APPENDIX 7: UNDERWATER NOISE MODELLING

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

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Executive Summary

TotalEnergies EP Namibia (TEEPNA) is the operator for offshore exploration license Block 2912 in southern Namibia. TEEPNA currently holds an Environmental Clearance Certificate for 3D seismic surveying and is now proposing to undertake further exploration drilling and associated activities.

SLR Environmental Consulting (Namibia) Pty Ltd. has been appointed by TEEPNA to undertake the required Environmental and Social Impact Assessment process and SLR Canada has, in turn, been appointed as the independent underwater acoustic specialist to undertake a Sound Transmission Loss Modelling (STLM) study for the proposed drilling program, in order to assist with the assessment of potential noise impacts on marine fauna species of interest.

This report provides a marine noise modelling study and assessment of relevant zones of impact associated with the proposed drilling operation activities. The study involves the following:

- Establishment of relevant assessment criteria for marine fauna species likely to be potentially impacted by the drilling operation noise emissions;
- Characterisation of the existing underwater noise environment based on a literature review of the general ocean noise environment and the site-specific metocean conditions;
- Identification of major noise sources and their noise emission characteristics;
- 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 identified major noise sources, including impulsive airgun signals from vertical seismic profiling (VSP), single pulse Sonar surveying, and continuous noise emissions from different stages of drilling operations (including the drilling unit and support vessels). In addition, the zones of noise impact from major noise sources have been estimated for different marine faunal species based on comparisons between STLM noise levels and noise impact criteria for both shallow-water and deep-water source location scenarios.

Assessments of relevant zones of impact are detailed in Section 6.0, with a summary of the maximum zones of impact estimates provided in Table 29 and Table 30 within the report.

The zones of impact assessment for the study are summaries as below.

Impact from VSP Seismic Pulses

It should be noted that the cumulative impact at a specific receiving location is modelled based on the assumption that the marine animals are constantly exposed to the VSP pulses at a fixed location over the entire operation period. Realistically, marine animals would not stay in the same location for the entire period. Therefore, the cumulative zones of impact represent the worst-case consideration and will reduce logarithmically with a decreased exposure time period.

Marine Mammals

The immediate impact from VSP pulses is predicted to cause physiological effects (both PTS and TTS onset) for all marine mammal species adjacent to the VSP source (up to 55 and 90 m, respectively). Potential behavioural disturbance from the VSP pulses is predicted to occur for marine mammals of all hearing groups up to 1,420 km from the source location.

The cumulative impacts from VSP pulses are predicted to be the highest for low-frequency (LF) cetaceans. Under the worst-case VSP pulse exposure scenario (i.e., 250 pulses within 9 hours), the zones of impact for PTS-onset and TTS-onset are predicted to be up to 70 m and 320 m from the VSP source, respectively. For other hearing group cetaceans, the cumulative impact for PTS-onset and TTS-onset is only predicted to occur at receiving locations up to 40 m and 60 m from the VSP source, respectively.

Fish

VSP pulses are predicted to cause immediate physiological impacts (both mortality and recovery injury) for fish, fish eggs, and fish larvae species directly adjacent to the VSP source (<35 m). Potential behavioural disturbance from the VSP pulses is predicted to occur for all fish species up to 4,2 km from the source location.

The cumulative impacts on fish, fish eggs, and fish larvae from VSP pulses (i.e., 250 pulses within 9 hours) are predicted to cause mortality within 50 m and potential recoverable injury within 65 m of the VSP source location. Temporary injury or TTS-onset is only predicted to occur at receiving locations up to 330 m from the source under the worst-case VSP pulse exposure scenario (i.e., 250 pulses within 9 hours).

Sea Turtles

The maximum zones of PTS and TTS due to a single pulse exposure for sea turtles are predicted to be within approximately <10 m from the source array. The potential behavioural disturbance from the VSP pulses is predicted to occur up to 340 m from the source.

Cumulative impact related to PTS and TTS on sea turtles is expected to be around 25 and 70 m respectively at the near field from the source location (i.e., 250 pulses within 9 hours).

Impact from Drilling Rig Operations

Marine Mammals

Under the worst-case consideration (i.e., with the highest cumulative non-impulsive drilling noise emissions with drillship plus support vessels operating over the entire 24-hour period), LF and VHF cetaceans have the highest impact zones among all marine mammal hearing groups. The PTS-onset zone over the 24-hour period for LF and VHF cetaceans is up to 290 m and 260 m, and the TTS-onset zone is up to 3,2 km and 2,9 km from the drilling location, respectively.

With a decreased exposure period, the zones of impact will be reduced significantly. For example, for an exposure period of half an hour, the PTS-onset zone is predicted to be within 40 m from the noise source for LF and VHF cetaceans, and the TTS-onset zone within 450 m for LF cetaceans and 410 m for VHF cetaceans. For marine mammals of other hearing groups, nearly no PTS-onset and TTS-onset are predicted to occur due to such a short duration exposure. It is highly unlikely that a marine mammal would remain in the same location for the full 24-hour period. It is expected that 0,5 hours of exposure is more realistic than 24 hours, and realistic zones of impact more closely resemble those for 0,5 hours. Therefore, 24-hour exposure duration is presented as a worst-case scenario.

Potential behavioural disturbance from the non-impulsive noise emissions from drilling operations is predicted to occur for marine mammals of all hearing groups up to 33,6 km from the assessed deep-water drilling location.

Fish and Sea Turtles

The non-impulsive drilling operation noise is not expected to cause physiological impacts (both mortality and recovery injury) on fish species. However, continuous noise from non-impulsive drilling operations that is detectable by fishes can mask signal detection and thus may have a pervasive effect on their behaviour. Fishes are expected to suffer of behaviour disruption if these are found within 1,560 km distance from the noise source.

For sea turtles, the maximum zones of cumulative PTS impact are predicted to range within 30 m if continuous sound prevails for 24 hours and within less than 10 m if continuous sound last 0,5 hours or less. The potential behavioural disturbance from the non-impulsive noise emissions from drilling operations is predicted to occur up to 150 m for the deepest (L1) and shallowest (L2) water drilling locations.

Impact from a single MBES pulse

Marine Mammals

For sonar surveys, the high-frequency noise emissions from the MBES sources are highly directional, predominantly towards cross-track directions. As a result, the noise impact is predicted to be highly localised for the majority of marine mammal species. VHF cetaceans are predicted to have the highest zones of impact (760 m for immediate PTS impact, 1 km for immediate TTS impact and 1,150 km for behavioural disturbance immediate impact), but only limited to cross-track directions. Therefore, the actual impact footprints are significantly smaller than the cases with omnidirectional noise emissions.

Cumulative exposure from single MBES pulses is predicted to be low for the majority of any marine mammal hearing group other than VHF cetaceans (320 m for PTS and 800 m for TTS impact). For cetaceans of other hearing groups, the maximum zones of cumulative TTS impact are predicted to range within less than 80 m from the MBES source location along the cross-track directions.

Fish and Sea Turtles

Due to the high-frequency range of (10 kHz or greater) from the MBES sources, which is far beyond the low-frequency hearing ranges of fish species (from below 100 Hz to up to a few kHz), the MBES sources used in the sonar surveys are not expected to cause an adverse hearing impact on fish species. Potential behavioural disturbance from a single MBES pulse is predicted to occur for all fish species up to 1,620 km from the source location.

For sea turtles, the maximum zones of immediate impact are predicted to range within 70 m for PTS, 125 m for TTS and 540 m for behavioural disturbance immediate impact. Cumulative exposure from single MBES pulses is not expected to occur at all.

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Acronyms and Abbreviations

CUI	Cubic Inch
ESIA	Environmental and Social Impact Assessment
dB	Decibel
GEBCO	General Bathymetric Chart of the Oceans
G-Gun	Gundalf-Gun manufactured by Sercel
HF	High Frequency
LF	Low Frequency
MPA	Marine Protected Area
NMFS	National Marine Fisheries Services
NOAA	National Oceanic and Atmospheric Administration
OCW	Other marine Carnivores in Water
PCW	Phocid Carnivores in Water
PE	Parabolic Equation
Pk	Peak
PSD	Power Spectral Density
PSI	Per Square Inch
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SEL	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SLR	SLR Consulting (Namibia) Pty Ltd.
SPL	Sound Pressure Level
STLM	Sound Transmission Loss Modelling
TEEPNA	TotalEnergies E&P Namibia B.V.
TTS	Temporary Threshold Shift
VHF	Very High Frequency
VSP	Vertical Seismic Profiling

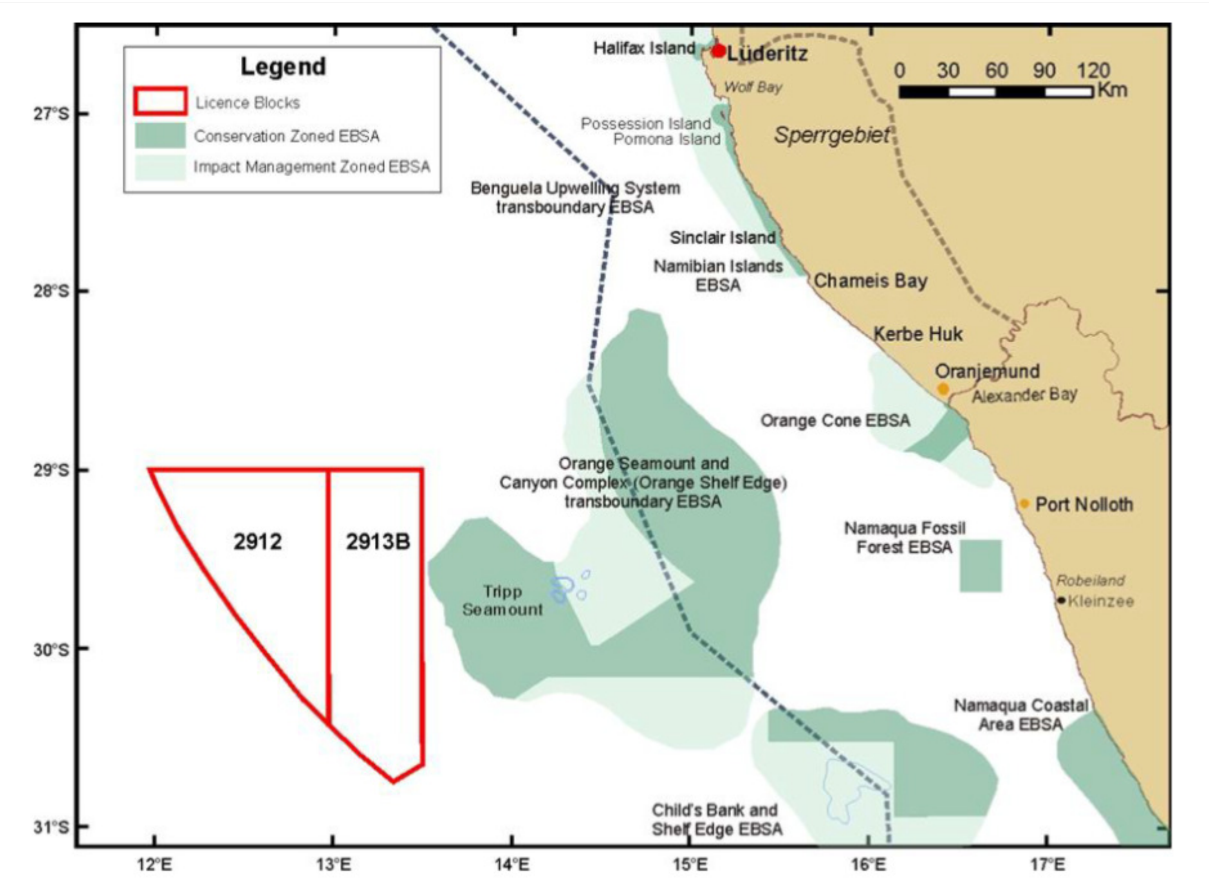
A glossary of acoustic terminology is provided in **Appendix A.**

1.0 Introduction

1.1 Project Background

TotalEnergies E&P Namibia B.V. (TEEPNA) is the operator for exploration license Block 2912 located in the deep water Orange Basin off the southern coast of Namibia (290 Km at its closest point). The licence block is 9 955 km^2 in extent, and water depths range from roughly 2 940 m to 3 850 m (Figure 1).

Figure 1: Locality of Licence Block 2912 off the Southern Coast of Namibia (showing adjacent Block 2913B)



TEEPNA currently holds an Environmental Clearance Certificate (ECC) for 3D seismic surveying across Block 2912, which was issued in June 2021. TEEPNA has now commissioned an Environmental and Social Impact Assessment (ESIA) for additional exploration activities within the block as part of the application for another ECC. These activities include:

- Offshore drilling for exploration/appraisal wells (up to 10), including;
    - Vertical Seismic Profiling (VSP)
    - Well testing operations
- Abandonment of deep offshore wellheads on the seafloor

- Sonar bathymetry surveys; and
- Seafloor sediment coring surveys

SLR Environmental Consulting (Namibia) Pty Ltd. (SLR) has been appointed by TEEPNA as the Independent Environmental Practitioner to undertake the ESIA process for the proposed drilling exploration activities. In order to assess the potential noise impacts on marine fauna and fishing, SLR Canada 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 and exploration programme.

1.2 Structure of the Report

There is no national legislation or regulatory guidelines in Namibia for the assessment of underwater noise impacts on marine fauna species. Therefore, the assessment has been undertaken considering current industry best practices applied internationally and being consistent with impact studies undertaken for other similar major offshore exploration projects elsewhere globally. The assessment methodology comprising a number of components is detailed in the report structure below.

- Section 2.0 gives an overview of the well drilling and exploration operations;
- Section 3.0 provides the characterisation of the existing acoustic environment based on a review of the general ocean noise environment, as well as the site-specific metocean data in relation to Block 2912;
- Section 4.0 outlines the assessment criteria for relevant general marine fauna species, including marine mammals, fish and sea turtle species, based on relevant guidelines and criteria that represent current industry best practices;
- Section 5.0 details detailed noise modelling prediction methodology and procedure, relevant modelling environmental inputs and assumptions, modelling drilling well locations and scenarios associated with the drilling operation activities with major noise emissions (i.e., drilling operations, VSP testing and Sonar survey), and source levels of these major noise emissions;
- Sections 6.0 provides the detailed modelling results and the subsequent zones of impact estimated for general marine fauna species based on criteria set out in Section 4.0;
- Section 0 provides a discussion of the acoustic modelling study; and
- Section 9.0 lists the relevant references cited throughout the report.

2.0 Exploration 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. TEEPNA is proposing to utilise a drillship such as SAMSUNG GF12000 drillship or ENSCO DS-10 / DS-12) due to its very large storage capacity and capability to work in water depths ranging from 500 to 3 600 m and under extreme metocean conditions.

Support Vessels

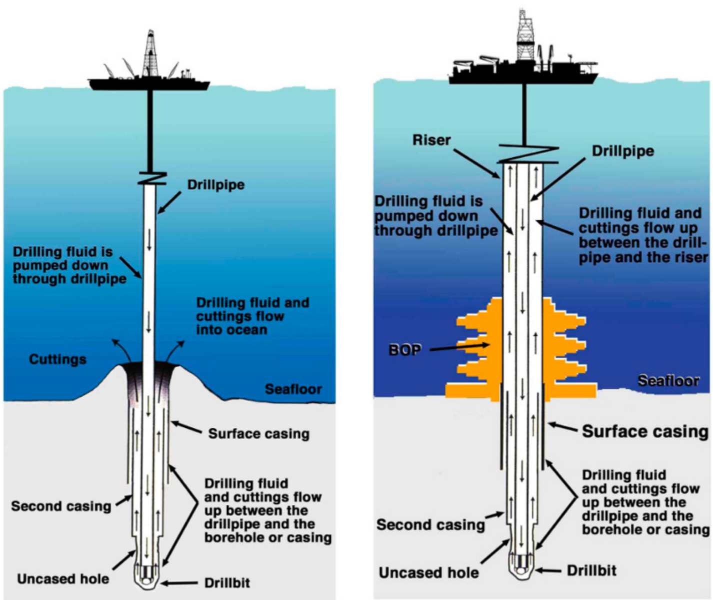
The drilling unit will be supported/serviced by up to three support vessels to facilitate moving equipment and materials between the drilling unit and the onshore base.

A supply vessel will always be on standby near the drilling unit to provide support for firefighting, oil containment/recovery, 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 transfer of crew if needed.

Helicopters

Transportation of personnel to and from the drilling unit by helicopter is the preferred transfer method. It is estimated that there will be at least four daylight flights per week between the drilling unit and the logistics base at Lüderitz. The helicopters can also be used for medical evacuations from the drilling unit to shore (day- or night-time) if required.

Figure 2: Riserless drilling stage (left) and risered drilling stage (right) (Source: http://www.kochi-core.jp/cuttings/)



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 hole diameter decreases with increasing depth.

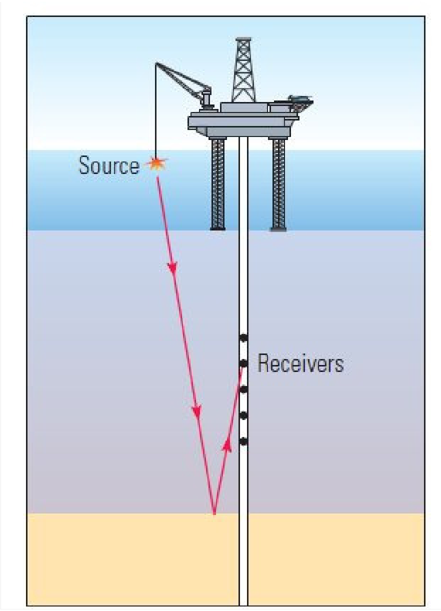
The expected target drilling depth is not yet confirmed, but the notional well depth is between 1 500 and 3 500 m below the seafloor. Drilling is essentially undertaken in two stages, namely the "riserless" and "risered" drilling stages, as shown in Figure 2.

