SOUTHDOWN MAGNETITE PROJECT

Construction Piling and Transhipment Activities
Underwater Noise Assessment

Prepared for:

Southern Ports Authority
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BASIS OF REPORT

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

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DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
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EXECUTIVE SUMMARY

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Grange Resources Limited (Grange) on behalf of the proponent Southern Ports Authority (SPA) to assess the potential underwater noise impacts from transhipment activities associated with the Southdown Project. This includes construction of marine facilities at Berth 5 Albany Port, transhipping vessel (TSV) docking, movements and loading of the Ocean Going Vessel (OGV) in the King George Sound.

A noise assessment has been completed which consider all potential sources of underwater noise from significant construction and transhipment operations associated with the Southdown Project. These scenarios included:

- Piling construction associated with TSV loading at Berth 5;
- Transhipment activities, comprising
    - TSV docked at Berth 5;
    - TSV movements between the port and OGV; and
    - Loading of the OGV.

During the construction phase of the project, major activities in regards to aquatic noise emissions include impact piling, sediment excavation and vessel movements. Of these activities, piling is considered to have the highest impact on the aquatic noise environment, due to its relatively high noise emissions, as well as its impulsive noise characteristics.

However once constructed, shipping vessel movements are expected to have significantly lower impact as their noise emissions are lower in levels and continuous in nature and are comparable to the existing shipping traffic from cargo ships and recreational vessels around the port area.

The sensitive aquatic receptors that are potentially to be adversely affected by the noise emissions from the construction activities include marine mammals (e.g. whales, dolphins), fish species and human divers/swimmers, particularly around the Former HMAS Perth Dive Wreck site.

Detailed modelling predictions have been undertaken for noise emissions from the impact piling operations and the most dominant noise-generating activities during transhipping operations. Various zones of impact have been estimated for each category of marine fauna species and human divers/swimmers, based on comparisons between predicted noise levels and impact assessment criteria.

It is important to note that the predicted noise levels are based on conservatively estimated noise emissions and actual noise levels may differ depending on factors such as the duration of use and vessel size and condition.

Based on the results, it is recommended that aquatic noise management measures be prepared for construction, including project specific management and monitoring procedures in order to minimise the piling noise impact on assessed aquatic sensitive receptors. These measures are outlined in Section 6 and will be further addressed in the document(s) to be submitted under the EP Act and EPBC Act for potential assessment and approval of waterside transhipping operations. These management measures should be reviewed and updated as detail in the design or operational profiles change.

CONTENTS

CONTENTS

TABLES

CONTENTS

FIGURES

1 Introduction

1.1 Project background

The Southdown Magnetite Project is an advanced project with over 1.2 billion tonnes of high-quality mineral resources, including 388 million tonnes (Mt) of ore reserves. On the basis of a 5 Mt per annum concentrate production design, this ore reserve provides for a mine life of 28 years, with the potential to extend over 50 years for the total Mineral Resource.

It is a pit to port operation, with shipping from the Port of Albany. The Southdown Magnetite Project has been granted primary environmental approvals by the Western Australian government under the *Environmental Protection Act 1986* (EP Act) and by the federal government under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The approved project includes:

- a mine, processing and associated infrastructure near Wellstead, approximately 90km east north east of Albany, Western Australia;
- a slurry/return water pipeline between the mine site and Albany Port;
- ore reclamation, storage, handling and ship loading of magnetite at Albany Port via a new berth (Berth 7) to be constructed;
- a desalination plant at Cape Riche; and
- a groundwater abstraction borefield at Wellstead (EPBC Act approval only)

Approvals for the mine, slurry/return water pipeline, ore reclamation, storage, handling and ship loading of Cape sized vessels from Berth 7 at Albany Port and the desalination plant at Cape Riche are held by Grange (Ministerial Statement (MS) 816, MS 904 and EPBC 2011/6053).

Approvals for the development of Berth 7 and associated dredging at Albany Port are held by the Southern Ports Authority (SPA) (MS846 and EPBC 2006/2540).

The existing project approvals do not cover all aspects of the 5 million tonne per annum (Mtpa) project pre-feasibility (PFS) design. Amended or new project elements in the 5 Mtpa PFS design will be included in referrals to the Environmental Protection Authority (EPA) for potential assessment under S38 of the EP Act.

Amended or new project elements in the 5 Mtpa PFS design not covered in the existing EPBC Act approvals (EPBC 2011/6053 and EPBC 2006/2540) and that have the potential to significantly impact on Matters of National Environmental Significance (MNES) will need to be submitted to the federal government for approval. The EPBC Act does not allow for amendments to existing projects, and therefore, any new or amended elements that have the potential to significantly impact on MNES will need to be assessed and obtain a separate approval.

The Southdown Magnetite Project is now also proposing to export stockpiled magnetite utilising a transhipment vessel (TSV) to be loaded at Berth 5 to transport to and load ocean-going vessels (OGVs) anchored in the King George Sound (KGS). These facilities and operations were not included in previous approvals granted under MS 816, MS 846, EPBC 2011/2053 or 2006/2540. Approvals for facilities to be built on land at and operated at Berth 5, including facilities to load the TSV, will be sought by Grange. Approvals for construction of marine facilities at Berth 5, TSV movements and loading of OGVs will be sought by SPA.

Transhipment will require construction of a loading facilities at Berth 5 within the Port of Albany, which will involve driving piles into the marine seabed. The operational transhipment activities involved in exporting the concentrate is detailed as follows:

- **Loading of the TSV**: A TSV will be loaded within the Port of Albany at Berth 5 with magnetite concentrate up to two times a day using a land based shiploader – approvals for land side operations of these facilities will be sought separately by Grange
- **TSV travels to OGV**: Once loaded, the TSV will travel from the dock at Berth 5 to one of four anchor points 'D', 'Z', 'W' and 'Y' within King George Sound (KGS) where an OGV is located. **Figure 1** presents the location of four anchorage locations. These anchorage areas indicate SPA's current operations. It is expected that anchorages "W" and "Y" will be used by the OGVs associated with these transhipment operations. During the design process, it is expected that the separation distance of the anchorage areas to be used will increase from 560 m to accommodate for the side-by-side vessel transhipping (e.g. 900 metres is similar to Transhipment operations in Whyalla).
- **Loading of the OGV**: Once the TSV arrives at the anchor point, it will be positioned alongside the OGV and begin to unload the magnetite concentrate using a boom and conveyor. Initial loading will take place at the more sheltered inner anchorage (most likely W) with the OGV moving into deeper water and further from noise sensitive receptors, to Anchorage Y to complete loading whilst maintaining under keel clearance for the vessel. Once unloaded, the TSV will travel back to the Port of Albany to be reloaded.

The overall process may take between 13 and 16 hours to complete. The TSV then returns to the Port to repeat the cycle as required. The modelling takes into account five scenarios; existing traffic, and four hypothetical future scenarios with transhipment activity taking place at each of the anchor points D, Z, W and Y. **Figure 2** presents an aerial overview of these anticipated travel routes of the TSV.

It should be noted that the OGV is expected to be partially loaded when moving from D, Z or W to anchor point Y. Therefore whilst all access paths to D, Z and W would likely finish at Y due to depth limitations, a worst-case scenario is modelled of the OGV being fully loaded when leaving anchor points D, Z or W and exiting directly out as per **Figure 2**.

Figure 3 presents a summary of the transhipment process and expected cycle times.

Currently there are approximately 150-170 vessels that arrive to the Port of Albany per year, with a typical size of 40,000 to 60,000 tonnes.

1.2 Scope

SLR was engaged by Grange on behalf of the proponent SPA, to:

- Review supplied / available documentation in regards to identified marine species in the study area.
- Develop a project specific set of criteria (marine fauna specific) against which predicted underwater noise emissions would be assessed.
- Assess the predicted underwater noise levels against the nominated criteria.
- Map noise levels against established noise impact criteria for a variety of marine fauna.
- Update/integrate into the report accordingly.

This assessment has been undertaken with consideration of the current best practice in assessing aquatic noise impact on marine fauna and human divers/swimmers applied both nationally and internationally. The assessment methodology is detailed within the report structure below.

Acoustic terminologies used throughout the report are provided in **Appendix A**.

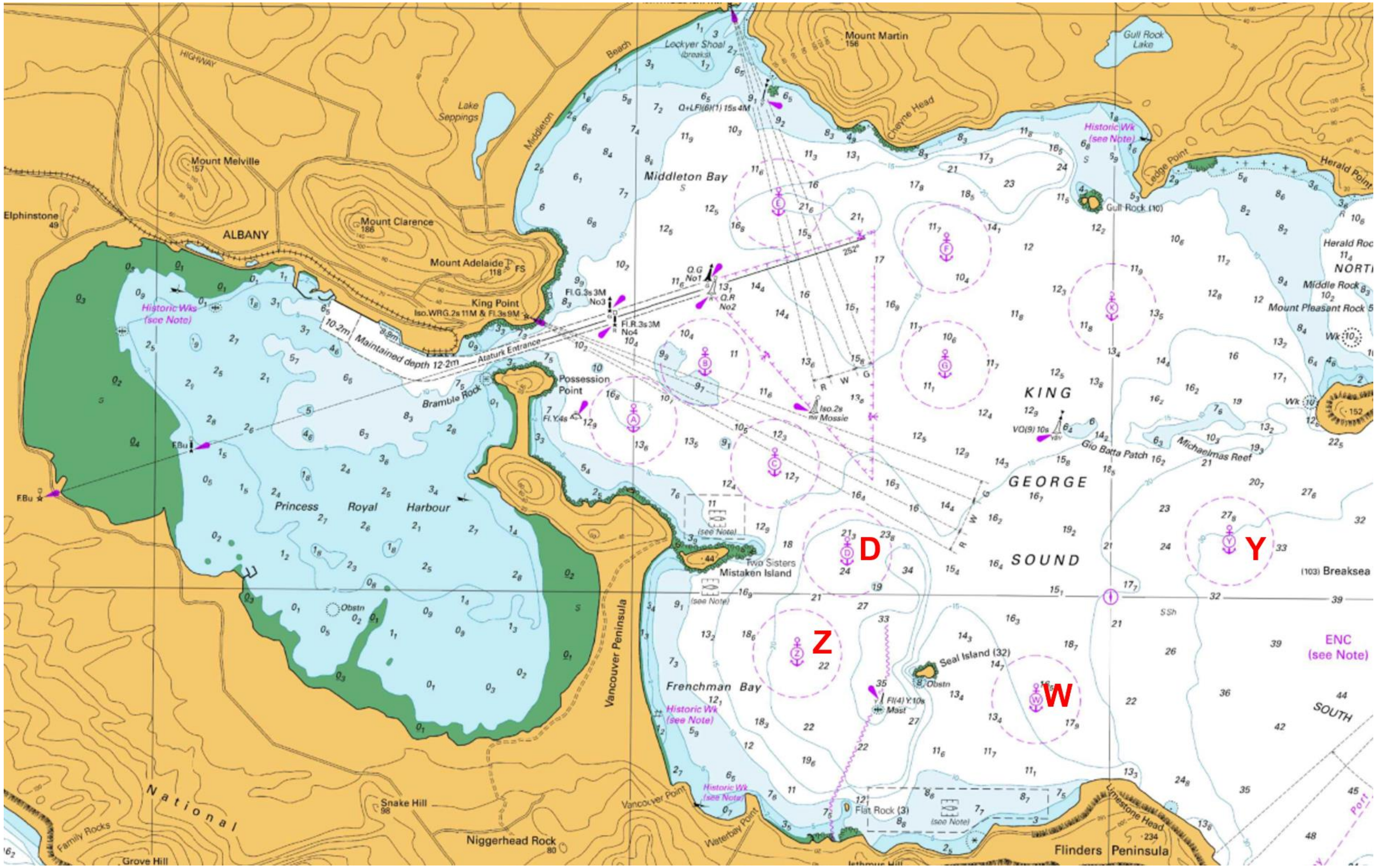

Figure 1 Annotated extract of AHO Australia chart AUS00118 indicating the four anchorages to be assessed for use for transhipping (Supplied)

