AOSAC: Exploration Drilling Campaign in Block 3B/4B

Underwater Sound Transmission Loss Modelling

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Making Sustainability Happen

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Executive Summary

Africa Oil South Africa Corp (AOSAC) is considering undertaking an offshore exploration drilling campaign of up to five appraisal wells within the Block 3B/4B license area of interest off the west coast of South Africa.

AOSAC has appointed Environmental Impact Management Services (Pty) Ltd (EIMS) as the Independent Environmental Practitioner to undertake the Environmental Impact Assessment (EIA) process for the proposed exploration activities. In order to assess the potential noise impacts on marine fauna, SLR Consulting (Canada) Ltd (SLR) has been commissioned to undertake a Sound Transmission Loss Modelling (STLM) study to determine the zones of impact for relevant marine fauna species of interest.

This report provides a STLM study and assessment of relevant zones of impact associated with the proposed exploration drilling campaign activities. The study involves the following:

- Establishment of relevant assessment criteria for marine fauna species likely to be potentially impacted by the exploration drilling activities;
- Characterisation of the existing underwater noise environment based on a literature review of the general ocean noise environment and the site-specific shipping traffic conditions;
- Description of the acoustic signature and noise emission characteristics of the vertical seismic profiling (VSP) airgun, well drilling sources, and sonar survey;
- Detailed modelling prediction of underwater noise propagation; and
- Assessment of subsequent zones of impact for different marine faunal groups.

Noise impact criteria have been established via a review of the most relevant guidelines and literature. These criteria include physiological and behavioural impacts on marine fauna, including marine mammals, fish, fish eggs, fish larvae, and sea turtle species.

Detailed modelling predictions have been undertaken for noise emissions from impulsive and non-impulsive signals. The zones of noise impact have been estimated for different marine faunal species based on comparisons between STLM noise levels and noise impact criteria for three deep-water source location scenarios.

Assessments of relevant zones of impact for physiological (i.e., hearing impairment) and behaviour responses are detailed in Section 7.0. The zones of impact assessment for the study are summarised below.

Impacts from VSP Airgun Pulses

A single airgun of 150 cubic inches (CUI) is proposed to be used for the VSP operations. The airgun has a depth of 8,0 m and an operating pressure of 450 pounds per square inch (PSI). The source levels for the VSP G-GunII array show peak sound pressure levels (Pk SPL, dB re 1 µPa @ 1 m) of 226 dB; root mean square pressure levels (RMS SPL, dB re 1 µPa @ 1 m) of 2 208,5 dB; and sound exposure level (SEL, dB re µPa^2·s @ 1 m) of 206 dB.

Marine mammals of all hearing groups are predicted to experience permanent injury (PTS) within approximately 60 m from the VSP airgun for immediate exposure. If exposed continuously to multiple VSP pulses (i.e., 50 pulses), only low-frequency (LF) cetaceans may experience PTS within 40 m from the VSP source, but if the number of VSP pulses increases to

125, the predicted distances to PTS exposure may increase to less than 20 m for the phocid carnivores in water (PCW) or pinnipeds (e.g., seals).

Very-high-frequency cetaceans are the group most susceptible to experiencing (temporary injury) TTS from a single VSP pulse. LF cetaceans are the marine mammal hearing group with the greatest zones of TTS impact for cumulative VSP pulses reaching up to 220 m (from the source) for 125 pulses.

The zones of potential injuries for all fish species, including fish eggs and fish larvae, are predicted to be within 40 m from a single VSP pulse. The zones of impact for cumulative exposure to either 50 or 125 pulses are within 40 m for potential mortal and recoverable injuries for all fish species. Zones of impacts for cumulative noise related to recoverable injury and TTS on fish eggs and larvae are expected to be moderate at the near field (tens of meters) from the source location and low for intermediate and far-field distances from the source location.

Turtles are predicted to not experience PTS from short-term exposure. They are predicted to experience TTS for less than 20 m from the noise source. If the 125 VSP pulses scenario is considered, turtles may experience TTS for greater zones of impact (up to 80 m).

Behavioural response caused by a single VSP pulse exposure is predicted to occur up to 580 m from the VSP source for marine mammals, up to approximately 2,24 km for fish, and within 80 m for turtles.

It should be noted that the cumulative impact at a specific receiving location was modelled based on the assumption that the marine animals are constantly exposed to multiple VSP pulses at a fixed location over the cumulative operation 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 or from feeding focal points (if located in the project area).

Impacts from Well Drilling Operations

The proposed semi-submersible drillship for this campaign is the Maersk Venturer. The maximum drilling water depth of the ship is ~12 000 m. It has 6 Wartsila DP3 5.5 MW thrusters. It also has dynamic positioning capabilities. The noise emissions from the drillship are predominantly generated by propeller and thruster cavitation especially when the dynamic-positioning system is operating, with a smaller fraction of sound produced by transmission through the hull, such as by engines, gearing, and other mechanical systems. The overall noise level from combined noise emissions from drillship and up to three support vessels is approximately 198,8 dB re 1 µPa @ 1 m (or dB re 1 $\mu Pa^2 \cdot S$ @ 1 m).

Marine mammals of all hearing groups except other marine carnivores in water (OCW) group (e.g., sea lions) are predicted to experience PTS within 60 m from the drilling operations for the 0.5-hour duration scenario considered. The LF and VHF cetacean groups are more susceptible to experience TTS than the rest of the marine mammal hearing groups. If continuous exposure increases to 24 hours duration (as the worst case) all marine mammal hearing groups may experience PTS. The onset of TTS due to continuous exposure for 24 hours may increase the maximum distances for LF and VHF cetaceans up to approximately 2,7 and 8,2 km from the source respectively.

No cumulative impact from the non-impulsive drilling noise sources is expected on fish species.

Turtles are predicted to experience PTS from short-term exposure (i.e., 0.5 hours) within 20 m from the drilling operations and TTS up to 60 m. However, if the exposure continues (i.e., 24 hours), turtles are predicted to experience TTS up to 320 m from the source.

Behavioural disturbance caused by immediate exposure to well drilling operations is predicted to occur up to approximately 27,5 km from the source for marine mammals, up to 420 m for fish, and 60 m for turtles.

The continuous scenario of 24 hour assumes that a receptor, i.e., marine animal, remains in proximity to (continuously moves with) the moving support vessel for a period of 24 hours, and thus remains within the impact zone. scenario. Realistically, marine animals would not stay in the vicinity of the vessel for the entire period. Therefore, the cumulative zones of impact represent the worst-case consideration, and as the exposure time decreases, the impact (and distance to corresponding thresholds) decreases even faster.

Impacts from a single MBES Pulse

AOSAC is proposing to utilise an MBES (70-100 kHz) with a single beam echo-sounder (38-200 kHz) and a sub-bottom profiler (2-16 kHz). The system consists of a fully integrated wide swath bathymeter and a dual frequency side scan sonar. The Kongsberg EM 712 MBES system with similar specifications to those proposed by AOSAC is used here to model the planned sonar survey. The EM 712 MBES is a high-resolution seabed mapping system with a frequency range of 40 – 100 kHz. The source levels for the Kongsberg EM 712 MBES system show a Pk SPL of 240 dB, an RMS SPL of 237 dB, and a SEL of 210 dB.

Marine mammals are predicted to experience PTS at very close proximity to the MBES sources due to the immediate exposure to individual pulses. The maximum zones of TTS due to a single pulse exposure for marine mammals of all hearing groups are predicted to be within 124 m from the MBES source.

High-frequency sonar MBES sources are not expected to cause an adverse hearing impact on fish species. Noise impacts related to PTS and TTS on sea turtles are minimal (within 4 m) and are only expected to occur along the cross-track direction from the MBES source.

The modelling results show that the maximum impact distance for the behavioural response caused by the immediate exposure to individual MBES pulses is predicted to affect only marine mammals (up to 290 m) and turtles (within 70 m) in the cross-track direction.

Overall, modelling results show little variation for the different source locations less than 2 000 m in depth (L1, L2, L4, and L5). The greatest variation, due to the spherical sound propagation, was noted at the deepest source location (L3) and in some scenarios of the behavioural response at multiple source locations.

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Acronyms and Abbreviations

AOI	Area Of Interest
AOSAC	Africa Oil South Africa Corp
CUI	Cubic Inch
dB	Decibel(s)
EIMS	Environmental Impact Management Services
GEBCO	General Bathymetric Chart of the Oceans
G-Gun	Gundalf-Gun manufactured by Sercel
HF	High Frequency
LF	Low Frequency
NMFS	National Marine Fisheries Services
NOAA	National Oceanic and Atmospheric Administration
OBN	Ocean Bottom Node Acquisition
OCW	Other marine Carnivores in Water
PCW	Phocid Carnivores in Water
Pk	Peak
PSD	Power Spectral Density
PSI	Per Square Inch
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SI	Sirenians
SEL	Sound Exposure Level
SELcum	Cumulative Sound Exposure Level
SLR	SLR Consulting (Canada) Ltd.
SPL	Sound Pressure Level
STLM	Sound Transmission Loss Modelling
TTS	Temporary Threshold Shift
VHF	Very High Frequency

Acoustic Terminology

Term	Definition
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
Continuous noise	Noise with a sound pressure level that remains above ambient sound during the entire observation period (e.g., drilling, and vibratory pile driving).
Decibel (dB)	The decibel (abbreviated dB) is the unit used to measure the intensity of a sound on a logarithmic scale.
Far-field	The sound field at a distance from a sound source array where the wave fronts created by the individual sound sources are in phase
Impulsive noise	Noise that is typically very short (in seconds), broadband and has high peak pressure with rapid time and decay back to ambient levels (e.g., noise from pile driving, seismic airguns and explosives).
Intermittent noise	Noise that has interrupted levels or low or no sound or bursts of sound separated by silent periods. This type of noise has a more predictable pattern of burst of sounds and silent periods (e.g., scientific sonar, impact pile driving).
Near-field	The sound field near a sound source array where complex constructive and destructive interference occurs among the wave fronts created by the individual sound sources
Non-Impulsive noise	It is typically continuous and produce sounds that can be narrowband, or tonal, and brief or prolonged. It does not have the high peak sound pressure with rapid rise time typical of impulsive sounds (e.g., drilling, and vibratory pile driving).
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
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 Exposure Level Cumulative (SELcum)	SELcum is calculated by summing the cumulative pressure squared (p^2), integrating over time or number of signal events (if the individual signal events are the same), and normalizing to 1 second.
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 1 micro pascal (μPa).
Source Level (SL)	The acoustic source level is the level referenced to a distance of 1 m from a point source

1.0 Introduction

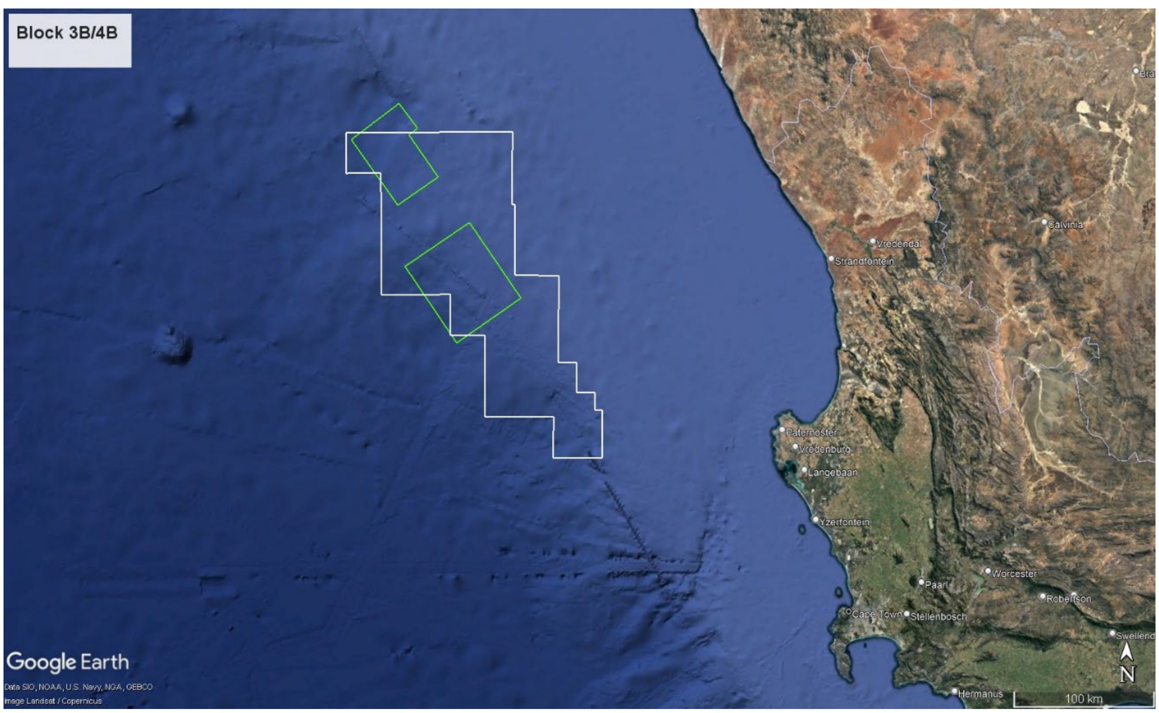
1.1 Project Background

Africa Oil South Africa Corp (AOSAC) is the operator for exploration license Block 3B/4B, which is located approximately 120 km west of St Helena Bay and approximately 145 km south-west of Hondeklip Bay off the West Coast of South Africa. The area of interest (AOI) is in the north of this block, but this could also cover other areas in future. The AOI for drilling within the license Block 3B/4B is 9 711.21 km^2 in extent. It is located offshore roughly between Port Nolloth and Hondeklip Bay, approximately 188 km from the coast at its closest point and 340 km at its furthest, in water depths between 1 000 m and 3 000 m (Figure 1).

AOSAC is considering undertaking an offshore exploration drilling campaign for up to five exploration wells within the AOI. The proposed exploration activities include:

- Offshore drilling for exploration/appraisal wells
- Vertical Seismic Profiling (VSP)

Figure 1: Locality of licence Block 3B/4B (white polygon) and AOI (green polygon) off the West Coast of South Africa



AOSAC has appointed Environmental Impact Management Services (Pty) Ltd (EIMS) as the Independent Environmental Practitioner to undertake the Environmental Impact Assessment (EIA) process for the proposed exploration activities. In order to assess the potential noise impacts on marine fauna, SLR Consulting (Canada) Ltd (SLR) has been commissioned to undertake a Sound Transmission Loss Modelling (STLM) study to determine the zones of impact for relevant marine fauna species of concern for the major noise sources associated with the proposed drilling programme.

1.2 Structure of the report

The methodology study for the proposed drilling activities within the 3B/4B Block off the west coast of South Africa includes the following modelling components:

- Vertical Seismic Profiling (VSP) modelling, i.e., modelling of sound energy emissions from the source proposed to be used in the VSP surveys, including the far-field signature and its power spectral density (PSD), as well as the beam pattern of the source.
- 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 sensitive marine areas, to assess the potential cumulative noise impact on marine fauna species of interest.
- Zones of impact, i.e., prediction for immediate exposure from single pulses and cumulative exposure from multiple pulses in order to assess noise impact on marine mammals, fish and sea turtle species.

The report content is summarised below:

- **Section 2.0** contains a description of the well drilling operations.
- **Section 3.0** of the report provides a summary of the existing underwater noise environment in the area, including shipping traffic.
- **Section 4.0** details relevant noise impact assessment criteria for marine fauna species of interest.
- **Section 5.0** outlines the methodologies and procedures for the exploration drilling modelling components (including vertical seismic profiling (VSP) testing, Sonar survey, and supporting vessel operations).
- **Sections 6.0** presents the STLM modelling results for the VSP and MBES modelling.
- **Section 7.0** includes the estimated zones of impact for marine fauna species of interest.
- **Section 8.0** provides a discussion of the acoustic modelling study.
- **Section 10.0** provides references cited in the report.

Additional technical information is provided in Appendices:

- **Appendix A** Classifications of various marine mammal hearing groups.
- **Appendix B** Explanation of marine mammal and sea turtle auditory weighting functions.
- **Appendix C** presents the noise contour figures for VSP and well drilling operation scenarios.
- **Appendix D** presents the noise results for MBES Pulse VSP modelling scenarios.

2.0 Exploration Well Drilling Operations Description

2.1 Vessel Activities

Drilling Unit

Various types of drilling technology can be used to drill an exploration well (e.g., barges, jack-up rigs, semi-submersible drilling units (rigs) and drill-ships) depending on the water depth and marine operating conditions experienced at the well site. Based on the anticipated sea conditions, AOSAC proposes utilizing a drillship (e.g., Venturer), with a dynamic positioning system suitable for the harsh deep-water marine environment.

A drillship is a purpose-built drilling vessel designed to operate in deep water conditions. The drilling "rig" is normally located towards the centre of the ship, with support operations from both sides of the ship utilizing fixed cranes. The advantages of a drillship over most semi-submersible units are that a drillship has much greater storage capacity and is independently mobile, not requiring any towing and a reduced complement of supply vessels.

Support Vessels

The drilling unit will be supported/serviced by two support vessels operating on expected service rotations each week, to facilitate the moving of equipment and materials between the drilling unit and the onshore base. A supply vessel will always be on standby near the drilling unit to provide support for firefighting, oil containment/recovery, and rescue in the unlikely event of an emergency and supply any additional equipment that may be required. Supply vessels can also be used for medical evacuations or crew transfer if needed.

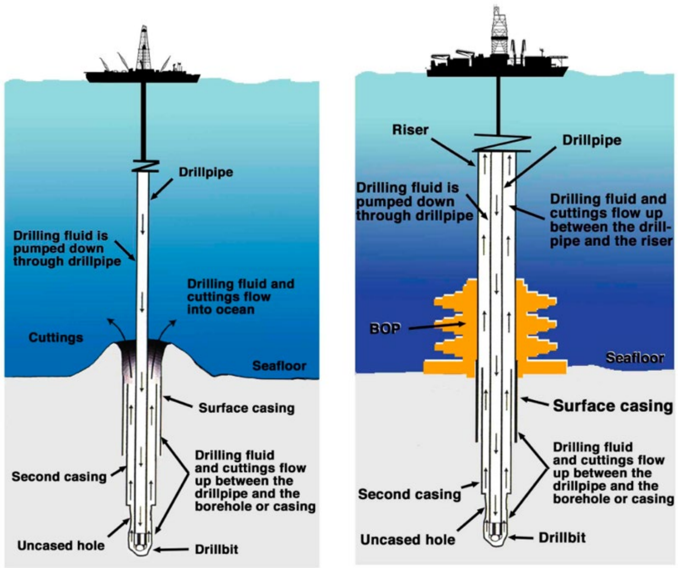
Helicopters

Transportation of personnel to and from the drilling unit by helicopter is the preferred method of transfer, and it is estimated that there will be at least four daylight flights (approximately 40 people) per week to and from the drilling unit and a suitable location nearby. If required, the helicopters can also be used for medical evacuations from the drilling unit to shore (at day- or night-time).

2.2 Seabed Drilling Sequences

The well will be created by drilling a hole into the seafloor with a drill bit attached to a rotating drill string, which crushes the rock into small particles, called "cuttings". After the hole is drilled, casings (sections of steel pipe), each slightly smaller in diameter, are placed in the hole and permanently cemented in place (cementing operations are described below). The expected target drilling depth is not confirmed yet, and a notional well depth, below the mudline, of 3 570 m is assumed at this stage. The hole diameter decreases with increasing depth. Drilling is essentially undertaken in two stages, namely the riserless and riser drilling stages (see Figure 2).

Figure 2: Riserless drilling stage (left) and riser drilling stage (right)

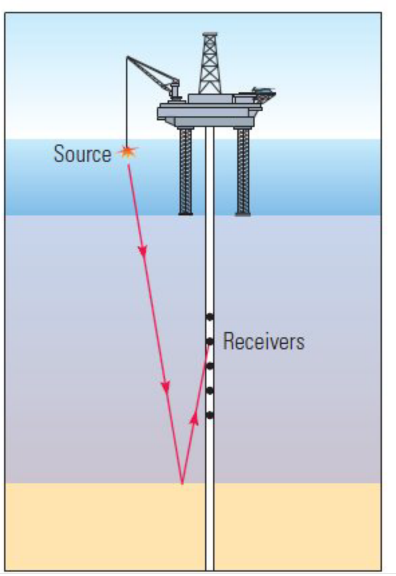


Source: http://www.kochi-core.jp/cuttings/

2.3 Vertical Seismic Profiling (VSP) Tool

Vertical Seismic Profiling (VSP) is an evaluation tool that would be undertaken as part of the conventional wireline logging programme when the well reaches target depth to generate a high-resolution seismic image of the geology in the well's immediate vicinity. The VSP images are used for correlation with surface seismic images and for forward planning of the drill bit during drilling. A typical VSP arrangement is provided in Figure 3.

Figure 3: Schematic of a typical VSP arrangement



Source: https://wiki.seg.org/wiki/Borehole_geophysics

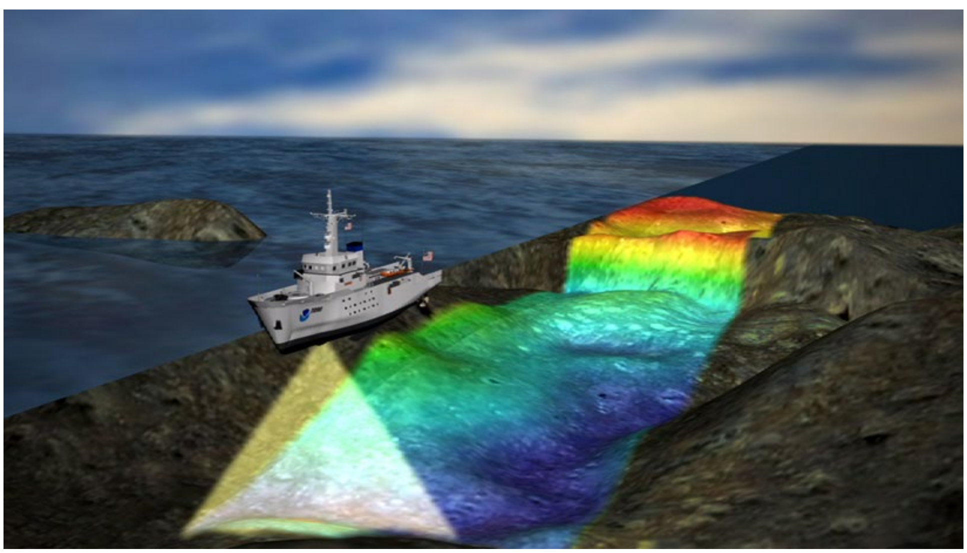
VSP uses a small airgun array, which is operated from the drilling unit. The airgun array is deployed between 6-7 m below sea level and has a gun pressure of 2 000 psi. During VSP operations, four to five receivers are positioned in a section of the borehole, and the airgun array is discharged approximately five times at 20 second intervals. The generated sound pulses are reflected through the seabed and are recorded by the receivers to generate a profile along a 60 to 75 m section of the well. This process is repeated as required for different stations in the well, and it may take up to 8 to 12 hours to complete approximately 250 shots, depending on the well's depth and the number of stations being profiled.

