Swan River Ferry Expansion

Construction and Operation Environmental Noise Assessment

Public Transport Authority

Public Transport Centre
Perth WA 6000

Prepared by:

SLR Consulting Australia

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Making Sustainability Happen

Revision Record

Revision	Date	Prepared By	Checked By	Authorised By
0	27 May 2025	Ying Liu Luke Zoontjens	Luke Zoontjens Tim Trewin	Tim Trewin
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Basis of Report

This report has been prepared by SLR Consulting Australia (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Public Transport 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.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

Executive Summary

The Public Transport Authority (PTA) is proposing a ferry service expansion for the Swan River area which requires new jetties to be constructed. This project is referred to as the Swan River Ferry Expansion Project.

This document presents assessments of the potential noise and vibration impacts from construction and operation of the project on nearby terrestrial and marine environments.

Marine

Aquatic sensitive receptors of concern include marine mammals, particularly Swan River Dolphins (i.e. Indo-Pacific bottlenose dolphins), fish species and human divers/swimmers. Noise impact criteria in terms of physiological and behavioural impacts for these sensitive receptors have been established via a review of the literature.

Detailed modelling predictions have been undertaken for noise emissions from construction piling and ferry operations. To inform environmental management measures, various zones of impact have been estimated, based on comparisons between predicted noise levels and impact assessment criteria.

Terrestrial

Airborne noise and ground vibration effects from construction and operation of the project have been reviewed in detail. Field measurements of background sound levels have been undertaken at each site to determine likely sensitivities to any new noise sources.

In regard to construction, noise from both general construction and piling activities are predicted to be well above typical ambient levels at the nearest noise sensitive premises and therefore have the potential to cause adverse impacts. Impact piling noise is considered most significant and is projected to be audible at distances beyond a kilometre, assisted by enhanced noise propagation over water.

During operation, the only significant source of noise assessable under state noise regulations is the charging infrastructure located near Matilda Bay. Noise emissions from the charging infrastructure is predicted to be above existing background levels, prior to any noise mitigation treatments. However, simple sound absorptive walls can be used to ensure noise emissions are reduced to levels equal to or less than applicable targets.

Accordingly, the project can be managed to comply with state noise regulations and other relevant airborne noise and vibration guidelines.

Recommendations

1. Implement an aquatic noise management plan as outlined in Section 2.5, with project specific management and monitoring procedures to minimise piling noise impacts on assessed aquatic sensitive receptors.
2. Allow for noise screening elements to be applied to manage noise from the electrical charging infrastructure to levels consistent with the existing environment.
3. Physical vibration monitoring is recommended for vibration intensive construction activity within 100 m of residential areas to provide certainty in received ground vibration levels.

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1.0 Introduction

1.1 Project background

The Public Transport Authority (PTA) is proposing a ferry service expansion for the Swan River area which involves new jetties to be constructed (Swan River Ferry Expansion Project). The Swan River Ferry Expansion Project is proposed to activate high density activity nodes along parts of the Swan and Canning River foreshores and provide appropriate levels of safety and transport capacity.

The project involves the development, design, construction and operation of new jetties in Matilda Bay and Applecross area close to Canning Bridge. It also involves the terrestrial development in Applecross, Matilda Bay, Elizabeth Quay, Ellam Street and Barrack Street Jetty area.

The three selected source locations are presented in **Figure 1.** The modelled results are presented based on the worst-case scenarios from these proposed locations.

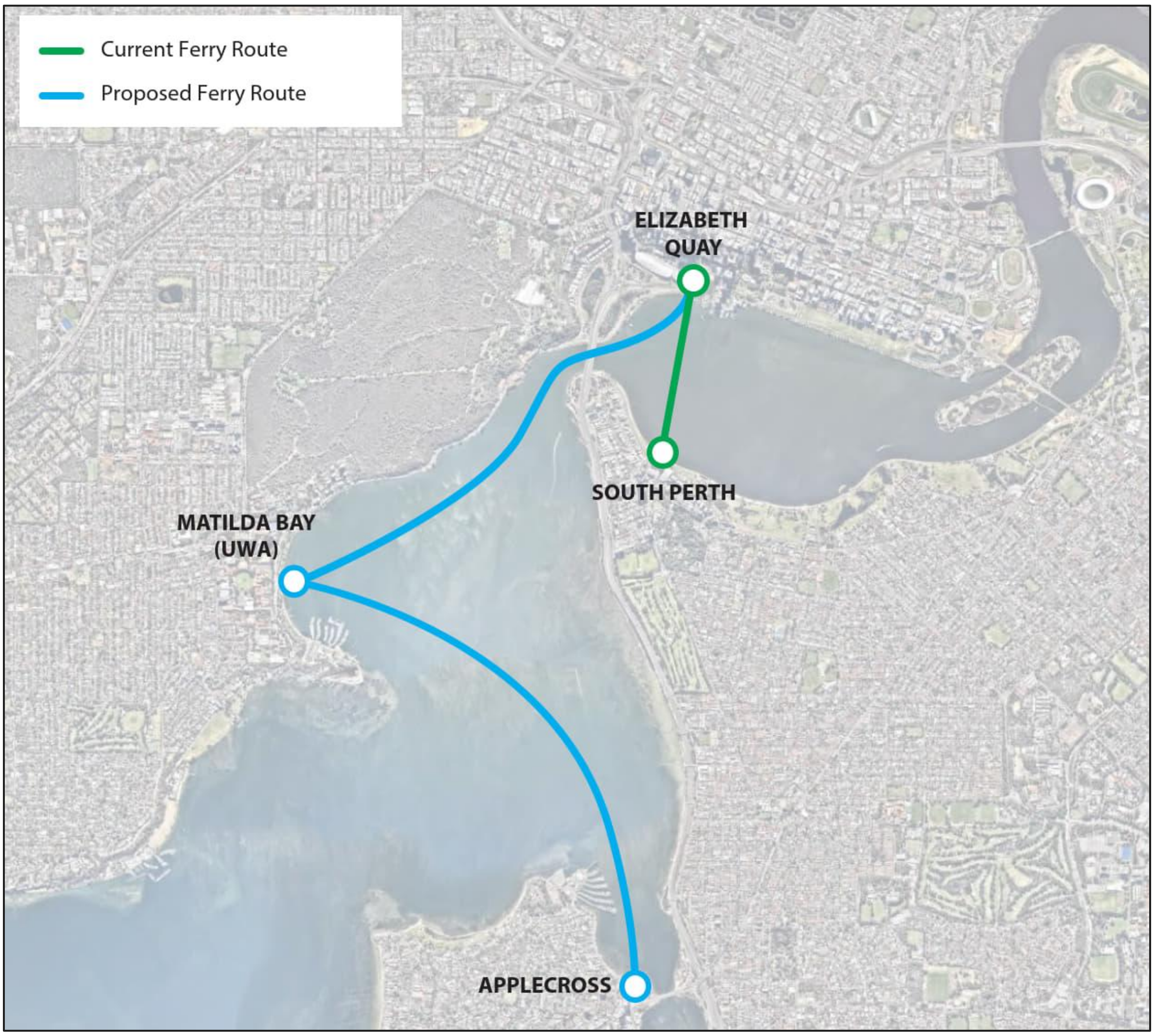

Figure 1 Proposed Ferry Network

For both construction and operational phases, SLR Consulting Australia Pty Ltd (SLR) has been appointed to

- Undertake aquatic noise modelling and impact assessment on marine fauna species and human divers/swimmers.
- Predict and assess airborne noise.
- Review ground vibration risks.

1.2 Structure of this report

This report is structured as follows:

- **Section 2.0** covers underwater noise:
  - **Section 2.1** provides characterisation of the existing aquatic noise environment, based on a review of general marine noise environment, as well as aquatic soundscape studies undertaken in the area.
  - **Section 2.2** presents assessment criteria for relevant general marine fauna species of concern (including marine mammals especially Swan River Dolphin i.e., Indo-Pacific Bottlenose Dolphins, fish species) and human divers/swimmers, based on relevant guidelines and criteria that represent the current industry best practice.
  - **Section 2.3** covers the detailed noise modelling prediction methodology and procedures used, and provides relevant modelling environmental inputs and assumptions, modelling source locations and scenarios associated with the piling operations, and source levels of the piling noise emissions.
  - **Section 2.4** provides the detailed modelling results, and the subsequent zones of impact estimated for general marine fauna species and human divers/swimmers.
  - **Section 2.5** details the aquatic noise management plan specific to the project, including recommended safety zones, monitoring and operation procedures, as well as potential for additional mitigation measures.
- **Section 3.0** provides an assessment of airborne noise emissions during construction and operation.
- **Section 4.0** presents an assessment of potential ground vibration risks arising from construction and operation.

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

2.0 Underwater noise assessments

2.1 Background

2.1.1 Introduction to Underwater Noise Concepts

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

In underwater acoustics, the word sound is used to describe all the pressure waves that are generated in an underwater medium. Sound waves propagate as alternate phases of compression and rarefaction.

There are two types of sound waves considered here: transverse and longitudinal. Sound typically propagates from a source as a longitudinal wave, where particle vibrations occur parallel to the direction of wave travel. In contrast, transverse waves involve particle motion that is perpendicular to the direction of wave propagation. While longitudinal waves are the primary mode for sound in fluids such as air and water, transverse waves can occur in solids, such as through the seabed or structural materials. Wavelength is the spatial distance between two successive peaks in a propagation wave; sound frequency is the number of waves passing through a fixed point per second.

Sound levels are typically reported in units of decibels (dB). The decibel is defined as a ratio of measured acoustic intensity and a reference intensity level and is expressed in a logarithmic scale. However, the sound is often measured as pressure rather than directly as intensity.

The sound pressure level (SPL) indicates the amplitude level of sound at a specific location in space and is a scalar quantity. The level is dependent on the location and distance the sound is observed relative to a sound source. Sound pressure is measured in Pascals but can be computed in decibels. A standard reference pressure is used to compare sound levels given in decibels to one another. In underwater acoustics, the traditional standard reference pressure is 1 micro-Pascal (μPa), leading to the use of the unit dB re 1 μPa, which represents a decibel referenced to a pressure of 1 μPa.

Measurement type refers to how the pressure was measured:

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

Spectral analyses display of the frequency content of a sound signal. It shows how sound level varies with frequency. Spectra are typically presented in third-octave bands (1/3-octave), which measure the sound level in frequency bands that widen exponentially with increasing frequency and are evenly spaced on a logarithmic frequency axis. In underwater acoustics, this is used to approximate the bandwidths of the marine mammals' fish' and turtles' auditory systems.

2.1.2 Major aquatic noise generating activities and sensitive receptors

Major activities in regard to aquatic noise emissions during the construction phase of the project include piling, pile spoil excavation and vessel movements. Of the proposed activities, piling is considered to have the highest impact on the aquatic noise environment, due to its very high noise emissions, as well as its impulsive noise characteristics. Excavation and vessel movements are expected to have much lower impact as their noise emissions are lower in levels and continuous in nature and are comparable to the existing ferrying traffic from recreational vessels around the port area.

Major activities in regard to aquatic noise emissions during operation are ferry movements associated with the new proposed routes.

The sensitive aquatic receptors that are potentially to be adversely affected by noise emissions from the construction and operation activities include marine mammals particularly Swan River Dolphins (i.e. Indo-Pacific Bottlenose Dolphins), fish species and human divers/swimmers.

2.1.3 General aquatic ambient noise

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.
  - 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.
  - 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 or ferrying 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.
- Dredging activities and other marine industry operations are additional man-made sources, generating broadband noise over relatively long durations.

Figure 2 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.

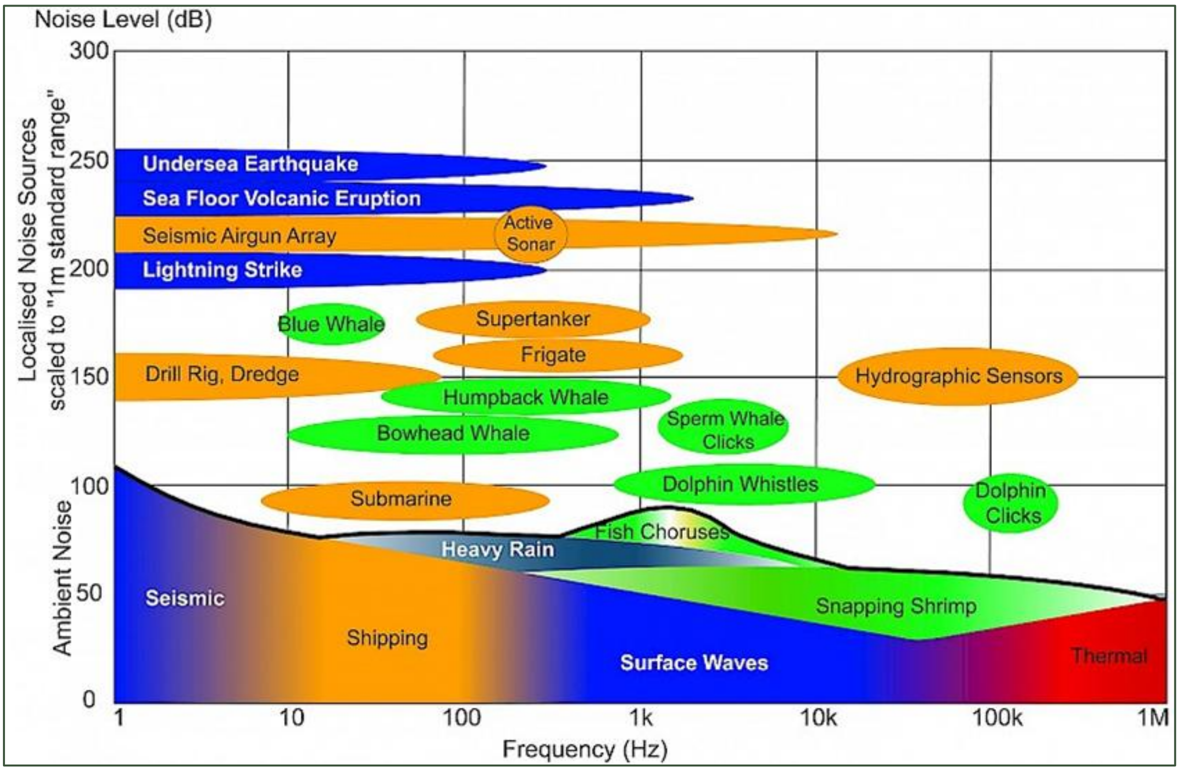

Figure 2 Levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment (from https://www.ospar.org/work-areas/eiha/noise). Natural physical noise sources represented in blue; marine fauna noise sources in green; human noise sources in orange

A summary of the spectra of various ambient noise sources based on a review study undertaken by Wenz (1962) is shown in **Figure 3**. 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.

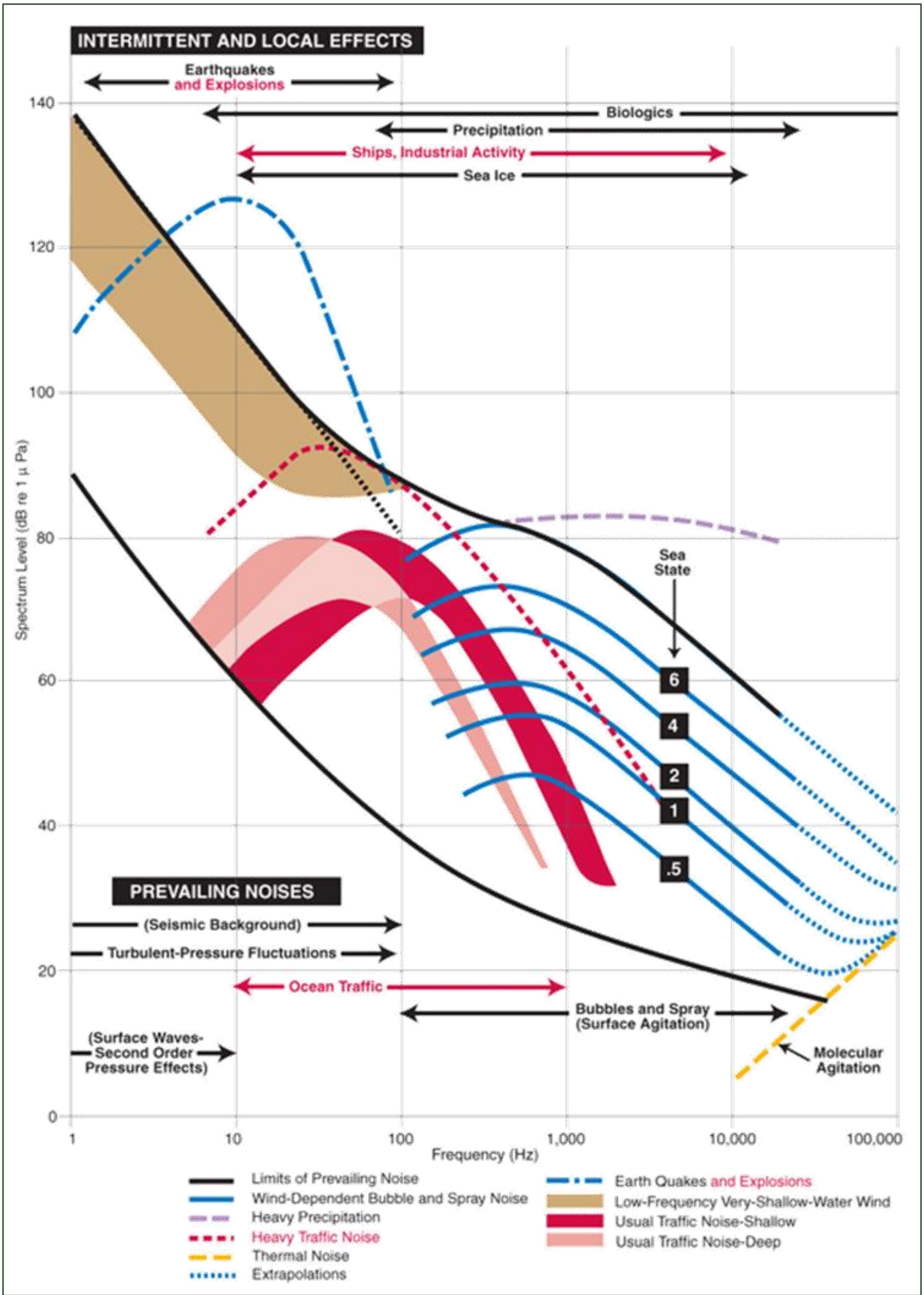

Figure 3 Wenz curves: spectra and frequency distribution of ocean ambient noise spectra (Miksis-Olds et al., 2013, reproduction from Wenz (1962))

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 4** 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 ship movements are generally consistent in level range between the two studies (Wenz, 1962 and Cato, 1997).

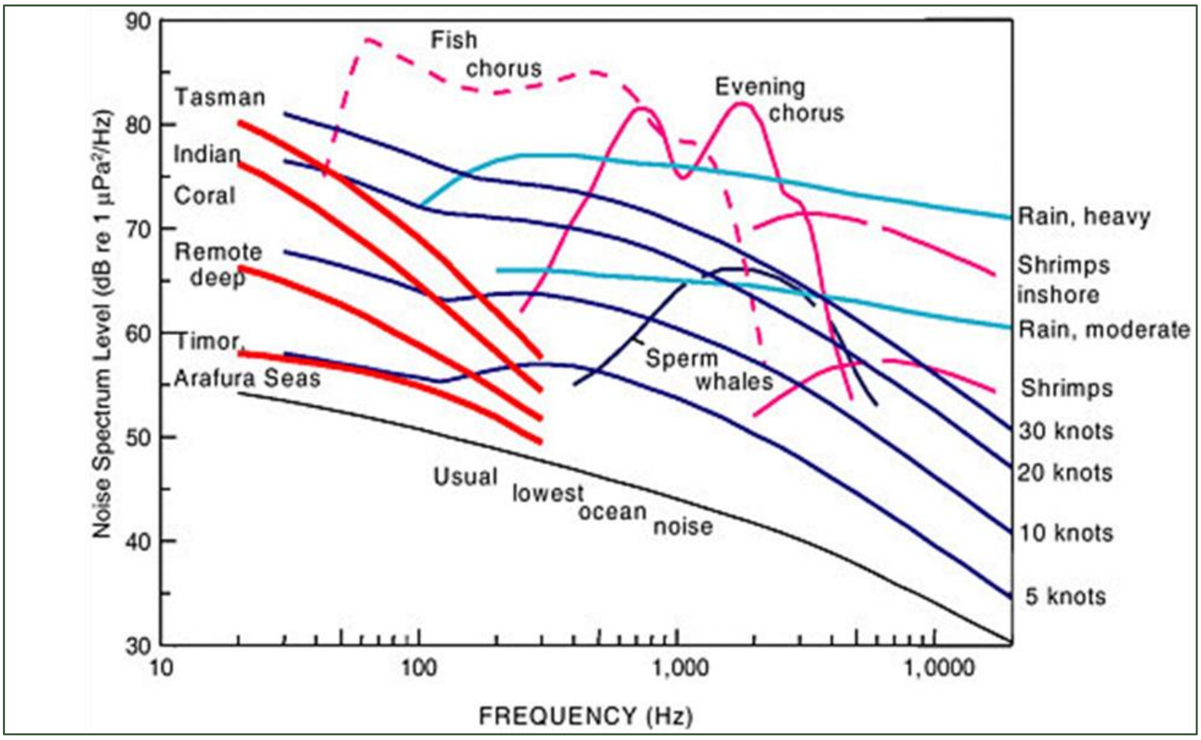

Figure 4 Summary of Aquatic Ambient Noise Spectra for the Australian Region (from Cato (1997))

2.1.4 Aquatic soundscape studies in project area

The aquatic noise environment for the middle reaches of the Swan River estuary has been well investigated based on the long-term noise monitoring studies at Narrow Bridge (Marley et al, 2016).

Soundscape analyses for the middle reach of the Swan River estuarine was undertaken based on underwater noise monitoring data over a six-week period (27th November to 4th January 2014) (Marley et al, 2016). The noise monitoring logger was deployed near the Narrow Bridge and adjacent to the ferry channels as shown in **Figure 5**.

The study found that the soundscape at the monitoring site comprised of natural events (waves, precipitation), anthropogenic noise (bridge traffic, machinery) and biological sources (fish, snapping shrimps and dolphins), and was strongly influenced by vessel traffic at relatively low frequency range (below 200 Hz) and particularly snapping shrimp clicks at very wide high frequency range (above 1 kHz). **Figure 6** presents an example spectrogram of the monitoring noise recording over a week period.

The noise level variation over the entire 6-week monitoring period, as shown in **Figure 7**, indicates that the overall noise levels are quite consistent over time, with levels fluctuate slightly around 120 dB re 1Pa RMS. The is due to the dominant noise contribution from consistent snapping shrimp clicks over time at high frequency range.

Figure 5 Long-term noise monitoring logger location near the Narrow Bridge

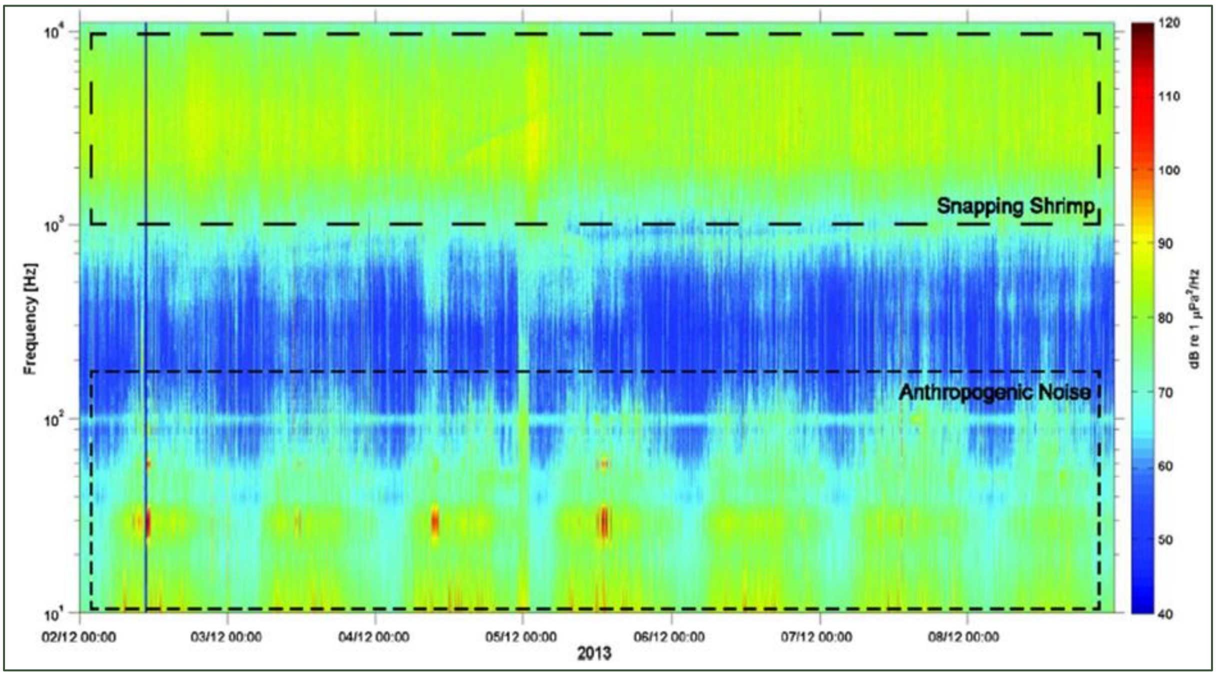

Figure 6 Spectrogram of underwater noise recorded over a week in December 2013, showing prominent anthropogenic noise sources at low frequency range, as well as snapping shrimps over higher frequency range

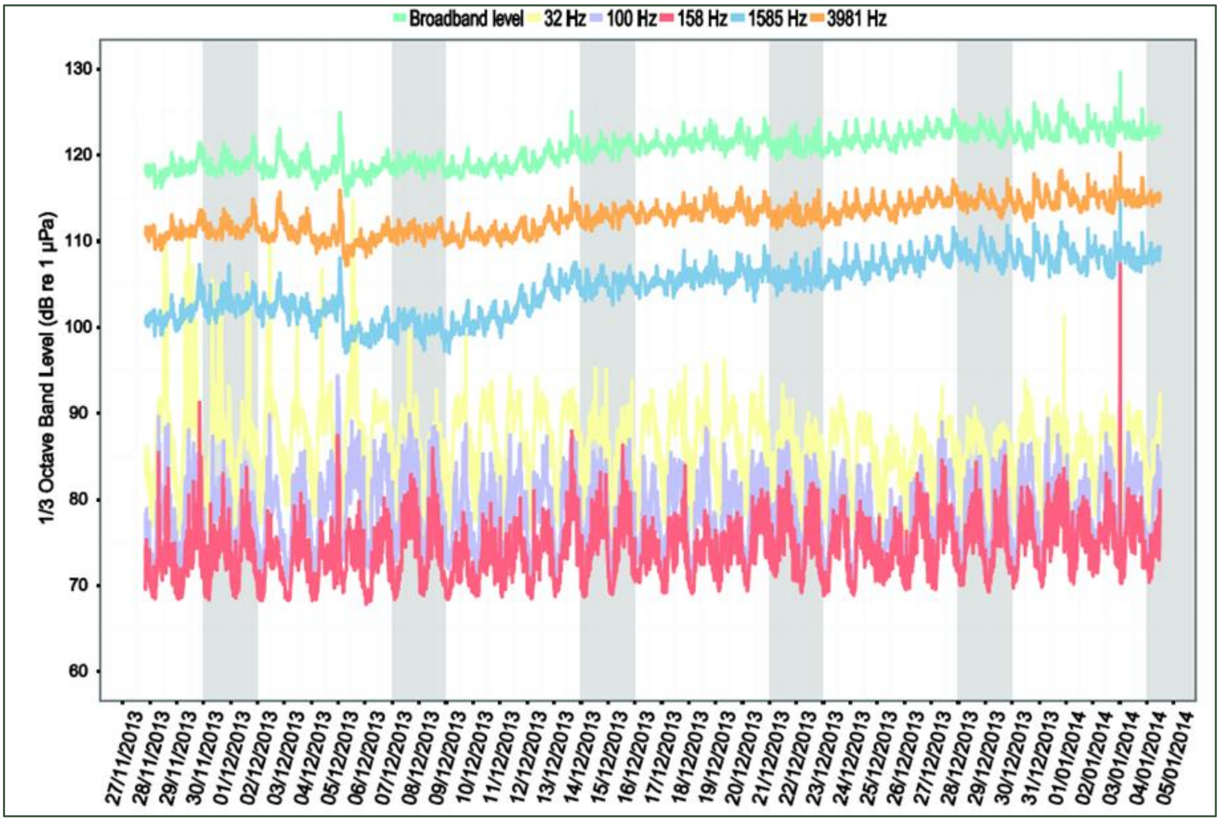

Figure 7 Recorded noise level variation in broadband (9 Hz to 9 kHz) and selected 1/3 octave band across the six-week monitoring period at Narrow Bridge

2.2 Aquatic noise impact assessment criteria

2.2.1 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

[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.