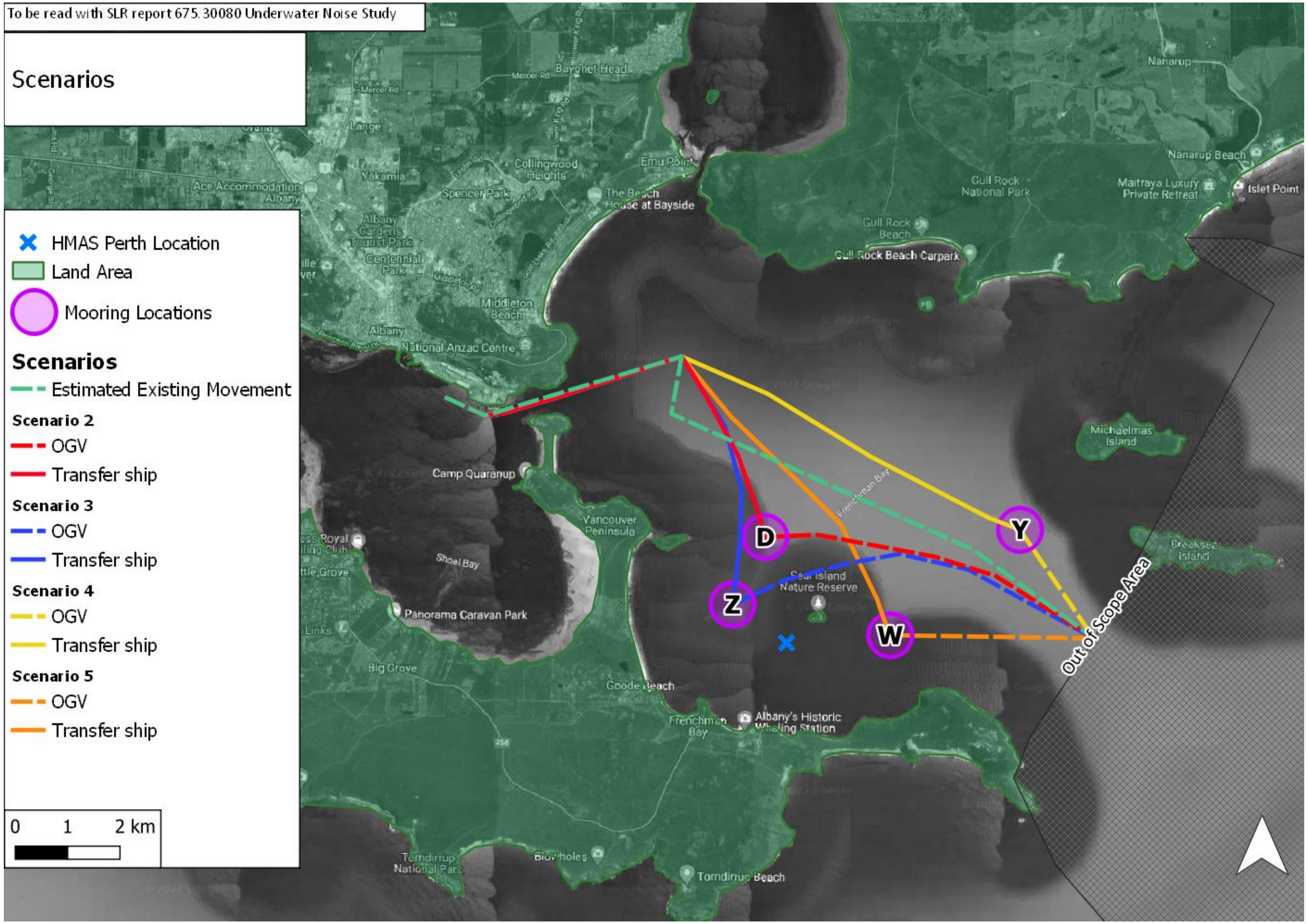

Figure 2 Overview of TSV and OGV travel routes

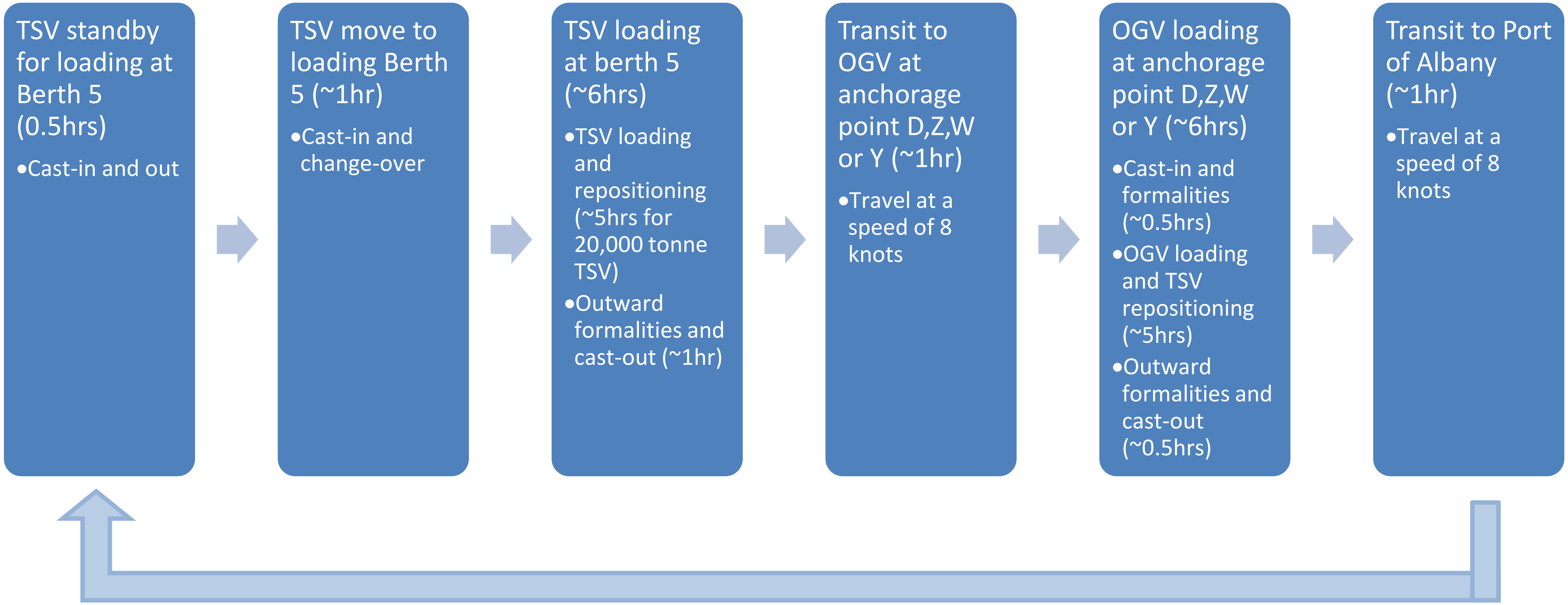

Figure 3 Summary of transhipment process

2 Criteria

2.1 Existing aquatic noise environment considerations

Aquatic ambient noise poses a baseline limitation on the use of sound by marine animals as signals of interest that must be detected against noise background. 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, 1995).

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

- Natural events: the major natural physical events contributing to aquatic 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):
    - Marine mammals. Baleen whales (e.g. great whales like humpback whales) regularly produce intense low-frequency sound (whale songs) that can be detected at long range in the open water. Odontocete whales, including dolphins, can produce rapid burst of high-frequency clicks (up to 150 kHz) that are primarily for echolocation purposes;
    - Fish. 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 season; and
    - Invertebrates. Snapping shrimps are important contributors among marine biological species to the aquatic 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 10k Hz; and
- Dredging activities and other marine industry operations are additional man-made sources, generating broadband noise over relatively long durations.

Figure 4 provides 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. 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 located 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, as well as fish choruses and snapping shrimp for coastal waters.

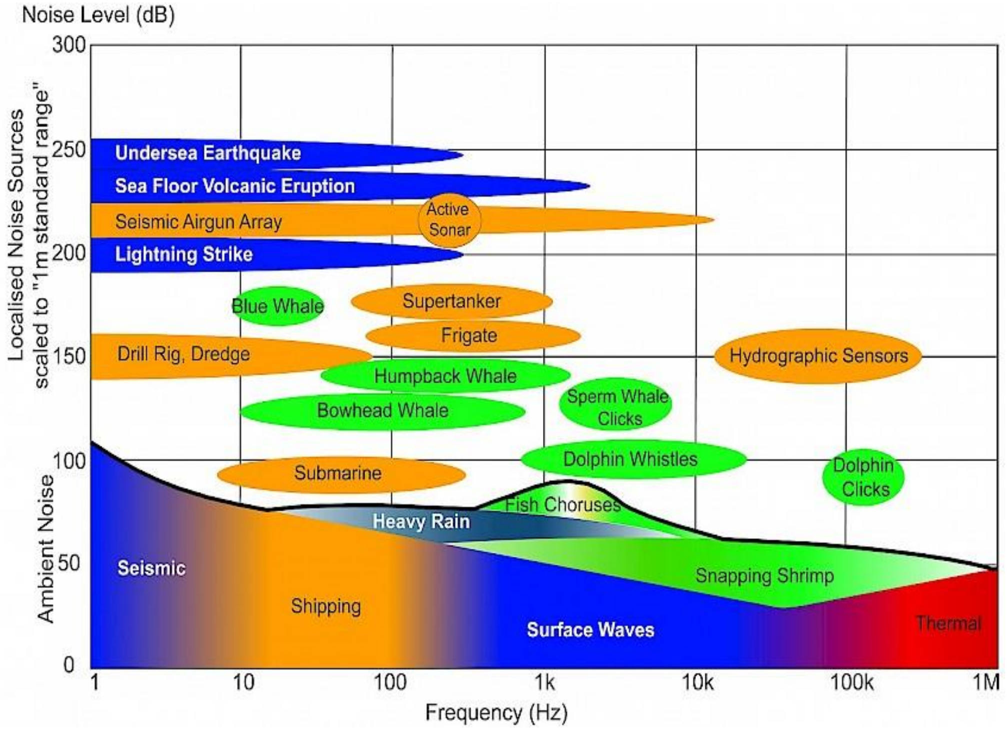

Figure 4 Levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment (from https://www.ospar.org/work-areas/eiha/noise). Natural physical noise sources represented in blue; marine fauna noise sources in green; human noise sources in orange

A summary of the spectra of various ambient noise sources based on a review study undertaken by Wenz (1962) is shown in **Figure 5**. 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 region, they are regarded as representative in general for respective ocean ambient noise spectral components.

Studies in Australian waters have shown that there are some significant differences in the ambient noise compared to the colder Northern Hemisphere waters where most existing measurements have been recorded.

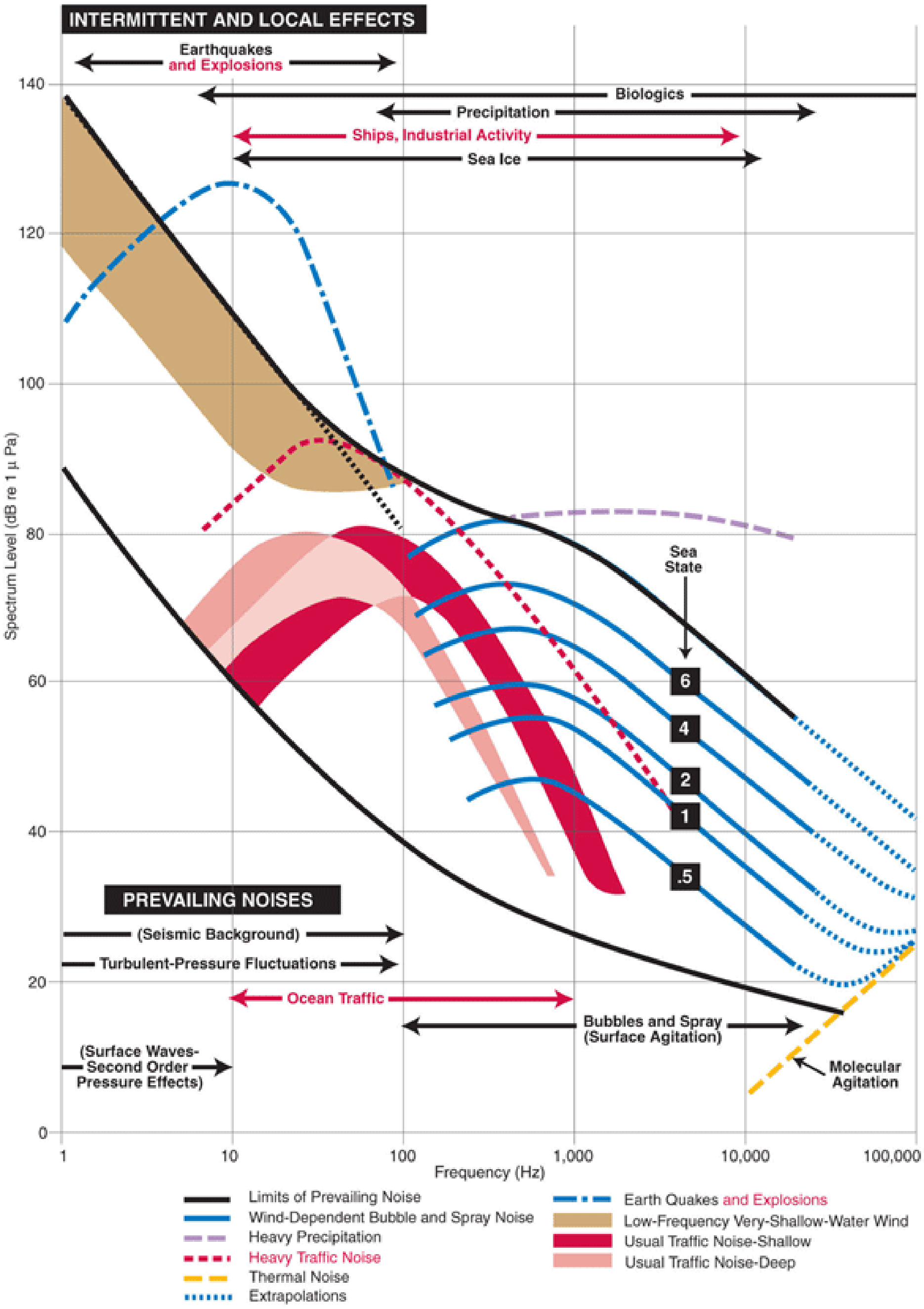

Figure 5 Wenz curves: spectra and frequency distribution of ocean ambient noise spectra (Miksis-Olds et al., 2013, reproduction from Wenz (1962))

Figure 6 summarises the main components of sea ambient noise for the Australian waters, where the differences from Wenz's ambient noise spectra are due to the different environment of tropical waters, particularly in respect to noise from marine animals. Wind-generated noise and the traffic noise due to shipping activities are generally consistent in level range between the two studies (Wenz, 1962 and Cato, 1997).

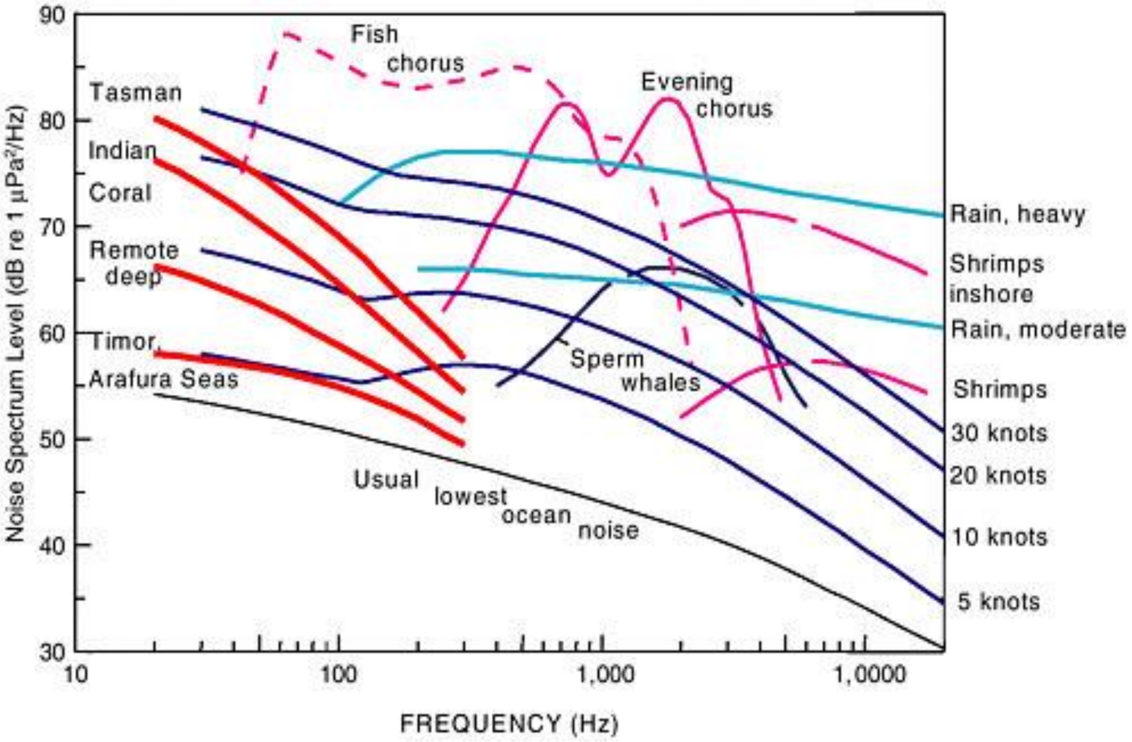

Figure 6 Summary of aquatic ambient noise spectra for the Australian region (from Cato (1997))

2.2 Impact of aquatic noise on marine fauna species

Underwater sound transmits effectively within the water column and is an important sensory modality for many marine organisms. A variety of marine fauna species, including marine mammals, fish species and invertebrates, have special mechanisms both for emitting and detecting underwater sound (Richardson et al, 1995; Popper et al, 2001 and 2003).

Marine mammals, including cetaceans and pinnipeds, use underwater sound in communication, orientation, predator avoidance and foraging (Tyack, 1998; Tyack et al, 2000; Janik, 2005). Many marine fish species produce sounds for communication (Fay and Popper, 1999; Popper et al, 2003 and 2004; Ladich et al, 2004 and 2006(a)&(b)), and potentially they also use acoustic environment for orientation (Montgomery et al, 2006). Some invertebrates such as decapod crustaceans are reported to be sensitive to low frequency underwater sound (Popper et al, 2001).

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

The theoretical zones of noise influence based on the severity of noise impact is illustrated in **Figure 7** below.

