the survey area.

Table 8 Details of the three selected source locations for the long range modelling

Source Location	Water Depth, m	Coordinates [Easting, Northing]	Locality
L1	1,900	[411159, 6653271]	north of the survey area adjacent to Childs Bank marine sensitive area
L2	3,100	[515091, 6394105]	mid-south of the survey area with average depths
L3	3,600	[396685, 6393331)	west of the survey area towards deeper water environment

Figure 11 The selected three source locations (L1, L2, & L3) indicated as orange dots. The white polygon shows the proposed 3D seismic survey area.



4.2.3 Cumulative SEL Modelling

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** 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 **Appendix B**), and the weighted SEL_{24} for individual hearing groups to be obtained by repeating the first two steps as above; and
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** 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.

4.2.3.1 Survey Scenarios

Based on relevant project information provided, the survey schedules for the survey are outlined in **Table 9**. One survey line section is assumed to be acquired within the 24-hour period for each scenario.

Table 9 Survey Schedule

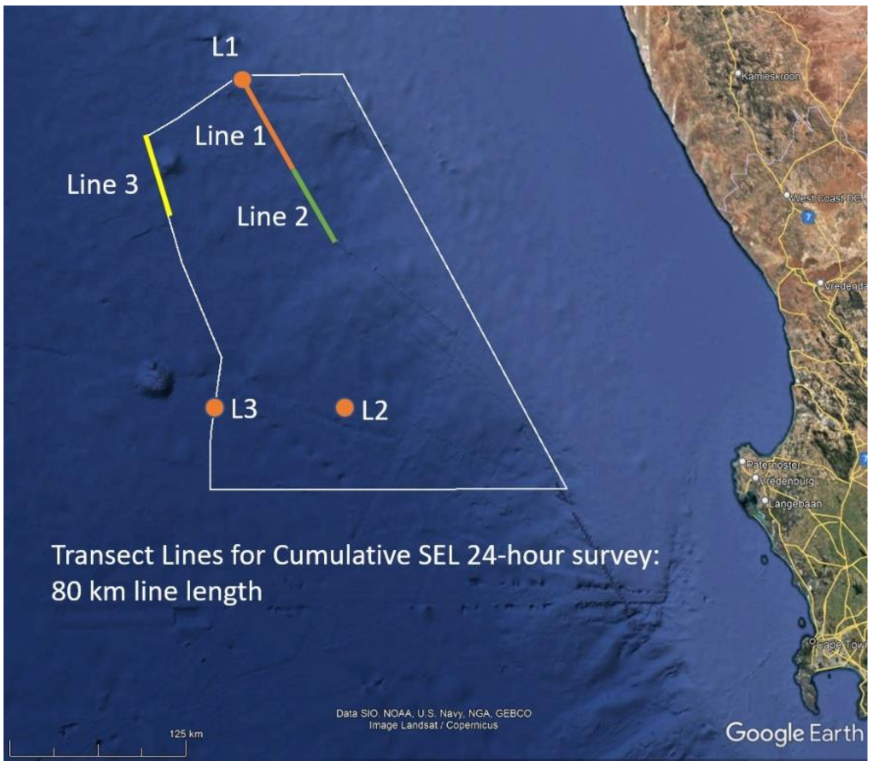
Survey	Shot spacing (m)	Vessel Speed (knots)	Survey Orientation
3D	12.5	4.5	NW-SE

The survey line details for the modelling scenario is detailed in **Table 10** and indicated in **Figure 12**. The rationale of the selected cumulative modelling scenarios is on the basis that the scenarios are representative with regards to the adjacent EBSAs (i.e., Childs Bank and Cape Canyon) and MPAs. The modelling is representative of the noise propagation within the proposed 3D seismic area.

Table 10 Details of the selected survey lines for the cumulative SEL modelling scenarios

Scenario	Survey Lines	[Easting, Northing], m	Length, km	Locality
Line1	1	[411150, 6653270]	80	near to EBSAs and MPAs
Line 2	1	[462322, 6591680]	80	near to EBSAs and MPAs
Line 3	1	[341354, 6605670]	80	northwest of the survey area towards deeper water environment

Figure 12 Representation of the selected three (3) Cumulative SEL 24-hour survey scenarios



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.

4.2.4.1 SEL and Pk SPL

As presented in **Section 3.3.2**, the difference between the Pk SPL and SEL of the far-field signature of the source arrays (at a reference distance of 1 m from the centre of the array) is 24.0 dB for the 3D array. 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.

4.2.4.2 SEL and 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).

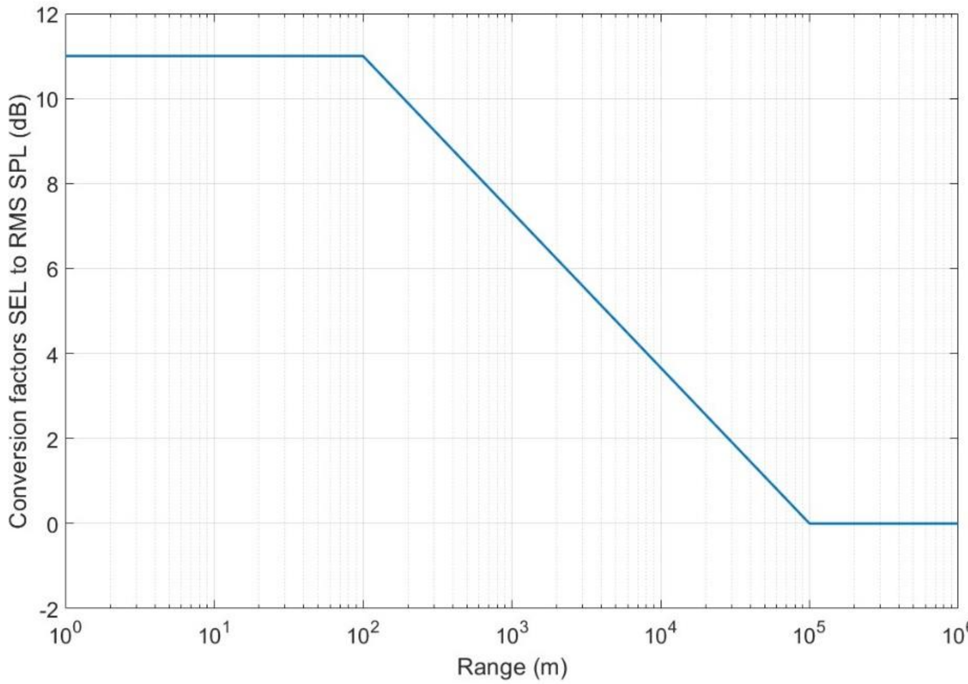
For this project, the RMS SPLs were estimated using the following conversion factors to be applied to the modelled SELs within different distance ranges.

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 11 dB. This is the difference between RMS SPL and SEL of the far-field signature of the 3 370 cubic inch (CUI) G-GunII array as modelled in **Section 3.3.2**;
- 100 – 1,000 m, conversion factors 11 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; and
- > 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**.

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 model and long range model 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); and
- The short range model and long range model 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; Li et al. 2021).

5.0 Modelling Results

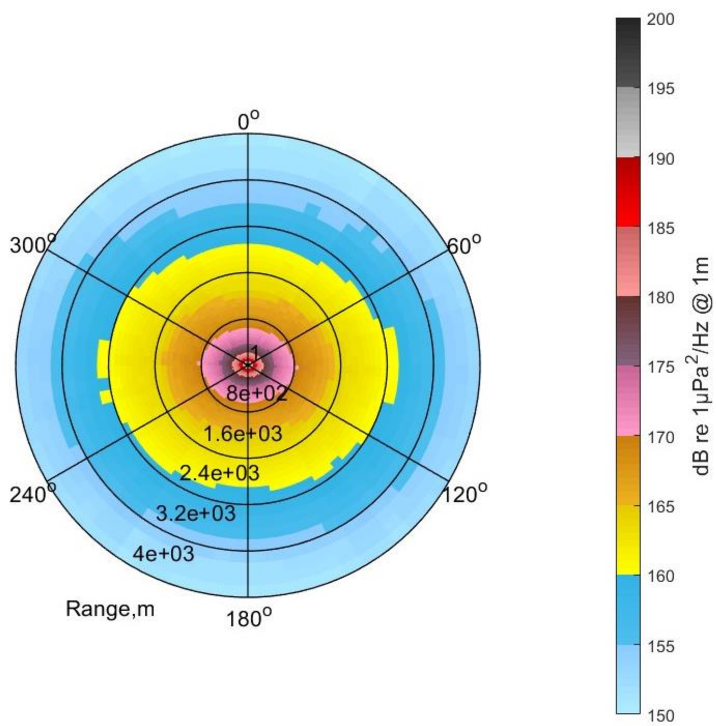
This section presents the modelling results for seismic surveys which include three modelling components (i.e., short range modelling, long range modelling and cumulative noise exposure modelling).