2.3 Vertical Seismic Profiling Testing

Vertical Seismic Profiling (VSP) is an evaluation tool that would be undertaken as part of the conventional wireline logging programme when the well reaches the 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.

VSP uses a small airgun array, which is operated from the drilling unit. The airgun array is deployed between 7 m and 10 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 around 9 hours to complete approximately 250 shots, depending on the well's depth and the number of stations being profiled. A typical VSP arrangement is provided in Figure 3.

Figure 3: Schematic of a typical VSP arrangement (Source: http://researchgate.net/figure/Rig-Source-Vertical-Seismic-Profile)

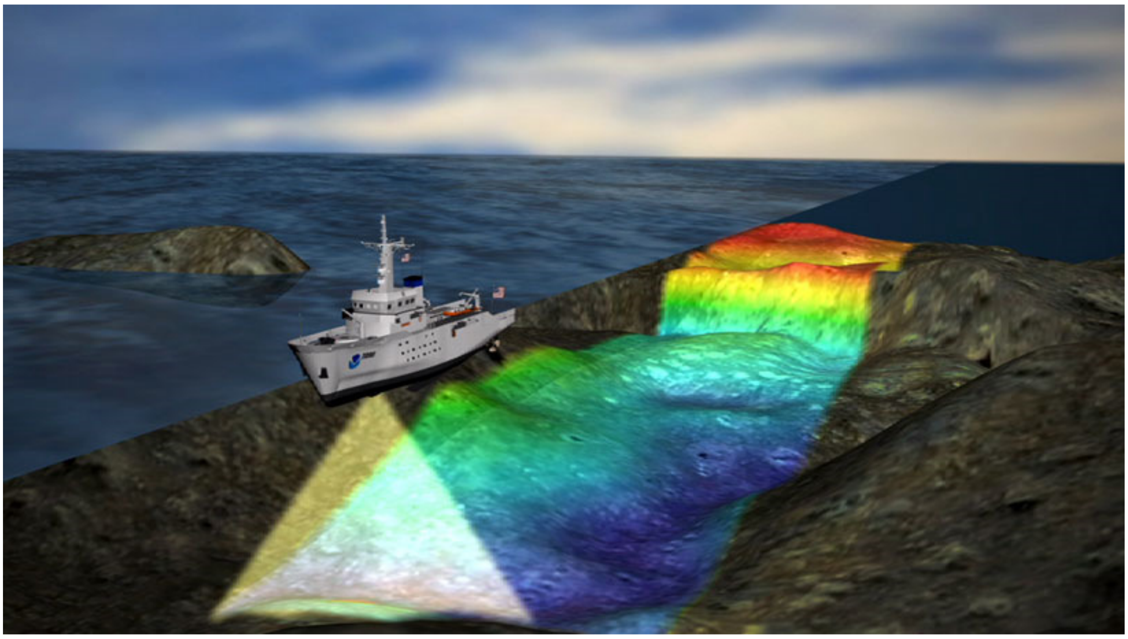


2.4 Sonar Survey

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 General Ocean Ambient Noise

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).

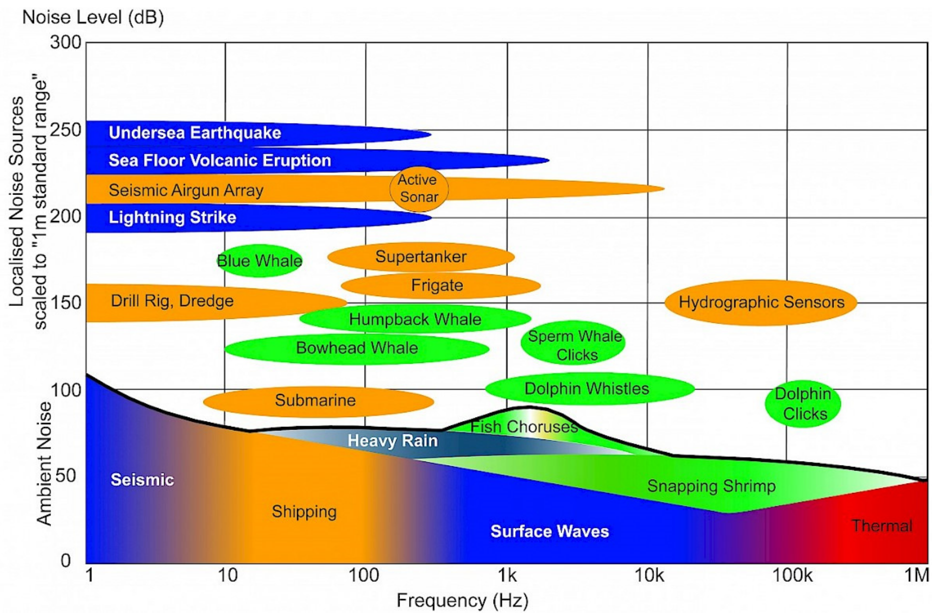
Ocean ambient noise is comprised of a variety of sounds of different origins at different frequency ranges, having both temporal and spatial variations. It primarily consists of noise from natural physical events, the noise produced by marine biological species and anthropogenic noise. These sources are detailed as follows:

- Natural events: 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.
- Bioacoustic production: some marine animals produce various sounds (e.g., whistles, clicks) for different purposes (e.g., communication, navigation, or detection):
    - 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. Snapping shrimp noise can interfere with other measurement and recording exercises; for example, it can adversely affect sonar performance.

- Anthropogenic sources: anthropogenic noise primarily consists of noise from shipping activities, offshore seismic 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, generating 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, with ambient noise in this frequency range being predominantly from distant shipping (Hildebrand 2009). In areas away from anthropogenic sources, background noise at higher frequencies tends to be dominated by natural physical or bioacoustics sources such as rainfall, surface waves and spray, fish choruses, and snapping shrimp for coastal waters.

Figure 5: Levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment (from https://www.ospar.org/work-areas/eiha/noise). Natural physical noise sources represented in blue; marine fauna noise sources in green; human noise sources in orange



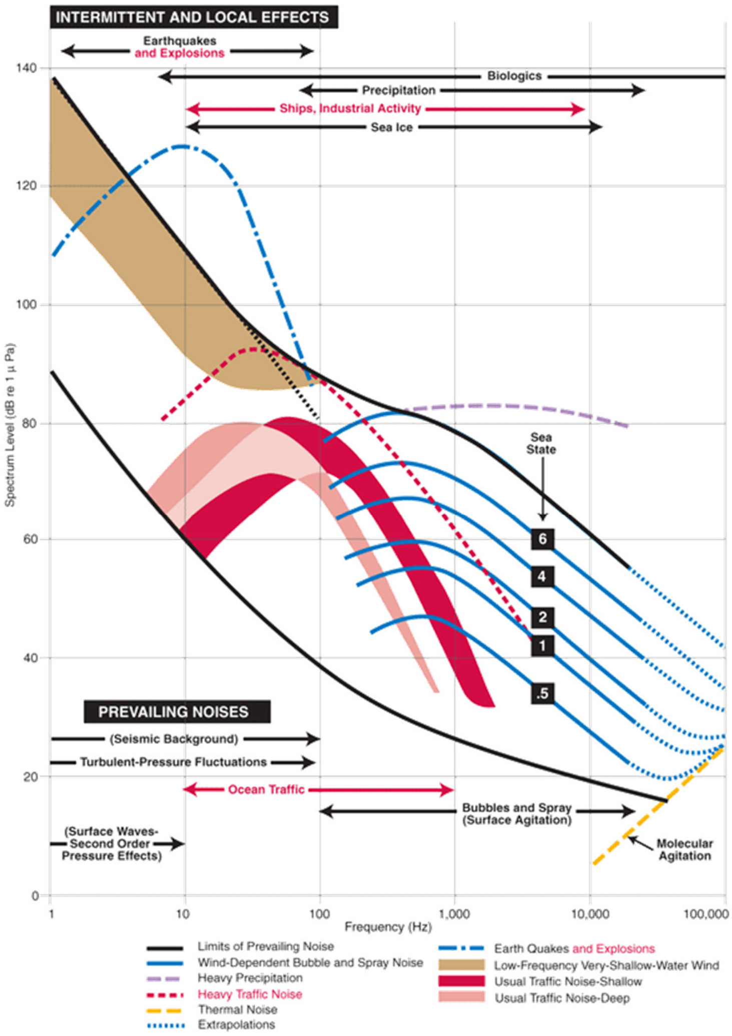
A summary of the spectra of various ambient noise sources based on a review study undertaken by Wenz (1962) is shown in Figure 6. It should be noted that although the spectral curves in the figure are based on average levels from reviewed references primarily for the North Atlantic Ocean, they are regarded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

Overall ambient noise levels typically range from approximately:

- As low as 80 dB re 1 µPa for the frequency range 10 – 10 kHz for light surrounding shipping movements and calm sea surface conditions, to;
- Up to 120 dB re 1 µPa for the frequency range 10 – 10 kHz for moderate to heavy remote shipping traffic and medium to high wind conditions.

Given the local shipping traffic and moderate metocean conditions specific to the adjacent area surrounding Block 2912B as described in the following relevant sections, the ambient noise levels are expected to be at least 5 dB higher than the lowest level, within the higher range of the typical ambient noise levels, i.e., 85 - 125 dB re 1 µPa for the frequency range 10 – 10 kHz.

Figure 6: Spectra and frequency distribution of ocean sound sources based on the Wenz curves (Miksis-Olds *et al*. 2013, adapted from Wenz (1962))



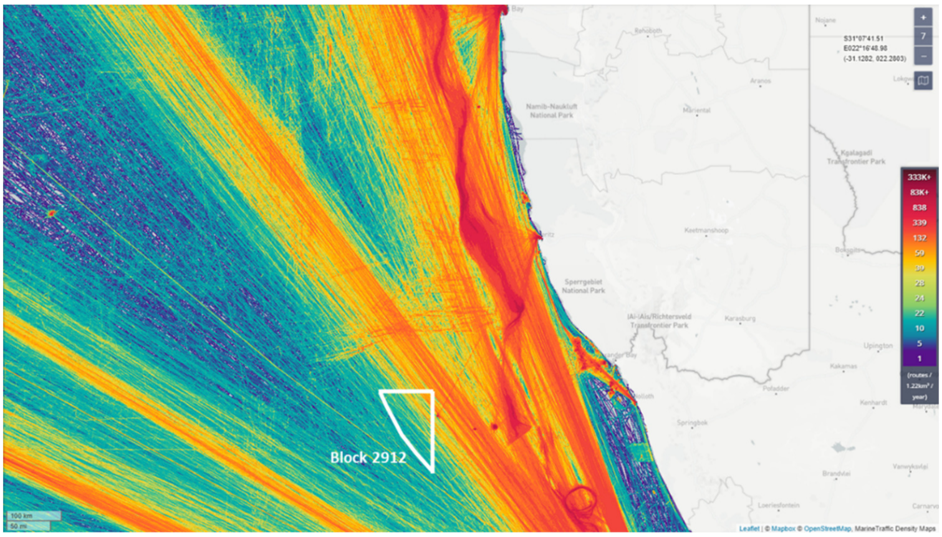
3.2 Shipping Traffic Offshore Southwestern Africa

Shipping traffic density offshore the Southwestern African coastal region and for the area surrounding Block 2912 is shown in **Figure 7**. There are a few ports near Block 2912 including Cape Town, Saldanha and Lüderitz. Major shipping routes are along the coastline, connecting either between these ports or internationally.

As seen from the bottom panel within the figure, Block 2912 has some shipping traffic density over the block area, particularly the north-eastern corner of the block.

As such, the shipping noise component of the ambient noise environment is expected to be significant within the north-eastern corner of the block.

Figure 7: Shipping traffic density offshore West African coastal region and surrounding Block 2912 (Source: http://www.marinetraffic.com/, accessed 18th July 2022)



3.3 Metocean conditions off south coast Namibia

A preliminary metocean study for neighbour Block 2913B (RPS, 2020) has provided monthly percentile distribution of wind speed based on site survey data adjacent to the block area, with the distribution of the percentiles detailed in **Table 1** and **Figure 8.** As can be seen from the results, the wind speed distribution varies slightly over one year, with maximum high wind speeds (~22 m/s) occurring during April and average high wind speeds (~8 m/s) during the period of October – January. There is also a tendency of wind direction towards the Southeast. For yearly distribution, wind speeds are within the range of 7,5 m/s (i.e., Beaufort scale 4) over the one-year period.

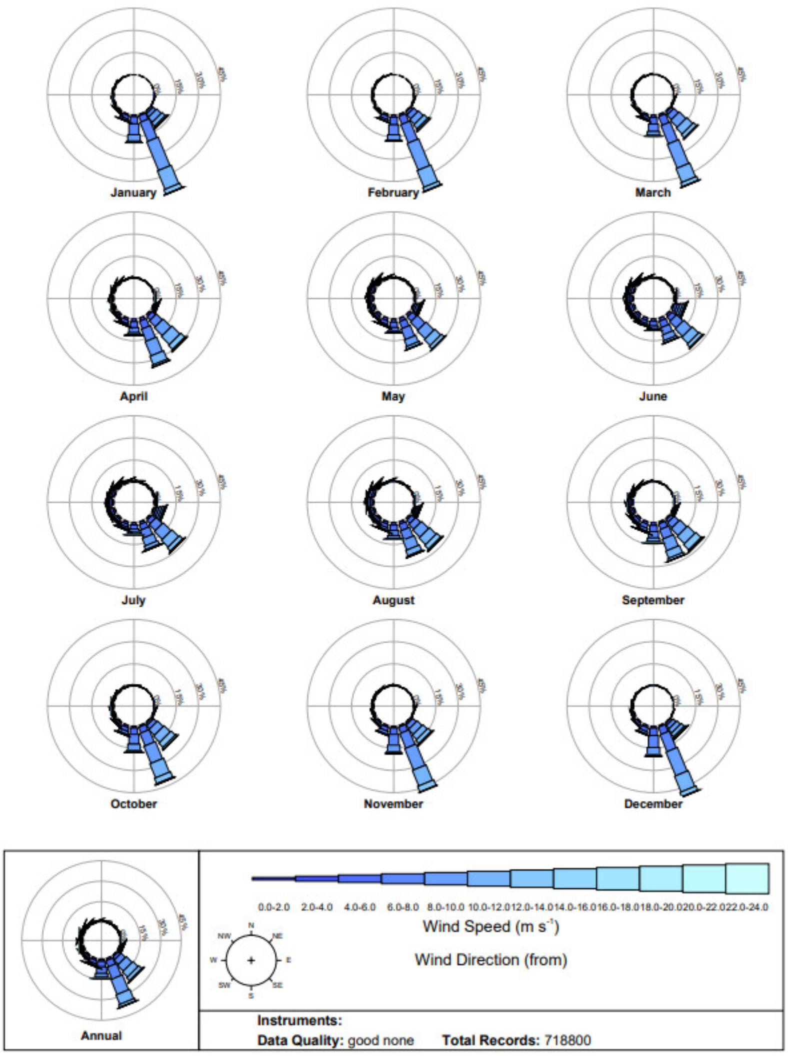
Based on Wenz's (1962) empirical "rule of fives" as an approximation for spectrum levels of wind-dependent ambient noise, it is expected that between 500 Hz and 5 kHz, spectrum levels may increase 5 dB with each doubling of wind speed from 1 to 20 m/s (Richardson *et al.* 2013). Therefore, compared with generic ambient noise spectra in Wenz's curve in **Figure 6**, it illustrates that the adjacent block area 2913B has a moderate range of wind speeds with the induced ambient noise of up to 20 dB to its spectral components.

Table 1: Monthly exceedance percentiles 30-min mean wind speed (m/s) (RPS, 2020). Period 00:00 01 January 1979 to 23:30 31 December 2019.

	Wind Speed ($m\ s^{-1}$)																
	Statistics				Total	Exceedence Percentile Wind Speed ($m\ s^{-1}$)											Main Direction(s)[1]
	Min	Max	Mean	Std. Dev	Records	99.0	95.0	90.0	75.0	50.0	30.0	20.0	10.0	5.0	2.0	1.0	(from)
January	0.26	16.65	8.02	2.5165	61008	1.92	3.69	4.66	6.32	8.16	9.45	10.18	11.17	11.95	12.94	13.44	SSE S
February	0.17	16.25	7.78	2.6069	55584	1.69	3.29	4.29	5.96	7.90	9.30	10.05	11.05	11.86	12.79	13.34	SE SSE S
March	0.15	16.39	7.90	2.7508	61008	1.52	3.16	4.21	5.96	8.01	9.43	10.26	11.39	12.33	13.24	13.85	SE SSE
April	0.10	22.20	7.42	3.0952	59040	1.20	2.46	3.35	5.05	7.40	9.21	10.21	11.47	12.52	13.72	14.34	SE SSE
May	0.04	17.79	6.58	2.9296	61008	1.01	2.07	2.82	4.41	6.40	8.06	9.17	10.62	11.75	12.85	13.46	SE SSE
June	0.14	18.26	6.83	3.1013	59040	1.09	2.17	2.91	4.49	6.56	8.49	9.64	11.10	12.24	13.54	14.26	SE SSE
July	0.11	18.93	7.10	3.1258	61008	1.08	2.20	3.02	4.73	6.96	8.83	9.90	11.27	12.44	13.69	14.33	SE SSE
August	0.14	18.54	7.28	3.0036	61008	1.32	2.59	3.41	5.03	7.11	8.97	9.96	11.32	12.37	13.51	14.34	SE SSE
September	0.08	19.88	7.56	3.1001	59040	1.32	2.65	3.49	5.24	7.44	9.30	10.35	11.79	12.81	13.74	14.43	SE SSE
October	0.04	17.53	8.16	2.9288	61008	1.73	3.33	4.31	6.05	8.18	9.83	10.73	12.01	12.99	14.00	14.58	SE SSE S
November	0.23	17.23	8.09	2.7688	59040	1.78	3.45	4.48	6.18	8.08	9.59	10.51	11.74	12.65	13.61	14.22	SE SSE S
December	0.04	17.07	7.69	2.6721	61008	1.61	3.15	4.19	5.81	7.76	9.20	10.03	11.08	11.99	12.97	13.62	SSE S
Annual	0.04	22.20	7.53	2.9317	718800	1.34	2.70	3.63	5.39	7.54	9.19	10.12	11.35	12.36	13.43	14.10	SE SSE

Notes: 1) Main directions are where occurrence is greater than 15.0%.