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

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

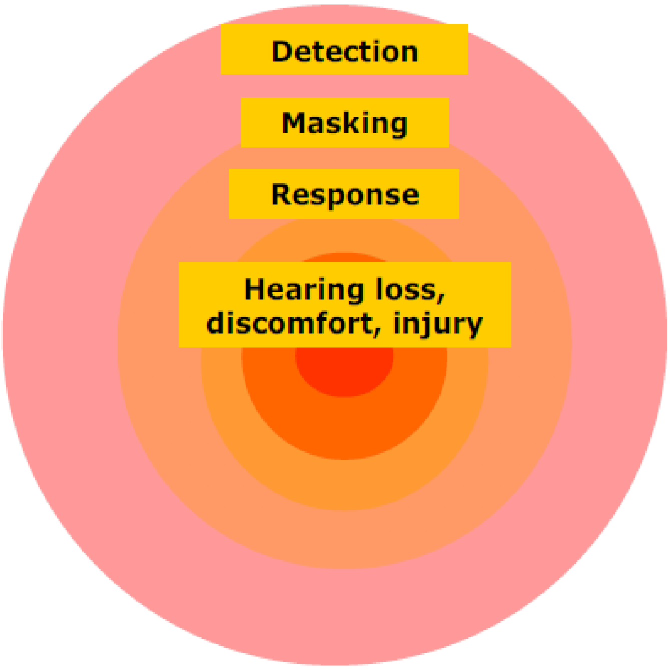

Figure 7 Theoretical zones of noise influence (Richardson et al. 1995)

2.2.1 Audibility/detection

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

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

2.2.2 Masking

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

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

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

2.2.3 Behavioural Responses

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

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

2.2.4 Physiological impacts / hearing loss and physical injury

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

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

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

2.3 Marine mammals

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

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

2.3.1 Marine mammal auditory weighting functions

Marine animals do not hear equally well at all frequencies within their functional hearing range. Based on the hearing range and sensitivities, Southall et al (2019) have categorised marine mammal species (i.e. cetaceans and pinnipeds) into six underwater hearing groups: low-frequency (LF), high-frequency (HF), very high-frequency (VHF) cetaceans, Sirenians (SI), Phocid carnivores in water (PCW) and Other marine carnivores in water (OCW).

The potential noise effects on animals depends on their hearing sensitivities. Sensitivities for specific marine mammal species are provided in Appendix I – 6 within the reference document (Southall et al, 2019), although a summary is presented as **Appendix D** in this report. Frequency weighting is a method of quantitatively compensating for the differential frequency response of sensory systems (Southall et al, 2007 & 2019).

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

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

where:

- ***W(f)*** is the weighting function amplitude (in dB) at frequency f (in kHz).
- ***f_1*** represents LF transition value (in kHz), i.e. the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- ***f_2*** represents HF transition value (in kHz), i.e. the upper frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- ***a*** represents the LF exponent value (dimensionless) which defines the rate of decline of the weighting function amplitude at low frequencies. The change in weighting function amplitude with frequency at low frequencies (the LF slope) is 20*a* 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 -20*b* dB/decade.
- ***C*** is the constant that defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Table 1 lists the auditory weighting parameters for the six hearing groups.

Table 1 Parameters for the auditory weighting functions

Marine mammal hearing group	*a*	*b*	*f_1 (Hz)*	*f_2 (Hz)*	*C (dB)*
Low-frequency cetaceans (LF)	1.0	2	200	19,000	0.13
High-frequency cetaceans (HF)	1.6	2	8,800	110,000	1.20
Very high-frequency cetaceans (VHF)	1.8	2	12,000	140,000	1.36
Sirenians (SI)	1.8	2	4,300	25,000	2.62
Phocid carnivores in water (PCW)	1.0	2	1,900	30,000	0.75
Other marine carnivores in water (OCW)	2.0	2	940	25,000	0.64

The corresponding auditory weighting functions for all hearing groups are presented in **Figure 8**.

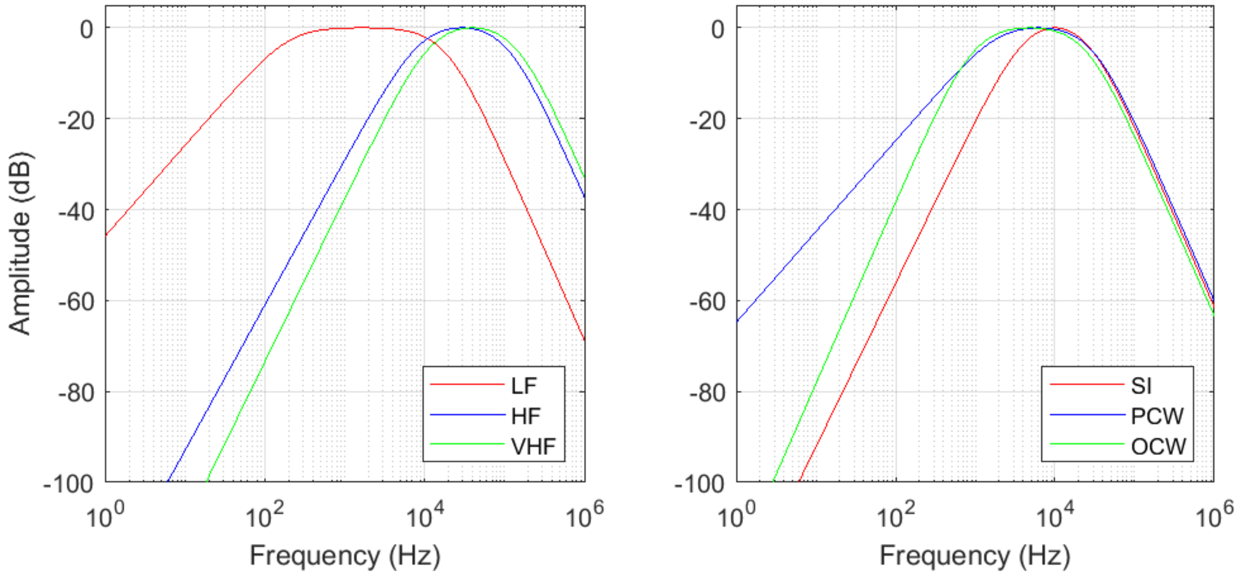

Figure 8 Auditory weighting functions - LF, HF, VHF, SI, PCW and OCW

2.3.2 Noise impact criteria for marine mammals

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

The newly updated scientific recommendations for marine mammal noise exposure criteria (Southall et al, 2019) propose PTS-onset and TTS-onset criteria for both impulsive noise and non-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 1µPa for impulsive noise and 120 dB re 1µPa for non-impulsive noise (NMFS, 2013), as shown in **Table 4**.

Table 2 PTS- and TTS-onset threshold levels for marine mammals exposed to impulsive noise (Southall et al, 2019)

Marine mammal hearing group	**PTS and TTS threshold levels – impulsive noise**			
	Injury (PTS) onset		TTS onset	
	Pk SPL, dB re 1µPa (unweighted)	SEL$_{24hr}$, dB re 1µPa^2·S (weighted)	Pk SPL, dB re 1µPa (unweighted)	SEL$_{24hr}$, dB re 1µPa^2·S (weighted)
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 marine mammals exposed to non-impulsive noise (Southall et al, 2019)

Marine mammal hearing group	PTS and TTS threshold levels – non-impulsive noise	
	Injury (PTS) onset	TTS onset
	SEL$_{24hr}$, dB re 1µPa^2·S (weighted)	SEL$_{24hr}$, dB re 1µPa^2·S (weighted)
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 The behavioural disruption threshold level for marine mammals – impulsive and non-impulsive noise (NMFS, 2013)

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

2.4 Fish and sea turtles

In general, limited scientific data are available regarding the effects of sound for fishes and sea turtles. As such, assessment procedures and subsequent regulatory and mitigation measures are often severely limited in their relevance and efficacy.

To reduce regulatory uncertainty for all stakeholders by replacing precaution with scientific facts, the U.S. National Oceanic and Atmospheric Administration (NOAA) convened an international panel of experts to develop noise exposure criteria for fishes and sea turtles in 2004, primarily based on published scientific data in the peer-reviewed literature. The panel was organized as a Working Group (WG) under the ANSI-Accredited Standards Committee S3/SC 1, Animal Bioacoustics, which is sponsored by the Acoustical Society of America.

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

The sound exposure criteria for sound sources relevant to the project including impulsive noise from pile driving and non-impulsive noise from marine vessels and other sources are presented in **Table 5** and **Table 6** respectively.

Table 5 Sound exposure criteria applicable for pile driving – fishes and sea turtles

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

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

Table 6 Noise exposure criteria for shipping and continuous sounds – fishes and sea turtles

Type of animal	Mortality and potential mortal injury	Impairment			Behaviour
		Recovery injury	**TTS**	**Masking**	
Fish: no swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB rms for 48h	158 dB rms for 48h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Fish eggs and fish larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) High	(N) Moderate (I) Moderate (F) Low

Notes: rms sound pressure levels (RMS SPL) dB re 1 µPa. 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).

It should be noted that the period over which the cumulative sound exposure level (SEL_{cum}) is calculated must be carefully specified. For example, SEL_{cum} may be defined over a standard period (e.g., 12 hours of pile driving) or for the duration of an activity (e.g., the full period of construction), or over the total period that the animal will be exposed. Whether an animal would be exposed to a full period of sound activity will depend on its behaviour, as well as the source movements.

2.5 Human divers/swimmers

Hearing underwater differs from hearing in air as the acoustic properties of water and air are different. Human hearing underwater, with a ‘wet’ ear (i.e. where the external ear canal is filled with water, and water is in direct contact with the tympanic membrane), is less sensitive than it is in air, and so noise underwater is believed to produce less hearing damage than airborne noise.

The comparison between hearing threshold levels for humans in the air and underwater (Parvin, 1998) is illustrated in **Figure 9**. As can be seen in the figure, the hood and face mask for recreational divers further increase the hearing threshold levels.

Many studies on the human diver exposure to underwater sound have been carried out, and relevant safety thresholds for both military and commercial/recreational divers under various frequency ranges have been proposed (Ainslie, 2008; Pestorius et al, 2009).

For a low frequency range, a study with the Low Frequency Active (LFA) sonar as the noise source (Pestorius et al, 2009) shows that underwater noise with dominant energy component within frequency range 100 – 500 Hz would not have an adverse effect on human divers at levels less than 145 dB re 1 µPa rms over certain exposure settings (i.e. maximum continuous exposure of 100 seconds or with a maximum duty cycle of 20% and a maximum daily cumulative total of 3 hrs).

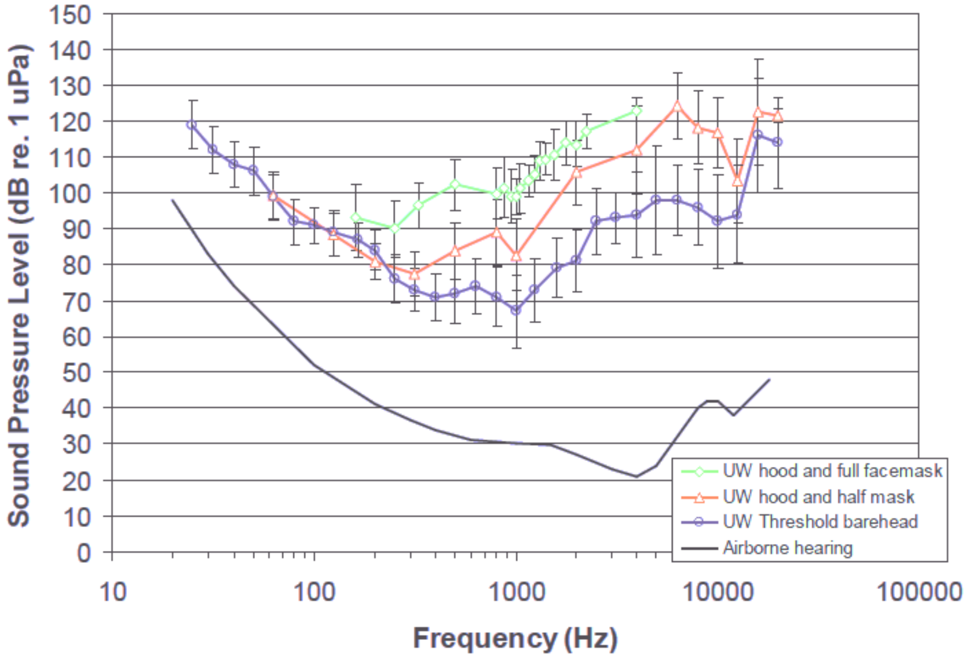

Figure 9 Hearing threshold levels for humans in the air and under water (Parvin, 1998).

For relatively high frequency range, a joint UK-US research published by Parvin et al (2002) reports that for sound in the frequency range 500-2500 Hz, advised threshold 'exposure level' for human divers of 155 dB re 1 µPa rms for use in environmental impact assessment.

As such, the recommended threshold levels for human divers and swimmers under both frequency ranges are summarised in **Table 7**, with the lower level of 145 dB re µPa rms to be used for assessment purpose based on a conservative consideration.

Table 7 Threshold levels for human divers and swimmers (Pestorius et al, 2009; Parvin et al, 2002)

Frequency range	SPL RMS (dB re 1 µPa rms)
100 – 500 Hz	145
500 – 2500 Hz	155

2.6 Zones of bioacoustic impact

The received noise levels within and around the project area 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 be determined by comparison of the predicted received levels to the noise exposure criteria.

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 a marine fauna species, 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 in the affected area.

3 Methodology

3.1 Scenarios

3.1.1 Construction piling

In order to broadly understand the extent of underwater noise impacts from piling operations throughout the proposed project development, a single source location has been nominated for the detailed noise modelling study. The selected source location is presented in **Figure 10**, and further detailed in **Table 8** below with the corresponding coordinate, water depth and locality.

Table 8 Details of the selected piling source location for noise modelling. The coordinate system is based on GDA94/MGA zone 50 projection.

Location	Water Depth, m	Coordinates, m [Easting, Northing]	Locality
L1	12.2	[5.82248 x 10^5, 6.12215 x 10^6]	At approximate location of easternmost pile to be constructed in the Princess Royal Harbour.

Figure 10 The selected piling source location indicated as a green 'X' with *Google Satellite* image underlay.

3.1.2 Transhipment activities

3.1.2.1 TSV docked

The assessment of future operations includes the noise produced by one 20,000 tonne TSV docked at Berth 5 during loading. The existing scenario has used a larger 60,000 tonne TSV docked in Berth 5 during loading. Noise from all landside operations, including the boom and conveyor that loads the TSV, were not included in the assessment. These are included in a separate assessment that will be used by Grange to obtain relevant environmental approvals.

3.1.2.2 TSV travelling to OGV

The assessment has included the following existing operations during an average 24-hour period:

- One 60,000 tonne vessel travelling to or from the existing berth; and
- One 60,000 tonne vessel docked at the existing berth for 12 hours.

Over an average 24-hour period, future operations have been modelled with the same inputs as the existing operations, with the addition of the following operations:

- One 20,000 tonne TSV travelling to and from Berth 5 (**Figure 2**) twice a day; and
- One 20,000 tonne TSV docked at Berth 5 for 10 hours.

3.1.2.3 TSV loading onto OGV

The standard scenario of only one OGV in King George Sound is used in the modelling. It is possible, although not common, for more than one OGV to be in King George Sound at any one time. The assessment has included the following operations while the TSV loads onto the OGV:

- One 20,000 tonne TSV loading onto the OGV with a boom and conveyor; and
- One Cape size 200,000 tonne OGV anchored at D, Z, W or Y shown in **Figure 2.** The 200,000 tonne OGV is in the upper weight range of the cape size vessel and is used in the modelling process as a worst case scenario.

3.2 Modelling principles

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

$$RL = SL - TL \tag{3.1}$$

The fluid parabolic equation (PE) modelling algorithm RAMGeo (Collins, 1993) is used to calculate the transmission loss between the source and the receiver. RAMGeo is an efficient and reliable PE algorithm for solving range-dependent acoustic problems with fluid seabed 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 sourced via empirical reference data out of the historical measurements carried out on relevant noise sources in similar construction setting (as detailed in **Section 3.1**);

- Transmission loss is calculated using RAMGeo at one-third octave band central frequencies from 10 Hz to 2 kHz, based on appropriate source depths corresponding to relevant source scenarios. The acoustic energy of higher frequency range is significantly lower, and therefore is not included in the modelling calculation;
- Propagation paths for the TL calculation have a maximum range of up to 5.0 km and bearing angles with a 2-degree azimuth increment from 0 degrees to 358 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.

For cumulative SEL estimates, the following cumulative factor (*CF*) is applied:

$$CF = 10 \times \log10 \left(N \text{ (or } T)\right) \tag{3.2}$$

Where *N* is the number of pulses for piling noise source and *T* is the exposure duration for a continuous (non-impulsive) noise source.