2.4 Sonar Survey

Accurate seafloor mapping is a key component of an integrated exploration and development program in the marine environment. Traditionally, bathymetry data used in the Oil and Gas Industry have been acquired using a single-beam echosounder technology, leaving large seafloor areas virtually unmapped. However, advances in multibeam sonar technology have improved lateral and vertical resolution seafloor mapping capabilities, providing complete and rapid coverage of the seafloor from multibeam-equipped vessels, as shown in Figure 4.

Multibeam Echosounder (MBES) data from numerous areas around the world have been used to produce highly detailed seafloor representations that have revealed the morphologically complex nature of the slope environment. In general, multibeam systems can acquire between 120 and 200 soundings per transmission pulse in a bandwidth of 3 to 7 times the water depth. The speed of the vessel during acquisition is limited only by the specified sounding space along the track and the acoustic characteristics of the vessel (Rutledge and Leonard 2001).

Figure 4: NOAA's vessel collecting seafloor mapping data using MBES



Source: https://www.usgs.gov/media/images/noaa-multibeam-mapping-diagram

3.0 Existing Underwater Noise Environment

3.1 Introduction to Underwater Noise Concepts

Sound is a form of energy made by vibrations. When an object vibrates, it causes the fluid particles around it to move. These particles collide with nearby particles, and this continues until they run out of energy.

In underwater acoustics, the word sound is used to describe all the pressure waves that are generated in an underwater medium. Sound waves propagate as alternate phases of compression and rarefaction. Compression occurs when molecules are pressed together. Rarefaction is just the opposite; molecules are allowed to expand.

There are two types of sound waves: transversal and longitudinal. Sound propagates from a source as a longitudinal wave. In a longitudinal wave, vibrations are parallel to the direction of the wave. Wavelength is the spatial distance between two successive peaks in a propagation wave; sound frequency is the number of waves passing through a fixed point per second.

Sound levels are typically reported in units of decibels (dB). The decibel is defined as a ratio of measured acoustic intensity and a reference intensity level and is expressed in a logarithmic scale. However, the sound is often measured as pressure rather than directly as intensity. The sound pressure level (SPL) indicates the amplitude level of sound at a specific location in space and is a scalar quantity. The level is dependent on the location and distance the sound is observed relative to a sound source. Sound pressure is measured in Pascals but can be computed in decibels. A standard reference pressure is used to compare sound levels given in decibels to one another. In underwater acoustics, the traditional standard reference pressure is 1 micro-Pascal (µPa), leading to the use of the unit dB re 1 µPa, which represents a decibel referenced to a pressure of 1 µPa.

Measurement type refers to how the pressure was measured. Root mean square (RMS) measures are essentially an average intensity over a given amount of time. Peak (Pk) SPL measurements simply measure the signal's maximum amplitude without considering time. Sound exposure level (SEL) is a measurement type that is applied to impulsive signals such as seismic pulses to determine their effect on marine fauna. It is the integration of sound energy produced from a source, normalized to the level necessary to produce that amount of energy in a single second. These values are reported with units of dB re 1 $\mu Pa^2 \cdot s$ and can represent the energy accumulated over a given time period (i.e., 24 hours).

Spectrum or spectra is the visual display of the frequency content of a sound signal. It shows how sound level varies when the frequency is given. The spectra are presented in third-octave bands (1/3-octave), which measure the sound level in frequency bands that widen exponentially with increasing frequency and are evenly spaced on a logarithmic frequency axis. In underwater acoustics, this is used to approximate the bandwidths of the marine mammals and turtle auditory systems.

3.2 General Ocean Ambient Noise

Acoustic cues are thought to be important to marine fauna in the perception of their environment as well as for navigation purposes, predator avoidance, and in mediating social and reproductive behaviour. Noise is generally an unwanted sound, a sound that clutters and masks other sounds of interest, such as those generated by marine fauna. Ocean ambient noise poses a baseline limitation on the use of sound by marine animals, as signals of interest must be detected against background noise. The level and frequency characteristics of the ambient noise environment are the two major factors that control how far away a given sound signal can be detected (Richardson et al. 2013).

Ocean ambient noise is comprised of a variety of sounds of different origins at different frequency ranges, with temporal and spatial variations. It primarily consists of noise from natural physical events, marine biological species, and anthropogenic sources (see Figure 5):

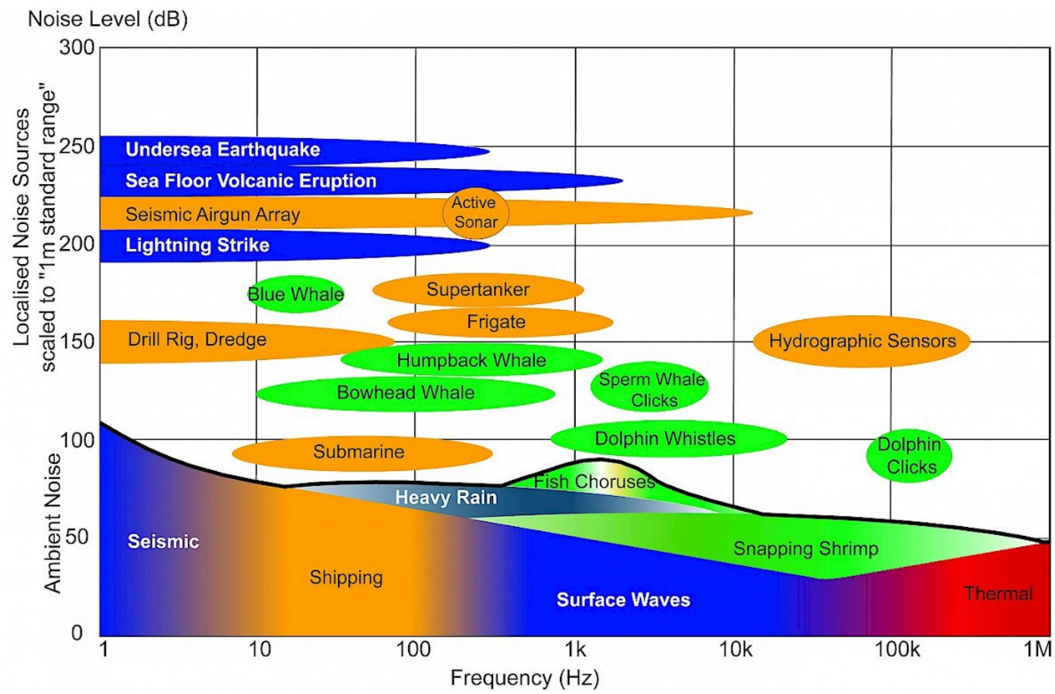
- Geophony: the major natural physical events contributing to ocean ambient noise include, but are not limited to, wave/turbulence interactions, wind, precipitation (rain and hail), breaking waves and seismic events (e.g., earthquakes/tremors):
  - The interactions between waves/turbulence can cause very low-frequency noise in the infrasonic range (below 20 Hz). Seismic events such as earthquakes/tremors and underwater volcanos also generate noise predominantly at low frequencies from a few Hz to a few hundred Hz;
  - Wind and breaking waves, as the prevailing noise sources in much of the world's oceans, generate noise across a very wide frequency range, typically dominating the ambient environment from 100 Hz to 20 kHz in the absence of biological noise sources. The wind-dependent noise spectral levels also strongly depend on sea states, which are essentially correlated with wind force; and
  - Precipitation, particularly heavy rainfall, can produce much higher noise levels over a wider frequency range of approximately 500 Hz to 20 kHz.
- Biophony: some marine animals produce various sounds (e.g., whistles, clicks) for different purposes (e.g., communication, navigation, reproductive displays, territorial defence, or detection and feeding):
  - Baleen whales (e.g., great whales like humpback whales) regularly produce intense low-frequency sounds (whale songs) that can be detected at long range in the open water. Odontocete whales, including dolphins, can produce rapid bursts of high-frequency clicks (up to 150 kHz) that are primarily for echolocation purposes;
  - Some fish species produce sounds individually, and some species also make noise in choruses. Typically, fish chorusing sounds depend on species, time of day and time of the season; and
  - Snapping shrimps are important contributors among marine biological species to the ocean ambient noise environment, particularly in shallow coastal waters. The noise from snapping shrimps is extremely broadband in nature, covering a frequency range from below 100 Hz to above 100 kHz. Therefore, snapping shrimp noise can interfere with other measurement and recording exercises; for example, it can adversely affect sonar performance.
- Anthrophony: anthropogenic noise primarily consists of noise from shipping activities, offshore seismic and drilling explorations, marine industrial developments, and operations, as well as equipment such as sonar and echo sounders:
  - Shipping traffic from various sizes of ships is the prevailing man-made noise source around nearshore port areas. Shipping noise is typically due to cavitation from propellers and thrusters, with energy predominantly below 1 kHz;
  - Pile driving and offshore seismic exploration generate repetitive pulse signals with intense energy at relatively low frequencies (hundreds of Hz) that can potentially

cause physical injuries to marine species close to the noise source. The full frequency range for these impulsive signals could be up to 10 kHz; and

- Dredging activities and other marine industry operations are additional man-made sources which generate broadband noise over relatively long durations.

An overview of the indicative noise spectral levels produced by various natural and anthropogenic sources relative to typical background or ambient noise levels in the ocean is shown in Figure 5. Human contributions to ambient noise are often significant at low frequencies, between about 20 Hz and 500 Hz, predominantly from distant shipping (Hildebrand 2009). Background noise at higher frequencies tends to be dominated by natural physical or bioacoustics sources such as rainfall, surface waves and spray, as well as fish choruses and snapping shrimp for coastal waters.

Figure 5: Levels and Frequencies of Anthropogenic and Naturally Occurring Sound Sources in the Marine Environment



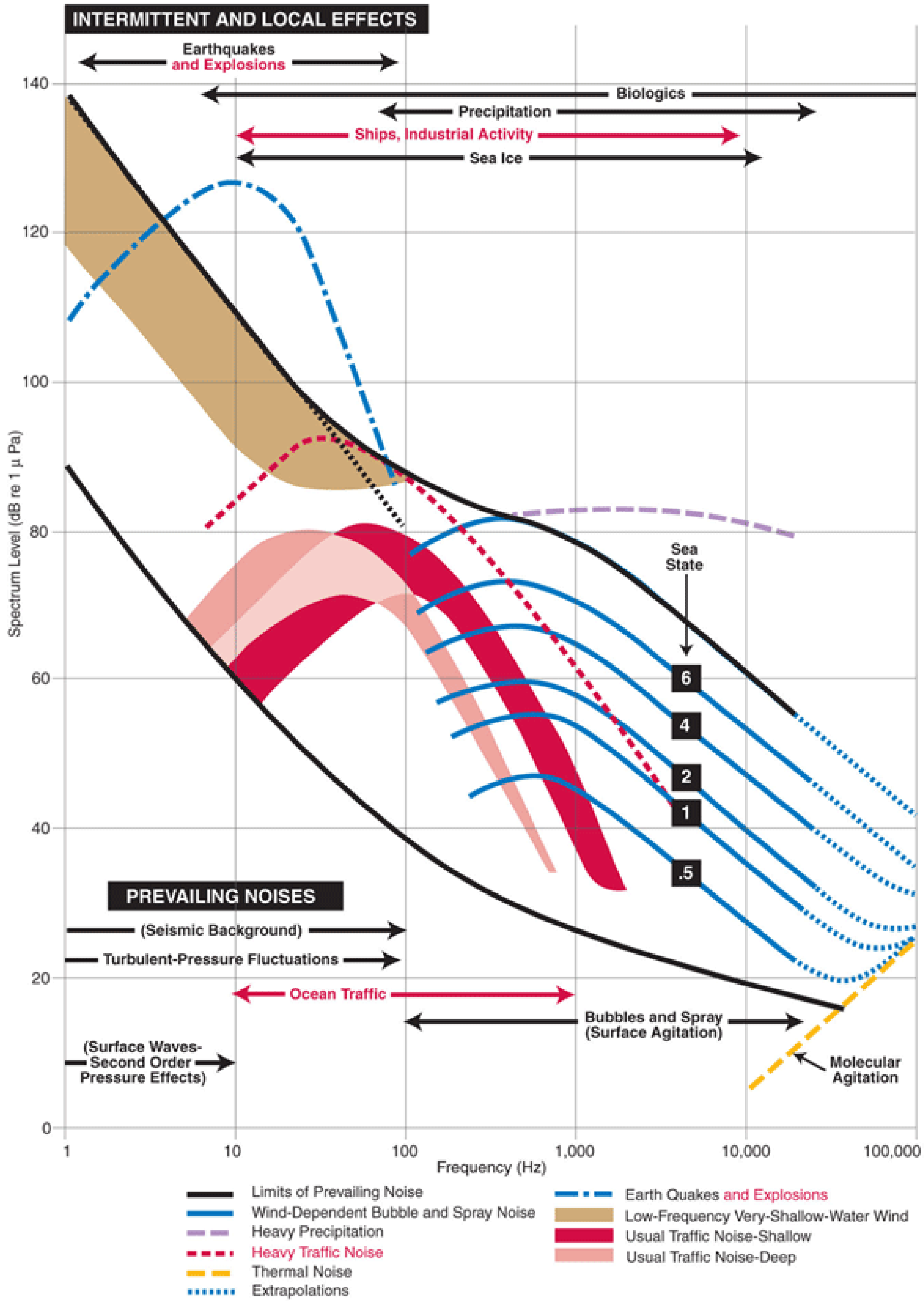
Source: from https://www.ospar.org/work-areas/eiha/noise. Notes: Natural physical noise sources are represented in blue; marine fauna noise sources are shown in green; human noise sources are shown in orange.

A summary of the spectra of various ambient noise sources, based on a review study undertaken by Wenz (1962), is shown in Figure 6. Although the spectral curves in the figure are based on average levels from reviewed references primarily for the North Atlantic Ocean, they are regarded as representative (in general) of the ocean ambient noise spectral components in the project region.

Ambient noise levels typically range:

- From as low as 80 dB re 1 μPa for the 10-10 kHz frequency range for areas with few shipping movements and calm sea surface conditions to;
- Up to 120 dB re 1 μPa for the 10-10 kHz frequency range for areas with moderate to heavy remote shipping traffic and medium to high wind conditions.

Figure 6: Spectra and Frequency Distribution of Ocean Sound Sources based on the Wenz Curves



Source: Miksis-Olds et al. 2013, adapted from Wenz (1962)

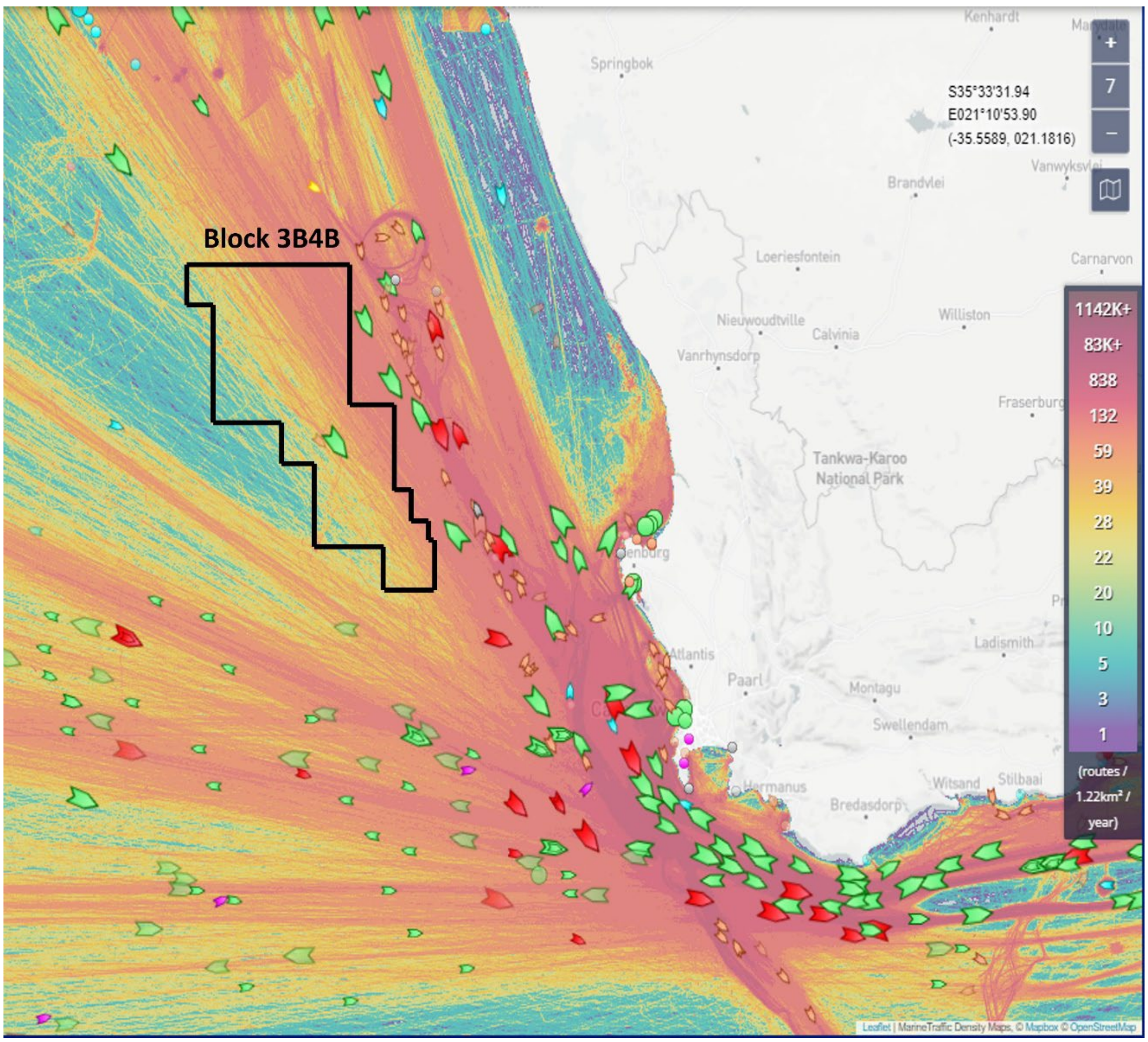
3.3 Ocean Ambient Noise in the Project Area

Shipping traffic is an important component of ocean ambient noise in the project area. Given the high shipping traffic in the drilling Block 3B/4B, the ambient noise levels are expected to be at least 20 dB higher than the lowest level, within 100 and 120 dB re 1 µPa for the 10-10 k Hz frequency range.

3.3.1 Shipping Traffic

Shipping traffic is the area's most notable anthropogenic source of ocean noise. As can be seen in Figure 7, Block 3B/4B has some shipping traffic density over the block area, in particular, through the eastern extent of the block. The shipping noise component of the ambient noise environment is expected to be significant within a larger part of the block area.

Figure 7: Shipping traffic density offshore West African coastal region and surrounding Block 3B/4B (black)



Source: http://www.marinetraffic.com/, accessed 1 October, 2023.

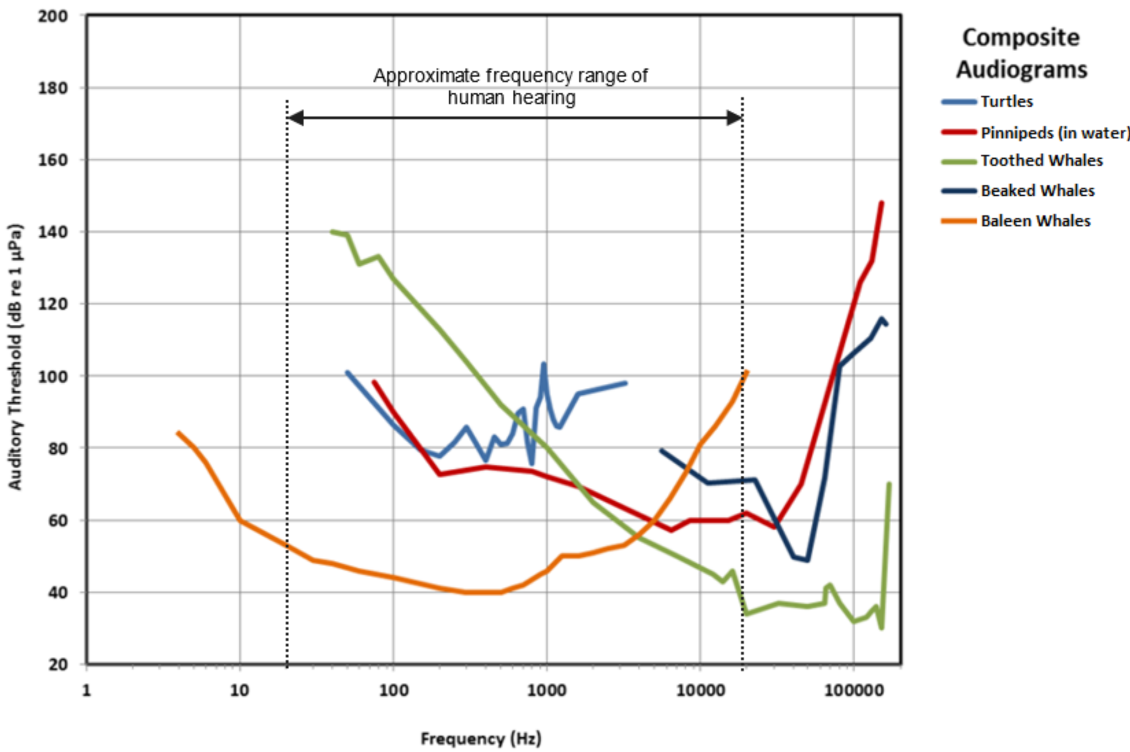
4.0 Underwater Noise Impact Assessment Criteria

4.1 Marine Fauna Hearing Sensitivity

A sound is audible when the receiver is able to perceive it over background noise. The audibility is also determined by the individual's threshold of hearing, which varies with frequency. Hearing ability is typically described using audiograms, which display hearing threshold (the sound level at which sound is just detectable) as a function of sound wave frequency. A low sound pressure level on an audiogram indicates a low hearing threshold at a given frequency, which means that even a very weak sound is still audible and indicates a higher auditory sensitivity.