Figure 8: Combined monthly exceedance percentiles 30-min mean wind speed (m/s) (RPS, 2020). Period 00:00 01 January 1979 to 23:30 31 December 2019.



4.0 Underwater Noise Impact Assessment Criteria

4.1 Impact of Noise on Marine Fauna Species

The effects of noise and the range over which these effects take place depend on the acoustic characteristics of the noise (e.g., source level, spectral content, temporal characteristics[1], directionality, etc.), the sound propagation environment, as well as the hearing ability and physical reaction of individual marine fauna species. The potential impacts of noise on marine fauna species include audibility/detection, masking of communication and other biologically important sounds, behavioural responses and physiological impacts, which generally include discomfort, hearing loss, physical injury, and mortality (Richardson *et al*. 2013; Erbe *et al*. 2018; Popper and Hawkins 2019).

When the animal is in close proximity to the acoustic source, physical injuries can occur. As the animal is further away from the source, the impacts are expected to decrease gradually, out to a distance where the impacts are negligible. The theoretical zones of noise influence, according to Richardson *et al*. (2013), based on the severity of the noise impact are illustrated in **Figure 9**.

Exploration Drilling in Block 2912 (off the south coast of Namibia)
733.20071.00005

Exploration Drilling in Block 2912 (off the south coast of Namibia)
733.20071.00005

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

Figure 9: Theoretical zones of noise influence (adapted from Richardson *et al*. 2013)

4.1.1 Audibility / Sound Detection

A sound is audible when the receiver is able to perceive it over background noise. The audibility is also determined by the threshold of hearing that varies with frequency. The frequency dependant hearing sensitivity is expressed in the form of a hearing curve (i.e., audiogram). In general, marine mammals and fish species usually have U-shaped audiograms, meaning that within their respective hearing ranges, they are more sensitive to the sound energy component in the mid-frequency range and less sensitive to the energy components in the lower and upper-frequency ranges (Finneran 2016, Southall *et al*. 2019; Popper *et al*. 2019).

For fish species, their 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 can detect sound pressure via gas-filled structures near the ear and/or extensions of the swim bladder that functionally affect the ear, in addition to purely the fluid particle motion, which as a result, increases hearing sensitivity and broaden the hearing bandwidth (Nedelec *et al*. 2016; Popper and Hawkins 2018).

4.1.2 Masking

Masking occurs when the noise is high enough to impair detection of biologically relevant sound signals, such as communication signals, echolocation clicks and passive detection cues that are used for navigation and finding prey. The zone of masking is defined by the range at which sound levels from the noise source are received above the threshold within the ‘critical band’[2] centred on the signal (Richardson *et al*. 2013) and, therefore, strongly dependent on the background noise environment.

The potential for masking can be reduced due to an animal’s frequency and temporal discrimination ability, directional hearing, co-modulation masking release (if noise is amplitude modulated over a number of frequency bands) and multiple looks (if the noise has gaps or the signal is repetitive), as well as anti-masking strategies (increasing call level, shifting frequency, repetition, etc.) (Erbe 2016).

4.1.3 Behavioural Response

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

The behavioural response effects can be very difficult to measure and depend on a wide variety of factors such as the physical characteristics of the signal, the behavioural and motivational state of the receiver, its age, sex and social status and many others. Therefore, the extent of behavioural disturbance for any given signal can vary within a population and within the same individual. Behavioural reactions can vary significantly, ranging from very subtle changes in behaviour to strong avoidance reactions (Ellison *et al*. 2012; Richardson *et al*. 2013).

4.1.4 Hearing loss / Discomfort

The physiological effects of underwater noise are primarily associated with the auditory system, which is likely to be most sensitive to noise. Therefore, the exposure of the auditory system to a high level of noise for a specific duration can cause a reduction in the animal’s hearing sensitivity or an increase in range to the threshold (Finneran, 2016, Popper and Hawkins, 2019; Southall *et al*., 2019).

If the noise exposure is below some critical sound energy level, the hearing loss is generally only temporary, and this effect is called temporary hearing threshold shift (TTS). However, if the noise exposure exceeds the critical sound energy level, the hearing loss can be permanent, and this effect is called permanent hearing threshold shift (PTS).

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Exploration Drilling in Block 2912 (off the south coast of Namibia)
733.20071.00005

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

4.1.5 Physical Injury

In a broader sense, physiological impacts also include non-auditory physiological effects. Other physiological systems of marine animals potentially affected by noise include the vestibular system, reproductive system, nervous system, liver or organs with high levels of dissolved gas concentrations and gas-filled spaces. Noise at high levels may cause concussive effects, physical damage to tissues and organs, cavitation or result in the rapid formation of bubbles in the venous system due to massive oscillations of pressure (Groton 1998).

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

4.2 Marine Mammals, Fish and Sea Turtles

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine mammal species, fish, and sea turtles. For example, Southall *et al*. (2019) have proposed noise exposure criteria associated with various sound types, including impulsive noise (e.g., piling noise and seismic airgun noise) and non-impulsive noise (e.g., vessel and drilling noise) for certain marine mammal species (i.e., cetaceans, sirenians and carnivores), based on 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 following subsection provides the noise exposure levels above which adverse effects on various groups of marine mammals, fish, and sea turtles could be expected. The latter is based on all available relevant data and published literature (i.e., the state of current knowledge). For more details, see Appendix B and Appendix C.

4.2.1 Noise Impact Criteria for Marine Mammals

The newly updated scientific recommendations in marine mammal noise exposure criteria (Southall *et al*. 2019) propose PTS-onset and TTS-onset criteria for impulsive noise events.

- The PTS-onset and TTS-onset criteria for impulsive noise are outlined in **Table 2**, which incorporate a dual-criteria approach based on both peak sound pressure level (SPL) and cumulative sound exposure level (SEL) within a 24-hour period (SEL_{24hr}).
- The PTS-onset and TTS-onset criteria for non-impulsive noise, as outlined in **Table 3,** are based on cumulative SEL within a 24-hour period (SEL_{24hr}) only.

For behavioural changes, the widely used assessment criterion for the onset of possible behavioural disruption in marine mammals is root-mean-square (RMS) SPL of 160 dB re 1 µPa for impulsive noise and 120 dB re 1 µPa for non-impulsive noise, as shown in **Table 4.**

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

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

Table 3: PTS- and TTS-onset threshold levels for individual marine mammals exposed to non-impulsive noise (Southall *et al*. 2019)

Marine mammal hearing group	PTS and TTS threshold levels – non-impulsive noise events	
	Injury (PTS) onset	TTS onset
	Weighted SEL_{24hr}, dB re $1µPa^2·S$	Weighted SEL_{24hr}, dB re $1µPa^2·S$
Low-frequency cetaceans (LF)	199	179
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

Table 4: Behavioural disruption threshold levels for individual marine mammals – impulsive and non-impulsive noise (NOAA 2019)

Marine mammal hearing group	Behavioural disruption threshold levels, RMS SPL, dB re 1µPa	
	Impulsive noise	Non-impulsive noise
All hearing groups	160	120

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

In general, limited scientific data are available regarding the effects of sound on fish. As such, assessment procedures and subsequent regulatory and mitigation measures are often severely limited in relevance and efficacy. To reduce regulatory uncertainty for all stakeholders by replacing precaution with scientific facts, the U.S. National Oceanic and Atmospheric Administration (NOAA) convened an international panel of experts to develop noise exposure criteria for fish and sea turtles in 2004, primarily based on published scientific data in the peer-reviewed literature. The panel was organized as a Working Group (WG) under the ANSI-Accredited Standards Committee S3/SC 1, Animal Bioacoustics, which 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 sound exposure criteria for sound sources relevant to the project, including impulsive noise from VSP airguns and sonar are presented in Table 5.

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

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).

It should be noted that the period over which the cumulative sound exposure level (SEL_{cum}) is calculated must be carefully specified. For example, SEL_{cum} may be defined over a standard period or over the total period that the animal will be exposed. Whether an animal would be exposed to a full period of sound activity depends on its behaviour and the sound source movements. To align with assessment criteria for marine mammals, an exposure period of 24 hours is specified for fish. The receiving exposure levels over this period are expected to reflect the total exposure in the near field where the major adverse impacts are expected to occur for fish species.

Currently, there is no direct evidence of mortality or potential mortal injury to fish from non-impulsive noise sources such as shipping noise or drilling activities (Popper *et al*. 2014). However, continuous noise of any level that is detectable by fishes can mask signal detection and have an impact on their behavior (Popper and Hawkins 2019). A wide range of behaviour patterns may be affected by increased noise levels over the long term. 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).

For behavioural disruption threshold level for all fish species, the National Marine Fisheries Services (NMFS) uses the U.S. Navy Phase III criteria for all noise thresholds (Navy, 2017). As of December 2021, potential effects to endangered listed fish species may occur when impulsive or non-impulsive activities produces sounds that exceed the thresholds according to Table 6.

Table 5: Exposure criteria for impulsive noise – fish, fish eggs and fish larvae (Popper *et al*. 2014)

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

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

Table 6: Exposure criteria for behavioural disruption - all fish species (Navy 2017)

Marine mammal hearing group	Behavioural disruption threshold levels, RMS SPL, dB re 1µPa	
	Impulsive noise	Non-impulsive noise
All hearing groups	150	150

4.2.3 Noise Criteria for Sea Turtles

Popper *et al*. (2014) suggested threshold levels for the occurrence of mortality and potential mortal injuries (PTS) of sea turtles. However, these adopted levels were extrapolated from other animal groups, such as fish, based on the logic that the hearing range of turtles is much closer to that of poorly hearing fish. More recently, Finneran *et al.* (2017) revised the sea turtle thresholds (PTS) by reviewing individual references from at least five different species (see Appendix C) to construct their composite audiograms and provide thresholds for the onset of temporary hearing impairment (TTS). Finneran *et al.* (2017) agreed that even within their best hearing range, sea turtles have low sensitivity with audiograms more similar to those of fish without specialized hearing adaptations for high frequency, like some marine mammals. The revised thresholds for sea turtles relevant to the project, including impulsive noise from VSP airguns and non-impulsive noise from shipping and other sources, are presented in Table 7 and Table 8.

McCauley *et al.* (2000) initially established the behavioural threshold for sea turtles at 166 dB re 1 µPa SPL RMS. Then it was adopted by NMFS to identify the distances at which behavioural response may occur. However, the received sound level at which sea turtles are expected to actively avoid repeated impulsive noise exposures is 175 dB re 1 µPa SPL RMS (McCauley *et al*. 2000) as shown in Table 9. Therefore, this threshold has been applied by NMFS to estimate sea turtle behaviour reactions to repeated impulsive noise activities such as VSP events (Finneran *et al.* 2017). Additionally, 175 re 1 µPa SPL RMS is expected to be the received sound level at which sea turtles would actively avoid exposure to non-impulsive noise activities, such as shipping drilling operations (Finneran *et al.* 2017).

Table 7: PTS and TTS threshold levels for sea turtles exposed to impulsive noise events (Finneran *et al*. 2017)

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

Table 8: PTS threshold levels for sea turtles exposed to non-impulsive noise events (Navy, 2017)

Type of animal	PTS threshold levels – non-impulsive noise events
	Injury (PTS) onset
	Criteria - Weighted SEL_{24hr}, dB re $1\mu Pa^2 \cdot S$
Sea turtles	220

Table 9: The behavioural disruption threshold level for individual sea turtles – impulsive and non-impulsive noise (McCauley *et al.* 2000; Finneran *et al.* 2017)

Type of animal	Behavioural disruption threshold levels, RMS SPL, dB re 1µPa	
	Impulsive noise	Non-impulsive noise
Sea turtles	175	175

4.3 Zones of Bioacoustics Impact

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

It is expected that the noise generated by the major drilling operation activities (i.e., VSP, drilling units and supporting vessels) can be significantly higher than the natural ambient noise levels (85 - 125 dB re 1 µPa as described in Section 3.0 above).

Predicted zones of impact define the environmental footprint of the noise-generating activities and indicate the locations within which the activities may have an adverse impact on marine fauna species of interest, either behaviourally or physiologically. 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.

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

5.0 Underwater Noise Modelling Predictions

5.1 Underwater Noise Assessment Scenarios and Source Levels

A list of modelling scenarios with relevant major noise-generating equipment is developed based on relevant exploration operation information provided and the general project description as in Section 2.0. These scenarios and relevant noise sources are summarised in Table 10.

Table 10: Potential scenarios to be assessed and relevant noise sources

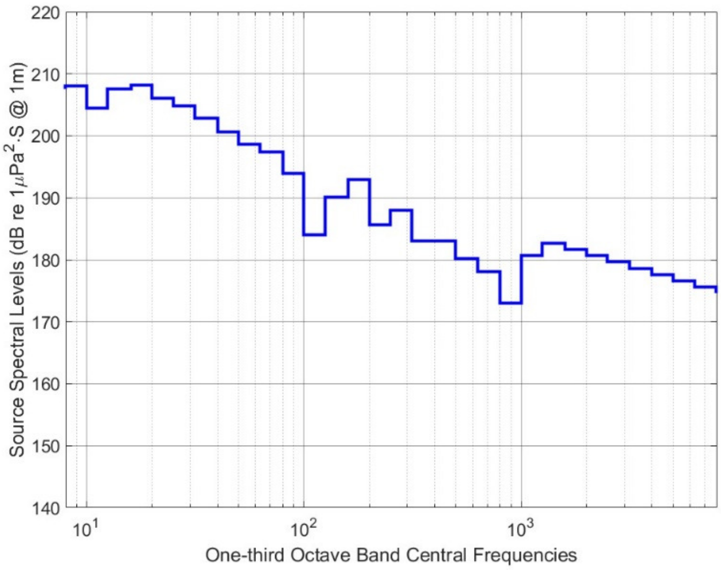
Activity / Scenario	Major Noise Source / Equipment
Vertical seismic profiling (VSP)	VSP airgun array, i.e., 1 000 cubic inch Avalon RSS2 G-Guns
Well drilling operations	Drillship (x 1) such as SAMSUNG GF12000 or ENSCO DS-10/DS-12
	Support vessel (x 3), i.e., The Bourbon Calm/ Rainbow or equivalent
	Transitional 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)

5.1.1 VSP Array Specifications

An Avalon RSS2 Gundalf-Gun (G-Gun, manufactured by Sercel) array of 1 000 cubic inch (CUI) supplied by Nitrogen gas quads is proposed to be used for the VSP operations. The array consists of 4 active G-Gun airgun units of 250 CUI and has an average towing depth of 7,0 m and an operating pressure of 2 000 pounds per square inch (PSI).

The noise emissions from the VSP airgun array, including the source spectral levels and directivities, are modelled based on the Gundalf Designer software package (2018). The full array source modelling process and results are detailed in Appendix D, and the one-third octave SEL source spectral levels out of the source modelling results and to be used as the sound transmission modelling inputs are presented in Figure 10 below.

Figure 10: One-third octave band SEL source spectral levels for the proposed VSP G-Gun array



The source modelling results for the VSP array show the peak sound pressure level (Pk SPL) is 245,8 dB re 1 µPa @ 1 m, the root-mean-square sound pressure level (RMS SPL) 227,2 re 1 µPa @ 1 m, and the sound exposure level (SEL) 224,5 dB re µPa^2·s @ 1 m.

It is expected that 250 VSP pulses are to be generated in total over approximately 9 hours of operation. Therefore, for cumulative noise modelling, two scenarios are considered for this study, including the worst case of 250 VSP pulses over the entire operation duration and 50 VSP pulses over approximately 2 hours.

5.1.2 Well Drilling Operations

The drillship modelled is the Samsung Green Future (GF) 12000. The maximum drilling water depth of the ship is 3 810 m. It has six retractable 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 11.