For non-impulsive noise, it is assumed the root-mean-square sound pressure levels (RMS SPLs) are equivalent to be the sound exposure levels (SELs) of 1-second duration.

The weighted SEL modelling results for different marine mammal hearing groups are based on weighted SEL source level inputs which are derived by applying relevant auditory hearing functions as in **Figure 8** of **Section 2.3.1** to the unweighted SEL source levels.

Note that the range of frequencies modelled is limited to the third octaves with centre frequencies 10 Hz to 2.5 kHz for ships and up to 8 kHz for piling. These frequency ranges are considered appropriate for the source content (considerate of likely spectral weightings), given available source data and the purposes of this study.

3.3 Source levels

3.3.1 Piling noise levels

The source spectral curve (one-third octave spectra) for the proposed piling activities is based on reference piling signals of an overall SEL source level 199 dB re 1 $\mu Pa^2 \cdot S$ from a 49 kNm impact hammer (Salgado Kent et al, 2009) which were averaged to account for hammer energy variability. To scale the piling noise emissions with the smaller 49 kNm hammer to the noise emissions with a 150 kNm impact hammer, it is assumed that the piling noise emissions from a piling strike is proportional to the energy delivered to the pile, according to the following relationship:

$$dB_o = 10 * \log10 \left(E/E_r\right) \tag{3.3}$$

where dB_o is the offset from the assessed pile to the reference pile in dB, E is the energy delivered to the assessed pile and E_r is the energy delivered to the reference pile (kNm). Using this equation (4.1) the piling noise emissions under the impact hammer energy of 150 kNm would have 4.9 dB increase over the reference piling noise emissions under the impact hammer energy of 49 kNm.

The overall SEL source level is estimated as 204 dB re 1 $\mu Pa^2 \cdot S$, with a conversion factor of 24 dB between the source Pk SPL and SEL levels, based on the previous assessment prediction results for the piling noise created by a hammer of the same diameter for port facility constructions (Hastings and Popper, 2005). A conversion factor of 14 dB applied between the source RMS SPL and SEL levels is derived from historical measurements described in the literature (Salgado Kent et al, 2009). For receiving distances further away from the source location (1 – 10 km) where significant pulse signal dispersion is expected, a conservative conversion factor between 15 – 10 dB with a logarithmic decline trend is applied to the predicted SEL values to derive the parameter RMS SPL.

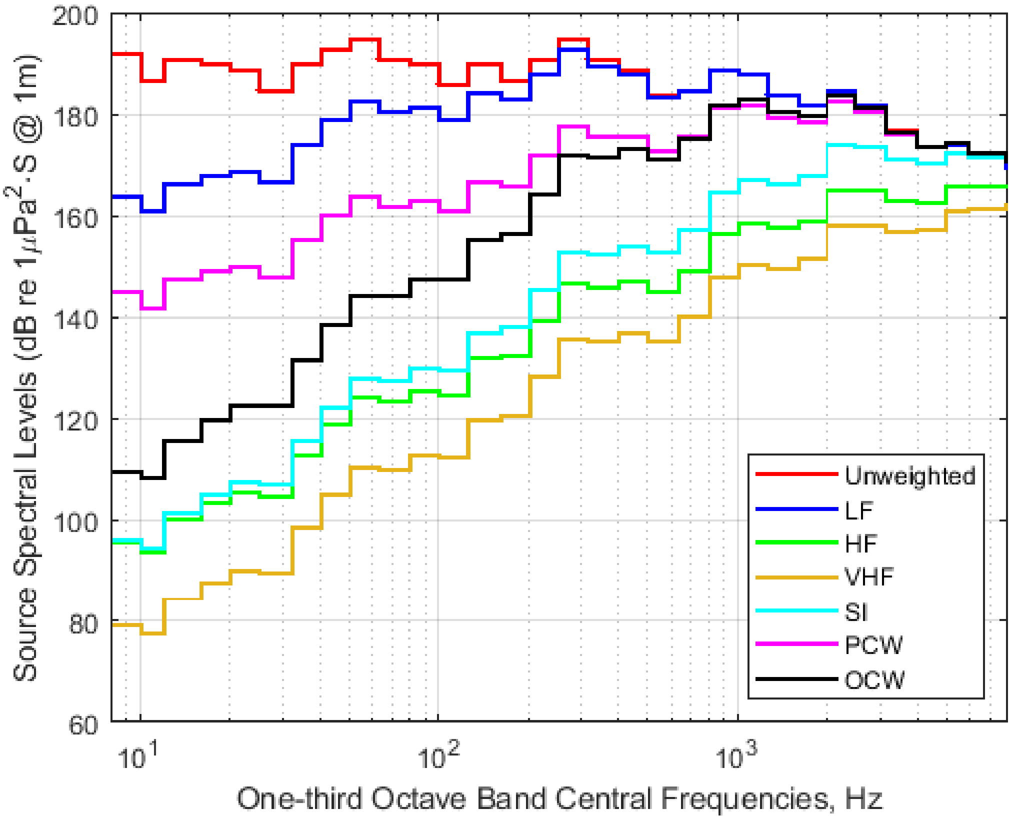

Figure 11 One-third octave SEL source spectral levels (unweighted and M-weighted) for the impact piling noise (overall unweighted level of 204 dB re 1 µPa^2·S).

3.3.2 Shipping noise levels

The source spectral curve (one-third octave spectra) for the modelled shipping noise were conservatively derived from power spectral density percentile levels in Australian waters for cargo ships (Erbe et al, 2021) as follows:

- the 90th percentile spectra levels (the levels that exceed 90% of the data) were chosen for the ocean-going vessel source levels, with an overall SEL source level of 203 dB re 1 µPa^2·S; and
- the 50th percentile spectra levels were chosen for the transfer ship levels, with an overall SEL source level of 196 dB re 1 µPa^2·S.

The spectral levels for both vessel types can be seen in **Figure 12**.

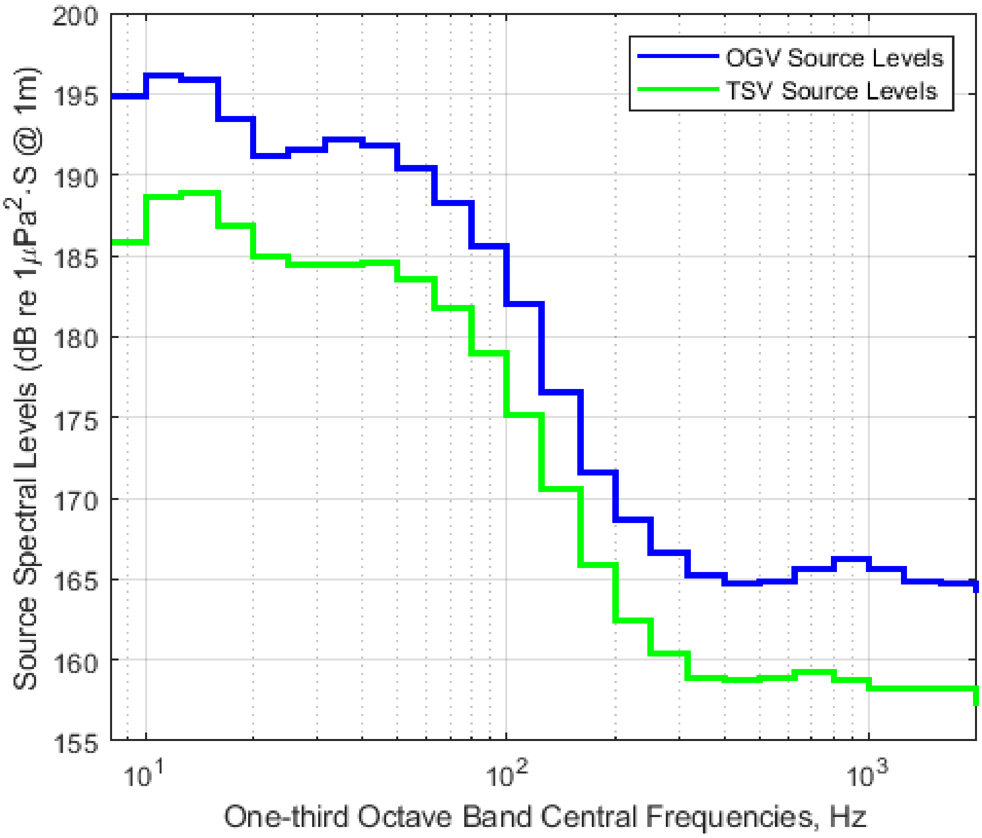

Figure 12 One-third octave SEL source spectral levels (unweighted) for modelled shipping noise (transfer ship and ocean-going vessel)

3.4 Environmental factors

3.4.1 Bathymetry

The bathymetry data used for the sound propagation modelling was based on the AUS118 Approaches to King George Sound Nautical Map. The bathymetry of Princess Royal Harbour and King George Sound is shown in **Figure 13**.

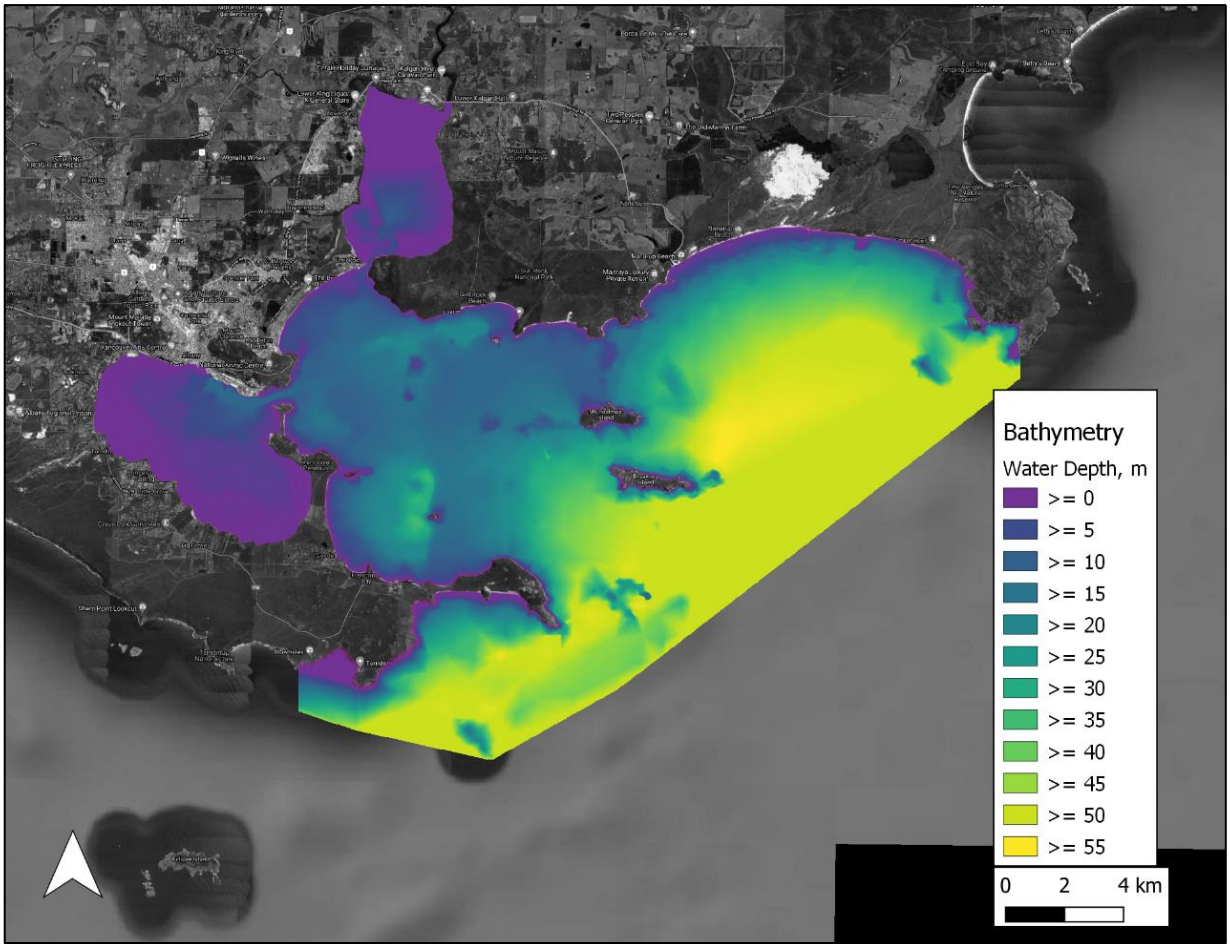

Figure 13 The modelled bathymetry extent of Princess Royal Harbour and King George Sound

3.4.2 Sound Speed Profiles

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

Figure 14 presents the typical sound speed profiles for the four seasons around King George Sound. The summer season has the strongest downwardly refracting feature among the four seasons, and the winter season exhibits a deeper surface duct than the other three seasons. Due to the stronger surface duct within the profile, it is expected that the winter season will favour the propagation of sound from a near surface acoustic source. Therefore, based on a conservative consideration, the winter season sound speed profile is selected as the modelling input.

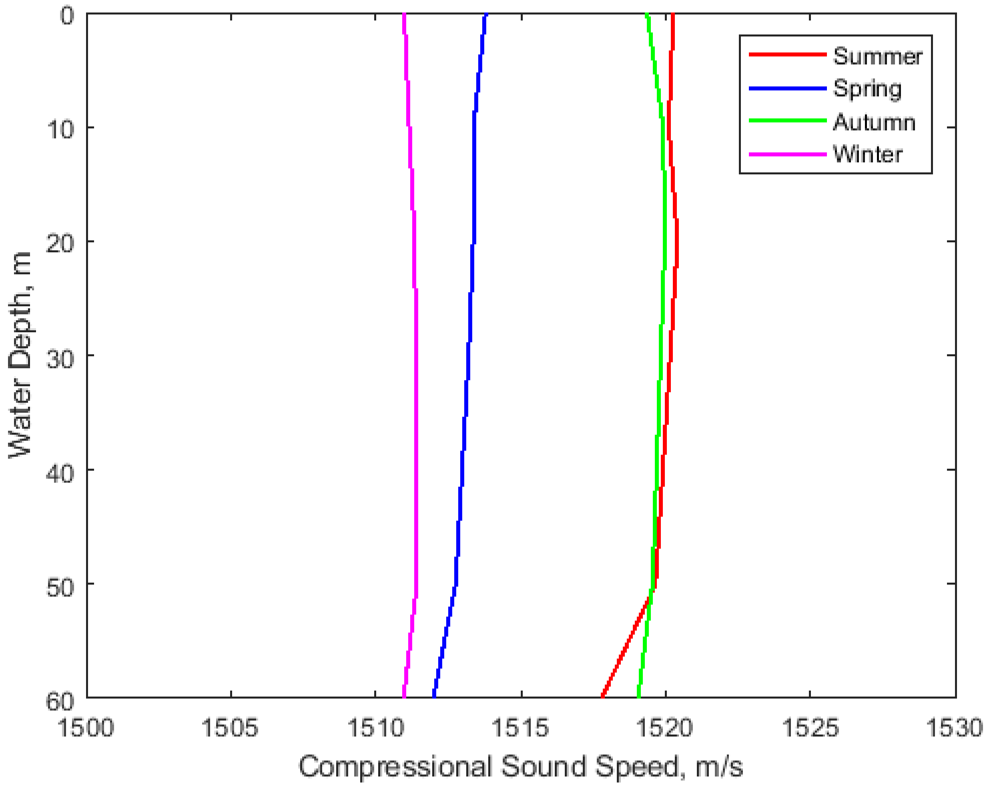

Figure 14 Sound speed profiles within the King George Sound area for different southern hemisphere seasons.

3.4.3 Seafloor Geoacoustic Model

Relevant studies on seafloor material of the study area have been completed as part of the Albany Port Authority' Albany Iron Ore Project Public Environmental Review (Mattinson, 2007) and the report entitled Geomorphology and Sedimentology of the South Western Planning Area of Australia from Geoscience Australia (Richardson et al., 2005).