Hearing capabilities differ between different groups of species, with some more sensitive to low-frequency sounds, while others hear better in the high-frequency range. Hipsey and Booth (2012) considered several marine mammal (and turtle) species and compiled composite audiograms for different groups (see Figure 8) below. Table 1 summarises the information on which the composite audiograms are based.

Figure 8: Composite audiograms of marine fauna based on various studies



Source: adapted from Hipsey & Booth 2012

Marine mammals and fish species usually have U-shaped audiograms, meaning that within their respective hearing ranges, they are more sensitive to the sound energy component in the mid-frequency range and less sensitive to the energy components in the lower and upper-frequency ranges (Finneran 2016, Southall et al. 2019; Popper et al. 2019).

Table 1: Hearing capabilities of marina fauna groups based on composite audiograms

Marine Species Group	Hearing Capability (Hz)		Peak Hearing Sensitivity (Hz)	
	Minimum	Maximum	Minimum	Maximum
Toothed whales (odontocetes)[1]	20 000	120 000	20 000	120 000
Beaked whales (ziphiids)[2]	5 600	160 000	40 000	50 000
Baleen whales (mysticetes)[3]	20	20 000	100	200
Pinnipeds (seals; under water)	70	>100 000	7 000	30 000
Turtles	50	3 000	100	800

[1]Some odontocete species can hear well below this range.
[2]Based on two studies in which single individuals were tested.
[3]Based on theoretical evidence only (no empirical data).
Sources: Hipsey & Booth 2012

For fish species, sound detection is based on the response of the auditory portion of their ears (i.e., the otolithic organs) to the particle motion of the surrounding fluid (Popper and Hawkins 2018). Some fish species also 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, resulting in higher hearing sensitivity and broader hearing bandwidth (Nedelec et al. 2016; Popper and Hawkins 2018).

For turtles, Finneran et al. (2017) agreed that these animals have low sensitivity to seismic noise, with audiograms more similar to those of fish but without specialized high-frequency hearing adaptations.

4.2 Possible Noise Impacts on Marine Fauna

The potential impacts of noise on marine fauna species include masking of communication and other biologically important sounds, behavioural responses, and physiological impacts (including discomfort, hearing impairment, and physical injury or mortality in extreme cases) (Richardson et al. 2013; Erbe et al. 2018; Popper and Hawkins 2019).

The type and distance of noise impacts on marine fauna depend on the acoustic characteristics of the noise (e.g., source level, spectral content, temporal characteristics, directionality, etc.), the sound propagation environment, as well as the hearing ability and physical reaction of an individual to detect sound. The severity of impacts decreases with increasing distance from the noise source, as illustrated by the theoretical zones of noise influence shown in Figure 9 (Richardson et al. 2013). The individual types of impacts are discussed below.

4.2.1 Masking

Masking occurs when the introduced noise is loud enough to impair the detection of biologically relevant sound signals, such as communication signals, echolocation clicks and passive detection cues that are used for navigation and finding prey (Clark et al. 2009).

The extent of the masking area depends on the differences in the animal's hearing frequency range, received sound levels, and the introduced anthropogenic and background ambient noise (Richardson et al. 2013). The masking effect can be partly compensated by 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).

4.2.2 Behavioural Response

Sound that is significantly above ambient noise levels and the animal's audiogram range can trigger behavioural responses that can include changes in vocalisation, resting, diving, and breathing patterns, changes in mother-infant relationships, and in most cases, the avoidance of the noise source (Wartzok et al. 2003).

The behavioural response effects can be 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 other aspects. Therefore, the type and magnitude of behavioural disturbance for any given signal can vary both within a population and for the same individual over time and can vary significantly, from very subtle changes in behaviour to strong avoidance reactions (Ellison et al. 2012; Richardson et al. 2013).

4.2.3 Hearing Impairment (Temporary or Permanent)

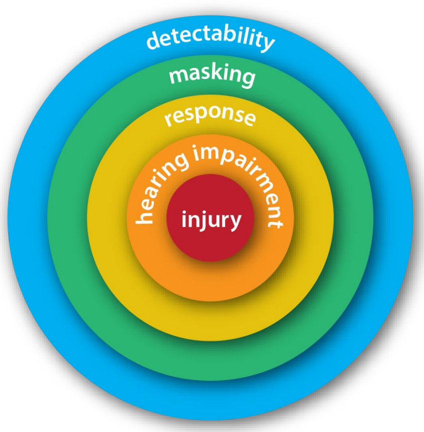
The physiological effects of underwater noise are primarily associated with the auditory system, which is likely to be most sensitive to noise. A loss of sensitivity to sound can occur from exposure to noise sources. If the noise exposure is below a critical sound energy level and/or duration, the hearing loss is generally only temporary, and the animal recovers – this effect is called a temporary hearing threshold shift (TTS). If the noise exposure exceeds a critical sound energy level, the hearing loss can be permanent - this effect is called permanent hearing threshold shift (PTS).

Exposure to noise can cause a reduction in the animal's hearing sensitivity or increase the hearing threshold (i.e., the sound level that is just audible to the animal) (Finneran 2016; Popper and Hawkins 2019; Southall et al. 2019).

4.2.4 Physical Injury

Noise at very high sound pressure levels may cause concussive effects, physical damage to tissues, organs, and cavitation, or result in the rapid formation of bubbles in the blood system due to massive pressure oscillations (Groton 1998). Physiological systems of marine animals potentially affected include the vestibular system, reproductive system, nervous system, liver, or organs with high concentrations of dissolved gas and gas-filled spaces (swim-bladders).

Figure 9: Theoretical Zones of Noise Influence



Source: adapted from Richardson et al. 2013

4.3 Criteria for Determining Adverse Noise Effects

This section outlines the impact assessment criteria for noise impacts on marine mammals, fish, and turtle species based on a review of relevant guidelines and/or literature published.

There has been extensive scientific study and research to determine quantitative links between marine noise and its impacts on marine mammal species, fish, and turtles. For example, Southall et al. (2019) have proposed noise exposure criteria associated with various sound types, including impulsive noise (i.e., seismic airgun noise) for marine mammal species based on a review of expanding literature on marine mammal hearing and physiological and behavioural responses to anthropogenic sounds.

Popper et al. (2014) and Popper and Hawkins (2019) proposed sound exposure guidelines for fish, 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 noise exposure levels above which adverse effects could be expected on various groups of marine mammals, fish, and turtles, presented in the following sections, are based on the most recent available data and published literature (i.e., the state of current knowledge, also see Appendix A and Appendix B). This research is considered applicable to fauna in the study area and appropriate as a basis of assessment as the species present in Block 3B/4B share the same physiological characteristics as the species that were subject to the cited research.

4.3.1 Marine Mammals

The newly updated scientific recommendations on marine mammal noise exposure criteria (Southall et al. 2019) propose PTS-onset and TTS-onset criteria for impulsive noise events such as VSP and scientific sonar.

The PTS-onset and TTS-onset for impulsive noise are outlined in Table 2 and provide threshold noise levels for (single pulse) Pk SPL and cumulative (multiple pulses) sound exposure levels over a 24-hour period (SEL_{24hr}).

As different mammals hear at different frequencies (see Section 4.1), they are grouped into different hearing groups and, hence, different threshold levels:

- Low-frequency cetaceans (LF) include baleen whales, e.g., humpback whales;
- High-frequency cetaceans (HF) are beaked whales;
- Very-high-frequency cetaceans (VHF) include toothed whales, e.g., sperm whales, dolphins, and porpoises;
- Sirenians (SI), e.g., manatees and dugongs;
- Phocid carnivores in water (PCW) include pinnipeds, i.e., seals; and
- Other marine carnivores in water (OCW), such as sea lions.

The widely used threshold level for the onset of possible behavioural response in all marine mammals is the RMS SPL of 160 dB re 1 µPa from a single airgun seismic pulse. For multiple detonations (within a 24-hour period), the National Marine Fisheries Service (NMFS 2023b) relies on a behavioural threshold of -5 dB from TTS onset, as shown in Table 2. For non-impulsive noise, such as drilling and shipping noise, the NMFS (2023b) acoustic threshold for all marine mammals is determined using the received level of 120 dB re 1 µPa RMS Table 3.

Table 2: Noise criteria for marine mammals exposed to impulsive noise

Marine mammal hearing group	PTS onset (injury)		TTS onset		Behavioural response
	Single pulse exposure	Cumulative 24-hr exposure	Single pulse exposure	Cumulative 24-hr exposure	Cumulative 24-hr exposure
	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 $1\mu Pa^2 \cdot S$	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$
Low-frequency cetaceans (LF)	219	183	213	168	163
High-frequency cetaceans (HF)	230	185	224	170	165
Very-high-frequency cetaceans (VHF)	202	155	196	140	135
Sirenians (SI)	226	203	220	175	170
Phocid carnivores in water (PCW)	218	185	212	170	165
Other marine carnivores in water (OCW)	232	203	226	188	183
Source: Southall et al. 2019					

Table 3: Noise criteria for marine mammals exposed to non-impulsive noise

Marine mammal hearing group	PTS onset (injury)	TTS onset	Behavioural response
	Cumulative 24-hr exposure	Cumulative 24-hr exposure	Continuous 24-hr exposure
	Weighted SEL_{24hr} dB re $1\mu Pa^2 \cdot S$	Weighted SEL_{24hr} dB re $1\mu Pa^2 \cdot S$	RMS SPL dB re 1μPa
Low-frequency cetaceans (LF)	199	179	120
High-frequency cetaceans (HF)	198	178	
Very-high-frequency cetaceans (VHF)	173	153	
Sirenians (SI)	206	186	
Phocid carnivores in water (PCW)	201	181	
Other marine carnivores in water (OCW)	219	199	
Source: Southall et al. 2019, NMFS 2023b			

4.3.2 Fish, Fish Eggs, and Fish Larvae

The U.S. National Oceanic and Atmospheric Administration (NOAA) convened an international panel of experts in 2004 to develop noise exposure criteria for fish and turtles, 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 the Acoustical Society of America sponsors.

The outcomes of the WG are broadly applicable sound exposure guidelines for fish, fish eggs and larvae (Popper et al. 2014, Popper and Hawkins 2019), considering the diversity of fish and the different ways they detect sound, as well as various sound sources and their acoustic characteristics. The exposure criteria for sound sources relevant to the project, notably impulsive noise from seismic airguns, are presented in Table 4, and it represents general consensus within the WG.

- where data to infer thresholds, peak (single pulse) and cumulative (24-hour exposure) threshold levels are reported; and
- where insufficient data exist to infer thresholds, the relative risk of an effect is qualitatively rated at “high,” “moderate,” or “low” for three distances from the source:
    - Near (N) at tens of meters from the noise source,
    - Intermediate (I) at hundreds of meters from the source, and
    - Far (F) at thousands of meters from the source.

Currently, there is no direct evidence of mortality or potential mortal injury to fish from non-impulsive noise sources such as drilling or shipping noise (Popper et al. 2014). However, continuous noise of any level that is detectable by fish can mask signal detection and impact their behaviour (Popper and Hawkins 2019). Increased noise levels may affect a wide range of behaviour patterns over the long term. For example, anthropogenic sounds can interfere with foraging behaviour by masking the relevant sounds or resembling sounds that prey may generate. Similarly, fish might avoid predators by listening to sounds that predators make deliberately or inadvertently (Popper and Hawkins 2019).

High-frequency active sonar sources, such as MBES sources with a frequency range of 10 kHz or greater, are not expected to cause an adverse hearing impact on fish species due to the low-frequency hearing ranges of these marine animals (from below 100 Hz to up to a few kHz) (Popper et al. 2014).

To determine the behaviour response threshold for all fish species, except fish eggs and fish larvae, to impulsive and non-impulsive noise, NMFS uses the common RMS SPL of 150 dB re 1 µPa (NMFS 2023a). The derivation and origin of the informal 150 dB threshold is not as well-defined as other thresholds. However, various recent publications do not refute that behavioural disturbance can occur around this level (Hawkins et al. 2014).

Table 4: Noise criteria for fish, fish eggs and fish larvae exposed to impulsive noise

Type of animal	Mortality and potential mortal injury		Impairment			Behaviour response
			Recovery injury		TTS	
	Single pulse exposure	Cumulative exposure	Single pulse exposure		Cumulative exposure	Single-pulse or Continuous exposure
	Pk SPL, dB re 1μPa	SEL_{cum}, dB re $1\mu Pa^2\cdot S$	Pk SPL, dB re 1μPa	SEL_{cum}, dB re $1\mu Pa^2\cdot S$	SEL_{cum}, dB re $1\mu Pa^2\cdot S$	RMS SPL, dB re 1μPa
Fish: no swim bladder (particle motion detection)	>213	>219	>213	>216	>>186	150[1]
Fish: swim bladder is not involved in hearing (particle motion detection)	>207	210	>207	203	>>186	150[1]
Fish: swim bladder involved in hearing (primarily pressure detection)	>207	207	>207	203	186	150[1]
Fish eggs and fish larvae	>207	>210	(N) Moderate (I) Low (F) Low		(N) Moderate (I) Low (F) Low	150[1]

Notes: Peak sound pressure levels (Pk SPL) dB re 1 μPa; Cumulative sound exposure level (SEL_{cum}) dB re 1 $\mu Pa^2\cdot s$. All criteria are presented as sound pressure, even for fish without swim bladders, since no data for particle motion exists. 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).

[1] Noise threshold for all fish species to impulsive and non-impulsive noise sources

Sources: Popper et al. 2014, [1]NMFS 2023a

4.3.3 Turtles

Popper et al. (2014) suggested threshold levels for potential permanent hearing injuries (PTS) of turtles, extrapolated from other animal groups, such as fish, on the basis that the hearing range of turtles is relatively close to that of certain fish. More recently, Finneran et al. (2017) revised thresholds based on a review of references from at least five different species of turtles (TU) to construct their composite audiograms and provide thresholds for the onset of PTS and TTS (see Appendix B). Finneran et al. (2017) agreed that turtles have low sensitivity with their audiograms more similar to those of fish without specialized hearing adaptations for high frequency.

Data on the behavioral reactions of sea turtles to sound sources is limited. Currently, there is not enough data to derive separate thresholds for different source types. However, behavioural disturbance from impulsive and non-impulsive noise generally occurs around 175 dB re 1 μPa SPL RMS (Finneran et al. 2017; McCauley et al. 2000), which has also been adopted by NMFS (NMFS 2023a). The revised thresholds for turtles to impulsive and non-impulsive noise are presented in Table 5 and Table 6, respectively.

Table 5: Noise criteria for turtles exposed to impulsive noise

Type of animal	Injury (PTS) onset		TTS onset		Behaviour response
	Single pulse exposure	Cumulative 24-hr exposure	Single pulse exposure	Cumulative 24-hr exposure	Single pulse exposure
	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 $1\mu Pa^2 \cdot S$	RMS SPL, dB re 1µPa
Turtles	232	204	226	189	175
Source: Finneran et al. 2017					

Table 6: Noise criteria for turtles exposed to non-impulsive noise

Marine mammal hearing group	PTS onset (injury)	TTS onset	Behavioural response
	Cumulative exposure	Cumulative exposure	Continuous exposure
	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	RMS SPL, dB re 1µPa
Turtles (TU)	220	200	175
Source: Finneran et al. 2017, McCauley et al. 2000			

4.4 Zones of Impacts on Marine Fauna

The distances from the sound source within which various types of impacts on marine fauna can be expected ("zones of impact") are determined by modelling the transmission loss of sound in water (i.e., the decrease in noise levels when moving away from the noise source) and determining the distance at which predicted noise levels fall below the various threshold levels described in Section 4.3.

Zones of impact thus identify the horizontal distance from and an area within which the surveys may have certain types of adverse impacts on certain marine fauna species.

In this report, zones of impact are defined as follows:

- Immediate impact from a single pulse – this is applicable if animals move out of or avoid entering the impact zone and are thus exposed at most for a short period; and
- Cumulative impact from a 24-hour exposure to impulsive and non-impulsive noise – this would be applicable if an animal remains or moves with the vessel over a 24-hour period and thus remains within the impact zone over an extended period of time. It is highly likely that animals will not remain in proximity of the noise source and that their exposure to sound levels above the various thresholds is much shorter than 24 hours. The distances identified for cumulative 24-hour thresholds are thus very conservative and very likely to overstate the extent of the typical impact area.

This information can be used to assess the risk (likelihood) of potential adverse noise impacts by combining the acoustic zones of impact with ecological information such as habitat significance and migratory routes in the affected area.

5.0 Sound Transmission Loss Modelling

5.1 Methodology and Procedure

The sub-sections below describe the modelling methodology and procedures for predicting received noise levels of relevant metrics associated with exploration drilling campaign activities.

The modelling components involve SELs and noise levels in relevant acoustic metrics (i.e., Peak SPLs and RMS SPLs) for single shots from the VSP source array, as well as for the cumulative SELs within a 24-hour period for the representative drilling operation scenarios.

5.1.1 VSP and Vessel Noise

For noise modelling predictions in relation to relatively low-frequency broadband noise emissions, such as VSP and vessel noise, the fluid parabolic equation (PE) modelling algorithm RAMGeo (Collins 1993) was 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 noise sources were assumed to be omnidirectional and modelled as point sources. With the known noise source levels, either frequency-weighted or unweighted, the received noise levels are calculated following the procedure outlined below.

- One-third octave source spectral levels are obtained, either via spectral integration of linear source spectra for VSP sources or via empirical formula for drilling rigs and support vessels;
- Transmission loss is calculated using RAMGeo at one-third octave band central frequencies from 10 Hz to 8 kHz, based on appropriate source depths corresponding to relevant source scenarios. The acoustic energy of the higher frequency range is significantly lower and, therefore is not included in the modelling.
- Propagation paths for the TL calculation have a maximum range of up to 200 km and bearing angles with a 10-degree azimuth increment from 0 to 350 degrees around the source locations. The bathymetry variation of the vertical plane along each modelling path is obtained via interpolation of the bathymetry dataset;
- The one-third octave source levels and transmission loss are combined to obtain the received levels as a function of range, depth, and frequency; and
- The overall received levels are calculated by summing all frequency band spectral levels.

The outputs of the G-Gun source modelling include its “notional” signature; and far-field signature of the airgun, including its directivity/beam patterns.

5.1.1.1 Notional signature

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

Notional signatures are modelled using the Gundalf Designer software package (2018). The Gundalf source model is developed on the basis of the well-understood fundamental physics of source bubble oscillation and radiation 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; Laws et al. 1988, 1990). Based on the preceding references, the related fundamental physics of bubble oscillation has been robustly understood for several decades.

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

5.1.1.2 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 the 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 array's overall array far-field signature for the direction of interest; and
- The far-field signature also accounts for ocean surface reflection effects by the inclusion of the "surface ghost". An additional ghost source is added for each acoustic source element using a sea surface reflection coefficient of -1.

5.1.1.3 Beam patterns

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

- The far-field signatures are calculated for all directions from the source using azimuthal and dip angle increments of 1-degree;
- The 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
- The PSDs of all resulting signature waveforms are combined to form the frequency-dependent beam pattern for the array.

5.1.1.4 Conversion Factors

For received individual signals emitted from impulsive sources such as VSP 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 an 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.

Numerous theoretical and empirical research studies reliably support the above statement, e.g., the relevant seismic survey signal modelling and measurement studies (e.g., Austin et al. 2013; Matthews and MacGillivray 2013; Galindo-Romero et al. 2015; McCauley et al. 2000, 2016) show that the differences between the three temporal parameters (i.e., Pk SPL, and RMS SPL) and SEL are increasingly higher at the receiver closer to the source location.

SEL and Pk SPL

The difference between the Pk SPL and SEL of the far-field signature of the 150 cubic inch (CUI) G-GunII array (at a reference distance of 1 m from the centre of the array) is 20 dB. This value is taken as the conversion factor applied to the SELs for calculating the received Pk SPLs over the receiving range close to the source location. This approach is regarded as conservative for estimating relevant near-field acoustic parameters based on SEL predictions.

SEL 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 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 VSP array modelling results.

5.1.2 MBES Modelling

Sound propagation modelling for the Kongsberg EM 712 MBES was carried out using the modelling algorithm BELLHOP (Porter 2019, 2020). BELLHOP is a highly efficient beam tracing modelling algorithm (Porter et al. 1987; Jensen et al. 2011) based on high-frequency approximation. The algorithm is designed to perform two-dimensional acoustic ray tracing for a given ocean environment with range-dependent sound speed and bathymetry profiles and is inherently applicable for high-frequency sound propagation modelling.

An overall sonar survey area is expected to be approximately 50 km^2 (approximately 7 km X 7 km) over a period of approximately 15 days. For modelling purposes, the same locations as the modelling drilling activities have been used. Based on the sonar source specifications, the proposed MBES source has extremely strong source directionalities towards cross-track directions, with a cross-track beam fan width of 140° and an along-track beam width of up to 2°. As a result, the sound field at cross-track directions is expected to be significantly higher than the along-track sound field.

Considering the extremely narrow source directionalities towards the cross-track directions and the moving MBES source during the survey, it is reasonable to expect that the adjacent receiving locations along the cross-track directions from the MBES source would be exposed to what would essentially be the acoustic energy from a single sonar pulse for the duration of the survey. As such, the sonar survey modelling is proposed to be based on the sound field modelling for a single MBES pulse at the represented source location (i.e., the selected discharge location). Consequently, the overall impact zones applied for the entire sonar survey are to be based on the impact zones estimated for the single MBES pulse, predominantly along the cross-track directions.

