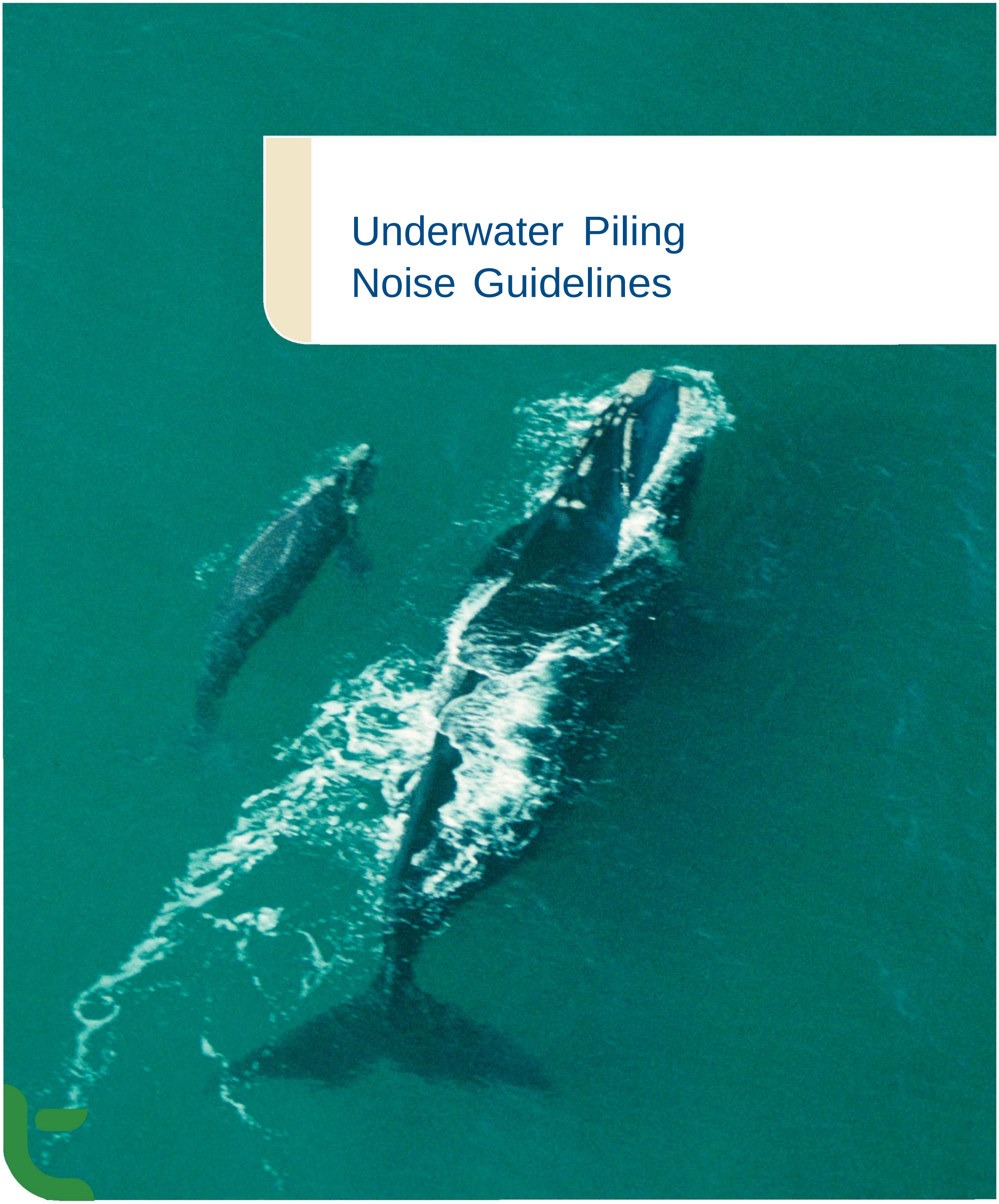
Underwater Piling Noise Guidelines



Government of South Australia
Department of Planning, Transport and Infrastructure

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21 November 2012

To ensure you have the most up-to-date version of this document refer to

http://cms.dpti.sa.gov.au/enviro_services/standards,_guidelines,_procedures

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Contents

Glossary

Ambient sound	Environmental background noise not of direct interest during a measurement or observation.
Decibel (dB)	Unit used in the logarithmic measure of sound strength.
Frequency	Rate at which water particles move backwards and forwards measured in cycles per seconds or Hertz (Hz).
Impulse sound	Transient sound produced by a rapid release of energy, e.g. from a piling impact or explosive. Impulse sound has extremely short duration and high peak sound pressure level.
TTS	Temporary threshold shift (TTS) is a temporary reduction in hearing sensitivity as a result of exposure to sound. Exposure to high levels of sound over relatively short time periods can cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The duration of TTS varies depending on the nature of the stimulus.
PTS	Permanent threshold shift (PTS) is a permanent reduction in hearing sensitivity caused by irreversible damage to the sensory hair cells of the ear.
Transmission loss	Reduction of the sound pressure level with distance from the noise source, which occurs through geometric spreading, absorption and scattering of sound energy.
Peak level	Peak level is the highest sound pressure level of an impulsive sound signal.
SEL	Sound exposure level (SEL) is most often used to compare the total energy in impulsive signals with different time durations, average pressure levels and temporal characteristics. Impulsive underwater noise sources for which the SEL noise descriptor is useful include piling, blasting and geophysical surveys.
SPL	Sound pressure level (SPL) is the sound pressure expressed in the decibel (dB) scale and with the standard reference pressures of 1 µPa for water.
SL	Source level (SL) is the noise level that would be measured at a standard reference distance of 1 m away from an ideal point source radiating the same amount of sound energy as the actual source.
Spectrum	Distribution of sound energy versus frequency.
Spherical spreading	Received level diminishes by 6 dB per doubling of distance from the source.
Hearing threshold	The hearing threshold represents the lowest signal level an animal can detect at a particular frequency, usually referred (and measured) as the threshold at which an animal will indicate detection 50% of the time.

1.0 Introduction

1.1 Background

Given the growing pressure on marine environments, it is important to minimise the impacts on marine biodiversity from infrastructure works. In addition to commonly recognised ecological marine impacts, such as disturbance to sensitive habitats and seagrasses, the impacts of underwater noise on marine fauna should also be considered. Underwater noise impacts on marine fauna are not as well understood as the impact in air, and are an area of continuing global research.

Marine animals live in an environment in which vision is not the primary sense because light does not penetrate far beneath the surface of the ocean. As such, marine mammals are reliant upon sound, instead of light, as their primary sense for communication and being aware of their surrounding environment. Marine mammal communication has a variety of functions such as mother/calf cohesion, group cohesion, individual recognition and danger avoidance.

The ocean is filled with many sounds, both naturally occurring and man-made, that may interfere with marine mammal communication, alter their behaviour, or even cause injury or death. Man-made sources of noise include shipping, geophysical surveys, and various construction activities such as drilling and piling.

Offshore piling produces noise levels that are amongst the highest recorded for construction activities, especially for impact piling. Minimising the impacts of underwater noise from piling activities is now considered an important environmental issue, with assessments undertaken for various marine infrastructure projects.

1.2 Application and objectives of the guidelines

The Department of Planning, Transport and Infrastructure (DPTI) Underwater Piling Noise Guidelines (Guidelines) apply to any proposed piling activity to be undertaken in South Australian (SA) state waters by DTEI staff and contractors that has the potential to impact significantly on marine mammals.

The aims of the Guidelines are as follows:

- Provide advice to DPTI staff and contractors on their legal responsibilities under the *Environment Protection and Biodiversity Conservation Act 1999*.
- Provide practical management and mitigation measures to minimise the risk of injury to occur in marine mammals within the vicinity of piling activities.
- Provide a framework that minimises the risk of significant impacts to occur on marine mammals in biologically important habitats or during critical behaviours (e.g. breeding and calving).

1.3 Limitations of the guidelines

The Guidelines do not intend to prevent all behavioural changes in marine mammals that might occur in response to audible but non-traumatic noise events. To some extent, avoidance behaviour is expected to provide a form of mitigation as it prevents the marine mammal from approaching the piling rig closely enough for noise-induced hearing injury to occur from intense or prolonged noise exposure.

Research into the effects of underwater noise on marine mammals is a rapidly evolving field and gaps in knowledge still exist. The Guidelines may be amended as further information becomes available.

2.0 Legislation and policy

This section presents the Commonwealth and State legislation that applies to offshore piling activities undertaken in SA state waters by DPTI staff and contractors. Links to useful websites and documents with more detailed information are included at the end of this section.

2.1 Commonwealth legislation

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) is the central piece of environmental legislation relevant to assessments of impacts on marine fauna. It provides the legal framework to protect and manage nationally and internationally important biota, ecological communities and heritage places, which are defined in the EPBC Act as matters of National Environmental Significance (NES).

There are seven matters of NES protected by the EPBC Act:

- World Heritage properties
- National Heritage places
- Wetlands of international importance (listed under the Ramsar Convention)
- Migratory species (listed under international agreements)
- Nationally threatened species and ecological communities (listed under the EPBC Act)
- The Commonwealth marine area
- Nuclear matters.

Nationally threatened species and ecological communities are listed under the EPBC Act as extinct in the wild, critically endangered, endangered or vulnerable.

Under the EPBC Act, a person must not take an action that has, will have or is likely to have a significant impact on any matters of NES without approval under the Act.

2.1.2 When are significant impacts on matters of NES likely to occur?

Significant impact criteria that assist in determining if the impacts of an action on any matter of NES are likely to be significant are provided in the *Significant impact guidelines 1.1 – Matters of National Environmental Significance* document (Significant impact guidelines 1.1).

Based on the significant impact criteria, significant impacts on matters of NES are more likely to occur if any of the following occur in the marine area:

- Habitat critical to the survival of a listed species or ecological community.
- Population of species listed as endangered or critically endangered
- Important population of species listed as vulnerable
- Important habitat for a migratory species
- Ecologically significant proportion of the population of a migratory species

Definitions for the terms included in the above, e.g. an important population or habitat, are given in the Significant impact guidelines 1.1 document.

2.1.3 Australian Whale Sanctuary

Section 225 of the EPBC Act establishes the Australian Whale Sanctuary in order to give formal recognition of the high level of protection and management afforded to cetaceans in Commonwealth marine areas and prescribed waters.

The Australian Whale Sanctuary includes all Commonwealth waters from the three nautical mile state waters limit out to the boundary of the Exclusive Economic Zone (EEZ), i.e. out to 200 nautical miles and further in some places and under certain circumstances (see Figure 1).