5.1 Short Range Modelling

The received SELs have been modelled for four (4) water depth cases for the 3D survey area (i.e., 1,900 m, 2,500 m, 3,100 m, and 3,700 m) from the G-Gun II 3 370 CUI source array.

Taking the 2,200 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^{o}) and near-field horizontal range (0 – 4 km) from the centre of the array. The figure illustrates slightly higher 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. The 0-degree azimuth corresponds to the in-line direction. Water depth: 1,900 m

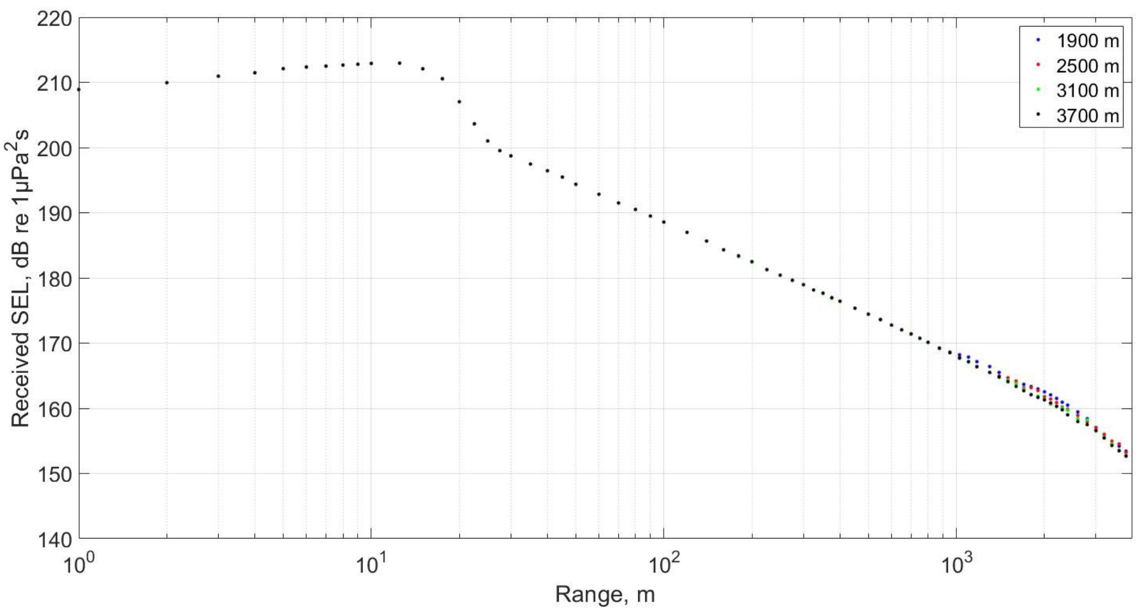


The scatter plots of the predicted maximum SELs across the water column for all azimuths as a function of horizontal range (0 – 4 km) from the source array are displayed in **Figure 15** for all relevant water depth cases. It is noted from the figure:

(a) For the proposed 3D seismic survey, the maximum received SELs for the four depth cases are nearly identical, as the water depths are all much higher than the deep water Sound Fixing and Ranging (SOFAR) channel (~1,000 m), and the maximum SELs are expected to be dominated by direct arrival acoustic energy from the array source.

(b) At horizontal distances further away from the array centre (> 1 000 m), the maximum received SELs are predicted to be slightly higher for 1 900 m and 2 500 m water depths. 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.

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 for the 3D source array



5.2 Long Range Modelling

Figure 16 shows the horizontal contour image of the predicted maximum SELs received at locations up to 200 km from source location L1, overlaying the local bathymetry contours. Figure 17 shows the vertical contour images of predicted SELs across the water column along the propagation paths to the west, east, north and south of the modelled location.

Both horizontal and vertical contour images for all other long range modelling locations are attached in Appendix D.

As can be seen from the horizontal and vertical contour figures, the received noise levels at far-field locations vary at different angles and distances from the source locations. This directivity 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.

In general, the bathymetry profiles with significant upslope section across the continental slope region have the sound propagations experiencing significant attenuation due to the strong interaction between the sound signal and the seabed. The bathymetry profiles with downslope section have much less sound attenuation. These effects are evident in all locations for propagation paths towards shoreline directions.

For all source locations and except for downslope sections, the seabed depth variations are not significant along the propagation paths within the deep-water region. Therefore, the directivity of received noise is dominated by the directionality of the source array.

Figure 16 Modelled maximum SEL (unweighted and maximum level across water column) contours for source location L1 to a maximum range of 200 km, overlayed with bathymetry contour lines. Coordinates in WGS 84/UTM Zone 33S.

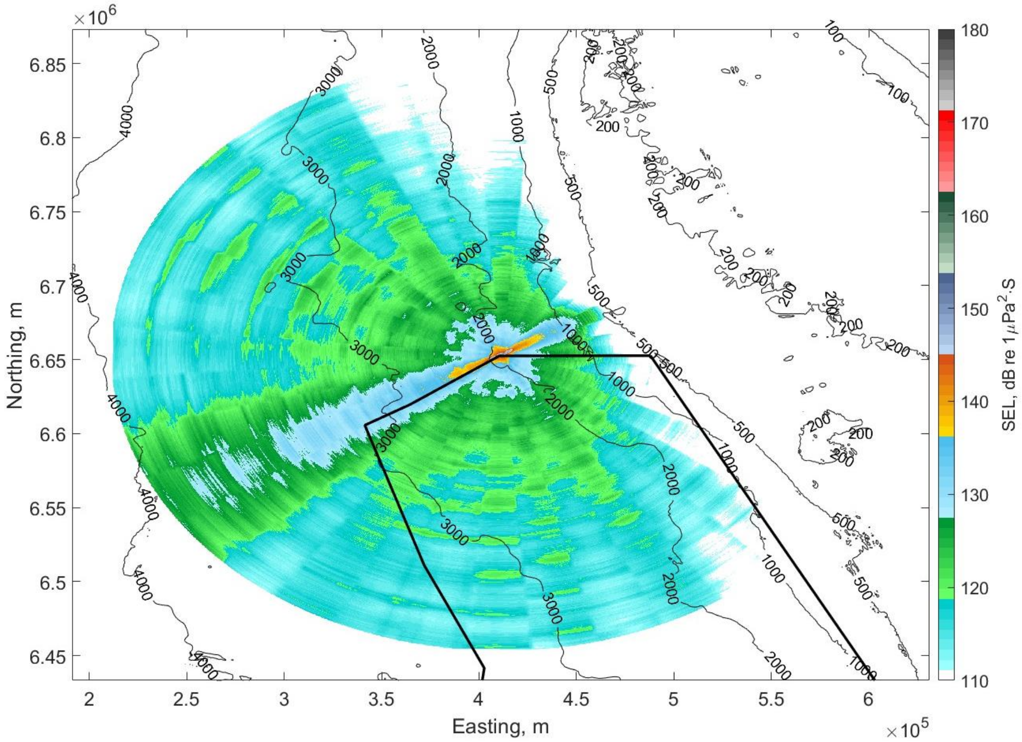
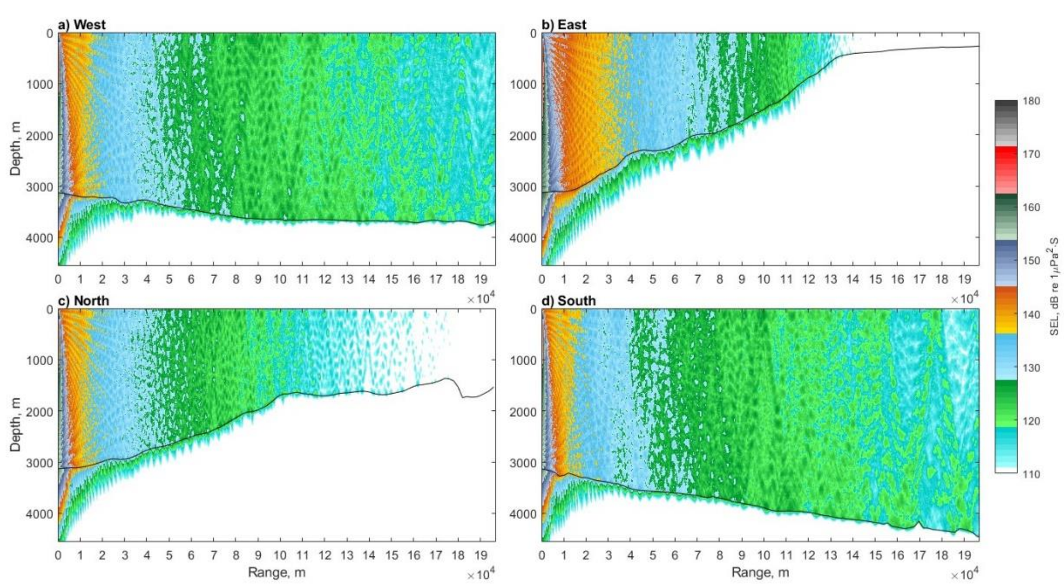


Figure 17 Modelled SELs (unweighted) vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L1. Black line shows the seabed depth.