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 8** below.

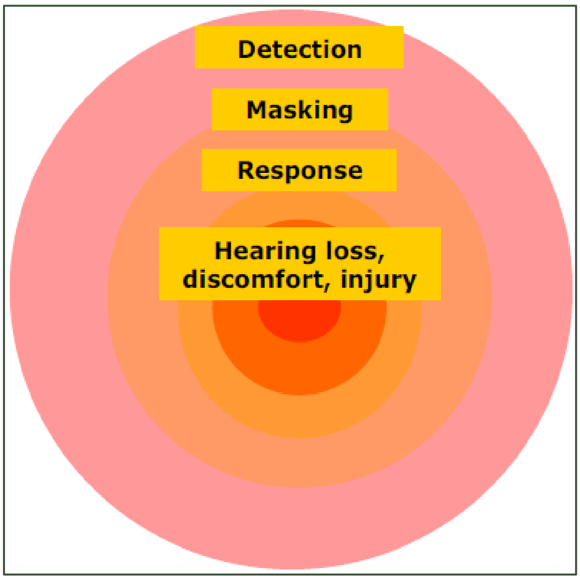

Figure 8 Theoretical zones of noise influence (Richardson et al. 1995)

2.2.1.1 Audibility/detection

A sound is considered audible when the receiver can 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).

2.2.1.2 Masking

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

2.2.1.3 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).

2.2.1.4 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.

2.2.2 Marine mammals

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine mammal species. For example, Southall et al (2007 & 2019) have proposed noise exposure criteria associated with various sound types, including impulsive noise (e.g. piling noise and seismic airgun noise) and non-

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

impulsive noise (e.g. vessel and drilling noise)) for certain marine mammal species (i.e. cetaceans and sirenians and carnivores), based on review of expanding literature on marine mammal hearing and on physiological and behavioural responses to anthropogenic sounds.

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

In this study, the Swan-Canning River system is home to a small resident community of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), plus juveniles and calves (Chabanne et al., 2012; SRT, 2015). For Indo-Pacific bottlenose dolphin species specifically, **Section 2.2.2.3** provides further details regarding its hearing sensitivity and responses to noise emissions from marine traffic and piling operations.

2.2.2.1 Marine mammal auditory weighting functions

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

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

When developing 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).

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

Where:

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

An updated Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 3.0) (NMFS 2024) updated the auditory weighting parameters for LF, HF, VHF, PCW and OCW hearing groups.

Table 1 lists the updated auditory weighting parameters for the six hearing groups with corresponding auditory weighting functions for all hearing groups presented in **Figure 9**. The auditory weighting functions are applied to weighted sound exposure levels (SEL_w) to calculate the cumulative exposure levels.

Table 1 Parameters for the auditory weighting functions

Marine mammal hearing group	*a*	*b*	*f₁ (Hz)*	*f₂ (Hz)*	*C (dB)*
Low-frequency cetaceans (LF)	0.99	5	168	26600	0.12
High-frequency cetaceans (HF)	1.55	5	1730	129000	0.32
Very high-frequency cetaceans (VHF)	2.23	5	5930	186000	0.91
Sirenians (SI)	1.8	2	4,300	25,000	2.62
Phocid carnivores in water (PCW)	1.63	5	810	68300	0.75
Other marine carnivores in water (OCW)	1.58	5	2530	43800	1.37

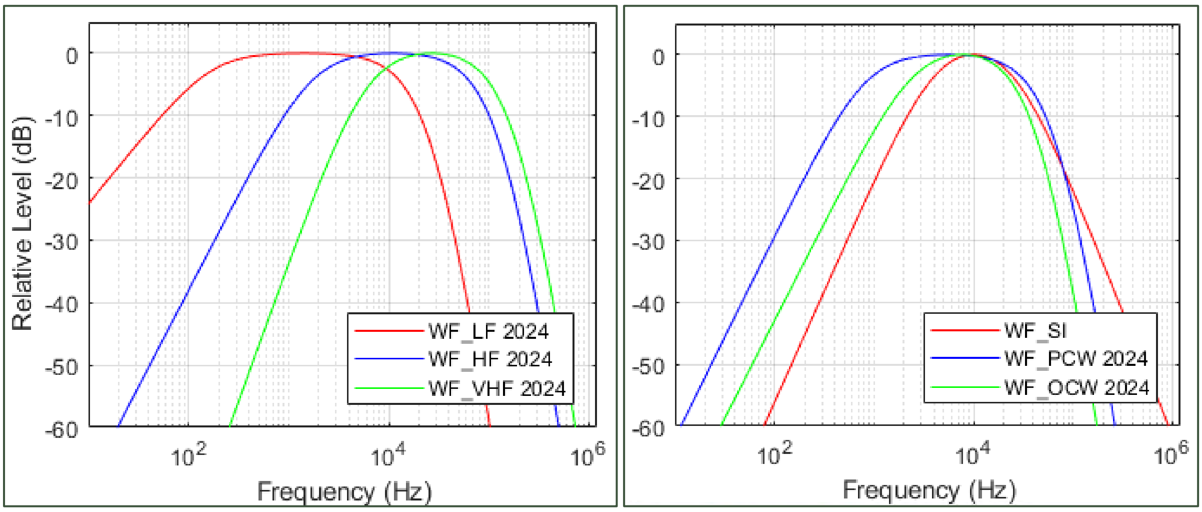

Figure 9 Auditory weighting functions - LF, HF, VHF, SI, PCW and OCW

2.2.2.2 Noise impact criteria for marine mammals

The newly updated scientific recommendations in marine mammal noise exposure criteria (Southall et al, 2019) propose PTS-onset and TTS-onset criteria for 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 (Pk SPL) and cumulative sound exposure level (SEL_w) within a 24-hour period (SEL_{24hr}).

Table 2 PTS- and TTS-onset threshold levels for marine mammals exposed to impulsive noise

Marine mammal hearing group	PTS and TTS threshold levels – impulsive noise			
	Injury (PTS) onset		TTS onset	
	Single exposure	Cumulative exposure	Single exposure	Cumulative exposure
	Pk SPL, dB re 1μPa (unweighted)	SEL24hr, dB re 1μPa2·S (weighted)	Pk SPL, dB re 1μPa (unweighted)	SEL24hr, dB re 1μPa2·S (weighted)
LF	219	183	213	168
HF	230	185	224	178 (Note [1])
VHF	202	155	196	140
SI	226	190	220	175
PCW	218	185	212	170
OCW	232	203	226	188

Note 1 Based on discussion with authorities which revealed preference to use the Underwater Piling and Dredging Noise Guidelines (Govt. South Australia, 2023) target for this specific group and effect.

For non-impulsive noise events, 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.

Table 3 PTS- and TTS-onset threshold levels for marine mammals exposed to non-impulsive noise

Marine mammal hearing group	PTS and TTS threshold levels – non-impulsive noise, cumulative exposure, SEL_{24hr}, dB re 1μPa2·S(weighted)	
	Injury (PTS) onset	TTS onset
Low frequency cetaceans (LF)	199	179
High frequency cetaceans (HF)	198	179 (Note [1])
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

Note 1 Based on discussion with authorities which revealed preference to use the Underwater Piling and Dredging Noise Guidelines (Govt. South Australia, 2023) target for this specific group and effect.

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 or ambient level for non-impulsive noise (NMFS, 2013), as shown in **Table 4.**

Table 4 The behavioural disruption threshold level for marine mammals – impulsive and non-impulsive noise

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

2.2.2.3 Species in project area

The Swan-Canning River system is home to a small resident community of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), plus juveniles and calves (Chabanne et al., 2012; SRT, 2015). The spatial and temporal patterns of dolphins' occurrence within the river has shown that animals are distributed heterogeneously, with the Matilda Bay area being identified as a sighting 'hotspot' used for foraging and Perth Waters being the transiting area between the middle and upper reaches of the Swan River (Moiler, 2008; Marley et al, 2017).

The auditory sensitivities of bottlenose dolphins are greatest at very high frequencies (15 – 130 kHz), where the hearing threshold is in the range 40 – 80 dB, as demonstrated in **Figure 10** below. Hearing is progressively less sensitive as the frequency decreases, failing to approximately 130 dB for 100 Hz sounds (Johnson, 1967). In general, bottlenose dolphins' hearing threshold curve is aversely in line with the auditory weighting function for High-frequency (HF) cetacean hearing group as shown in **Figure 9**.

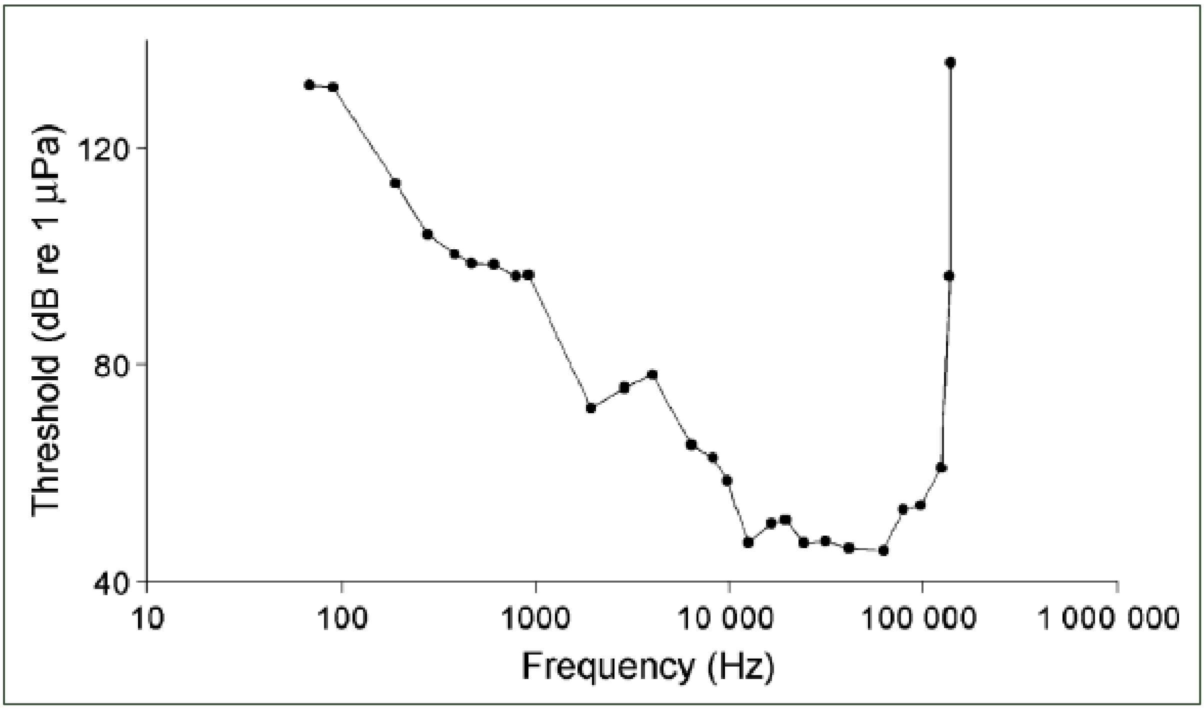

Figure 10 Hearing thresholds of a bottlenose dolphin (Johnson, 1967)

There has been limited research into detailed noise impact on Indo-Pacific bottlenose dolphin species (Southall et al, 2019). Their likely sensitivity to pile-driving and vessel traffic noise have been investigated previously (David, 2006; Marley et al, 2017), on the basis of potential noise effects on movements, behavior and vocalizations of the species, rather than more severe physiological effects. The assessment criteria for Indo-Pacific bottlenose dolphin species are based on those criteria for HF cetaceans.

Based on existing records and ecological knowledge of the Swan River estuary, this area is not known to support resident populations of low-frequency (LF) cetaceans, such as baleen whales, very high frequency (VHF) cetaceans (e.g., porpoises) or other cetacean species that fall outside the HF hearing group. However, to ensure a conservative and precautionary approach to underwater noise management, the modelled noise levels have been assessed against auditory thresholds for all hearing groups. This ensures that, should additional species be identified or recorded in the area in the future, the noise modelling remains valid and protective. It also enables management strategies to be adapted proactively to avoid potential impacts on a broader range of marine fauna.

2.2.3 Fish and turtles

In general, limited scientific data are available regarding the effects of sound for fishes and 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 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.

While sea turtles are not commonly reported within the Swan River, the applied guideline may have been used in reference to other turtle species, such as freshwater turtles, or as a conservative measure in the absence of species-specific auditory data. The sound exposure criteria for sound sources of impulsive noise from pile driving are presented in **Table 5**.

Table 5 Sound exposure criteria applicable for impulsive noise (piling) – fishes and 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
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 $\mu Pa^2 \cdot s$. 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 SPL, SEL). Where insufficient data exist to make a recommendation for guidelines, a subjective approach is adopted in which the relative risk of an effect is placed in order of rank at three distances from the source – near (N), intermediate (I), and far (F) (top to bottom within each cell of the table, respectively). In general, “near” might be considered to be in the tens of meters from the source, “intermediate” in the hundreds of meters, and “far” in the thousands of meters. The relative risk of an effect is then rated as being “high,” “moderate,” and “low” with respect to source distance and animal type. The rating for effects in these tables is highly subjective and represents general consensus within the WG.

It should be noted that the period over which the cumulative sound exposure level (SEL_{cum}) is calculated must be carefully specified. For example, SEL_{cum} may be defined over a standard period (e.g., 12 hours of 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.

The sound exposure criteria for sound sources of non-impulsive noise from ferrying and other sources are presented in **Table 6**.

Table 6 Noise exposure criteria for continuous sounds (ferrying) – 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	150 dB (RMS SPL)
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	
Fish: swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB (RMS SPL))	158 dB (RMS SPL)	(N) High (I) High (F) High	
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	175 dB (RMS SPL)
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) are in terms of dB re 1 μPa. All criteria are presented as sound pressure even for fish without swim bladders. 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).

Currently, there is no direct evidence of mortality or potential mortal injury to fish from non-impulsive noise sources such as noise from DPS (Popper et al. 2014). However, continuous noise of any level that is detectable by fish can mask signal detection and impact their behaviour (Popper and Hawkins 2019). Increased noise levels may affect a wide range of behaviour patterns over the long term.

For example, anthropogenic sounds can interfere with foraging behaviour by masking the relevant sounds or resembling sounds that prey may generate. Similarly, fish might avoid predators by listening to sounds that predators make deliberately or inadvertently (Popper and Hawkins 2019).

To determine the behaviour response (to single exposure) threshold for all fish species, except fish eggs and fish larvae, to impulsive and non-impulsive noise, NMFS uses the common SPL of 150 dB re 1 µPa (NMFS 2024b). The derivation and origin of the informal 150 dB threshold is not as well-defined as other thresholds. However, recent publications do not refute that behavioural disturbance can occur around this level (Hawkins et al. 2014).

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

2.2.4 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 11**.

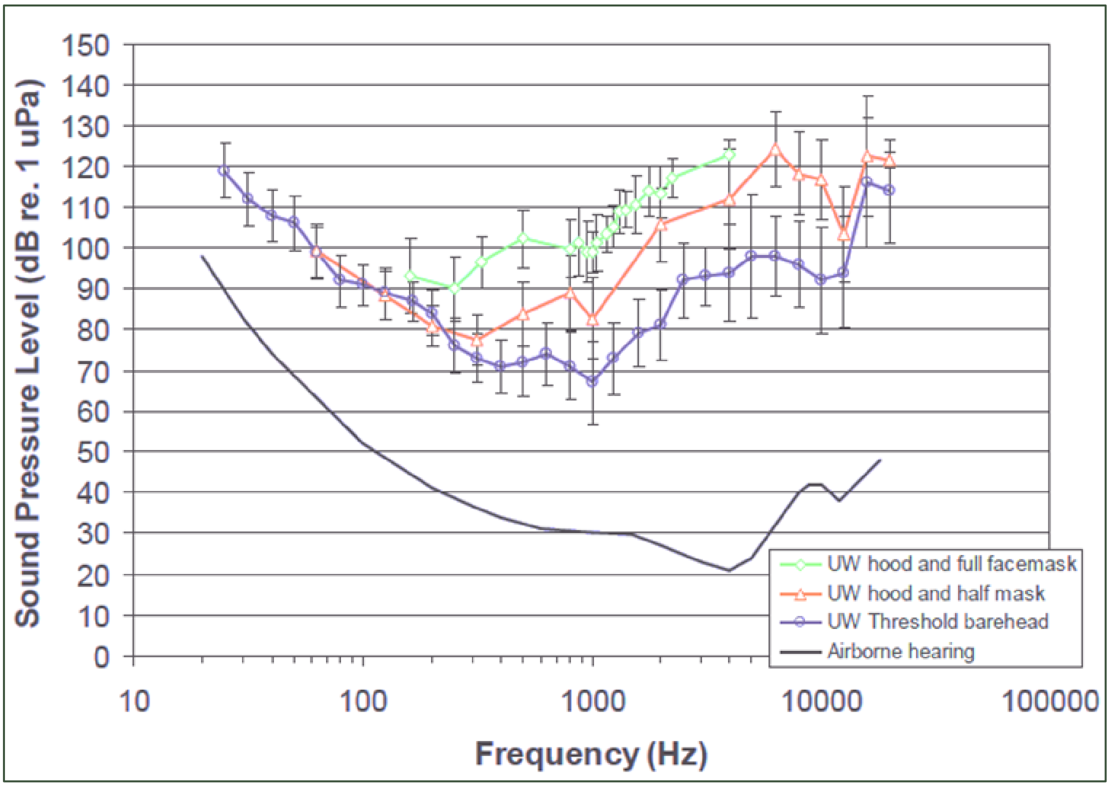

Figure 11 Hearing threshold levels for humans in the air and under water (Parvin, 1998).

As can be seen in the figure, the hood and face mask for recreational divers further increase the hearing threshold levels. A number of studies on the human diver exposure to underwater sound has been carried out, and relevant safety thresholds for both military and commercial/recreational divers under various frequency range have been proposed (Ainslie, 2008; Pestorius et al, 2009).

For 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).

For relatively high frequency range, 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 µPa RMS for use in environmental impact assessment.

As such, the 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 SPL 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	RMS SPL (dB re 1 µPa RMS)
100 – 500 Hz	145
500 – 2500 Hz	155

2.2.5 Zones of bioacoustics impact

The distances from the sound source within which various types of impacts on marine fauna can be expected ("zones of impact") are determined by modelling the transmission loss of sound in water (i.e., the decrease in noise levels when moving away from the noise source) and determining the distance at which predicted noise levels fall below the various threshold levels described in Section 4.1 to 4.4.

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

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

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

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

2.3 Underwater noise modelling prediction methods

2.3.1 Scenarios

2.3.1.1 Construction piling

To understand the extent of underwater noise impacts from piling operations throughout the proposed project development, three positions were nominated considerate of the propagation environment to the surrounding upstream and downstream river areas. Similar distributions in noise are predicted for the other piles.

2.3.1.2 Ferry operation

The assessment of potential future ferry operations considers noise emissions from a 24-metre catamaran electric passenger ferry operating between Elizabeth Quay, Matilda Bay, and Applecross. Three operational scenarios have been evaluated:

- Scenario 1: Ferry operation between Elizabeth Quay and Matilda Bay (return trip).
- Scenario 2: Ferry operation between Matilda Bay and Applecross (return trip).
- Scenario 3: Ferry operation between Elizabeth Quay and Applecross without stopping (return trip).
- Scenario 4: Ferry operation from Elizabeth Quay to Matilda bay, and then to Applecross (return trip).

In each scenario, the ferry operates at a speed of 20 knots (approximately 10 m/s) and follows the current Transperth Ferry Service timetable. The worst-case scenario assumes up to 67 return trips (a total of 134 single trips) per 24-hour period, operating from 6:00 am to 12:30 am.

2.3.2 Key noise sources

2.3.2.1 Construction piling

It is conservatively assumed that hammer (impact) piling will be used for installation of the piles. Based on the diameter of each pile and the scale of each project area, modelled source levels assume use of a 150 kNm impact class hydraulic hammer by default.

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 of 199 dB re 1 μPa^2·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:

$$dB_o = 10 * \log10 (E/E_r) \quad (4.2.1)$$

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 (4.2.1) 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, with the overall SEL source level is estimated as 204 dB re 1 μPa^2·S. **Figure 12** presents the one-third octave SEL source spectral levels (unweighted and M-weighted) for the piling noise.

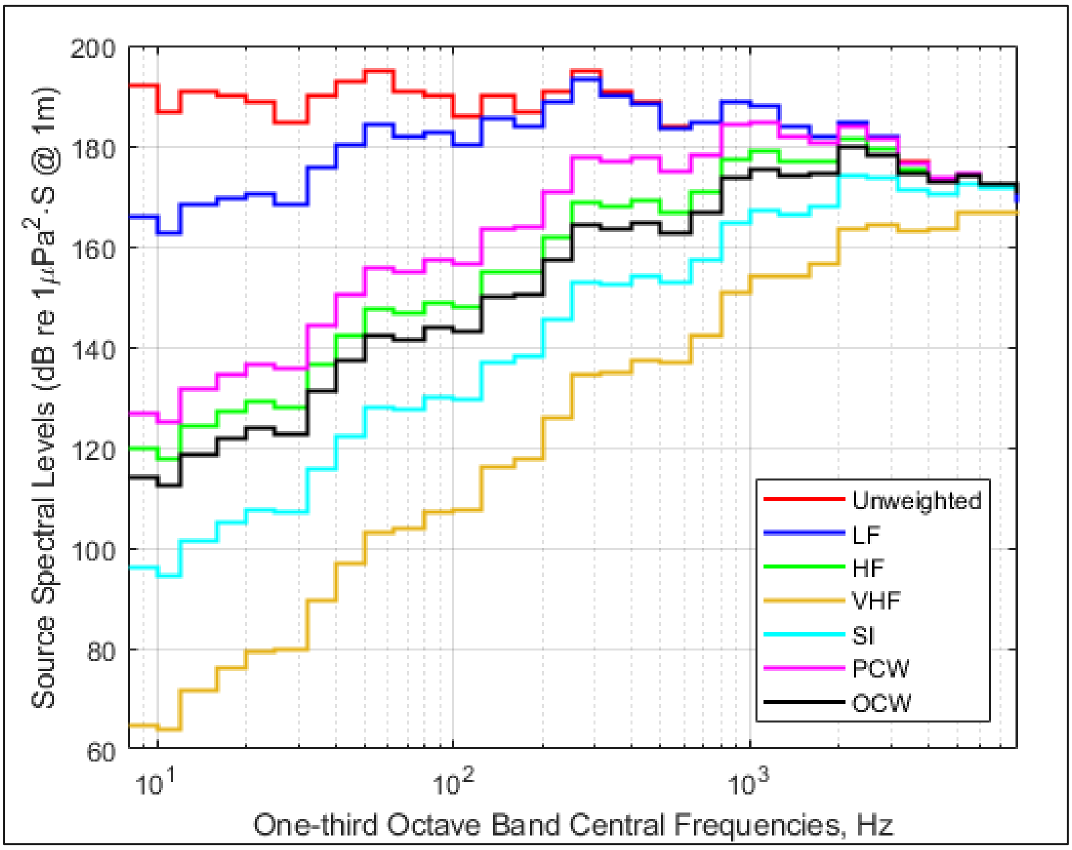

Figure 12 One-third octave SEL source spectral levels (unweighted and M-weighted) for the piling noise (overall unweighted level of 204 dB re 1 μPa²·S)

Source noise mitigation options have also been considered in the modelling. **Table 8** lists the mitigation options considered and overall unweighted reductions modelled.