The modelling environmental inputs include the winter sound speed profile, and the seafloor geo-acoustic model**.** Based on the conservative consideration, the following MBES source parameters are used for the modelling:

- Operating survey frequency of 40 kHz, with seawater sound attenuation of approximately 12.95 dB/km (Jensen et al. 2011); The seawater sound attenuation within the MBES operating frequency range increases significantly with frequency, from approximately 12.95 dB/km at 40 kHz to up to approximately 34.32 dB/km at 100 kHz, due to the acoustic energy absorption as a result of the chemical relaxation of magnesium sulphate $MgSO_4$ within seawater (Jensen et al. 2011). As such, the lowest MBES operating frequency selected for the modelling represents the worst-case consideration from a noise impact perspective.
- Vertical beam patterns are zero dB within the performing beam/swath width for both along-track and cross-track directions (2° and 140°, respectively) and have 30 dB per 10° beam angle decline. In contrast, the rest of the beam angles are attenuated by -30 dB.
- Due to the low noise emissions and strong source directivity, near-field exposure from single MBES pulses along both along-track and cross-track directions are considered.

5.2 Modelling Input Parameters

The noise levels generated by the exploration drilling operations will be significantly higher than current ambient noise levels (100-120 dB re 1 µPa as described in Section 3.3), and ambient noise does not contribute to the cumulative noise levels with the noise of drilling operations. Therefore, ambient noise is not considered in (or material for) the determination of zones of impact.

The propagation of sound is determined by how fast a sound wave travels in a medium and is slowest in gases (~343 m/s in air), faster in liquids (~1 481 m/s in water), and fastest in solids (~5 120 m/s in iron). For any one medium, sound speed is further determined by aspects that cause smaller changes in density, e.g., temperature, depth/height and (in water) salinity.

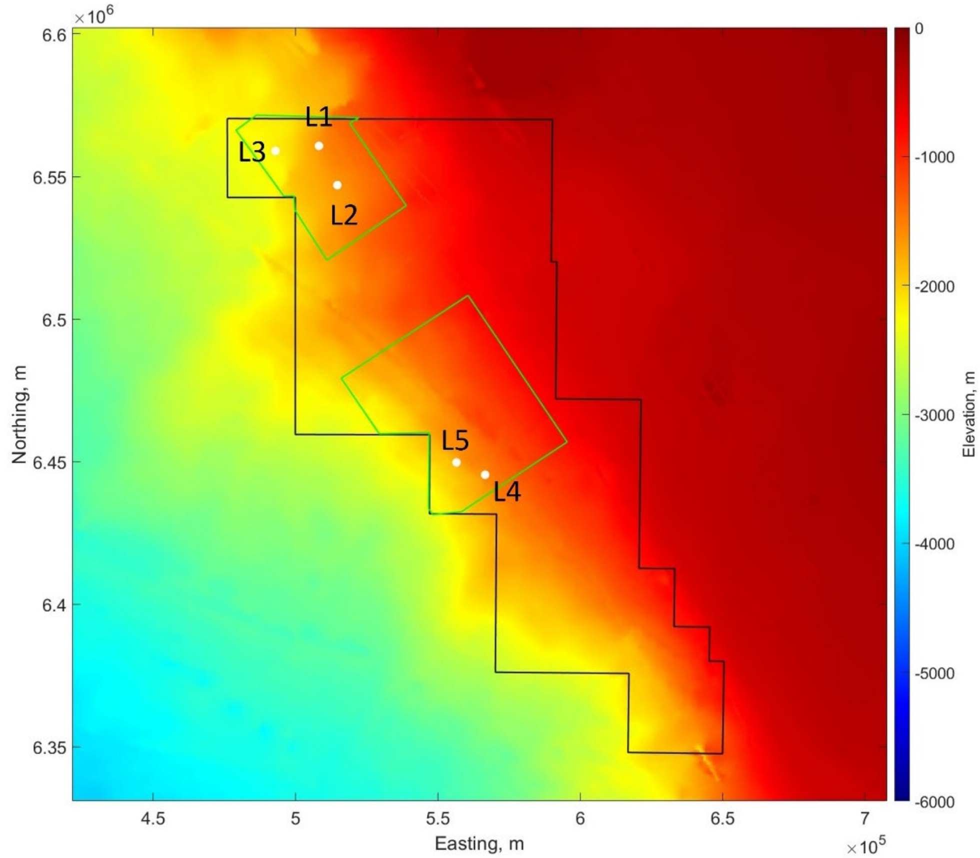
This model thus takes into account the water depth (see Section 5.2.1), salinity and water temperature (see Section 5.2.2) and seabed composition (see Section 5.2.3) in the block area.

5.2.1 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 the sound speed within typical sea water. The bathymetric imagery within and surrounding the acquisitions area is presented in Figure 10.

Figure 10: Bathymetric Imagery within and Surrounding the Seismic Survey Block



5.2.2 Sound Speed Profiles

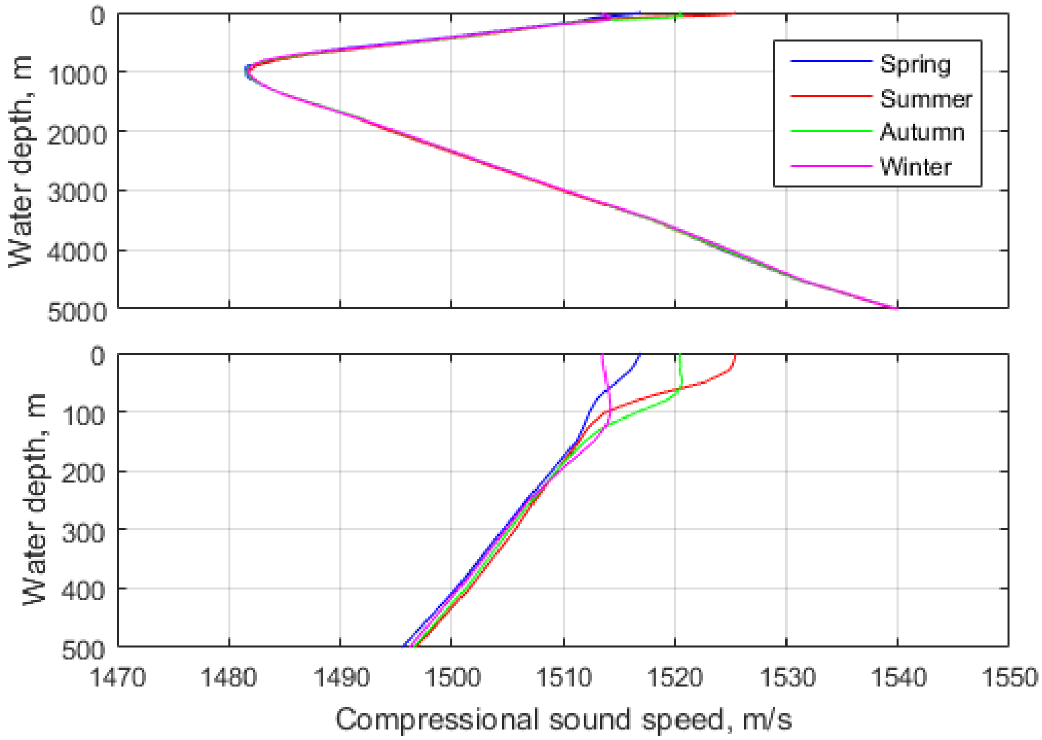
Temperature and salinity data required to derive the sound speed profiles were obtained from the World Ocean Atlas 2009 (WOA09) (Locarnini et al. 2010; Antonov et al. 2010). The hydrostatic pressure needed for the calculation of the sound speed based on the depth and latitude of each particular sample 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 11 presents the typical sound speed profiles for four seasons in the survey area. The figure demonstrates that the most significant distinctions for the profiles of the four seasons occur within the mixed layer near the surface (to a depth of approximately 200 m), in which the speed of sound is susceptible to daily and local changes of heating, cooling, and wind action. The seasonal thermocline is characterized by a negative sound speed gradient that varies with the seasons.

Due to the stronger gradient variation, the winter season is expected to favour the propagation of sound from a near-surface acoustic source array. The winter sound speed profile was thus selected as the most conservative modelling input, i.e., the worst-case scenario.

As the overall sound speed profiles of different seasons across the water column are quite similar, the differences in sound fields between different seasons are not expected to be significant.

Figure 11: Typical sound speed profiles within the block area for different Southern Hemisphere seasons



5.2.3 Seafloor Geo-acoustic 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 shelves is primarily composed of silty, muddy sediments with a noticeable proportion of sand.

Relevant literature also shows that from the continental shelf to the deep-sea basin, the sediment spatial distribution has a 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.

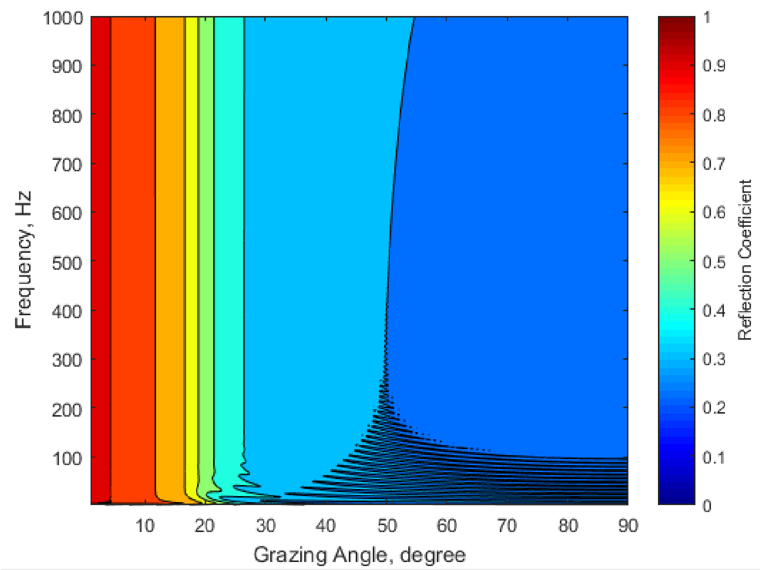
Based on the above, as well as a conservative consideration, it was proposed that for the entire modelling area, the seafloor geo-acoustic model comprises a 50-metre thick fine and silty sand sediment layer, followed by a soft to semi-cemented mudstone/shale sediment layer and a semi to full-cemented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

Table 7: Geo-acoustic 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)
Silty mud	100	1 700	1 575	1.0
Sand half-space	∞	1 900	1 600	0.8

Figure 12 shows the reflection coefficient variation with grazing angle and frequency for the proposed seafloor geo-acoustic scenario, calculated using the plane-wave reflection coefficient model (Porter 2001, 2020). The seafloor acoustic reflection is dominated by the top sediment layer across the frequency range, with high reflection at low grazing angles and low reflection (high refraction) at higher grazing angles.

Figure 12: Reflection coefficient vs grazing angle and frequency for the proposed geo-acoustic model



5.3 Modelling Scenarios and Source Levels

A list of modelling scenarios with relevant major noise-generating equipment are developed based on relevant drilling operation information provided and the general project description as in Section 3.0. These scenarios and relevant noise sources are summarised in Table 8.

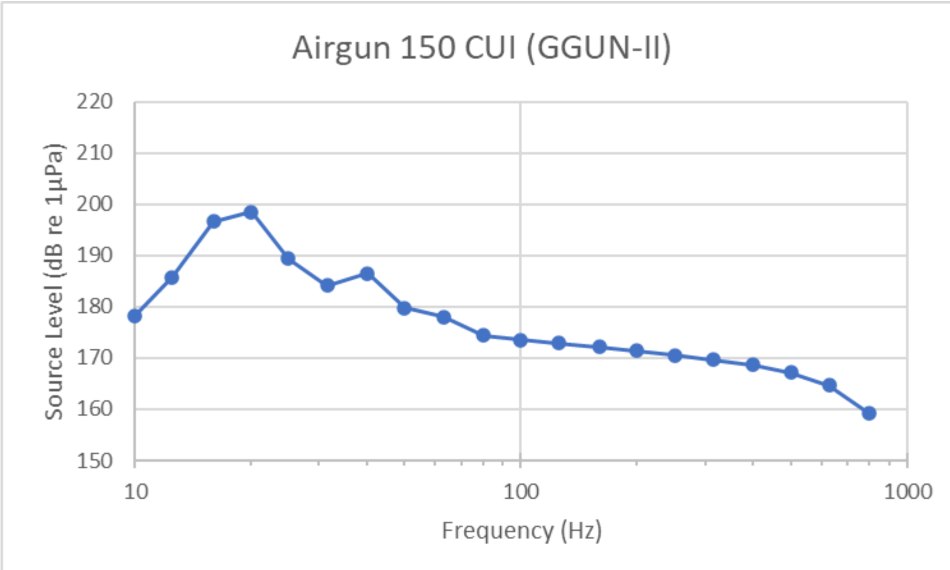
Table 8: Potential scenarios to be assessed and relevant noise sources

Activity / Scenario	Major Noise Source / Equipment
Vertical seismic profiling (VSP)	VSP airgun array, i.e., 150 cubic inch GGUN-II
	Operating depth 8 m with a pressure of 450 PSI
Well drilling operations	Drillship (x 1) such as Maersk Venturer
	Support vessel (x 3), i.e., The Bourbon Calm or equivalent
	Transitional helicopter (x 1)
Sonar survey specifications	Sonar system: Kongsberg EM 712 MBES
	Maximum ping rate: more than 30 Hz
	Number of swaths per ping: 2
	Number of beams: 200, 400, 800, 1 600
	Beam spacing: equidistant, equiangular, high density
	Depth range from transducers: 3 to approximately 3 600 m
	Frequency range: 40 – 100 kHz
	Pulse Lengths: CW: 0.2, 0.5 and 2 ms CW; FM (chirp): up to 120 ms
	Beamwidths: 0.25° x 0.5°, 0.5° x 0.5°, 0.5° x 1°, 1° x 1°, 1° x 2° or 2° x 2°
	Across-track beam fan width: up to 140°
	Source level: up to 237 dB re 1 μPa rms @ 1 m up to 240 dB re 1 μPa peak @ 1 m up to 210 dB re 1 $\mu Pa^2 \cdot s$ @ 1 m (i.e., with 2 ms duration)

5.3.1 VSP

A single gun of 150 cubic inch (CUI) is proposed to be used for the VSP operations. The airgun has a depth of 8,0 m and an operating pressure of 450 pounds per square inch (PSI). The noise emissions from the VSP airgun, including the source spectral levels and directivities, are modelled based on the Gundalf Designer software package (2018). The one-third octave SEL source spectral levels to be used as the sound transmission modelling inputs are presented in Figure 13.

Figure 13: One-third octave band SEL source spectral levels for the VSP G-Gun



The source levels for the VSP G-Gun array show the Pk SPL to be 226,0 dB re 1 µPa @ 1 m, the RMS SPL 208,5 dB re 1 µPa @ 1 m, and the SEL 206,0 dB re µPa^2·s @ 1 m.

5.3.2 Well Drilling Operations

The semi-submersible drillship is the Maersk Venturer. The maximum drilling water depth of the ship is ~12 000 m. It has 6 Wartsila DP3 5.5 MW thrusters. It also has dynamic positioning capabilities.

The noise emissions from the drillship are predominantly generated by propeller and thruster cavitation especially when the dynamic-positioning system is operating, with a smaller fraction of sound produced by transmission through the hull, such as by engines, gearing, and other mechanical systems.

The drillship and support vessel noise levels are estimated based on a source level predicting empirical formula suggested by Brown (1977). The formula predicts the source level of a propeller based on the propeller diameter (m) and the propeller revolution rate (rpm). The relevant parameters for the prediction and the predicted source SEL levels are presented in Table 9.

Table 9: Drillship and Support Vessel Specifications

Parameter	Maersk Venturer	Support Vessel #1	Support Vessel #2	Support Vessel #3
Pitch	NA	Fixed	variable	variable
Speed	NA	variable	variable	variable
Number of thrusters	6 (4*)	3	3	3
Propeller diameter (m)	3,5	2,02	2,02	2,02
Nominal propeller speed (rpm)	187	307	307	307

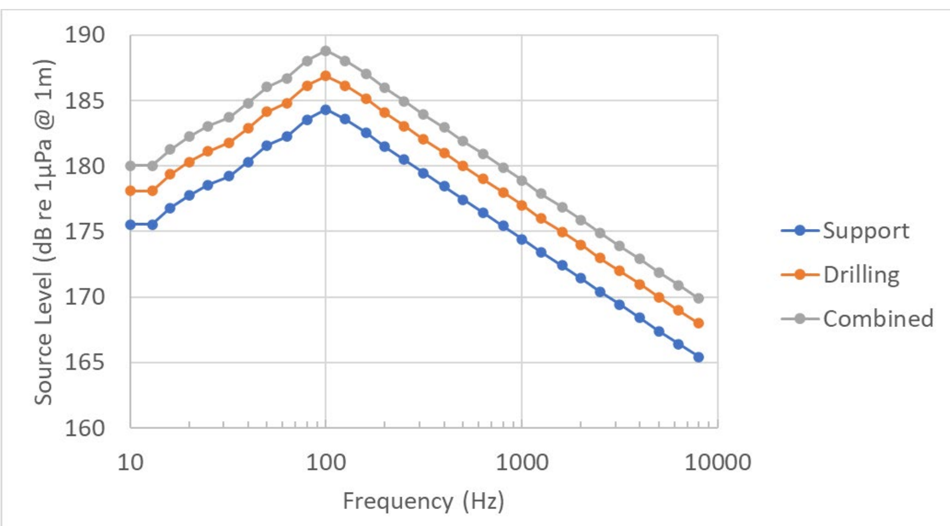
Parameter	Maersk Venturer	Support Vessel #1	Support Vessel #2	Support Vessel #3
Maximum continuous power input (kW)	5 500	2 500	2 500	2 500
Predicted source noise emissions SEL (dB re 1 μPa^2·S @ 1 m)	196,2	195.4 (overall support vessels)		
	198,8 (drilling unit and two support vessels)			
*Number of propeller blades per thruster				

For modelling predictions, all thrusters were assumed to operate at nominal speed. The vertical position of the drill rig thrusters is assumed to be 27,75 m below the sea surface at the operating draft.

For offshore support vessels to maintain position in strong current conditions, they are required to have two bow thrusters plus an azimuth thruster forward. The vertical positions of the thrusters are assumed to be 5 m below the sea surface. There are two support vessels acting simultaneously as a worst-case consideration.

For non-impulsive drilling noise, it is assumed that the source SEL levels are equivalent to their corresponding RMS SPL source levels, considering the consistency and longer durations of the typical continuous drilling noise emissions. The overall noise level from combined noise emissions from drillship and two support vessels is approximately 198,8 dB re 1 μPa @ 1 m (or dB re 1 μPa^2·S @ 1 m). The one-third octave SEL source spectral levels for the drillship, supported vessels and combined total level is shown in Figure 14.

Figure 14: One-third octave SEL source spectral levels for the proposed well drilling operation



For cumulative noise modelling, two scenarios are considered, including the worst-case 24-hour continuous exposure duration and a much shorter, half hour continuous exposure duration. It should be noted the transitional Anchor Handling Tug Support (AHTS) vessels are not included in the modelling study as they are in the transitional operational stage and are not considered major noise sources compared with the drillship operations. Also, compared with the near surface drillship operations, the noise emissions from actual drill bit underground and the vibrating drill string and casing are expected to be much lower (Gales 1982; Erbe and McPherson 2017), and therefore are not considered in the modelling study.

The potential for underwater noise to be generated by helicopters is limited as broadband noise levels underwater due to helicopters flying at altitudes of 150 m or more are expected to be around 109 dB re 1 µPa (Richardson et al. 2013) at the most noise-affected point. This noise level is considerably less than the underwater noise generated by support vessels or the drilling platform and can be considered negligible in terms of the overall noise levels.

5.3.3 MBES System Specifications

AOSAC is proposing to utilise an MBES (70-100 kHz) with a single beam echo-sounder (38-200 kHz) and a sub-bottom profiler (2-16 kHz). The system consists of a fully integrated wide swath bathymeter and a dual frequency side scan sonar. The positional data of the bathymetry and side scan data are complementary, allowing a precise target location and highly detailed maps and 3D models.

The Kongsberg EM 712 MBES system with similar specifications to those proposed by AOSAC is used here to model the planned sonar survey. The EM 712 MBES is a high-resolution seabed mapping system with a frequency range of 40 – 100 kHz (see Table 8). The system can meet all relevant survey standards for acquisition depth from less than 3 m below its transducers to up to 3 600 m. The source levels for the Kongsberg EM 712 MBES system show a Pk SPL of 240 dB re 1 µPa @ 1 m, an RMS SPL of 237 dB re 1 µPa @ 1 m, and a SEL of 210 dB re $\mu Pa^2 \cdot s$ @ 1 m.

5.4 Modelling Source Locations

Noise modelling locations for the drilling programme are consistent with the northern and central part of the AOI, as indicated in Figure 15, and further detailed in Table 10 below with their corresponding coordinates, water depths and localities.

Figure 15: Source locations (L1, L2, L3, L4, and L5) modelled in the STLM

Locations are indicated as white squares. The white polygon shows the Block 3B/4B and the green polygon the AOI.