5.3 Cumulative SEL Modelling

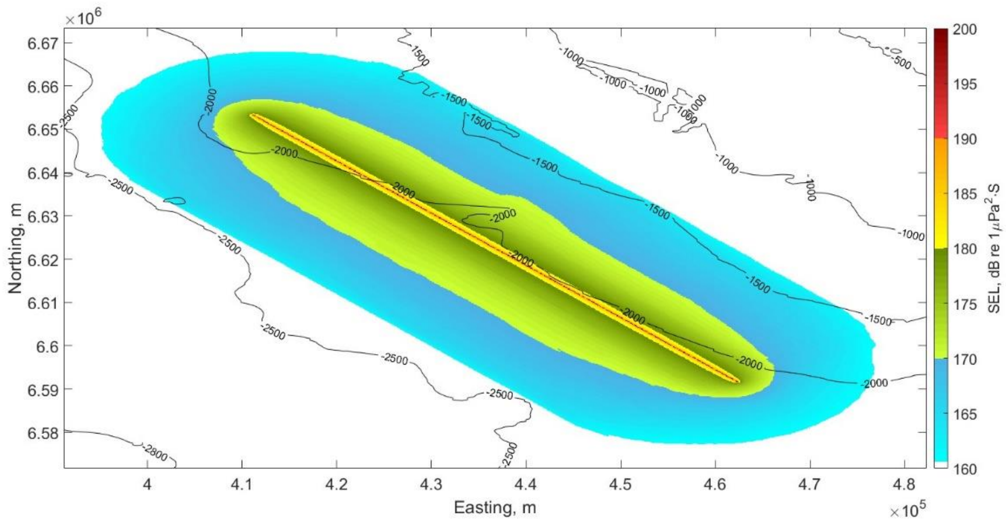
The sound exposure contributions from adjacent survey shots vary with the distances from the receiving locations to the survey line. From the short range modelling results as presented in Section 5.1, sound exposure level from a survey shot received at a receiving location with a distance of 1.0 km is 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 metre 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 the 24-hour survey operation scenarios as described in Section 4.2.3.1, based on the modelling methodology and procedure as laid out in Section 4.2.3, 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 survey scenario S1 of the 3D seismic survey is presented in Figure 18. All other survey scenarios are attached in Noise Modelling Figures

Figure 18 The predicted maximum unweighted SEL_{24hr} across the water column for assessed survey scenario S1 (Line 1) for the 3D survey



5.4 Zones of Impact -Immediate Exposure from Single Pulses

Based on the noise modelling prediction results presented above, the single pulses immediate exposure zones of impact (i.e., maximum horizontal threshold distance from array source location/survey lines) for marine fauna species of interest are summarized as follows.

Table 11 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 11 The maximum SELs, Pk SPLs and RMS SPL across the water column for all azimuths as a function of distance from the source array for water depth range within the 3D 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 µPa²·s	Pk SPL, dB re 1µPa	RMS SPL, dB re 1µPa
10	213	237	224
20	207	231	218
50	194	218	205
80	191	214.5	201.5
100	189	213	200
200	182	206	193
500	174	198	185
800	170	194	180
1 000	168	192	178
2 000	162	185	170
4 000	156	180	163

The zones of impact from seismic surveys based on per-pulse SEL, Pk SPL and RMS SPL metrics are estimated and presented in **Table 12** for PTS and TTS effects for marine mammals, **Table 13** for fish, **Table 14** for sea turtles, and **Table 15** for behavioural disturbance for marine mammals and sea turtles.

5.4.1 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 arrays due to the immediate exposure to individual pulses. Based on zones of impact estimated Pk-SPL metric criteria as in **Table 12** marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within approximately 50 m from the 3D source array at all assessed water depth scenarios. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 325 m from the 3D 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 100 m from the source array. The maximum zones of TTS effect for very-high-frequency cetaceans are predicted to be within 650 m from the array source as presented in **Table 12**.

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 12 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	45	213	90
High-frequency cetaceans (HF)	230	21	224	27
Very-high-frequency cetaceans (VHF)	202	325	196	650
Sirenians (SI)	226	25	220	40
Phocid carnivores in water (PCW)	218	50	212	100
Other marine carnivores in water (OCW)	232	19	226	24

5.4.2 Fish Physiological Effects

For seismic surveys, as presented in **Table 13**, the zones of potential injuries for fish species with a swim bladder, fish eggs and fish larvae are predicted to be within 180 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 90 m from the airgun array source.

Table 13 Zones of immediate impact from single 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	90	>213	90
Fish: swim bladder is not involved in hearing (particle motion detection)	>207	180	>207	180
Fish: swim bladder involved in hearing (primarily pressure detection)	>207	180	>207	180
Fish eggs and fish larvae	>207	180	-	-
Note: A dash indicates the threshold is not applicable.				

5.4.3 Sea Turtle Physiological Effects

The sea turtles are predicted to experience PTS effect in the close proximity to the source array due to the immediate exposure to individual pulses within approximately 19 m. The maximum zones of TTS due to a single pulse exposure for sea turtles are predicted to be within approximately 24 m from the array source as presented in Table 14.

Table 14 Zones of immediate impact from single seismic airgun array pulses for PTS and TTS – sea turtles

Type of animal	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
Sea turtles	232	19	226	24
Note: A dash indicates the threshold is not applicable.				

5.4.4 Marine Mammal, 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 15 below.

The results show that behavioural disturbance caused by the immediate exposure to individual pulses are predicted to be within 3.8 km from the array source for marine mammals of all hearing groups, and within 1.3 km from the array source for sea turtles.

Based on the noise exposure criteria provided by Popper et al. (2014), relatively high to moderate behavioural risks are expected for fish species 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 15 Zones of immediate impact from single seismic airgun array pulses 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	3,800
Sea turtles	175	1,300

5.5 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 an assumed survey scenario for the 3D survey.

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 16** presents the cumulative PTS and TTS effects for marine mammals, and **Table 17** the cumulative mortality, injury and TTS effects for fish; and **Table 18** the cumulative PTS and TTS effects for sea turtles.

5.5.1 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 16**. The zones of PTS impact are predicted to range up to 340 m from the source location, from the adjacent survey lines for the relevant typical 24-hour survey operation scenarios considered, and the maximum zone of TTS impact is predicted to be around 5 km from their relevant adjacent survey lines.

The cumulative PTS and TTS criteria SEL_{24hr} are predicted not to be exceeded for high-frequency cetaceans, sirenians and other marine carnivores in water.

The cumulative PTS criteria SEL_{24hr} are predicted to be exceeded for both very-high-frequency cetaceans and phocid carnivores in water, with zones of impact within 40 m from the adjacent survey lines. For very-high frequency cetaceans the zones of TTS impact are predicted to range around 1,200 m from the source location, and for phocid carnivores in water around 500 m from the source location, from the relevant 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. Thus, cumulative effects would only be expected where the animals do not move away from the area, e.g., from specific coastal areas used as calving sites of from feeding focal points such as Tripp Seamount. As Tripp Seamount is approximately 70 km from the north point of the survey area, cumulative effects would not be expected.

Table 16 Zones of cumulative impact from multiple airgun array pulses of the 3D survey 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 µPa²·s	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183	340	168	5,050
High-frequency cetaceans (HF)	185	-	170	-
Very-high-frequency cetaceans (VHF)	155	40	140	1,200
Sirenians (SI)	203	-	175	-
Phocid carnivores in water (PCW)	185	10	170	500
Other marine carnivores in water (OCW)	203	-	188	-
Note: A dash indicates the threshold is not reached.				

5.5.2 Cumulative impacts for fish

As presented in **Table 17,** the zones of potential mortal injuries for fish species with a swim bladder, fish eggs and fish larvae are predicted to be within 30 m from the adjacent survey lines for all the 24-hour survey operation scenarios considered. For recoverable injury, the zones of impact are predicted to be within 80 m from the adjacent survey lines for fish with a swim bladder for all the operation scenarios considered. Fish without swim bladder are not expected to suffer or any potential injury. The zones of TTS effect for fish species with and without swim bladders are predicted to be within 2.9 km, from the adjacent survey lines for the 24-hour survey operation scenario considered.

Existing experimental data regarding recoverable injury and TTS impacts for fish eggs and larvae is sparse and no guideline recommendations have been provided. However, based on a subjective approach as indicated in **Table 3**, noise impacts related to recoverable injury and TTS on fish eggs and larvae are expected to be moderate at the near field from the source location. Impact is expected to be low for all of them at intermediate and far field from the source location.

Table 17 Zones of cumulative impact from multiple airgun array pulses of 3D surveys for mortality and recovery injury– fish, 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 µPa^2·s	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	219	-	216	-	186	2,900
Fish: swim bladder is not involved in hearing (particle motion detection)	210	10	203	80	186	2,900
Fish: swim bladder involved in hearing (primarily pressure detection)	207	30	203	80	186	2,900
Fish eggs and fish larvae	210	10	-	-	-	-
Note: A dash indicates the threshold is not applicable.						