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

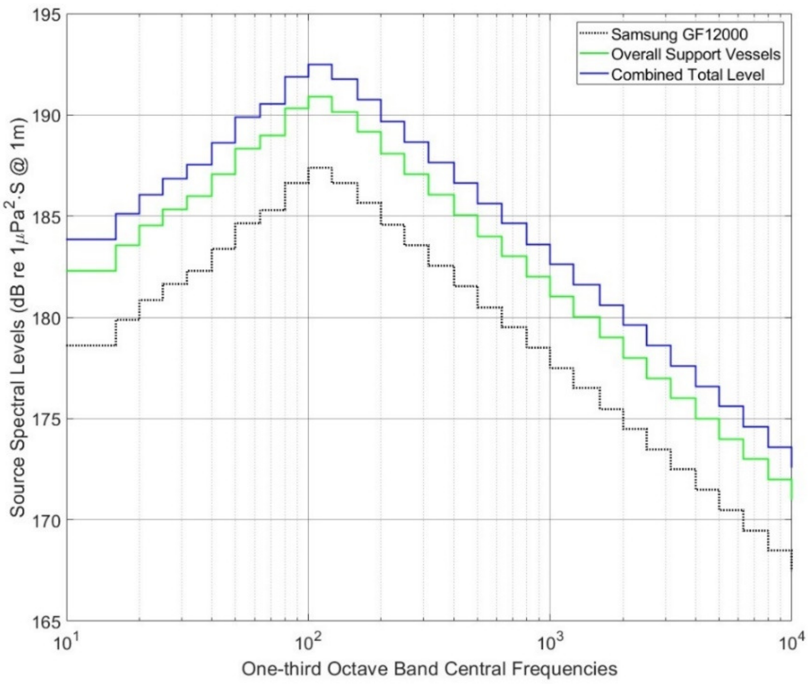
For offshore support vessels to maintain position in strong current conditions, they are required to have two bow thrusters plus an azimuth thruster forward. The vertical positions of the thrusters are assumed to be 5 m below the sea surface. There are three support vessels acting simultaneously as a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

Table 11: Drillship and Support Vessel Specifications

Parameter	Samsung GF12000 drillship (UUC 455 FP type thrusters)	**Support Vessel #1** (Fixed pitch & variable speed)	**Support Vessel #2 (Variable pitch & variable speed)**	**Support Vessel #3** (Variable pitch & variable speed)
Number of thrusters	6 (4*)	3	3	3
Propeller diameter (m)	4.1	2.02	2.25	1.65
Nominal propeller speed (rpm)	157	307	307	382
Maximum continuous power input (kW)	5 500	2 500	1 200	850
SEL (dB re 1 µPa^2·S @ 1 m)	196,7	200,3 (Overall simultaneous support vessel level)		
*Number of propeller blades per thruster				

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 the drillship and three support vessels is approximately 201,9 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 are shown in **Figure 11**.

Figure 11: 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 hours continuous exposure duration and a much shorter half-hour continuous exposure duration.

It should be noted that transitional Anchor Handling Tug Support (AHTS) vessels are not included in the modelling study as they are not planned and are not major noise sources compared with the drillship operations. Also, compared with the near-surface drillship operations, the noise emissions from the 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.

5.1.3 MBES System Specifications

TEEPNA 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 TEEPNA 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 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 detailed system performance specifications for Kongsberg EM 712 MBES are listed in Table 10.

5.2 Modelling Methodology and Procedure

Underwater noise propagation models predict the sound transmission loss between the noise source and the receiver. When the source level (SL) of the noise source based on is known, the predicted transmission loss (TL) is then used to indicate the received level (RL) at the receiver location as:

$$RL = SL - TL \qquad (1)$$

5.2.1 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 geoacoustic 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 (as detailed in Section 5.1);
- 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.

5.2.2 MBES Modelling Algorithm

Sound propagation modelling for the Kongsberg EM 712 MBES was carried out using 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 as in **Table 10**, 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 season sound speed profile, as detailed in **Section 5.3.2**, and the seafloor geoacoustic model, as in **Section 5.3.3.** 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 $MgSO4$ 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.

5.3 Modelling Input Parameters

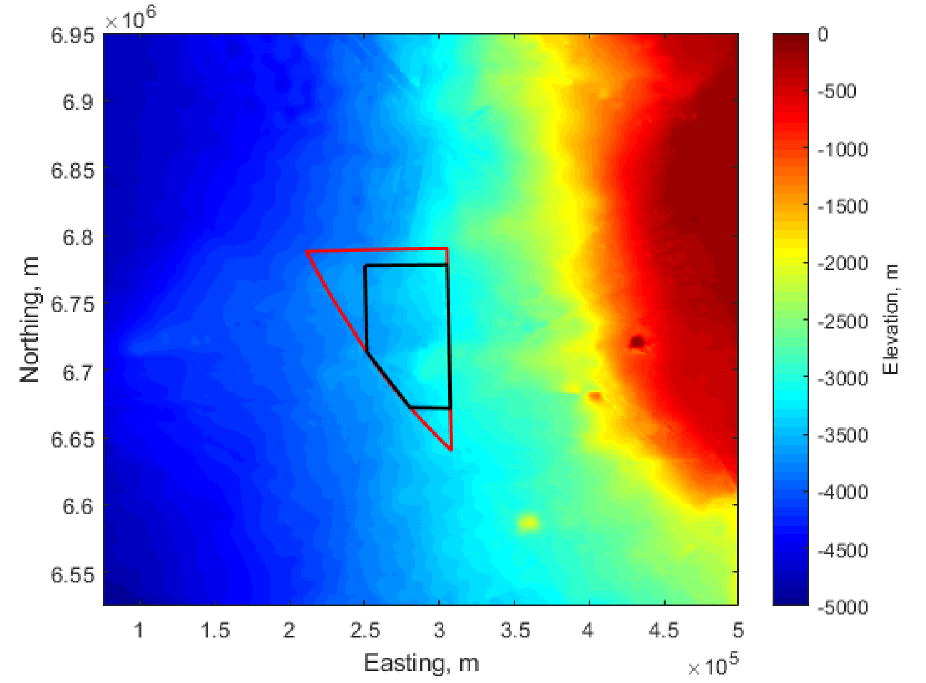
5.3.1 Bathymetry

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

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

The bathymetric imagery within and surrounding the licence block 2912 is presented in **Figure 12**.

Figure 12: The bathymetric imagery within and surrounding the survey block. The coordinate system is based on WGS 84 Zone 33 South. The red polygon shows the survey block 2912, and the black polygon shows the operations area.



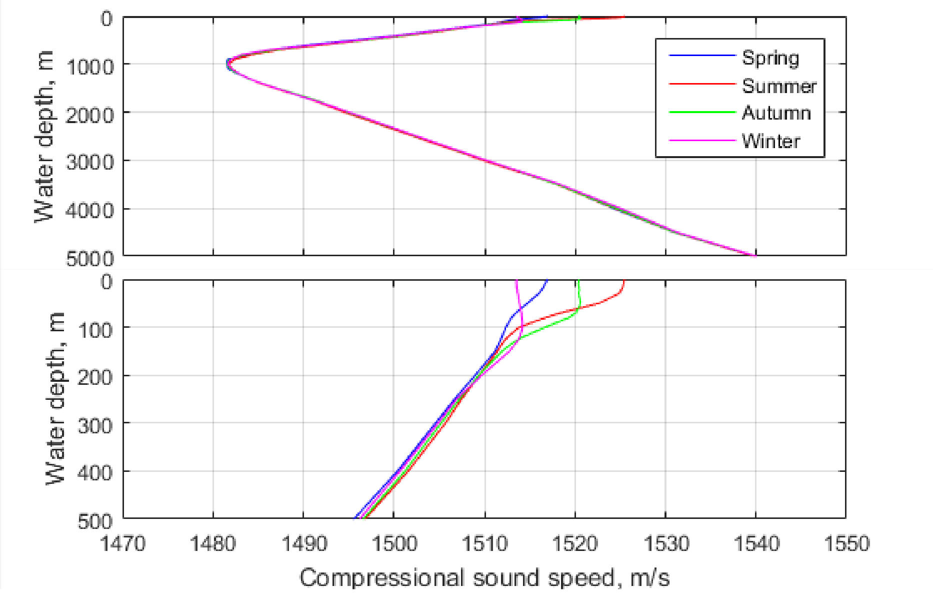
5.3.2 Sound Speed Profile

Temperature and salinity data required to derive the sound speed profiles were obtained from the World Ocean Atlas 2009 (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 13 presents the typical sound speed profiles for four seasons around the survey area. The figure demonstrates that the most significant distinctions for the profiles of the four seasons occur within the mixed layer near the surface. The summer season has the strongest downwardly refracting feature among the four seasons, and the winter season exhibits a deeper surface duct than the other three seasons. Due to the stronger surface duct within the profile, it is expected that the winter season will favour sound propagation from a near-surface acoustic source array. The winter season sound speed profile was selected as the modelling input based on a conservative consideration.

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

Figure 13: Typical sound speed profiles within the survey area for different Southern Hemisphere seasons. The top panel shows profiles across the entire water column, and the bottom panel shows profiles across the water column section near the surface



5.3.3 Seafloor Geoacoustic Model

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

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

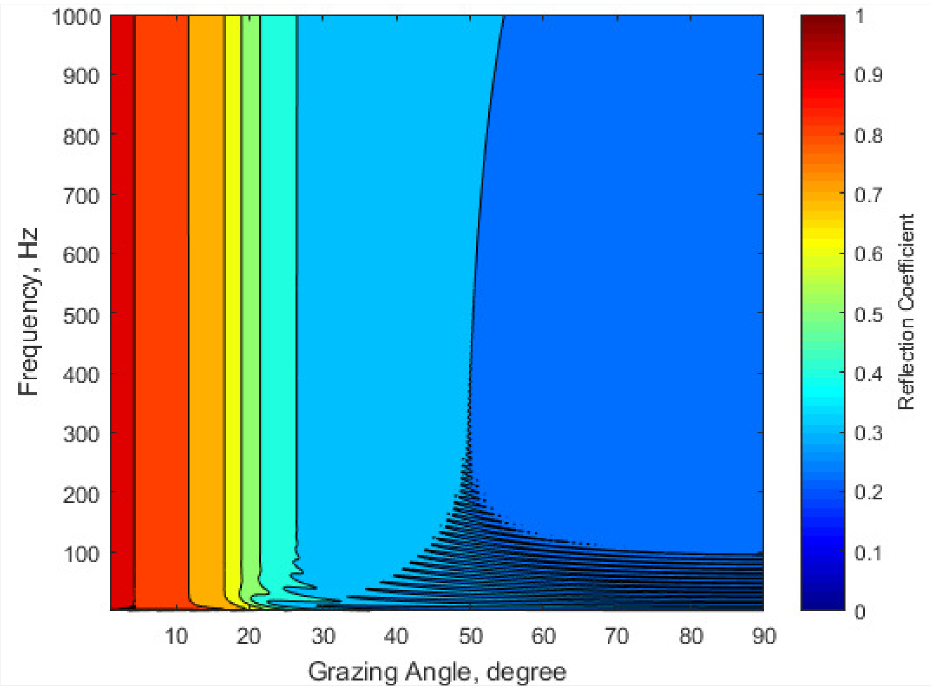
Based on the above, as well as a conservative consideration, it was proposed that the seafloor geoacoustic model comprises a 100-m fine and silty sand sediment layer for the entire modelling area, followed by a sandy half-space/substrate as detailed in **Table 12**. The geoacoustic properties of silty mud and sand are as described in Hamilton (1980), with attenuations referred to by Jensen *et al.* (2011). In addition, the elastic properties of silt and sand are treated as negligible.

Figure 14 shows the reflection coefficient variation with grazing angle and frequency for the proposed seafloor geoacoustic model, calculated using the plane-wave reflection coefficient model (Porter 2001, 2020). As shown in the figure, the seafloor acoustic reflection is dominated by the top sediment layer across the frequency range, with high reflection at low grazing angles and low reflection (high refraction) at higher grazing angles.

Table 12: Geoacoustic parameters for the proposed seafloor model

Seafloor Materials	Depth Range, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, c_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Silty mud	100	1700	1575	1.0
Sand half-space	∞	1900	1600	0.8

Figure 14: Reflection coefficient vs grazing angle and frequency for the proposed geoacoustic model



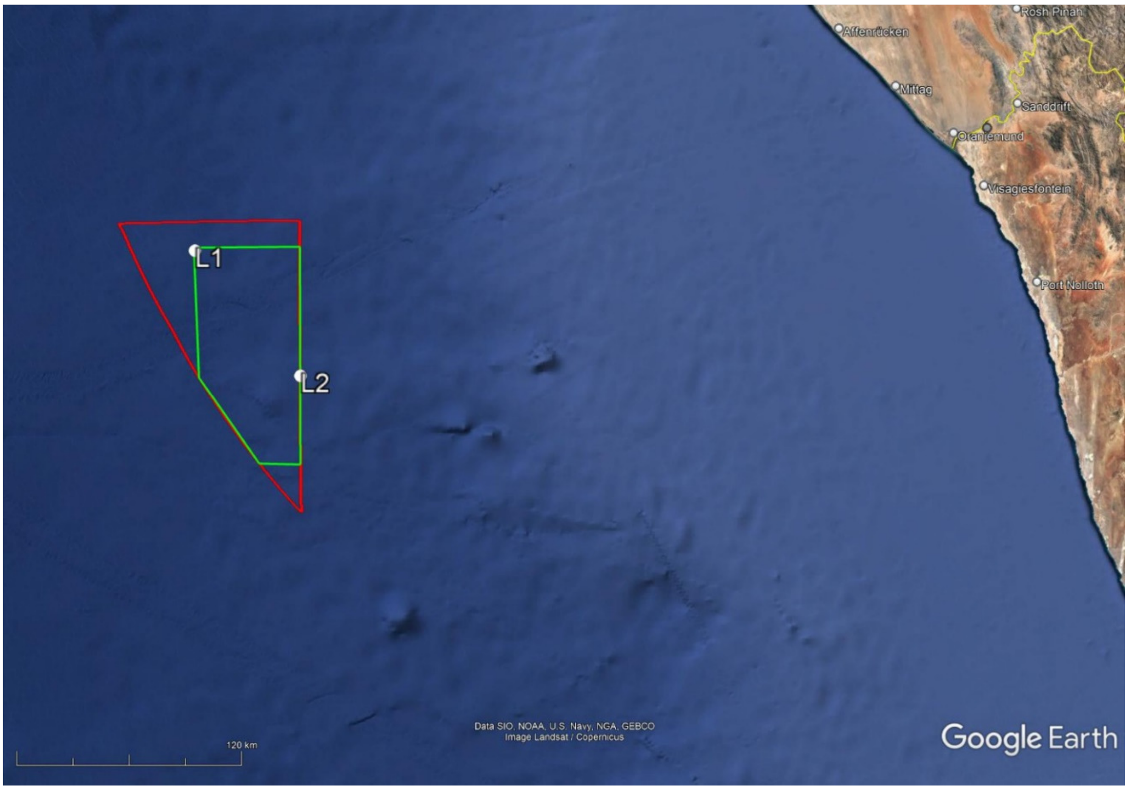
5.4 Modelling Source Locations

Noise modelling locations for the exploration programme are consistent with the proposed exploration operation areas, as indicated in **Figure 15**, and further detailed in **Table 13** below with their corresponding coordinates, water depths and localities. Two scenarios were chosen, one with a deep-water location (L1) and a second (L2) with the shallowest water range and closest to an MPA.

Table 13: Details of the two selected source locations for noise modelling

Source Location	Water Depth, m	Coordinates [Easting, Northing]	Locality
L1	3 700	[250 100, 6 777 528]	North-western corner of the drilling area, deep water location
L2	3 040	[306 555, 6 711 040]	Eastern boundary of drilling area, shallowest water range site of the area, closest to Tripp Seamount

Figure 15: The selected two source locations (L1 & L2) are indicated as white dots. The red polygon shows Block 2912, and the green polygon represents the proposed exploration operations area.



6.0 STLM Results and Zones of Impact

The weighted SEL modelling results for different marine mammal hearing groups (**Appendix B**) 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 C**.

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 **Appendix D.**

The noise contour figures for VSP and well-drilling operation scenarios are presented in **Appendix E**. The contour figures are the modelling results based on unweighted SEL source level inputs in dB re 1 $\mu Pa^2 \cdot s$ for single VSP pulses and well drilling noise of 1-second duration as given in **Section 5.1**.

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

$$CF = 10 \times \log 10\,(N \text{ (or } T)) \qquad (2)$$

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

The predicted noise levels of all considered modelling scenarios were compared with relevant threshold criteria as listed in **Section 4.0**. The zones of different levels of noise impact for marine mammals and fish and sea turtle species were calculated, and all results are presented in **Table 14** to **Table 28**, including:

- Impact zones from the VSP scenarios with impulsive noise emissions are shown in **Table 14** to **Table 16** regarding the immediate impact for marine mammals, fish, fish eggs, fish larvae and sea turtles; and **Table 17** shows the impact zones regarding behavioural disturbance for fish, marine mammals, and sea turtles. **Table 18** to **Table 20** show the impact zones regarding the cumulative impact for marine mammals under two exposure scenarios (250 VSP pulses and 50 VSP pulses);
- Impact zones from the drilling operation scenarios with non-impulsive noise emissions are shown in **Table 21** to **Table 23** regarding cumulative impact for marine mammals and sea turtles under two continuous exposure scenarios (i.e., 24-hour exposure and 0,5-hour exposure), respectively. **Table 24** shows the impact zones regarding behavioural disturbance for marine mammals, fish, and sea turtles; and
- Impact zones from a single MBES pulse scenarios with impulsive noise emissions are shown in **Table 25** and **Table 26** regarding immediate impact for marine mammals, and sea turtles; and **Table 27** shows the impact zones regarding behavioural disturbance for fish, marine mammals, and sea turtles. **Table 28** shows the impact zones regarding the cumulative impact for marine mammals and sea turtles.

For estimated impact zones that are within close proximity (tens of meters) to the source locations, the zones are presented as single maximum threshold distances to the sources for the two drilling source locations assessed. When impact zones extend out to the far-field (hundreds to thousands of meters) from the source locations, individual impact zones will be provided for the two modelling source locations (i.e., L1 or L2) if their impact zones are different.

Based on noise modelling prediction results and relevant post-processing analysis as described above, the zones of impact for marine fauna species assessed from all modelling scenarios are detailed in the following sections.

6.1 Zones of impact - Immediate Exposure from VSP Pulses

6.1.1 Marine Mammals

The Peak SPLs from VSP pulses, as seen in Table 14, are predicted to cause physiological impacts (both PTS and TTS on-set) for most marine mammal species directly adjacent to the VSP source (20 m), except VHF cetaceans. VHF cetaceans have relatively larger zones of impact due to Peak SPLs and are predicted to experience PTS-onset and TTS-onset within 55 m and 90 m from the VSP source, respectively.