Figure 1 – Australian Whale Sanctuary (dark blue)

Under the EPBC Act (Part 13, Division 3, Subdivision C), it is an offence to kill, injure, take, trade, keep, move, harass, chase, herd, tag, mark or brand a cetacean within the Australian Whale Sanctuary.

Section 228 of the EPBC Act states that if the Minister is satisfied that a law of a State or the Northern Territory adequately protects cetaceans in the coastal waters, or a part of the coastal waters, of the State or Territory, the Minister may make a declaration accordingly, whether or not those coastal waters or that part are prescribed waters.

Section 229 of the EPBC Act states that a person is guilty of an offence if the person takes an action that results in the death or injury of a cetacean, and the cetacean is in the Australian Whale Sanctuary (but not the coastal waters, or part of the coastal waters, of a State or the Northern Territory for which a declaration under Section 228 is in force), or waters beyond the outer limits of the Australian Whale Sanctuary.

2.1.4 How does the EPBC Act apply to piling activities in SA state waters?

Actions undertaken outside the Commonwealth marine area that have, will have, or are likely to have a significant impact on the environment in a Commonwealth marine area require approval by the Minister. This includes impacts on marine species in state waters that use Commonwealth marine areas.

If piling activities and the associated underwater noise have a significant impact on listed migratory species, threatened species, or commonwealth species, a referral under the EPBC Act and approval of the Minister is required.

2.1.5 EPBC Act Policy Statement 2.1

The *EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales* (Policy Statement 2.1) provides a framework and standards for minimising the risk of acoustic injury to whales from seismic surveys, and acoustic disturbance to whales in biologically important habitats or during critical behaviours.

Seismic surveys use air-guns that generate short and intense pulses of sound directed at the sea floor. The resulting noise is similar in character and frequency content to impact piling noise but usually of a higher level, especially in comparison to piling activities typically conducted by DPTI staff and contractors. The management and mitigation framework and standard procedures outlined in Policy Statement 2.1 have been used to form the basis of the Guidelines.

The background paper to Policy Statement 2.1 recognises the uncertainties related to understanding the sound levels that cause hearing injury as well as the cumulative effect of multiple exposures in whales. The policy therefore adopts a sound energy level (SEL) threshold of 160 dB re 1 $\mu Pa^2 \cdot s$ for a single seismic shot at 1 km which should not be exceeded for 95% of the time.

The SEL threshold value is used in the policy to determine the extent of the *low power* zone. When a whale enters this zone, seismic surveys must lower their acoustic power output in order to prevent significant exposure to sound levels that could induce hearing injury. If SELs from air-gun shots fall below this threshold, they can operate with a reduced 1 km low power zone while if they are above this threshold, the surveys are required to operate with the default 2 km low power zone.

When a whale is sighted within or appears to enter the *shut-down* down, which extend to 500 m, the acoustic source must immediately be shut down completely. The *observation zone* extends to 3+ km and whales and their movements should be monitored to determine whether they are approaching or entering the low power zone.

2.2 State legislation

2.2.1 Adelaide Dolphin Sanctuary Act 2005

The *Adelaide Dolphin Sanctuary Act 2005* establishes the Adelaide Dolphin Sanctuary within the Port Adelaide River and Barker Inlet marine area, and aims to protect dolphins and their habitat within the sanctuary. Section 32 of this Act states that there is a general duty of care for a person to take all reasonable measures to prevent or minimise any harm to the sanctuary through his or her actions or activities.

2.2.2 National Parks and Wildlife Act 1972

Section 68 of the *National Parks and Wildlife Act 1972* states that a person must not interfere with, harass or molest a protected animal, or undertake or continue an act or activity that is, or is likely to be, detrimental to the welfare of a protected animal unless authorised by a permit granted by the South Australian Minister for the Department of Environment and Natural Resources. The marine mammal species listed as 'protected animals' under the Act are also listed under the EPBC Act.

2.2.3 Fisheries Management Act 2007

Section 77 of the *Fisheries Management Act 2007* states that a person must not engage in an operation involving or resulting in interference with aquatic animals of any waters forming part of an aquatic reserve, except as authorised by the regulations or a permit issued by the Minister.

2.2.4 Marine Parks Act 2007

Section 37 of the *Marine Parks Act 2007* states that there is a general duty of care for a person to take all reasonable measures to prevent or minimise harm to a marine park through his or her actions or activities.

Useful websites

EPBC Act

http://www.environment.gov.au/epbc/index.html

EPBC protected matters search tool

http://www.environment.gov.au/erin/ert/epbc/index.html

Listed threatened species and ecological communities under EPBC Act

http://www.environment.gov.au/epbc/protect/species-communities.html

Listed migratory species under EPBC Act

http://www.environment.gov.au/epbc/protect/migarory.html

Whales, dolphins and porpoises

http://www.environment.gov.au/coasts/species/cetaceans/index.html

Australian Whale Sanctuary

http://www.environment.gov.au/coasts/species/cetaceans/conservation/sanctuary.html

http://www.environment.gov.au/coasts/species/cetaceans/conservation/pubs/sanctuary-map.pdf

Adelaide Dolphin Sanctuary

http://www.environment.sa.gov.au/coasts/ads/index.html

http://www.environment.sa.gov.au/coasts/ads/pdfs/ads_map.pdf

Aquatic reserves and marine parks

http://www.pir.sa.gov.au/fisheries/recreational_fishing/closures/aquatic_reserves_and_marine_parks

http://www.environment.sa.gov.au/marineparks/pdfs/Boundaries_SA_A4200709.pdf

Useful documents

Significant impact guidelines 1.1 – Matters of National Environmental Significance

http://www.environment.gov.au/epbc/publications/pubs/nes-guidelines.pdf

Significant impact guidelines 1.2 – Actions on, or impacting upon, Commonwealth land, and actions by Commonwealth agencies

http://www.environment.gov.au/epbc/publications/pubs/commonwealth-guidelines.pdf

EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales

http://www.environment.gov.au/epbc/publications/pubs/seismic-whales.pdf

Background paper to EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales

3.0 The nature of underwater noise

3.1 What is underwater noise?

Sound is a vibration or acoustic wave that travels through some medium, in this case water, and occurs as a backward and forward motion of the medium's particles driven by a vibrating source.

The magnitude of the water particle motion determines the intensity of the sound. The rate at which the water particles oscillate backward and forward determines its frequency given in Hertz (Hz) or cycles per second.

Sound travels about four-and-a-half times faster in water than in air. Absorption of sound energy is much smaller in water at lower frequencies, where man-made noise generally has most energy. As a result, man-made noise generally travels much further underwater than in air.

A tone is a sound of a constant frequency. Most underwater noise sources are not tonal but include a broad range of frequencies. Screeching or whistling noises are composed mainly of high frequency sound while rumbles or booms are composed mainly of low frequency sound.

Underwater sounds are classified according to whether they are continuous or impulsive in character.

- Continuous sounds occur without pauses and are typically produced by the ambient environment, ships, or rotating machinery such as pumps.
- Impulsive sounds are of short duration and occur singly, irregularly, or as part of a repeating pattern. An explosion represents a single impulsive event whereas the periodic impacts from a piling rig or a geophysical survey result in a patterned impulsive sequence. Pulses typically sound like clicks or bangs and may include a broad range of frequencies.

3.2 Sound pressure and decibels (dB)

In water, the sound pressure is typically measured with a hydrophone – the underwater equivalent of a microphone. The international standard unit of sound pressure is the Pascal (Pa).

Typical sound pressures encountered in underwater acoustics range from levels just detectable by the marine animal ear (hundreds of µPa) to much greater levels causing hearing damage (billions of µPa). Because this range is so enormous, it would be impractical to express sound pressures in units of Pascal. Sound pressure is therefore described in terms of a sound pressure level (SPL) in units of decibel (dB), with reference to a standard pressure of 1 µPa for underwater sound. In decibel notation, the range of sound pressures typically encountered ranges from 50 to 250 dB re 1 µPa.

> Underwater sound pressure levels are usually expressed on a linear decibel scale in dB rather than on an A-weighted decibel scale in dB(A) as normally used for environmental noise assessments of traffic and industrial sources. The A-weighting accounts for the fact that the human ear is most sensitive to mid-range and high frequencies (1–8 kHz) and is less sensitive to the lower frequencies. Underwater noise assessments generally consider the impacts on marine animals rather than humans, such that the A-weighting is not applicable.

3.3 Underwater noise descriptors

3.3.1 Measured or received levels

Noise descriptors that are commonly used in underwater acoustics to present measured or received levels include the following:

- *Sound pressure level* (SPL) – Average noise level over the measurement period expressed in dB re 1 µPa. For impulsive sources, such as impact piling and blasts, the measurement period is the time period that contains 90% of the sound energy (Southall et al. 2007). Continuous sources, such as vibro-piling and shipping, are commonly described in terms of an SPL.
- *Sound exposure level* (SEL) – Total noise energy over the measurement period expressed in dB re 1 $\mu Pa^2 \cdot s$. The SEL is commonly used for impulsive sources because it allows a comparison of the energy contained in impulsive signals of different duration and peak levels.
- *Peak level* – Maximum noise level recorded during the measurement period expressed in dB re 1 µPa. The peak level is commonly used as a descriptor for impulsive sources.
- *Peak-to-peak level* – Difference between the maximum and minimum noise level recorded during the measurement period, expressed in dB re 1 µPa. The peak-to-peak level is used as a descriptor for impulsive sources.

SPLs and SELs can be presented either as overall levels or as frequency dependent levels showing the frequency content of a source.

Overall SPLs and SELs present the total average noise and energy level of a source within a given frequency bandwidth, which usually is the band that contains most of the signal's energy.

Frequency dependent representations include spectral density levels, one-third octave band levels, or octave band levels. Spectral density levels give a greater frequency resolution, which is sometimes desirable for identifying narrowband sources such as rotating machinery, and are expressed in unit of dB re 1 $\mu Pa^2/Hz$. One-third octave and octave band levels are expressed in units of dB re 1 µPa.

> It is important to note that an underwater noise level of 150 dB re 1 µPa is not equivalent to an in-air noise level of 150 dB re 20 µPa. To obtain an approximate comparison between underwater and in-air noise levels, 61.5 dB should be subtracted from the underwater noise level. This is to account for the differences in density and speed of sound between water and air, and the different reference pressures that are used to calculate the decibel levels, i.e. 1 µPa for water and 20 µPa for air. For example, ambient noise levels in South Australian coastal water are typically in the order of 100 to 120 dB re 1 µPa. This corresponds to in-air levels of 39 to 59 dB re 20 µPa.