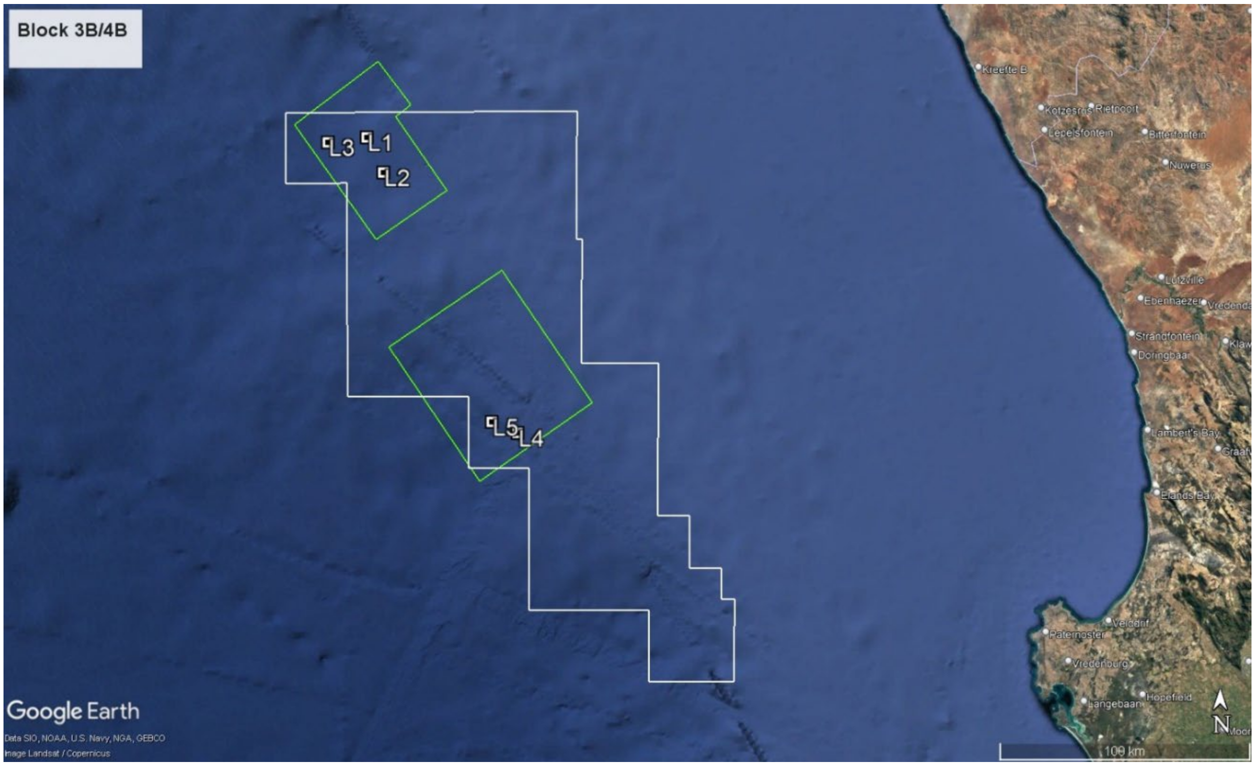


Table 10: Details of the three selected source locations for the long-range modelling

Source Location	Water Depth, m	Coordinates [Easting, Northing]	Locality
L1	1 665	[508227, 6560735]	North to the license Block towards shallow water environment
L2	1 645	[514681, 6546969]	North to the license Block towards shallow water environment
L3	2 100	[492950, 6558963]	North to the license Block towards deeper water environment
L4	1 580	[566540, 6445387]	Central to the license Block towards the shallow water environment and adjacent to marine sensitive areas
L5	1 792	[556504, 6449741]	Central to the license Block towards the deeper water environment and adjacent to marine sensitive areas

6.0 STLM Modelling Results

This section presents the modelling results for the exploration drilling activities, including VSP and sonar survey modelling scenarios as described in Section 5.1.

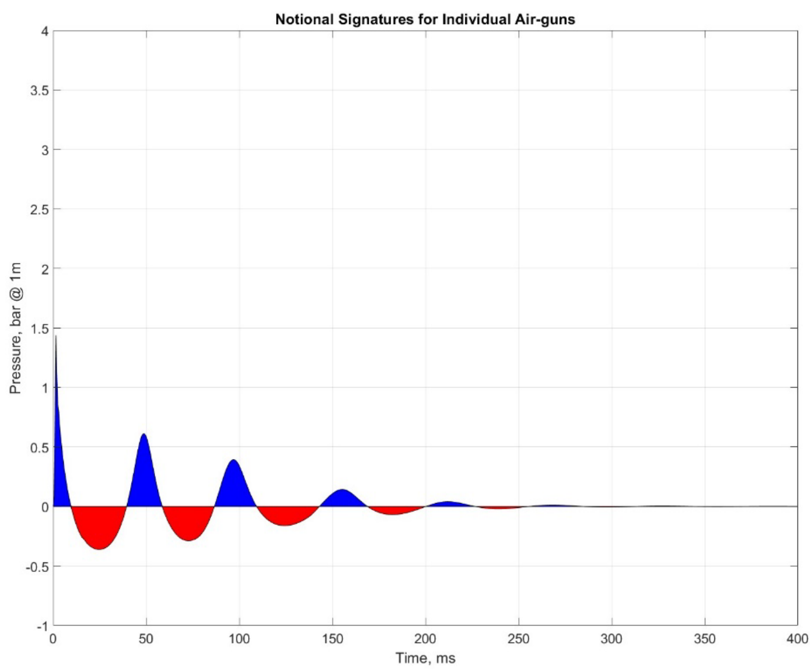
6.1 VSP airgun

The full VSP airgun modelling results are detailed as follows.

6.1.1.1 Notional signature

Figure 16 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.

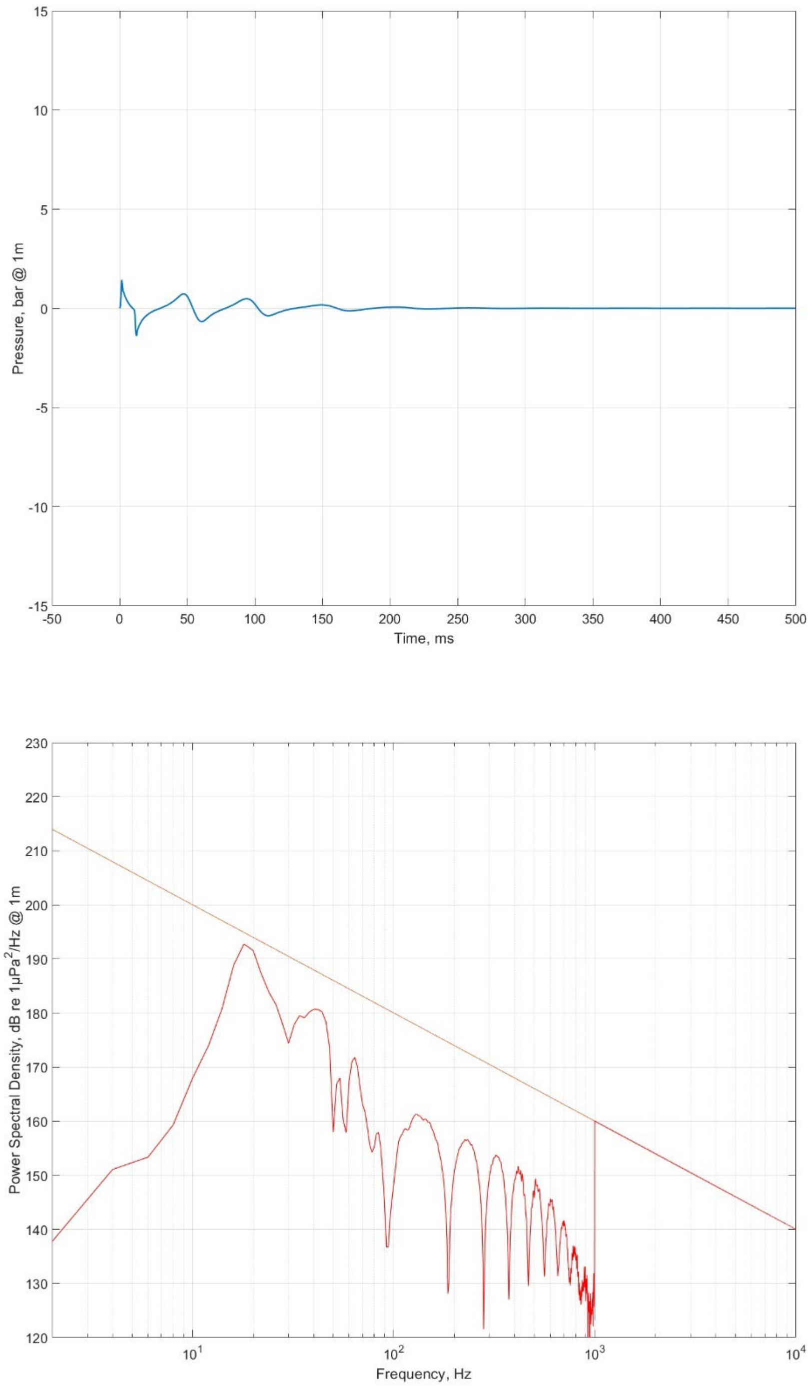
Figure 16: Notional source signatures for the 150 CUI G-Gun array



6.1.1.2 Far-field signature and its power spectral density

Figure 17 shows the far-field signature waveform and its power spectral density simulated by the Gundalf Designer software. The signatures are for the vertically downward direction with surface ghost included.

Figure 17: The far-field signature in vertically downward direction (top) and its power spectral density (bottom) for the 150 CUI G-Gun array



6.1.1.3 Beam patterns

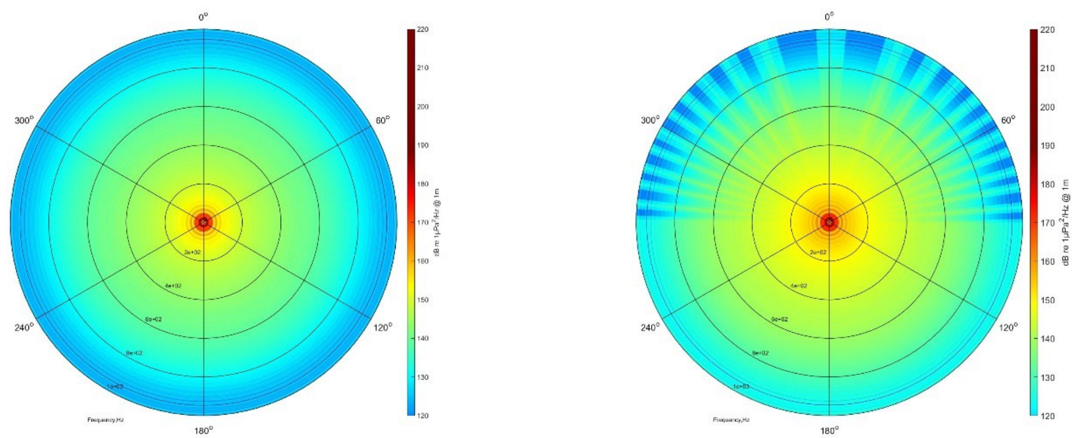
Array far-field beam patterns of the following three cross sections are presented in Figure 18.

- The horizontal plane (i.e., dip angle of 90 degrees) with an azimuthal angle of 0 degrees corresponding to the in-line direction;
- The vertical plane for the in-line direction (i.e., azimuthal angle of 0 degrees) with dip angle of 0 degrees corresponding to the vertically downward direction; and
- The vertical plane for the cross-line direction (i.e., azimuthal angle of 90 degrees) with dip angle of 0 degrees corresponding to the vertically downward direction.

The beam patterns illustrate the angle and frequency dependence of the energy radiation from the array. The horizontal plane shows strong interference stripes in parallel with the cross-line direction. The cross-line vertical plane has the strongest radiation in the vertical direction, with no interference patterns as in the in-line vertical plane.

Figure 18: Array far-field beam patterns for the 150 CUI G-Gun array, as a function of orientation and frequency.

The horizontal plane with 0 degrees corresponds to the in-line direction (left). The vertical plane for the in-line direction and downward direction (right).



6.2 MBES pulse

The vertical sound fields from a single MBES pulse of the sonar survey at both along-track and cross-track directions that have been modelled based on the modelling inputs described in Section 5.3 (with the sound fields in SEL dB re 1 µPa^2 ·s) are presented in Figure 19 and Figure 20. As can be seen, the sound field in cross-track directions is significantly higher than the along-track sound field due to the large beam-width difference between the two directions (140° cross-track versus 2° along-track).

Considering the extremely narrow directivity at the along-track directions and the moving MBES source during the survey, it is reasonable to expect that the fixed location receivers would be exposed predominantly to acoustic energy from a single pulse during the entire survey.

As a result of the above, the maximum noise levels across the water column along the range at the cross-track direction are significantly higher than the maximum levels at the along-track direction, with the level comparison as shown in more detail in the figures presented in Appendix D.

Figure 19: The vertical sound field of the single MBES pulse in SEL (dB re 1 µPa2 ·S) at along-track (left) and cross-track (right) directions for L1 (top), and L2 (middle)

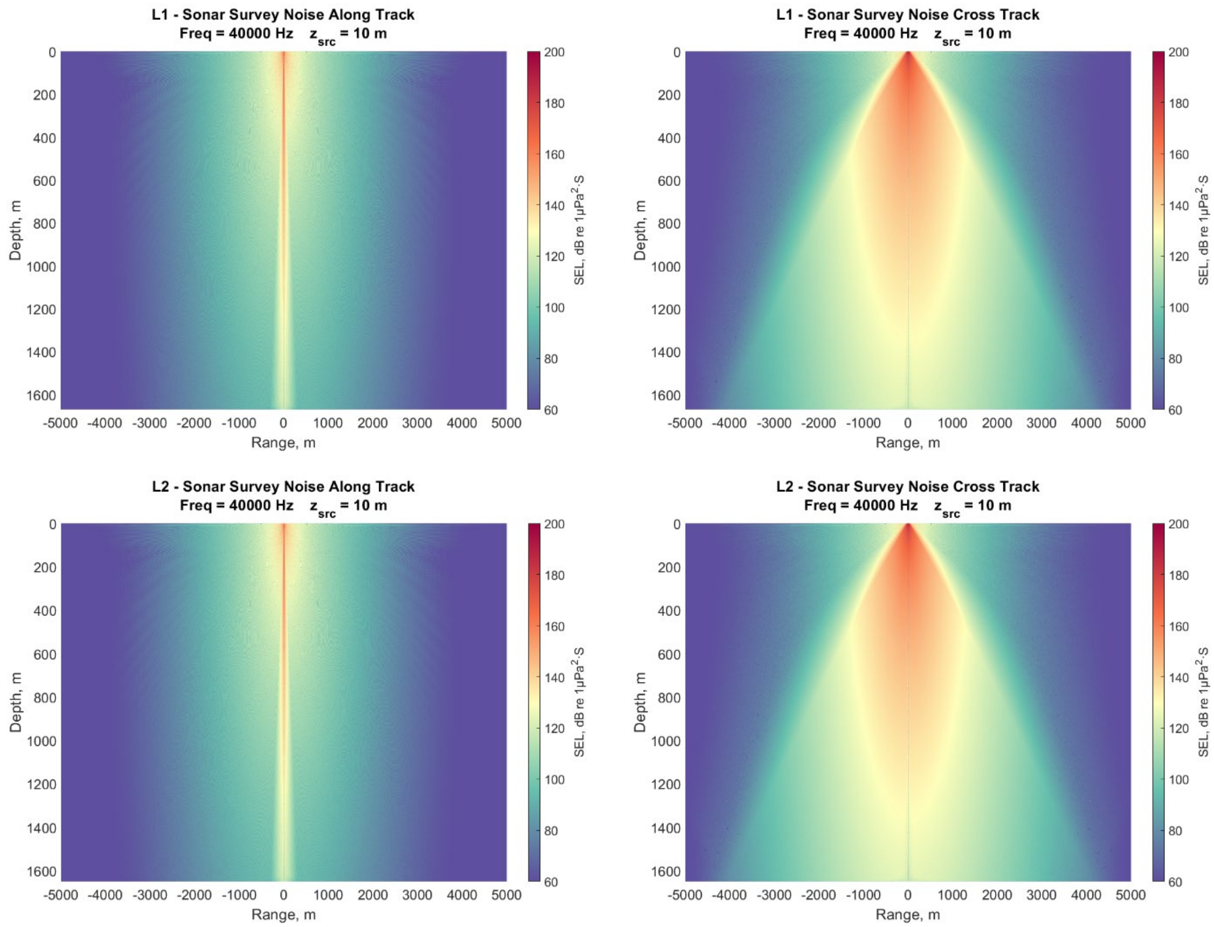
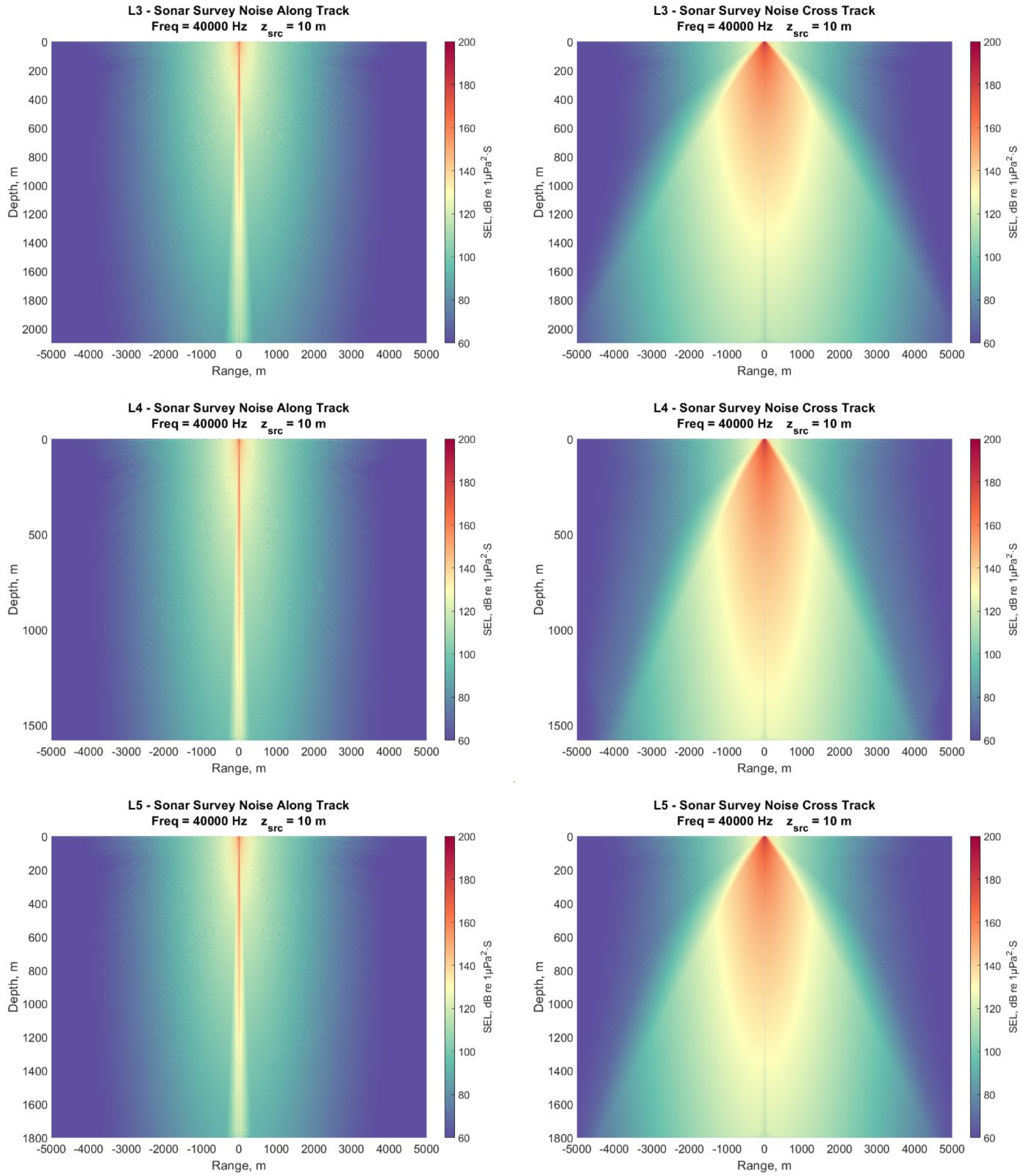


Figure 20: The vertical sound field of the single MBES pulse in SEL (dB re 1 μPa2 ·S) at along-track (left) and cross-track (right) directions for L3 (top), L4 (middle) and L5 (bottom)



7.0 Zones of Impact

The modelled noise levels of all scenarios were compared to relevant threshold criteria for potential fauna impacts listed in Section 4.3. The resulting extent of impact zones for different types of noise impact on marine mammals, fish and sea turtles are presented below.

The weighted SEL modelling results for different marine mammal hearing groups (Appendix A) are based on weighted SEL source level inputs which are derived by applying relevant auditory hearing functions to the unweighted SEL source levels as presented in Appendix B.

For cumulative SEL estimates for VSP, well drilling operations and sonar surveys, the following cumulative factor (*CF*) is applied:

$CF = 10 \times \log10\ (N\ (\text{or}\ T))$

Where *N* is the number of pulses for the VSP source and *T* is the exposure duration for the well drilling noise source, respectively.

A maximum horizontal distance is provided for all source locations. Since the difference is minimal for most of the source locations, impact zones are divided into two groups: deep (less than 2 000 m, i.e., L1, L2, L4, and L5) and deepest (over 2 000 m depth; i.e., L3). Where impact zones extend to the far field (thousands of meters from the source locations), separate impact zone distances are provided for each source-modelled location, where they differ.

7.1 Immediate Exposure to a single VSP Pulse

For impulsive signals from VSP operations, the additional two relevant SPL parameters, i.e., RMS SPL and Pk SPL, which are relevant to the impact assessment, are derived based on conservative conversion factors applied to the predicted SEL values for the various receiving distances from the VSP source location. These conversion factors are detailed in Section 5.1.1.4.

Overall, the maximum distances from the source to the edge of the impact zone are greater for the deepest location (L3).

7.1.1 Marine Mammals

Marine mammals of all hearing groups are predicted to experience PTS within approximately 60 m from the VSP airgun for short-term exposure, based on thresholds provided in Table 11.

The onset of TTS due to a single pulse (short-term exposure) for marine mammals is predicted within approximately 80 m from the VSP airgun source (see Table 11). VHF cetaceans are the group most susceptible to experiencing PTS and TTS from a single VSP pulse.

7.1.2 Fish

The zones of potential injuries for all fish species, including fish eggs and fish larvae, are predicted to be within 40 m from the VSP airgun (see Table 12) based on thresholds provided in Table 4.

7.1.3 Turtles

Turtles are predicted to not experience PTS. They are only predicted to experience TTS for less than 20 m from the VSP airgun array (see Table 13) based on thresholds provided in Table 5.

Table 11: Zones of immediate PTS and TTS impact from single VSP pulse (short-term exposure) – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distance from source to edge of the impact zone					
	PTS			TTS		
	Criteria Pk SPL dB re 1µPa	Maximum distance (m)		Criteria Pk SPL dB re 1µPa	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Low-frequency cetaceans (LF)	219	<20	20	213	20	40
High-frequency cetaceans (HF)	230	-	-	224	-	<20
Very-high-frequency cetaceans (VHF)	202	40	60	196	60	80
Sirenians (SI)	226	-	<20	220	<20	20
Phocid carnivores in water (PCW)	218	<20	20	212	20	40
Other marine carnivores in water (OCW)	232	-	-	226	-	<20

Table 12: Zones of immediate impact from single VSP pulses (short-term exposure) for mortality and recovery injury – fish, turtles, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from source to edge of impact zone					
	Mortality and potential mortal injury			Recoverable injury		
	Criteria Pk SPL dB re 1µPa	Maximum distance (m)		Criteria Pk SPL dB re 1µPa	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Fish: no swim bladder (particle motion detection)	> 213	20	40	>213	20	40
Fish: swim bladder is not involved in hearing (particle motion detection)	>207	20	40	>207	20	40
Fish: swim bladder involved in hearing (primarily pressure detection)	>207	20	40	>207	20	40
Fish eggs and fish larvae	>207	20	40	-	-	
Note: A dash indicates the threshold is not applicable.						