Table 8 Summary of overall adjustments to source levels for mitigation

#	Mitigation scenario	Modelled adjustment in source levels at one metre, dB unweighted	Basis
1	Substitution of hydraulic hammer for a 150 kgm class vibratory hammer (e.g. PVE 150M or similar) at ca. 1,400 rpm	-15 (SEL) -25 (Peak and RMS)	Published field measurements (HDR Environmental 2017, CALTRANS 2015)
2	Hammer piling with an effective unconfined single row bubble curtain	-6	CALTRANS (2009, 2015)
3	Hammer piling with an effective unconfined double row bubble curtain	-10	
4	Use of effective isolation casings or double pile sleeve technology, including confined air bubble curtains	-15	
5	Combination of vibratory hammer (#1) and bubble curtain (#2)	-22 (SEL) -32 (Peak and RMS)	As above

Spectral adjustments were applied to the source levels in **Figure 12** to represent each mitigation option. Note that actual performance will vary from these estimates. It is difficult to reliably quantify the actual benefit of measures that provide noise reductions of more than 10 dB.

2.3.2.2 Ferry operation

Ferries are modelling along the route shown in **Figure 13**.

Figure 13 Swan River Ferry Expansion Project overview – Site names and indicative ferry operational route

The source spectral curve (one-third octave spectra) for the proposed ferry operation is based on historical measurements on Elvy hybrid electric ferry in fully electric battery powered propulsion as well as in hybrid propulsion with the on-board diesel generator running (Andersson Carl etc. 2023).

The one-third octave SEL source spectral levels (unweighted and M-weighted) for the ferry operation noise is presented in **Figure 14**.

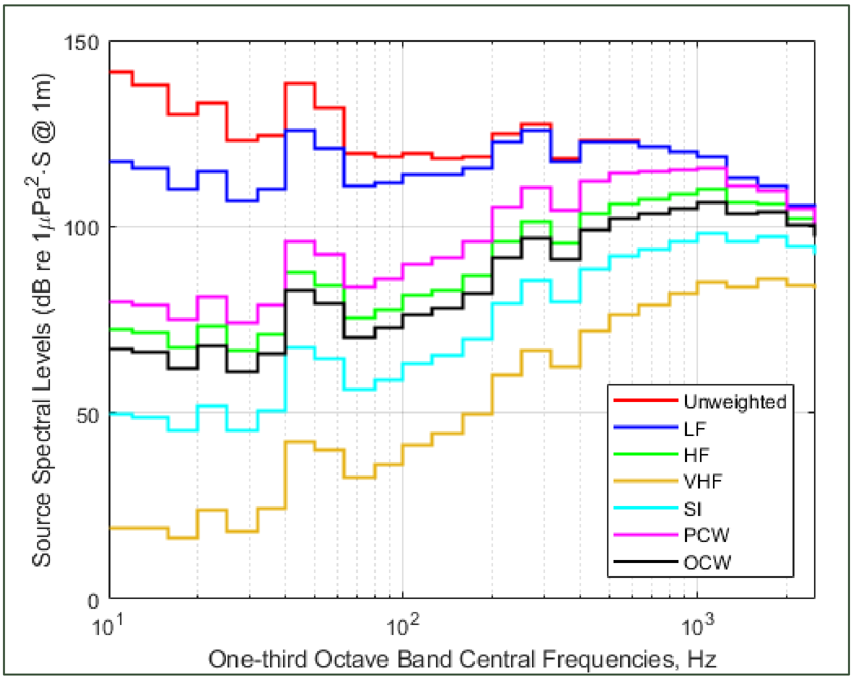

Figure 14 One-third octave SEL source spectral levels (unweighted and M-weighted) for the ferry operation noise (overall unweighted level of 145 dB re 1 μPa²·S)

2.3.3 Modelling methodology

2.3.3.1 Long Range Modelling

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:

$$RL=SL - TL \qquad (5.3.1)$$

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 5.2).
- Transmission loss is calculated using RAMGeo at one-third octave band central frequencies from 40 Hz to 8 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 10.0 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.
- The overall received levels are calculated by summing all frequency band spectral levels.

2.3.3.2 Cumulative SEL Modelling

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

$$CF = 10 \times \log10 (N \text{ (or } T)) \qquad (5.3.2)$$

Where *N* is the number of pulses for piling noise source or the number of ferrying trips during the assessed time period and *T* is the exposure duration for a continuous 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 9 of Section 4.2.1 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.

2.3.3.3 SEL Conversion Factors for impulsive sources

For received individual signals emitted from impulsive sources such as piling noise sources, the differences between the SEL and other sound parameters, such as the Pk SPL, are expected to be greatest at the source location and gradually decrease with an increasing range from the source.

This is because, theoretically, the source pulse experiences increasing waveguide distortion effects (e.g., dispersion, interference effects, seafloor and surface reflections, differences of time arrivals, etc.) with increasing distance from the source, which impact predominantly the pulse's temporal characteristics (e.g., lower peak level, extended pulse duration, etc.) rather than the energy-based metric levels.

SEL and Pk SPL

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).

SEL and RMS SPL

For this project, the SPLs were estimated using the following conservative conversion factors, derived from the historical measurements described in relevant literature and study report (Hastings and Popper, 2005; Parnum et al, 2015), to be applied to the modelled SELs at different distance ranges:

- 0 – 20 m: Conversion factor of 15 dB.
- 20 – 200 m: Conversion factors of 15 to 10 dB, following a logarithmic trend with distance.

- 200 – 500 m: Conversion factors of 10 to 5 dB, following a logarithmic trend with distance.
- 500 m and beyond: Conversion factor of 5 dB.

The SEL to RMS SPL conversion factors, as a function of horizontal distance from the source, are illustrated in **Figure 15**.

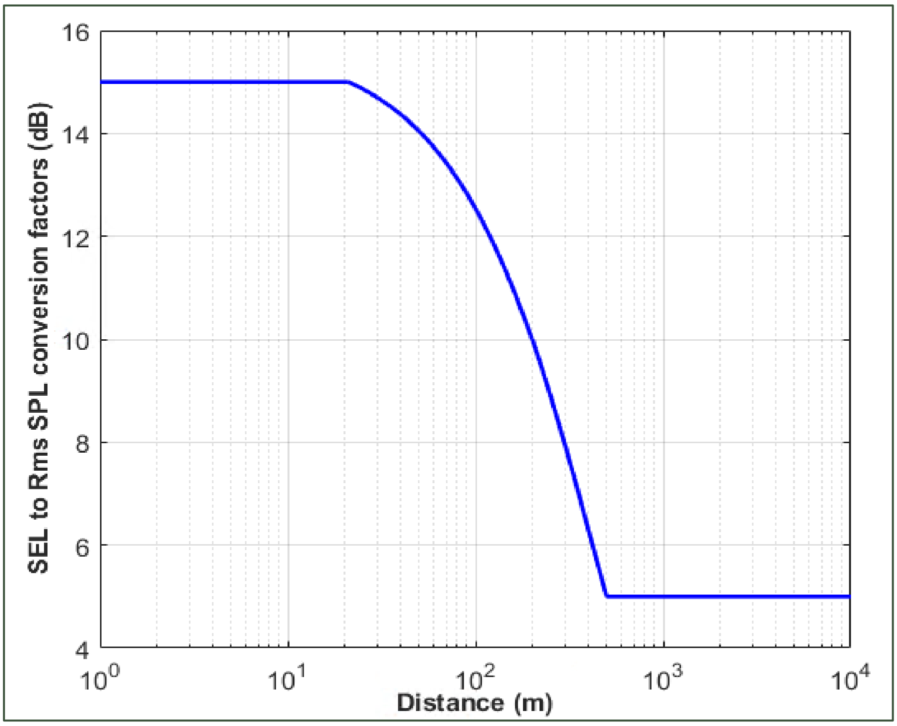

Figure 15 SEL to SPL conversion factor versus distance.

2.3.4 Input parameters

2.3.4.1 Bathymetry

The bathymetry data used for the sound propagation modelling were based on provided bathymetric/hydrographic point survey datasets held within the Western Australian Department of Transport (DoT) and WA898 Swan and Canning Rivers e7-45.

The two datasets were merged and reconstructed for the modelling inputs, with consideration of filling data gaps for the areas without survey data based on adjacent survey points of similar estuary conditions, as well as determining riverbank boundaries based on satellite images.

Based on the Australian National Tide Tables (ANTT, 2021) and Admiralty Tide Tables Volume 4 (ATT, 2020), the Highest Astronomical Tide (HAT) for the project area is around 1.40m. As such, an adjustment of 1.40m is applied to the bathymetry dataset based on a conservative consideration.

The imagery of merged and reconstructed bathymetry dataset of Swan River is shown in **Figure 16**. From this figure it can be seen that the study area of interest involves relatively shallow water.

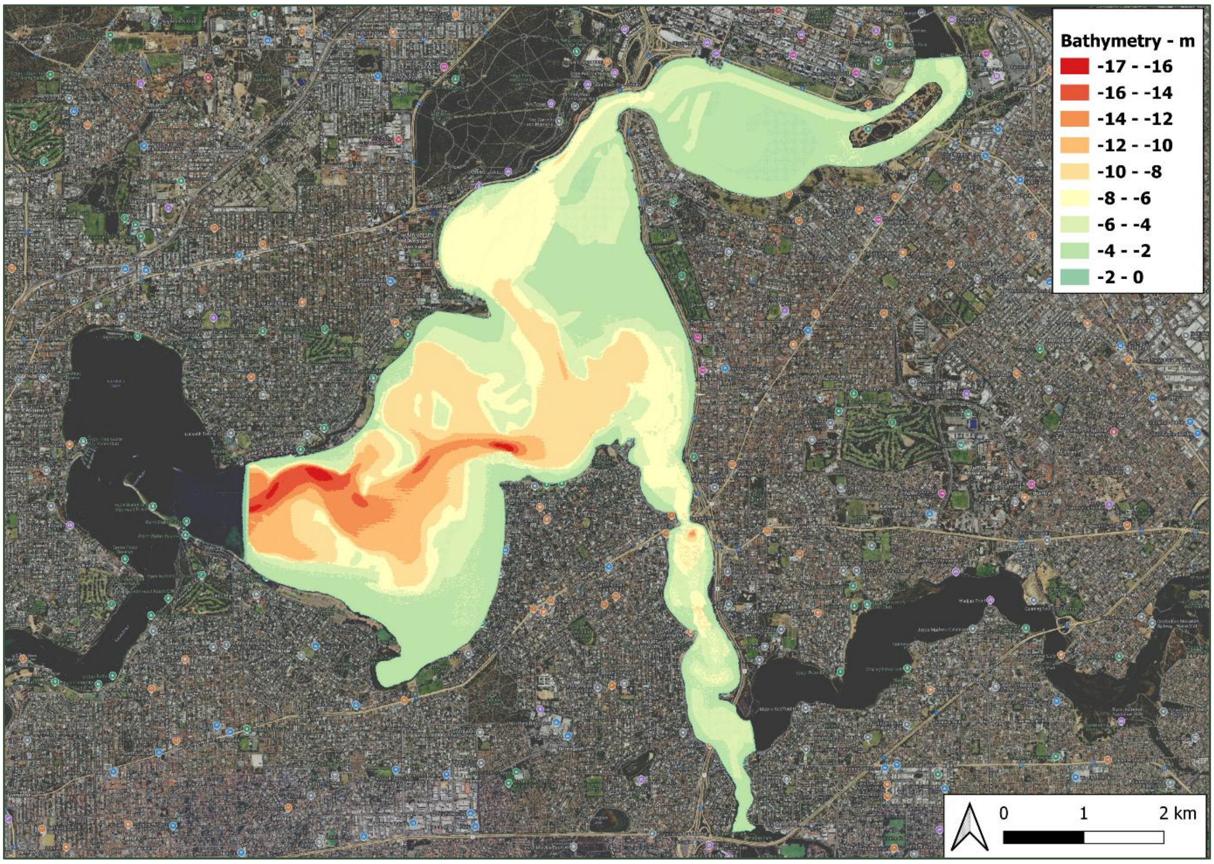

Figure 16 The imagery of merged and reconstructed bathymetry dataset around the project area.

2.3.4.2 Sound Speed Profiles

Temperature and salinity data required to derive the sound speed profiles were obtained from the Annual Swan Canning Estuarine Data Report (DWER, 2018). This data report is developed during the financial year 2017 – 2018 and presents data from June 2017 to May 2018 over background data generally from June 2012 to May 2017. The in-situ monitoring was conducted at multiple sites, and weekly sampling data were collected for the surface and bottom water at each monitoring site from June 2017 to May 2018, with monthly data values presented in Figure 17 below.

The sound speed profiles were derived based on an empirical function of the three independent variables (temperature (T) in degrees centigrade, salinity (S) in parts per thousand, and depth (z) in meters) (Medwin et al, 1997). Seasonal averages of the monthly median values of the sampling data collected over the monitoring sites within the Lower Swan Canning Estuary were used to derive the sound speed profiles.

Figure 18 presents the derived seasonal sound speed profiles within the Lower Swan Canning Estuary near the project area.

It can be seen that for Spring, Summer and Autumn seasons, the water column is relatively well mixed and sound speeds are relatively stable across the water depths. For Winter season, the surface water has low temperature and salinity compared with the bottom water, and the speed profile generally has relatively stronger upward refraction characteristics and is expected to be most favourable to propagation of sound from acoustic sources within the water column. As such, the winter season sound speed profile has been used for the sound propagation modelling in this study.

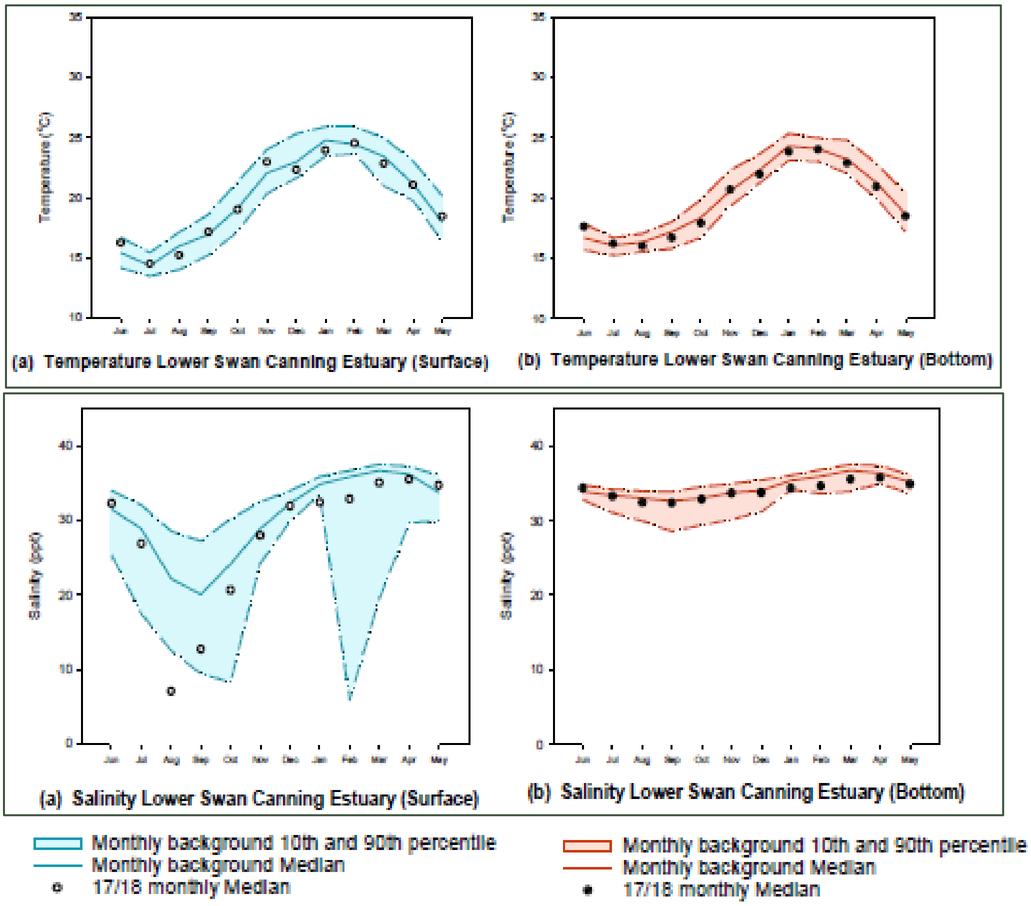

Figure 17 2017 – 2018 in situ temperature (°C) (top panels) and salinity (ppt) (bottom panels) in surface and bottom water, background (June 2012 – May 2017) sampling data, Swan Canning Estuary.

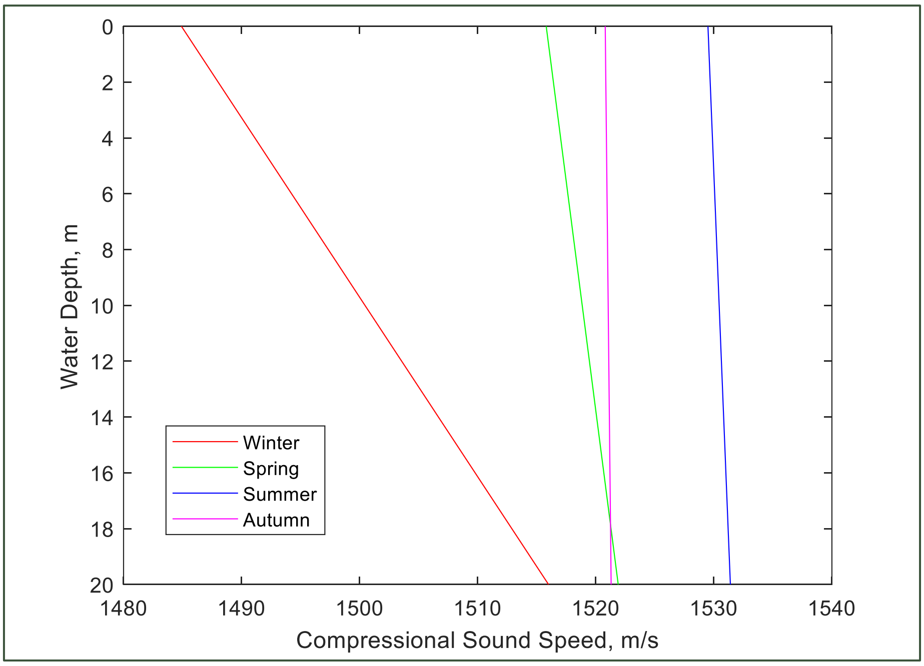

Figure 18 Sound speed profiles, Swan Canning Estuary for different southern atmosphere seasons

2.3.4.3 Seafloor geoacoustic model

The seafloor geoacoustic model for the modelling area is developed based on the sediment distribution assessment over the Swan River estuary (Quilty et al, 2006), as well as the regional geologic and geomorphic settings for the Perth region (McPerson et al, 2005; Davidson, 1995).

Sediment samples from 51 locations between the Narrow Bridge and Fremantle Harbour have been examined to assess the sediment distribution over the Swan River estuary (Quilty et al, 2006). The study revealed that the sediments over the estuary are dominantly clastic but include a significant biogenic content in certain areas. The distribution of the clastic component is controlled by water energy (and thus, secondarily, by depth). Fine-grained material (grey mud) is restricted to the basin and deeper, quieter channel setting. Sand is in the higher energy, shallow, floodplain and beach environments, including the estuary section between North Fremantle and Mosman Park.

A detailed review study on the geological settings and the geomorphic settings for the Perth region (Davidson, 1995) indicates that, along the coastal trip of the Perth region, the superficial formation is predominantly the Tamala Limestone as defined by Playford et al (1976). The Tamala Limestone contains various proportions of quartz sand, fine- to medium-grained shell fragments, and minor clayey lenses. Depending on the location, this formation has a maximum known thickness of 110 m in the Perth region. Its upper surface is exposed and leached to the extent that the upper part of the formation comprises unconsolidated limestone sand. This superficial formation is consistent with the site classification results based on the analysis of numerous geological borehole survey data within the central Perth region (Davidson, 1995).

Based on the above relevant studies on the top layer sediment distribution over the Swan River estuary, as well as the superficial geological formation over the Perth Basin, it is proposed that the seafloor geoacoustic model for the modelling area comprises of

- A 5.0-m sandy surface sediment layer.
- A 15-m slightly to semi-cemented sand/calcarenite 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		Shear Wave	
			Speed c_p, (m/s)	Attenuation α_p, (dB/λ)	Speed c_s, (m/s)	Attenuation α_s, (dB/λ)
Unconsolidated sandy layer	5.0	1,800	1,750	0.80	-	-
Slightly to semi-cemented sand/calcarenite layer	15	1,900	2,100	0.12	550	0.25
Semi-cemented sand/calcarenite half space	∞	2,200	2,600	0.20	1,200	0.40

It is noted that the modelling algorithm (i.e. RAMGeo) proposed for this modelling study, as detailed in **Section 2.3.2**, 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 shear wave parameter values set as zeros.

2.4 Underwater noise prediction results and discussion

2.4.1 Summary

The predicted piling noise levels were compared with relevant threshold criteria as listed in **Section 2.2** based on the scaled SEL level of a 150 kNm impact hammer with overall unweighted SEL level of 204 dB re 1 μPa2·S or equivalent, to determine distances at which the criteria are considered to be met. In summary, ***with direct line of sight and prior to any mitigation measures***:

- For Indo-Pacific bottlenose dolphins which carry particular interest:
  - The immediate impact from the piling noise is unlikely to cause physiological effects and is predicted to only have behavioural disturbance effects within 1.5 km from the piling locations.
  - The cumulative impacts from piling noise are predicted to have increasing zones of PTS and TTS effects with piling strikes. A cumulative exposure from up to 3,000 piling pulses within a 24-hour period is predicted to cause PTS effect within 700 metres and TTS effect within 2.0 km from the piling locations *if* the mammals remain in the area continuously.
- For fish species:
  - The immediate impact from the piling noise is predicted to have physiological effects within 20 metres from the piling locations.
  - The cumulative impacts from piling noise are predicted to have increasing zones of recoverable injury and TTS effects with piling strikes. A cumulative exposure from up to 3,000 piling pulses within a 24-hour period is predicted to cause recoverable injury up to 400 metres and TTS within 2.5 km from the piling locations, if these species remain in the area continuously.
- For human divers and swimmers:
  - Immediate impact from piling noise is predicted to present risk of adverse hearing effects out to 4.5 km, where there is an unobstructed noise path.

These distances are likely impracticable within a management plan, however please note that these distances are based on 'direct line of sight' and prior to any mitigation measures, i.e. assumes no screening from terrain, no specific mitigation and are conservatively rounded.

With the following mitigation scenarios as discussed in **Section 2.3.2.1**, the modelled management distances reduce as per **Table 10**.

Table 10 Zones of immediate impact for specific mitigation scenarios

#	Mitigation Scenario (Table 8)	Zones of impact – maximum horizontal distances, metres with direct line of sight to source	
		Indo-Pacific bottlenose dolphins	Human divers
1	Base case, no mitigation (150 kNm impact hammer piling)	1,400	> 4,500

#	Mitigation Scenario (Table 8)	Zones of impact – maximum horizontal distances, metres with direct line of sight to source	
		Indo-Pacific bottlenose dolphins	Human divers
2	Substitution of hydraulic hammer for a 150 kgm or lower class of vibratory hammer (e.g. PVE 150M or similar) at ca. 1,400 rpm or less	140	480
3	Hammer piling with an effective single row bubble curtain	750	2,980
4	Hammer piling with an effective double row bubble curtain	480	2,510
5	Use of effective isolation casings or double pile sleeve technology	330	1,410
6	Combination of vibratory hammer and bubble curtain	60	290

The predicted ferrying noise levels were compared with relevant threshold criteria as listed in **Section 3.0** to determine distances at which the criteria are considered to be met. The model is based on measurement on similar electric ferry with overall unweighted SEL level of 145 dB re 1 μPa2·S or equivalent, speed of 20 knots and current ferry service timetable. In summary, with direct line of sight:

- With proposed additional ferry operational, the threshold levels of PTS and TTS are not reached for marine mammal under 24-hour continuous exposure.
- The noise from ferry operations in considered to have very low physiological impacts (both mortality and recovery injury) on fish with swim bladder involved in hearing as the threshold levels are not reached.
- Potential behavioural disturbance from the non-impulsive noise emissions from ferry operations is predicted to be withing 10 m from the assessed ferry routes for marine mammals of all hearing groups, human divers and swimmers. For fish and turtle, the threshold levels are not reached.
- Even though adverse noise impacts are not anticipated based on the modelled results, there remains a potential risk of vessel collision with dolphins, particularly in high-use areas and during critical activity states such as resting or socialising. The quieter operation of electric vessels, while beneficial for reducing underwater noise pollution, may inadvertently increase collision risks by making vessels harder for dolphins to detect. As such, dolphin mitigation strategies should still be considered as the project progresses to minimise potential impacts.

The following sub-sections further detail these zones of impact estimated for all generic marine mammals, fish and turtle species, and human divers and swimmers.

2.4.2 Construction piling

2.4.2.1 Individual strike events

Table 11, **Table 12** and **Table 13** present zones of potential ‘immediate’ impact for various species and effects in response to a single strike.

From **Table 11** it can be seen that:

- Marine mammals of all hearing groups except VHF cetaceans are predicted to experience PTS effects within 10 metres from the 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 metres from the piling locations.
- The maximum zones of TTS effect for VHF cetaceans are predicted to be within 170 metres from the piling locations based on the modelled piling source level.

Table 11 Zones of immediate impact from single piling strikes for PTS and TTS – marine mammals, prior to mitigation

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL, dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL, dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	219	<10	213	<10
High-frequency cetaceans (HF)	230	-	224	<10
Very high-frequency cetaceans (VHF)	202	55	196	170
Sirenians (SI)	226	<10	220	<10
Phocid carnivores in water (PCW)	218	<10	212	<10
Other marine carnivores in water (OCW)	232	-	226	<10

Note A dash indicates the threshold is not reached.

Table 12 presents the zones of potential injuries for fish species with and without swim bladders, turtles and fish eggs and fish larvae. From this table it can be seen that:

- Most zones are predicted to be of 20 metres distance.
- Fish species without swim bladders have slightly higher injury impact thresholds, and the zone of potential injury is within 10 metres from piling locations.