3.3.2 Source levels

The strength of underwater noise sources can be compared by their source level (SL). The source level is defined as the sound pressure or energy level that would be measured at 1 m from an ideal point source radiating the same amount of sound as the actual source being measured.

The source level is often back-calculated from a measured level at a distance R from the source, assuming a transmission loss (dB) of $N \cdot \log_{10} R$. The value of N determines the noise decay rate with distance from the source, with N = 20 for spherical spreading. Typical values for N range from 15 to 25, depending on the source characteristics and sound propagation within the marine environment.

Example calculation of noise descriptors

An example calculation of the noise descriptors is presented based on the impulsive signal shown in Figure 1.

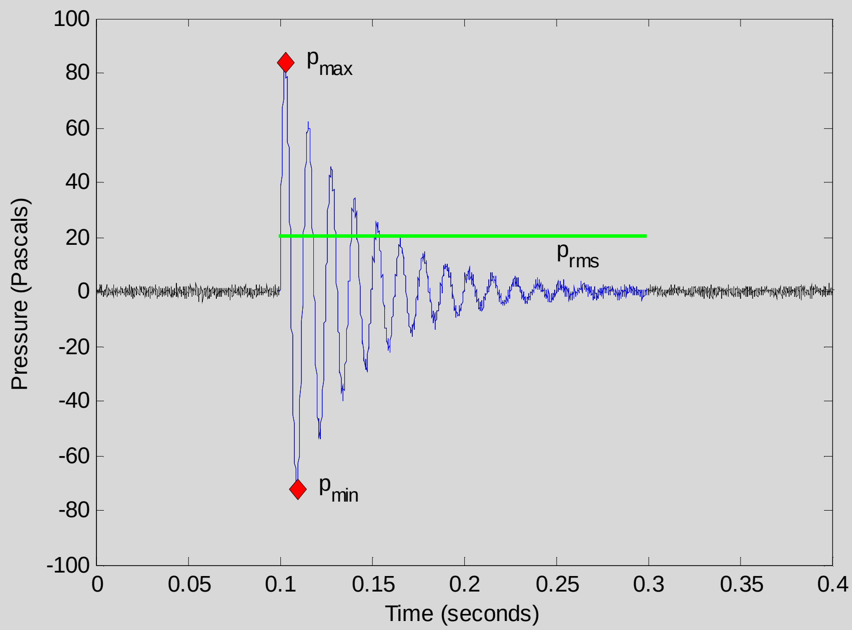

Figure 2 – Example of an impulsive signal

The pulse (blue line) starts at 0.1 seconds and has decayed back to ambient noise levels (black line) at 0.3 seconds, such that the pulse duration is T = 0.2 seconds.

The noise descriptors are now calculated as follows:

$$SPL = 20 \cdot \log_{10} \frac{p_{rms}}{p_{ref}}$$

$$SEL = 10 \cdot \log_{10} \frac{p_{rms}^2 \cdot T}{p_{ref}^2}$$

$$Peak = 20 \cdot \log_{10} \frac{p_{max}}{p_{ref}}$$

$$\text{Peak-to-peak} = 20 \cdot \log_{10} \frac{p_{max} - p_{min}}{p_{ref}}$$

The reference pressure p_{ref} is 1 µPa, the root-mean-square (rms) sound pressure p_{rms} presents the average level over the duration of the pulse, p_{max} is the maximum sound pressure, and p_{min} is the minimum sound pressure, all in Pascals.

The resulting levels are SPL 146 dB re 1 µPa, SEL 139 dB re 1 µPa^2·s, peak 159 dB re 1 µPa, and peak-to-peak 164 dB re 1 µPa.

3.4 Underwater piling noise characteristics

Piling noise varies with the size of the pile being installed and the pile driving method used. The most common pile driving methods include impact pile driving, where a pile is hammered into the ground by a hydraulic ram, and vibro-driving, where rotating eccentric weights create an alternating force on the pile, vibrating it into the ground.

- *Impact piling* – Impulsive in character with multiple pulses occurring at blow rates in the order of 30 to 60 impacts per minute. Typical source levels range from SEL 170–225 dB re 1 µPa^2·s for a single pulse, and peak level 190–245 dB re 1 µPa. Most of the sound energy usually occurs at lower frequencies between 100 Hz and 1 kHz. Factors that influence the source level include the size, shape, length and material of the pile, the weight and drop height of the hammer, and the seabed material and depth.
- *Vibro-driving* – Continuous in character and usually of a much lower level than impact piling. Typical source levels range from SPL 160–200 dB re 1 µPa, with most of the sound energy occurring between 100 Hz and 2 kHz. Strong tones at the driving frequency and associated harmonics may occur with the driving frequency typically ranging between 10 and 60 Hz. Sound propagation at such low frequencies is often poor in shallow water environments, such that the tones may not be noticeable at greater distances from the source.

Table 1 summarises the characteristics of impact piling and vibro-driving noise. By comparison, a typical seismic survey produces source levels in the order of SPL 200–250 dB re 1 µPa (see Policy Statement 2.1).

Table 1 – Piling noise characteristics

Piling method	Character	Noise descriptor	Source levels	Most energy
Impact	Impulsive	SEL	170–225 dB re 1 µPa^2·s	100 Hz and 1 kHz
		SPL	180–235 dB re 1 µPa	
		Peak level	190–245 dB re 1 µPa	
Vibro-driving	Continuous	SPL	160–200 dB re 1 µPa	100 Hz and 2 kHz

3.5 Ambient underwater noise environments

The level and frequency characteristics of the ambient noise environment are two factors that control how far away a given noise source can be detected (Richardson et al. 1995).

In general, noise is only detectable if it is of a higher level than the ambient noise environment at similar frequencies. A lower ambient noise environment results in noise propagating out to greater ranges before diminishing below the background noise level. The potential zone in which noise emissions from a piling rig are detectable thus depends on the levels and types of ambient noise in the ocean waters surrounding the site.

The main sources of ambient noise in the ocean are man-made sources including shipping and sonar activity, and environmental sources including wind-dependent noise and biological noise from a variety of sources such as snapping shrimp (Richardson et al. 1995). Other environmental sources include surf noise typically localised near the coast, precipitation noise from rain and hail, seismic noise from volcanic and tectonic activity, and thermal noise.

Typical levels and spectral contents of the identified ambient noise sources were compiled into generalised ambient noise spectra by Wenz (1962). These generalised spectra are often used to make predictions about the ambient noise environment for a specific site when measurements are not available.

3.6 Underwater noise propagation modelling

Underwater noise propagation models predict the spreading of sound from a noise source throughout the marine environment. The *source-path-receiver* model illustrated in Figure 3 presents the basic principles of underwater sound propagation modelling.

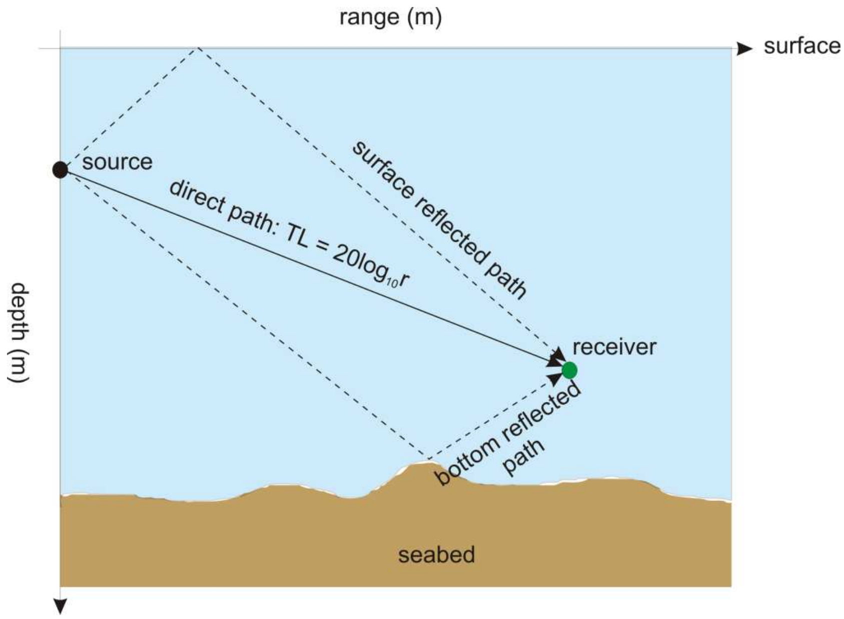

Figure 3 – Source-path-receiver model used for predicting sound transmission from source to receiver

An underwater noise model can predict the sound transmission loss (TL) between the source and a receiver. Given the source level (SL) of the considered noise source, the predicted TL across the transmission path is used to predict the sound pressure level (SPL) at the receiver location as SPL = SL – TL. Factors that determine the transmission loss are discussed below.

- *Spherical spreading* – Along the direct path between the source and the receiver, spherical spreading of the sound energy causes the noise level to drop off at $20\log_{10}R$ with R the distance from the source.
- *Reflection, absorption, scattering and refraction* – The transmission path is often not only the direct path between the source and receiver. Multiple transmission paths can occur due to reflections from the surface and seafloor. A rough surface or seafloor causes scattering of the source noise, and some of the noise impacting on the seafloor is absorbed. Temperature variations in the water column cause refraction of sound. These transmission loss mechanisms are generally frequency dependent, and depend on the seafloor geo-acoustic properties and the surface and seafloor roughness.

- *Total transmission loss* – The combination of the various transmission loss mechanisms give a total transmission loss that may be smaller than due to spherical spreading alone, especially in shallow water environments. For example, this occurs when surface and seafloor reflected sound waves interfere at the receiver location such that the noise level is increased, i.e. the transmission loss is reduced.

Both computational and semi-empirical models have been developed for shallow water environments (Richardson et al. 1995). Semi-empirical models are least complex to implement, and generally give reasonable transmission loss predictions if the bottom is either flat or slopes uniformly and the speed of sound is not varying much with water depth. If the speed of sound varies greatly within the water column or there is significant bathymetry, such as a shipping channel, more complex computational models are required to obtain reasonable predictions.

A suitable modelling method can be determined based on the properties of the marine environment, including the bathymetry of the site, the acoustic properties of the sea bottom, the speed of sound profile within the water column, and the frequency characteristics of the noise source.

4.0 Marine mammals and sound

4.1 Marine mammal sounds

Marine animals live in an environment in which vision is not the primary sense because light does not penetrate far beneath the surface of the ocean. As such, marine mammals have become reliant upon sound, instead of light, as their primary sense for communication and being aware of their surrounding environment. Marine mammal communication has a variety of functions such as intra-sexual selection, mother/calf cohesion, group cohesion, individual recognition and danger avoidance.