5.5.3 Cumulative impacts for sea turtles

Noise impacts related to recoverable injury and TTS on sea turtles are expected to be high at the near field from the source location as shown in **Table 18** maximum zones of PTS impact are predicted to range within 10 m from the source location, from the adjacent survey line for the relevant typical 24-hour survey operation scenario considered. The maximum zones of TTS impact are predicted to be around 500 m.

Table 18 Zones of cumulative impact from multiple airgun array pulses of the survey for PTS and TTS – sea turtles

Type of animal	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 µPa^2·s	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m
Sea turtles	204	10	189	500

6.0 Discussion

As detailed in **Section 2.0**, 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 12** and **Table 16** are presented in **Table 19**. 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 19 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 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria applied - Pk SPL, dB re 1 µPa / Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183 Weighted SEL_{24hr}	340	168 Weighted SEL_{24hr}	5,050
High-frequency cetaceans (HF)	230 Pk SPL	21	224 Pk SPL	27
Very-high-frequency cetaceans (VHF)	202 Pk SPL	325	140 Weighted SEL_{24hr}	1,200
Sirenians (SI)	226 Pk SPL	25	220 Pk SPL	40
Phocid carnivores in water (PCW)	218 Pk SPL	50	170 Weighted SEL_{24hr}	500
Other marine carnivores in water (OCW)	232 Pk SPL	19	226 Pk SPL	24

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 13** and the zones of TTS impact from seismic surveys for fish species based on cumulative impact criteria SEL as in **Table 17**.

For sea turtles, the combined zones of impact from seismic surveys based on the noise criteria for PTS and TTS are presented in **Table 14** and **Table 18**.

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, such as marine mammals, fish species and sea turtles, 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 cannot move away (e.g., plankton and fish eggs/larvae).

Therefore, the zones of impact assessed for marine mammals, fish species and sea turtles represent the worst-case consideration.

6.1 Recommended Management Measures

This section includes recommended management measures from seismic survey activities related to zones of impact and implementation of a noise monitoring programme and soft-starts.

- Noise Monitoring Programme – a best practice to minimize the potential for deliberate injury to marine mammal by monitoring a defined area (safety zone) before a noise source is activated and delaying operations in the event a marine mammal is observed.
- Safety zones – these are observation and shut-down zones sized based on the likely noise levels produced by the seismic activity.
- Soft-starts – these procedures are recommended for all seismic activities, irrespective of location and time of year, when marine mammal species may potentially be present within the noise footprint of the seismic activity.

6.1.1 Noise Monitoring Programme

Baseline noise measurements can provide useful information (prior to operations) when interpreting underwater noise predictions for the introduction of a new noise source. As such, it is recommended that underwater noise measurements be implemented which would include the deployment of underwater sound monitoring equipment to establish an actual baseline prior to the commencement of the survey and then operational levels of noise during the survey.

Additionally, monitoring can be further achieved through a combination of visual and passive acoustic methods. No marine mammal detection method is 100% effective for all species, rather it is considered that these methods seek to complement each other.

Visual monitoring is done by a Marine Mammal Observer (MMO). It should be done from the source vessel with the MMO located on a suitable platform that allows the best view of the safety zone and ahead of the vessel.

The use of Passive Acoustic Monitoring (PAM) is a viable monitoring method during operation periods when effective visual monitoring (due to poor visibility conditions or during night) is not possible. Specialist trained PAM operators are needed to set up and deploy the equipment and to interpret detected sounds.

6.1.2 Safety Zones

Recommended safety zones around the survey vessel and seismic array based on the seismic activity to be performed:

- Immediate Exposure from Single Pulses – refer to maximum threshold distances in PTS for marine mammals and sea turtles, and potential mortal injury for fish.

- Cumulative Exposure from Multiple Pulses - refer to maximum threshold distances in PTS for marine mammals and sea turtles, and potential mortal injury for fish.

6.1.3 Soft-Starts

Implement a soft-start procedure if testing multiple seismic sources. The soft-start should be carried out over a time proportional to the number of seismic sources being tested and not exceed 20 minutes; source arrays should be tested in order of increasing volume.

- If testing the seismic source at full operational capacity, a 20-minute soft-start is required.
- If testing a single lowest power source, a soft-start is not required.
- Delay soft-starts if shoaling large pelagic fish, turtles, or marine mammals are observed within the zone of impact.
- A soft-start should not begin until 30 minutes after cetaceans depart the zone of impact or 30 minutes after they are last seen or acoustically detected in the zone of impact.
- Schedule soft-starts to minimise, as far as possible, the interval between reaching full power operation and commencing a survey line. The period between the end of the soft start and commencing with a survey line must not exceed 20 minutes.

6.1.4 Cumulative impacts from multiple simultaneous survey campaigns

In the unlikely event that multiple surveys would take place at the same time within the same survey area, the risk of cumulative noise impact must be considered and is suggested to be managed as follows:

- The maximum number of simultaneous surveys in the entire survey area would be limited to three;
- Each of the additional activities to that described in this report would be modelled or otherwise considered in terms of the cumulative noise level and with reference to the criteria described in this report; and
- During airgun releases, each survey vessel is at least 40 kilometres from any other survey vessel until sufficient objective evidence is obtained to demonstrate that a reduced buffer distance is acceptable.

Note: This 40km buffer maintained by any other survey vessels aligns to advice by authorities[4] *and is considered sufficient on the basis that it provides a corridor between vessels where airgun noise approaches ambient levels such that animals may pass between, and/or the potential cumulative effect beyond this distance is considered to be negligible. Further modelling is only considered required in the case where a 40 km buffer distance between active survey ships cannot be maintained.*

[4] U.S. Department of the Interior Bureau of Ocean Energy Management 2014, Proposed Geological and Geophysical Activities, Mid-Atlantic and South Planning Areas, Final Programmatic Environmental Impact Statement, Gulf of Mexico OCS Region. New Orleans, https://www.loc.gov/item/2014450290/ Volume 1, Section 2.2.2.3; p2-37.

7.0 Statement of Limitations

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8.0 Closure

SLR trusts this report meets the requirements to assist EIMS with regulatory approval of the Environmental and Social Impact Assessment. If you have any questions, please do not hesitate to contact Jonathan Vallarta or Justin Eickmeier at the information below:

Sincerely,

On behalf of SLR Consulting Australia Pty Ltd.

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Appendix A Acoustic Terminology

TGS: South Africa Orange Basin 3D Seismic Survey

Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

SLR Project No. 675.30163.00000

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Acoustic Terminology

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
Decibel (dB)	The decibel (abbreviated dB) is the unit used to measure the intensity of a sound on a logarithmic scale.
Peak Sound Pressure Level (Pk 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 (Pk-Pk 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
Power Spectral Density (PSD)	PSD describes how the power of a signal is distributed with frequency
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
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
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
Sound Speed Profile	A graph of the speed of sound in the water column as a function of depth
Source Level (SL)	The acoustic source level is the level referenced to a distance of 1 m from a point source

Appendix B Auditory Weighting Functions

TGS: South Africa Orange Basin 3D Seismic Survey

Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

SLR Project No. 675.30163.00000

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Auditory Weighting Functions

This appendix provides the recommended frequency-weighting functions for use in assessing the effects of relatively intense sounds on hearing. This information is derived based on all available relevant data and published literature (i.e., the state of current knowledge).

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.

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., 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 (2016) and are consistent with the U.S. National Oceanic and Atmospheric Administration (NOAA) technical guidance (NMFS, 2016 & 2018). Finneran et al. (2017) revised the auditory-weighting functions for sea turtle (TU). Audiogram slopes were calculated across a frequency range of one octave for five species (refer to Appendix C) with composite audiograms based on experimental data.

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

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.