Both sources suggest that the area on the Recherché Shelf is covered mainly by sand. From the above relevant studies,it is proposed that the general seafloor geoacoustic model for the modelling area comprises of a 50-m sandy surface sediment layer, followed by a semi-cemented sand/calcarenite half space as detailed in **Table 9**. The geoacoustic properties for relevant sediments are as described in Hamilton (1980) and Jensen et al (2011).

Table 9 Geoacoustic parameters for the proposed seafloor model

Seafloor Materials	Thickness, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, C_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Fine sand	50	1,900	1650	0.8
Sand half-space	∞	2,000	1800	0.6

It is noted that the modelling algorithm (i.e. RAMGeo) proposed for this modelling study, as detailed in **Section 3.2**, is based on a fluid geo-acoustic model (all layers are modelled as fluid). Therefore, the geo-acoustic model inputs only consider the compressional wave parameters for the substrate layer materials as listed in **Table 9**, with the shear wave parameter values set as zeros.

4 Results and discussion

The following sub-sections detail the zones of impact estimated for all generic marine mammals, fish and sea turtle species, and human divers and swimmers for construction and operational phases respectively.

4.1 Construction piling

Predicted noise contour figure for the piling noise modelling scenario is presented in **Appendix B**. The contour figures are the modelling results based on unweighted SEL source level inputs in dB re 1µPa^2·S as given in **Section 3.1**.

The predicted noise levels of considered piling modelling scenarios were compared with relevant threshold criteria as listed in **Section 2**.

4.1.1 In terms of short term exposure

Table 10 presents forecast zones of PTS and TTS impact based on estimated Pk-SPL metric criteria for marine mammals. This table indicates that

- marine mammals of all hearing groups (except VHF cetaceans) are predicted to experience PTS effect if within 10 metres plan distance from the piling locations; and
- VHF cetaceans are predicted to experience PTS effects if within 35 m from piling locations.

The zones of TTS effect due to a single pulse exposure for marine mammals of all hearing groups except VHF cetaceans are predicted to be within 10 m from the piling locations. The maximum zones of TTS effect for VHF cetaceans are predicted to within 85 m from the piling locations.

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

Marine mammal hearing group	**Zones of impact – maximum plan distances from source to impact threshold levels**			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	219	< 10	213	< 10
High-frequency cetaceans (HF)	230	-	224	< 10
Very high-frequency cetaceans (VHF)	202	35	196	85
Sirenians (SI)	226	< 10	220	< 10
Phocid carnivores in water (PCW)	218	< 10	212	< 10
Other marine carnivores in water (OCW)	232	-	226	< 10

Table 11 presents zones of immediate impact from single impact piling. This table indicates that criteria for avoiding potential injuries for fish species with swim bladders, turtles and fish eggs and fish larvae are predicted within 20 m from the piling locations. Fish species without swim bladders have slightly higher injury impact thresholds, and therefore have a relatively smaller zone of potential injuries (within 10 m from the piling locations).

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

Type of animal	Zones of impact – maximum plan distances from source to impact threshold levels			
	Mortality and potential mortal injury		Recovery injury	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	213	< 10	213	< 10
Fish: swim bladder is not involved in hearing (particle motion detection)	207	20	207	20
Fish: swim bladder involved in hearing (primarily pressure detection)	207	20	207	20
Sea turtles	207	20	-	-
Fish eggs and fish larvae	207	20	-	-

Note: a dash indicates the threshold is not applicable.

Table 12 presents distances at which there would likely be behavioural changes in marine mammals during piling. From this table it can be seen that marine mammals of all hearing groups are likely to be exposed to noise above this design threshold within 650 m of the piling locations.

This table also indicates that at distances of up to 2.5 km, piling noise levels are considered to be above the threshold used to indicate potential adverse effects on human divers and swimmers (**Table 7** in **Section 2.5**).

Table 12 Zones of immediate impact from single impact piling pulses – marine mammals and human divers/swimmers

Receiver	Zones of impact – maximum plan distances from source to impact threshold levels	
	Behavioural disturbance	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals – all hearing groups	160	650
Human divers and swimmers	145	2,500

4.1.2 In terms of cumulative / long term exposure

Impact zones from impact piling as shown in **Table 13** and **Table 14** regarding cumulative impact from multiple piling pulses exposure (i.e. under selected 100, 1000, 1500, 3000 pulses exposure) over a 24-hour period.

Among marine mammals of all six hearing groups, LF and VHF cetaceans have the highest zones of potential PTS and TTS impact, as can be seen in **Table 13**. The zones of PTS impact are predicted to be within 340 m from piling locations with 100 piling pulses exposure per day and within 1.5 km from piling locations with 1,000 piling pulses exposure per day. Compared with LF and VHF cetaceans, the remaining hearing group cetaceans have much lower impact zones.

For cetaceans of all hearing groups, the zones of TTS impact are significantly higher than the corresponding PTS impact due to the much lower TTS threshold level (by at least 15 dB).

Table 13 Zones of cumulative impact from multiple impact piling pulses for PTS and TTS – marine mammals – 100, 1000, 1500, 3000 pulses per day exposure

Marine mammal hearing group	Zones of impact – maximum plan distances from source to 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	100 pulses: 320 1,000 pulses: 1,400 1,500 pulses: > 1,600 3,000 pulses: > 1,800	168	100 pulses: 1,800 1,000 pulses: > 4,000 1,500 pulses: > 4,000 3,000 pulses: > 4,000
High-frequency cetaceans (HF)	185	100 pulses: < 10 1,000 pulses: 20 1,500 pulses: 25 3,000 pulses: 40	170	100 pulses: 40 1,000 pulses: 340 1,500 pulses: 480 3,000 pulses: 900
Very high-frequency cetaceans (VHF)	155	100 pulses: 340 1,000 pulses: 1,500 1,500 pulses: 1,900 3,000 pulses: 2,300	140	100 pulses: 2,300 1,000 pulses: > 4,000 1,500 pulses: > 4,000 3,000 pulses: > 4,000
Sirenians (SI)	203	100 pulses: < 10 1,000 pulses: < 10 1,500 pulses: < 10 3,000 pulses: < 10	175	100 pulses: 60 1,000 pulses: 470 1,500 pulses: 630 3,000 pulses: 1,300
Phocid carnivores in water (PCW)	185	100 pulses: 50 1,000 pulses: 340 1,500 pulses: 500 3,000 pulses: 940	170	100 pulses: 940 1,000 pulses: 2,200 1,500 pulses: 2,500 3,000 pulses: 4,000
Other marine carnivores in water (OCW)	203	100 pulses: < 10 1,000 pulses: 15 1,500 pulses: 20 3,000 pulses: 40	188	100 pulses: 40 1,000 pulses: 250 1,500 pulses: 290 3,000 pulses: 620

As presented in **Table 14**, within an example of 1,000 piling pulses exposure, the zones of potential mortal injury for fish species with swim bladder are predicted to be within 10 m from the piling locations, and within 60 m for fish without swim bladder, sea turtles and fish eggs and fish larvae.

For recoverable injury, the zones of impact are predicted to be within 15 m from the piling locations for fish without swim bladder, and within 100 m for fish with swim bladders. The zones of TTS effects for fish species with and without swim bladders are predicted to be within 1.05 km from the piling locations for the exposure scenario considered.

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

Type of animal	Zones of impact – maximum plan perpendicular distances from source to cumulative impact threshold levels					
	Mortality and potential mortal injury		Recoverable injury		TTS	
	Criteria - SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 $\mu Pa^2 \cdot s$	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	219	100 pulses: < 10 1,000 pulses: < 10 1,500 pulses: 10 3,000 pulses: 20	216	100 pulses: < 10 1,000 pulses: 15 1,500 pulses: 20 3,000 pulses: 30	186	100 pulses: 350 1,000 pulses: 1,050 1,500 pulses: 1,100 3,000 pulses: 1,700
Fish: swim bladder is not involved in hearing (particle motion detection)	210	100 pulses: <10 1,000 pulses: 40 1,500 pulses: 50 3,000 pulses: 70	203	100 pulses: 20 1,000 pulses: 100 1,500 pulses: 160 3,000 pulses: 260	186	
Fish: swim bladder involved in hearing (primarily pressure detection)	207	100 pulses: 10 1,000 pulses: 60 1,500 pulses: 70 3,000 pulses: 140	203		186	
Sea turtles	210	100 pulses: <10 1,000 pulses: 40 1,500 pulses: 50 3,000 pulses: 70	-	-	-	-
Fish eggs and fish larvae	210		-		-	

Note: a dash indicates the threshold is not applicable.

4.2 Transhipping operations

Predicted noise contour figures for the shipping noise scenarios are in **Appendix C**.

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 section.

4.2.1 Marine mammals

Impact zones from the shipping operation scenarios are shown in **Table 15** and **Table 16** regarding cumulative impact for marine mammals under two continuous exposure scenarios (i.e. 24-hour exposure and 0.5-hour exposure) respectively.

Table 15 and **Table 16** below present the zones of cumulative impact based on cumulative SELs from the shipping operation scenario with the highest non-impulsive noise emissions for marine mammals.

For the worst-case consideration (i.e. the shipping operations are continuous and affected marine animals stay at the fixed location over the entire 24-hour period), LF cetaceans and phocid carnivores in water (PCW) have the highest PTS-onset and TTS-onset impact zones among all marine mammal hearing groups. From **Table 15**, the PTS-onset zones for LF cetaceans and phocid carnivores in water (PCW) is up to 600 m and 150 m respectively. The TTS-onset zones for LF cetaceans and phocid carnivores in water (PCW) is up to 2.8 km and 1.2 km from the shipping 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 150 m from the noise source for LF cetaceans, and TTS-onset zone within up to 1,400 m for LF 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.

Table 15 Zones of cumulative impact from non-impulsive noise for PTS and TTS – marine mammals - 24 hours exposure duration

Marine mammal hearing group	**Zones of impact – maximum plan perpendicular 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
Low-frequency cetaceans (LF)	199	600	179	2,800
High-frequency cetaceans (HF)	198	50	178	150
Very high-frequency cetaceans (VHF)	173	140	153	800
Sirenians (SI)	206	45	186	150
Phocid carnivores in water (PCW)	201	150	181	1,200
Other marine carnivores in water (OCW)	219	50	199	120

Note: a dash indicates the threshold is not reached.

Table 16 Zones of cumulative impact from non-impulsive noise for PTS and TTS – marine mammals – 0.5 hours exposure duration

Marine mammal hearing group	Zones of impact – maximum **plan perpendicular 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
Low-frequency cetaceans (LF)	199	150	179	1,400
High-frequency cetaceans (HF)	198	-	178	60
Very high-frequency cetaceans (VHF)	173	50	153	120
Sirenians (SI)	206	-	186	50
Phocid carnivores in water (PCW)	201	60	181	130
Other marine carnivores in water (OCW)	219	-	199	50

Note: a dash indicates the threshold is not reached.

As presented in **Table 17**, potential behavioural disturbance from the non-impulsive noise emissions from shipping operations is predicted to occur for marine mammals of all hearing groups up to 600 m from the assessed shipping routes and up to 100 m for human divers or swimmers.

Table 17 Zones of immediate impact from non-impulsive noise for behavioural disturbance – marine mammals and human divers/swimmers

Type	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	120	600
Human divers/swimmers	145	100

4.2.2 Fish and sea turtle species

Table 18 presents relevant zones of cumulative impact from shipping and continuous sounds for mortality and recovery injury. From this table it can be seen that the non-impulsive, cumulative noise from shipping operations is considered to have low physiological impacts (both mortality and recovery injury) on fish beyond 10 metres distance.

Table 18 Zones of cumulative impact from shipping and continuous sounds for mortality and recovery injury– fish, turtles, fish eggs and fish larvae

Type	Zones of impact – maximum plan perpendicular distances from source to cumulative impact threshold levels					
	Mortality and potential mortal injury		Recoverable injury		TTS	
	Criteria - SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m	Criteria - SEL_{24hr} dB re 1 µPa^2·s	Maximum threshold distance, m
Fish: no swim bladder (particle motion detection)	-	-	-	-	-	-
Fish: swim bladder is not involved in hearing (particle motion detection)	-	-	-	-	-	-
Fish: swim bladder involved in hearing (primarily pressure detection)	-	-	170 dB rms for 48h	< 10	158 dB rms for 12h	40
Sea turtles	-	-	-	-	-	-
Fish eggs and fish larvae	-	-	-	-	-	-

Note: a dash indicates the threshold is not applicable.

5 Summary and discussion

SLR has been appointed to undertake aquatic noise modelling and assessment of relevant potential impacts on marine fauna species and human divers/swimmers as a result of the marine construction of facilities at Berth 5 (piling) and transhipping operations between Berth 5 Albany Port and anchorages in King George Sound, associated with the Southdown Magnetite Project.

Detailed modelling predictions have been undertaken for noise emissions from the impact piling operations, the most dominant noise-generating activities during transhipping operations. Various zones of impact have been estimated for marine fauna species and human divers/swimmers based on comparisons between predicted noise levels and impact assessment criteria with results.

Based on the results, it is recommended that aquatic noise management measures be prepared for construction, including project specific management and monitoring procedures, in order to minimise the piling noise impact on assessed aquatic sensitive receptors. These measures are outlined in **Section 6** and will be further addressed in document(s) to be submitted under the EP Act and EPBC Act for potential assessment and approval of waterside transhipping operations.

6 Aquatic Noise Management

6.1 Impact piling operation as the major noise source emissions

Marine mammals, particularly whales, the Indo-Pacific bottlenose dolphins, and human divers and swimmers are the major sensitive receptors to consider for this management plan.

Impact piling during construction has the highest noise emissions with impulsive characteristics, and therefore is predicted to have the highest potential for adverse impact on assessed marine fauna species and human divers and swimmers, in terms of both immediate impact and cumulative impact. As such, it should be the major focus for this aquatic noise management plan.

Other noise-generating construction activities, such as sediment excavation and supporting vessels, have much lower noise emissions and their characteristics are continuous in nature. Moreover, the noise emissions from supporting vessel activities under the full-load operation conditions generally occur under their full travel speeds which are not expected to take place during construction.

The emission levels from vessel operations are expected to be comparable to noise emissions from the existing vessel traffic along the project area. As such, the extent of potential impact from vessel operations are not significant compared with the impact piling operations.

6.2 Piling noise management framework

The Government of South Australia's *Underwater Piling Noise Guidelines* (2012) sets out guidance on procedures for piling noise mitigation as illustrated in **Figure 15** below.

The guideline includes a framework for management and mitigation of underwater noise from piling, incorporating:

- **Safety zones** – these are observation and shut-down zones sized based on the likely noise levels produced by the piling activity.
- **Standard management and mitigation procedures** – these procedures are recommended for all piling activities, irrespective of location and time of year, when marine mammal species or human divers/swimmers may potentially be present within the noise footprint of the piling activity.
- **Additional management and mitigation procedures** – to be used when the impacts of the piling activity on concerned marine mammal species or human divers/swimmers are likely to be significant and standard management and mitigation procedures are not sufficient to minimise the impact.

This management plan follows the management framework as outlined above, with project specific requirements for each framework element being detailed in the following subsections.