- Baleen whales form one of the two suborders of cetaceans, and include all of the great whales such as the Southern Right and Humpback Whales. These species produce sounds that are primarily at frequencies below 1 kHz, and have durations from approximately 0.5 to over 1 second and sometimes much longer (Richardson et al. 1995). Humpback whales and some other species produce sounds with frequencies above 1 kHz. Many baleen whale sounds are uncomplicated tonal moans or sounds described as knocks, pulses, ratchets, thumps, and trumpet-like. Blue whales for example produce low frequency moans in the frequency range of 10–15 Hz.
- Toothed whales form the other of the two suborders of cetaceans, and include all dolphins, porpoises, beaked whales, sperm whales, and killer whales. These species communicate underwater with whistles at frequencies below 20 kHz with most energy typically occurring around 10 kHz (Richardson et al. 1995). The killer whale produces whistles with energy between 1–6 kHz and most of its sounds are pulsed. Sperm whales and some porpoises (phocoenid) produce clicks that are sometimes used for communication. Toothed whales also use echolocation sounds to determine the physical features of their surroundings. The echolocation sounds are pulses with most energy generally occurring at high frequencies between 30–130 kHz or higher (Richardson et al. 1995). Killer whale echolocation clicks, however, have most energy at 12–25 kHz.
- Pinnipeds include all seals and sea lions, and produce underwater vocalisations sounding like bark and clicks with frequencies ranging from below 1–4 kHz. Pinnipeds are especially vocal during the breeding season.

In summary, baleen whales produce sounds that are dominant at frequencies that overlap with man-made industrial noise, such as piling. In contrast, the social sounds produced by toothed whales occur above the low-frequency range where most man-made sounds have their dominant energy.

It is noted that the source levels, directionality, maximum detection distances, and functions of most marine animal sounds are unknown or poorly documented (Richardson et al. 1995). It is therefore generally not possible to evaluate with accuracy the severity of animal sound masking by man-made noise.

4.2 Marine mammal hearing sensitivity

4.2.1 Hearing thresholds and audiograms

The hearing sensitivity of marine mammals varies with frequency. Audiograms are used to represent an animal's sensitivity to sounds of different frequencies. An audiogram of a species relates the absolute threshold of hearing (in dB re 1 µPa) of that species to frequency. An animal is most sensitive to sounds at frequencies where its absolute threshold of hearing is lowest. As an example, humans are most sensitive to sounds between 2–4 kHz where the absolute threshold is lowest.

- *Toothed whales* – Hearing is most sensitive at frequencies ranging from 8–90 kHz. The upper limits of auditory sensitivity are believed to range from 100 kHz in the killer whale to over 150 kHz and sensitivity is typically poor below 1 kHz (Richardson et al. 1995). The hearing of the beluga whale and bottlenose dolphin extends at least as low as 75 Hz but their sensitivity at these low frequencies seems quite poor.
- *Baleen whales* – There are no underwater audiograms available for baleen whales, and there is a little data available on their hearing sensitivity. Baleen whale vocalisations are low in frequency content for a number of species, and the frequency range of acute hearing presumably includes the frequency range of vocalisations. From behavioural observations, it is apparent that baleen whales are quite sensitive to frequencies below 1 kHz, but can hear sounds up to a considerably higher but unknown frequency (Richardson et al*.* 1995).
- *Pinnipeds* – In comparison to toothed whales, pinnipeds tend to have lower frequencies of maximum hearing sensitivity, poorer sensitivity at frequencies of maximum hearing sensitivity, and lower high-frequency hearing cut-offs. However, some species may have better sensitivity at frequencies below 1 kHz than toothed whales.

4.2.2 Marine mammal functional hearing groups

Species of cetaceans and pinnipeds were assigned to functional hearing groups based on their hearing characteristics by Southall et al. (2007). Table 2 presents the four functional hearing groups, the estimated auditory bandwidth for each group, the listed species that may occur in SA state waters for each functional hearing group, and the group-specific frequency weightings.

Table 2 – Marine mammal functional hearing groups, estimated auditory bandwidth, listed species under the EPBC Act that may occur in SA state waters, and group-specific frequency weightings (Southall et al. 2007)

Functional hearing group	Estimated auditory bandwidth	Listed species that are known to, likely to, or may occur in SA state waters	Frequency-weighting
Low-frequency cetaceans (All baleen whales)	7 Hz to 22 kHz	Southern Right Whale (*Eubalaena australis*) – Migratory, endangered Minke Whale (*Balaenoptera acutorostrata*) – Migratory Bryde's Whale (*Balaenoptera edeni*) – Migratory Blue Whale (*Balaenoptera musculus*) – Migratory, endangered Pygmy Right Whale (*Caperea marginate*) – Migratory Humpback Whale (*Megaptera novaeangliae)* – Migratory, vulnerable	M_{lf}
Mid-frequency cetaceans (Majority of toothed whales)	150 Hz to 160 kHz	Bottlenose Dolphin (*Tursiops truncates*) Common Dolphin (*Delphinus delphis*) Dusky Dolphin (*Lagenorhynchus obscures)* – Migratory Killer Whale (*Orcinus orca*) – Migratory Spotted Bottlenose Dolphin (*Tursiops aduncus*)	M_{mf}
High-frequency cetaceans (Other toothed whales)	200 Hz to 180 kHz	None that may occur	M_{hf}
Pinnipeds (Seals and sea lions)	75 Hz to 30 kHz	Australian Sea Lion (*Neophoca cinerea*) – Vulnerable Australian Fur Seal (*Arctocephalus pusillus*) New Zealand Fur Seal (*Arctocephalus forsteri*)	M_{pw}

The low-frequency cetaceans group includes all baleen whales. Most toothed whales are represented in the mid-frequency cetaceans group. The high-frequency cetaceans group contains the pygmy and dwarf sperm whales.

The group-specific frequency weightings account for the fact that marine mammals do not hear equally well at all frequencies within their functional hearing range. Noise levels are M-weighted to de-emphasize frequencies that are near the lower and upper frequency end of the estimated hearing range, where noise levels have to be higher to result in the same auditory effect. The M-weighting functions are similar in intent to the C-weighting function that is commonly used when assessing the impact of high-amplitude sounds on humans.

4.3 Behavioural and physiological impacts of noise

Underwater noise impacts on marine mammals are often divided into behavioural and physiological impacts (Southall et al. 2007).

4.3.1 Behavioural impacts

Behavioural responses to noise include changes in vocalisation, resting, diving and breathing patterns, changes in mother-infant spatial relationships, and avoidance of the noise source (NRC 2005). Masking of biologically important sounds may interfere with communication and social interaction, and cause changes in behaviour as well.

Table 3 summarises noise exposure criteria for behavioural impacts. The noise exposure criteria are based on current interim criteria adopted by the US National Oceanic and Atmospheric Administration (NOAA 2011). The noise exposure criteria for impact piling and vibro-driving are different due to their different noise character (i.e. impulsive versus continuous).

Table 3 – Underwater noise exposure criteria for behavioural impacts (NOAA 2011)

Species	Behavioural noise exposure criteria	
	Impact piling	**Vibro-driving**
Cetaceans	SPL 160 dB re 1 µPa	SPL 120 dB re 1 µPa
Pinnipeds	SPL 160 dB re 1 µPa	SPL 120 dB re 1 µPa

M-weighting functions

The M-weighting (dB) is calculated as a function of frequency (f) as follows (Southall et al. 2007):

$$M(f) = 20 \cdot \log_{10}\frac{R(f)}{\max|R(f)|} \quad \text{with } R(f) = \frac{f_{high}^2 f^2}{(f_{high}^2 + f^2)(f_{low}^2 + f^2)}$$

Table 2 presents the estimated lower (f_{low}) and upper (f_{high}) functional hearing limits for each of the four marine mammal functional hearing groups.

As an example, consider an underwater piling noise impact assessment for the Southern Right Whale. This species is represented in the low-frequency cetacean functional hearing group. The estimated lower and upper functional hearing limits are f_{low} = 7 Hz and f_{high} = 22 kHz, respectively for this group. The resulting M-weighting function for the Southern Right Whale is illustrated in Figure 4.

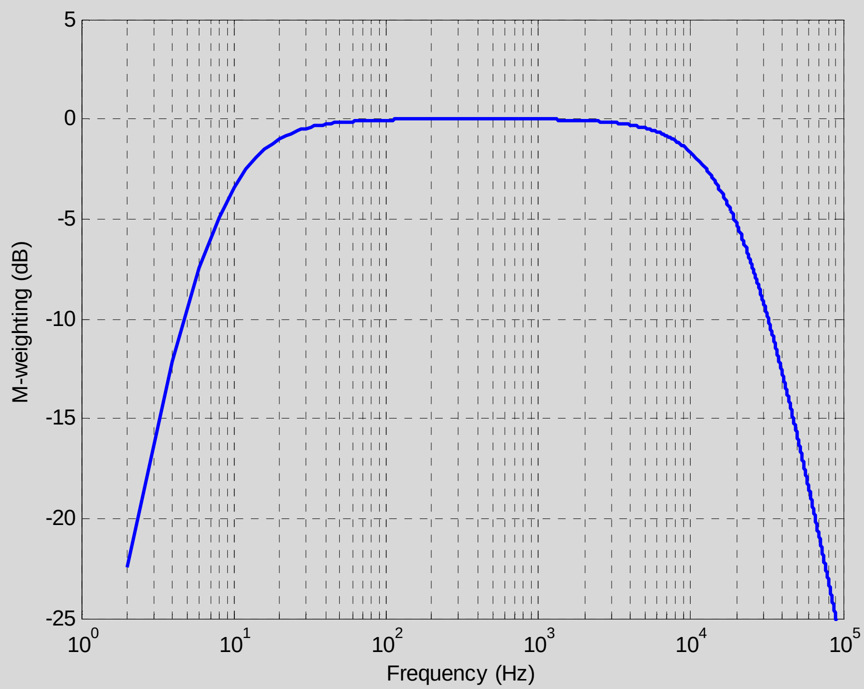

Figure 4 – M-weighting function for Southern Right Whale. This species is represented in the low-frequency cetaceans functional hearing group.

The M-weighting function in Figure 4 de-emphasises noise energy below 7 Hz and above 22 kHz, where the hearing sensitivity of the Southern Right Whale is thought to be poor. If the received noise has significant energy in these frequency ranges, the M-weighted level in dB(M) will be significantly lower than the linear level in dB.

4.3.2 Physiological impacts (TTS and PTS)

Most discussions of physiological effects of underwater noise have centred on the auditory system, as this system is likely to be most sensitive to noise.

