Assets | Engineering | Environment | Noise | Spatial | Waste

Underwater Noise Assessment – Mardie Salt Project

Mardie, Western Australia

Prepared for BCI Minerals

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1 Introduction

Talis has been engaged by O2 Marine to undertake modelling of underwater noise emissions for Mardie Minerals Pty Ltd (Mardie Minerals) development of a high-quality salt and Sulphate of Potash (SOP) port export facility at Mardie, located 80km south west of Karratha.

A regional map of the Mardie project is shown in Figure 1-1, and the marine based components of the project which are the basis of this underwater noise assessment, are presented in Figure 1-2.

1.1 Overview

1.1.1 Project

The Mardie Project includes the development of a variety of land and marine based infrastructure. The marine development includes the construction of a trestle jetty and the dredging of a shipping channel.

Dredging will be undertaken using a backhoe digger secured to a barge while the trestle jetty will be mounted on steel piles which will be hammered in using a hydraulic piling hammer.

During the operational phase of Mardie Minerals a barge will be used to ferry product from the jetty to bulk carriers that are located in deeper water.

1.1.2 Marine Fauna

A likelihood of occurrence assessment was undertaken by O2 Marine (2019) to identify key conservation significant marine fauna species that have high potential of, or have previously been recorded in the Project Area. These conservation significant species are considered to be at most risk from underwater noise related impacts. They include:

- Dugong;
- Turtles (Loggerhead Turtle, Green Turtle, Flatback Turtle);
- Humpback Whales;
- Australian Humpback Dolphins; and
- Green Sawfish.

The impacts of underwater noise on Dugongs, and Green Sawfish are not well known and, as a result, the assessment criteria adopted for these fauna have been inferred based on their hearing bandwidths. This study has relied on the following literature:

- **Turtles**. For Turtles, the threshold levels for Temporary Threshold Shift (TTS) and behavioural response will be adopted from work undertaken by CMST[1] for behavioural response of turtles to seismic airguns[2].

- **Humpback Whales and Australian Humpback Dolphins**. For Humpback whales and dolphins, it is assumed that the threshold levels for Temporary Threshold Shift (TTS) and behavioural response for low and mid frequency cetaceans as defined in NOAA's 'Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing' [1], are appropriate for this study.

- **Dugongs**. For dugongs there is very little known about their TTS and behavioural response levels. As their hearing bandwidths are similar to low frequency cetaceans it has been assumed that their TTS and behavioural responses are similar to that of a low frequency cetacean. As a result, the TTS threshold levels for low-frequency cetaceans defined in NOAA's 'Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing' [1], will be utilised for this study.

- **Green Sawfish**. There is almost no publically available information on the sensitivity of Sawfish to noise. As they are classed as a ray it has been assumed that they are hearing generalists with a hearing bandwidth similar to turtles. It will also be assumed that their TTS levels will be similar to that of turtles.

1.2 Aim

The aim of this study is to predict underwater noise levels associated with dredging and piling activities for the development and shipping activities for the operations phase of the port facility and assess the potential impacts on relevant marine fauna.

1.3 Scope

This report summarises the predicted underwater noise impacts from piling and dredging activities for the port facility construction on marine fauna. The marine fauna considered in this study are turtles, dugongs, Green Sawfish, Humpback Whales and Australian Humpback Dolphins.

This study is intended to address the following Environmental Scoping Document requirements:

> *Item 57: Undertake underwater noise risk assessment that includes a sensitivity assessment of the marine fauna likely to occur in the area during construction activities such as piling and*

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[1] Centre of Marine Science and Technology.

[2] 'Marine Seismic Surveys: analysis and propagation of air-gun signals and effects of exposure on humpback whales, sea turtles, fishes and squid' [3] and 'Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals for injury' [2].

dredging. The risk assessment is to include (but not limited to) disturbance to resting or nursing Humpback Whale mothers and calves;

Item 66: Quantify and assess the impacts of all shipping and proposal-related boat traffic and identify mitigation measures to avoid and minimise marine fauna collisions and ***noise*** */ light* ***related impacts****;*

1.4 Applicable Documents

[1] Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, National Oceanic and Atmospheric Administration (NOAA), July 2016.