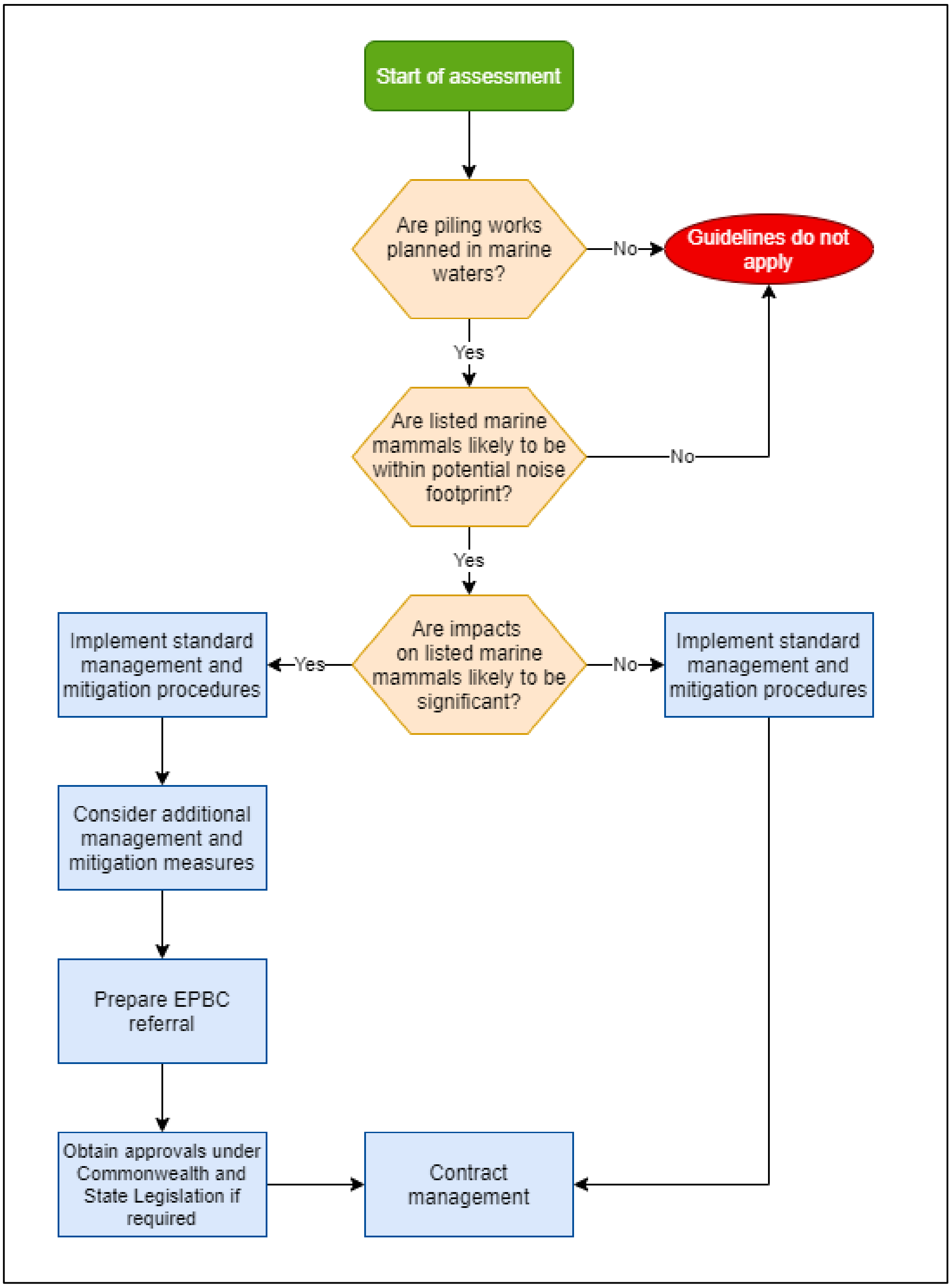

Figure 15 Piling noise management and mitigation framework (Government of South Australia, 2012)

6.2.1 Safety Zones

Two safety zones would be applied around each piling location:

- **An observation zone**, within which the movement of marine mammals or human divers/swimmers would be monitored to identify any approach to the shut-down zone.
- **A shut-down zone**, within which the sighting of a marine mammal or human divers/swimmers would trigger piling activities to be ceased as soon as reasonably practical.

Suggested observation zones and shut-down zones are outlined in **Table 19** below. It should be particularly noted that the shut-down zones for marine mammals are based on potential cumulative TTS impact, which is dependent on number of piling strikes and animal movements over the assessment period. Based on a precautionary measure, it is recommended to implement a shut-down zone of 1,000 m particularly for southern right whales, which is equivalent to a cumulative TTS impact zone under 100 piling strikes within a 24 hour period.

Table 19 Proposed observation zones and shutdown zones

Sensitive Receptor	Observation Zone **radius, m**	Shutdown Zone **radius, m**	Rationales and Actions
Marine mammals	1,000	650	Shutdown zones depend upon cumulative TTS impact which depends on number of piling strikes within 24 hours period and animal movements. A shutdown for zone for TTS of LF cetaceans Observation zone extends 300 m beyond the shutdown zone
Human divers / swimmers	2,500		Areas within the zones to be cleared for diving and swimming during the piling operation. Based on threshold for adverse reactions from human divers and swimmers

6.2.2 Standard management and mitigation measures

In addition to the proposed safety zones, the following management and mitigation measures are to be implemented:

- Contract documentation – include these requirements for pilingF noise management and mitigation measures in the contract documentation.
- Trained crew – ensure a suitably qualified person is available during piling to conduct the recommended standard operational procedures to manage noise impacts.
- Standard operational procedures – standard operating procedures undertaken by contractors during piling activities include pre-start, soft start, normal operation, stand-by operation, and shut-down procedures, as follows and as shown in **Figure 16**.
    - Pre-start monitoring – the presence of marine mammals or human divers/swimmers will be visually monitored by a suitably trained crew member (i.e. qualified marine mammal observer (MMO)) for at least 30 minutes before piling commences using a soft start procedure.
    - Soft start – if marine mammals or human divers/swimmers have not been observed inside the shut-down zone during the pre-start observations, soft start (6 strikes/min at low impact energy) may commence with piling impact energy gradually increased over a 10-minute time period. A soft start will also be used after long breaks of more than 30 minutes in piling activity.
    - Normal piling – if marine mammals or human divers/swimmers have not been observed inside the shut-down or observation zones during the soft start, piling at full impact energy may commence. Visual observations will continue throughout piling activities.
    - Stand-by – if marine mammals or human divers/swimmers are sighted within the observation zone during the soft start or normal operation piling, the operator of the piling rig will be placed on stand-by to shut down the piling rig, while visual monitoring of the animal or divers/swimmers continues.

  - Shut-down – if a marine mammal or human divers/swimmers is sighted within or are about to enter the shut-down zone, piling activity should be stopped immediately. If the animal is observed to move outside the zone again, or 30 minutes have elapsed with no further sightings, piling activities will recommence with the soft start procedure. If a marine mammal or human divers/swimmers is detected in the shut-down zone during a period of poor visibility, operations will stop until visibility improves.
- Compliance and sighting report – maintenance of a record of procedures employed during piling, including information on any marine mammals or human divers/swimmers sighted, and their reaction to the piling activity. A report will include the location, date, start and completion time, information on the piling rig (hammer weight and drop height), pile size, number of piles, number of impacts per pile, details of the trained crew members (i.e. MMOs) conducting the visual observations, times when observations were hampered by poor visibility or high winds, times when start-up delays or shut-down procedures occurred, and the time and distance of any marine mammal or human divers/swimmers sightings.

6.2.3 Additional mitigation measures

The following additional mitigation measures could be considered to further minimise noise impact on marine mammals. However, the practicality of implementing these measures needs to be investigated, and the actual effectiveness to be validated via site acoustic testing.

- Lower piling duration/piling strike number per day. Lower number of piling strikes for impact piling within a 24-hour period results in lower cumulative SELs, and therefore has smaller impact extent.
- Use of piling noise attenuation measures. Various attenuation measures have been developed to attenuate underwater piling noise to minimise exposure of marine mammals during piling activities (Caltrans, 2015; Jimenez-Arranz et al, 2020). These measures include but are not limited to the following:
  - **Isolation casings/pile sleeves**. Isolation casings are hollow casing slightly larger in diameter than the pile to be driven. The casing is inserted into the water column and bottom substrate, and then dewatered so that the work area could be isolated from the surrounding water column in order to attenuate the sound propagation. Dewatered isolation casings generally can be expected to provide attenuation 10 dB or above. However, it could be challenging to integrate the placement and removal of the pile sleeve into the piling driving operation.
  - **Cushion blocks/pile cap**. Cushion blocks consist of blocks of material atop a pile during piling to minimise the noise generated during impact hammering. Materials typically used for cushion blocks include wood, nylon and micarta blocks. The resulted noise reduction could be from close to 10 dB to over 20 dB. The cushion blocks will results in loss of peak force during the piling operation, and this may strongly affect the piling effectiveness (or the piling may even fail) at this location with hard geological conditions.
  - **Air bubble curtains**. Air bubble curtains are designed to infuse the water column surrounding the pile with air bubbles, generating a bubble screen that attenuate the sound propagation from the pile. The previous experiment data indicates that an air bubble curtain will provide up to 10 dB of noise reduction for a mid-sized steel pile. It should be noted however, if there are strong tidal conditions at the project location, the effectiveness of the bubble curtain could be significantly compromised.

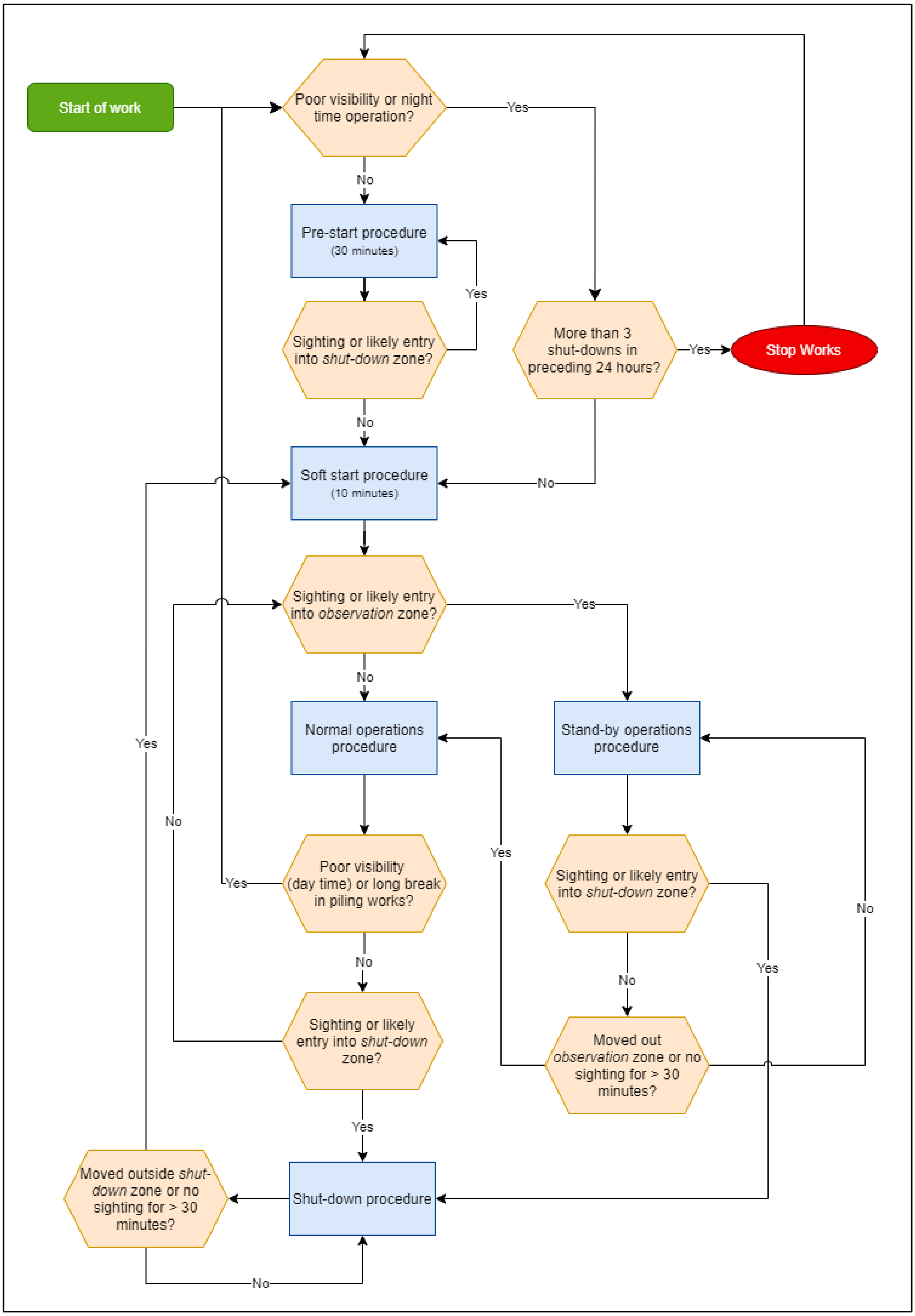

Figure 16 Impact piling noise management procedures (Government of South Australia, 2012)

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APPENDIX A

Key terms

1 Sound Level or Noise Level

The terms ‘sound’ and ‘noise’ are almost interchangeable, except that in common usage ‘noise’ is often used to refer to unwanted sound.

Sound (or noise) consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. The human ear responds to changes in sound pressure over a very wide range. The loudest sound pressure to which the human ear responds is ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms.

The symbols SPL, L or LP are commonly used to represent Sound Pressure Level. The symbol LA represents A-weighted Sound Pressure Level. The standard reference unit for Sound Pressure Levels in air expressed in decibels is 2 x 10^{-5} Pa. The standard reference unit for Sound Pressure Levels in water expressed in decibels is 1 x 10^{-6} Pa

2 ‘A’ Weighted Sound Pressure Level

The overall level of a sound is usually expressed in terms of dBA, which is measured using a sound level meter with an ‘A-weighting’ filter. This is an electronic filter having a frequency response corresponding approximately to that of human hearing.

People’s hearing is most sensitive to sounds at mid frequencies (500 Hz to 4,000 Hz), and less sensitive at lower and higher frequencies. Thus, the level of a sound in dBA is a good measure of the loudness of that sound. Different sources having the same dBA level generally sound about equally loud.

A change of 1 dB or 2 dB in the level of a sound is difficult for most people to detect, whilst a 3 dB to 5 dB change corresponds to a small but noticeable change in loudness. A 10 dB change corresponds to an approximate doubling or halving in loudness. The table below lists examples of typical noise levels.

Sound Pressure Level (dBA)	Typical Source	Subjective Evaluation
130	Threshold of pain	Intolerable
120	Heavy rock concert	Extremely noisy
110	Grinding on steel	
100	Loud car horn at 3 m	Very noisy
90	Construction site with pneumatic hammering	
80	Kerbside of busy street	Loud
70	Loud radio or television	
60	Department store	Moderate to quiet
50	General Office	
40	Inside private office	Quiet to very quiet
30	Inside bedroom	
20	Recording studio	Almost silent

Other weightings (e.g. B, C and D) are less commonly used than A-weighting. Sound Levels measured without any weighting are referred to as ‘linear’, and the units are expressed as dB(lin) or dB.

3 Sound Power Level

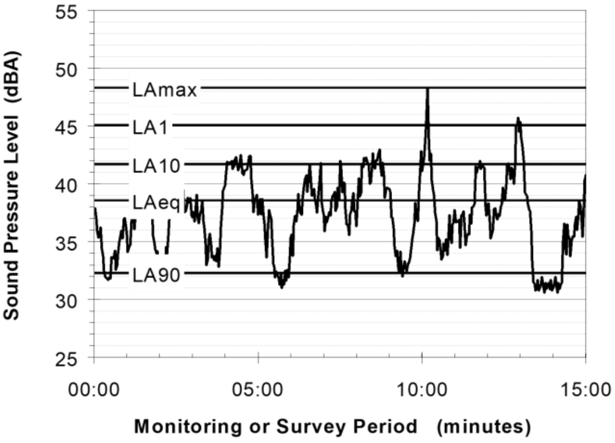
The Sound Power of a source is the rate at which it emits acoustic energy. As with Sound Pressure Levels, Sound Power Levels are expressed in decibel units (dB or dBA), but may be identified by the symbols SWL or Lw, or by the reference unit 10^{-12} W.