When the auditory system is exposed to a high level of sound for a specific duration, the sensory hair cells begin to fatigue and do not immediately return to their normal shape. This causes 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 hair cells will eventually return to their normal shape. This effect is called a temporary threshold shift (TTS) as the hearing loss is temporary. If the noise exposure exceeds the critical sound energy level, the hair cells become permanently damaged and the effect is called permanent threshold shift (PTS).

Table 4 summarises noise exposure criteria for physiological impacts, which are based on the study presented by Southall et al. (2007), and noise exposure criteria adopted by the NOAA (2011). Note that the SEL noise exposure criteria are M-weighted levels expressed in dB(M) re 1 µPa^2·s.

Table 4 – Underwater noise exposure criteria for physiological impacts

Functional hearing group	Impact	Physiological noise exposure criteria	
		Impact piling	**Vibro-driving**
Low-frequency cetaceans	TTS	Peak 224 dB re 1 µPa SEL 183 dB(M_{lf}) re 1 µPa^2·s	SPL 180 dB re 1 µPa
	PTS	Peak 230 dB re 1 µPa SEL 198 dB(M_{lf}) re 1 µPa^2·s	Peak 230 dB re 1 µPa SEL 215 dB(M_{lf}) re 1 µPa^2·s
Mid-frequency cetaceans	TTS	Peak 224 dB re 1 µPa SEL 183 dB(M_{mf}) re 1 µPa^2·s	SPL 180 dB re 1 µPa
	PTS	Peak 230 dB re 1 µPa SEL 198 dB(M_{mf}) re 1 µPa^2·s	Peak 230 dB re 1 µPa SEL 215 dB(M_{mf}) re 1 µPa^2·s
High-frequency cetaceans	TTS	Peak 224 dB re 1 µPa SEL 183 dB(M_{hf}) re 1 µPa^2·s	SPL 180 dB re 1 µPa
	PTS	Peak 230 dB re 1 µPa SEL 198 dB(M_{hf}) re 1 µPa^2·s	Peak 230 dB re 1 µPa SEL 215 dB(M_{hf}) re 1 µPa^2·s
Pinnipeds	TTS	Peak 212 dB re 1 µPa SEL 171 dB(M_{pw}) re 1 µPa^2·s	SPL 190 dB re 1 µPa
	PTS	Peak 218 dB re 1 µPa SEL 186 dB(M_{pw}) re 1 µPa^2·s	Peak 218 dB re 1 µPa SEL 203 dB(M_{pw}) re 1 µPa^2·s

Note: TTS = Temporary threshold shift, PTS = Permanent threshold shift

4.3.3 Zones of impact

Given the source noise characteristics, a model that predicts the propagation of sound away from the source, and the noise exposure criteria, the radii within which impacts are expected to occur can be predicted. The resulting radii define zones of impact which are illustrated in Figure 5.

The following zones of impact can be defined (Richardson et al. 1995):

- *Zone of audibility* – Area within which marine mammal might hear the source noise but not show any significant behavioural response. The size of the zone of audibility is highly dependent on the ambient noise environment.
- *Zone of responsiveness* – Area within which the considered marine mammal might react behaviourally to the noise source. This zone can be smaller than the zone of audibility as marine mammals usually do not show significant behavioural responses to noises that are faint but audible.
- *Zone of hearing injury* – Area closest to the noise source where the noise levels may be high enough to cause a physiological impact such as TTS or PTS.

The zones of impact define the likely environmental footprint of a noise source and indicate how far away a noise source is expected to have an impact on a marine mammal species, either behaviourally or physiologically. This information, together with information on the biological importance of the marine site as a habitat for the considered species, e.g. breeding, calving or resting areas, or confined migratory routes or feeding areas, is used to assess the likely impact of a noise source.

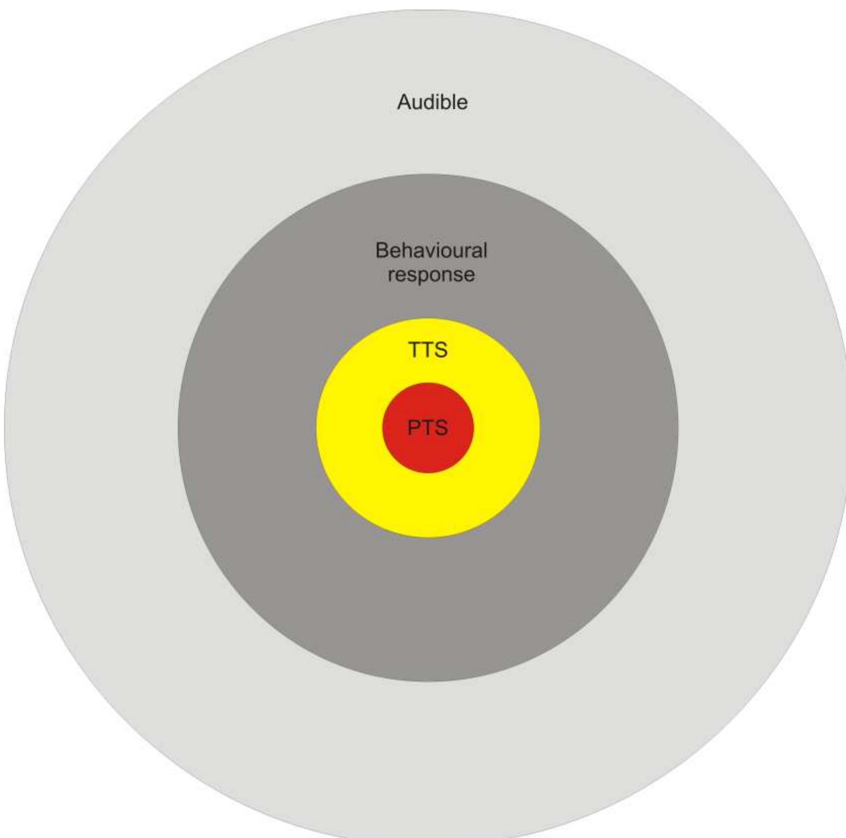

Figure 5 – Impact zones for underwater noise sources, including zone of audibility, responsiveness, and hearing injury. The zone of hearing injury is further divided into temporary and permanent threshold shift (TTS and PTS) zones.

5.0 Management and mitigation procedures

5.1 Framework

The framework for management and mitigation of underwater noise impact form piling activities has been adapted from Policy Statement 2.1, and includes safety zones, standard management and mitigation procedures, and additional management and mitigation measures. These are to be implemented as follows.

- *Safety zones* – The safety zones include observation and shut-down zones that are sized based on the likely noise levels produced by the piling activity. The safety zones should be used in the operational procedures that are part of the standard management and mitigation procedures. A diagram showing safety zones around a jetty is included in Figure 6.
- *Standard management and mitigation procedures* – These procedures are to be used for all piling activities irrespective of location and time of year, unless no marine mammal species listed under the EPBC Act are identified within the potential noise footprint of the piling activity.
- *Additional management and mitigation measures* – Additional management and/or mitigation measures to the standard management and mitigation procedures are to be used when the impacts of the piling activity on listed marine mammal species are likely to be significant (refer to Section 2.1.2).
- *Underwater noise impact assessment* – An underwater noise impact assessment should be conducted when the impacts of the piling activity on listed marine mammal species are likely to be significant (refer to Section 2.1.2). The noise impact assessment should be in general accordance with the methodology outlined in Sections 3.0 and 4.0.

Details on the safety zones, standard procedures, and additional measures are presented below.

5.2 Safety zones

The safety zones to be used in the standard management and mitigation procedures for piling activities include *observation* and *shut-down* zones. In the observation zone, the movement of marine mammals should be monitored to determine whether they are approaching or entering the shut-down zone. When a marine mammal is sighted within or appears to enter the shut-down zone, piling activities must be stopped as soon as reasonably practical.

The safety zones aim to minimise the likelihood of hearing injury to occur to marine mammals, and do not intend to prevent behavioural responses to audible but non-traumatic noise events. It is likely that marine mammals in the vicinity of a piling activity will show an avoidance reaction to the noise, which reduces the chance of marine mammals approaching the source close enough to enter the zone of hearing injury. The impacts of such a temporary displacement are unlikely to be significant unless it occurs during critical behaviours, such as breeding, feeding and resting, or in important areas such as migratory corridors.

The shut-down zones allow for the cumulative effect of multiple impacts, i.e. in the order of 30 minutes of exposure to pile driving noise for cetaceans and 2 minutes for pinniped. This allows some time to move away from the noise source thereby reducing the likelihood of hearing injury to occur.

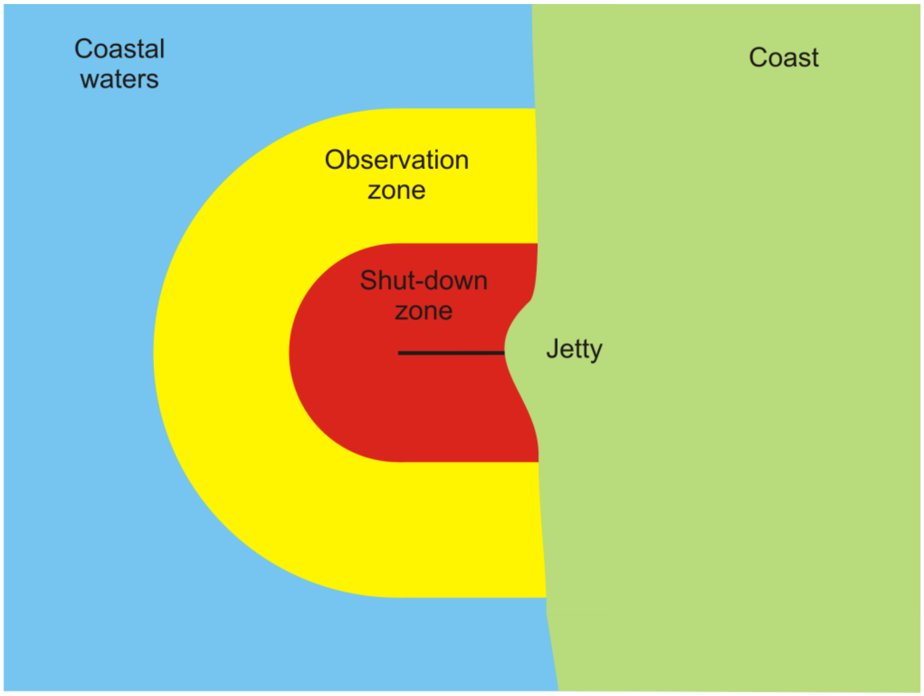

Figure 6 – Diagram showing safety zones around a jetty.