Table 13: Zones of immediate PTS and TTS impact from single VSP pulses (short-term exposure) – turtles

Type of animal	Zones of impact – maximum horizontal distances from source to edge of the impact zone					
	Injury (PTS) onset			TTS onset		
	Criteria Pk SPL dB re 1µPa	Maximum distance (m)		Criteria Pk SPL dB re 1µPa	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Sea turtles	232	-	-	226	-	<20
Note: A dash indicates the threshold is not applicable.						

7.1.4 Behavioural Responses of Marine Fauna

The extent of the areas where behavioural response or disturbance of marine animals are expected is presented in Table 14, based on thresholds provided in Table 2, Table 4, and Table 5. Behavioural response caused by a single VSP pulse exposure is predicted to occur up to 580 m from the VSP source for marine mammals, up to 2,24 km for fish, and within 80 m for turtles. Overall, the maximum distances from the source to the edge of the impact zone are greater for the deepest location (L3).

Table 14: Zones of immediate behavioural response impact from single VSP pulses (short-term exposure)

Type of animal	Zones of impact – maximum horizontal distance from source to edge of the impact zone		
	Behavioural response		
	Criteria RMS SPL dB re 1µPa	Maximum distance (m)	
		Deep	Deepest
Marine Mammals	160	220	580
Fish	150	600	2 240
Turtles	175	60	80

7.2 Cumulative Exposure to Multiple Pulses

For cumulative noise modelling, two scenarios are considered for this study, including the worst case of 125 VSP pulses over the span of 6 hours of operation, and 50 VSP pulses over approximately 2 hours.

It should be noted that the worst-case scenario presented here is conservative. Since marine mammals are highly mobile, they are likely to have moved considerable distances away from the source over the cumulative operation 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 or from feeding focal points (if located in the project area).

7.2.1 Marine Mammals

The details of zones of impact for cumulative exposure to 50 VSP pulses are presented in Table 15, based on thresholds provided in Table 2. From all marine mammal hearing groups, LF cetaceans are the only group predicted to experience PTS from multiple VSP pulses. LF cetaceans may experience PTS within 40 m from the VSP source if exposed continuously.

The onset of TTS due to multiple pulses (cumulative exposure) may affect only LF, VHF, and PCW marine mammal hearing groups, (with LF cetaceans subject to the greater zone of impact, up to 80 m from the VSP source). The same groups are predicted to show a behavioural response within maximum distances of 100 m for LF cetaceans, 40 m for PCW pinnipeds, and 20 m for VHF cetaceans.

Table 15: Zones of impact for cumulative exposure to 50 VSP pulses for PTS, TTS and behavioural response – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from assessed survey lines to the edge of the cumulative impact zone								
	Injury (PTS) onset			TTS onset			Behavioural Response		
	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance (m)		Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance (m)		Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest		Deep	Deepest
Low-frequency cetaceans (LF)	183	40	<20	168	80	40	163	100	40
High-frequency cetaceans (HF)	185	-	-	170	-	-	165	-	-
Very-high-frequency cetaceans (VHF)	155	-	-	140	<20	-	135	20	-
Sirenians (SI)	203	-	-	175	-	-	170	-	-
Phocid carnivores in water (PCW)	185	-	-	170	20	-	165	40	<20
Other marine carnivores in water (OCW)	203	-	-	188	-	-	183	-	-

Note: A dash indicates the threshold is not reached.

The zones of impact for cumulative exposure to 125 pulses are predicted to be exceeded for LF cetaceans and PCW pinnipeds, with maximum distances of 40 and <20 m from the source, respectively. For LF cetaceans, the zones of TTS impact are predicted to range up to 80 m from the source at the less deep locations. The PCW group slightly increased their maximum distances to TTS onset.

LF cetaceans may show a behaviour response up to 220 m, PCW pinnipeds within 60 m, and VHF cetaceans at 20 m from the VSP source. The cumulative PTS and TTS criteria SEL_{24hr} are predicted not to be exceeded for the HF, sirenians and OCW hearing groups. The details of zones of impact for cumulative exposure to 125 VSP pulses are presented in Table 16.

Table 16: Zones of impact for cumulative exposure to 125 VSP pulses for PTS, TTS and behavioural response – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from assessed survey lines to the edge of the cumulative impact zone								
	Injury (PTS) onset			TTS onset			Behavioural Response		
	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance (m) Deep	Maximum distance (m) Deepest	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance (m) Deep	Maximum distance (m) Deepest	Criteria – Weighted SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance (m) Deep	Maximum distance (m) Deepest
Low-frequency cetaceans (LF)	183	40	<20	168	80	40	163	220	40
High-frequency cetaceans (HF)	185	-	-	170	-	-	165	-	-
Very-high-frequency cetaceans (VHF)	155	-	-	140	<20	-	135	20	-
Sirenians (SI)	203	-	-	175	-	-	170	-	-
Phocid carnivores in water (PCW)	185	<20	-	170	40	-	165	60	<20
Other marine carnivores in water (OCW)	203	-	-	188	-	-	183	-	-

Note: A dash indicates the threshold is not reached.

7.2.2 Fish

As presented in Table 17 and based on thresholds provided in Table 4, the zones of potential mortal and recoverable injuries for all fish species (except for fish with no swim bladder involved in hearing) are predicted to be within 40 m from the source for the 50 VSP pulses scenario considered.

Fish with no swim bladders are expected to suffer potential mortal injury for less than 20 m and recovery injury within 20 m from the VSP source. The zones of the TTS effect for fish species with and without swim bladders are predicted to be up to within 60 and 180 m from the VSP source depending on the depth of the source location.

Table 17: Zones of impact for cumulative exposure to 50 VSP pulses for mortality, recovery injury and TTS – fish, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from assessed survey lines to the edge of the cumulative impact zone								
	Mortality and potential mortal injury			Recoverable injury			TTS		
	Criteria - SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance m		Criteria - SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance m		Criteria - SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum distance m	
		Deep	Deepest		Deep	Deepest		Deep	Deepest
Fish: no swim bladder (particle motion detection)	219	<20	<20	216	<20	20	186	60	180
Fish: swim bladder is not involved in hearing (particle motion detection)	210	40	20	203	20	40	186	60	180
Fish: swim bladder involved in hearing (primarily pressure detection)	207	40	20	203	20	40	186	60	180
Fish eggs and fish larvae	210	40	20	-	-		-	-	
Note: A dash indicates the threshold is not applicable.									

The zones of impact for cumulative exposure to 125 pulses remained within 40 m for potential mortal and recoverable injuries for all fish species. The details of these zones of impact are presented in Table 18. The zones of the TTS effect for fish species with and without swim bladders increased double to 260 m from the VSP source.

Existing experimental data regarding recoverable injury and TTS impacts on fish eggs and larvae is sparse, and no guideline recommendations have been provided. However, based on the approach indicated in Table 4, noise impacts related to recoverable injury, and TTS on fish eggs and larvae are expected to be moderate at the near field (tens of meters) from the source location and low for intermediate and far-field distances from the source location.

Table 18: Zones of impact for cumulative exposure to 125 VSP pulses for mortality, recovery injury and TTS – fish, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from assessed survey lines to the edge of the cumulative impact zone								
	Mortality and potential mortal injury			Recoverable injury			TTS		
	Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum distance m		Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum distance m		Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum distance m	
		Deep	Deepest		Deep	Deepest		Deep	Deepest
Fish: no swim bladder (particle motion detection)	219	20	<20	216	<20	20	186	80	260
Fish: swim bladder is not involved in hearing (particle motion detection)	210	40	20	203	40	60	186	80	260
Fish: swim bladder involved in hearing (primarily pressure detection)	207	40	20	203	40	60	186	80	260
Fish eggs and fish larvae	210	40	20	-	-		-	-	
Note: A dash indicates the threshold is not applicable.									

7.2.3 Turtles

Maximum zones of PTS impact on turtles is predicted to occur less than 20 m from the source for the 50 VSP pulses operation scenario considered as shown in Table 19 and based on thresholds provided in Table 5. The maximum zones of TTS impact are predicted to be up to 60 m from the VSP source.

It is predicted that turtles may experience TTS for greater zones of impact if the 125 VSP pulses scenario is considered. The maximum zones of PTS and TTS impact are predicted to be up to 20 and 80 m from the VSP source, respectively, as shown in Table 20. The maximum zones of TTS impact at the deepest location (L3) are minimal, less than 20 m only.

Table 19: Zones of impact for cumulative 24-hour exposure to 50 VSP pulses of the survey for PTS and TTS – Turtles

Type of animal	Zones of impact – maximum horizontal distances from assessed survey lines to the edge of the cumulative impact zone					
	Injury (PTS) onset			TTS onset		
	Criteria Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum distance (m)		Criteria Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Turtles	204	<20	-	189	60	<20

Table 20: Zones of impact for cumulative 24-hour exposure to 125 VSP pulses of the survey for PTS and TTS – Turtles

Type of animal	Zones of impact – maximum horizontal distances from assessed survey lines to the edge of the cumulative impact zone					
	Injury (PTS) onset			TTS onset		
	Criteria Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum distance (m)		Criteria Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Turtles	204	20	-	189	80	<20

7.3 Non-impulsive Drilling Operation Sources

For well drilling operations (drillship and support vessels), two scenarios are considered for this study, a typical scenario of 0.5 hours duration and a worst case of 24 hours duration. As noted earlier, this latter scenario assumes that a receptor, i.e., marine animal, remains in proximity to (continuously moves with) the moving support vessel for a period of 24 hours and thus remains within the impact zone, which is unlikely but presents a very conservative worst-case scenario.

7.3.1 Marine Mammals

Marine mammals of all hearing groups except the OCW group (e.g., sea lions) are predicted to experience PTS within 60 m from the drilling operations for the 0.5 hour scenario considered, as shown in Table 21 and based on thresholds provided in Table 3. The LF and VHF cetacean groups are more susceptible to experiencing TTS than the rest of the marine mammal hearing groups, with maximum distances of up to 380 and 400 m from the drilling operations sources, respectively.

The zones of impact for continuous exposure for 24 hours (worst case) of drilling operations increased rapidly, so all marine mammal hearing groups may experience PTS, with LF and VHF cetacean groups reaching up to 280 m from the source. The onset of TTS due to continuous exposure for 24 hours may increase the maximum distances for LF and VHF cetaceans up to approximately 2,7 and 8,2 km from the source, respectively, as shown in Table 22.

Table 21: Zones of cumulative PTS and TTS impact from non-impulsive noise (continuous exposure 0.5 hours) – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distance from source to edge of the impact zone					
	PTS			TTS		
	Criteria Weighted SEL_{24hr}, dB re $1 \mu Pa^2 \cdot S$	Maximum distance (m) Deep	Maximum distance (m) Deepest	Criteria Weighted SEL_{24hr}, dB re $1 \mu Pa^2 \cdot S$	Maximum distance (m) Deep	Maximum distance (m) Deepest
Low-frequency cetaceans (LF)	199	60	60	179	360	360
High-frequency cetaceans (HF)	198	<20	<20	178	60	60
Very-high-frequency cetaceans (VHF)	173	60	60	153	400	400
Sirenians (SI)	206	<20	<20	186	60	60
Phocid carnivores in water (PCW)	201	40	40	181	80	80
Other marine carnivores in water (OCW)	219	-	-	199	40	40
Note: A dash indicates the threshold is not applicable.						

Table 22: Zones of cumulative PTS and TTS impact from non-impulsive noise (continuous exposure 24 hours) – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distance from source to edge of the impact zone					
	PTS			TTS		
	Criteria Weighted SEL_{24hr}, dB re $1 \mu Pa^2 \cdot S$	Maximum distance (m) Deep	Maximum distance (m) Deepest	Criteria Weighted SEL_{24hr}, dB re $1 \mu Pa^2 \cdot S$	Maximum distance (m) Deep	Maximum distance (m) Deepest
Low-frequency cetaceans (LF)	199	280	280	179	2 700	2580
High-frequency cetaceans (HF)	198	60	60	178	280	280
Very-high-frequency cetaceans (VHF)	173	280	280	153	8 160	8 160
Sirenians (SI)	206	40	40	186	220	220
Phocid carnivores in water (PCW)	201	80	80	181	800	800
Other marine carnivores in water (OCW)	219	40	40	199	80	80

7.3.2 Fish

As stated in Section 4.3.2, non-impulsive noise sources such as drilling and shipping are not expected to cause mortality or potential mortal injury on fish species. There would thus also be no cumulative impact from the non-impulsive drilling noise sources expected on fish species.

7.3.3 Turtles

Turtles are predicted to experience PTS from short-term exposure (i.e., 0.5 hours) within 20 m from the drilling operations and TTS up to 60 m from the source, as shown in Table 23 and based on thresholds provided in Table 5.

On the other hand, turtles are predicted to experience PTS from long-term exposure (i.e., 24 hours) within 60 m from the drilling operations and TTS up to 320 m from the source, as shown in Table 24.

Table 23: Zones of cumulative PTS and TTS impact from non-impulsive noise (continuous exposure 0.5 hours) – turtles

Type of animal	Zones of impact – maximum horizontal distances from source to edge of the impact zone					
	Injury (PTS) onset			TTS onset		
	Criteria Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Maximum distance (m)		Criteria Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Sea turtles	220	20	20	200	60	60
Note: A dash indicates the threshold is not applicable.						

Table 24: Zones of cumulative PTS and TTS impact from non-impulsive noise (continuous exposure 24 hours) – turtles

Type of animal	Zones of impact – maximum horizontal distances from source to edge of the impact zone					
	Injury (PTS) onset			TTS onset		
	Criteria Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Maximum distance (m)		Criteria Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Sea turtles	220	60	60	200	320	320
Note: A dash indicates the threshold is not applicable.						

7.3.4 Behavioural Responses of Marine Fauna

The extent of the areas where behavioural response or disturbance of marine animals are expected is presented in Table 25, based on thresholds provided in Table 2, Table 4, and Table 5.

Behavioural disturbance caused by immediate exposure to well drilling operations is predicted to occur up to approximately 27,5 km from the source for marine mammals, up to 420 m for fish, and 60 m for turtles.

Table 25: Zones of immediate behavioural response impact from non-impulsive noise (short-exposure)

Type of animal	Zones of impact – maximum horizontal distance from source to edge of the impact zone					
	Behavioural response					
	Criteria RMS SPL dB re 1μPa	Maximum distance (m)				
		L1	L2	L3	L4	L5
Marine Mammals	120	25 940	21 760	27 480	22 120	26 300
Fish	150	420	420	420	420	420
Turtles	175	60	60	60	60	60

7.4 Immediate Exposure to a single MBES pulse

Sonar surveys using the MBES sources have much lower noise emissions than VSP airgun sources and have extremely narrow source directivity at the along-track direction as previously described in Section 6.2.

7.4.1 Marine Mammals

Marine mammals are predicted to experience PTS at very close proximity to the MBES sources due to the immediate exposure to individual pulses.

Based on predicted zones of impact as shown in Table 26, marine mammals of all hearing groups except VHF cetaceans are predicted to experience PTS effect within 18 m from the MBES source. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 66 m from the MBES source along the cross-track direction.

The zones of TTS due to a single pulse exposure for marine mammals of all hearing groups except VHF cetaceans are predicted to be within 24 m from the MBES source. The maximum zones of TTS effect for VHF cetaceans are predicted to be within 124 m from the MBES source along the cross-track direction.

Table 26: Zones of immediate PTS and TTS impact from a single MBES pulse (short-term exposure) – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distance from source to edge of the impact zone					
	PTS			TTS		
	Criteria Pk SPL dB re 1μPa	Maximum distance (m)		Criteria Pk SPL dB re 1μPa	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Low-frequency cetaceans (LF)	219	18	18	213	24	24
High-frequency cetaceans (HF)	230	2	2	224	8	8
Very-high-frequency cetaceans (VHF)	202	66	66	196	124	124
Sirenians (SI)	226	4	4	220	14	14
Phocid carnivores in water (PCW)	218	18	18	212	24	24
Other marine carnivores in water (OCW)	232	2	2	226	4	4

7.4.2 Fish

As stated in Section 4.3.2, high-frequency sonar MBES sources are not expected to cause an adverse hearing impact on fish species.

7.4.3 Turtles

Noise impacts related to PTS and TTS on sea turtles are expected to occur along the cross-track direction from the MBES source. The maximum zones of impact are predicted to range within 2 and 4 m from the MBES source for PTS and TTS, respectively, as shown in Table 27.

Table 27: Zones of immediate PTS and TTS impact from a single MBES pulse (short-term exposure) – turtles

Type of animal	Zones of impact – maximum horizontal distances from source to edge of the impact zone					
	Injury (PTS) onset			TTS onset		
	Criteria Pk SPL dB re 1μPa	Maximum distance (m)		Criteria Pk SPL dB re 1μPa	Maximum distance (m)	
		Deep	Deepest		Deep	Deepest
Sea turtles	232	2	2	226	4	4
Note: A dash indicates the threshold is not applicable.						

7.4.4 Behavioural Responses of Marine Fauna

The zones of behavioural response for marine mammals and sea turtles caused by the immediate exposure to individual MBES pulses for sonar surveys are presented in Table 28.

The modelling results show that the maximum impact distance for the behavioural disturbance caused by the immediate exposure to individual MBES pulses is predicted to reach 290 m from the source for marine mammals of all hearing groups and up to 70 m from the MBES source for sea turtles at cross-track directions.

Table 28: Zones of immediate behavioural response impact from a single MBES pulse (short-exposure)

Type of animal	Zones of impact – maximum horizontal distance from source to edge of the impact zone		
	Behavioural response		
	Criteria RMS SPL dB re 1μPa	Maximum distance (m)	
		Deep	Deepest
Marine Mammals	160	290	290
Turtles	175	70	70

8.0 Discussion

As detailed in Section 4.0, 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 turtles. The combined threshold distance for each impact effect is considered as the maximum threshold distance (i.e., the worst-case scenario) estimated from either metric criteria being applied.

Overall, modelling results show little variation for the different source locations less than 2 000 m in depth (L1, L2, L4, and L5). The greatest variation, due to the spherical sound propagation, was noted at the deepest source location (L3) and in some scenarios of the behavioural response at multiple source locations.

For exposure to multiple VSP pulses, the cumulative level at the proposed locations is modelled based on the assumption that the animals are constantly exposed to the VSP airgun noise at a fixed location over the entire hour period. However, 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).

Likewise, the continuous exposure for 24 hours to well drilling operations assumes that a receptor, i.e., marine animal, remains in proximity to (continuously moves with) the moving support vessel for a period of 24 hours and thus remains within the impact zone, which is unlikely but presents a very conservative worst-case scenario.

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

9.0 Closure

Thank you for retaining SLR to provide this service.

Regards,

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10.0 References

Antonov, J. I., Seidov, D., Boyer, T. P., Locarnini, R. A., Mishonov, A. V., Garcia, H. E., Baranova, O. K., Zweng, M. M., and Johnson, D. R. 2010. World Ocean Atlas 2009, Volume 2: Salinity. S. Levitus, Ed. NOAA Atlas NESDIS 69, U.S. Government Printing Office, Washington, D.C., 184 pp.

Austin, M., McCrodan, A., Wladichuk, J. 2013. Marine mammal monitoring and mitigation during Shell's activities in the Chukchi Sea, July–September 2013: Draft 90-Day Report. (Chapter 3) In Reider, H. J., L. N. Bisson, M. Austin, A. McCrodan, J. Wladichuk, C. M. Reiser, K.B. Matthews, J.R. Brandon, K. Leonard, et al. (eds.). Underwater Sound Measurements. LGL Report P1272D–2. Report from LGL Alaska Research Associates Inc., Anchorage, AK, USA, and JASCO Applied Sciences, Victoria, BC, Canada, for Shell Gulf of Mexico, Houston, TX.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method, J. Acoust. Soc. Am., 93: 1736-1742.

Del Grosso, V. A. 1974. New equation for the speed of sound in natural waters (with comparisons to other equations), J. Acoust. Soc. Am. 56: 1084-1091.

Dingle, R.V., Birch, G. F., Bremner, J. M., De Decker, R. H., Plessis, A. D., Engelbrecht, J. C, Fincham, M. J., Fitton, T., Flemming, B. W., Gentle, R. I., Goodlad, S. W., Martin, A. K., Mills, E. G, Moir, G. J., Parker, R. J., Robson, S. H., Rogers, J., Salmon, D. A., Siesser, W. G., Simpson, E. S. W., Summerhayes, C. P., Westall, F., Winter, A. and Woodborne, M. W. 1987. Deep sea sedimentary environments around southern Africa (South-East Atlantic and South- West Indian Oceans), Annals of the South African Museum, 98. 1-27. DOC (Ed). 2016. Report of the Sound Propagation and Cumulative Exposure Models Technical Working Group, Marine Species and Threats, Department of Conservation, Wellington, New Zealand, 59p.

Dutkiewicz, A., Müller, R. D., O'Callaghan, S. and Jónasson H. 2015. Census of seafloor sediments in the world's ocean, GEOLOGY, September 2015; v. 43; no. 9; p. 795–798, doi:10.1130/G36883.1.

Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.S. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology, 26(1), pp.21-28.

Erbe, C. and McPherson, C. 2017. Underwater noise from geotechnical drilling and standard penetration testing, J. Acoust. Soc. Am. 142 (3) EL281 – EL285.

Erbe, C., Dunlop, R. and Dolman, S. 2018. Effects of noise on marine mammals. In Effects of anthropogenic noise on animals (pp. 277-309). Springer, New York, NY.

Erbe, C., Reichmuth, C., Cunningham, K., Lucke, K. and Dooling, R. 2016. Communication masking in marine mammals: A review and research strategy. Marine pollution bulletin, 103(1-2), pp.15-38.

Finneran, J. J. 2016. Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposure to underwater noise, Technical Report, 49 pp.

Finneran, J.J., E.E. Henderson, D.S. Houser, K. Jenkins, S. Kotecki, and J. Mulsow. 2017. Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 p.