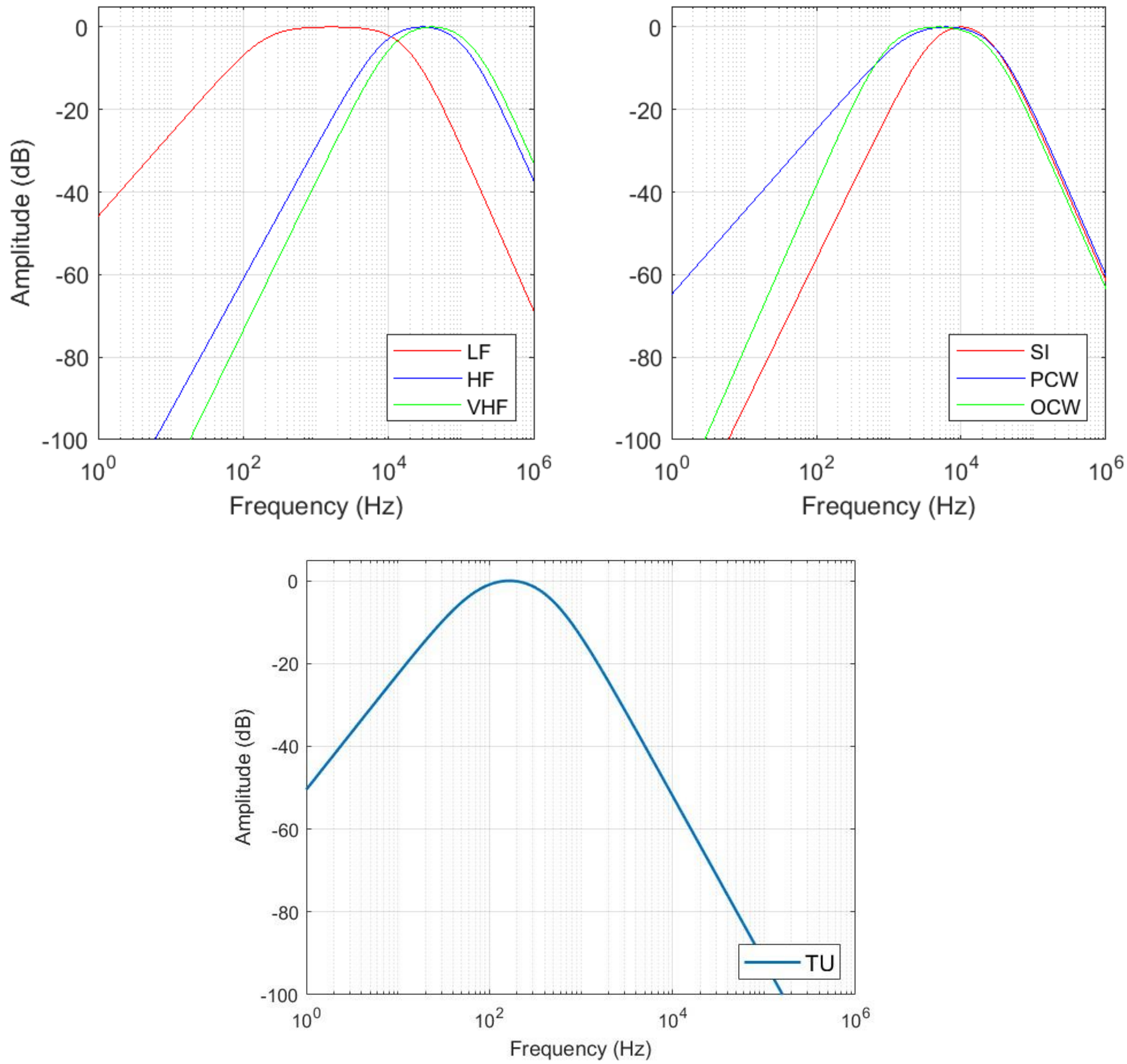
C is the constant that defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Table B.1 lists the auditory weighting parameters as defined above for the seven hearing groups. The corresponding auditory weighting functions for all hearing groups are presented in Figure B.1.

Table B.1 Auditory weighting functions - parameters (Southall et al. 2019; Finneran et al. 2017)

Marine mammal hearing group	*a*	*b*	*f1 (kHz)*	*f2 (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
Sea turtles (TU)	1.4	2	0.077	0.44	2.35

Figure B.1 Auditory weighting functions – spectral plots (Southall et al. 2019; Finneran et al. 2017)



Appendix C Marine Mammal Classification

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Marine Mammal Classification

The following appendix gives a summary of marine mammal hearing group classification and sea turtles. Not all animals listed in Table C.1 are expected to be found in the vicinity of the project area.

Table C.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*

Classification	Common Name	Scientific Name
	Hector's beaked whale	*Mesoplodon hectori*
	Deraniyagala's beaked whale	*Mesoplodon hotaula*
	Layard's beaked whale	*Mesoplodon layardii*
	True's beaked whale	*Mesoplodon mirus*
	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*

Classification	Common Name	Scientific Name
	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*
	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*

Classification	Common Name	Scientific Name
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*
	Harbor seal	*Phoca vitulina*
	Caspian seal	*Pusa caspica*
	Ringed seal	*Pusa hispida*
	Baikal seal	*Pusa sibirica*

Classification	Common Name	Scientific Name
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*
Sea Turtles (extracted from Finneran *et al.*, 2017)	Green sea turtle	*Chelonia mydas*
	Kemp's ridley sea turtle	*Lepidochelys kempii*
	Loggerhead sea turtle	*Caretta*
	Leatherback sea turtle	*Dermochelys coriacea*
	Hawksbill sea turtle	*Eretmochelys imbricata*

Appendix D Noise Modelling Figures

TGS: South Africa Orange Basin 3D Seismic Survey

Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

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Noise Modelling Figures

Figure D.1 Modelled maximum SEL (unweighted and maximum level across water column) contours for source location L2 to a maximum range of 200 km, overlayed with bathymetry contour lines. Coordinates in WGS 84/UTM Zone 33S.

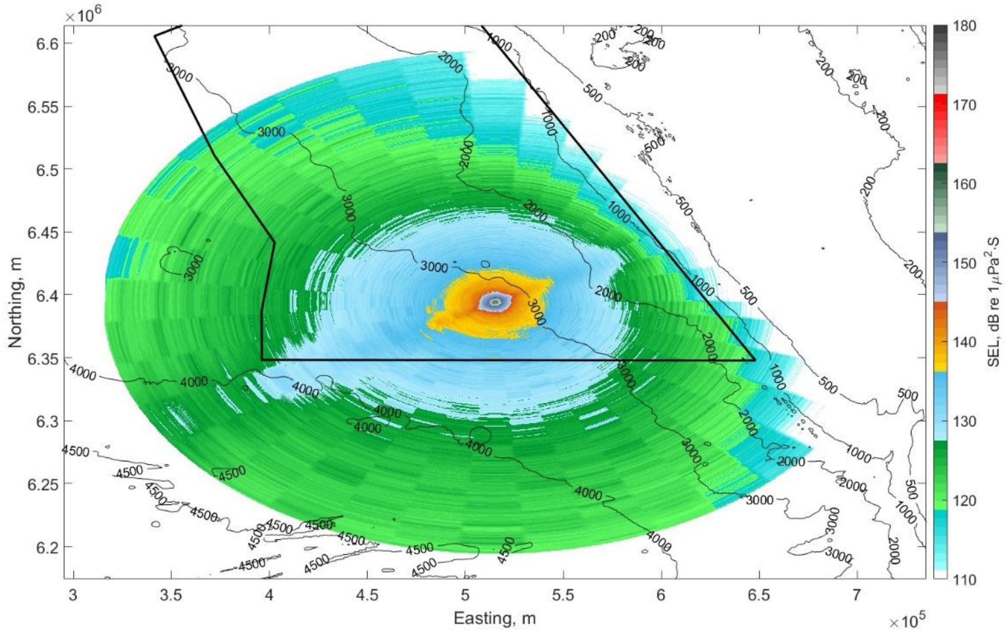


Figure D.2 Modelled maximum SEL (unweighted and maximum level across water column) contours for source location L3 to a maximum range of 200 km, overlayed with bathymetry contour lines. Coordinates in WGS 84/UTM Zone 33S.

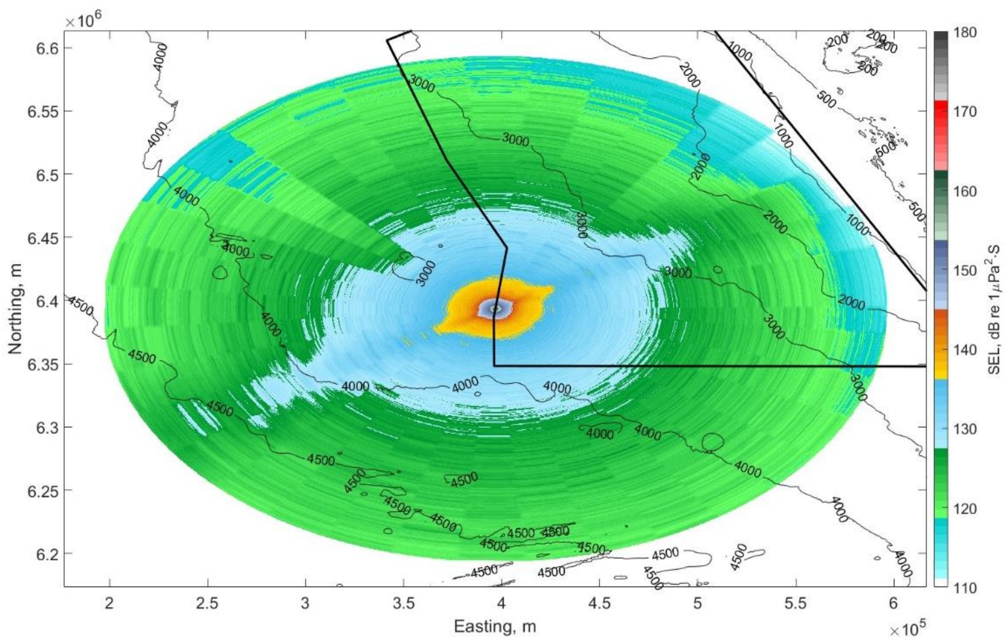


Figure D.3 Modelled SEL (unweighted) vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L2. Black line shows the seabed depth.