Safety zones for impact piling and vibro-driving activities are presented in Table 5, together with the estimated zone of behavioural response. The safety zones are sized by comparing expected received noise levels with the following noise exposure thresholds.

- *Impact piling* – Noise exposure threshold is SEL 150 dB(M) re 1 µPa^{2}s for a single impact at either 100 m or 300 m.
- *Vibro-driving* – Noise exposure threshold is SPL 180 dB re 1 µPa at 10 m for cetaceans and SPL 190 dB re 1 µPa at 10 m for pinniped.

Compliance with the noise exposure thresholds may be demonstrated through noise modelling or empirical measurements of a similar piling activity, i.e. similar piling rig and marine environment.

Table 5 – Summary of safety zones for impact piling and vibro-driving

Species	Noise exposure threshold	Observation zone	Shut-down zone	Zone of behavioural response
Impact piling	**SEL in dB(M) re 1 µPa^{2}s for single impact**			
Low-frequency cetaceans	≤ 150 dB(M_{lf}) at 100 m	1 km	100 m	≤ 150 m
	≤ 150 dB(M_{lf}) at 300 m	1.5 km	300 m	≤ 500 m
	> 150 dB(M_{lf}) at 300 m	2 km	1 km	≤ 3 km
Mid-frequency cetaceans	≤ 150 dB(M_{mf}) at 100 m	1 km	100 m	≤ 150 m
	≤ 150 dB(M_{mf}) at 300 m	1.5 km	300 m	≤ 500 m
	> 150 dB(M_{mf}) at 300 m	2 km	1 km	≤ 3 km

Species	Noise exposure threshold	Observation zone	Shut-down zone	Zone of behavioural response
High-frequency cetaceans	≤ 150 dB(M_{hf}) at 100 m	1 km	100 m	≤ 150 m
	≤ 150 dB(M_{hf}) at 300 m	1.5 km	300 m	≤ 500 m
	> 150 dB(M_{hf}) at 300 m	2 km	1 km	≤ 3 km
Pinnipeds	≤ 150 dB(M_{pw}) at 100 m	1 km	100 m	≤ 150 m
	≤ 150 dB(M_{pw}) at 300 m	1.5 km	300 m	≤ 500 m
	> 150 dB(M_{pw}) at 300 m	2 km	1 km	≤ 3 km
Vibro-driving	**SPL in dB re 1 µPa for single impact**			
Cetaceans	≤ 180 dB at 10 m	500 m	10 m when no avoidance	≤ 5 km
	> 180 dB at 10 m	1 km	100 m when no avoidance	≤ 10 km
Pinnipeds	≤ 190 dB at 10 m	500 m	10 m when no avoidance	≤ 5 km
	> 190 dB at 10 m	1 km	100 m when no avoidance	≤ 10 km

5.3 Standard management and mitigation procedures

5.3.1 Planning of piling activities

The planning stage of piling activities should consider the following:

- *Timing and duration* – Avoid conducting piling activities during times when marine mammals are likely to be breeding, calving, feeding, or resting in biologically important habitats located within the potential noise impact footprint. Where possible, also avoid conducting piling activities in areas adjacent migratory corridors or important feeding areas during migration season. If work is proposed in these areas, the piling activities and associated mitigation measures may require further assessment under the EPBC Act.
- *Piling method* – Use low noise piling methods, such as vibro-driving, instead of impact piling methods where possible. Vibro-driving methods produce lower noise levels and are not impulsive in character. This reduces the likelihood of hearing injury to occur within marine mammals. The piling method should be optimised taking into account time on-site and likely noise levels.
- *Contract documentation* – Include the standard management and mitigation procedures, and any additional measures to be put in place, in the contract documentation.
- *Trained crew* – Ensure that a suitably qualified person is available during piling activities to conduct the standard operational procedures outlined below. A suitably qualified person must have qualifications in ecology, zoology or environmental sciences and demonstrated experience with the identification and management of dolphins or whales. A briefing on environmental matters, including information on these guidelines, marine mammal identification, and the environmental legal obligations for companies operating in SA state waters, should be provided to all staff involved in the piling activities. Likely marine mammal concentration areas, peak migration paths and times, key feeding sites, and other aggregation areas should be identified during the planning stage and this information should be provided to trained crew members and the marine mammal observer to improve the identification and observation of marine mammals.

5.3.2 Standard operational procedures

Standard operation procedures that must be undertaken by contractors during piling activities include pre-start, soft start, normal operation, stand-by operation, and shut-down procedures.

- *Pre-start procedure* – The presence of marine mammals should be visually monitored by a suitably trained crew member for at least 30 minutes before the commencement of the soft start procedure. Particular focus should be put on the shut-down zone but the observation zone should be inspected as well, for the full extent where visibility allows. Observations should be made from the piling rig or a better vantage point if possible.
- *Soft start procedure* – If marine mammals have not been sighted within or are likely to enter the shut down zone during the pre-start procedure, the soft start procedure may commence in which the piling impact energy is gradually increased over a 10 minute time period. The soft start procedure should also be used after long breaks of more than 30 minutes in piling activity. Visual observations of marine mammals within the safety zones should be maintained by trained crew throughout soft starts. The soft start procedure may alert marine mammals to the presence of the piling rig and enable animals to move away to distances where injury is unlikely.
- *Normal operation procedure* – If marine mammals have not been sighted within or are not likely to enter the shut down or observation zone during the soft start procedure, piling may start at full impact energy. Trained crew should continuously undertake visual observations during piling activities and shut-down periods. After long breaks in piling activity or when visual observations ceased or were hampered by poor visibility, the pre-start procedure should be used. Night-time or low visibility operations may proceed provided that no more than 3 shut-downs occurred during the preceding 24 hour period.
- *Stand-by operations procedure* – If a marine mammal is sighted within the observation zone during the soft start or normal operation procedures, the operator of the piling rig should be placed on stand-by to shut-down the piling rig. An additional trained crew member should continuously monitor the marine mammal in sight.
- *Shut-down procedure* – If a marine mammal is sighted within or about to enter the shut-down zone, the piling activity should be stopped immediately. If a shut-down procedure occurred and marine mammals have been observed to move outside the shut-down zone, or 30 minutes have lapsed since the last marine mammal sighting, then piling activities should recommence using the soft start procedure. If marine mammals are detected in the shut-down zone during poor visibility, operations should stop until visibility improves.

A flow chart illustrating the standard operation procedures is included in Appendix A.

5.3.3 Compliance and sighting report

The contractor conducting the piling activities should maintain a record of procedures employed during operations. Information on any marine mammals sighted during the piling activity, and their reaction to the piling activity, may be used in the planning and assessment of future projects.

A report on the piling activity should at a minimum contain the location, date, start and completion time of the piling activity, information on the piling rig (hammer weight and drop height, pile size, number of piles, number of impacts per pile, etc.), details on the trained crew members 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 sightings.

5.4 Additional management and mitigation measures

If the piling work will have, or is likely to have, a significant impact on any matters of NES under the EPBC Act, additional mitigation measures need to be considered to further minimise the likelihood for impacts to occur.

It may not be necessary, practical or possible to apply the additional management and mitigation measures outlined below. In planning a piling activity, the contractor conducting the piling should consider which of the measures best apply to their circumstances. Details of the measures to be applied should be provided to DPTI by the contractor.

In considering additional measures, there may be a trade-off between the noise reduction that can be achieved and the additional construction time that results from the mitigation measures. This needs to be taken into account when assessing the overall benefit of any additional measures.

5.4.1 Management measures

Additional management measures that need to be considered include some or all of the following.

- *Increased safety zones* – For biologically important habitats, such as breeding, resting or feeding areas, the shut-down zone should be increased to ensure that behavioural disturbance of marine mammals does not occur. Such a measure may not be needed for all marine mammal species or the entire construction period. As an example, it should be used for piling activities undertaken adjacent known whale breeding and calving sites during whale migration season. The size of increased safety zones should be established on a precautionary basis. Noise propagation modelling and relevant scientific evidence should be used to determine and justify an appropriate size of the safety zones.
- *Marine mammal observers* – The contractor conducting the piling should engage a suitably qualified marine mammal observer(s) (MMO) when migratory, vulnerable or endangered marine mammals are likely to be present within the area surrounding the piling activity. A suitably qualified MMO must have qualifications in ecology, zoology or environmental sciences and demonstrated experience with the identification and management of dolphins or whales. They should be experienced in marine mammal identification and behaviour and distance estimation, assist other trained crew members, and provide advice should marine mammals enter the observation zone.
- *Operations during night time or poor visibility* – The soft start procedure should not be initiated until conditions allow visual inspection of the safety zones. Daylight spotter vessels or aircraft should search the area to determine the presence of marine mammals. If marine mammals are spotted within or likely to enter the safety zones during night time operations, piling activities should be postponed.
- *Spotter vessel or aircraft* – If clear observations cannot be made from land or the piling rig, visual observations for the presence of marine mammals within the safety zones may be improved by employing a spotter vessel and/or aircraft. The spotter vessel and aircraft should maintain continuous contact with the piling operator. An MMO should be on board of both the vessel and aircraft.
- *Emerging technologies* – Passive acoustic monitoring (PAM) is an emerging technology that, once reliable commercial PAM systems are available, may be used to complement visual observations for the presence of marine mammals. PAM consists of listening to marine mammal's underwater vocalisations using hydrophones, and aims to identify and locate a variety of vocal marine mammals.

PAM presently has some limitations, and commercially available systems used to date are generally of poor quality, have left-right ambiguity (i.e. cannot determine which side the signal is coming from), and have no range-finding ability. However, extensive research into PAM is set to improve the performance of passive acoustic monitoring for marine mammals.

5.4.2 Mitigation measures

Additional mitigation measures that need to be considered include some or all of the following.