Table 12 Zones of immediate impact single piling strikes for mortality and recovery injury – Fish and turtles, prior to mitigation

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

Type of animal	Zones of impact – maximum horizontal distances from source to impact threshold levels			
	Mortality and potential mortal injury		Recovery injury	
	Criteria - Pk SPL, dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL, dB re 1µPa	Maximum threshold distance, m
Turtles	207	< 20	-	-
Fish eggs and fish larvae	207	< 20	-	-

Note A dash indicates that the threshold is not applicable.

Table 13 presents zones of impact from the piling locations for behavioural disturbance for marine mammals and humans. Immediate exposure to individual strikes is predicted to be approximately within:

- 1,400 metres for all hearing groups of marine mammals.
- More than 4,500 metres for human divers and swimmers.

Table 13 Zones of immediate behavioural response impact from single piling strikes – All types of receivers, prior to mitigation

Receivers	Zones of impact – maximum horizontal distances with direct line of sight to source	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals, behavioural distance – all hearing groups	160	1,400
Human divers and swimmers	145	>4,500

2.4.2.2 Multiple strikes / cumulative effects

For *multiple piling strikes per day*, **Table 14** presents 'direct line of sight' distances for managing the potential cumulative impact of PTS and TTS.

It can be seen that:

- Among marine mammals of all six hearing groups, LF and VHF cetaceans have the highest potential zones of PTS and TTS impact.
- For LF cetaceans, the zones of PTS impact are predicted to be within 490 metres from piling locations with 100 piling strikes exposure and over 2,720 metres from piling locations with 3,000 piling strikes exposure.
- Compared with LF and VHF cetaceans, the remaining hearing group cetaceans have much lower impact zones.
- For HF cetaceans, the zones of PTS impact are predicted to be within 60 metres from piling locations with 100 piling strikes exposure and over 650 metres from piling locations with 3,000 piling strikes exposure.
- 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 14 Zones of cumulative impact from multiple piling strikes for PTS and TTS – marine mammals – varying strike exposures, prior to mitigation

Marine mammal hearing group	Zones of impact – maximum horizontal distances with direct line of sight to source			
	Injury (PTS) onset		TTS onset	
	Criteria - Weighted SEL24hr dB re 1 µPa2·s	Maximum threshold distance, m	Criteria - Weighted SEL24hr dB re 1 µPa2·s	Maximum threshold distance, m
Low-frequency cetaceans (LF)	183	100 strikes: 490 500 strikes: 1,080 1,500 strikes: 2,000 3,000 strikes: 2,720	168	100 strikes: 2,720 500 strikes: > 4,500 1,500 strikes: > 5,000 3,000 strikes: > 5,000
High-frequency cetaceans (HF)	185	100 strikes: 60 500 strikes: 190 1,500 strikes: 390 3,000 strikes: 650	178	100 strikes: 190 500 strikes: 550 1,500 strikes: 1,190 3,000 strikes: 1,890
Very high-frequency cetaceans (VHF)	155	100 strikes: 780 500 strikes:2,900 1,500 strikes: >4,500 3,000 strikes: >5,000	140	100 strikes: >5,000 500 strikes: > 5,000 1,500 strikes: > 5,000 3,000 strikes: > 5,000
Sirenians (SI)	203	100 strikes: 10 500 strikes: 10 1,500 strikes: 10 3,000 strikes: 20	175	100 strikes: 110 500 strikes: 340 1,500 strikes: 670 3,000 strikes: 1,080
Phocid carnivores in water (PCW)	185	100 strikes: 130 500 strikes: 360 1,500 strikes: 710 3,000 strikes: 1,130	170	100 strikes: 1,130 500 strikes: 3,060 1,500 strikes: > 4,500 3,000 strikes: > 4,500
Other marine carnivores in water (OCW)	203	100 strikes: 10 500 strikes: 10 1,500 strikes: 20 3,000 strikes: 30	188	100 strikes: 30 500 strikes: 80 1,500 strikes: 190 3,000 strikes: 300

As presented in **Table 15**, with an example of 3,000 piling pulses exposure,

- The zones of potential mortal injury are predicted to be within 20 metres from the piling locations for fish without swim bladder, increasing to 170 metres for fish with swim bladders involved in hearing.
- For recoverable injury, the zones of impact are predicted to be:
  - within 30 m from the piling locations for fish without swim bladder.
  - within 310 m for fish with swim bladder.
- The zones of TTS effects for fish species with and without swim bladders are predicted to be within 2,430 metres from the piling locations for the exposure scenario considered.

Table 15 Zones of cumulative impact from varying piling pulses – fish, turtles, fish eggs and fish larvae, prior to mitigation

<table>
<tr><th rowspan="3">Type of animal</th><th colspan="6">Zones of impact – maximum horizontal perpendicular distances from source to cumulative impact threshold levels</th></tr>
<tr><th colspan="2">Mortality and potential mortal injury</th><th colspan="2">Recoverable injury</th><th colspan="2">TTS</th></tr>
<tr><th>Criteria - SEL24hr dB re 1 μPa2·s</th><th>Maximum threshold distance, m</th><th>Criteria - SEL24hr dB re 1 μPa2·s</th><th>Maximum threshold distance, m</th><th>Criteria - SEL24hr dB re 1 μPa2·s</th><th>Maximum threshold distance, m</th></tr>
<tr><td>Fish: no swim bladder (particle motion detection)</td><td>219</td><td>100 strikes: 10
500 strikes: 10
1,500 strikes: 20
3,000 strikes: 20</td><td>216</td><td>100 strikes: 10
500 strikes: 10
1,500 strikes: 20
3,000 strikes: 30</td><td>186</td><td rowspan="3">100 strikes: 410
500 strikes: 900
1,500 strikes: 1,580
3,000 strikes: 2,430</td></tr>
<tr><td>Fish: swim bladder is not involved in hearing (particle motion detection)</td><td>210</td><td>100 strikes: 10
500 strikes: 20
1,500 strikes: 60
3,000 strikes: 100</td><td>203</td><td rowspan="2">100 strikes: 20
500 strikes: 80
1,500 strikes: 200
3,000 strikes: 310</td><td>186</td></tr>
<tr><td>Fish: swim bladder involved in hearing (primarily pressure detection)</td><td>207</td><td>100 strikes: 20
500 strikes: 40
1,500 strikes: 100
3,000 strikes: 170</td><td>203</td><td>186</td></tr>
<tr><td>Turtles</td><td>210</td><td rowspan="2">100 strikes: 10
500 strikes: 20
1,500 strikes: 60
3,000 strikes: 100</td><td>-</td><td rowspan="2">-</td><td>-</td><td rowspan="2">-</td></tr>
<tr><td>Fish eggs and fish larvae</td><td>210</td><td>-</td><td>-</td></tr>
</table>

Note A dash indicates that the threshold is not applicable.

2.4.2.3 Effect of mitigation

With reference to **Table 10**, **Figure 19** and **Figure 20** illustrate the predicted change in maximum threshold distances with the use of mitigation measures for human divers near each piling location.

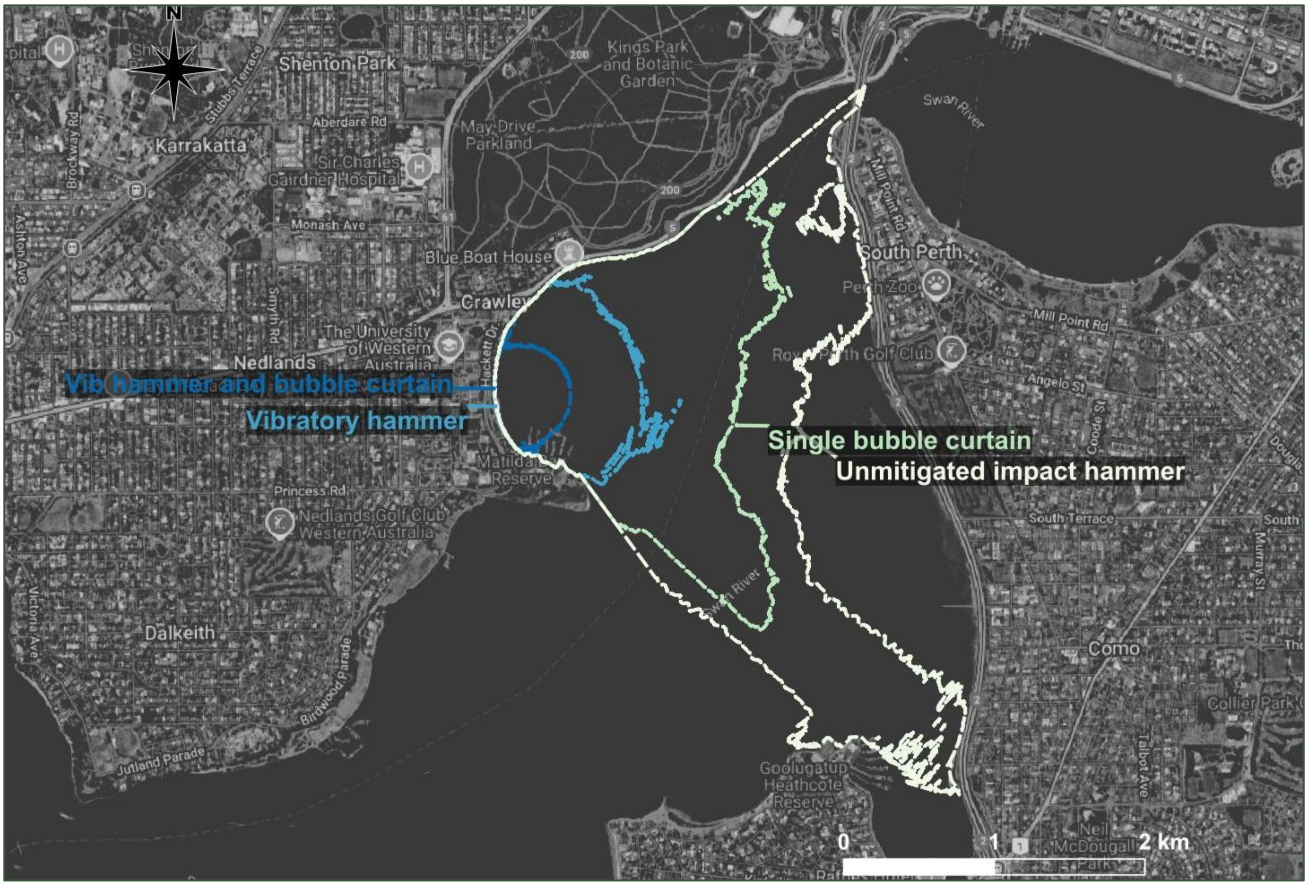

Figure 19 Aerial image indicating maximum threshold distances for selected management measures, piling location P2

Figure 19 indicates that the predicted threshold area for human divers is almost entirely within the Matilda Bay area should the piling method be substituted for a vibratory piling system and a bubble curtain used.

From **Figure 20** it can be seen that the predicted threshold area for human divers is relatively smaller for the piling position P3 given the more constrained channel area.

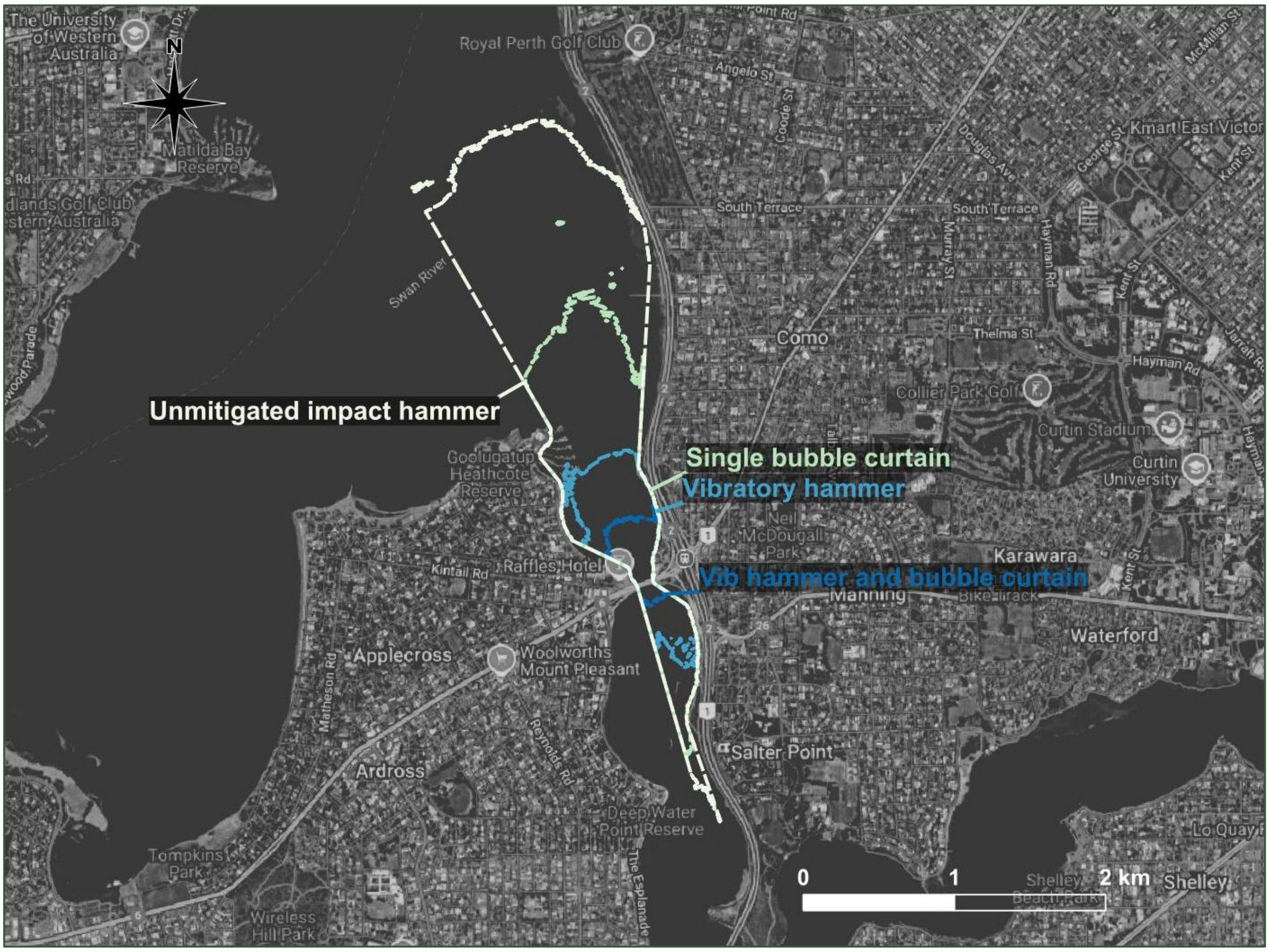

Figure 20 Aerial image indicating maximum threshold distances for selected management measures, piling location P3

2.4.3 Ferry operation

Impact zones from the ferry operation are calculated and assessed regarding cumulative 24-hour continuous exposure for marine mammals.

The modelled results show that, with proposed ferry operational source level or equivalent, speed of 20 knots and current ferry service timetable, the threshold levels of PTS and TTS are not reached for marine mammals.

There is also a significant margin of more than 20 dB between the assessed levels and the relevant criteria. If the ferry speed were reduced — for example, halved — while maintaining the same sound power level (which is considered unlikely), noise emissions would still not exceed the threshold levels.

Modelled ferrying results show that noise from ferry operations is considered to have very low physiological impacts (both mortality, recovery injury and TTS) on fish with swim bladder involved in hearing as the threshold levels are not reached.

Table 16 presents zones of impact from ferry operation for behavioural disturbance for marine mammals and humans. Potential behavioural disturbance from the non-impulsive noise emissions from ferry operations is predicted to be within 10 metres from the assessed ferry routes for marine mammals of all hearing groups, human divers and swimmers. For other groups, the threshold levels are not reached.

Table 16 Zones of immediate impact from non-impulsive noise for behavioural disturbance – marine mammals and human divers/swimmers

Receivers	Zones of impact – maximum horizontal distances with direct line of sight to source	
	Criteria - RMS SPL, dB re 1μPa	Maximum threshold distance, m
Marine mammals, behavioural distance – all hearing groups	120	<10
Human divers and swimmers	145	<10
Fish	150	-
Turtles	175	-

Note A dash indicates the threshold is not reached.

2.5 Aquatic Noise Management Plan

2.5.1 Overview

This plan is principled on the fact that, of the activities proposed, piling operations during construction have the highest noise emissions with impulsive characteristics. Therefore, piling operations are 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 is the major focus for this aquatic noise management plan.

Marine mammals, particularly the Indo-Pacific bottlenose dolphins, and human divers and swimmers are the major sensitive receptors to consider for this management plan. Biologically important areas within the Swan River region as part of the Swan Estuary Marine Park[4] are all not adjacent to the project area. Therefore, piling activities are not expected to result in significant impacts on key fish species that are acknowledged to be biologically important for the Swan River region.

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 curing 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 piling operations.

2.5.2 Noise management framework

The Government of South Australia's *Underwater Piling and Dredging Noise Guidelines* (2023) sets out guidance on procedures for piling underwater noise management as partially reproduced in **Figure 21** 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.

[4] http://www.fish.wa.gov.au/Sustainability-and-Environment/Aquatic-Biodiversity/Marine-Protected-Areas/Pages/Recreational-fishing-in-Swan-Estuary-Marine-Park.aspx

- **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.

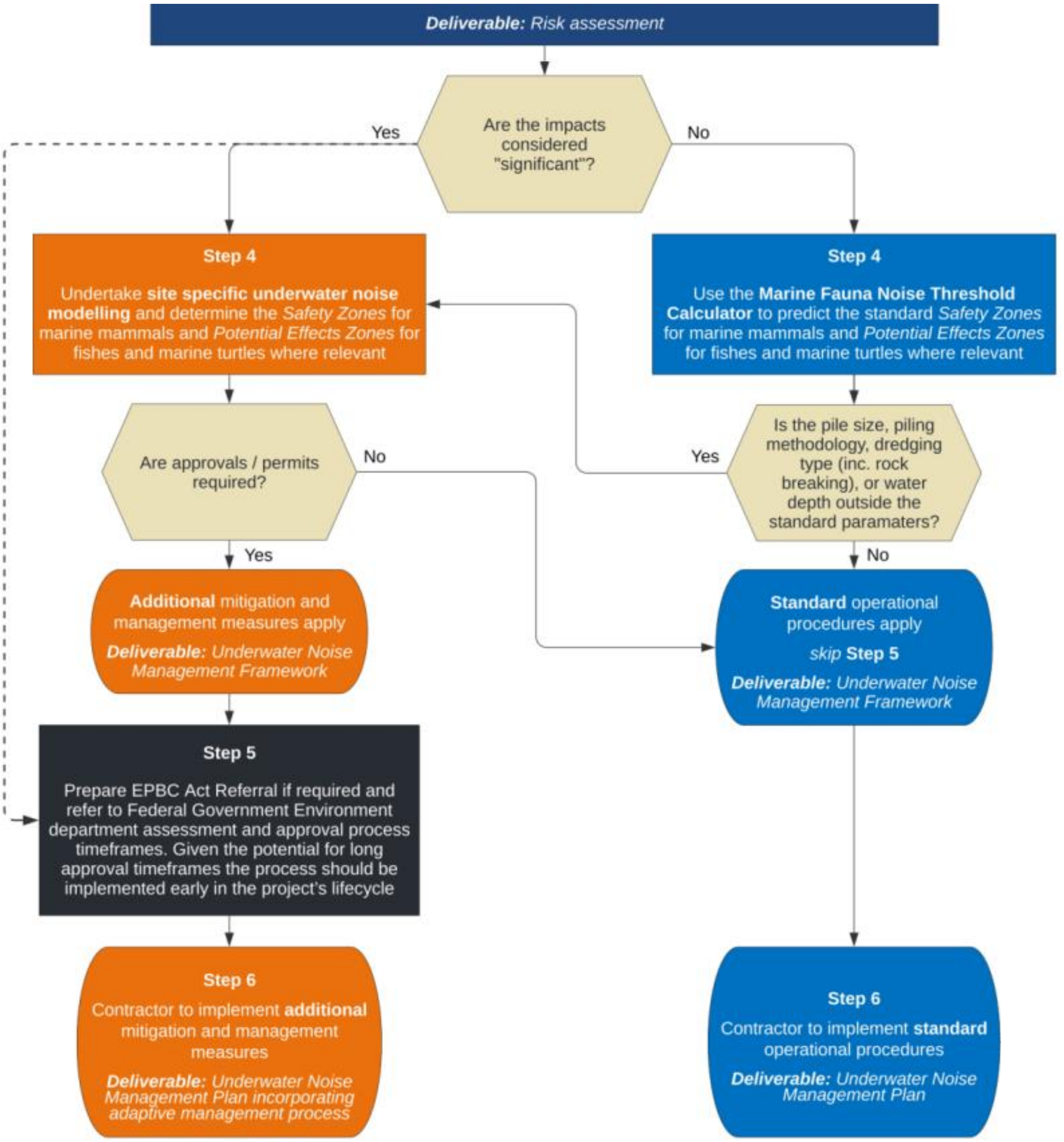

Figure 21 Piling noise management and mitigation framework (Government of South Australia, 2023)

2.5.2.1 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 immediately.

Suggested observation zones and shut-down zones are outlined in **Table 17** below and shown in Appendix C. 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.

Table 17 Proposed observation zones and shutdown zones

Key receptor of interest	Scenario (Mitigation as per Table 8)	Zone, metres (Note 1)		Rationale / Actions
		Shutdown	Observation	
Marine mammals	Base case / impact piling, unmitigated	190	440	Shutdown zones depend upon cumulative TTS impact which depends on 100 piling strikes within 24 hours period and animal movements of HF cetaceans. **Shutdown immediately if:** • Any animal observed to be in distress within the Observation Zone (Note 2); or • Otherwise within the Shutdown Zone. Zones are specific to areas with direct line of sight to each piling rig area.
	With any of the mitigation measures in **Table 8**, e.g. substitution for vibratory hammer, bubble curtains, isolation casings or double pile sleeves, or combination thereof	20	270	
Human divers / swimmers	Base case / impact piling, unmitigated	4,500 (Direct line of sight, i.e. **Figure C.1** and **Figure C.2**)		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. Refer to **Figure 19** and **Figure 20** for plan extents of indicative shutdown zones for each mitigation measure.
	Substitution for vibratory hammer	500		
	Hammer piling with single row bubble curtain	3,000		
	Hammer piling with double row bubble curtain	2,500		
	Hammer piling with isolation casings or double pile sleeves	1,500		
	Vibratory hammer with bubble curtain	300		

Note 1 Based on a precautionary measure, for HF cetaceans it is recommended to implement a shut-down zone equivalent to a cumulative TTS impact zone under 100 piling strikes within a 24-hour period. The observation zone is based on a nominal 250 metre distance from the outer edge of the shut-down zone as per industry guidelines.

Note 2 Signs of distress as per (Parnum et al, 2015) include: uncoordinated swimming or difficulty in swimming, neonate or very young calf separated, entangled animal, continuous aggressive behaviours not directed at any other dolphin, and not part of foraging (over 5 minutes), mother pushing up a young calf to breath (indicative of a calf struggling to breath, or of a mother in distress pushing her dead calf to the surface), animal with obvious injury or unhealthy appearance (lesions, etc.), aggressive behaviour or any other erratic behaviour in direct response to pile driving activity.

2.5.2.2 Standard management and mitigation measures

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

- Contract documentation – include these requirements for piling 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 22**:
  - 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 diver/swimmer 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.
- Field monitoring of underwater piling noise levels – consideration will be given to undertaking attended field monitoring to confirm source emission levels and propagation rates and verify predicted levels and this Plan as required.

2.5.2.3 Additional mitigation measures

The following additional mitigation measures will be considered to further minimise noise impact on marine mammals, based on the practicality and effectiveness of these measures.

- Reduced strike count per day, if feasible. Fewer piling strikes within a 24-hour period results in lower cumulative SELs, and therefore reduced impact extents.
- 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 2009; Jimenez-Arranz et al, 2020).

  These measures include but not limited to the following:

  - **Isolation casings/pile sleeves, e.g., IQIP Noise Mitigation Screen (NMS).** 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 (or filled with a constant flow of bubbles) so that the work area could be isolated from the surrounding water column and attenuate the sound propagation. Dewatered isolation casings generally can be expected to provide 10-15 dB of attenuation. However, it could be challenging to integrate the placement and removal of the pile sleeve into the piling driving operation.
  - **Hydro-Sound-Damper-System** (HSD-System) nets are proprietary sheets that wrap around the working pile, providing typically 10 to 20 dB reduction in SEL.
  - **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 result 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, due to the strong tidal conditions at the project location, the effectiveness of the bubble curtain could be significantly compromised.