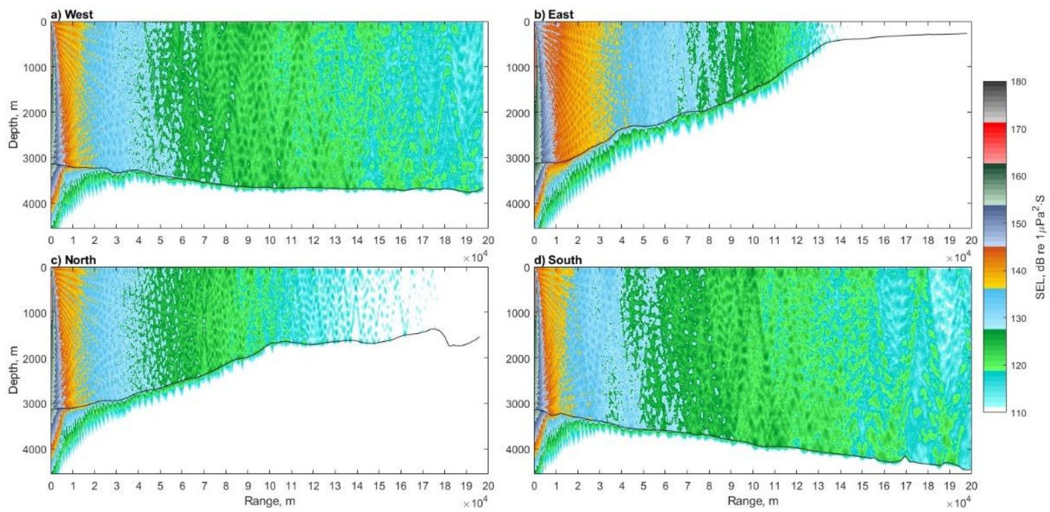


Figure D.4 Modelled SEL (unweighted) vs range and depth along the propagation path towards a) west b) east c) north and d) south direction from the source location L3. Black line shows the seabed depth.

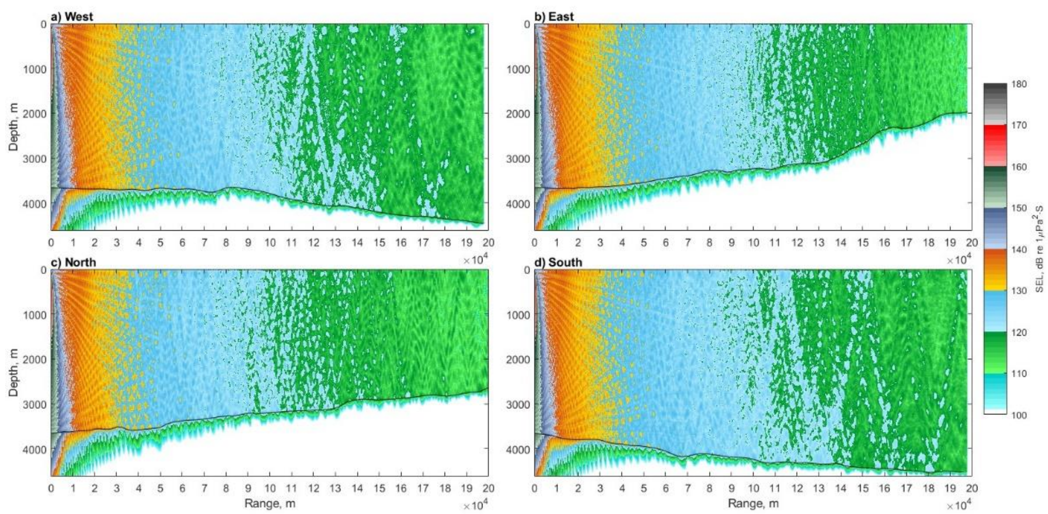


Figure D.5 The predicted maximum unweighted SEL_{24hr} across the water column for assessed survey scenario S2 for the 3D survey

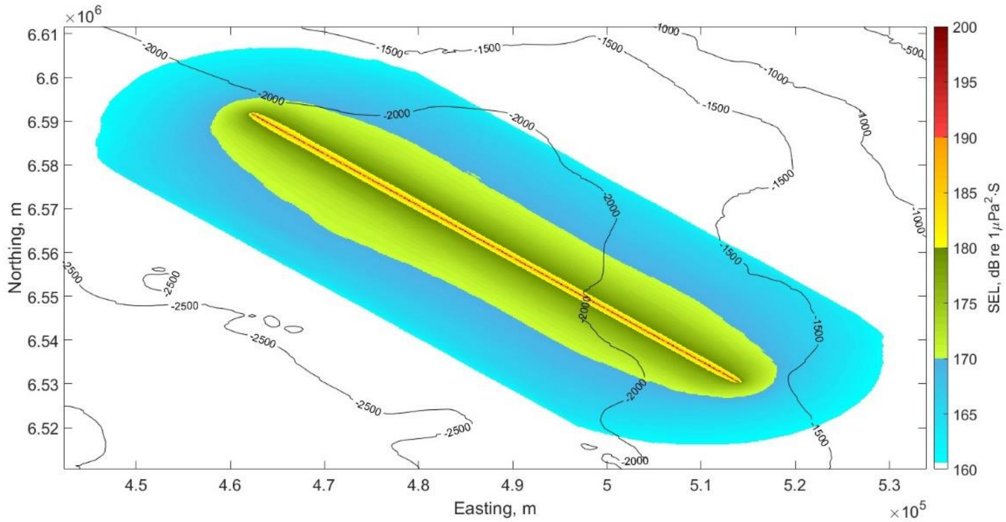
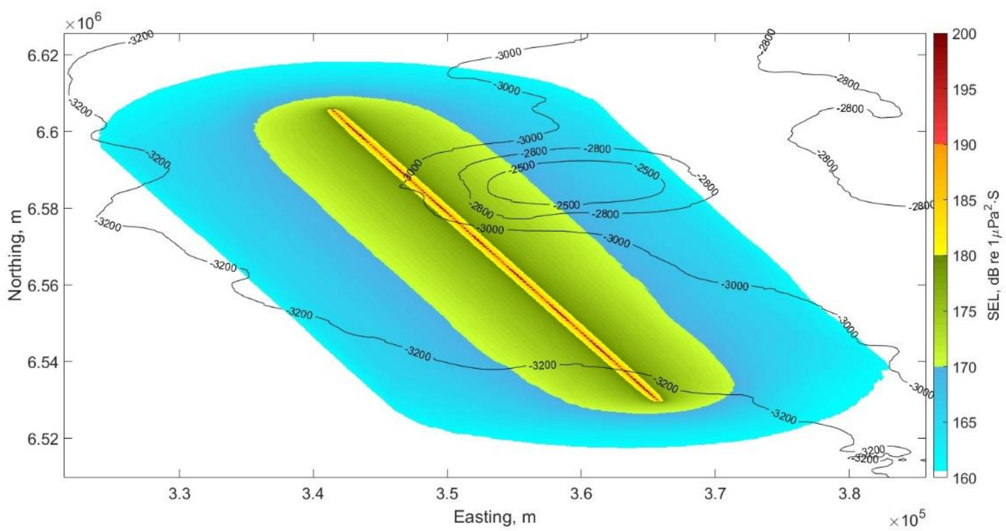


Figure D.6 The predicted maximum unweighted SEL_{24hr} across the water column for assessed survey scenario S3 for the 3D survey



JONATHAN VALLARTA, Ph.D.

Underwater Acoustics Business Lead

EDUCATION

- Ph.D., School of Engineering and Physical Sciences, Heriot-Watt University, UK 2009
- B.Eng., Electronics & Communications (Hons), Ibero-American University Mexico 2001
- B.Sc., Biological Sciences, National Autonomous University of Mexico, 1999

EXPERTISE

- Underwater acoustics
- Passive Acoustic Monitoring
- PAM Localization
- Hydrophone-Arrays: design, implementation, and deployment
- Noise and wildlife
- Noise impact assessments
- Environmental noise monitoring
- Computer noise modeling

CERTIFICATIONS

- Basic Safety Course for Rigs and Mobile Offshore Units
- Mexican Seamans Book
- Medical Fit Certificate
- Master Suba Diving, NAUI

MEMBERSHIPS

- Acoustical Society of America, ASA
- International Association Impact Assessment, IAIA
- Mexican Society of Marine Mammals, SOMEMMA

Dr. Jonathan Vallarta has eighteen years of experience in underwater acoustics in a wide range of positions including teaching, design, project management, acoustic consulting, and collaborative research. His expertise is in the design of new configurations for hydrophone arrays and development of localization algorithms using passive sonar techniques to track the migratory patterns of cetaceans in areas where there is increased anthropogenic activity. He has considerable experience providing training courses in fundamentals of underwater noise and monitoring techniques.