- *Press-in piling* – Press-in piling machines use static forces to install piles such that impacts are not required. Underwater noise levels have not been reported but are expected to be significantly less than those produced by conventional piling methods as all impulsive type of noise associated with the impact are removed. The technology has been used on land and in shallow waters when low noise construction methods were required. The current technology allows for installation of piles with diameters of up to 1.5 metres, with larger piles being replaced by multiple smaller piles.
- *Suction piling* – Suction piling uses tubular piles that are driven into the seabed, or dropped a few metres into a soft seabed, after which air and water are sucked out the top of the tubular pile thereby sinking the pile into the ground. Suction piles are often used to secure offshore floating platforms, in both shallow and deep waters. Although noise levels have not been reported, they are expected to be low as the only source of noise is the pump.
- *Pile type selection* – There is some evidence that steel H-piles produce significantly lower peak levels, potentially in the order of 10 to 20 dB, than circular concrete and steel piles. Use of alternative piles that produce less noise should be considered but may be somewhat limited as H-piles may not be suitable for all situations.
- *Bubble curtain* – A bubble curtain is a sheet of air bubbles that are produced around the location where the piling activity occurs. The bubbles are created by forcing air through small holes drilled in metal or PVC rings using air compressors, with either one ring deployed on the sea bottom or several vertically stacked rings forming a bubble ‘tree’. The bubbles in the bubble curtain create an acoustic impedance mismatch between the water and air trapped in the bubble, which results in sound attenuation across the bubble curtain. Reported noise reductions range from 3 to 20 dB. The use of bubble curtains may be limited by the water depth and practical or cost reasons, but may be considered when piling activities are expected to produce high noise levels and marine mammals are likely to be present within the area.
- *Cofferdam* – A cofferdam is created by placing a solid casing around a pile and removing the water from the casing. This approach has the potential to result in significant noise reductions as noise from the pile is radiated into the cofferdam rather than the water. The solid casing can be constructed from a single hollow pile or by interlocking sheet piles. The down-side is that construction of cofferdams often requires piling of the solid casing to achieve a water tight seal at the sea bottom, which should be of a significantly lower noise level and duration than the piling activity the cofferdam is put in place for. The use of cofferdams may be limited by the water depth and practical or cost reasons, but may be considered where significant impacts are likely to occur.

6.0 Underwater piling noise assessment

This section describes the typical steps that need to be taken as part of an underwater piling noise assessment. A flow chart for a typical assessment is presented in Figure 7.

Step 1 – What works are planned when, how, and where?

- Establish what works are planned at what location, and whether piling will be undertaken in SA state waters as part of the proposed works. These guidelines only apply if piling will occur in marine waters.
- Identify what piling method is likely to be used for the proposed works (e.g. impact piling or vibro-driving), and get information on the size, shape, length and material of the pile, the weight and drop height of the hammer, and the type and depth of the seabed, if available.
- Determine the duration, time of the day, and time of the year (e.g. during whale season) of the piling activity.

Step 2 – What marine mammal species are potentially affected?

- Determine the potential noise footprint of the piling activity, which is the marine area where piling noise could potentially impact on marine mammals. This footprint extends up to 10 km for impact piling activities and 5 km for vibro-driving activities.
- Use the EPBC protected matters search tool to identify listed marine mammal species that are likely to be present within the potential noise footprint of the piling activity. A link to this search tool is included on page 7. The status of the identified species may be listed as migratory, threatened, commonwealth marine species, or a combination of the aforementioned. Note that threatened species are listed as vulnerable, endangered, or critically endangered species.
- If no listed marine mammal species are found within the potential noise footprint, the piling activity may proceed without implementation of management and mitigation measures for underwater noise.

Step 3 – Are potential impacts on listed marine mammals likely to be significant?

- Where listed species are present, determine if the work will occur in a biologically important habitat for the species, such as a breeding, calving or resting area, or a migratory route or feeding area during season (refer to Section 2.1.2 for more details).
- If the piling work will not have, or is not likely to have, a significant impact on any matters of NES under the EPBC Act, implement the standard management and mitigation procedures from Section 5.3. The safety zones to be used in these procedures should be determined as follows:
    - Engage an acoustic consultant to determine the safety zones that apply from Table 5. The acoustic consultant needs information on the piling method to be used, the size, shape, length and material of the pile, the weight and drop height of the hammer, and the type and depth of the seabed, if available. Refer to Section 5.2 for more details on the safety zones.
    - The acoustic consultant may document noise levels and identify the relevant project noise exposure thresholds in Table 5 through noise modelling or empirical measurements of a similar piling activity, i.e. similar piling rig and marine environment.

- If the piling work will have, or is likely to have, a significant impact on any matters of NES under the EPBC Act:
  - Engage an acoustic consultant to undertake a site specific acoustic assessment. The underwater noise impact assessment should address the following as a minimum:
    - Determine the existing ambient noise environment based on measurements or predictions from available empirical models (Wenz 1962).
    - For the considered marine mammal species, establish the likely hearing sensitivity and bandwidth, and determine noise exposure criteria for behavioural and physiological impacts based on Tables 4 and 5.
    - Determine the expected source levels for the piling activity, and predict received levels versus distance from the piling activity using a suitable noise propagation modelling method.
    - Estimate the size of the zone of audibility, responsiveness, and hearing injury based on the above information, and determine suitable sizes for the safety zones.
  - Consider additional management and mitigation measures (Section 5.4).
  - Prepare a referral under the Commonwealth legislation (EPBC Act). The EPBC referral should detail the management and mitigation procedures that will be put in place to minimise the impacts of underwater piling noise.
  - Obtain approval under State legislation if required.
    - If the potential noise footprint of the piling activity overlaps with the Adelaide Dolphin Sanctuary, advise the Adelaide Dolphin Sanctuary Advisory Board on the proposed works. Refer to Section 2.2.1.
    - If the potential noise footprint of the piling activity overlaps with an aquatic reserve or marine park, establish whether legislative approvals are required under the *Fisheries Management Act 2007* or *Marine Parks Act 2007*. Refer to Sections 2.2.3 and 2.2.4.

Step 4 – Contract management

- Include management and mitigation procedures, and additional management and mitigation measures if applicable, into contract documentation.
- Ensure contractor provides a compliance and sighting report. Refer to Section 5.3.3.
- Undertake auditing of the piling activity.

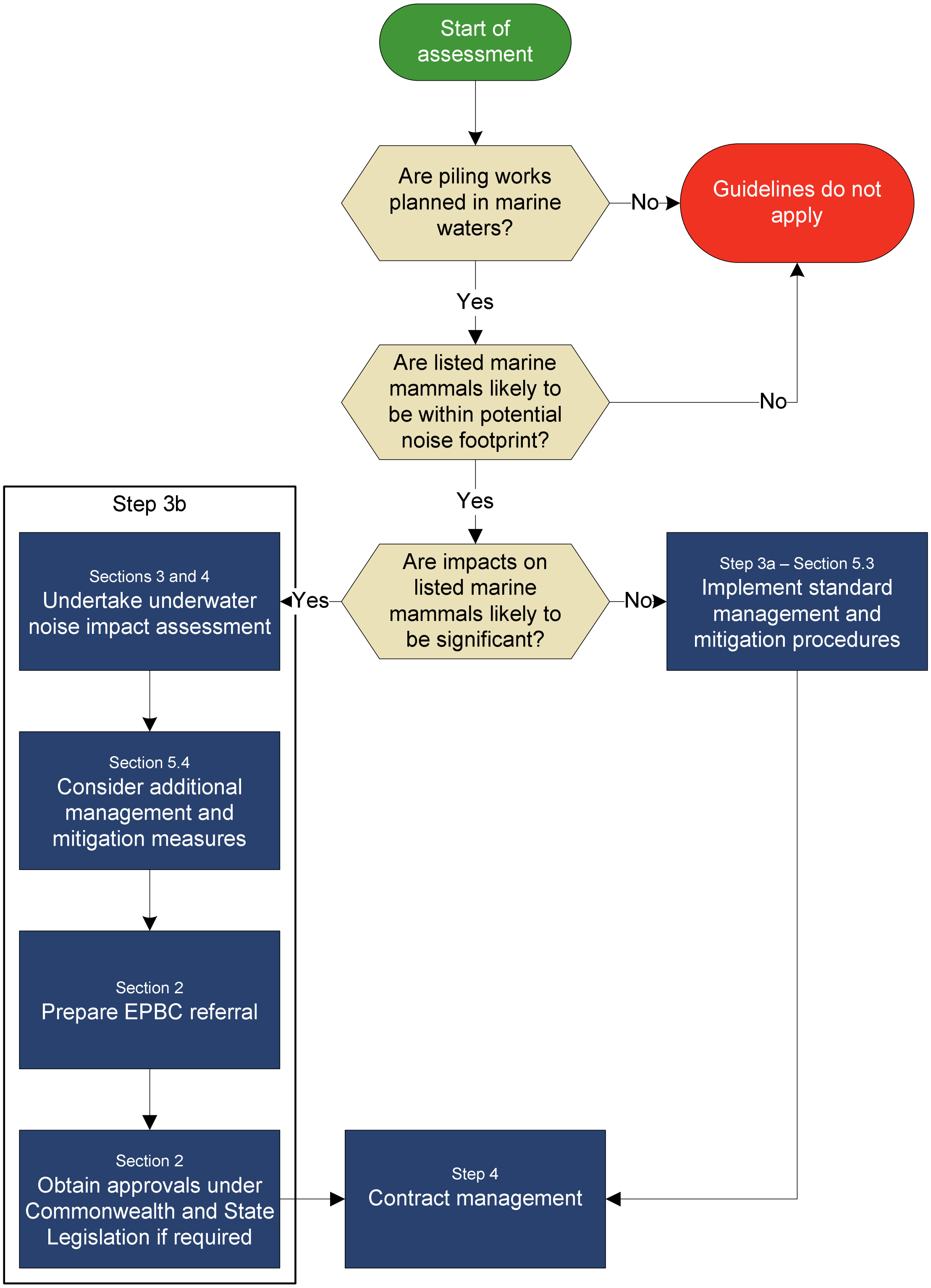

Figure 7 – Noise impact assessment

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Appendix A – Procedures flow chart