Table 14: Zones of immediate impact from single VSP pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to peak impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	**219**	10	**213**	20
High-frequency cetaceans (HF)	**230**	<10	**224**	<10
Very-high-frequency cetaceans (VHF)	**202**	55	**196**	90
Sirenians (SI)	**226**	<10	**220**	10
Phocid carnivores in water (PCW)	**218**	10	**212**	20
Other marine carnivores in water (OCW)	**232**	<10	**226**	<10

6.1.2 Fish, Fish Eggs, and Fish Larvae

VSP pulses are predicted to cause immediate physiological impacts (both mortality and recovery injury) for fishes directly adjacent to the VSP source (<35 m), as presented in Table 15.

6.1.3 Sea Turtles

The maximum zones of PTS and TTS due to a single pulse exposure for sea turtles are predicted to be within approximately <10 m from the source array, as presented in Table 16.

Table 15: Zones of immediate impact from single VSP pulses for mortality and recovery injury– fish, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from source to peak impact threshold levels			
	Mortality and potential mortal injury		Recovery injury	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	> 213	20	>213	20
Fish: swim bladder is not involved in hearing (particle motion detection)	>207	35	>207	35
Fish: swim bladder involved in hearing (primarily pressure detection)	>207	35	>207	35
Fish eggs and fish larvae	>207	35	-	-
Note: A dash indicates the threshold is not applicable.				

Table 16: Zones of immediate impact from single VSP pulses for PTS and TTS – sea turtles

Type of animal	Zones of impact – maximum horizontal distances from the source to peak impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Sea turtles	232	<10	226	<10
Note: A dash indicates the threshold is not applicable				

6.1.4 Behavioural Responses

Table 17 below presents the distances to potential behavioural disturbance from the impulsive noise emissions from VSP pulses for marine mammals, fish, and sea turtles.

For marine mammals of all hearing groups, potential behavioural disturbance from the VSP pulses is predicted to occur up to 1,35 km from the deepest water drilling location (i.e., L1) and up to 1,42 km from the shallowest water drilling location (i.e., L2).

Potential effects of behavioral disruption from VSP pulses for all fish species may occur within 4,23 km from the assessed deepest water drilling location (i.e., L1) and within 2,05 km from the assessed shallowest water drilling location (i.e., L2).

For sea turtles the maximum distance for potential behavioural disturbance is within 340 m from both assessed drilling locations (i.e., L1 & L2).

Table 17: Zones of immediate impact from single VSP pulses for behavioural disturbance – fish, marine mammals, and sea turtles

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels	
	Behavioural disturbance	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals	160	L1: 1 350 L2: 1 420
Fish	150	L1: 4 230 L2: 2 050
Sea turtles	175	340

6.2 Zones of Impact - Cumulative Exposure from VSP Multiple Pulses

6.2.1 Marine Mammals

Table 18 below presents the zones of cumulative impact from repetitive VSP pulses for marine mammals under two exposure scenarios: one with 250 VSP pulses (up to 9 hours exposure duration) and another with 50 VSP pulses (up to 2 hours exposure duration).

Table 18: Zones of cumulative impact from multiple VSP pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels					
	Injury (PTS) onset			TTS onset		
	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m		Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	
		50 pulses	250 pulses		50 pulses	250 pulses
Low-frequency cetaceans (LF)	**183**	35	70	**168**	150	L1: 320 L2: 250
High-frequency cetaceans (HF)	**185**	-	<10	**170**	<10	<10
Very-high-frequency cetaceans (VHF)	**155**	<10	15	**140**	20	40
Sirenians (SI)	**203**	-	-	**175**	<10	10
Phocid carnivores in water (PCW)	**185**	<10	40	**170**	25	60
Other marine carnivores in water (OCW)	**203**	-	<10	**188**	<10	15

Note: A dash indicates the threshold is not reached.

As illustrated in the table, the cumulative impacts based on cumulative SELs from VSP pulses are predicted to be the highest for LF cetaceans. Under the worst-case VSP pulse exposure scenario of 250 pulses, the zones of impact for PTS-onset and TTS-onset are predicted to be up to 70 m and 320 m from the VSP source, respectively. For the rest of the five hearing group cetaceans and under the worst-case VSP pulse exposure scenario, the cumulative SELs are predicted to cause PTS-onset impacts within up to 40 m and the TTS-onset impact within up to 60 m from the VSP source.

It should be noted that the cumulative impact at a specific receiving location is modelled based on the assumption that the marine animals are constantly exposed to the VSP pulses at a fixed location over the entire operation period. Realistically, marine animals would not stay in the exact location for the entire period. Therefore, the zones of impact assessed in Table 18 for 250 pulses represent the worst-case consideration and will reduce logarithmically with a decreased exposure time period. As an example, if marine mammals are exposed to only 50 VSP pulses as presented in the table, then the maximum PTS-onset impact zones will be well within 35 m from the VSP source location, and the maximum TTS-onset impact zones within 150 m from the VSP source location.

6.2.2 Fish, Fish Eggs, and Fish Larvae

Table 19 below presents the zones of cumulative SEL impact from repetitive VSP pulses for fish and sea turtle species under two exposure scenarios (250 VSP pulses and 50 VSP pulses), respectively.

Table 19: Zones of cumulative impact from multiple VSP pulses - fish, fish eggs and fish larvae

Type of animal	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels								
	Mortality and potential mortal injury			Recoverable injury			TTS		
	Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m		Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m		Criteria - SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	
		50 pulses	250 pulses		50 pulses	250 pulses		50 pulses	250 pulses
Fish: no swim bladder (particle motion detection)	**219**	<10	20	**216**	10	25	**186**	150	330
Fish: swim bladder is not involved in hearing (particle motion detection)	**210**	15	40	**203**	30	65	**186**	150	330
Fish: swim bladder involved in hearing (primarily pressure detection)	**207**	20	50	**203**	30	65	**186**	150	330
Fish eggs and fish larvae	**210**	15	40	**-**	-	-	**-**	-	-
Note: A dash indicates the threshold is not reached.									

The zone of impact relevant to fish, fish eggs, and larvae for potential mortal injury is within 50 m of the VSP source location. The cumulative impacts from VSP pulses are predicted to cause potential recoverable injury for fish adjacent to the VSP source (within 65 m) and TTS-onset up to 330 m from the source under the worst-case VSP pulse exposure scenario (i.e., 250 pulses within 9 hours). Under the exposure scenario of 50 pulses over approximately 2 hours, the maximum TTS impact zones are predicted to be less than 150 m from the VSP source.

6.2.3 Sea Turtles

Noise impacts related to injury and TTS on sea turtles are expected to be around 70 m at the near field from the source location, as shown in Table 20. The maximum zones of PTS impact are predicted to range within 25 m from the adjacent survey line for the worst-case VSP pulse exposure scenario (i.e., 250 pulses within 9 hours) considered.

Table 20: Zones of cumulative impact from multiple VSP pulses for PTS and TTS – sea turtles

Type of animal	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels					
	Injury (PTS) onset			TTS onset		
	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m		Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	
		50 pulses	250 pulses		50 pulses	250 pulses
Sea turtles	**204**	<10	25	**189**	30	70

6.3 Zones of Impact - Non-Impulsive Drilling Operation Sources

6.3.1 Marine Mammals

Table 21 and Table 22 below present the zones of cumulative impact based on cumulative SELs from the drilling operation scenario with the highest non-impulsive noise emissions (i.e., drillship plus three support vessels) for marine mammals.

For the worst-case consideration (i.e., the drilling operations are continuous and affected marine animals stay at the fixed location over the entire 24-hour period), LF and VHF cetaceans have the highest PTS-onset and TTS-onset impact zones among all marine mammal hearing groups. From Table 21, the PTS-onset zone for LF and VHF cetaceans is up to 290 m and 260 m, and the TTS-onset zone is up to 3,2 km and 2,9 km from the drilling location, respectively.

With a decreased exposure period, the zones of impact will be reduced significantly, as shown in Table 22. For example, for an exposure period of half an hour, the PTS-onset zone is predicted to be within 40 m from the noise source for LF and VHF cetaceans, and the TTS-onset zone within up 450 m for LF cetaceans and 410 m for VHF cetaceans. For marine mammals of other hearing groups, nearly no PTS-onset and TTS-onset are predicted to occur due to a short-duration exposure (less than 10m for PTS and less than 40m for TTS).

Table 21: Zones of cumulative impact from non-impulsive noise for marine mammals – 24 hours

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria – Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	**199**	290	**179**	L1: 3 100 L2: 3 200
High-frequency cetaceans (HF)	**198**	20	**178**	260
Very-high-frequency cetaceans (VHF)	**173**	260	**153**	L1: 2 700 L2: 2 900
Sirenians (SI)	**206**	20	**186**	200
Phocid carnivores in water (PCW)	**201**	80	**181**	800
Other marine carnivores in water (OCW)	**219**	<10	**199**	100

Table 22: Zones of cumulative impact from non-impulsive noise for marine mammals – 0.5 hours

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria – Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	**199**	40	**179**	450
High-frequency cetaceans (HF)	**198**	<10	**178**	40
Very-high-frequency cetaceans (VHF)	**173**	40	**153**	410
Sirenians (SI)	**206**	<10	**186**	30
Phocid carnivores in water (PCW)	**201**	10	**181**	130
Other marine carnivores in water (OCW)	**219**	<10	**199**	15

6.3.2 Fish and Sea Turtles

As stated in Section 4.2.2, 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.

Table 23 below present the zones of cumulative impact for sea turtles based on cumulative SELs from two drilling operation scenarios (0.5 and 24 hours) with the highest non-impulsive noise emissions (i.e., drillship plus three support vessels). The PTS-onset zone for 24 hours is within to 30 m distance from the drilling location and less than 10 m for the 0.5 hours drilling operation scenario.

Table 23: Zones of cumulative impact from non-impulsive noise for PTS – sea turtles

Type of animal	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels		
	Injury (PTS) onset		
	Criteria – Weighted SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	
		0.5 hours	24 hours
Sea turtles	220	<10 m	30 m

6.3.3 Behavioural Responses

Table 24 below presents the distances to potential behavioural disturbance from the non-impulsive noise emissions from drilling operations for marine mammals, fish, and sea turtles. The predicted zones of impact to occur for marine mammals of all hearing groups are up to 33,6 km from the assessed deepest water drilling location (i.e., L1) and up to 30,6 km from the assessed shallowest water drilling location (i.e., L2).

For fish species, the predicted maximum zones of immediate impact from non-impulsive drilling operation noise are expected to occur within 1,56 km distance from the noise source.

For sea turtles, the potential behavioural disturbance from the non-impulsive noise emissions is predicted to occur up to 150 m from both assessed drilling locations (i.e., L1 & L2).

Table 24: Zones of immediate impact from non-impulsive noise for behavioural disturbance – marine mammals, fish, and sea turtles

Type of animal	Zones of impact – maximum horizontal distances from the source to impact threshold levels	
	Behavioural disturbance	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals	120	L1: 33 600 L2: 30 600
Fish	150	1 560
Sea Turtles	175	150

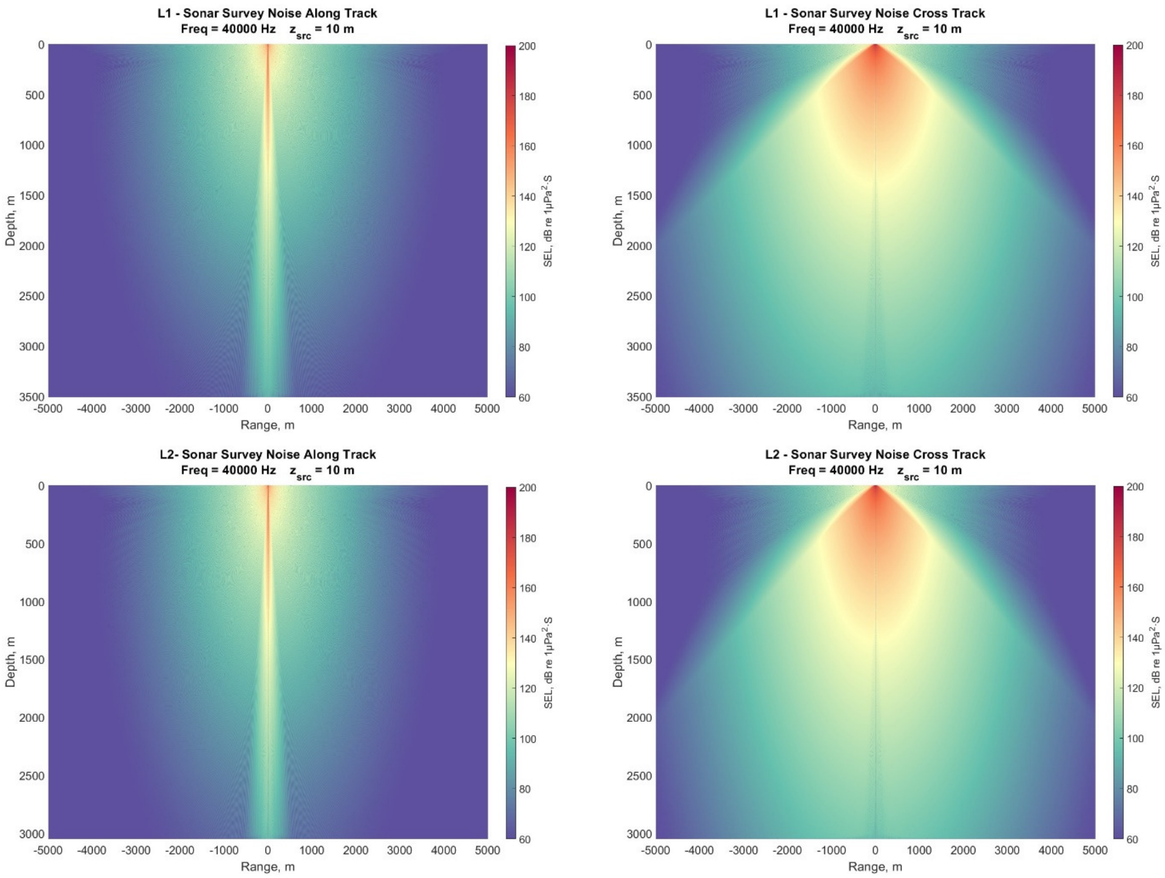
6.4 Zones of Impact – Immediate Exposure from a single MBES pulse

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 16**. 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 towards the cross-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 F**.

Figure 16: 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 (bottom).



6.4.1 Marine Mammals

Sonar surveys using the MBES sources have much lower noise emissions than seismic airgun sources and have extremely narrow source directivity along the cross-track direction. 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 zones of impact estimated Pk-SPL metric criteria as provided in **Table 25,** marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience PTS effect within 260 m from the MBES source. The maximum zones of PTS effect for very-high-frequency cetaceans are predicted to be within 760 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 very-high-frequency cetaceans are predicted to be within approximately 400 m from the MBES source. The maximum zones of TTS effect for very high-frequency cetaceans are predicted to be within 1,02 km from the MBES source along the cross-track direction.

Table 25: Zones of immediate impact from a single MBES pulse for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to peak impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	**219**	220	**213**	380
High-frequency cetaceans (HF)	**230**	85	**224**	150
Very-high-frequency cetaceans (VHF)	**202**	760	**196**	L1: 1 020 L2: 990
Sirenians (SI)	**226**	125	**220**	220
Phocid carnivores in water (PCW)	**218**	260	**212**	400
Other marine carnivores in water (OCW)	**232**	70	**226**	125

6.4.2 Fish and Sea Turtles

As stated in **Section 4.2.2**, 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 expected to occur along the cross-track direction from the MBES source. The maximum zones of impact are predicted to range within 70 m for PTS and 125 m for TTS, as shown in **Table 26**.

Table 26: Zones of immediate impact from a single MBES pulse for PTS and TTS – sea turtles

Type of animal	Zones of impact – maximum horizontal distances from the source to peak impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Sea turtles	**232**	70	**226**	125

6.4.3 Behavioural Responses

The zones of behavioural disturbance for marine mammals, fish and sea turtles caused by the immediate exposure to individual MBES pulses for sonar surveys are presented in Table 27. 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, within 1,15 km from the source for marine mammals of all hearing groups, up to 1,62 km from the source for fish and up to 540 m from the array source for sea turtles at cross-track directions.

Table 27: Zones of immediate impact from a single MBES pulse for behavioural disturbance – fish, marine mammals, and sea turtles

Type of animal	Zones of impact – maximum horizontal distances from the source to impact threshold levels	
	Behavioural disturbance	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals	160	L1: 1 150 L2: 1 125
Fish	150	L1: 1 610 L2: 1 620
Sea turtles	175	540

6.5 Zones of Impact – Cumulative Exposure from single MBES pulses

6.5.1 Marine Mammals

Cumulative exposure is predicted to be low for the majority of any marine mammal hearing group other than VHF cetaceans, as shown in Table 28. The maximum zones of cumulative impact for VHF cetaceans are predicted to range up to 320 m for PTS and within 800 m for TTS from the MBES source location along the cross-track directions. For cetaceans of other hearing groups, such as HF and LF, the zones of TTS impact are predicted to be less than 80 m from the source location.

6.5.2 Fish and Sea Turtles

As stated in Section 4.2.2, high-frequency SONAR MBES sources are not expected to cause an adverse hearing impact on fish species. For sea turtles, cumulative exposure of individual MBES pulses is not expected to occur at all.

Table 28: Zones of cumulative impact from single sonar MBES pulses for PTS and TTS – marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria – Weighted SEL_{24hr} dB re 1 μPa^2·s	Maximum threshold distance, m	Criteria – Weighted SEL_{24hr} dB re 1 μPa^2·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	**183**	-	**168**	30
High-frequency cetaceans (HF)	**185**	25	**170**	80
Very-high-frequency cetaceans (VHF)	**155**	320	**140**	800
Sirenians (SI)	**203**	-	**175**	20
Phocid carnivores in water (PCW)	**185**	-	**170**	25
Other marine carnivores in water (OCW)	**203**	-	**188**	-
Note: A dash indicates the threshold is not reached.				