Jonathan joined SLR in January 2020 and is based in Vancouver. His previous experience includes running a passive acoustic monitoring business, while lecturing several university courses and consulting for JASCO Applied Sciences over four years. Jonathan holds a Ph.D. from Heriot-Watt University in Edinburgh, Scotland, awarded for research into the significance of passive acoustic array configuration on sperm whale range estimation.

Jonathan has published numerous papers in academic journals and presented at various international conferences. In June 2018, his expertise was recognized as an invited panellist and as Mexican advisor to the United Nations Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS) at the headquarters of the United Nations in New York. He has a particular interest in marine conservation issues, particularly in reference to threatened species, noise pollution and mitigation.

SELECT PROJECT EXPERIENCE

UNDERWATER ACOUSTICS PROJECTS

- **3D Seismic Survey Underwater Noise Modeling, West Coast of South Africa**
  Detailed underwater sound propagation modeling for 3D seismic survey activities were performed to assist with the assessment of a new source array with two high-volume active elements proved to have less impact on marine fauna species of interest (in terms of maximum zones) than the conventional airgun array.
- **Cumulative Effects of Marine Shipping on Esquimalt Nation Territory, Canada**
  The study analyzed numerous automatic identification system transits from 2019 of recreational and commercial vessels in the Salish Sea. Several peer-reviewed papers, and regional reports relevant to the impacts of underwater noise from commercial vessels on marine mammals were reviewed and assembled into a literature review matrix based on topics relevant to Esquimalt Nation.
- **2D Seismic Survey Underwater Noise Modeling, East Coast of South Africa**
  Detailed underwater sound propagation modeling for 2D seismic survey activities were performed to assist with the assessment of potential noise impact on marine fauna species of interest. The noise modelling results were then used to identify zones of impact for marine mammals and other species of concern based on relevant noise impact assessment criteria.
- **Tugboats Towing Drill Rig Underwater Noise Modeling, Cook Inlet, Alaska**
  Technical study on the underwater noise emissions from tugboats in various scenarios in Cook Inlet, Alaska. It included sound propagation modelling, understanding the range of different noise levels produced by tugs, and the distances at which tug noise is predicted to exceed impact assessment thresholds for marine mammals.
- **Offshore Wind Underwater Noise Impact Assessment, Lake Ontario**
  Technical study on underwater noise issues relevant to the project, identifying the relevant regulations and criteria and provided an assessment of potential project

underwater noise impacts from dredging and tugboat noise specifically for the installation of 66 gravity base structures for turbine generators.

- **TOTAL Mozambique LNG Underwater Noise Analysis**
  Analysis and review of underwater noise impacts due to the construction of the Mozambique LNG project on Tungue Bay. Included an independent review of two modelling reports, analysis and recommendations of available piling noise attenuation options, verification of the impact of sound pressure thresholds on human divers and interpretation of the extent to which underwater noise levels may affect the catch rates for local fishermen, in mitigated and un-mitigated scenarios.
- **Alaska LNG, Cook Inlet, Alaska**
  Detailed frequency and range dependent underwater noise propagation modelling to identify the extent of project construction noise impacts on marine mammals, including the endangered Cook Inlet beluga whale. Included model validation with reference to historical measurements in Cook Inlet, and investigation of the sensitivity of results to variations in environmental parameters used as model inputs to determine realistic areas above defined thresholds.
- **Monitoring the Soundscape of Coral Reef, Cozumel, Mexico**
  A Passive Acoustic Monitoring (PAM) survey was conducted in the Paradise Coral Reef of Cozumel to obtain 1) the first scientific recording of the endangered splendid toadfish vocalizations; 2) record the volume and source of anthropogenic sounds on the coral reef; and 3) estimate possible impacts of anthropogenic noise (masking and exposure) on splendid toadfish. The project involved the deployment of PAM equipment by scientific personnel and scuba divers. Noise mitigation recommendations were provided to local authorities.
- **Sound Characterization of Pile Driving, Virginia, USA**
  Sound characterization of different test piling noise levels during the construction of a harbour terminal in Thimble Shoal, Virginia, USA. Assessment of marine and fish noise impacts and potential for project cumulative impacts.
- **Acoustic Modelling for VSP Offshore Operations, Australia**
  Acoustic modelling for assessing marine fauna sound exposures during Vertical Seismic Profiling (VSP) operations for the CarbonNet Offshore appraisal in Australia. The acoustic modelling included the use of parabolic equation and ray tracing methods.
- **Marine Mammal Acoustic Detections, Chukchi Sea, Artic**
  A five-year project in the northeast of the Chukchi Sea that included passive acoustic detections of bowhead whale and other marine mammals, while seismic exploration activities occurred during summer season every year. A passive acoustic localization algorithm was implemented to assess the impact of anthropogenic noise on the migration patterns of bowhead whale.
- **Modern LNG Carrier Sound Source Characterization, Trinidad**
  Underwater acoustic monitoring at one of the LNG port sites of Trinidad in order to obtain a sound source characterization of modern LNG carriers. The emphasis of this project was due to the lack of data registered and the need to acoustically model the noise levels of a new LNG station in Canada.
- **Acoustic Modelling and Monitoring of the Tappan Zee Bridge, New York**
  Underwater acoustic monitoring during the pile installation project of the new Tappan Zee Bridge. The project included both underwater acoustic modelling and monitoring as a validation method for the different pile driving tests. Assessment of several mitigation techniques, such as different types of bubble curtains, were also modelled and monitored.
- **Underwater Acoustic Monitoring of Power Plant, Dominican Republic**
  Underwater passive acoustic monitoring of an active Power Plant close to offshore in the Dominican Republic. The initiative came along from the need to explore the noise level impacts on manatees and fish. Noise mitigation recommendations were given to local authorities and project managers.

UNDERWATER ACOUSTICS WORKSHOPS

- **SOMEMMA, La Paz-Baja California 2021**. A one-day virtual acoustic workshop based in La Paz, Baja California to train scientists in PAMGuard software as the preamble to the international meeting for the study of marine mammals "Research, Conservation Foundation".
- **TRITON Environmental Consultants, Vancouver-BC 2020.** A two-day acoustic workshop based in Vancouver to train three scientists in PAMGuard software to engage in acoustic monitoring of offshore dredging in Prince Rupert, BC.
- **Edgewise Environmental, St John's-Newfoundland 2019.** A four-day acoustic workshop based in St. John's to address the need to train new passive acoustic monitoring operators to engage in seismic exploration vessels in the Arctic Sea.
- **TALOS Energy, Villahermosa-Tabasco 2019**. A two-day acoustic workshop based in Villahermosa to train two new passive acoustic monitoring operators to engage in VSP offshore operations in the Gulf of Mexico by TALOS Energy Company.
- **CICESE, Ensenada-Baja California 2018**. A three-day acoustic workshop based in Ensenada to address the specific needs of a Center for Scientific Research and Higher Education, CICESE.
- **PAMOS, Mexico City-Mexico 2015-2017.** A three-day acoustic workshop based in Mexico City to address the need to train new passive acoustic monitoring operators to engage in seismic exploration vessels in the Gulf of Mexico.

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- Vallarta J. 2009. *'The Significance of Passive Acoustic Array-Configuration on Sperm whale Range Estimation when using the Hyperbolic Algorithm'.* PhD thesis in Underwater Acoustics, Ocean Systems Laboratory, School of Engineering and Physical Sciences, Heriot-Watt University Edinburgh, UK.
- Vallarta J. 2007. *3D Passive Acoustic Localization -Homogeneous Vs Non-homogeneous Medium.* 17th Biennial Conference on the Biology of Marine Mammals, Cape Town, South Africa.
- Vallarta J., McHugh R. and Record P. 2007. *The effect of different array-configurations on the accuracy of passive acoustic location of cetaceans.* Proceedings of the Institute of Acoustics, Fourth International Conference on Bio-Acoustics, Loughborough, UK, 29(3):141-148.
- Vallarta J. 2005. *The effect of Passive Acoustic Array Configuration and Element Aberrations on Cetacean Localisation*. 16th Biennial Conference on the Biology of Marine Mammals. San Diego, Cal. USA.