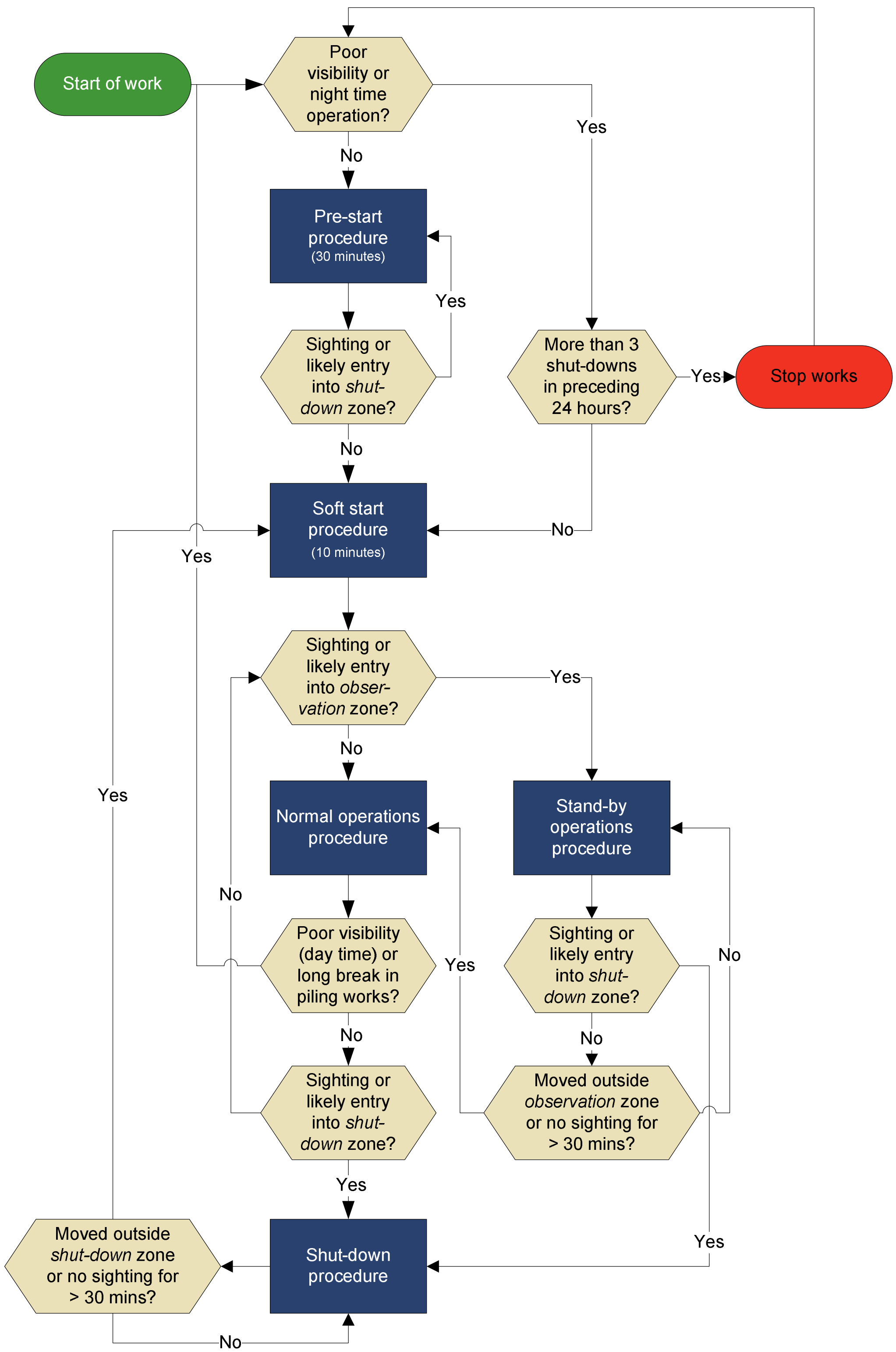

Figure 8 – Flow chart for procedures to be undertaken by contractor during piling activities

Appendix B – Listed species information

Cetaceans & Pinnipeds found in South Australian Neritic Zone Waters that appear on Protected Matters Search Tool searches of South Australian Marine Facilities

Key: Species or species habitat - ✓ known to occur; # Likely to occur; + May occur; * Foraging, feeding or related behaviour known to occur; ^ Breeding known to occur

			Regions**							
Cetaceans – Whale Species	**Pelagic/ Oceanic/ Neritic**	**EPBC Listing**	**Eyre & Upper Eyre**	**Far West**	**Fleurieu**	**Kangaroo Island**	**Metro**	**Mid North**	**South East**	**Comments**
Antarctic Minke Whale *(Balaenoptera bonaerensis)*		Migratory; Marine	**+**	**+**	**+**	**+**			**+**	Pelagic species; Likely occurrence in state waters during winter months; Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=67812
Blue Whale (*Balaenoptera musculus*)	Oceanic	Threatened (Endangered); Migratory; Marine		+	+	+		+	#*	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=36 Distribution Map available at: http://www.environment.gov.au/coasts/species/cetaceans/pubs/blue-map.pdf Listed as Endangered under the National Parks & Wildlife Act, 1972;
Bryde's Whale (*Balaenoptera edeni*)	Oceanic and inshore	Migratory; Marine	+	+	+	+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=35 ; Listed as Rare under the National Parks & Wildlife Act, 1972; Likely to be found along either east or west coast, less so along the south coast.
Humpback Whale (*Megaptera novaeangliae*)	Antarctic pelagic, (summer); temperate–subtropical/tropical coastal (winter)	Threatened (Vulnerable); Migratory; Marine	#	#	#	#	#	#	#	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=38 Distribution map available at: http://www.environment.gov.au/coasts/species/cetaceans/pubs/humpback-map.pdf Listed as Vulnerable under the National Parks & Wildlife Act, 1972;
Killer Whale (*Orcinus orca*)	Oceanic, pelagic and neritic	Migratory; Marine		+	+	+			+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=46 May be more common in cold, deep waters. Off Australia, often seen along continental slope and on shelf. Often seen near seal colonies.
(Dwarf) Minke Whale Ssp. (*Balaenoptera acutorostrata*)	Generally oceanic	Marine		+	+	+			+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=82013 ; Listed as Rare under the National Parks & Wildlife Act, 1972; Sub-species of the Antarctic Minke Whale.
Pygmy Right Whale (*Caperea marginata*)	oceanic, pelagic and inshore	Migratory; Marine	+	+	+	+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=39 Concentrations of stranded animals have occurred at the entrance of the gulfs in South Australia and around Tasmania, but live sightings have predominated in the former region (Kemper 2002a).
Southern Right Whale **(*Eubalaena australis*)**	Pelagic (summer), Onshore (winter),	Threatened (Endangered); Migratory; Marine	✓^	✓^	✓^	✓	✓	✓	✓	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=40 ; Listed as Vulnerable under the National Parks & Wildlife Act, 1972; Distribution map available at: http://www.environment.gov.au/coasts/species/cetaceans/pubs/southern-right-map.pdf

Cetaceans & Pinnipeds found in South Australian Neritic Zone Waters that appear on Protected Matters Search Tool searches of South Australian Marine Facilities

Cetaceans – Dolphin Species	**Pelagic/ Oceanic/ Neritic**	**Listing**	**Eyre & Upper Eyre**	**Far West**	**Fleurieu**	**Kangaroo Island**	**Metro**	**Mid North**	**South East**	**Comments**
Bottlenose Dolphin (*Tursiops truncatus s.str.*)	Coastal, Estuarine, Pelagic & Oceanic	Marine	+	+	+	+	+	+	+	Species fact sheet available at : http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=68417 From the sighting and stranding records the Bottlenose Dolphin appears to occur in at least two main locations in Australia: south Pacific Ocean and southern Indian Ocean. **All seasons**
Common Dolphin, Short-beaked Common Dolphin (*Delphinus delphis*)	Neritic, pelagic and oceanic	Marine	+	+	+	+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=60 Common Dolphins appear to occur in two main locations around Australia, with one cluster in the southern south-eastern Indian Ocean and another in the Tasman Sea. **All seasons**
Dusky Dolphin (*Lagenorhynchus obscurus*)	Primarily neritic but also pelagic at times when water temp >18ºC	Migratory; Marine	+	+	+	+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=43 Only 13 reports since 1828, however confirmed sightings near Kangaroo Island
Indian Ocean Bottlenose Dolphin, spotted Bottlenose Dolphin *(Tursiops aduncus)*		Marine	#	#	#	#	#	#	#	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=68418 **All seasons**
Risso's Dolphin, Grampus (*Grampus griseus*)	Generally considered pelagic and oceanic.	Marine		+	+	+			+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=64 ; Listed as Rare under the National Parks & Wildlife Act, 1972; Fraser Island has the only known 'resident' population in Australia. (Kemper, 1996)
Mammals – Pinniped Species		**Listing**	**Eyre & Upper Eyre**	**Far West**	**Fleurieu**	**Kangaroo Island**	**Metro**	**Mid North**	**South East**	**Comments**
Australian Fur Seal, Australo-African Fur-seal (*Arctocephalus pusillus*)		Marine	+		+	+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=21
Australian Sea-lion (*Neophoca cinerea*)		Threatened (Vulnerable); Marine	+	#	+	#+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=22 Listed as Vulnerable under the National Parks & Wildlife Act 1972.
New Zealand Fur-seal (*Arctocephalus forsteri*)		Marine	+	+	+	+	+	+	+	Species fact sheet available at: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=20

****Regions**: ***Eyre & Upper Eyre*** – **Cowell (Franklin Harbour)**, Port Lincoln; ***Far West*** – **Fowlers Bay**, **Port Kenney**, **Streaky Bay**, Venus Bay; *Fleurieu* – **Bluff (Rosetta Head)**, Cape Jervis, **Causeway (Granite Island)**, Rapid Bay, **Screwpile;** *Kangaroo Island* **– American River, Kingscote, Penneshaw, Vivonne;** *Metropolitan* – **Grange**, **Henley**, **Largs**, North Arm, **Outer Harbour**, **Semaphore;** *Mid North* – **Moonta Bay**, **Port Broughton**, **Port Wakefield**, **Wallaroo Spur;** *South East* – Beachport, **Blackfellows Caves**, **Cape Jaffa**, **Port MacDonnell, Southend**

NB – Each region has sites which may or may not contain any given species within a Protected Matters Search Tool search. It is recommended that an individual search be undertaken for each site where an activity is proposed to be undertaken to determine the likelihood (known, likely, may) of the presence of any given species.

Cetaceans & Pinnipeds found in South Australian Neritic Zone Waters that appear on Protected Matters Search Tool searches of South Australian Marine Facilities

Although the species listed in the above table are those listed as occurring on EPBC PMST reports for the regions as stated above, consultation with Catherine Kemper, Senior Curator of Mammalogy at the South Australian Museum has revealed that some of those species listed do not occur in South Australian waters either frequently if at all (Kemper pers. Comm.) as some are pelagic (oceanic) as opposed to Neritic (inshore). Of those species listed above found on the PMST reports for the marine regions as defined by DPTI, Catherine Kemper indicated that the species listed below are most likely to present in South Australian waters:

- **Southern Right Whale** — **Seasonal – April through October**
- **Pygmy Right Whale** — **Possibly seasonal – may occur any time but mainly spring and summer**
- **Humpback Whale** — **Any season but mainly June, July and August**
- **Short-beaked Common dolphin** — **All seasons**
- **Killer Whale** — **Unknown**
- **Indo-Pacific Bottlenose Dolphin** — **All seasons**
- **Common Bottlenose Dolphin** — **All seasons**

Those species unlikely or not known to be present in South Australian waters (Kemper Pers. Comm.):

- **Dwarf Minke Whale**
- **Bryde's Whale**

For the purposes of risk assessment that the likelihood of any given species to be present at any location is:

Known = High; Likely = Medium; May = Low