The relationship between Sound Power and Sound Pressure may be likened to an electric radiator, which is characterised by a power rating, but has an effect on the surrounding environment that can be measured in terms of a different parameter, temperature.

4 Statistical Noise Levels

Sounds that vary in level over time, such as road traffic noise and most community noise, are commonly described in terms of the statistical exceedance levels LAN, where LAN is the A-weighted sound pressure level exceeded for N% of a given measurement period. For example, the LA1 is the noise level exceeded for 1% of the time, LA10 the noise exceeded for 10% of the time, and so on.

The following figure presents a hypothetical 15 minute noise survey, illustrating various common statistical indices of interest.



Of particular relevance, are:

LA1	The noise level exceeded for 1% of the 15 minute interval.
LA10	The noise level exceeded for 10% of the 15 minute interval. This is commonly referred to as the average maximum noise level.
LA90	The noise level exceeded for 90% of the sample period. This noise level is described as the average minimum background sound level (in the absence of the source under consideration), or simply the background level.
LAeq	The A-weighted equivalent noise level (basically, the average noise level). It is defined as the steady sound level that contains the same amount of acoustical energy as the corresponding time-varying sound.

When dealing with numerous days of statistical noise data, it is sometimes necessary to define the typical noise levels at a given monitoring location for a particular time of day. A standardised method is available for determining these representative levels.

This method produces a level representing the ‘repeatable minimum’ LA90 noise level over the daytime and night-time measurement periods, as required by the EPA. In addition, the method produces mean or ‘average’ levels representative of the other descriptors (LAeq, LA10, etc.).

5 Tonality

Tonal noise contains one or more prominent tones (i.e. distinct frequency components), and is normally regarded as more offensive than ‘broad band’ noise.

6 Impulsiveness

An impulsive noise is characterised by one or more short sharp peaks in the time domain, such as occurs during hammering.

7 Frequency Analysis

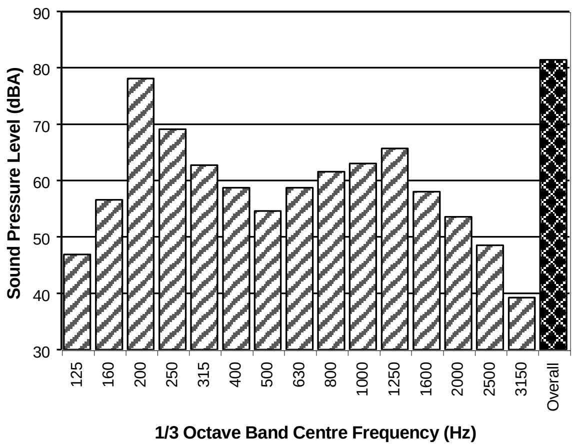
Frequency analysis is the process used to examine the tones (or frequency components) which make up the overall noise or vibration signal. This analysis was traditionally carried out using analogue electronic filters, but is now normally carried out using Fast Fourier Transform (FFT) analysers.

The units for frequency are Hertz (Hz), which represent the number of cycles per second.

Frequency analysis can be in:

- Octave bands (where the centre frequency and width of each band is double the previous band)
- 1/3 octave bands (3 bands in each octave band)
- Narrow band (where the spectrum is divided into 400 or more bands of equal width)

The following figure shows a 1/3 octave band frequency analysis where the noise is dominated by the 200 Hz band. Note that the indicated level of each individual band is less than the overall level, which is the logarithmic sum of the bands.



8 Vibration

Vibration may be defined as cyclic or transient motion. This motion can be measured in terms of its displacement, velocity or acceleration. Most assessments of human response to vibration or the risk of damage to buildings use measurements of vibration velocity. These may be expressed in terms of 'peak' velocity or 'rms' velocity.

The former is the maximum instantaneous velocity, without any averaging, and is sometimes referred to as 'peak particle velocity', or PPV. The latter incorporates 'root mean squared' averaging over some defined time period.

Vibration measurements may be carried out in a single axis or alternatively as triaxial measurements. Where triaxial measurements are used, the axes are commonly designated vertical, longitudinal (aligned toward the source) and transverse.

The common units for velocity are millimetres per second (mm/s). As with noise, decibel units can also be used, in which case the reference level should always be stated. A vibration level V, expressed in mm/s can be converted to decibels by the formula 20 log (V/V₀), where V₀ is the reference level (10^{-9} m/s). Care is required in this regard, as other reference levels may be used by some organisations.

9 Human Perception of Vibration

People are able to 'feel' vibration at levels lower than those required to cause even superficial damage to the most susceptible classes of building (even though they may not be disturbed by the motion). An individual's perception of motion or response to vibration depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as 'normal' in a car, bus or train is considerably higher than what is perceived as 'normal' in a shop, office or dwelling.

10 Over-Pressure

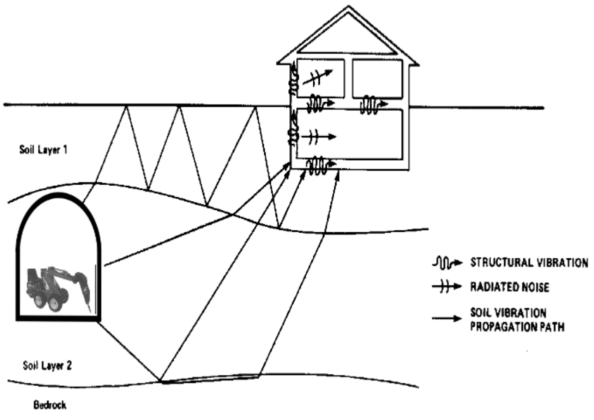
The term 'over-pressure' is used to describe the air pressure pulse emitted during blasting or similar events. The peak level of an event is normally measured using a microphone in the same manner as linear noise (i.e. unweighted), at frequencies both in and below the audible range.

11 Ground-borne Noise, Structure-borne Noise and Regenerated Noise

Noise that propagates through a structure as vibration and is radiated by vibrating wall and floor surfaces is termed 'structure-borne noise', 'ground-borne noise' or 'regenerated noise'. This noise originates as vibration and propagates between the source and receiver through the ground and/or building structural elements, rather than through the air.

Typical sources of ground-borne or structure-borne noise include tunnelling works, underground railways, excavation plant (e.g. rockbreakers), and building services plant (e.g. fans, compressors and generators).

The following figure presents an example of the various paths by which vibration and ground-borne noise may be transmitted between a source and receiver for construction activities occurring within a tunnel.



The term 'regenerated noise' is also used in other instances where energy is converted to noise away from the primary source. One example would be a fan blowing air through a discharge grill. The fan is the energy source and primary noise source. Additional noise may be created by the aerodynamic effect of the discharge grill in the airstream. This secondary noise is referred to as regenerated noise