Gales R. S. 1982. Effects of Noise of Offshore Oil and Gas Operations on Marine Mammals—An Introductory Assessment (U.S. Naval Ocean Systems Center, San Diego, CA).

Galindo-Romero, M., Lippert, T. and Gavrilov, A. 2015. Empirical prediction of peak pressure levels in anthropogenic impulsive noise. Part I: Airgun arrays signals. J. Acoust. Soc. Am. 138 (6), December: EL540-544.

GEBCO Compilation Group. 2022. The GEBCO 2022 Grid (https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2022/). (Accessed 1 Sep 2022).

Groton, C.T. 1998. Non-hearing physiological effects of sound in the marine environment. Workshop on the effects of anthropogenic noise in the marine environment, 10-12 February 1998 (p. 58).

Gundalf Designer, Revision AIR8.1n, 30 March 2018, Oakwood Computing Associates Limited. (https://www.gundalf.com/) (Accessed 1 Sep 2022).

Hamilton, E. L. 1980. Geoacoustic modelling of the sea floor, J. Acoust. Soc. Am. 68: 1313:1340.

Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series, 395, pp.5-20.

Jensen, F. B., Kuperman, W. A., Porter, M. B. and Schmidt, H. 2011. Computational Ocean Acoustics, Springer-Verlag New York.

Laws, M., Hatton, L. and Haartsen, M. 1990. Computer Modelling of Clustered Airguns, First Break, 8(9): 331-338.

Laws, R. M., Parkes, G. E., and Hatton, L. 1988. Energy-interaction: The long-range interaction of seismic sources, Geophysical Prospecting, 36: 333-348.

Locarnini, R. A., Mishonov, A. V., Antonov, J. I., Boyer, T. P., Garcia, H. E., Baranova, O. K., Zweng, M. M., and Johnson, D. R. 2010. World Ocean Atlas 2009, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., 184 pp.

Matthews, M. N. and Macgillivray, A. O. 2013. Comparing modeled and measured sound levels from a seismic survey in the Canadian Beaufort Sea, Proceedings of meetings on acoustics Acoustical Society of America, 2 – 7 June 2013, Montreal, Canada.

McCauley R. D., Fewtrell J., Duncan A. J., Jenner, C., Jenner M. N., Penros J. D., Prince R. I. T., Adhitya A., Murdoch J. and McCabe K. 2000. Marine Seismic Surveys: Analysis and Propagation of Air Gun Signals, and Effects of Exposure on Humpback Whales, Sea Turtles, Fishes and Squid. Prepared for the APPEA. CMST, Curtin University.

McCauley, R. D., Duncan, A. J., Gavrilov, A. N. and Cato, D. H. 2016. Transmission of marine seismic survey, air gun array signals in Australian waters. Proceedings of ACOUSTICS 2016, 9-11 November 2016, Brisbane, Australia.

Miksis-Olds, J.L., Bradley, D.L. and Maggie Niu, X. 2013. Decadal trends in Indian Ocean ambient sound. The Journal of the Acoustical Society of America, 134(5), pp.3464-3475.

National Marine Fisheries Service (NMFS). 2018. 2018 Revisions to: Technical guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum, NMFS-OPR-59.

National Marine Fisheries Service (NMFS). 2023a. Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea turtles) January 2023. Marine Mammal Acoustic Technical Guidance | NOAA Fisheries (Accessed 28 August 2023).

National Marine Fisheries Service (NMFS). 2023b. Summary of Marine Mammal Protection Act Acoustic Thresholds, February 2023. Marine Mammal Acoustic Technical Guidance | NOAA Fisheries (Accessed 28 August 2023).

National Marine Fisheries Services (NMFS). 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustics Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Administration, U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 pp.

National Oceanic and Atmospheric Administration (NOAA) (U.S.) 2019. ESA Section 7 Consultation Tools for Marine Mammals on the West Coast (webpage), 28 Apr 2021. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west (Accessed 28 August 2023).

Paton, D., di Primio, R., Kuhlmann, G. and Van der Spuy, D. 2007. Insights into the Petroleum System Evolution of the southern Orange Basin, South Africa, SOUTH AFRICAN JOURNAL OF GEOLOGY, 2007, VOLUME 110 PAGE 261-274, doi:10.2113/gssajg.110.2-3.261.

Popper A. N., Hawkins A. D., Fay R. R., Mann D. A., Bartol S., Carlson T. J., Coombs S., Ellison W. T., Gentry R. L., Halworsen M. B., Lokkeborg S., Rogers P. H., Southall B. L., Zeddies D. G. and Tavolga W. N. 2014. ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI.

Popper, A.N. and Hawkins, A.D. 2018. The importance of particle motion to fishes and invertebrates. The Journal of the Acoustical Society of America, 143(1), pp.470-488.

Popper, A.N. and Hawkins, A.D. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of fish biology, 94(5), pp.692-713.

Popper, A.N., Hawkins, A.D., Sand, O. and Sisneros, J.A. 2019. Examining the hearing abilities of fishes. The Journal of the Acoustical Society of America, 146(2), pp.948-955

Porter, M. B. and Bucker, H. P. 1987. Gaussian beam tracing for computing ocean acoustic fields, J. Acoust. Soc. Amer. 82, 1349—1359.

Porter, M. B. 2001. The KRAKEN Normal Mode Program. SACLANT Undersea Research Centre. May 17, 2001 (http://oalib.hlsresearch.com/Modes/kraken.pdf).

Porter, M. B. 2019. The BELLHOP Manual and User's Guide: PRELIMINARY DRAFT, Heat, Light, and Sound Research, Inc. La Jolla, CA, USA.

Porter, M. B. 2020. Acoustics Toolbox in Ocean Acoustics Library (http://oalib.hlsresearch.com/).

Richardson W. J., Charles R. G. J., Charles I. M. and Denis H.T. 2013. Marine mammals and noise: Academic press.

Rutledge, A.K. and Leonard, D.S. 2001. Role of multibeam sonar in oil and gas exploration and development. In Offshore Technology Conference. OnePetro.

Simon, C., Matthew, P. and David, P. 2018. Results of deployment of acoustic monitoring equipment for Taranaki Ltd for 2018 Māui 4D Seismic Survey, Report No. PM-18-Shell-Report 3 Results of acoustic equipment deployment 2018 Māui 4D MSS-v1.1.

Sink, K. J., Harris, L. R., Skowno, A. L., Livingstone, T., Franken, M., Porter, S., Atkinson, L. J., Bernard, A., Cawthra, H., Currie, J., Dayaram, A., de Wet, W., Dunga, L. V., Filander, Z., Green, A., Herbert, D., Karenyi, N., Palmer, R., Pfaff, M., Makwela, M., Mackay, F., van Niekerk, L., van Zyl, W., Bessinger, M., Holness, S., Kirkman, S. P., Lamberth, S., Lück-Vogel, M. 2019. Chapter 3: Marine Ecosystem Classification and Mapping. In: Sink KJ, van der Bank MG, Majiedt PA, Harris LR, Atkinson LJ, Kirkman SP, Karenyi N (eds), 2019, South African National Biodiversity Assessment 2018 Technical Report Volume 4: Marine Realm. South African National Biodiversity Institute, Pretoria. South Africa. http://hdl.handle.net/20.500.12143/6372.

Southall B. L., Finneran J. J., Reichmuth C., Nachtigall P. E., Ketten D. R., Bowles A. E., Ellison W. T., Nowacek D. P., Tyack P. L. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. The Journal of the Acoustical Society of America, 34(12), pp.1936-1956.

Ziolkowski, A. M. 1970. A method for calculating the output pressure waveform from an airgun, Geophys.J.R.Astr.Soc., 21: 137-161.

Ziolkowski, A. M., Parkes, G. E., Hatton, L. and Haugland, T. 1982. The signature of an airgun array: computation from near-field measurements including interactions, Geophysics, 47: 1413-1421.

Appendix A Marine Fauna Classification

AOSAC: Exploration Drilling Campaign in Block 3B/4B

Underwater Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

SLR Project No.: 201.088774.00001

November 24, 2023

A.1 Marine Fauna Classification

The following appendix gives a summary of marine fauna hearing group classification. Not all animals listed in **Table A.1** are expected to be found in the vicinity of the project area.

Table A.1 Summary of marine mammal classification

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

Classification	Common Name	Scientific Name
	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*
	Australian humpback dolphin	*Sousa sahulensis*
	Atlantic humpback dolphin	*Sousa teuszii*
	Tucuxi	*Sotalia fluviatilis*

Classification	Common Name	Scientific Name
	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*
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*

Classification	**Common Name**	**Scientific Name**
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*
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*

Classification	Common Name	Scientific Name
	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 B Auditory Weighting Functions

AOSAC: Exploration Drilling Campaign in Block 3B/4B

Underwater Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

SLR Project No.: 201.088774.00001

November 24, 2023

B.1 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.

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

Where:

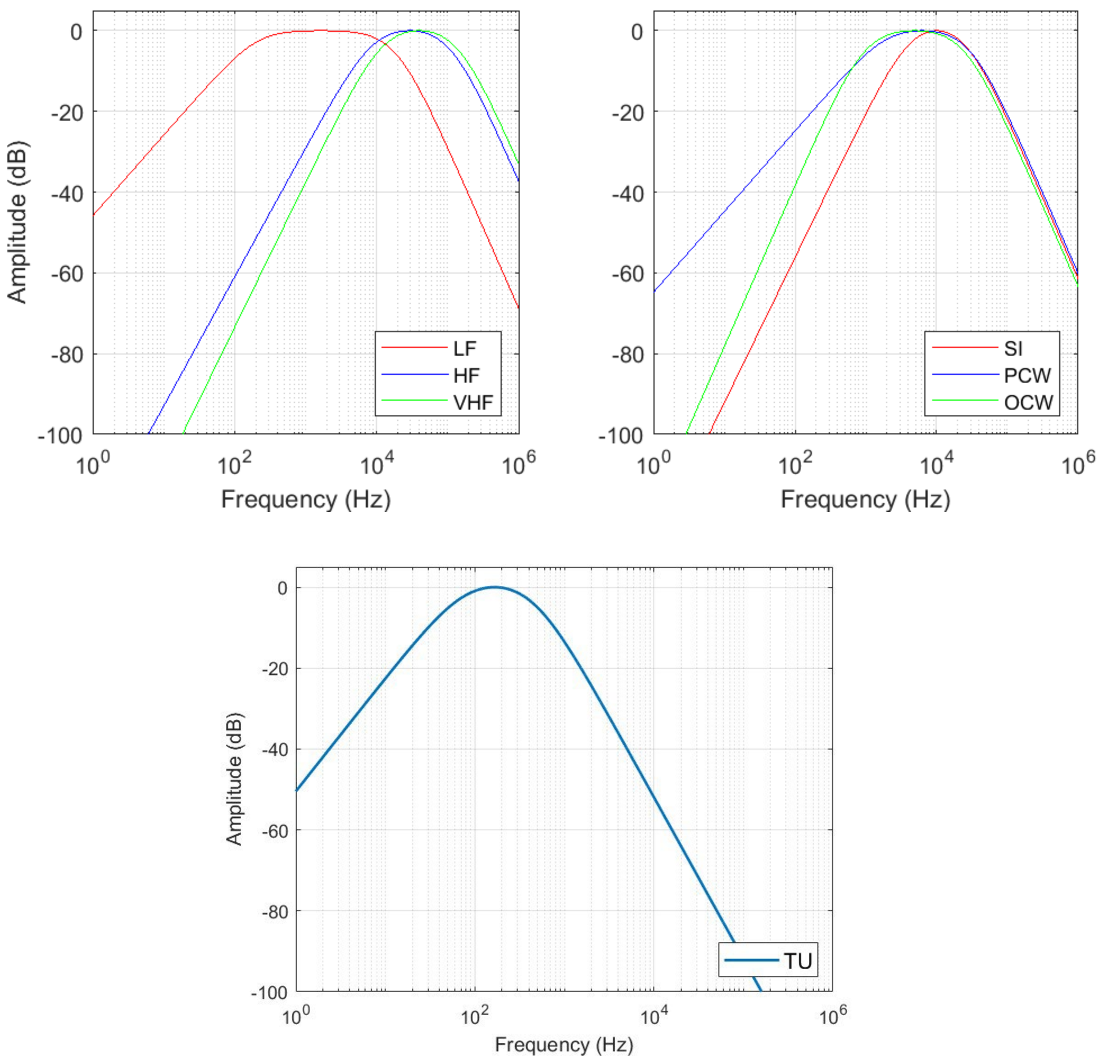
- ***W(f)*** is the weighting function amplitude (in dB) at frequency f (in kHz).
- $\boldsymbol{f_1}$ represents LF transition value (in kHz), i.e., the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- $\boldsymbol{f_2}$ represents HF transition 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 Noise Modelling Contour Figures

AOSAC: Exploration Drilling Campaign in Block 3B/4B

Underwater Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

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Figure C.1: Modelled maximum SEL contours for single VSP pulse at source location L1

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

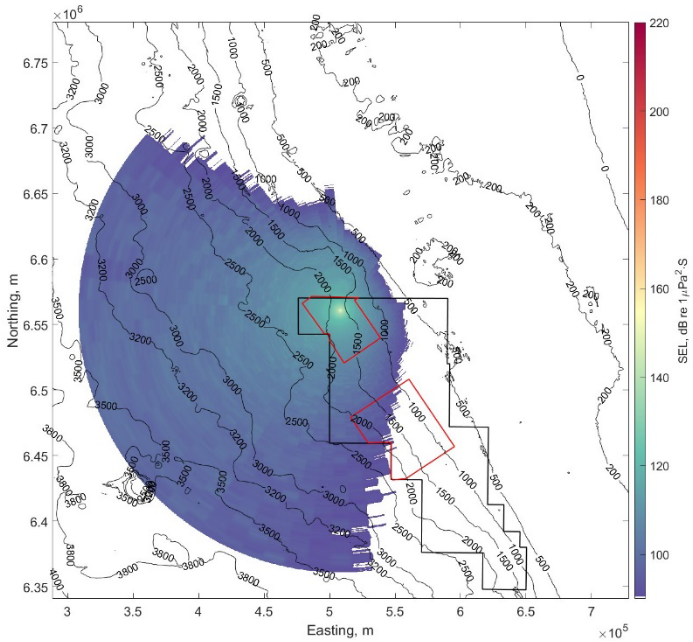


Figure C.2: Modelled maximum SEL contours for single VSP pulse at source location L2

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

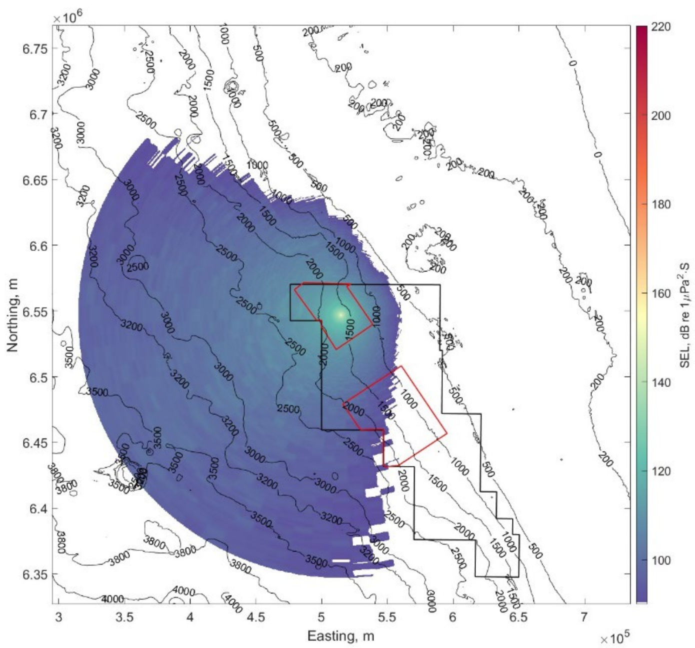


Figure C.3: Modelled maximum SEL contours for single VSP pulse at source location L3

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

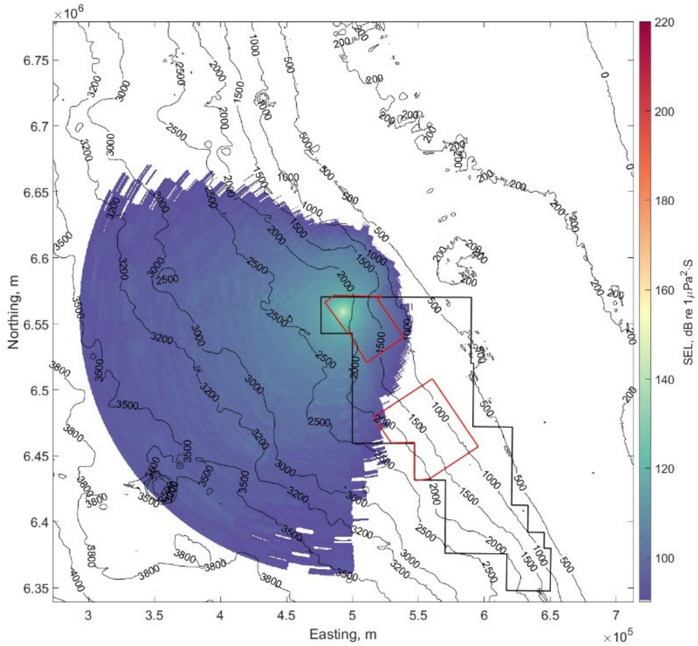


Figure C.4: Modelled maximum SEL contours for single VSP pulse at source location L4

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

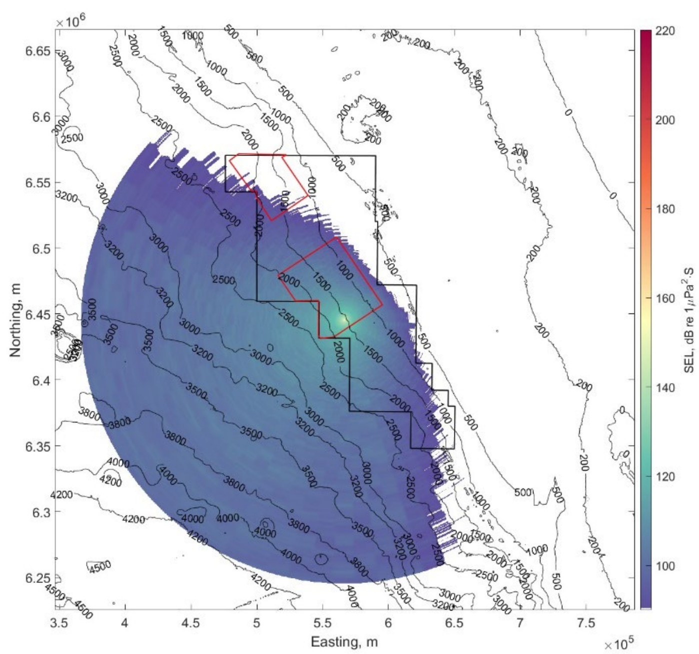


Figure C.5: Modelled maximum SEL contours for single VSP pulse at source location L5

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

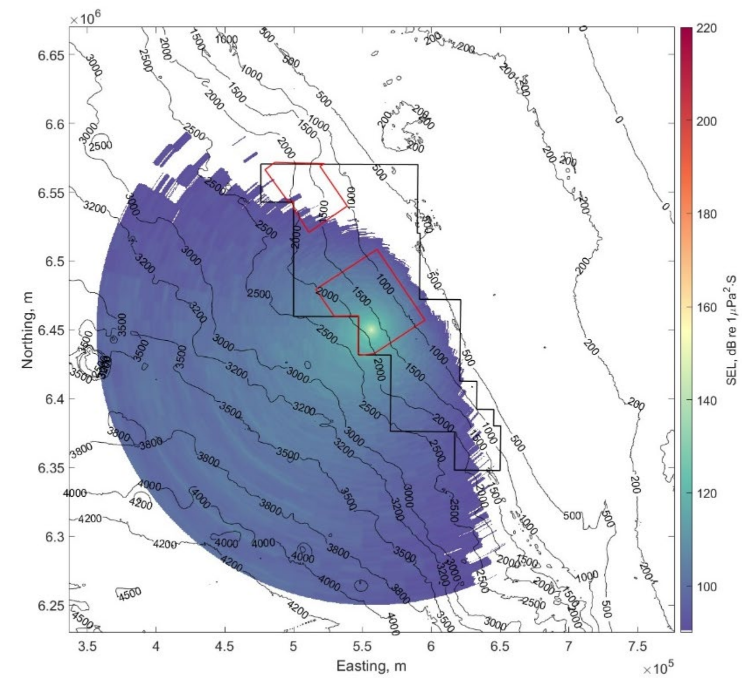


Figure C.6: Modelled maximum SEL contours for drilling operation at source location L1

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

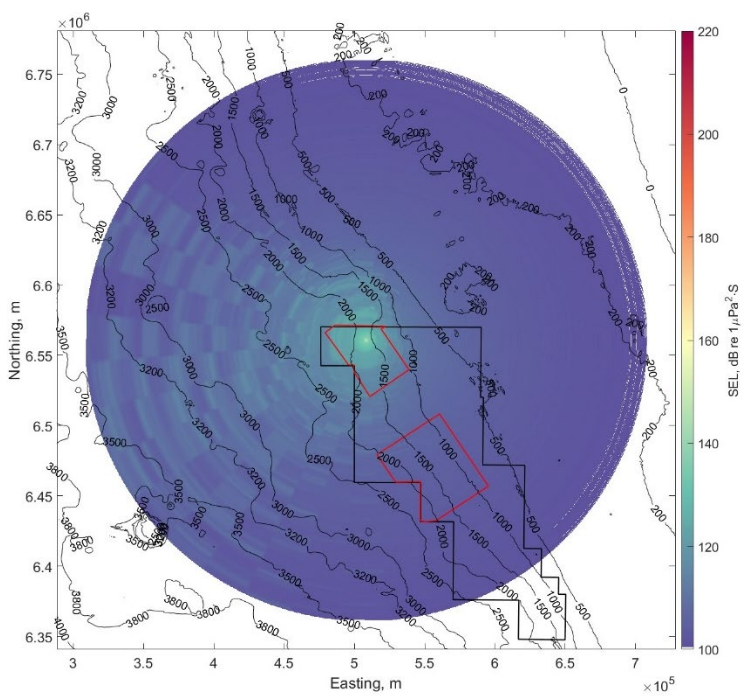


Figure C.7: Modelled maximum SEL contours for drilling operation at source location L2