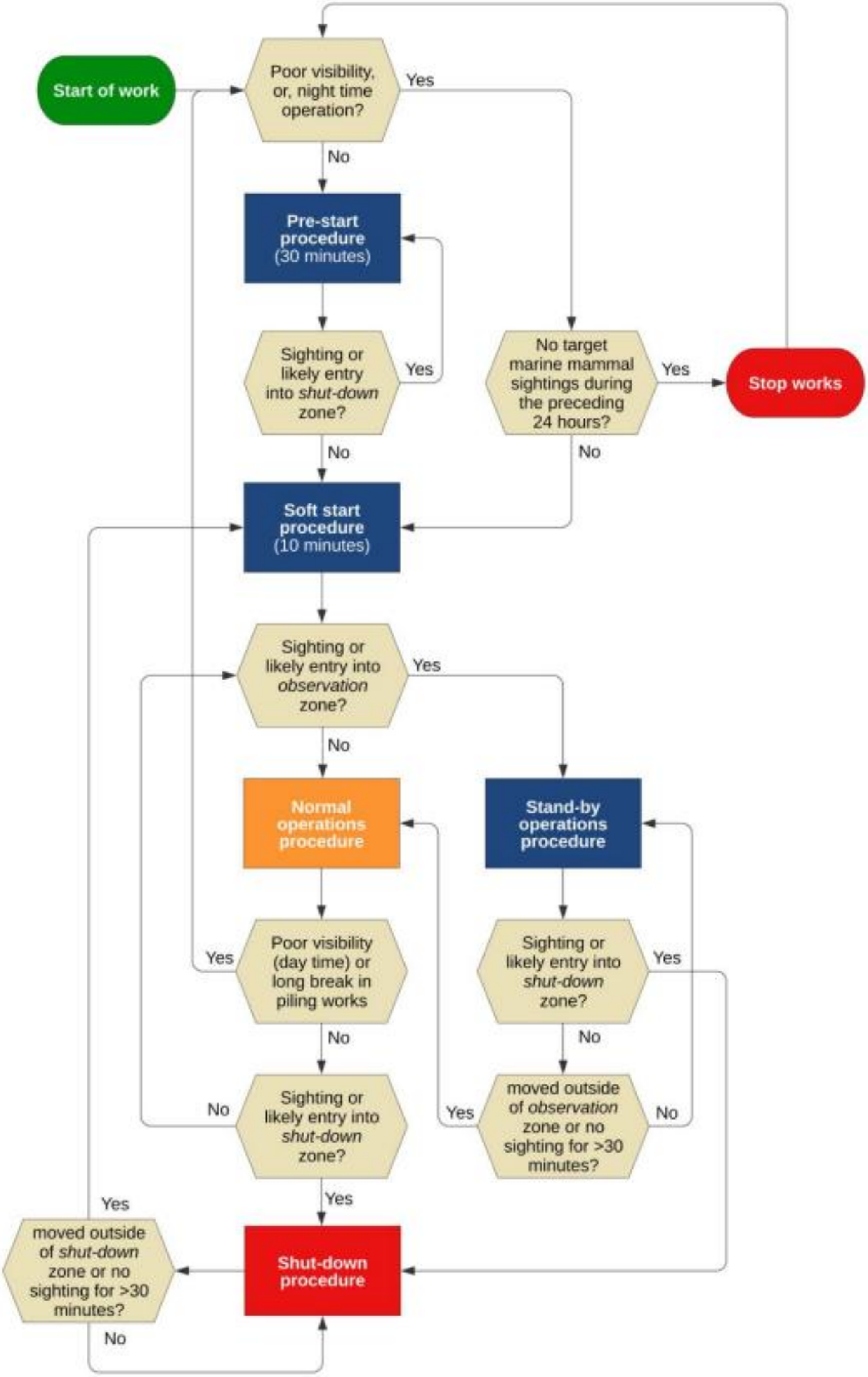

Figure 22 Piling noise management procedures (Government of South Australia, 2023)

3.0 Airborne noise assessments

3.1 Background

Airborne noise emissions from construction and operation of the ferry services have the potential to impact nearby areas.

The following subsections present studies undertaken to quantify these potentials for impact.

3.2 Existing environment

Appendix E details ambient sound level measurements undertaken in the vicinity of each construction area.

These measurements indicate ambient sound levels are driven by local resident activities, local and distant road traffic, movement of flora under wind and local fauna. Evening background sound levels were measured to be in the range of L_{A90} 50 to 53 dB across all sites. Night period background sound levels were measured to be about L_{A90} 45 dB, due to distant road traffic.

Noise sources above L_{Aeq} 40 dB are therefore considered to have the potential to influence background levels in these locations.

3.3 Criteria

Project noise emissions are addressed by state noise policy in the form of the *Western Australia Environmental Protection (Noise) Regulations 1997* (EPNR). To achieve compliance with this policy, noise levels at nearby residential areas are not to exceed defined limits referred to as Assigned Noise Levels. These limits are determined from consideration of prevailing background noise levels and ‘influencing factors’ that considers the level of commercial and industrial zoning in the locality.

The influencing factor (IF) considers zoning and road traffic around the nearest sensitive receiver of interest, within 100 metre and 450 metre distances. A summary of applicable noise limits is provided in **Table 18**.

Table 18 Assigned noise levels summary

Part of premises receiving noise	Time of day	Assigned level, dB		
		L_{A10}	L_{A1}	L_{Amax}
Noise Sensitive premises at locations within 15 metres of a building directly associated with a noise sensitive use	0700 to 1900 hours Monday to Saturday *(‘Day’)*	45 + IF	55 + IF	65 + IF
	0900 to 1900 hours Sunday and public holidays *(‘Sundays’)*	40 + IF	50 + IF	65 + IF
	1900 to 2200 hours all days *(‘Evening’)*	40 + IF	50 + IF	55 + IF
	2200 hours on any day to 0700 Monday to Saturday and 0900 hours Sunday and public holidays *(‘Night’)*	35 + IF	45 + IF	55 + IF
Noise Sensitive premises at locations further than 15 metres from a building directly	All hours	60	75	80

Part of premises receiving noise	Time of day	Assigned level, dB		
		L_{A10}	L_{A1}	L_{Amax}
associated with a noise sensitive use.				
Commercial premises	All hours	60	75	80
Industrial and utility premises	All hours	65	80	90

The only site with operational noise emissions is in the Matilda Bay area. In this area, Hackett Drive is considered a major road, and ignoring potential commercial zoning, the minimum IF for foreshore areas would be at least 6. During the evening period, the minimum assigned level in the area would therefore be L_{A10} 46 dB.

If noise emitted from any premises when received at any other premises cannot reasonably be free of intrusive characteristics of tonality, modulation and impulsiveness, then a series of adjustments must be added to the emitted levels (measured or calculated) and the adjusted level must comply with the assigned level.

The adjustments are detailed in **Table 19** and are further defined in Regulation 9(1) of the Environmental Protection (Noise) Regulations 1997.

Table 19 Table of adjustments

Noise characteristic	Definition	Adjustment if present (Note[1])
Tones	Where the difference between the A weighted sound pressure level in any one third octave ban and the arithmetic average of the A weighted sound pressure levels in the two adjacent one third octave bands is greater than 3 dB in terms of $L_{Aeq,T}$ where the time period T is greater than 10% of the representative assessment period, or greater than 8 dB at any time when the sound pressure levels are determined as L_{ASlow} levels.	+5 dB
Modulation	A variation in the emission of noise that: • Is more than 3 dB L_{AFast} overall or is more than 3 dB L_{AFast} in any one third octave band. • Is present for at least 10% of the representative assessment period. • Is regular, cyclic and audible.	+5 dB
Impulsiveness	Present where the difference between the L_{APeak} and L_{Amax} is more than 15 dB when determined for single representative event.	+10 dB

Note 1 where noise emission is not music, these adjustments are cumulative to a maximum of 15 dB.

3.4 Airborne noise modelling prediction methods

3.4.1 Scenarios

3.4.1.1 Construction

General construction activities have been modelled at each construction site. Impact piling activities were modelled at the Matilda Bay and Applecross locations.

3.4.1.2 Operation

Key sources of potential noise emissions during operations are considered to be:

- Ferry movements.
- Bus movements on existing roads, or roads that are not significantly modified in the context of State Planning Policy 5.4.
- Battery charging systems and fixed plant. These sources are expected to operate once the ferries are returned to Matilda Bay in order to charge the ferry batteries.

From this list, only the charging infrastructure and fixed plant is considered assessable against the criteria listed in **Section 3.3**.

Crowd noise from ferry terminal areas are considered insignificant in the context of this assessment, given that patrons using the service generally do not converse with each other except in occasional limited groups.

Passenger and station announcements are not considered to be broadcast using a distributed / long line public address (LLPA) system, so are considered insignificant.

3.4.2 Source levels

As detailed in the following subsections, source levels for each phase were estimated from manufacturer documentation, industry standards such as AS 2436[5] and SLR historical data.

3.4.2.1 Construction

Table 20 lists the typical time-averaged sound power level of various plant items modelled. This table is not exhaustive but considered to fairly represent the most significant noise emissions over typical assessment periods. It is important to note that actual construction noise emissions will vary significantly over the course of a typical day and also over the entire construction program. The 'consolidated site' level is considered to represent typical noise emissions during peak construction activity.

Table 20 Modelled sound power levels of construction plant, unweighted dB

Source, metric	Octave band centre frequency, Hz								Sum dB(A)
	63	125	250	500	1000	2000	4000	8000	
Piling rig strike, L_{wAmax}	130	136	128	130	126	123	118	115	132
Crane, L_{Aeq}	103	102	108	108	109	107	104	108	114
Hand tools, L_{Aeq}	111	105	95	93	90	88	82	73	96
Concrete Agitator, L_{Aeq}	102	92	92	91	91	93	83	77	97
Concrete Vibrator, L_{Aeq}	92	104	87	89	90	88	88	82	96
Concrete Pump, L_{Aeq}	100	100	90	89	87	86	80	72	93
Tracked Excavator, L_{Aeq}	105	108	101	98	97	95	94	91	103
Consolidated site level, L_{Aeq}	113	112	109	109	109	107	104	108	115

5 AS 2436:2010 Guide to noise and vibration control on construction, demolition and maintenance sites

From this table it can also be seen that impact piling noise will generate the highest noise levels at distance. Such impact piling noise is produced at an elevated height and may have fewer options for mitigation (besides substitution for screw or press-in methods).

3.4.2.2 Operation

Table 21 lists the source levels modelled for operational plant at Matilda Bay.

Table 21 Modelled sound power levels of operational plant, unweighted dB

Source	Octave band centre frequency, Hz							Sum, dB(A)	Basis
	63	125	250	500	1000	2000	4000		
Transformer, L_{A10}	61	65	63	53	49	43	-	58	SLR field data of 500 kVA units
Distribution Charging Unit (DCU), L_{A10}	63	69	70	69	64	62	63	71	Manufacturer claim of L_{Aeq} 55 dB(A) at 1 metre or less

The model conservatively assumes two transformers and eight DCUs in operation at 100% duty during the evening. The chargers are noted to ventilate on one side which would increase noise emissions in that direction. In the absence of test data and similar to axial fans, a shaped +5 dB on-axis directivity adjustment has been applied.

3.4.3 Environmental effects

Environmental effects were accounted for using ISO 17534[6] compliant software (iNoise 2024.02) as follows:

- Detailed 3-dimensional representation of the site terrain model and local environment inclusive of key receptor locations.
- Buildings and property fences were retained in the noise model where they could provide screening or reflection of sound.
- Grass / vegetated surfaces were modelled with a 0.6 absorption (60% soft ground) coefficient which is considered reasonably representative of semi-compacted soil. Water and road surfaces were modelled as acoustically hard (no absorption).
- Barrier and screening effects according to ISO 9613-3:2024[7].
- Propagation and air absorption losses according to CONCAWE methods, using the DWER 'default' environmental conditions for the evening period.
- Receiver positions were located one metre from nearby building facades, conservatively 2 metres above local floor or ground level.

3.5 Results

3.5.1 Construction

For the Matilda bay area, **Figure 23** and **Figure 24** present the predicted distribution in noise contours for piling and general construction activities respectively.

[6] ISO 17534-1:2015 Acoustics — Software for the calculation of sound outdoors

[7] ISO 9613-2:2024 Acoustics — Attenuation of sound during propagation outdoors Part 2: Engineering method for the prediction of sound pressure levels outdoors

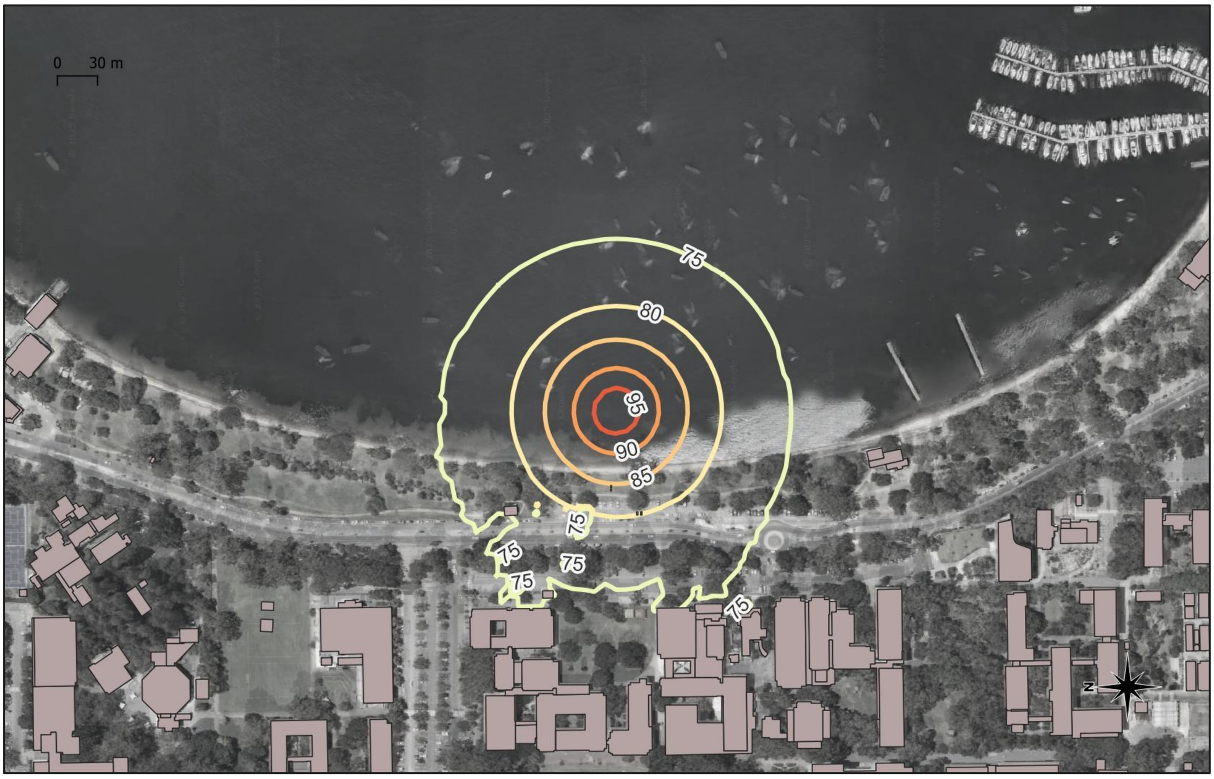

Figure 23 Predicted distribution in noise level (L_{Amax}), piling scenario in Matilda Bay, dB

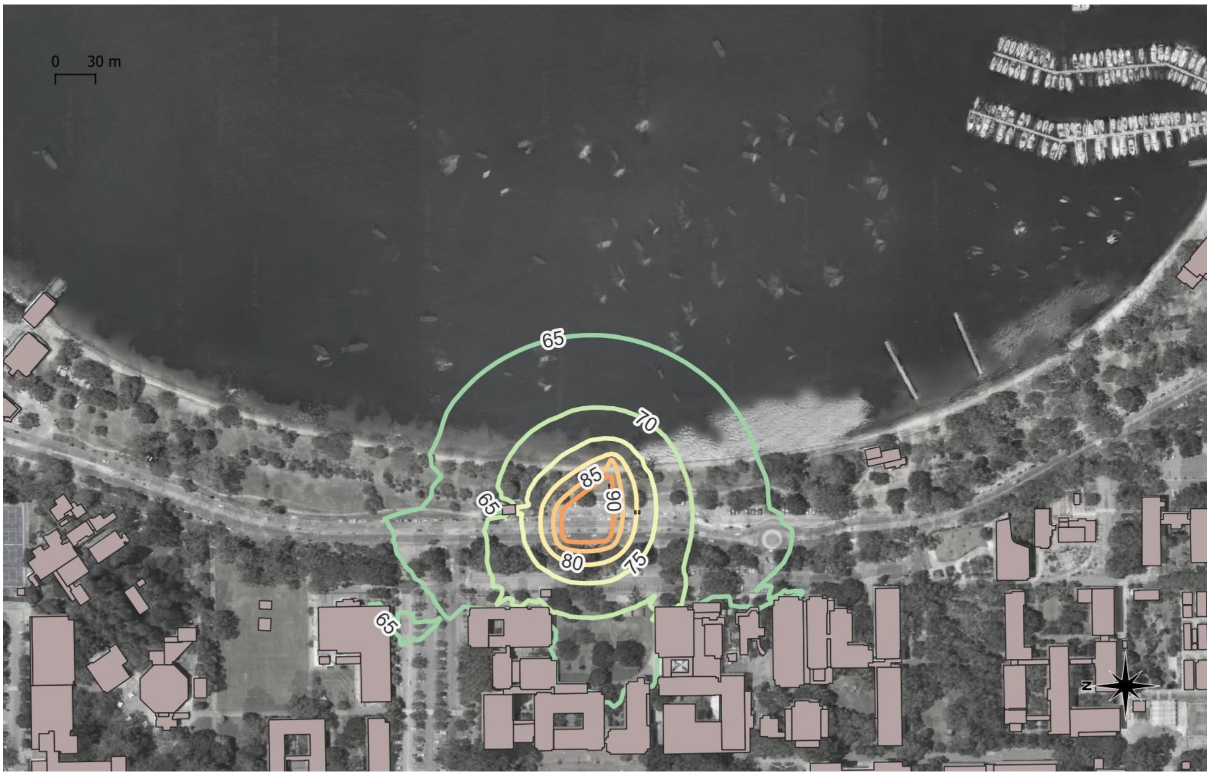

Figure 24 Predicted distribution in noise level (L_{Aeq}), general construction scenario in Matilda Bay, dB

For the Applecross site, **Figure 25** and **Figure 26** present the predicted distribution in noise contours for piling and general construction activities respectively.

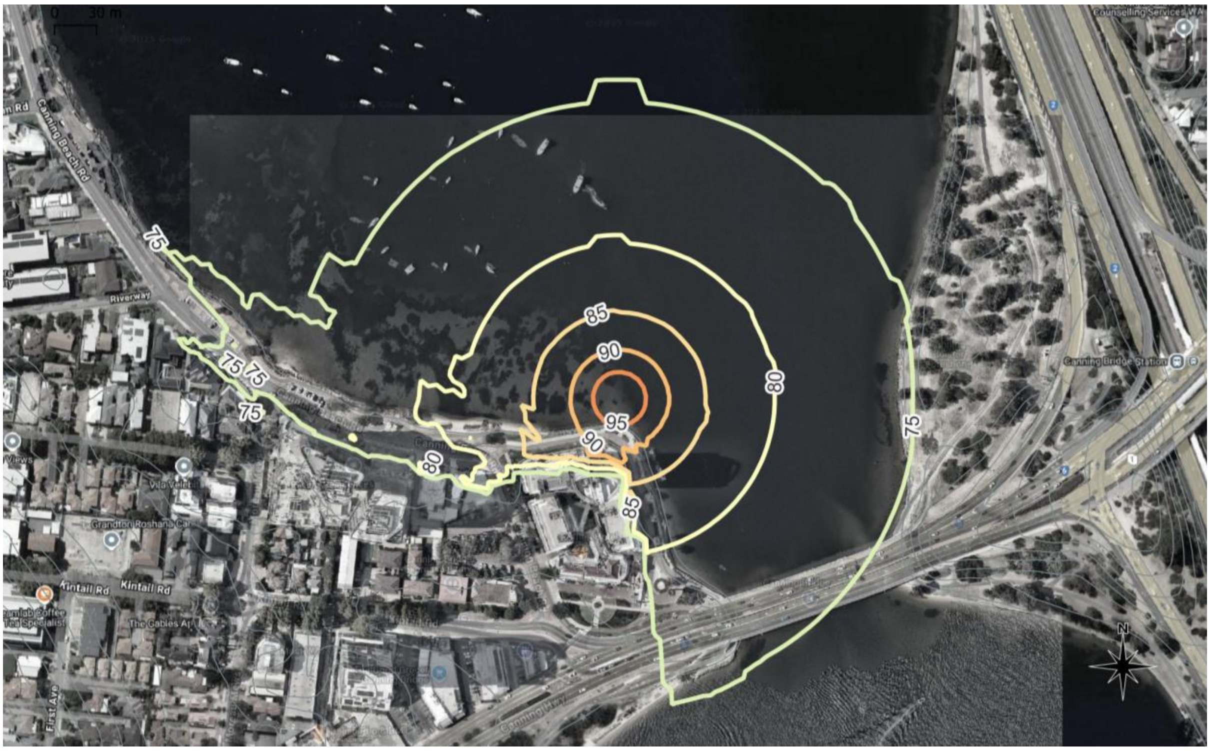

Figure 25 Predicted distribution in noise level (L_{Amax}), piling scenario in Applecross, dB

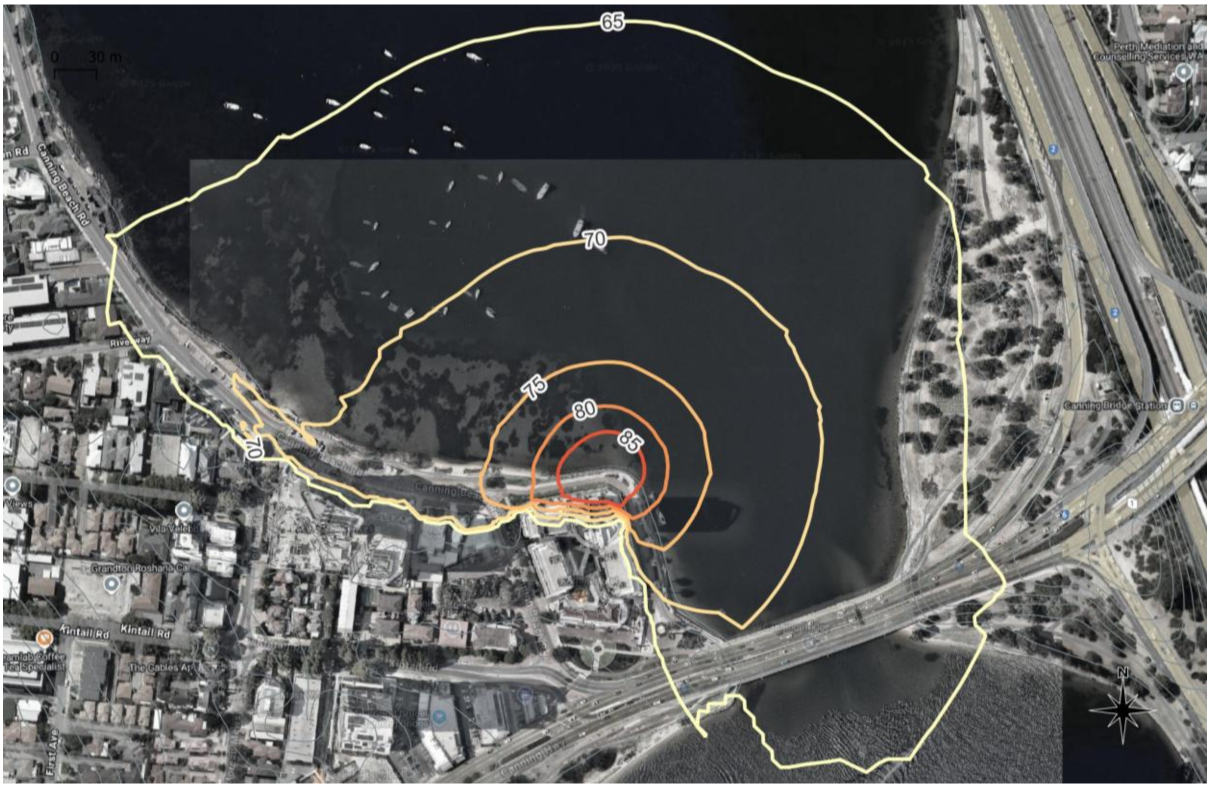

Figure 26 Predicted distribution in noise level (L_{Amax}), general construction scenario in Applecross, dB

Figure 27 indicates the predicted noise level distribution within the Elizabeth Quay area.

Figure 27 Predicted distribution in noise level (L_{Amax}), general construction scenario in Elizabeth Quay, dB

Without mitigation or management, all scenarios indicate high potential for noise impact on nearby sensitive areas, with predicted levels well above ambient levels and with character dissimilar to the existing environment.

Impact piling noise without mitigation presents the highest risk of impact during the life of the project. Without mitigation, it is likely to be occasionally audible from opposite sides of the river and distances more than a kilometre away.

Procedures around these activities should be addressed within an approved noise management plan in addition to any underwater noise management measures.

3.5.2 Operation

Figure 28 presents the predicted distribution in noise levels from charging infrastructure in the Matilda Bay area. This distribution is dominated by the DCUs and is above the L_{Aeq} 40 dB level at positions well outside the spatial footprint of the facility. This indicates increased noise impacts on surrounding areas unrelated to the project.

During the evening period and on Sundays, the predicted noise levels may be considered to be above an assigned noise level of L_{Aeq} 46 dB outside the facility.

One option is to insert a screen behind the northern and southern facades with a sound absorptive surface facing the DCUs. Such a wall was modelled as constructed from modular steel panels with an acoustically absorptive lining (ISO 11654 Class B, nominally 50 mm thick scrim mesh faced mineral fibre insulation) on wall sections directly opposite the DCUs. Solid screens could also be constructed from transparent acrylic, timber or other sustainable materials provided the construction is airtight and with a surface mass of over 10 kg/m^2, however with hard internal noise reflective surfaces, wall extents would need to be significantly wider or more angled in order to provide similar noise containment.

Figure 29 presents the resultant distribution of noise from this mitigation option.

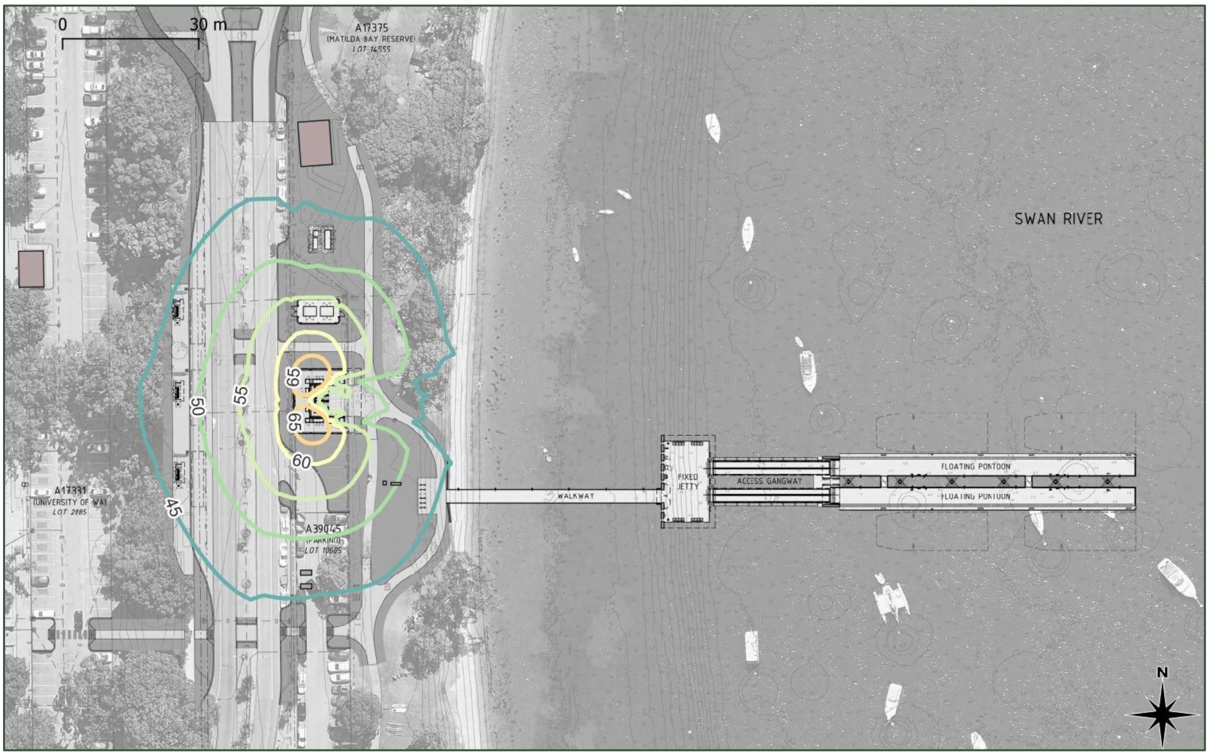

Figure 28 Predicted distribution in operational noise level (L_{Aeq}), evening charging scenario in Matilda Bay, dB – with proposed layout.