CO-AUTHOR OF PUBLICATIONS AND REPORTS

- Pyć, C. D., Vallarta, J., Rice, A. N., Zeddies, D. G., Maxner, E. E., & Denes, S. L. 2021. *Vocal behavior of the endangered splendid toadfish and potential masking by anthropogenic noise.* Conservation Science and Practice, e352.
- Denes, S., Vallarta, J., and D. Zeddies. 2019. *Sound Source Characterization of Down-the-Hole Hammering: Thimble Shoal, Virginia*. Document 001888, Version 1.0. Technical report by JASCO Applied Sciences for Chesapeake Tunnel Joint Venture.
- McPherson, C., Z, Li and J. Vallarta. 2018. *VSP Operations for the CarbonNet Offshore Appraisal Well: Acoustic Modelling for Assessing Marine Fauna Sound Exposures.* Document 01706, Version 1.0. Technical report by JASCO Applied Sciences for AGR Australia Pty Ltd.
- Mouy, X., Oswald, J., Leary, D., Delarue, J., Vallarta, J., Rideout, B., Mellinger, D., Erbe, C., Hannay, D., and Martin, B., 2013. *Passive Acoustic Monitoring of Marine Mammals in the Arctic (Chapter 9). In: Detection, Classification and Localisation of Marine Mammals using Passive Acoustics; 2003–2013: 10 years of International Research.* Dirac NGO, Paris. France.
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- Martin, B., A. MacGillivray, J. MacDonnell, J. Vallarta, T. Deveau, G. Warner, D. Zeddies, and X. Mouy. 2012. *Underwater Acoustic Monitoring of the Tappan Zee Bridge Pile Installation Demonstration Project: Comprehensive Report.* JASCO Document 00355, Version 1.2. Technical report for AECOM by JASCO Applied Sciences.
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- Lucke, K, B. Martin, C. Erbe, D. Leary, J. Vallarta, N.E. Chorney, and C. McPherson. 2011. *Potential Impact and Mitigation of Pile-Driving Noise at Cape Lambert: A Review of the Literature and International Regulations.* JASCO Document 00241, Version 4.0. Report for Sinclair Knight Merz by JASCO Applied Sciences.
- Martin, B, MacDonnell, J, Vallarta, J, Lumsden, E and Burns, R. 2011*. HYWIND Acoustic Measurement Report: Ambient Levels and HYWIND Signature.* Technical report for Statoil by JASCO Applied Sciences.
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JUSTIN EICKMEIER, Ph.D.

Underwater Acoustics Team Lead

EDUCATION

- University of Delaware

  Ph.D. Oceanography (Acoustical Oceanography) 2009 - 2016

- Florida Institute of Technology

  MS in Ocean Engineering (Ocean Instrumentation), 2007 – 2009

  BS in Ocean Engineering (Hydrographic Surveying), 2003 - 2007

EXPERTISE

- Underwater acoustics
- Underwater noise modelling
- Target localization using beamforming methods
- Passive acoustic monitoring
- Physical oceanography
- Ocean engineering
- Ocean instrumentation
- Advanced signal processing
- Data analysis
- High-performance computational methods with large data sets

SOFTWARE SKILLS

- Matlab (GPU and Parallel Processing)
- dBSea (underwater sound transmission loss modelling)
- Large (multiple TBs) dataset analysis
- BELLHOP (ray tracing)
- Parabolic Equation & Normal Modes Modelling

Dr. Justin Eickmeier is an experienced researcher and consultant with nine years of graduate studies and three years of post-doctoral work in Acoustical Oceanography at the University of Delaware. He joined SLR's underwater acoustics team in February 2019 and has quickly become involved in managing and delivering underwater noise consulting projects, specifically marine mammal impact assessments. In addition to underwater acoustics projects, he has supported the wider SLR acoustics group in a signal processing/data analyst role. Beginning in June 2019, he was on a 1-year secondment to the Port of Vancouver's ECHO (Enhancing Cetacean Habitat and Observation) program and continues to provide technical support on underwater acoustics. At the start of 2022, Justin took on the role of Underwater Acoustics Team Lead for SLR Canada.

Before joining SLR, Dr. Eickmeier's research focus areas were collecting and analyzing acoustical and ocean environmental data from the Arctic (Beaufort Sea) during the Canadian Basin Acoustic Propagation Experiment (CANAPE). His field research experience followed the completion of BS and MS degrees in Ocean Engineering at the Florida Institute of Technology, specializing in hydrographic surveying and ocean instrumentation, respectively.

Dr. Eickmeier has participated in numerous research cruises in the Arctic and elsewhere in the Atlantic and Pacific. His role on these projects has included working autonomously or in small teams, designing, deploying, and recovering multi-sensor oceanographic moorings, undertaking acoustic monitoring using hydrophone arrays, and analyzing acoustic data, including marine mammal detections, ambient noise, and contributions from anthropogenic noise sources. He specializes in managing large data sets collected during long-term (multi-year) monitoring experiments.

His substantial experience in underwater acoustics complements Dr. Eickmeier's background in oceanography, ocean engineering, and instrumentation. His technical skills include underwater noise propagation modelling and prediction, measurement and monitoring, data processing and analysis, impact assessment, mitigation, and control.

SELECTED PROJECT EXPERIENCE

- **Hilcorp, Tugboat Underwater Noise in Cook Inlet, Alaska 2021**

  Technical study predicting the underwater noise emissions from tugboats in various marine construction scenarios in Cook Inlet, Alaska. This study was prepared to understand the range of different noise levels produced by tugs and the distances at which tug noise is predicted to exceed impact assessment thresholds for marine mammals.

- **Baird, Technical Advice on Underwater Noise for Offshore Wind Project, Ontario 2021**

  The Windstream Wolfe Island Shoals Wind Energy Project is located 5 km off the southwest shore of Wolfe Island, in Lake Ontario. This technical advice report describes underwater noise issues relevant to the project, identifies relevant regulations and criteria, and assesses potential underwater noise impacts via sound transmission loss modelling for wind turbine installation,

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including marine construction, dredging, dynamic position systems, and transits of commercial vessels.

- **Hilcorp Cook Inlet Exploration Drilling, Alaska 2019**
  SLR International Corporation prepared an environmental impact analysis of Hilcorp's proposed four-well 2020 outer continental shelf exploration drilling program in the Cook Inlet. As project manager and technical lead for SLR Canada's portion of the assessment, a desktop study identifying the baseline noise environment and the underwater noise impacts of the proposed activities (drill rig tow, impact pile driving, drilling, and vertical seismic profiling) considering marine mammal behavioral disturbance thresholds was undertaken.

- **Vancouver Fraser Port Authority Enhancing Cetacean Research and Observation (ECHO) Program, British Columbia 2019 - 2022 (ongoing)**
  - Technical guidance to program managers within the ECHO Program
  - Salish Sea ambient noise study and best practices report
  - Evaluation of underwater radiated noise from commercial vessels, quieting technology, energy savings devices, and hybrid propulsion systems.

- **Confidential Client Offshore Seismic Survey, Brazil 2019**
  Project manager for a desktop underwater noise impact assessment, predicting extents of various zones of marine mammal impact during a large-scale offshore seismic survey. Project requirements included coordinating SLR team members in Australia and Canada and working on a tight schedule to meet client targets.

- **Lehigh Hanson Materials, British Columbia 2019 & 2021**
  Data analyst supporting ongoing airborne noise monitoring for a quarry in Sechelt, British Columbia (2019). Data collection and analysis for a 2-week overnight airborne noise study (2021).

- **TransLink, British Columbia 2019**
  Data analysis and signal processing support for ongoing SkyTrain noise mitigation studies, including axle box vibration data analysis to infer rail surface conditions).

RESEARCH EXPERIENCE

- **Post-Doctoral Research, University of Delaware, 2016 - 2018**

  Advanced signal processing of broadband acoustic data and water column measurements in shallow water environments. Specialization in managing large data sets (including multi-year experiments) and high-performance computational methods.

  Dr. Eickmeier has extensive experience with beamforming (array localization) from multi-hydrophone arrays and modelling with rough boundary conditions and range-dependent environmental parameters using ray tracers, normal modes, and parabolic equation models.

  A passive acoustic study of soniferous fish and marine mammals in Delaware Bay included the acoustic classification of several species of fish native to Delaware Bay and the acoustic signatures of short-nosed common dolphins during daily feeding cycles.

  The design, fabrication, and deployment of 7 environmental arrays were completed for a year-long study in the Beaufort Sea. Array lengths spanned from 150 to 700 m, including 10 to 30 thermistors, 2 CTDs per mooring, and tandem acoustic release kits. High-frequency sampling rates on thermistors allowed for investigation of the acoustic waveguide, while low pass filtering matched time scales of fluctuations in upwelling and sub-mesoscale eddy formation.

SELECT PUBLICATIONS

- Eickmeier, J., Tollit, D., Trounce, K., Warner, G., Wood, J., MacGillivray, A. and Zizheng Li (2021) Salish Sea Ambient Noise Study: Best Practices (2021). Vancouver, British Columbia, Vancouver Fraser Port Authority, Enhancing Cetacean Habitat and Observation (ECHO) Program, 50pp. DOI: http://dx.doi.org/10.25607/OBP-1068
- Eickmeier, J. and Badiey, M., (2018) Influence of Short Time-Scale Water-Column Temperature Fluctuations on Broadband Signal Angular Beam Spreading. J. Marine Sci. App. DOI: https://doi.org/10.1007/s11804-018-0020-x
- Badiey, M., Eickmeier J., and Song A. (2014) Arrival-time fluctuations of coherent reflections from surface gravity water waves. J Acoust Soc Am 135(5): EL226–EL231. DOI: https://doi.org/10.1121/1.4871577
- Ainslie, M., Martin S., Trounce, K., Hannay, D., Eickmeier, J., Deveau, T., Lucke, K., MacGillivray, A., Nolet, V., and P. Borys (2022). International harmonization of procedures for measuring and analyzing of vessel underwater radiated noise. Marine Pollution Bulletin 174: 113124 (2022).
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