7.0 Discussion and Summary

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 sea 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 criterion being applied.

The estimated maximum zones of impact for all operational activities (e.g., VSP, Sonar and drilling) are summarised in **Table 29** and **Table 30** below, based on the STLM results and the zones of impact estimated as detailed in the above sub-sections within **Section 6.0.**

Table 29: Summary of the maximum zones of impact for marine mammals

<table>
<tr><th rowspan="2">Animal type</th><th rowspan="2" colspan="2">Exploration Operations Activity</th><th colspan="3">Maximum threshold distances, m</th></tr>
<tr><th>PTS onset</th><th>TTS onset</th><th>Behavioural disturbance</th></tr>
<tr><td rowspan="9">Marine mammals</td><td colspan="2">VSP – immediate impact (Table 14 & Table 15)</td><td>55</td><td>90</td><td>1 420</td></tr>
<tr><td rowspan="2">VSP – cumulative (Table 18)</td><td>250 VSP pulses</td><td>70</td><td>320</td><td rowspan="2">-</td></tr>
<tr><td>50 VSP pulses</td><td>35</td><td>150</td></tr>
<tr><td colspan="2">Drilling – immediate behavioural impact (Table 24)</td><td>-</td><td>-</td><td>33 600</td></tr>
<tr><td>Drilling – cumulative (Table 21)</td><td>24 hr</td><td>290</td><td>3 200</td><td>-</td></tr>
<tr><td>Drilling – cumulative (Table 22)</td><td>0,5 hr</td><td>40</td><td>450</td><td>-</td></tr>
<tr><td colspan="2">Single MBES Pulse - immediate impact (Table 25 & Table 27)</td><td>760</td><td>1 020</td><td>1 150</td></tr>
<tr><td colspan="2">Single MBES Pulse - cumulative impact (Table 28)</td><td>320</td><td>800</td><td>-</td></tr>
<tr><td colspan="6">Note: A dash indicates the threshold is not applicable.</td></tr>
</table>

Table 30: Summary of the maximum zones of impact for sea turtles, fish, fish eggs, and fish larvae

Animal type	Exploration Operations Activity		Maximum threshold distances, m			
			PTS onset	Recovery injury	TTS onset	Behavioural disturbance
Sea turtles	VSP – immediate impact (Table 16 & Table 17)		<10	-	<10	340
	VSP cumulative (Table 20)	250 VSP pulses	25	-	70	-
		50 VSP pulses	<10	-	30	
	Drilling - cumulative (Table 23)	24 hr	30 m	-	-	-
	Drilling - cumulative (Table 23)	0.5 hr	<10 m	-	-	-
	Drilling - immediate behavioural impact (Table 24)		-	-	-	150
	Single MBES Pulse - immediate impact (Table 26 and Table 27)		70	-	125	540
Fish, fish eggs and fish larvae	VSP – immediate impact (Table 15)		35	35	-	-
	VSP – cumulative (Table 19)	250 VSP pulses	50	65	330	
		50 VSP pulses	20	30	150	
Fish	VSP - behavioural impact (Table 15)		-	-	-	4 230
	Drilling - behavioural impact (Table 24)		-	-	-	1 560
	Single MBES Pulse - behavioural impact (Table 27)		-	-	-	1 620

Note: A dash indicates the threshold is not applicable.

For all drilling activities, the cumulative exposure level at certain locations is modelled based on the assumption that the marine animals are constantly exposed to the source at a fixed location over the entire operational period (e.g., up to 9 hours for 250 VSP pulses or up to 24 hours for continuous drilling). However, marine fauna species, such as marine mammals, fish, and sea turtles, would not (under realistic circumstances) stay in the same location for the entire period unless the individual animals were attached to a specific feeding/breeding area. In addition, immobile species, such as plankton and fish eggs/larvae, must also be considered. Therefore, the zones of impact assessed for marine mammals, fish species, and sea turtles represent the worst-case consideration.

For sonar survey activities, maximum noise levels are significantly higher throughout the water column along the range in the cross-track direction at both modelled locations. Although MBES sources have much lower noise emissions compared with seismic airgun sources, marine mammals are predicted to experience PTS at very close proximity to the MBES sources due to the immediate exposure to single pulses. The maximum impacts fall on the group of VHF cetaceans. High-frequency sonar MBES sources are not expected to cause an adverse hearing impact on fish species. For sea turtles, the zones of impact are lower. Cumulative impacts from single MBES pulses are predicted to be low for the majority of any marine mammal hearing group other than VHF cetaceans. For fish and sea turtles, cumulative exposure of individual MBES pulses is not expected to occur at all.

8.0 Statement of Limitations

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9.0 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 Memorandu, NMFS-OPR-59.

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 1 September 2022).

Navy, U.S. Department, 2017. Technical Report: Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). San Diego, California: SSC Pacific

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.

RPS Group, 2020, Metocean design criteria study - Namibia - 2913B. MMC03586.000. 100-CN-REP-1900 Rev 0. 05 May 2020.

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 Acoustic Terminology

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

TotalEnergies E&P Namibia B.V.

SLR Project No. 733.20071.00005

January 12, 2023

Acoustic Terminology

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

Appendix B Marine Mammal Hearing Classification

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

TotalEnergies E&P Namibia B.V.

SLR Project No. 733.20071.00005

January 12, 2023

Marine Mammal Hearing Classification

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

Table B.1: Summary of marine mammal classification

Hearing 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*

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

Hearing Classification	Common Name	Scientific Name
	Indo-Pacific humpback dolphin	*Sousa chinensis*
	Indian Ocean humpback dolphin	*Sousa plumbea*
	Australian humpback dolphin	*Sousa sahulensis*
	Atlantic humpback dolphin	*Sousa teuszii*
	Tucuxi	*Sotalia fluviatilis*
	Guiana dolphin	*Sotalia guianensis*
	Pantropical spotted dolphin	*Stenella attenuata*
	Clymene dolphin	*Stenella clymene*
	Striped dolphin	*Stenella coeruleoalba*
	Atlantic spotted dolphin	*Stenella frontalis*
	Spinner dolphin	*Stenella longirostris*
	Rough-toothed dolphin	*Steno bredanensis*
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
	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*

Hearing Classification	Common Name	Scientific Name
	Franciscana	*Pontoporia blainvillei*
	Pygmy sperm whale	*Kogia breviceps*
	Dwarf sperm whale	*Kogia sima*
Sirenians (extracted from Appendix 4 Southall *et al.* (2019))	Amazonian manatee	*Trichechus inunguis*
	West Indian manatee	*Trichechus manatus*
	West African manatee	*Trichechus senegalensis*
	Dugong	*Dugong dugon*
Phocid carnivores (extracted from Appendix 5 Southall *et al.* (2019))	Hooded seal	*Cystophora cristata*
	Bearded seal	*Erignathus barbatus*
	Gray seal	*Halichoerus grypus*
	Ribbon seal	*Histriophoca fasciata*
	Leopard seal	*Hydrurga leptonyx*
	Weddell seal	*Leptonychotes weddellii*
	Crabeater seal	*Lobodon carcinophaga*
	Northern elephant seal	*Mirounga angustirostris*
	Southern elephant seal	*Mirounga leonina*
	Mediterranean monk seal	*Monachus monachus*
	Hawaiian monk seal	*Neomonachus schauinslandi*
	Ross seal	*Ommatophoca rossii*
	Harp seal	*Pagophilus groenlandicus*
	Spotted seal	*Phoca largha*
	Harbor seal	*Phoca vitulina*
	Caspian seal	*Pusa caspica*
	Ringed seal	*Pusa hispida*
	Baikal seal	*Pusa sibirica*

Hearing Classification	Common Name	Scientific Name
Other marine carnivores (extracted from Appendix 6 Southall *et al.* (2019))	Walrus	*Odobenus rosmarus*
	South American fur seal	*Arctocephalus australis*
	New Zealand fur seal	*Arctocephalus forsteri*
	Galapagos fur seal	*Arctocephalus galapagoensis*
	Antarctic fur seal	*Arctocephalus gazella*
	Juan Fernandez fur seal	*Arctocephalus philippii*
	Cape fur seal	*Arctocephalus pusillus*
	Subantarctic fur seal	*Arctocephalus tropicalis*
	Northern fur seal	*Callorhinus ursinus*
	Steller sea lion	*Eumetopias jubatus*
	Australian sea lion	*Neophoca cinerea*
	South American sea lion	*Otaria byronia*
	Hooker's sea lion	*Phocarctos hookeri*
	California sea lion	*Zalophus californianus*
	Galapagos sea lion	*Zalophus wollebaeki*
	Polar bear	*Ursus maritimus*
	Sea otter	*Enhydra lutris*
	Marine otter	*Lontra feline*
Sea Turtles (extracted from Finneran *et al.* 2017)	Green sea turtle	*Chelonia mydas*
	Kemp's ridley sea turtle	*Lepidochelys kempii*
	Loggerhead sea turtle	*Caretta*
	Leatherback sea turtle	*Dermochelys coriacea*
	Hawksbill sea turtle	*Eretmochelys imbricata*

Appendix C Auditory Weighting Functions

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

TotalEnergies E&P Namibia B.V.

SLR Project No. 733.20071.00005

January 12, 2023

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.

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

Where:

W(f) is the weighting function amplitude (in dB) at frequency f (in kHz).

f_1 represents LF transition value (in kHz), i.e., the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve.

f_2 represents HF transition value (in kHz), i.e., the upper frequency at which the function amplitude begins to change from the flat, central portion of the curve.

a represents the LF exponent value (dimensionless) which defines the rate of decline of the weighting function amplitude at low frequencies. The change in weighting function amplitude with frequency at low frequencies (the LF slope) is 20a dB/decade.

b represents the HF exponent value (dimensionless) which defines the rate of decline of weighting function amplitude at high frequencies, becoming linear with the logarithm of frequency. The change in weighting function amplitude with frequency at high frequencies (the HF slope) is -20b dB/decade.

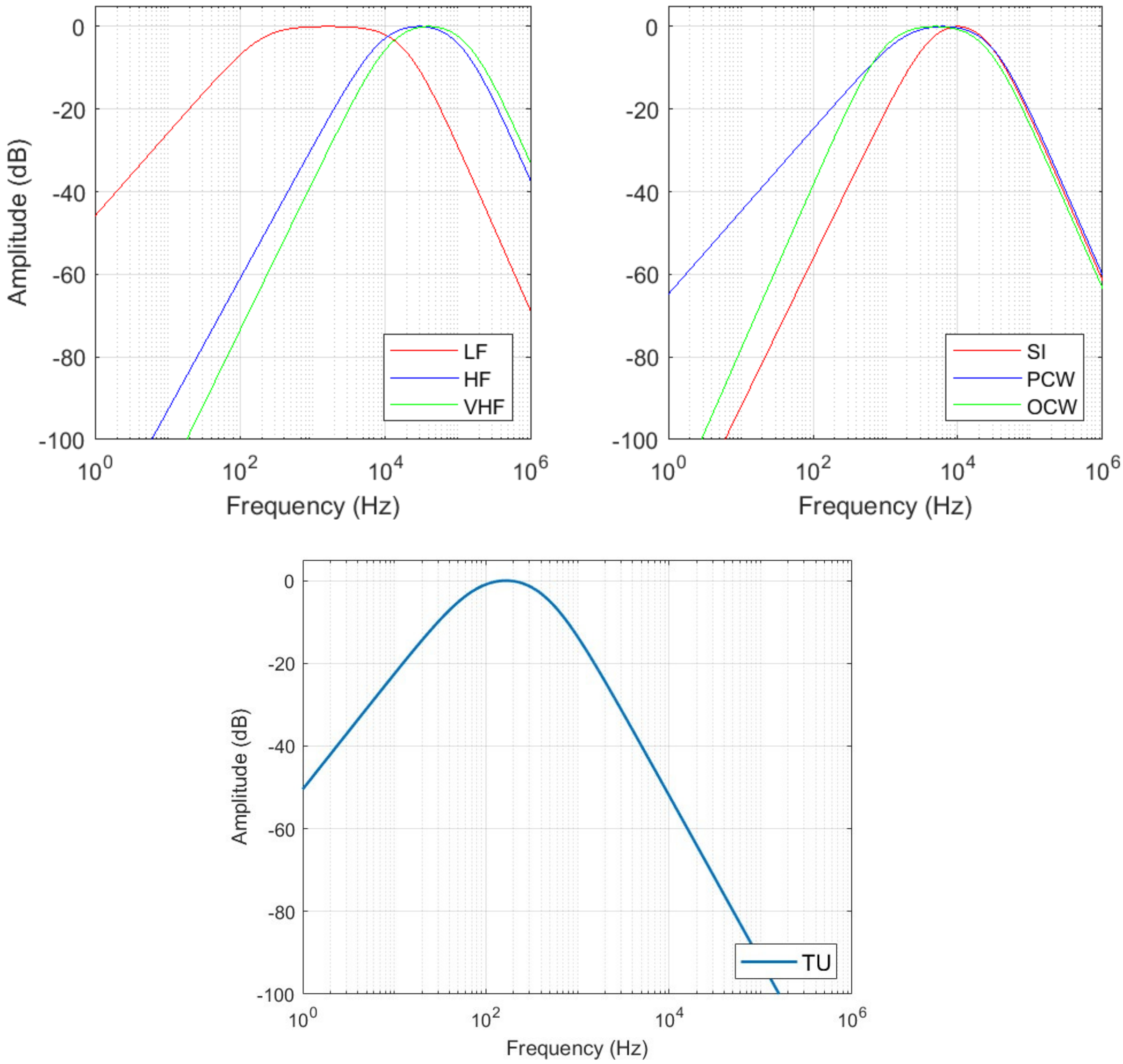
C is the constant that defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Table C.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 C.1.**

Table C.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 C.1: Auditory weighting functions – spectral plots (Southall *et al.* 2019; Finneran *et al.* 2017)



Appendix D VSP Source Modelling

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

TotalEnergies E&P Namibia B.V.

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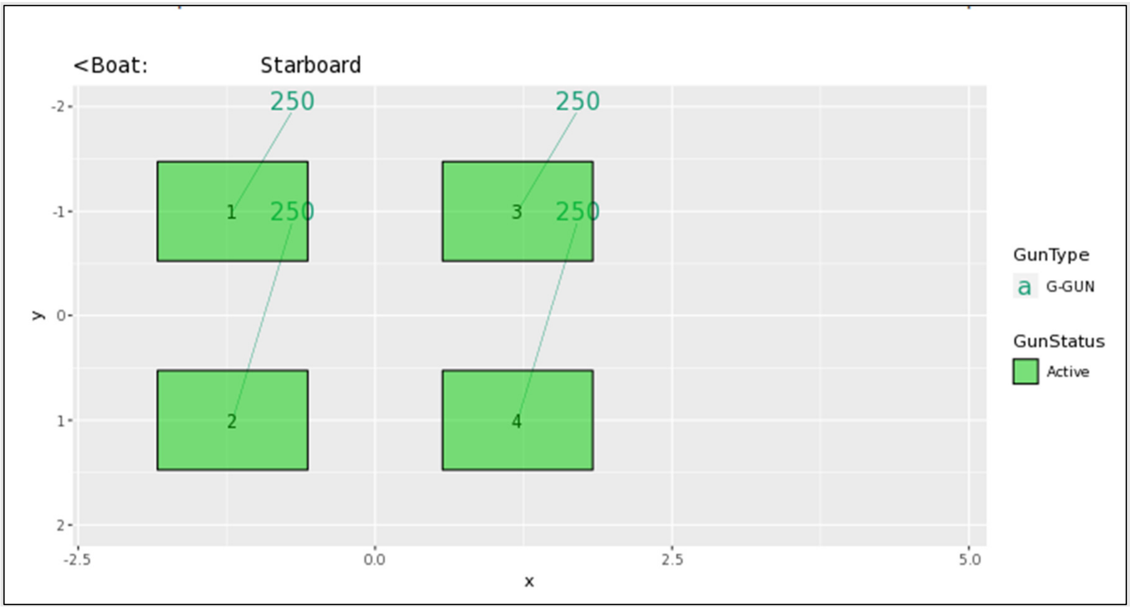
Airgun array configuration

The VSP airgun array proposed is the 1 000 cubic inch (CUI) Avalon RSS2 G-Gun array with its configuration shown in Figure D.1 as below. The array consists of 4 active G-Gun airgun units each with a volume of 250 CUI and has an average towing depth of 7,0 m and an operating pressure of 2 000 pounds per square inch (PSI).

Figure D.1: The configuration of the 1 000 CUI Avalon RSS2 G-Gun array



Modelling methodology

The outputs of the G-Gun array source modelling include:

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

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.

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 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.