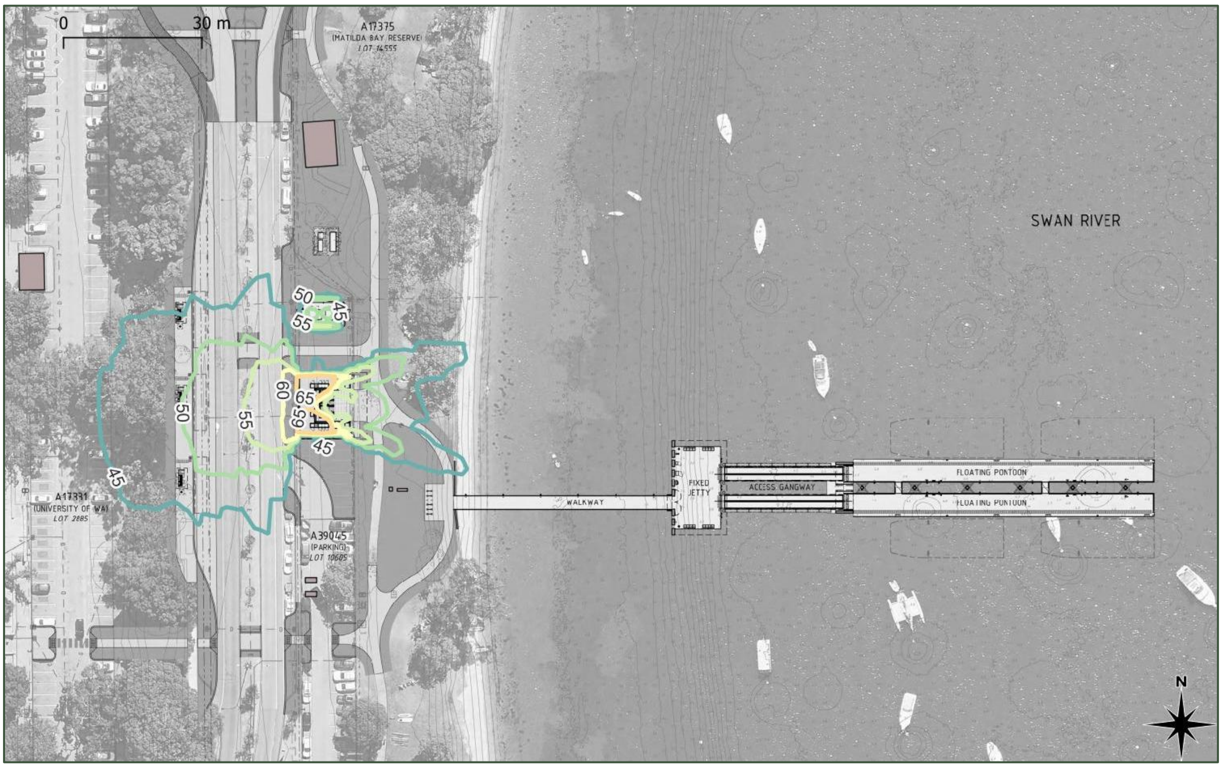

Figure 29 Predicted distribution in operational noise level (L_{Aeq}), evening charging scenario in Matilda Bay, dB – with example mitigation

Some emission to the east is projected however this is considered acceptable in relativity close proximity to the facility and nearby toilet amenities. Increasing ambient levels near toilet amenities assists with improving privacy and the user experience.

The results presented show that noise from the DCUs can be effectively contained to areas associated with the facility, with any remaining noise spill limited to existing road and carpark locations. Accordingly, the project can be managed to comply with state noise regulations.

4.0 Ground vibration assessment

4.1 Background

This section considers the potential impact of vibration from construction and operation of the project on surrounding terrestrial areas.

Considering the construction and operation of this project, only construction activities are expected to generate significant levels of ground vibration.

The construction activities with significant potential for vibration emissions on this project are

- Piling, particularly impact piling with a hydraulic hammer.
- Civil earthworks, such as excavation and compaction.

4.2 Criteria

It is important to note that vibration can affect the environment in several ways. Vibration can reduce comfort and enjoyment of an area, and at significantly higher levels can reduce the serviceability and/or condition of a structure. It is important to understand that the levels at which vibration is noticeable and annoying to residents are at least an order of magnitude lower than the lowest limits at which it is considered to present actual risk of damage.

Vibration limits are not specifically defined within state legislation but could be considered under the *Environment Protection Act 1986* as a form of unreasonable noise.

4.2.1 Structural condition

For existing buildings, British Standard BS 7385 - Part 2 has historically been used set vibration targets. These criteria are defined in terms of the Peak Particle Velocity (PPV). As shown in **Figure 22**, this Standard provides frequency dependent vibration guideline values and assessment values for estimating damage risks associated with structures.

These levels are judged to give a minimum risk of vibration-induced damage, where minimal risk is usually taken as a 95% probability of no effect.

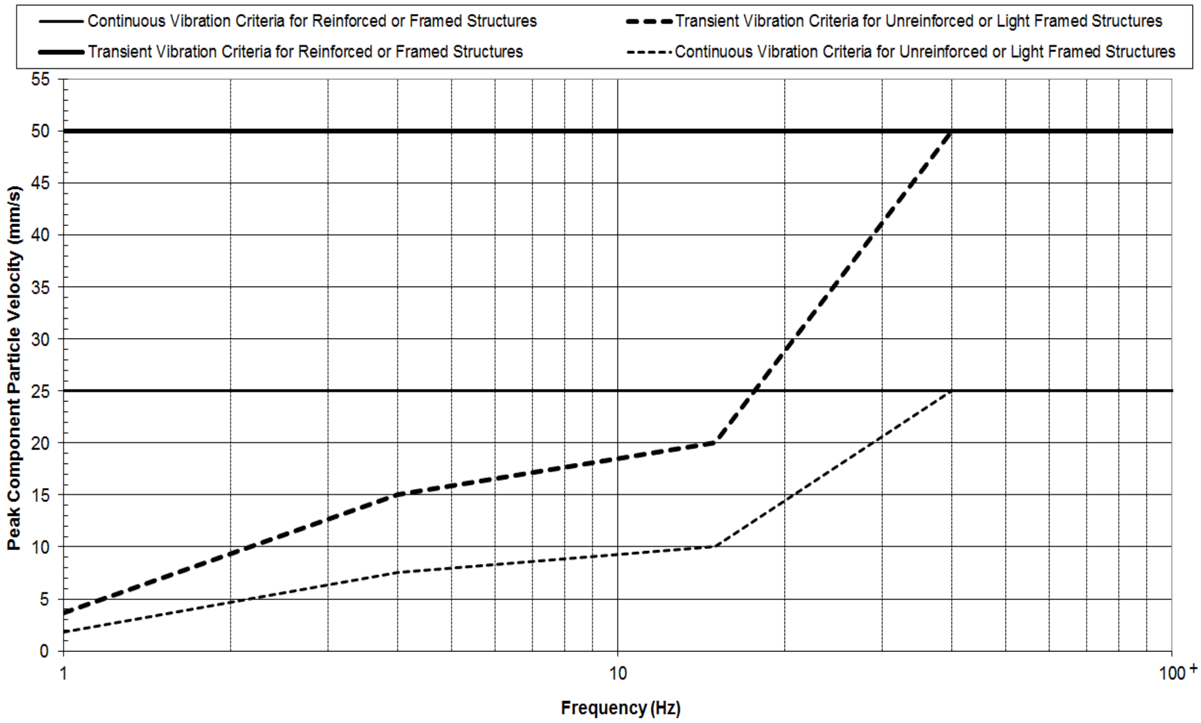

Figure 30 Guide limits for continuous and transient vibration relating to cosmetic damage (adapted from BS 7385.2:1993)

DIN 4150-3:2016-12 Vibrations in buildings – Part 3: Effects on structures is considered more conservative. It states that “Experience shows that no damage due to vibration adversely affecting serviceability will occur if these guideline values are complied with. If damage nevertheless occurs, it is to be assumed that other causes are responsible. Exceeding the guideline values does not necessarily lead to damage.”

For short term vibration (meaning that which is relatively short in duration or of limited cycles such that it would not induce resonant behaviour), it suggests a PPV target of 20 mm/s on a building floor slab (vertical direction).

For longer term vibration (such as vibratory rollers and earthworks), it recommends a reduced target of PPV 10 mm/s measurable on the building floor slab.

Therefore, the recommended guideline peak particle velocity (PPV) limits to minimise risk of cosmetic damage to reinforced concrete buildings are as follows:

- 20 mm/s for piling.
- 10 mm/s for all other construction vibration such as truck movements and vibratory rollers.

There may be opportunity to revise the construction vibration targets, following on-site inspection of existing conditions.

4.2.2 Underground services

The guideline '*Additional Information for Working Around Gas Infrastructure'* by ATCO[8] states that:

> *"To avoid pipeline damage, vibrations from any site-works or activities must not exceed 5 mm/sec Peak Particle Velocity (PPV) as measured at the gas pipeline, by an ISO 9000 quality-accredited vibration monitoring company. If requested, you must provide ATCO with the results of the vibration readings by the next working day."*

Therefore, near any gas pipelines in the area, the vibration target is 5 mm/s Peak Particle Velocity (PPV).

From DIN 4150

4.2.3 Human comfort

Industry standards and guidelines that have been adopted by industry within Australia for the assessment of impacts of vibration from construction activities on human comfort include:

- Australian Standard AS 2670.2-1990: Evaluation of Human Exposure to Whole-body Vibration, Part 2: Continuous and Shock-induced Vibrations in Buildings (1 Hz to 80 Hz). This standard sets out objective targets but has been withdrawn.
- British Standard BS6472-2008: Guide to evaluation of Human Exposure to Vibration in Buildings – Part 1: Sources of vibration other than blasting. Instead of the PPV referred to in previous sections above, this standard sets out criteria in terms of the fourth power Vibration Dose Value (VDV), which is based on weighted acceleration levels over time. It can be readily measured but not able to be estimated with confidence for general construction activities, or from existing field data in terms of PPV.
- NSW DEC, Assessing Vibration: a Technical Guideline, 2006. This document contains RMS criteria aligned to AS 2670 and international guidelines.

Appendix C of the NSW guidelines references the following maximum root-mean-square (RMS) criteria:

- Residences – continuous vibration target of 0.28 (day) to 0.4 (night) mm/s RMS.
- Residences – impulsive vibration target of 4 to 12 mm/s RMS.

RMS units may be related to PPV units by a ratio referred to as the crest factor, which varies depending on a variety of factors associated with the construction activity and distance from site. With a conservatively low crest factor estimate of 4, the above targets are at least 1 mm/s PPV for continuous vibration (say from vibratory rollers) and 16 mm/s PPV for impulsive vibration (say from impact piling).

For context, human tactile perception of random motion, as distinct from human comfort considerations, was investigated by Diekmann and subsequently updated in German Standard DIN 4150 Part 2 1975. On this basis, the resulting degrees of perception for humans are suggested by the continuous vibration level categories given in **Table 22.**

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8 Document No: AGA-O&M-PR24, Revision No:12, Issue Date: 25/10/2021.

Table 22 Guide to human perception responses to vibration levels

Approximate Vibration Level, PPV mm/s	Degree of Perception
0.10	Not felt
0.15	Threshold of perception
0.35	Barely noticeable
1	Noticeable
2.2	Easily noticeable
6	Strongly noticeable
14	Very strongly noticeable

Note: These approximate vibration levels (in floors of building) are for vibration having frequency content in the range of 8 Hz to 80 Hz.

This table suggests that people will just be able to feel continuous floor vibration at levels of about 0.15 mm/s and that the motion becomes "noticeable" at a level of approximately PPV 1 mm/s.

4.3 Assessment

Figure 31 presents measured and/or published vibration levels in sandy soil ground with distance for plant which could be used for construction of this project. It is important to note that there will be some variability in practice due to local ground soil conditions and the actual equipment and plant selected.

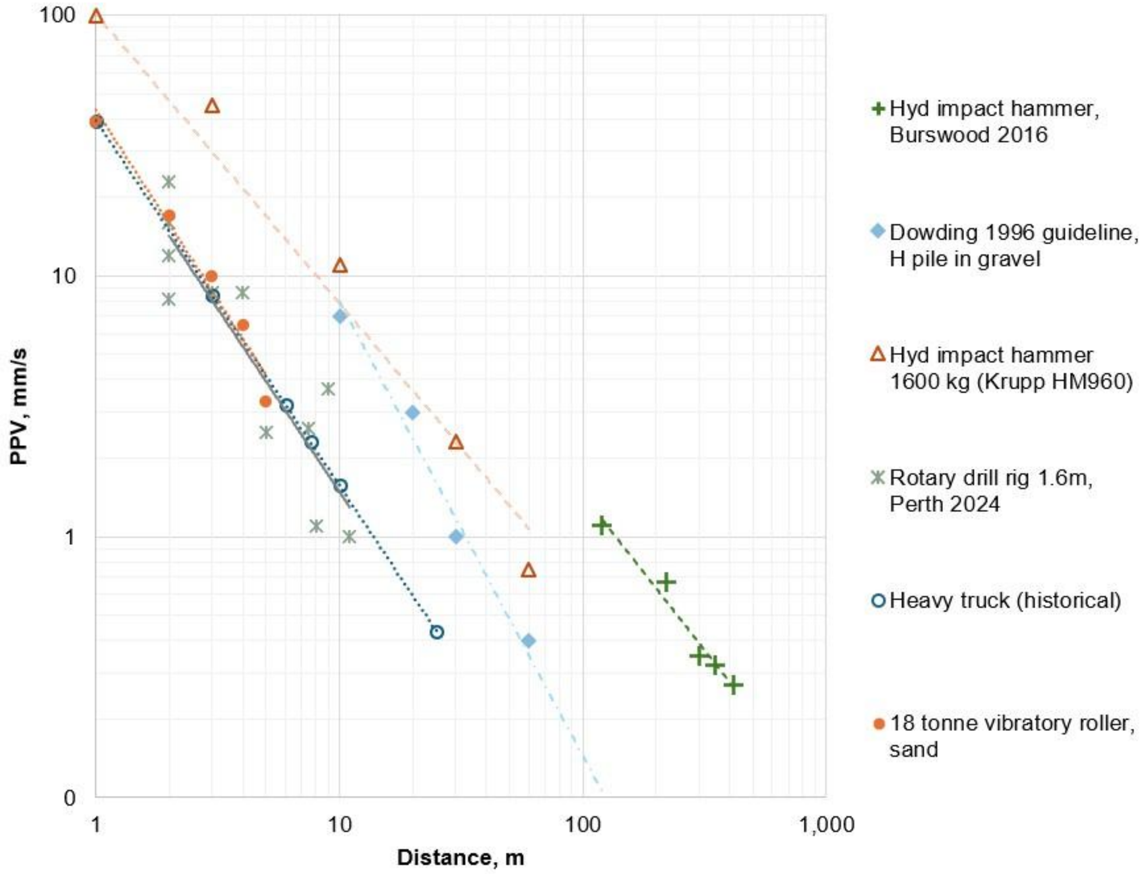

Figure 31 Typical ground vibration levels with distance for selected plant

From this figure it can be seen that in regard to the potential for structural damage:

- The recommended piling vibration target of 20 mm/s is expected to be met within 10 metres.
- The recommended general construction vibration target of 10 mm/s is expected to be met within the order of 6 metres or less.

Regarding human comfort, general construction activities are expected to meet the PPV 1 mm/s target at around 20 metres distance. Construction and piling activities are expected to be noticeable to residents at distances around 100 metres.

These safe working distances presented are indicative and will vary depending on the item of plant and local geotechnical conditions, in addition to how vibration propagates into and within nearby buildings.

In-situ vibration monitoring is therefore recommended to provide more certainty in received ground vibration levels and propagation rates.

5.0 Summary

The Swan River Ferry Expansion Project involves the development, design, construction and operation of new jetties in Matilda Bay and Applecross area close to Canning Bridge. It also involves the terrestrial development in Applecross, Matilda Bay, Elizabeth Quay, Ellam Street and Barrack Street Jetty area.

This document presents assessments of the potential noise and vibration impacts from construction and operation of the project on nearby terrestrial and marine environments.

The studies presented in this report demonstrate that:

- The project as proposed can comply with state noise regulations, via a combination of noise mitigation and/or source control measures enforced within environmental management plans.
- The project should implement an aquatic noise management plan based on **Section 2.5**, with project specific management and monitoring procedures to minimise the piling noise impact on assessed aquatic sensitive receptors.

Sincerely,

SLR Consulting Australia

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Technical Director – Acoustics & Vibration

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Appendix A Acoustic Terminology

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

Appendix B Marine Mammal Hearing Group Classification

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

Table B1 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*
	Perrin's beaked whale	*Mesoplodon perrini*
	Pygmy beaked whale	*Mesoplodon peruvianus*
	Stejneger's beaked whale	*Mesoplodon stejnegeri*
	Spade-toothed whale	*Mesoplodon traversii*

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

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

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

Appendix C Noise contour plots – Piling Noise

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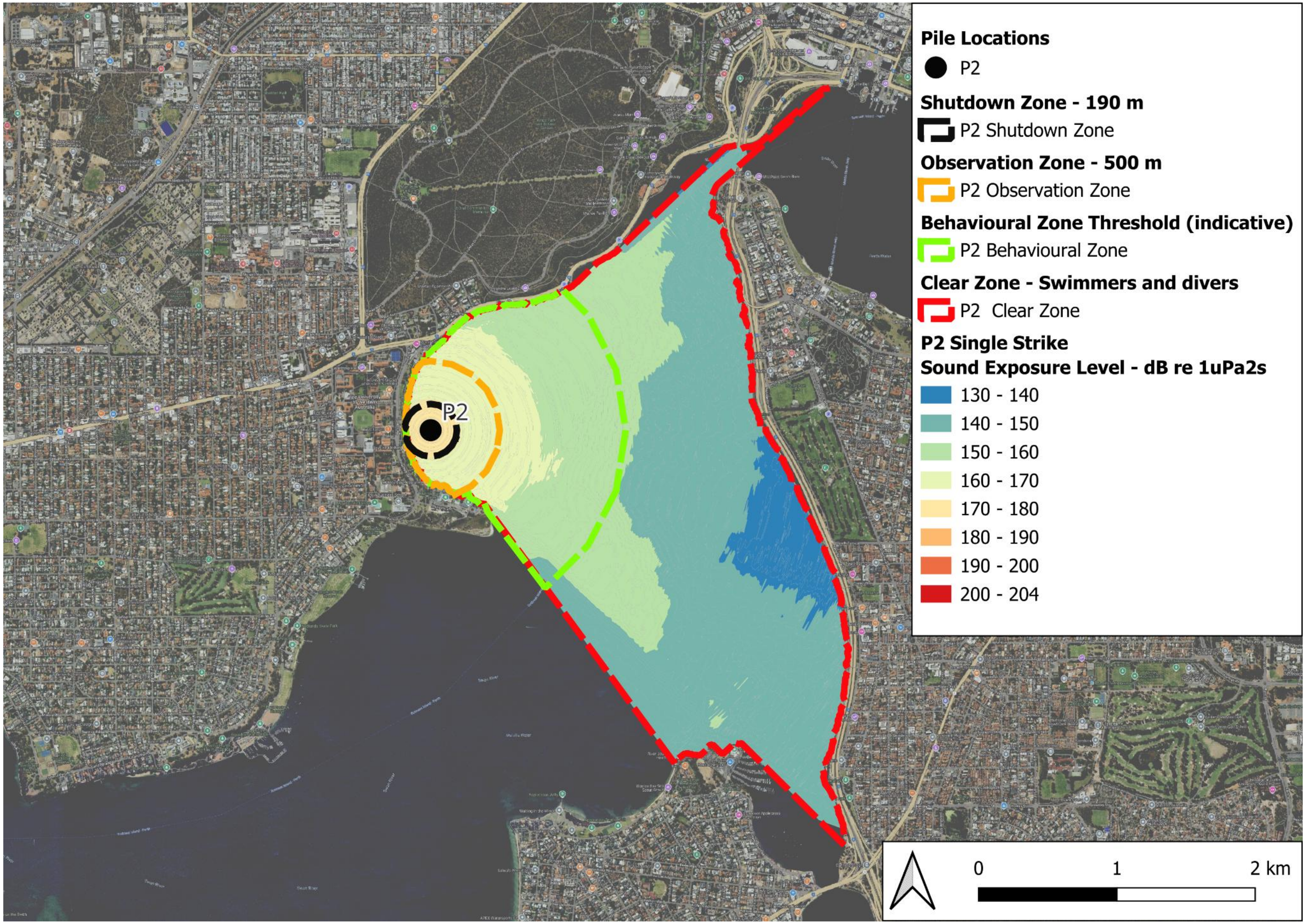

Figure C.1 Modelled noise contour plot, piling location P2, prior to mitigation

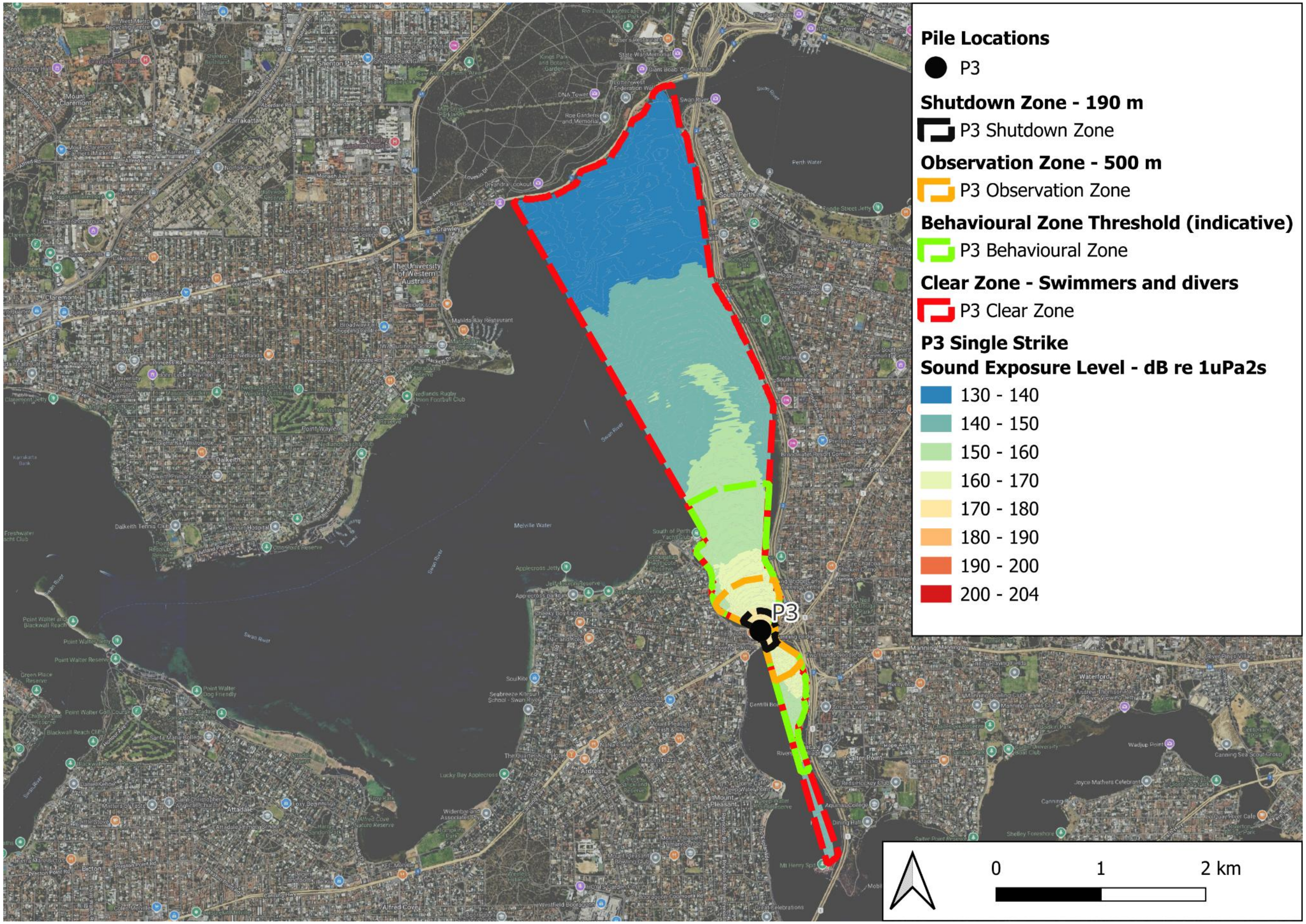

Figure C.2 Modelled noise contour plot, piling location P3, prior to mitigation

Appendix D Noise contour plots – Ferrying Noise

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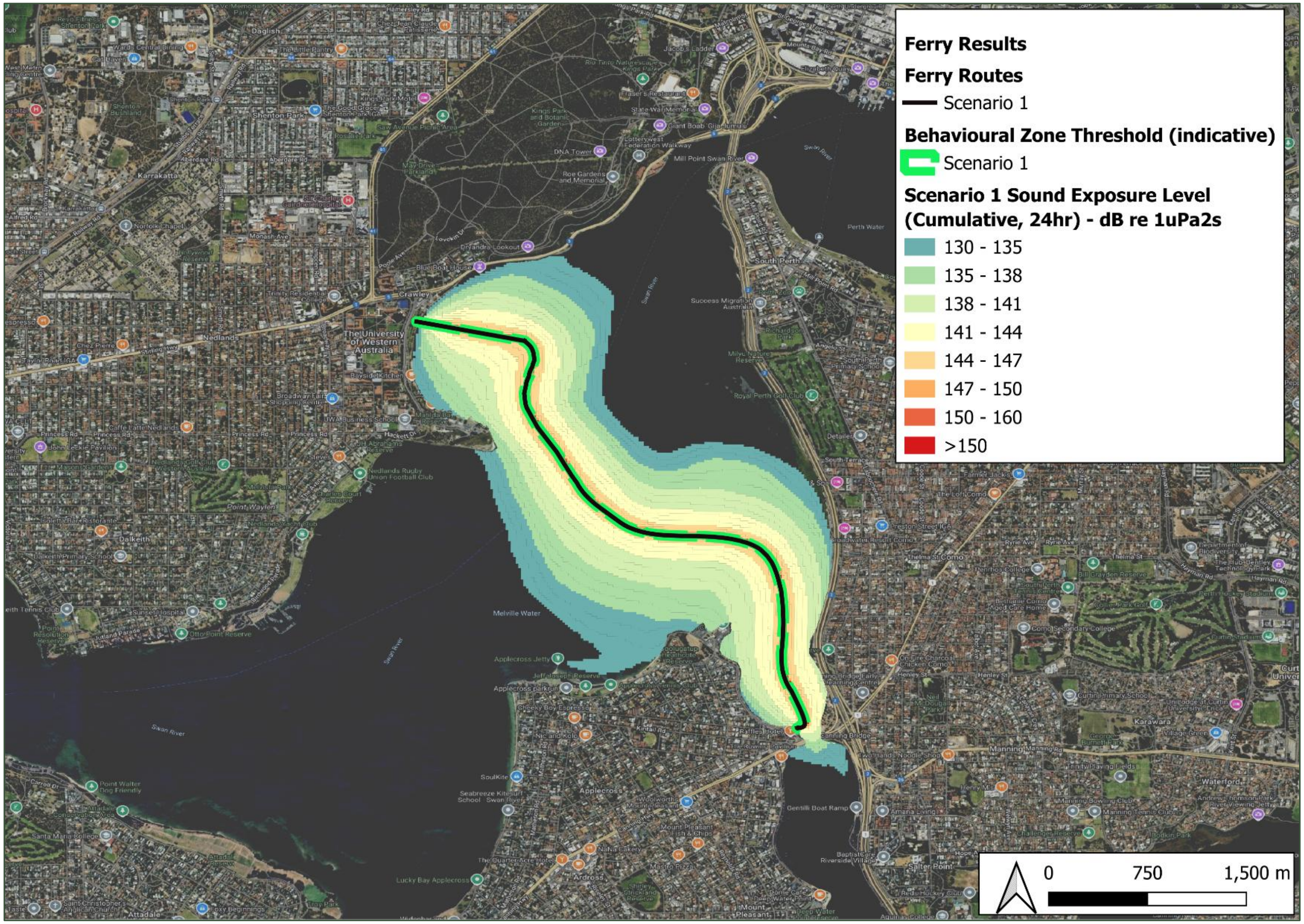