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

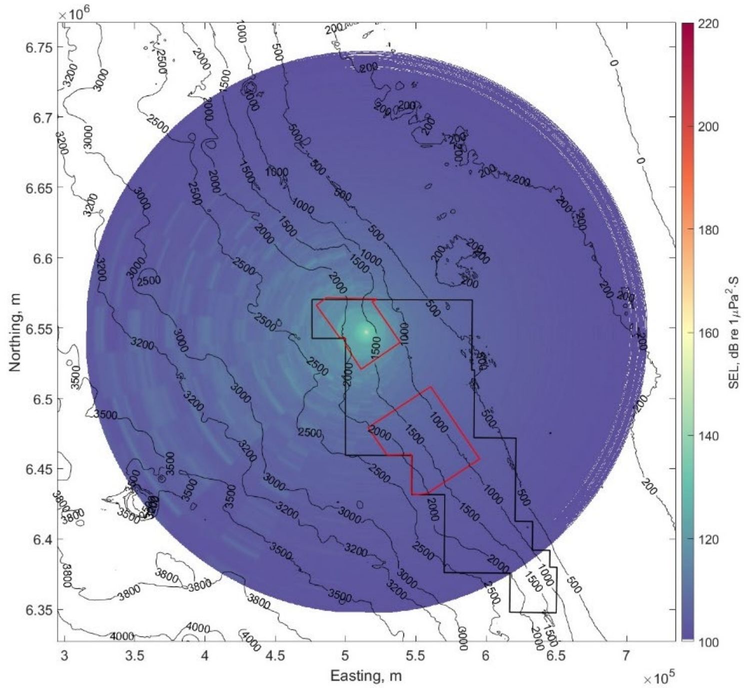


Figure C.8: Modelled maximum SEL contours for drilling operation at source location L3

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

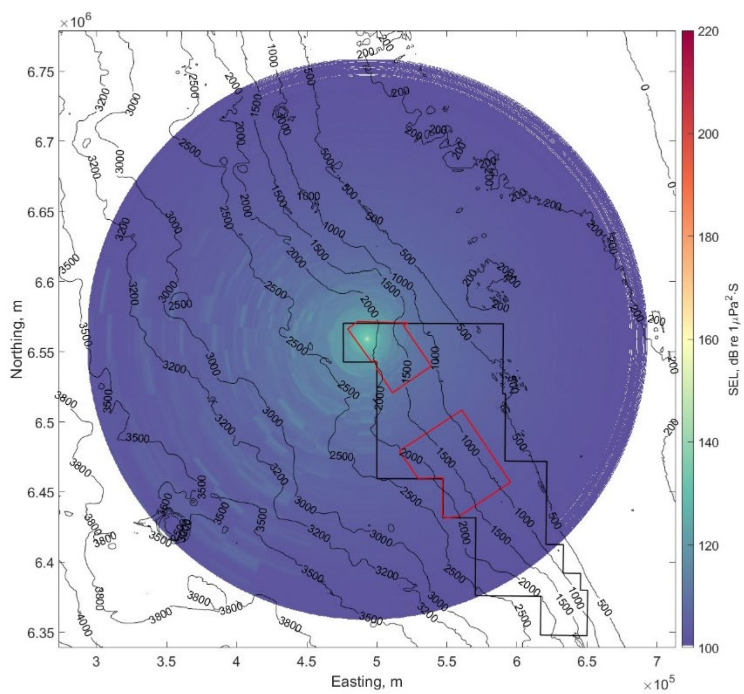


Figure C.9: Modelled maximum SEL contours for drilling operation at source location L4

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km

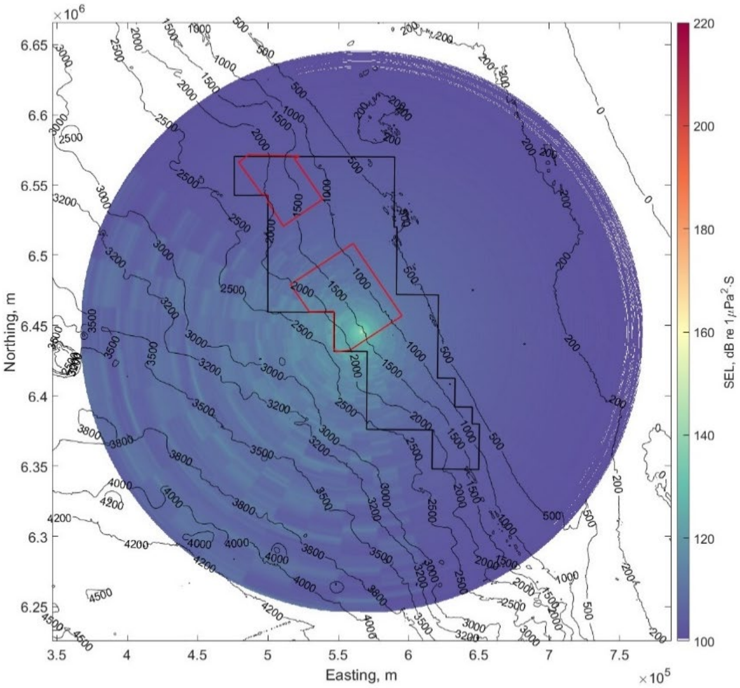
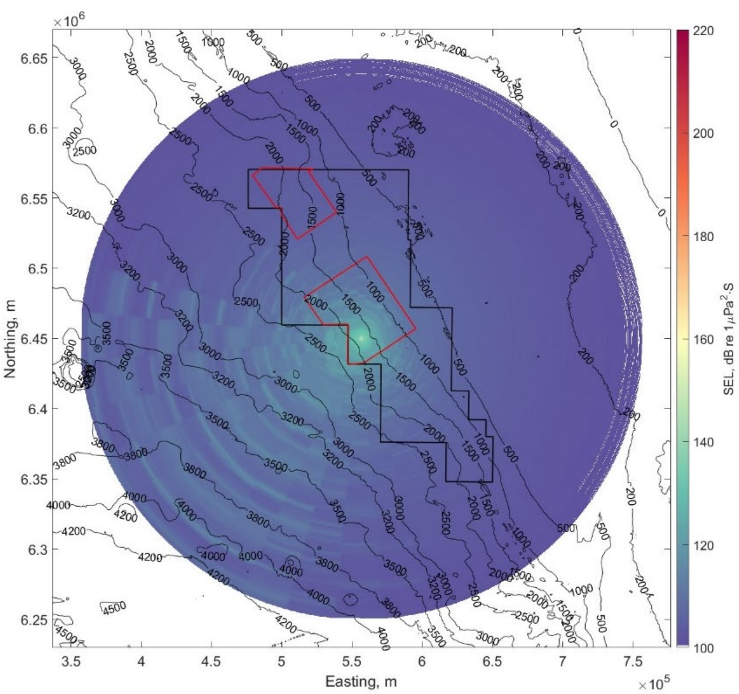


Figure C.10: Modelled maximum SEL contours for drilling operation at source location L5

SELs are unweighted and maximum level across water column. Image depicts maximum range of 200 km



Appendix D Single MBES Pulse Modelling Results

AOSAC: Exploration Drilling Campaign in Block 3B/4B

Underwater Sound Transmission Loss Modelling

Environmental Impact Management Services Pty Ltd.

SLR Project No.: 201.088774.00001

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Figure D.1: Modelled maximum Peak SPL for a single MBES pulse at source location L1 (top), L2 (middle), and L3 (bottom)

Maximum level across water column. Image depicts directions for the source along-track (left) and cross-track (right).

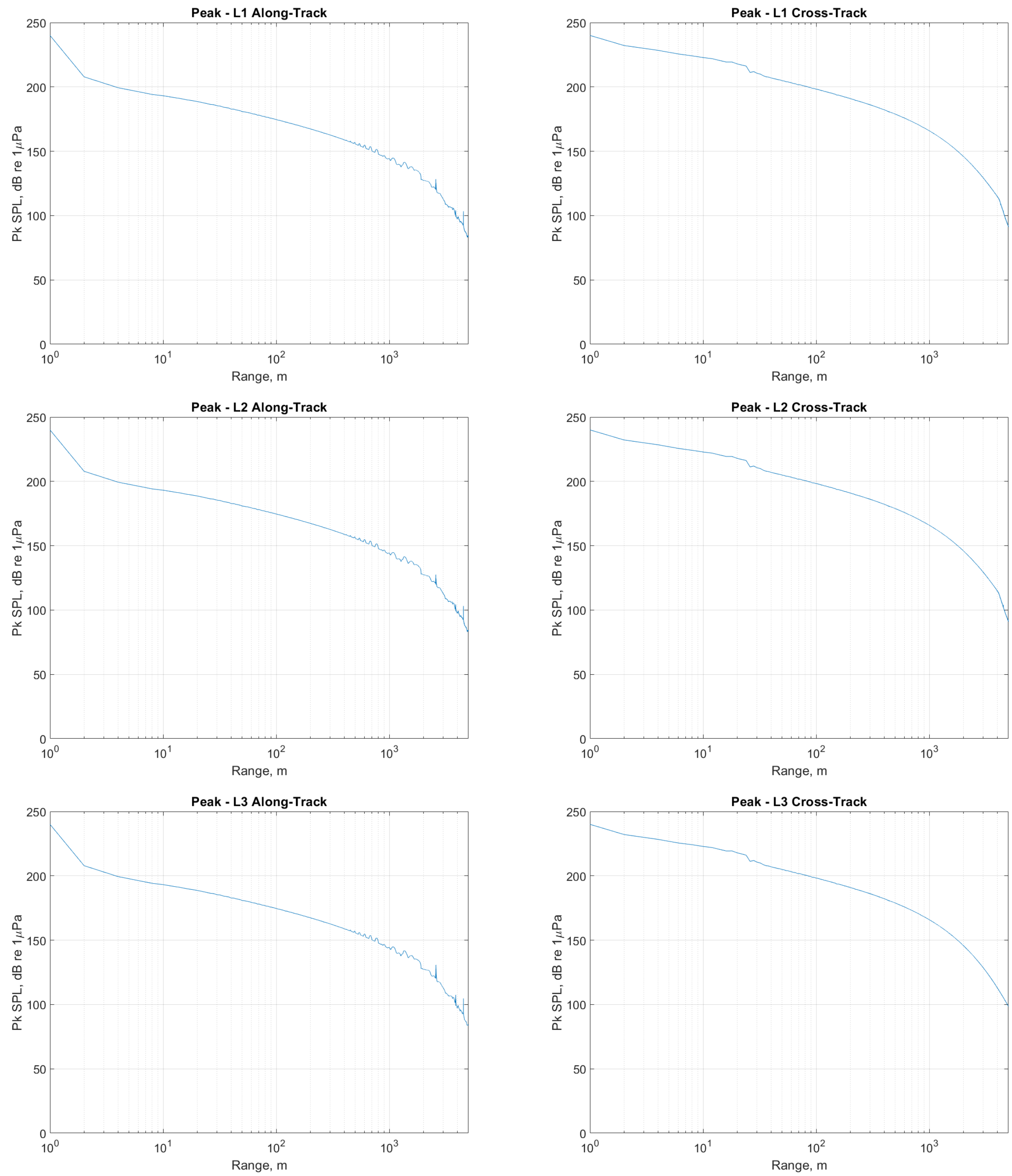


Figure D.2: Modelled maximum Peak SPL for a single MBES pulse at source location L4 (top), and L5 (bottom)

Maximum level across water column. Image depicts directions for the source along-track (left) and cross-track (right).

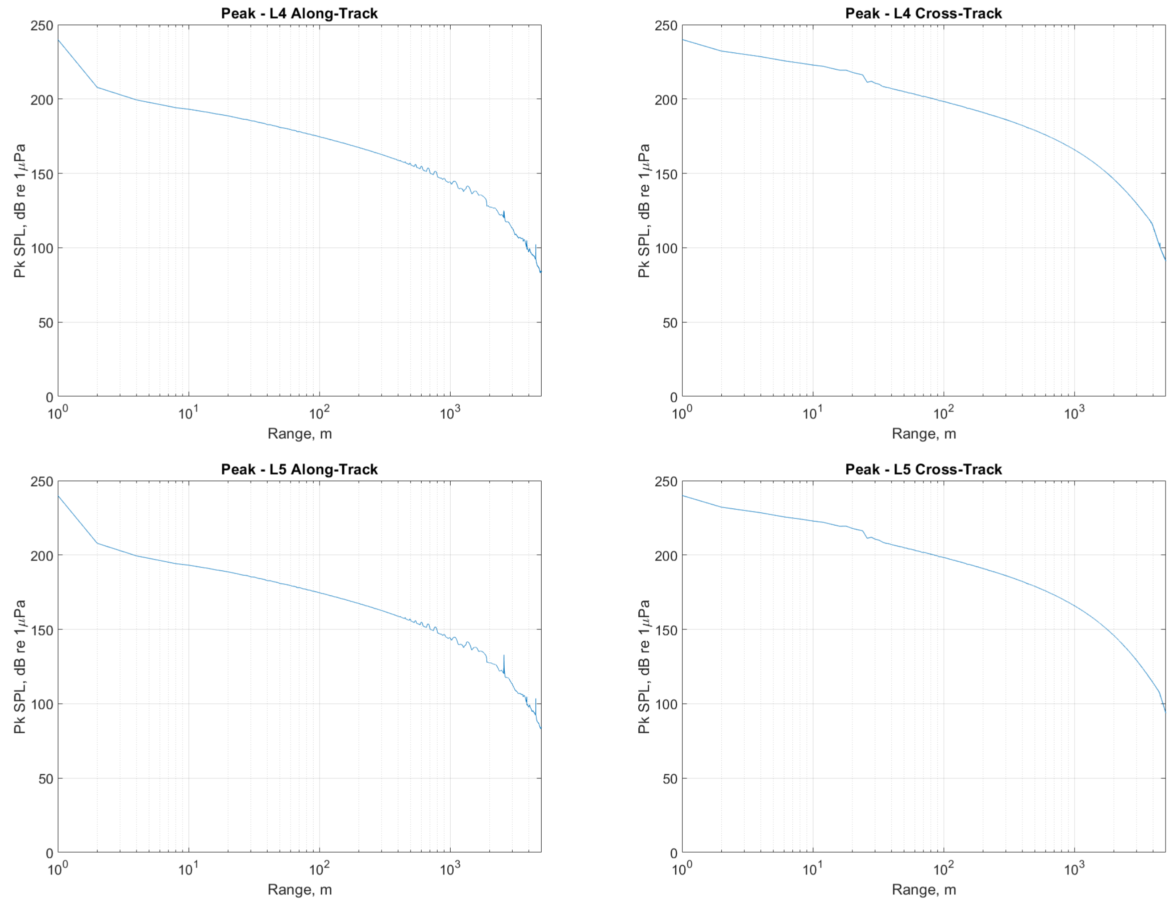


Figure D.3: Modelled maximum RMS SPL for a single MBES pulse at source location L1 (top), L2 (middle), and L3 (bottom)

Maximum level across water column. Image depicts directions for the source along-track (left) and cross-track (right).

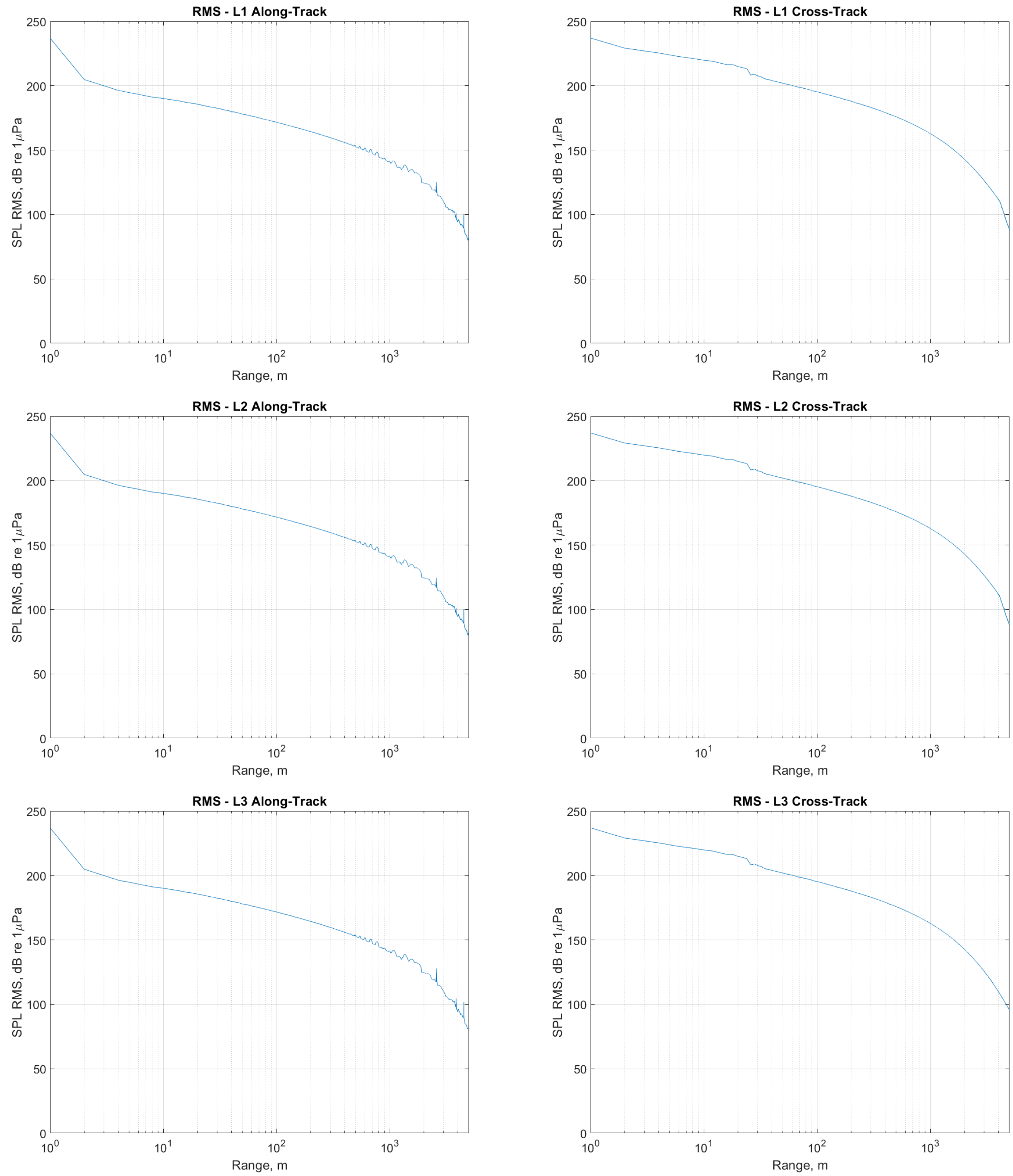
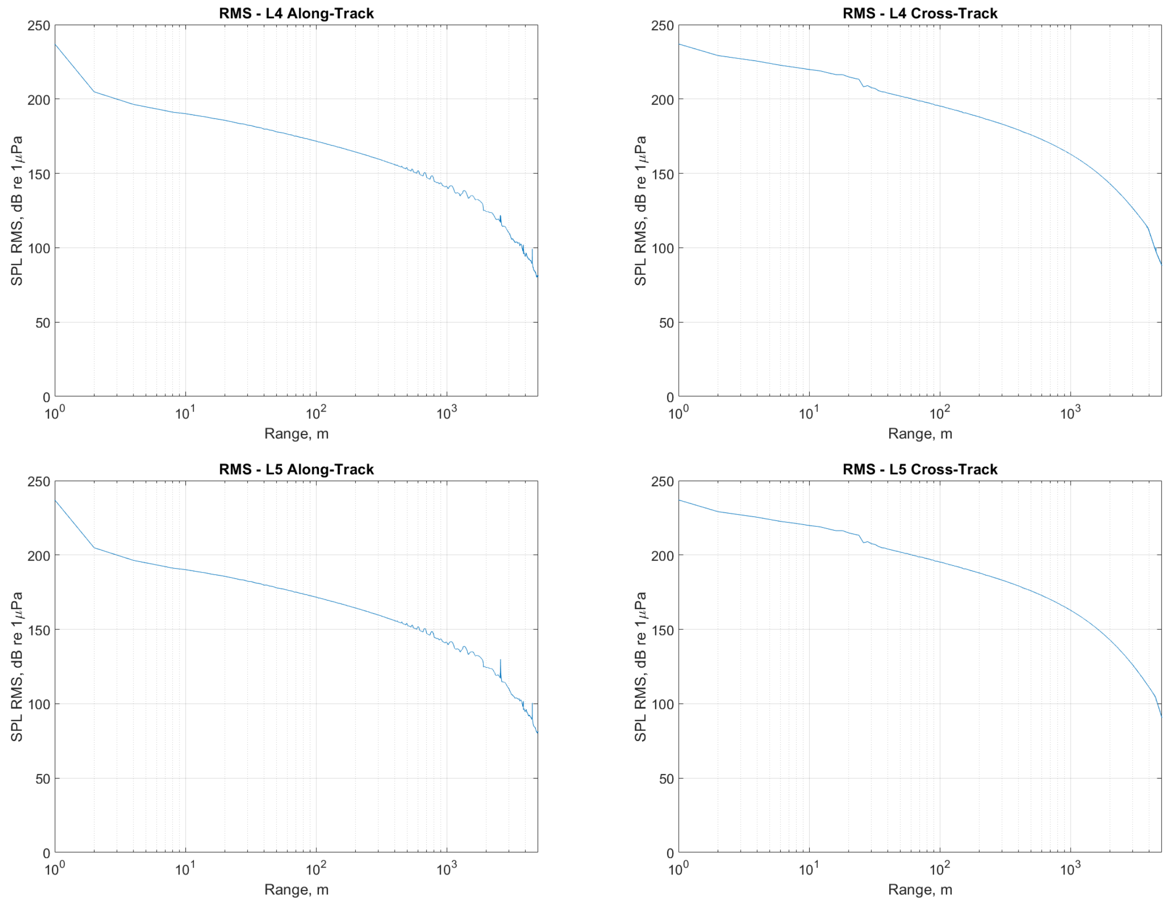


Figure D.4: Modelled maximum RMS SPL for a single MBES pulse at source location L4 (top), and L5 (bottom)

Maximum level across water column. Image depicts directions for the source along-track (left) and cross-track (right).



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