Beam patterns

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

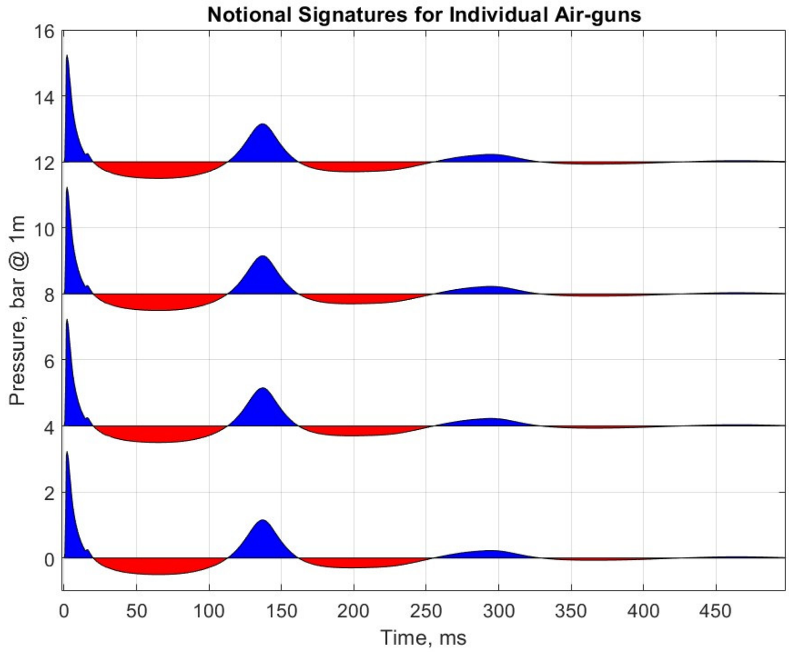
- The far-field signatures are calculated for all directions from the source using azimuthal and dip angle increments of 1-degree;
- The power spectral density (PSD) (dB re 1 $\mu Pa^2 s/Hz$ @ 1 m) for each pressure signature waveform is calculated using a Fourier transform technique; and
- The PSDs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

Modelling results

Notional signatures

Figure D.2 shows the notional source signatures for the four airgun array elements. Each line within the figure represents the notional source signature of the corresponding array element, as shown in Figure D.1.

Figure D.2: Notional source signatures for the 1 000 CUI G-Gun array

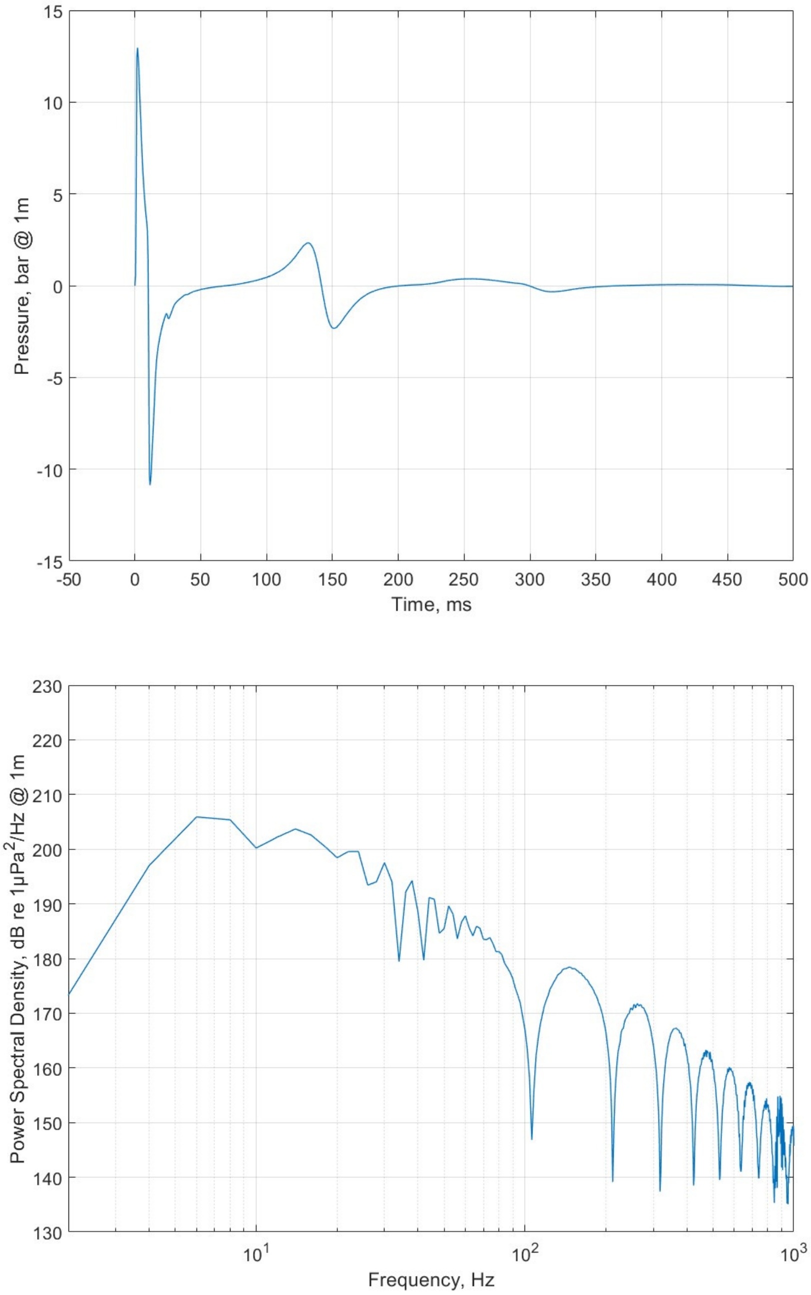


Far-field signature and its power spectral density

Figure D.3 shows the far-field signature waveform and its power spectral density simulated by the Gundalf Designer software. The signatures are for the vertically downward direction with surface ghost included.

The source modelling results for the VSP array show the peak sound pressure level (Pk SPL) is 245,8 dB re 1 µPa @ 1m, the root-mean-square sound pressure level (RMS SPL) 227,2 re 1 µPa @ 1m, and the sound exposure level (SEL) 224,5 dB re µPa^2·s @ 1m.

Figure D.3: The far-field signature in vertically downward direction (top) and its power spectral density (bottom) for the 1 000 CUI G-Gun array



Beam patterns

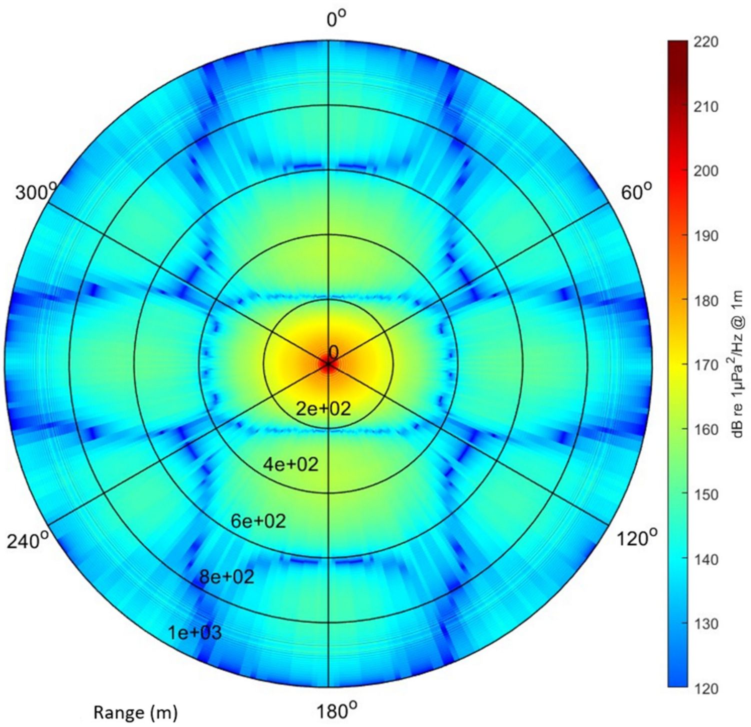
Array far-field beam patterns of the following three cross sections are presented in **Figure D.4**:

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

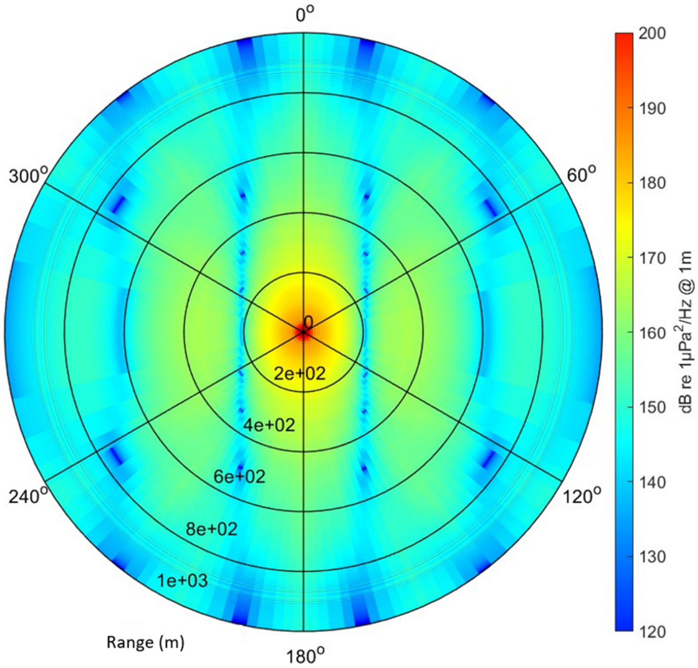
The beam patterns in **Figure D.4** illustrate angle and frequency dependence of the energy radiation from the array. The horizontal plane shows strong interference stripes in parallel with the cross-line direction. The cross-line vertical plane has the strongest radiation in the vertical direction, with no interference patterns as in the in-line vertical plane.

Figure D.4: Array far-field beam patterns for the 1 000 CUI G-Gun array, as a function of orientation and frequency. (a) - The horizontal plane with 0 degree corresponding to the in-line direction; (b) – The vertical plane for the in-line direction; (c) – The vertical plane for the cross-line direction. 0 degree dip angle corresponds to vertically downward direction

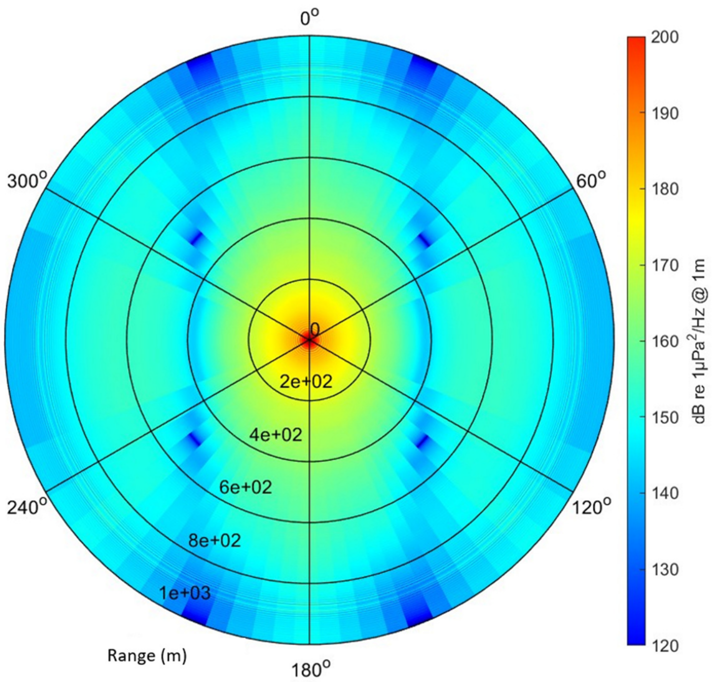
(a)



(b)


0°
60°
120°
180°
240°
300°
0
2e+02
4e+02
6e+02
8e+02
1e+03
Range (m)
200
190
180
170
160
150
140
130
120
dB re 1μPa²/Hz @ 1m

(c)


0°
60°
120°
180°
240°
300°
0
2e+02
4e+02
6e+02
8e+02
1e+03
Range (m)
200
190
180
170
160
150
140
130
120
dB re 1μPa²/Hz @ 1m

Pk SPLs and RMS SPLs – estimate methodology from modelled SELs

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

As presented in Section B.3.2, the difference between the Pk SPL and SEL of the far-field signature of the 1 200 cubic inch (CUI) G-Gun array (at a reference distance of 1 m from the centre of the array) is 23,1 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 the increasing distances beyond 10 km (Simon *et al.* 2018).

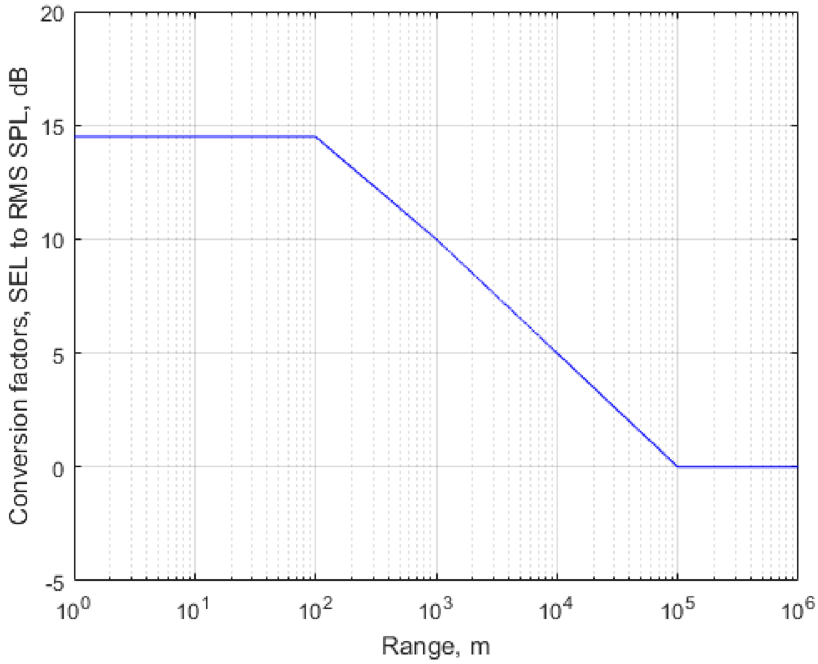
For this project, the RMS SPLs were estimated using the following conversion factors to be applied to the modelled SELs within different distance ranges. These conversion factors are conservatively estimated based on the VSP array modelling results and above previous measurement results:

- 0 – 100 m, a conversion factor of 14,5 dB. This is the difference between RMS SPL and SEL of the far-field signature of the 1 200 cubic inch (CUI) G-Gun array;
- 100 – 1 000 m, conversion factors 14,5 dB to 10,0 dB, following a logarithmic trend with distance;
- 1 000 – 10 000 m, conversion factors 10,0 dB to 5,0 dB, following a logarithmic trend with distance;
- 10 000 – 100 000 m, conversion factors 5,0 dB to 0,0 dB, following a logarithmic trend with distance;

- > 100 000 m, a conversion factor of 0,0 dB.

The SEL to RMS SPL conversion factors as a function of horizontal ranges from the source array is demonstrated in **Figure D.5** as below.

Figure D.5: SEL to RMS SPL conversion factors as a function of horizontal range from the source array



Appendix E VSP and Drilling Noise Modelling Contour Figures

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

TotalEnergies E&P Namibia B.V.

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Figure E.1: Modelled maximum SEL (maximum level across water column) contours for single VSP pulse from deepest water source location L1 to a maximum range of 200 km, overlaying with bathymetry contour lines

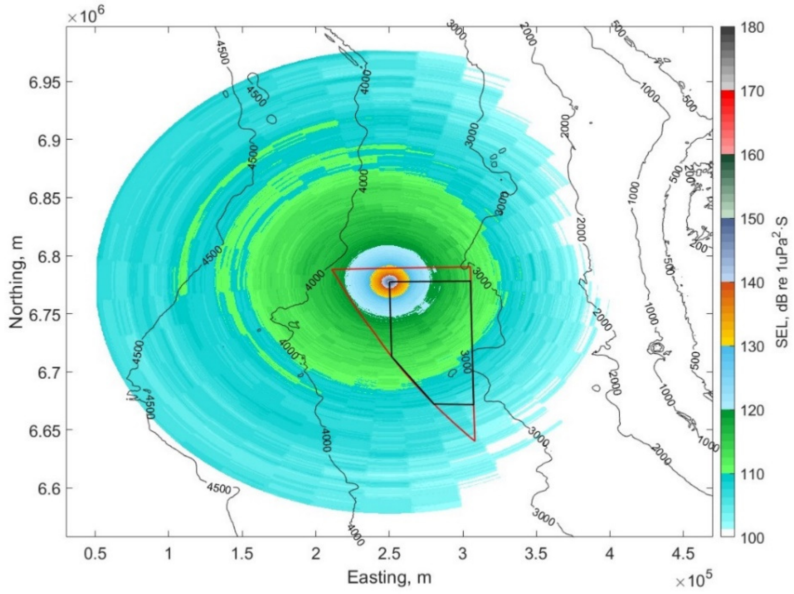


Figure E.2: Modelled maximum SEL (maximum level across water column) contours for all continuous noise (including drillship and support vessels) of 1-s duration from deepest water source location L1 to a maximum range of 200 km, overlaying with bathymetry contour lines

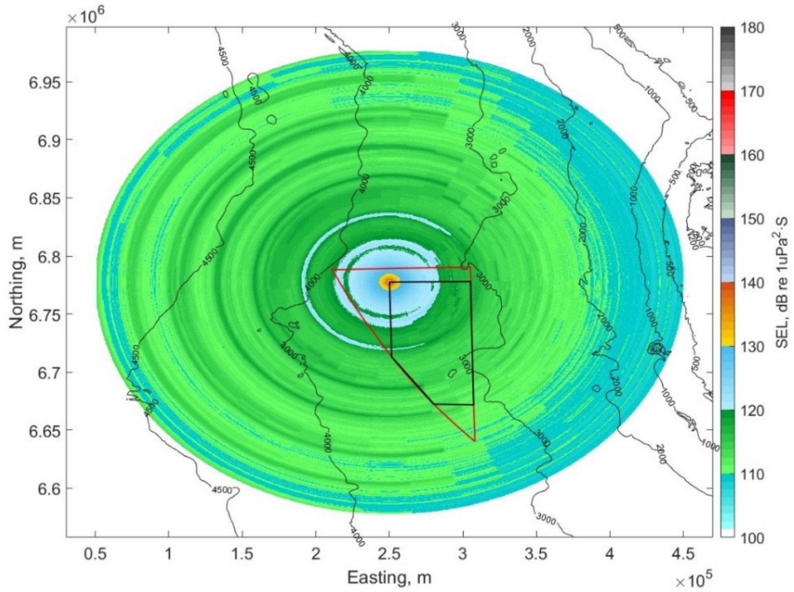


Figure E.3: Modelled maximum SEL (maximum level across water column) contours for continuous drilling platform noise of 1-s duration from deepest water source location L1 to a maximum range of 200 km, overlaying with bathymetry contour lines