Figure D.1 **Modelled noise contour plot for ferrying scenario 1**

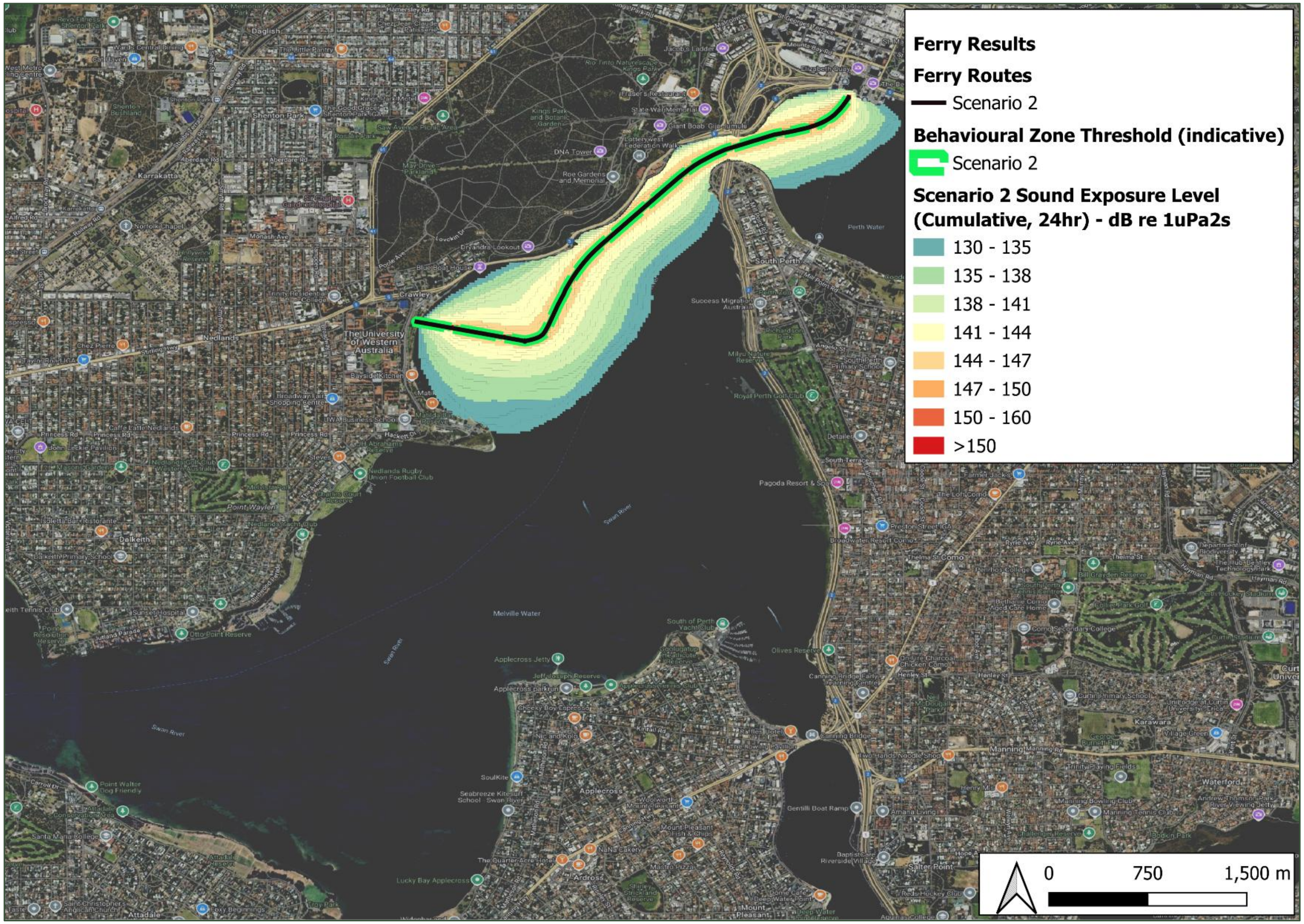

Figure D.2 Modelled noise contour plot for ferrying scenario 2

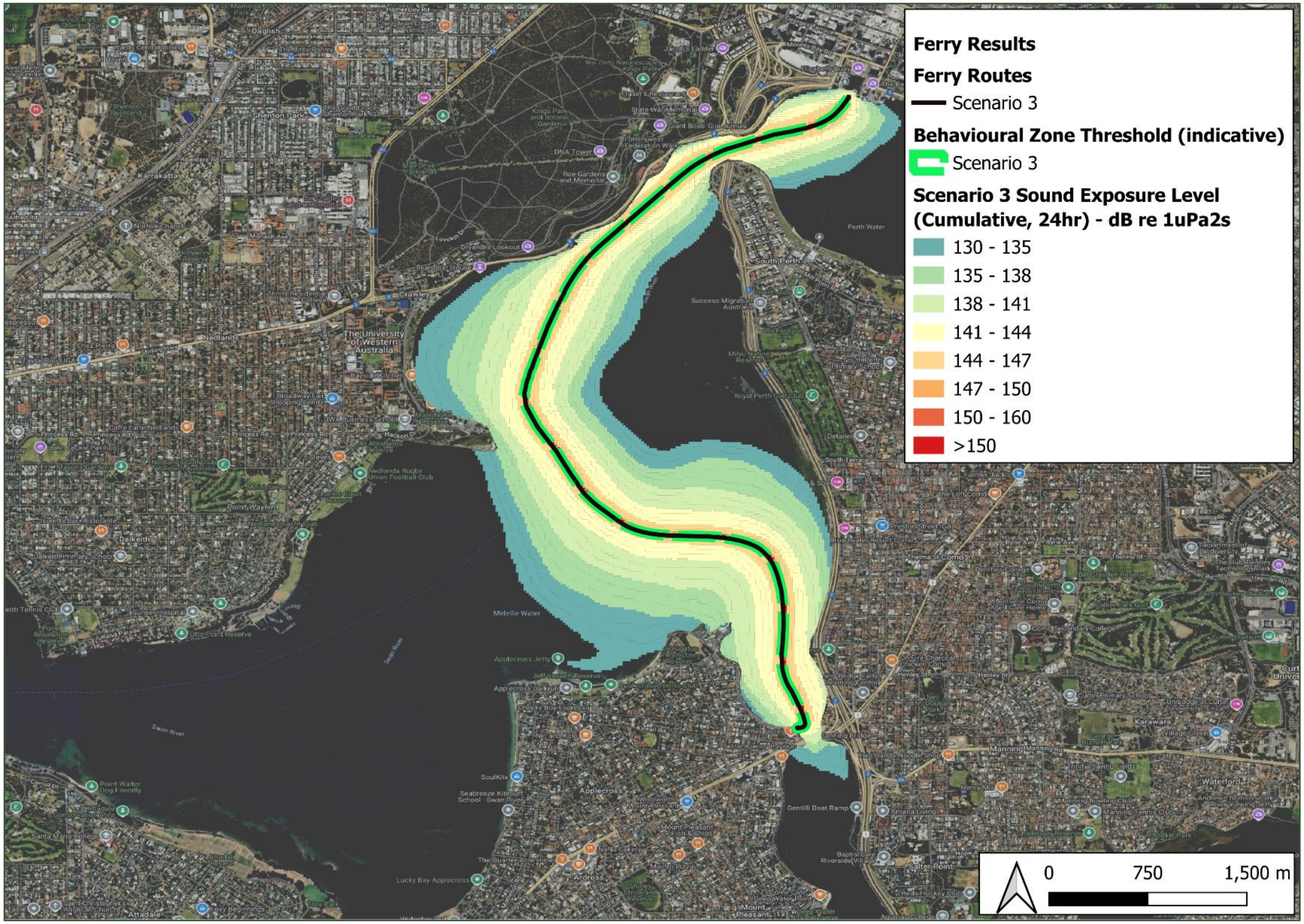

Figure D.3 **Modelled noise contour plot for ferrying scenario 3**

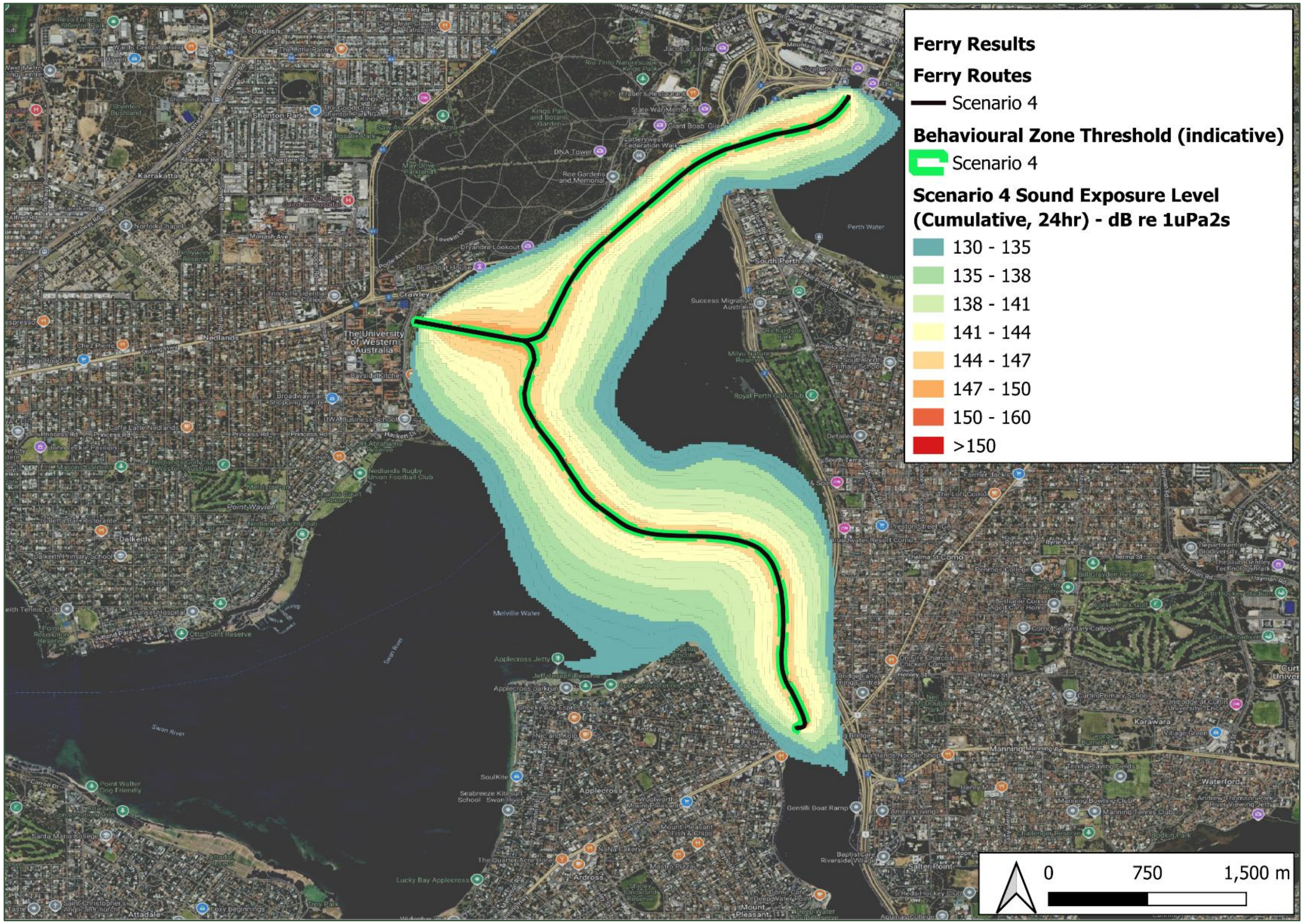

Figure D.4 Modelled noise contour plot for ferrying scenario 4

Appendix E Ambient airborne sound level monitoring

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E.1 Methodology

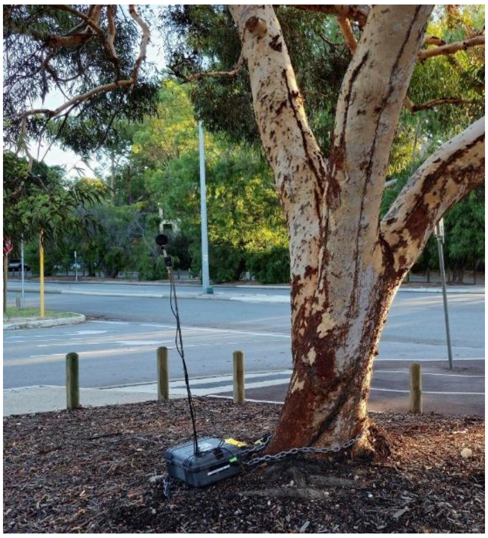
Sound level measurements were undertaken at two locations near the proposed sites over a period of several days.

E.1.1 Locations and equipment

Monitoring of ambient sound levels was undertaken in the Matilda Bay and Applecross areas over the period of several days in April 2025.

Table E-1 provides details of the equipment used for unattended monitoring. All monitoring equipment used is IEC 61672 Type 1 accredited and has been independently calibrated by a NATA laboratory within the last 2 years. A Type 1 field calibrator independently calibrated by a NATA laboratory within the last year was used to check the calibration of each unit on installation and retrieval.

Table E-1 Equipment details

Location	A – Matilda Bay	B – Applecross
Photo		
Position	-31.976356, 115.821464	-32.010481, 115.852101
Equipment model	Svantek 957	Svantek 957
Serial	27580	20668
Notes	Chained to tree in vicinity of Hackett Drive.	Chained to tree near the water's edge. Similar distance to construction site as nearest balconies

Attended measurements were also undertaken around the Elizabeth Quay area on the evening of March 31, 2025.

E.1.2 Uncertainty of measurement

All measurements have some level of error. The expected level of system measurement uncertainty as estimated according to international standards is outlined below.

Table E-2 Estimated measurement uncertainty by system

Parameter	System	U_{95} [9]	Student's t-factor
Airborne noise L_{Aeq}, L_{Amax}	SVAN 957	1.5 dB	2.00

Note 1 The U_{95} is the expanded uncertainty of measurement for a 95% confidence interval. It represents the estimated range in which the true value lies for 95 out of 100 repeated events.

E.2 Results

Tables E-3 and **E-4** present overall results measured each day at each location. Results presented exclude any periods of adverse weather[10].

Table E-3 Results, Location A (Matilda Bay)

Date	Background (L_{A90})			Typical avg. (L_{Aeq})			Daily Max (L_{Amax})		
	Day	Even.	Night	Day	Even.	Night	Day	Even.	Night
Monday, 31 March 2025	52	48	34	62	60	55	77	83	82
Tuesday, 1 April 2025	53	48	47	63	60	58	88	83	81
Wednesday, 2 April 2025	54	52	47	64	61	57	94	82	79
Thursday, 3 April 2025	54	52	45	64	61	61	99	83	96
Friday, 4 April 2025	59	-	-	66	-	-	81	-	-
Overall	54	50	46	64	60	57	88	83	82

Table E-4 Results, Location B (Applecross)

Date	Background (L_{A90})			Typical avg. (L_{Aeq})			Daily Max (L_{Amax})		
	Day	Even.	Night	Day	Even.	Night	Day	Even.	Night
Monday, 31 March 2025	51	50	44	55	55	54	67	74	76
Tuesday, 1 April 2025	50	51	46	56	57	56	85	81	80
Wednesday, 2 April 2025	57	55	44	61	60	56	80	82	76
Thursday, 3 April 2025	57	55	44	61	59	57	87	73	72
Friday, 4 April 2025	60	-	-	62	-	-	74	-	-
Overall	57	53	44	61	58	56	80	77	76

These tables indicate that ambient sound levels are generally around L_{A90} 50 dB in the evening and about L_{A90} 45 dB at night for both locations. Location A tends to have more sudden loud events however this is attributed to the proximity of the monitor to Hackett Drive and the likelihood of loud individual road vehicle movements there.

The background (L_{A90}) levels measured at various locations near Elizabeth Quay are indicated in the below figure. Weather conditions on the night are noted as generally fine with nil to light wind.

9 The U_{95} is the expanded uncertainty of measurement for a 95% confidence interval. It represents the estimated range in which the true value lies for 95 out of 100 repeated events.

10 Periods where there was recorded rain or 15-minute mean wind speeds at 1.5 metres over 5 metres per second, according to the Bureau of Meteorology Perth Metro weather station (009225).

Figure E-1 Elizabeth Quay monitoring positions (with L_{A90} results indicated)

Further details of the attended measurement results at the positions shown in this figure are presented in **Table E-5**. Overall measured background sound levels were around L_{A90} 51 dB.

Table E-5 Attended monitoring results at Elizabeth Quay

#	Time	Duration (mm:ss)	Measured result, dB						Observations
			L_{A95}	L_{A90}	L_{Aeq}	L_{A10}	L_{A1}	L_{Amax}	
1	9:15 PM	09:41	52	53	62	66	70	74	Medium traffic, occasional construction activity nearby.
2	9:25 PM	05:00	49	49	53	54	65	69	Low traffic, occasional car engine revving from a distance, seagulls and distant conversation. Sounds of a ferry engine starting
3	9:31 PM	06:22	51	52	55	58	60	64	light conversation, running water from drinking fountain,

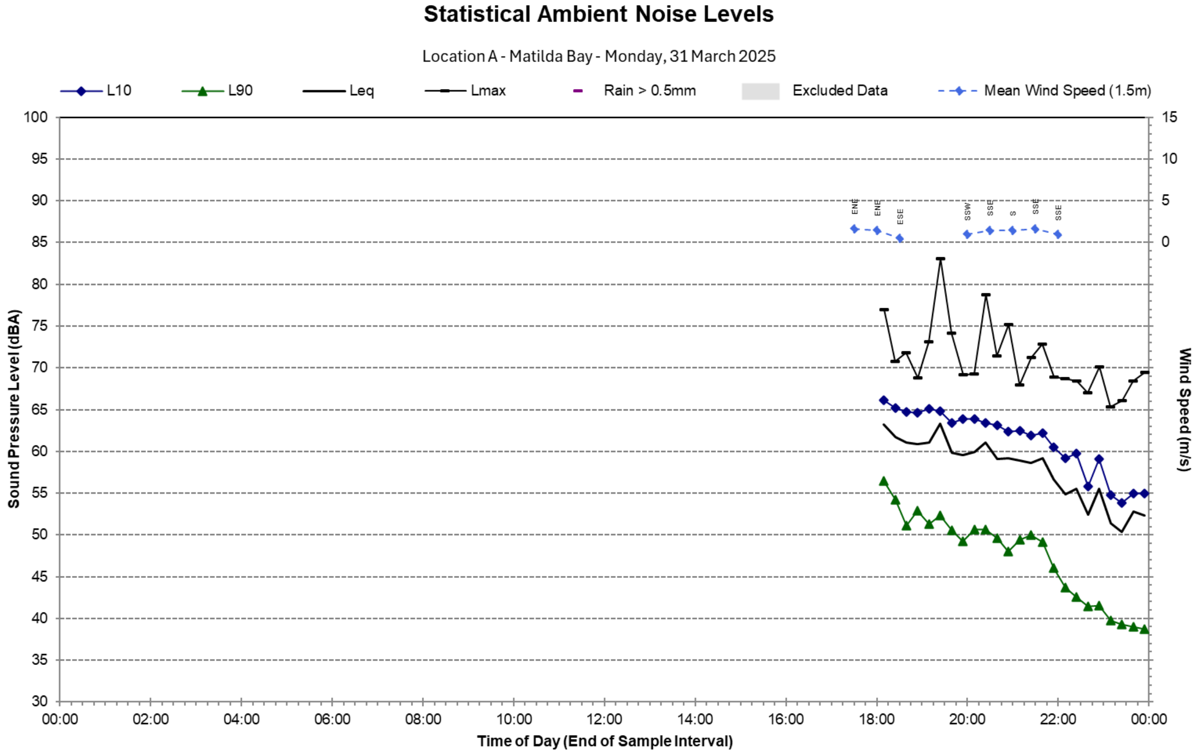
#	Time	Duration (mm:ss)	Measured result, dB						Observations
			L_{A95}	L_{A90}	L_{Aeq}	L_{A10}	L_{A1}	L_{Amax}	
									distant light traffic (100m), small dog barking
4	9:40 PM	05:33	48	48	50	52	57	62	Light conversation, seagulls (50m) faint traffic noise (150m)
5	9:46 PM	04:18	50	50	56	57	66	72	Walking across bridge, creaking wood, light conversation, distant road traffic indistinguishable
6	9:50 PM	06:03	50	51	54	57	61	63	20m from restaurant, light music, light foot traffic and conversation, loud car (150m)
7	9:56 PM	06:41	50	50	54	56	60	70	Light conversation, minimal foot traffic, low engine hum
8	10:05 PM	05:22	52	53	60 (Note[1])	61	70	82 (Note[1])	Seagulls (30m) light conversation, light machinery noises from construction.
	Overall	-	50	51	55	57	63	70	-

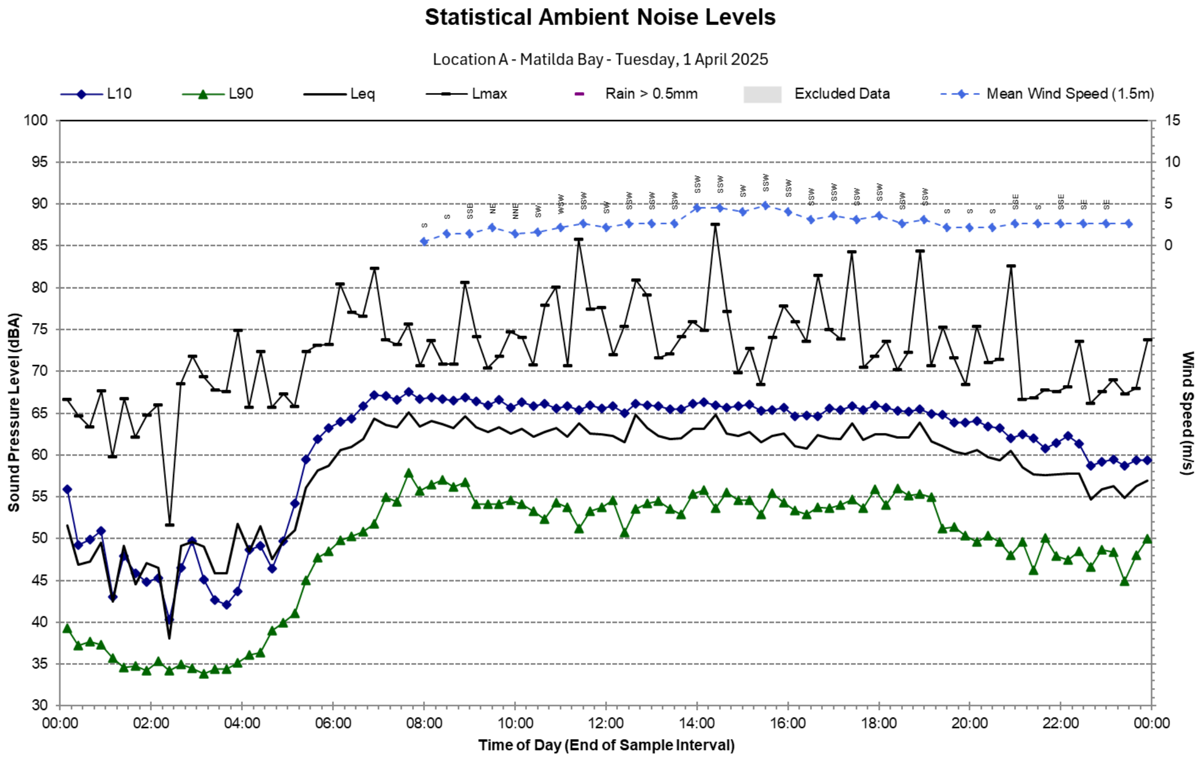
Note 1 During measurement #8, the SLM was accidentally contacted, affecting L_{Amax} and L_{Aeq} results only.