APPENDIX B

Piling noise result figures

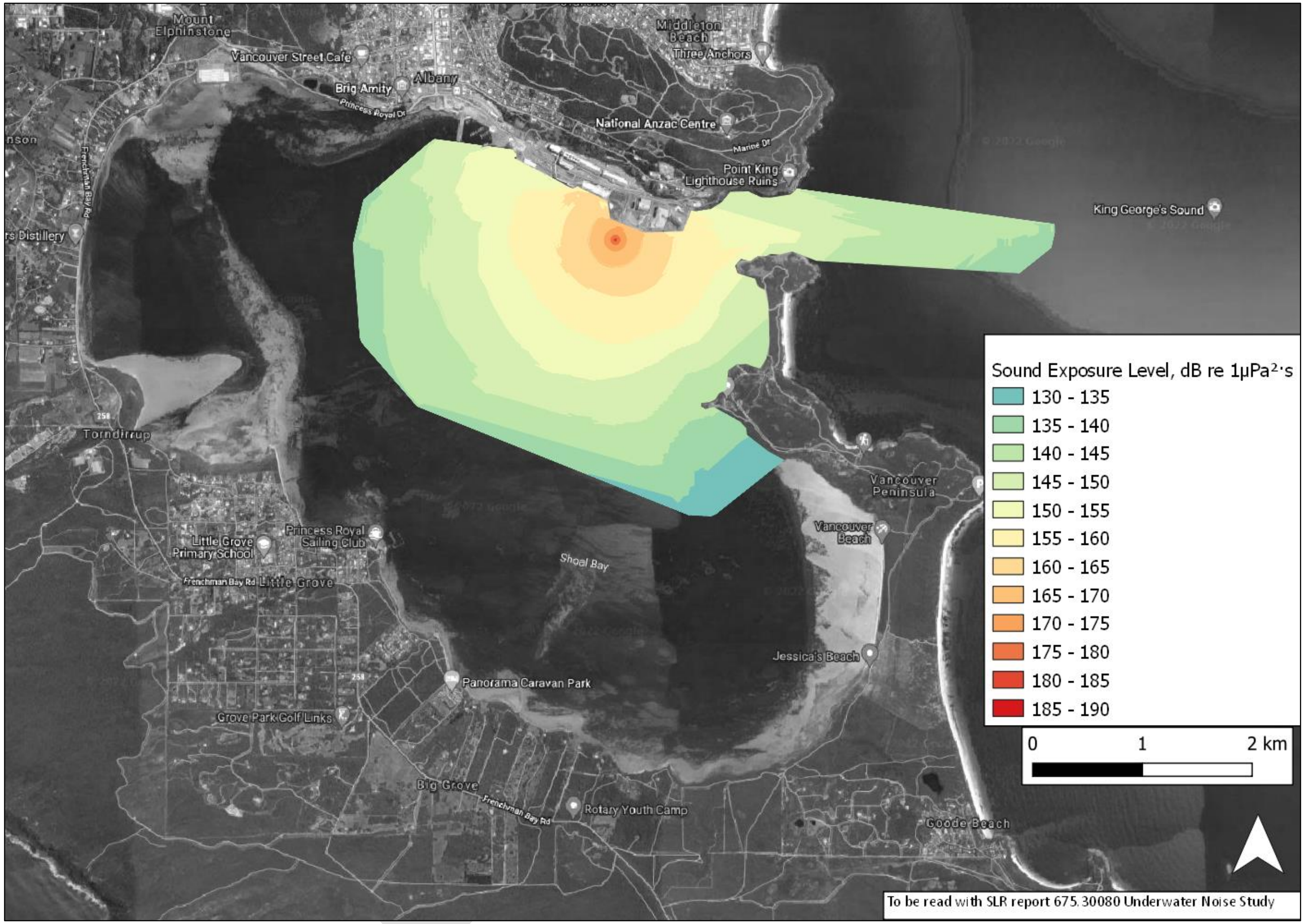


Figure B.1 Modelled noise contour plot for piling noise scenario

APPENDIX C

Shipping noise result figures

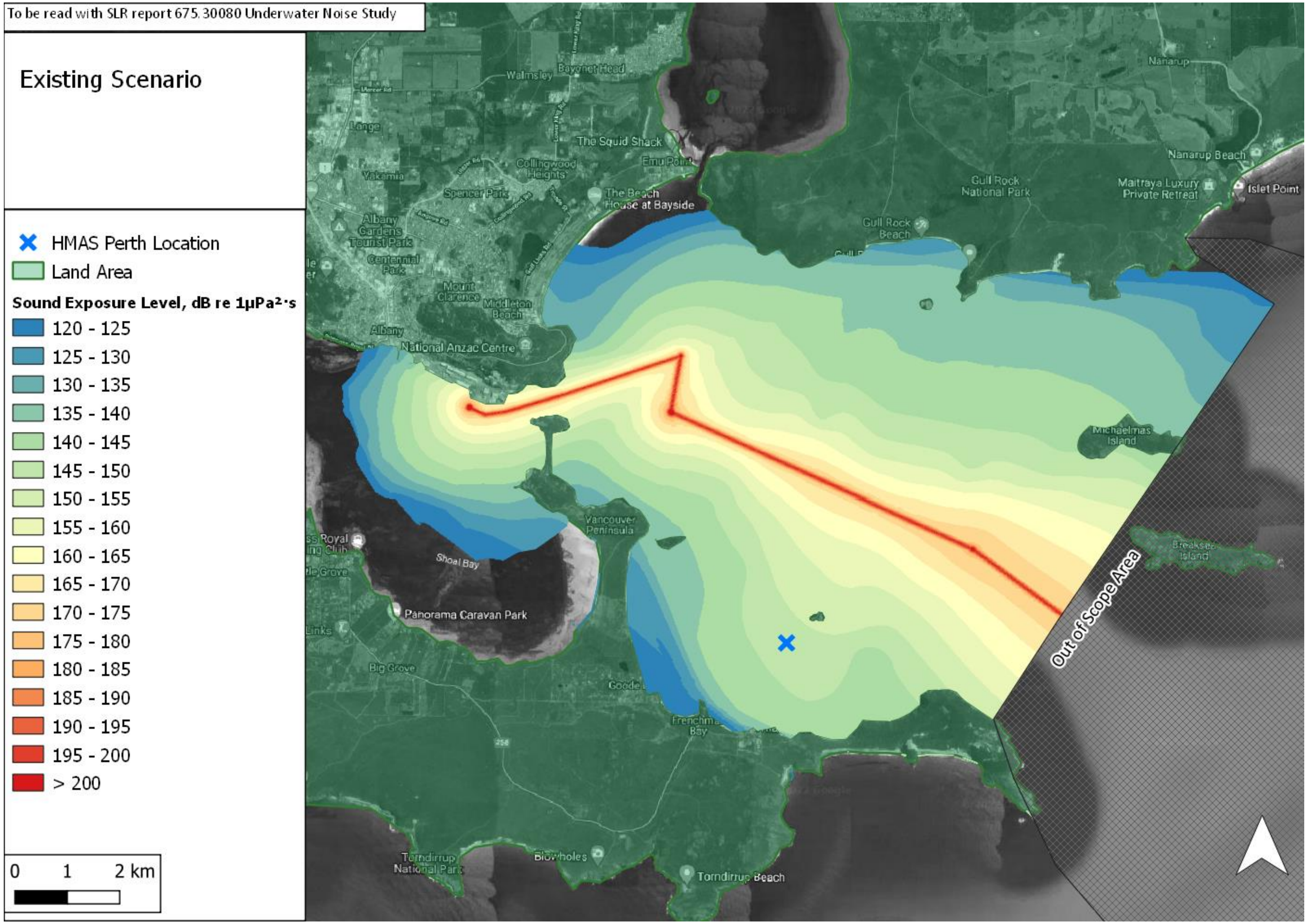


Figure C.1 Modelled noise contour plot for Scenario 1

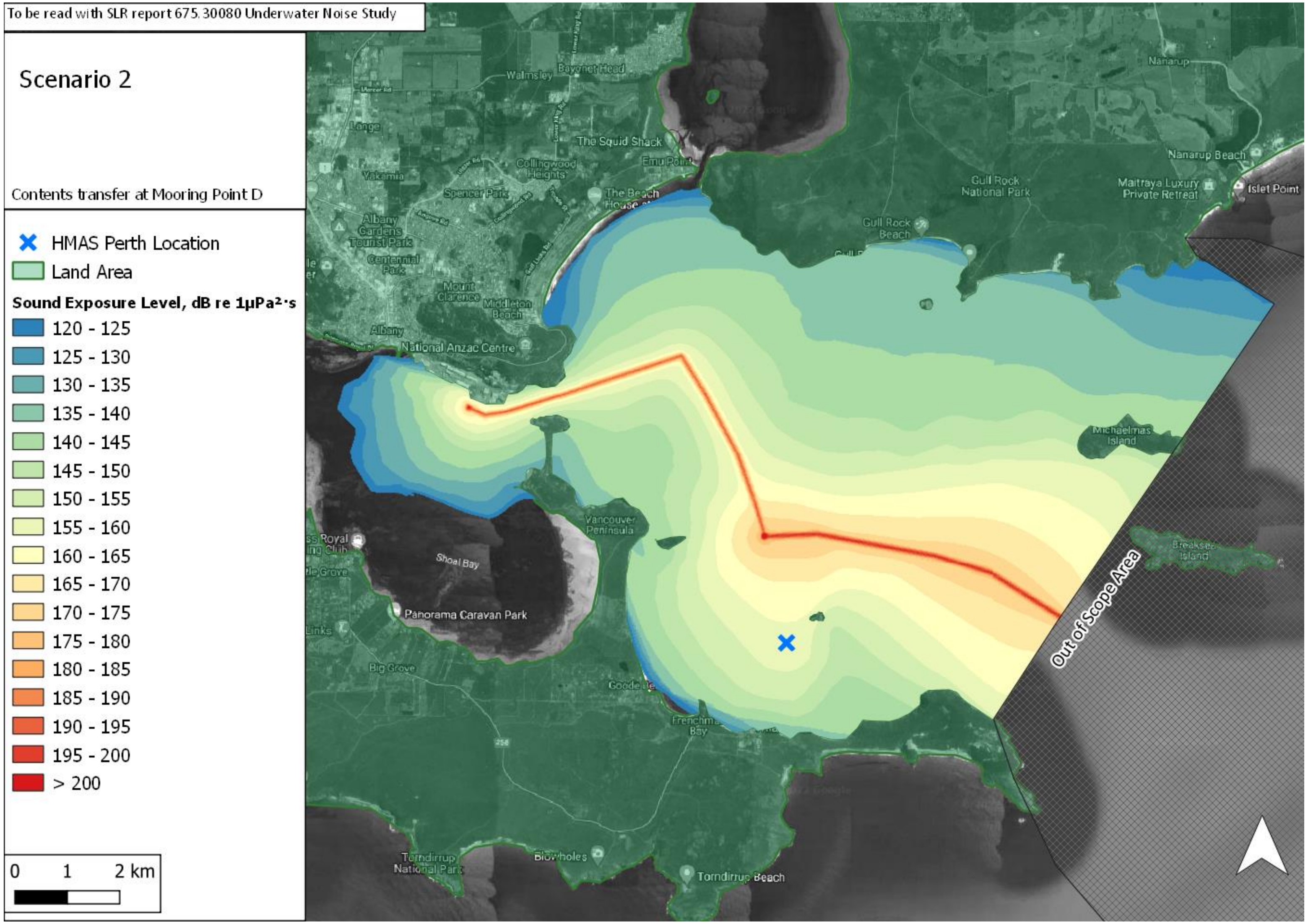


Figure C.2 Modelled noise contour plot for Scenario 2

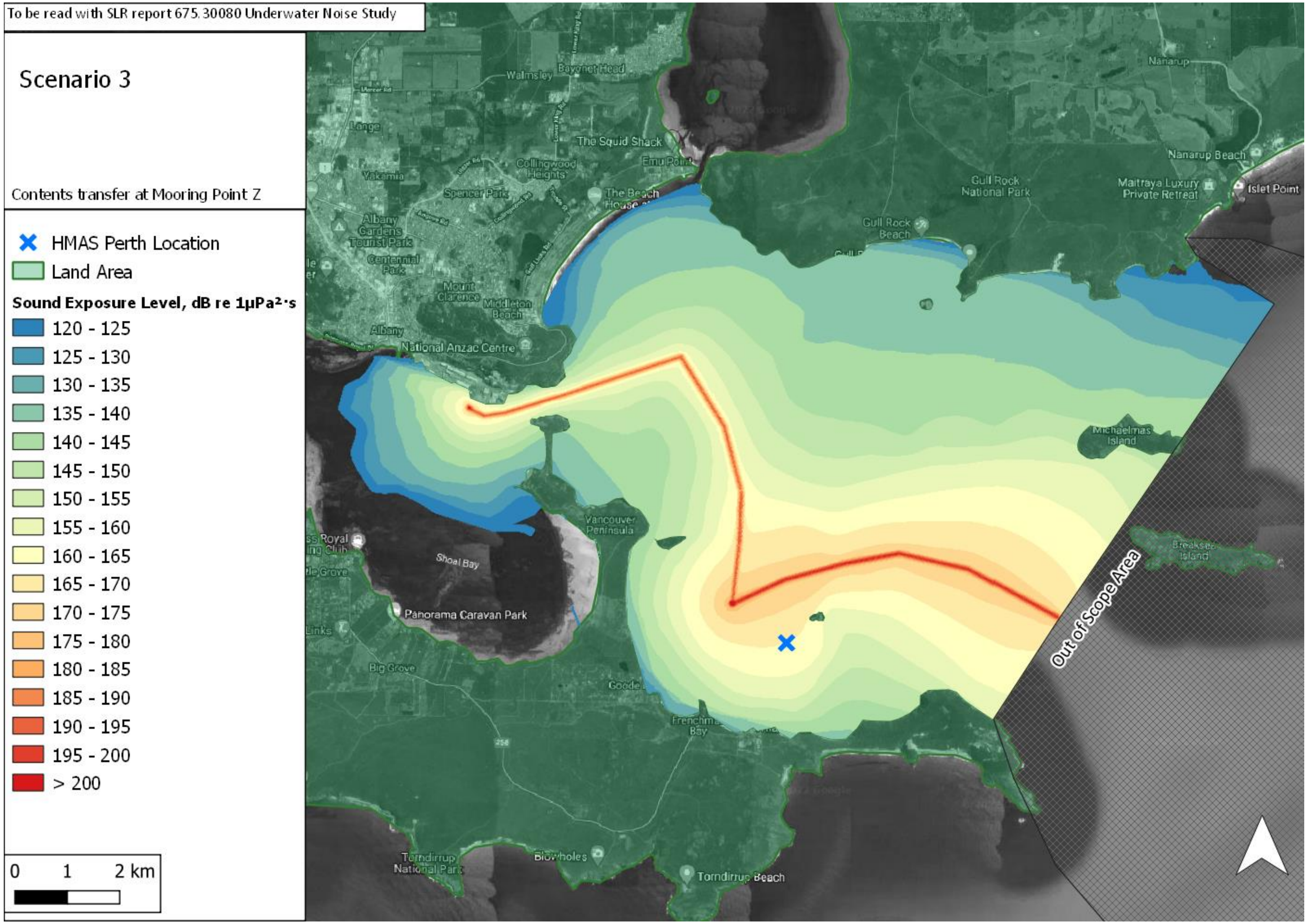


Figure C.3 Modelled noise contour plot for Scenario 3

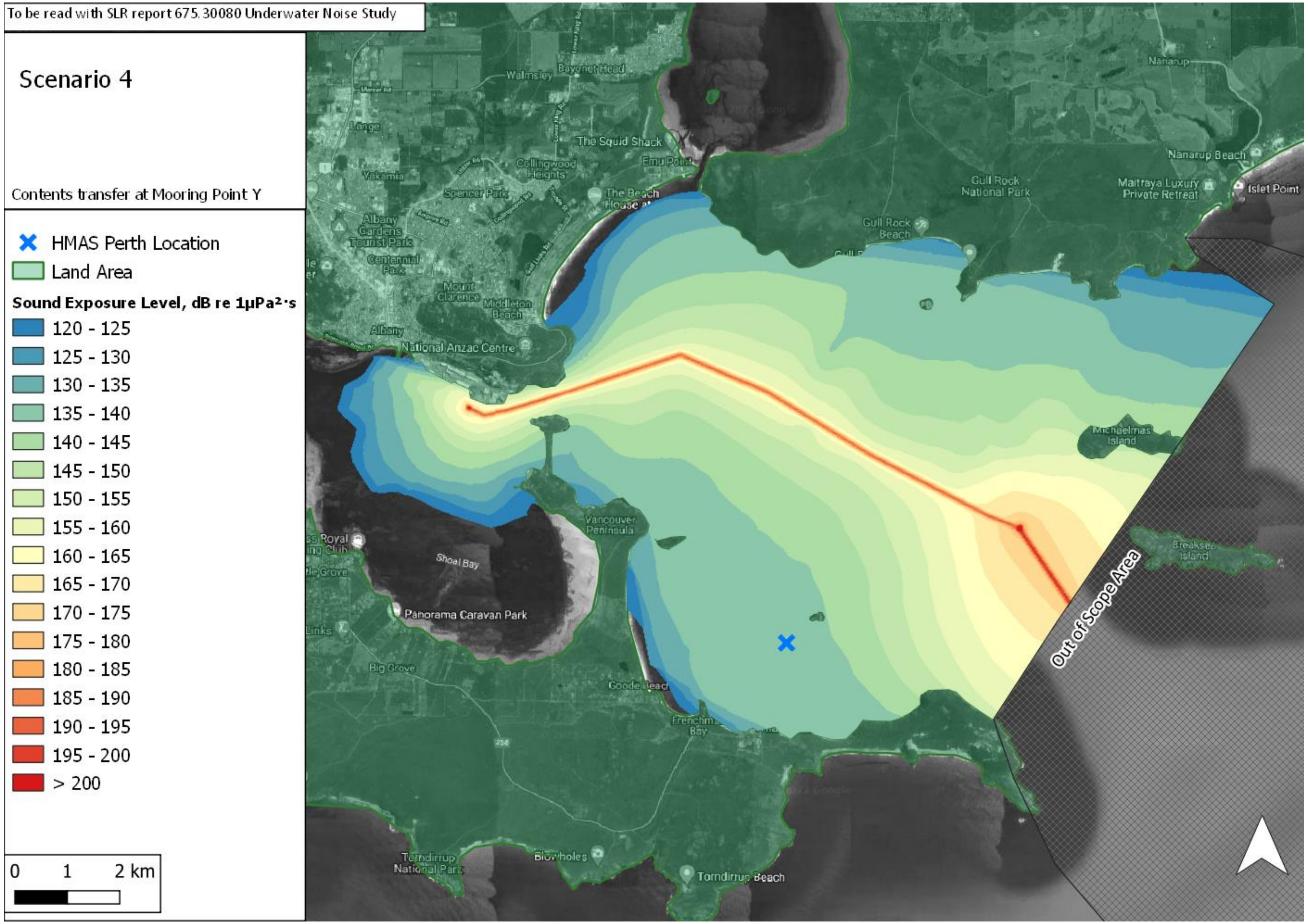


Figure C.4 Modelled noise contour plot for Scenario 4

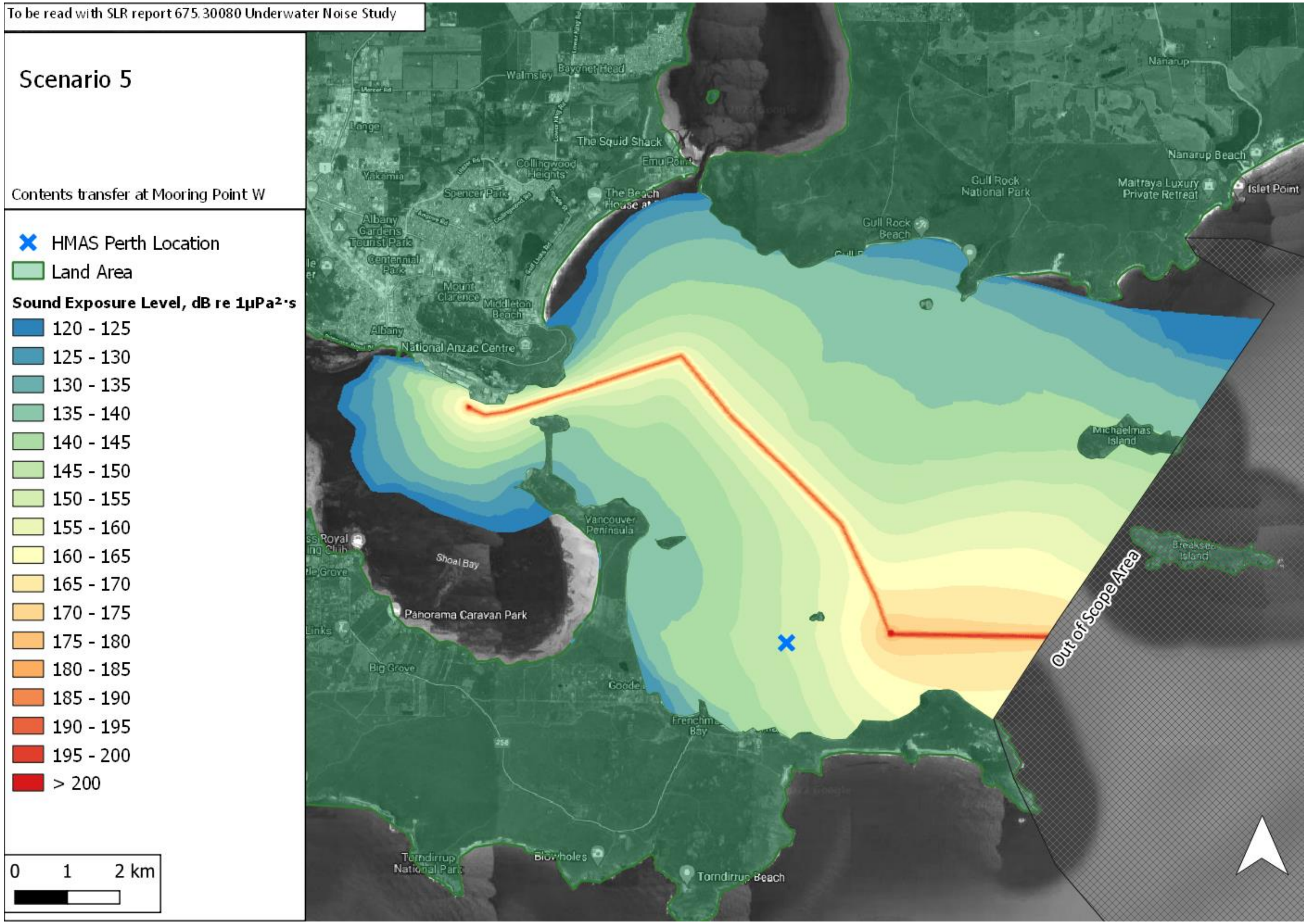


Figure C.5 Modelled noise contour plot for Scenario 5

APPENDIX D

Marine Mammal Hearing Group Classification

The following table gives a summary of marine mammal hearing group classification.

Table C.1 Summary of marine mammal classification

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

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

Classification	Common Name	Scientific Name
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
	Common bottlenose dolphin	*Tursiops truncatus*
	South Asian river dolphin	*Platanista gangetica*
Very high frequency cetaceans (extracted from Appendix 3 Southall *et al.* (2019))	Peale's dolphin	*Lagenorhynchus australis*
	Hourglass dolphin	*Lagenorhynchus cruciger*
	Commerson's dolphin	*Cephalorhynchus commersonii*
	Chilean dolphin	*Cephalorhynchus eutropia*
	Heaviside's dolphin	*Cephalorhynchus heavisidii*
	Hector's dolphin	*Cephalorhynchus hectori*
	Narrow-ridged finless porpoise	*Neophocaena asiaeorientalis*
	Indo-Pacific finless porpoise	*Neophocaena phocaenoides*
	Spectacled porpoise	*Phocoena dioptrica*
	Harbor porpoise	*Phocoena phocoena*
	Vaquita	*Phocoena sinus*
	Burmeister's porpoise	*Phocoena spinipinnis*
	Dall's porpoise	*Phocoenoides dalli*
	Amazon river dolphin	*Inia geoffrensis*
	Yangtze river dolphin	*Lipotes vexillifer*
	Franciscana	*Pontoporia blainvillei*
	Pygmy sperm whale	*Kogia breviceps*
	Dwarf sperm whale	*Kogia sima*
Sirenians (extracted from Appendix 4 Southall *et al.* (2019))	Amazonian manatee	*Trichechus inunguis*
	West Indian manatee	*Trichechus manatus*
	West African manatee	*Trichechus senegalensis*
	Dugong	*Dugong dugon*
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*

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

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