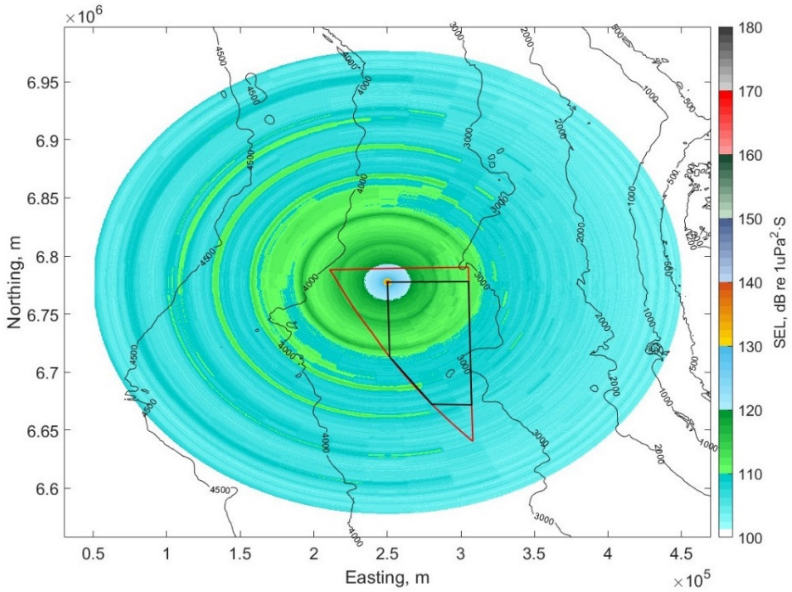


Figure E.4 Modelled maximum SEL (maximum level across water column) contours for continuous support vessel noise of 1-s duration from deepest water source location L1 to a maximum range of 200 km, overlaying with bathymetry contour lines

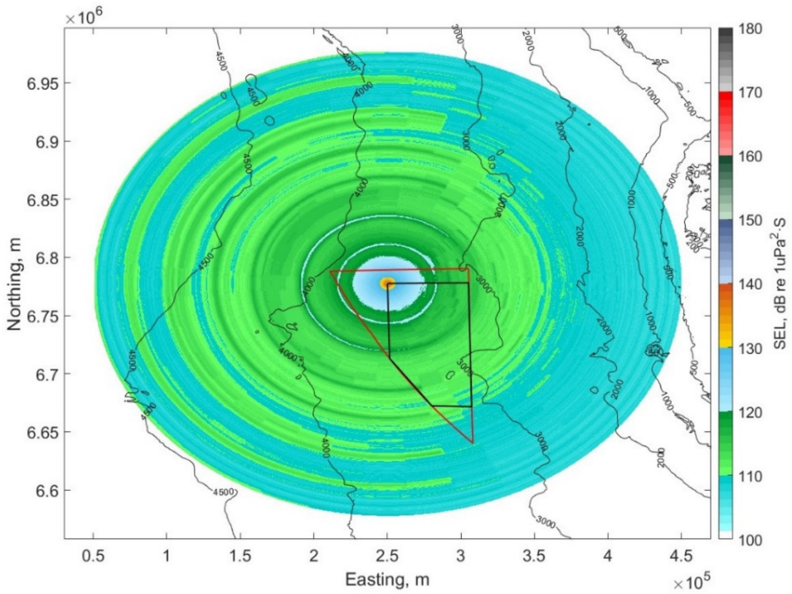


Figure E.5: Modelled maximum SEL (maximum level across water column) contours for single VSP pulse from shallowest water source location L2 to a maximum range of 200 km, overlaying with bathymetry contour lines

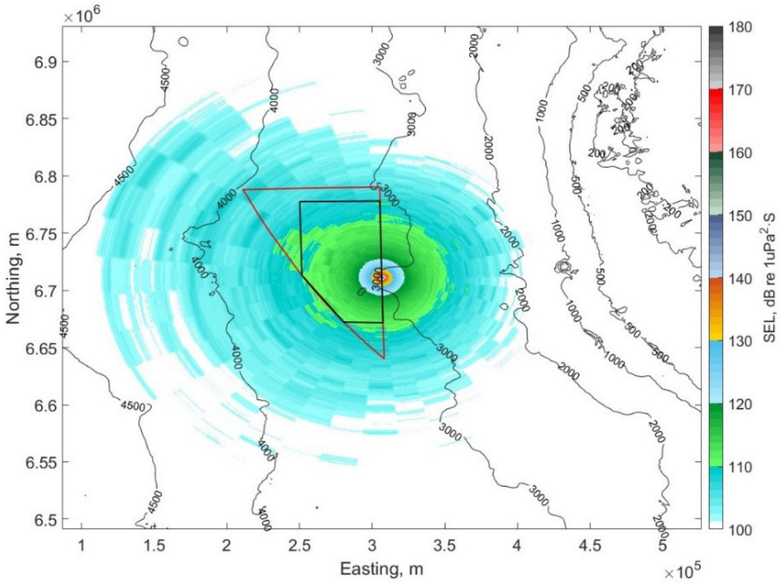
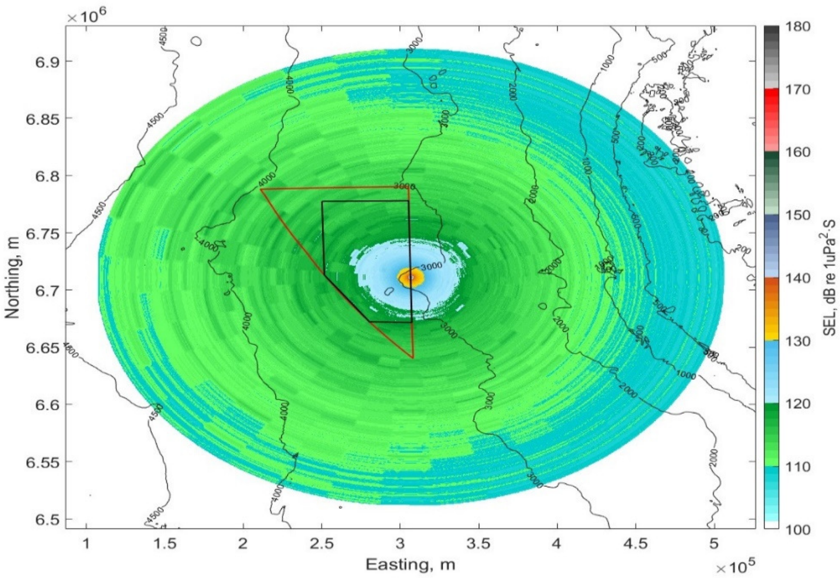


Figure E.6 Modelled maximum SEL (maximum level across water column) contours for all continuous noise (including drilling platform and support vessels) of 1-s duration from shallowest water source location L2 to a maximum range of 200 km, overlaying with bathymetry contour lines



SLR

Figure E.7: Modelled maximum SEL (maximum level across water column) contours for continuous drilling platform noise of 1-s duration from shallowest water source location L2 to a maximum range of 200 km, overlaying with bathymetry contour lines

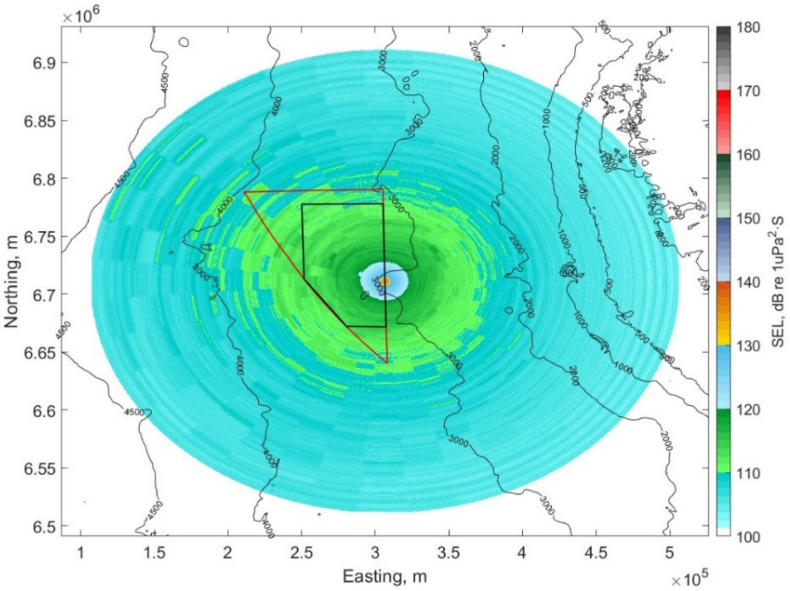
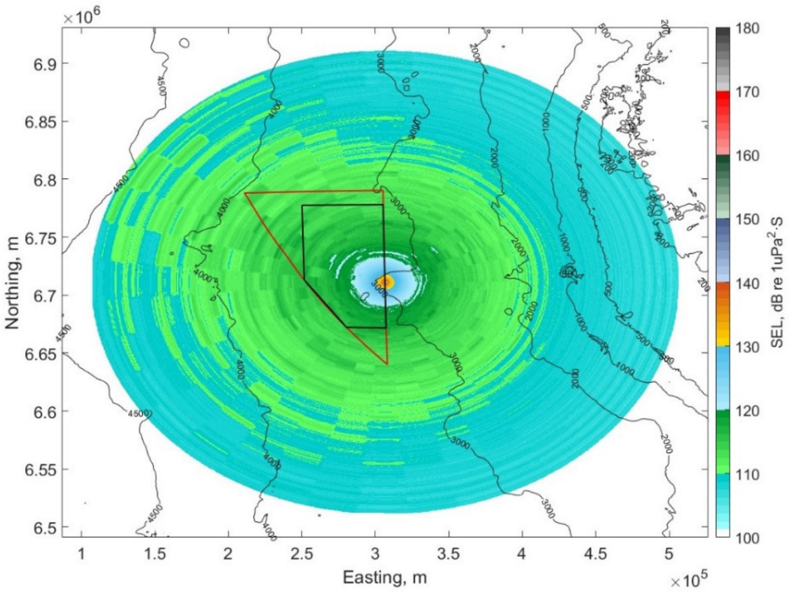


Figure E.8 Modelled maximum SEL (maximum level across water column) contours for continuous support vessels noise of 1-s duration from shallowest water source location L2 to a maximum range of 200 km, overlaying with bathymetry contour lines



Appendix F Single MBES Pulse Results

Exploration Drilling in Block 2912 (off the south coast of Namibia)

Sound Transmission Loss Modelling

TotalEnergies E&P Namibia B.V.

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Figure F.1 The maximum SELs (dB re 1 µPa2 ·S) across the water column vs range from the single MBES pulse at along-track (lefft) and cross-track (right) directions for L1 (top) and L2 (bottom).

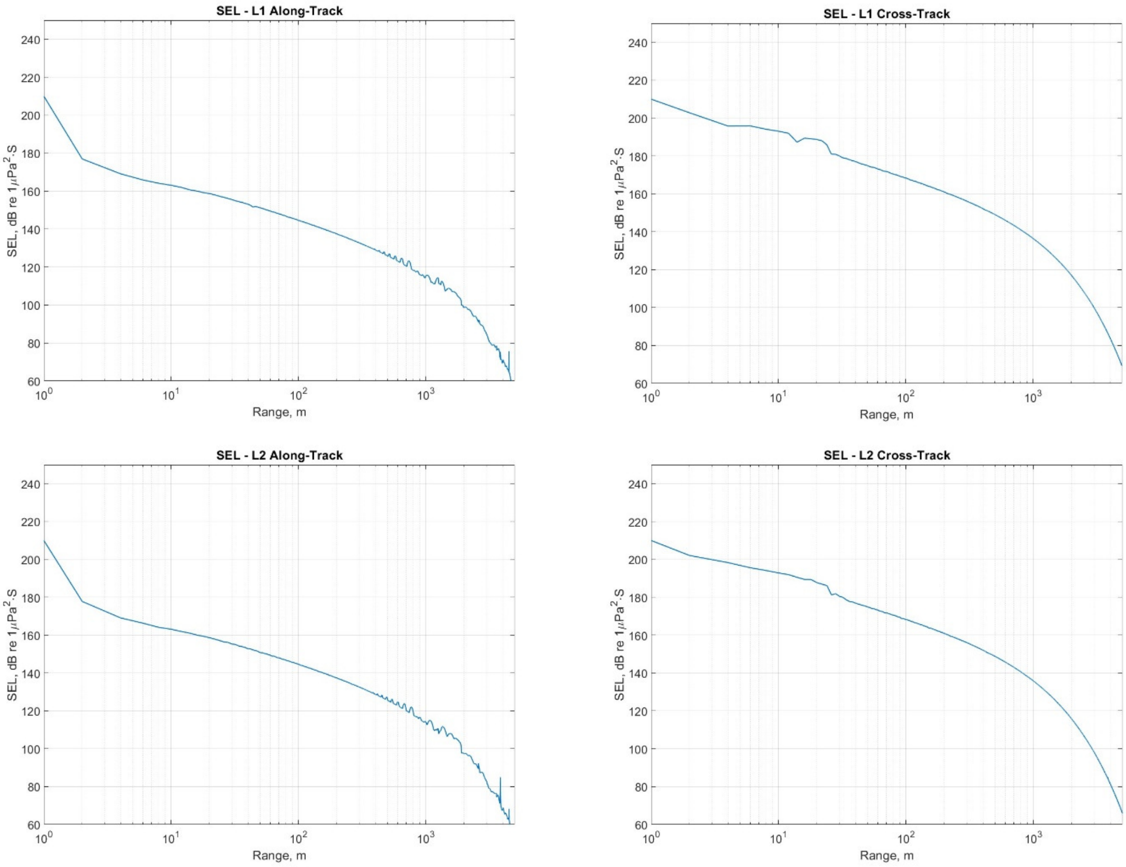

Figure F.2 The maximum RMS (dB re 1 µPa) across the water column vs range from the single MBES pulse at along-track (left) and cross-track (right) directions for L1 (top) and L2 (bottom).

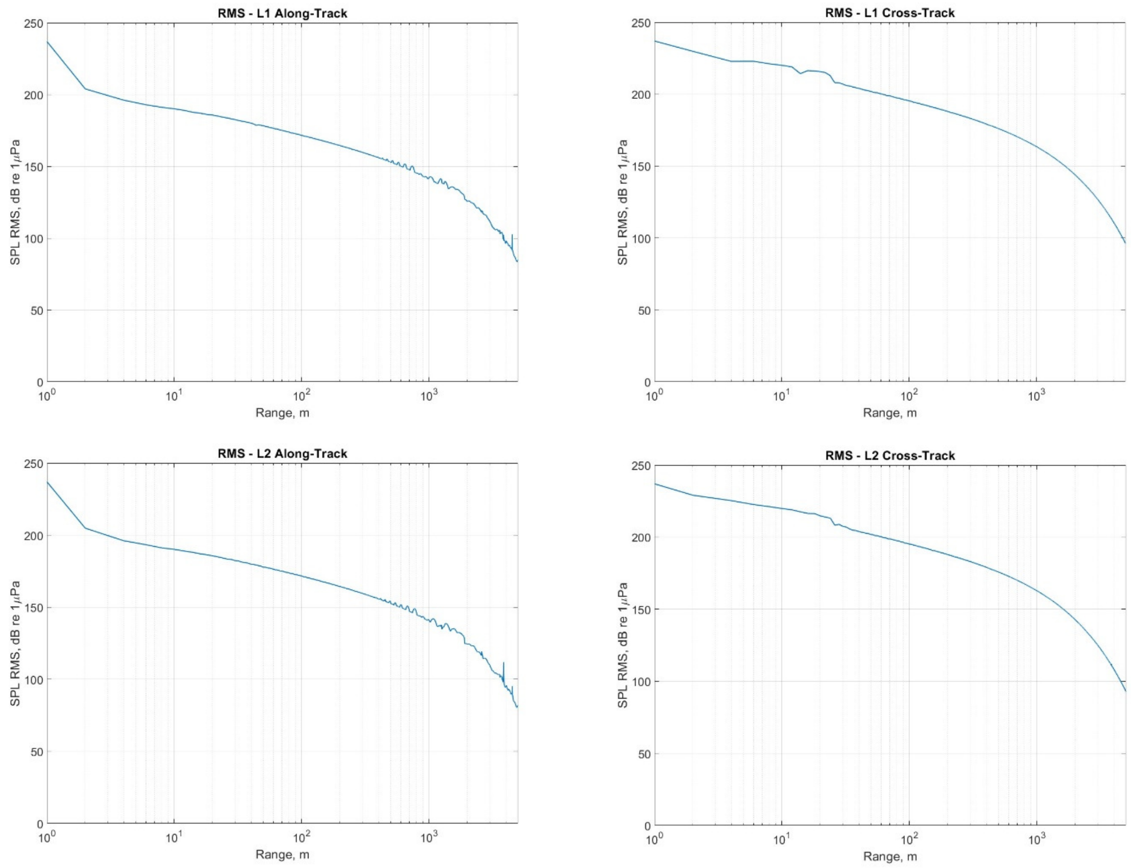

Figure F.3 The maximum Peak SPL (dB re 1 µPa) across the water column vs range from the single MBES pulse at along-track (lefft) and cross-track (right) directions for L1 (top) and L2 (bottom).