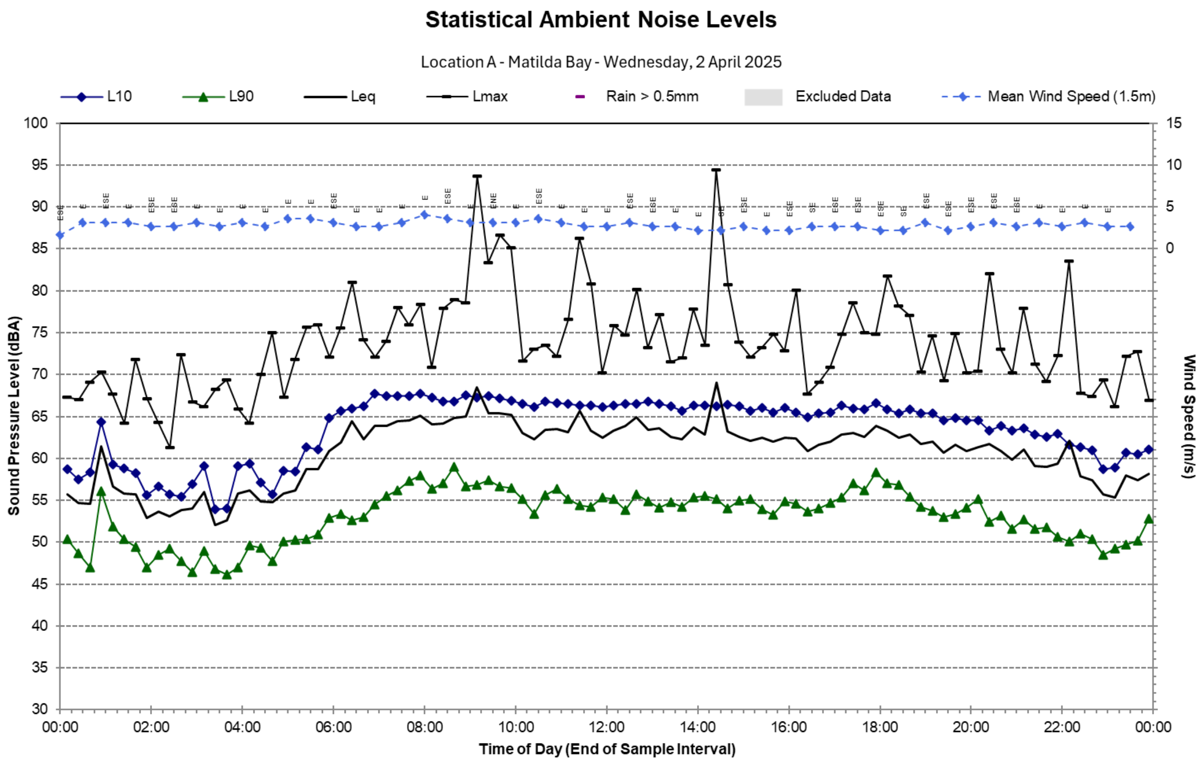
E.3 Daily monitoring figures

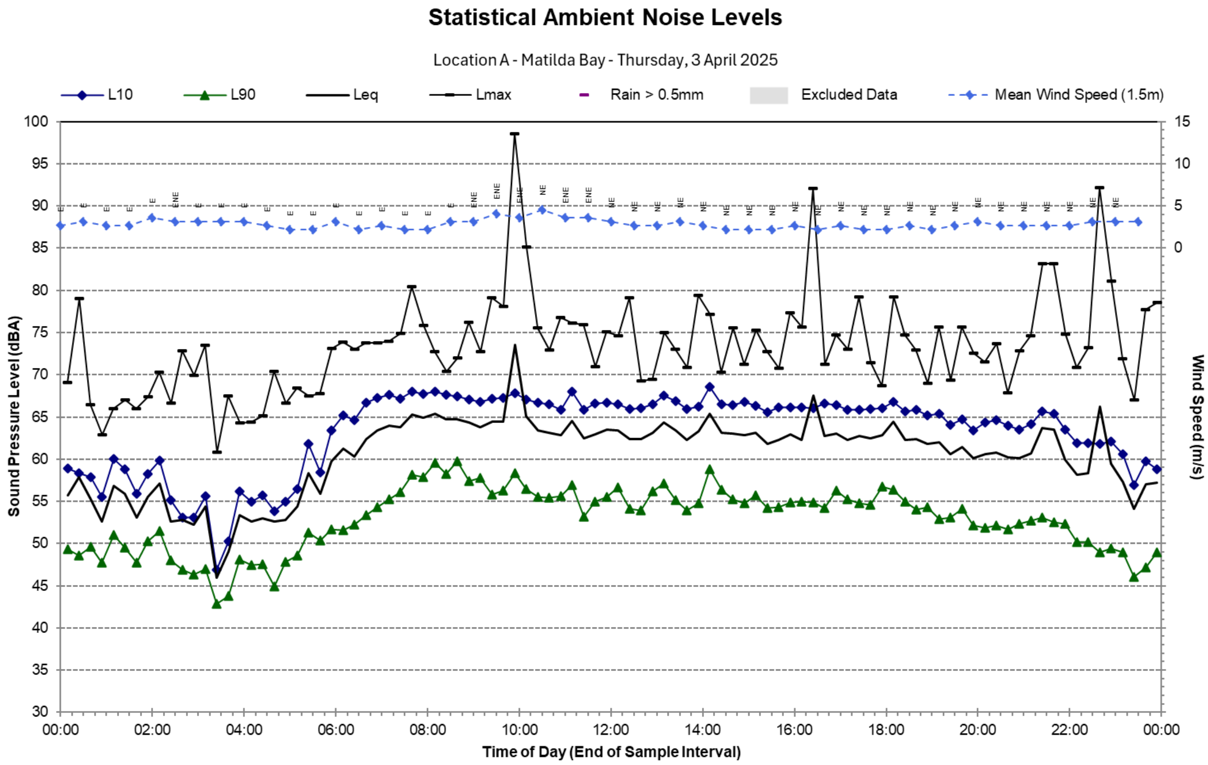
The following subsections present 15-minute period results at each location, including weather data.

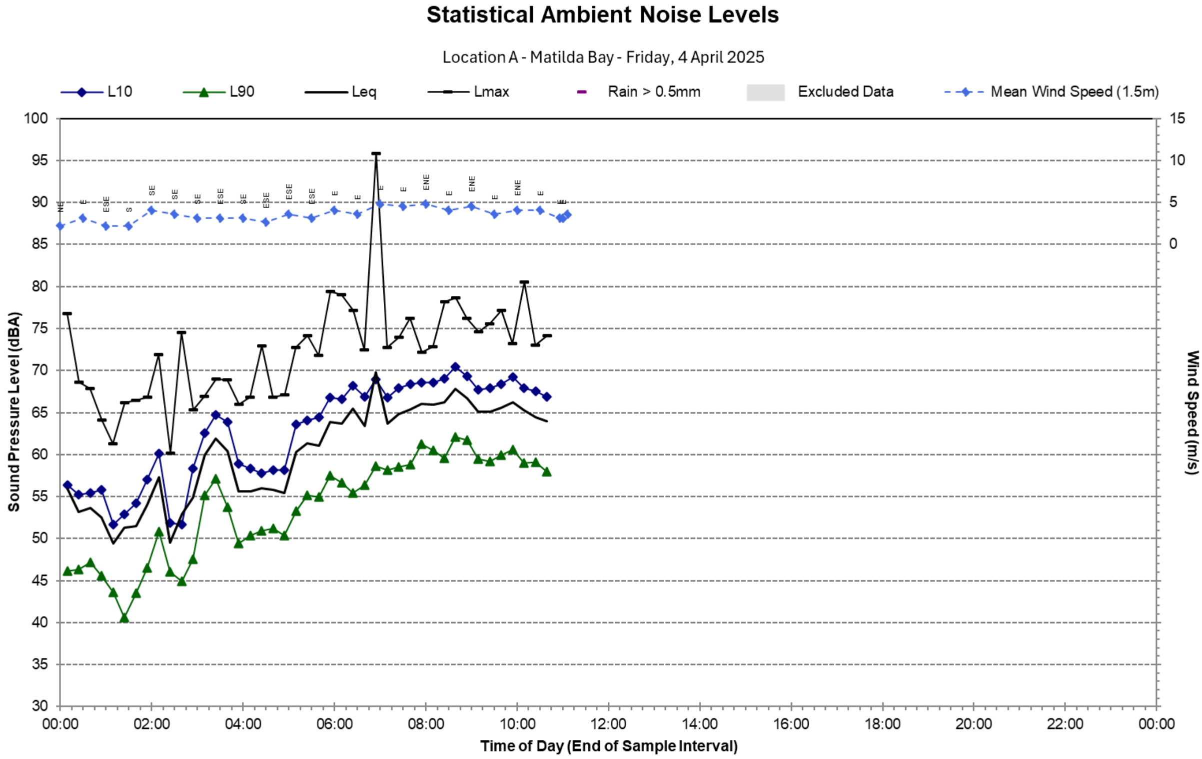
E.3.1 Location A – Matilda Bay



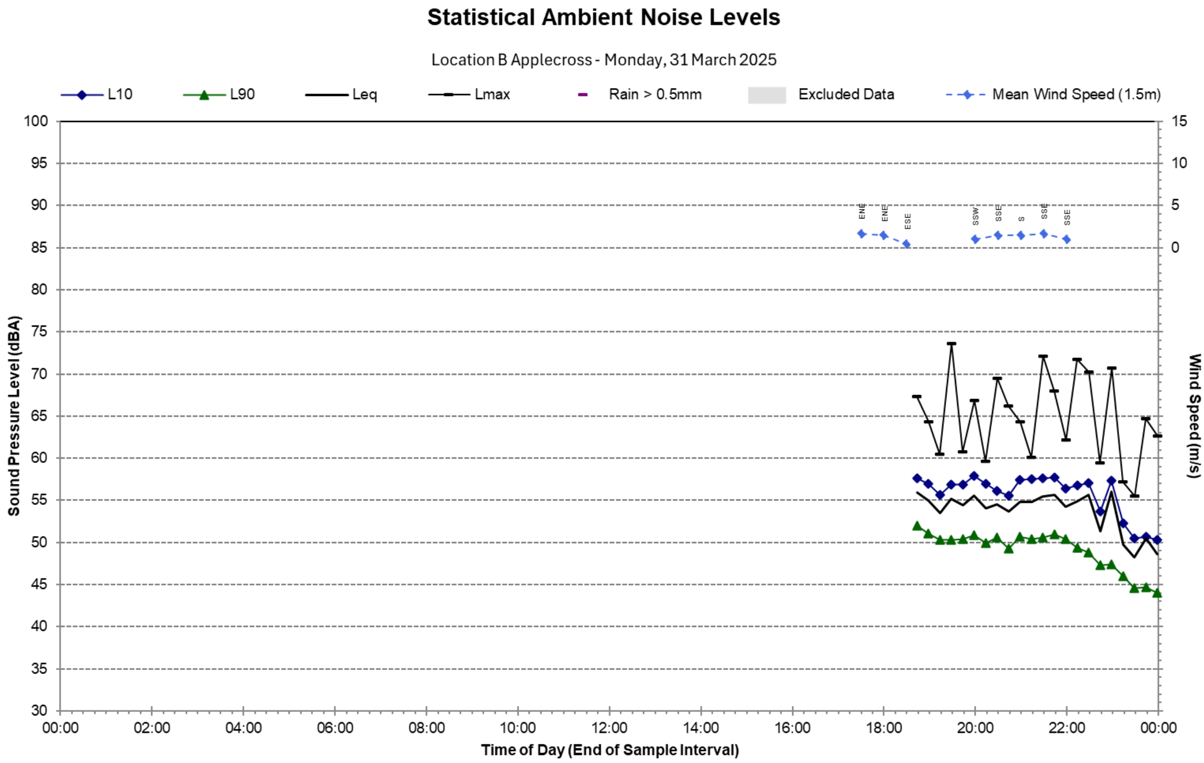


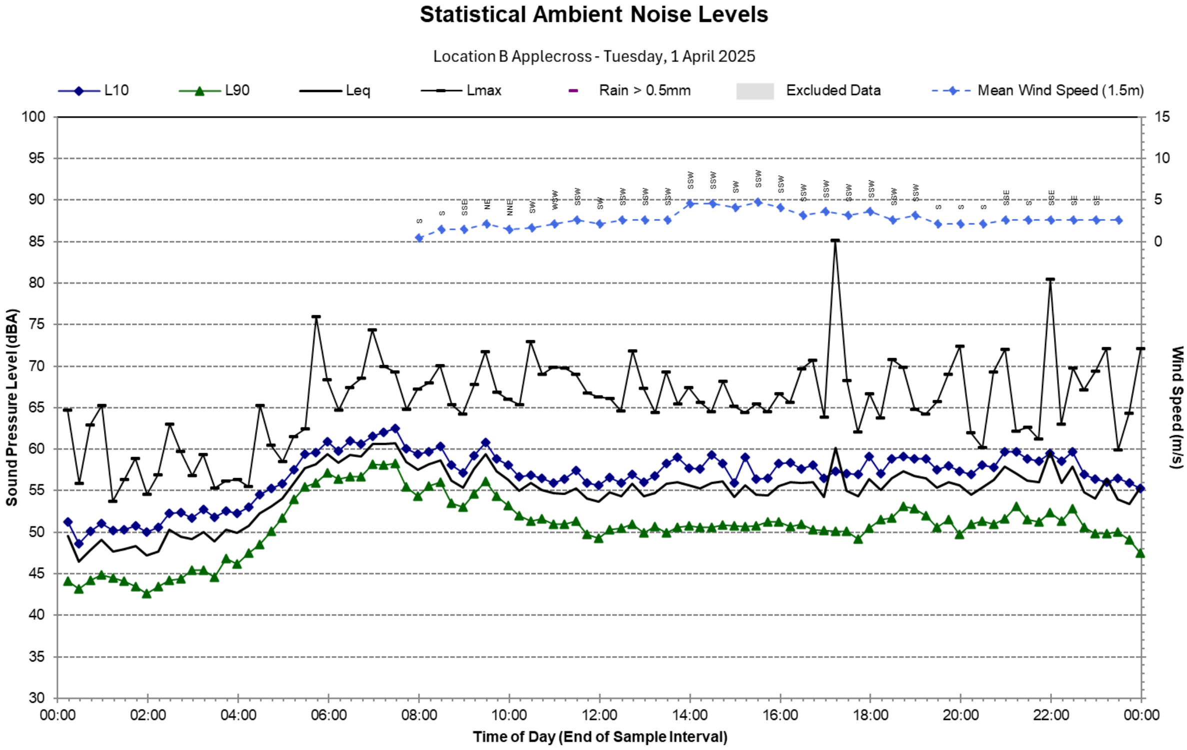

Statistical Ambient Noise Levels
Location A - Matilda Bay - Wednesday, 2 April 2025
L10
L90
Leq
Lmax
Rain > 0.5mm
Excluded Data
Mean Wind Speed (1.5m)
Sound Pressure Level (dBA)
Wind Speed (m/s)
Time of Day (End of Sample Interval)

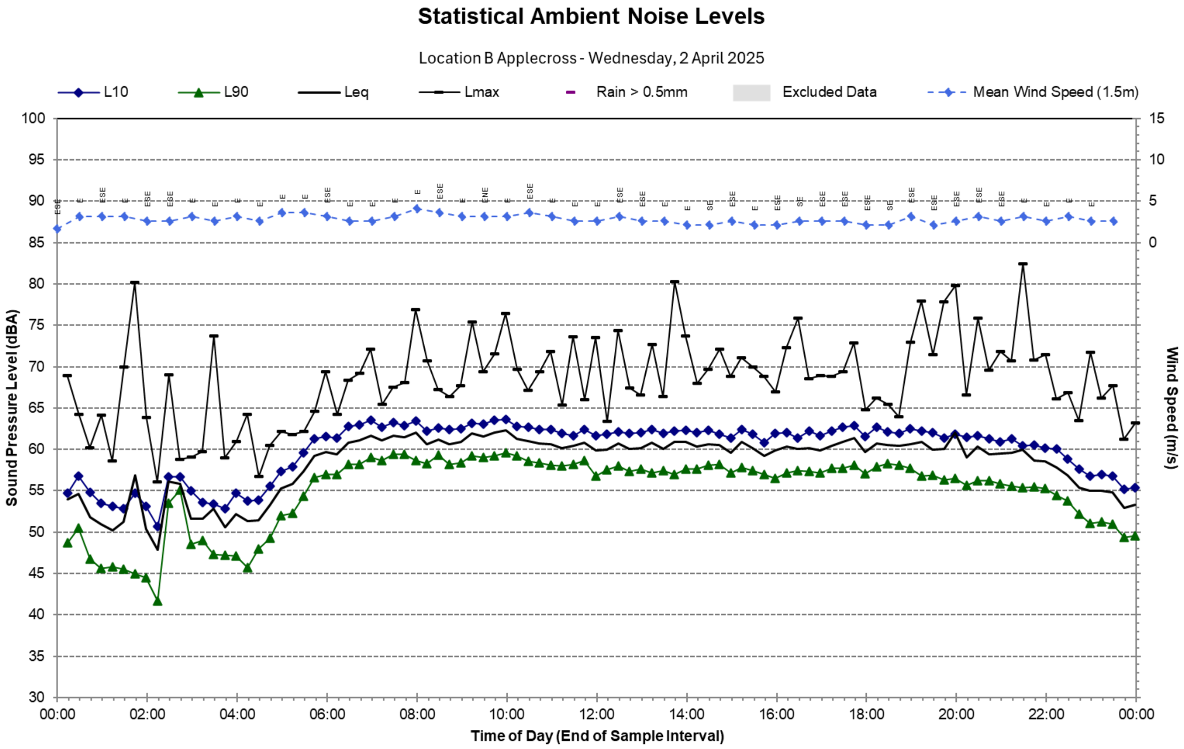

Statistical Ambient Noise Levels
Location A - Matilda Bay - Thursday, 3 April 2025
L10
L90
Leq
Lmax
Rain > 0.5mm
Excluded Data
Mean Wind Speed (1.5m)
Sound Pressure Level (dBA)
Wind Speed (m/s)
Time of Day (End of Sample Interval)

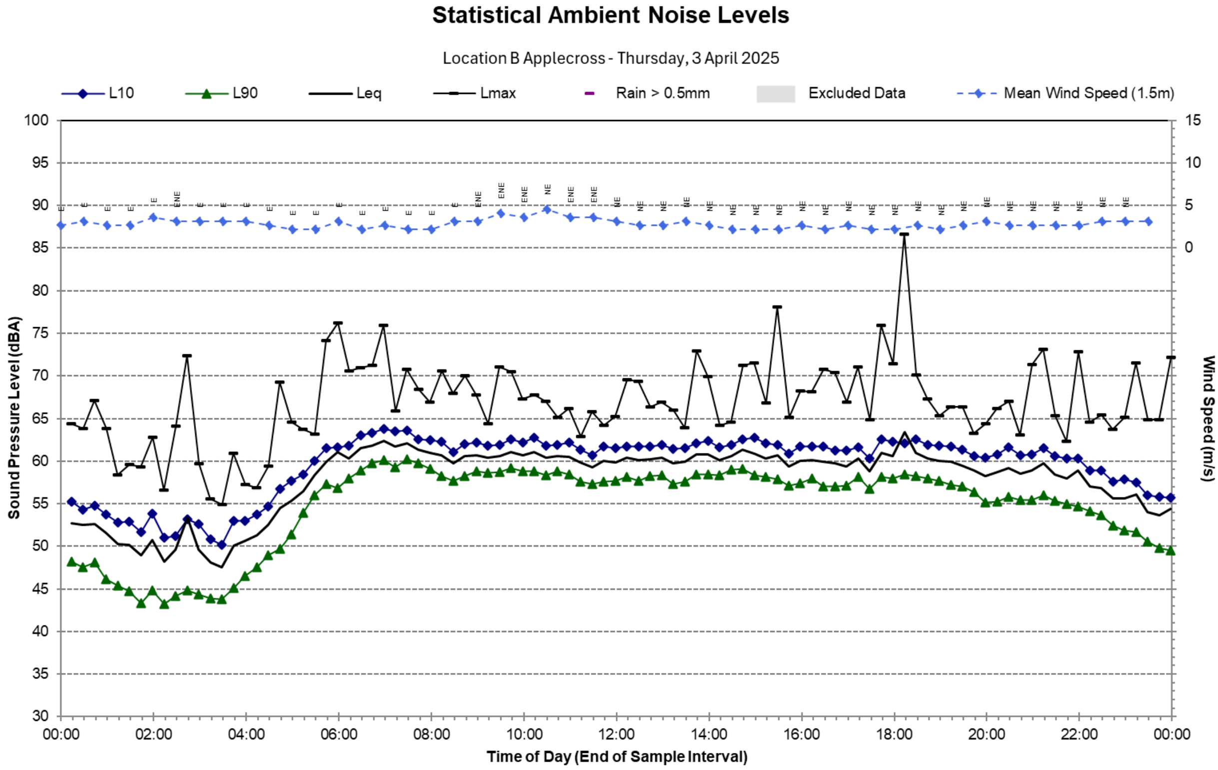


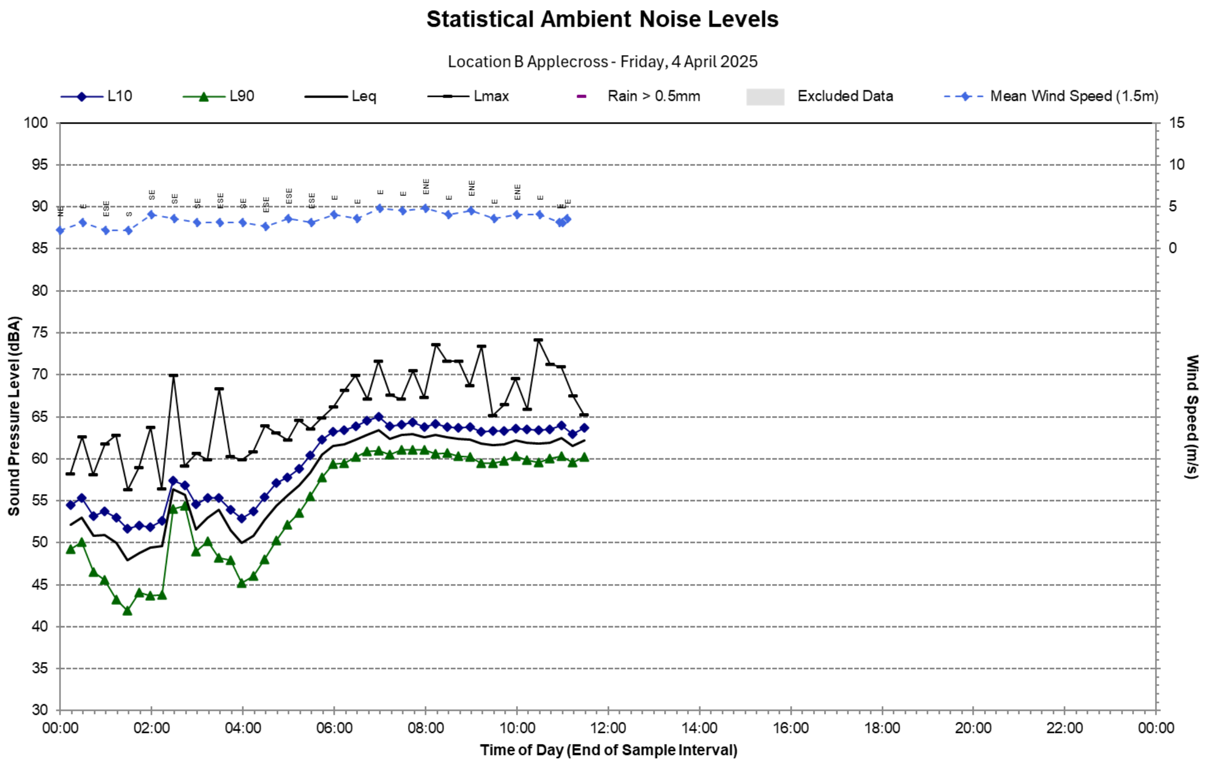
E.3.2 Location B – Applecross




Statistical Ambient Noise Levels
Location B Applecross - Tuesday, 1 April 2025
L10
L90
Leq
Lmax
Rain > 0.5mm
Excluded Data
Mean Wind Speed (1.5m)
Sound Pressure Level (dBA)
Wind Speed (m/s)
Time of Day (End of Sample Interval)


Statistical Ambient Noise Levels
Location B Applecross - Wednesday, 2 April 2025
L10
L90
Leq
Lmax
Rain > 0.5mm
Excluded Data
Mean Wind Speed (1.5m)
Sound Pressure Level (dBA)
Wind Speed (m/s)
Time of Day (End of Sample Interval)


Statistical Ambient Noise Levels
Location B Applecross - Thursday, 3 April 2025
L10
L90
Leq
Lmax
Rain > 0.5mm
Excluded Data
Mean Wind Speed (1.5m)
Sound Pressure Level (dBA)
Wind Speed (m/s)
Time of Day (End of Sample Interval)


Statistical Ambient Noise Levels
Location B Applecross - Friday, 4 April 2025
L10
L90
Leq
Lmax
Rain > 0.5mm
Excluded Data
Mean Wind Speed (1.5m)
Sound Pressure Level (dBA)
Wind Speed (m/s)
Time of Day (End of Sample Interval)

Making Sustainability Happen