[2] Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals, Science Applications International, May 2000.

[3] McCauley RD, et al, 2000,'Marine Seismic Surveys: analysis and propagation of air-gun signals and effects of exposure on humpback whales, sea turtles, fishes and squid'. R99-15, Perth Western Australia.

[4] McCauley et al, 'Marine Seismic Surveys- A study of Environmental Implications' APPEA Journal 200, pg 692-708.

[5] O2 Marine (2019) Mardie Project - Marine Fauna Assessment. Report prepared for BCI Minerals Limited.

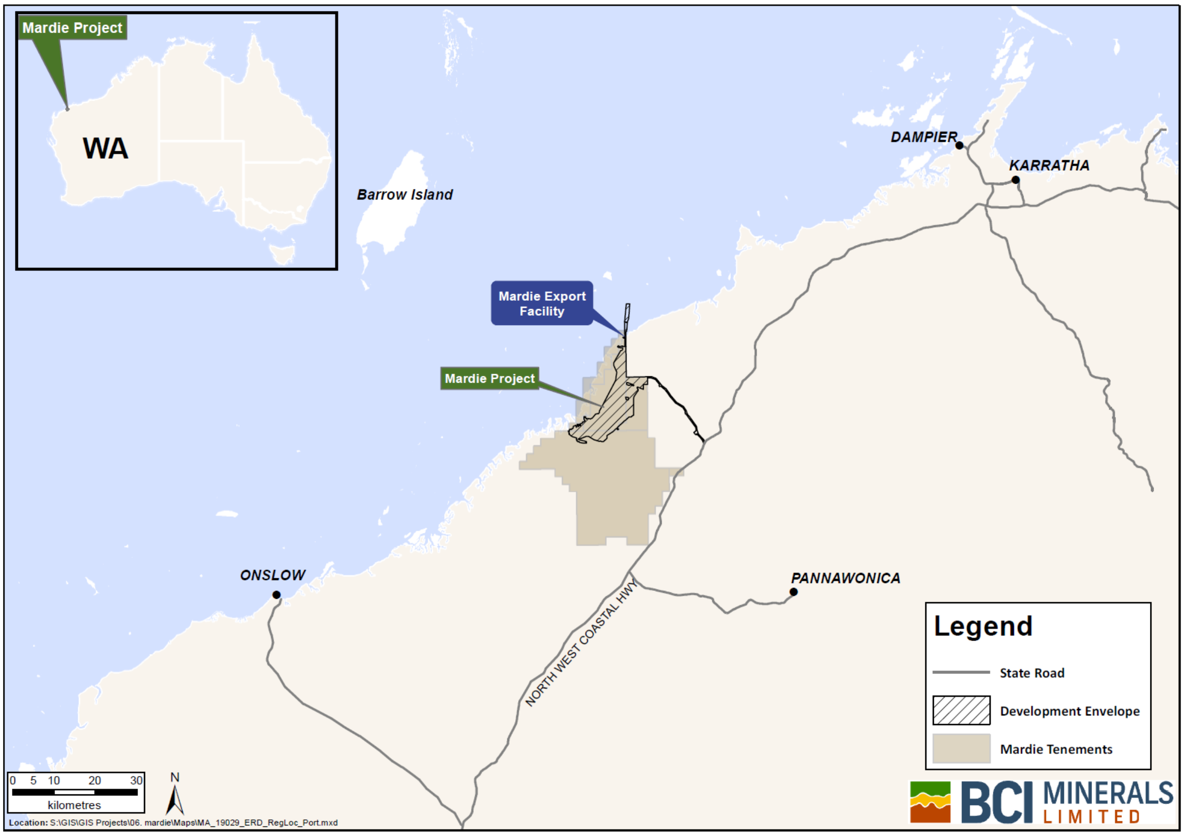

Figure 1-1 : Regional Context (Source: Mardie Project Environmental Scoping Document)

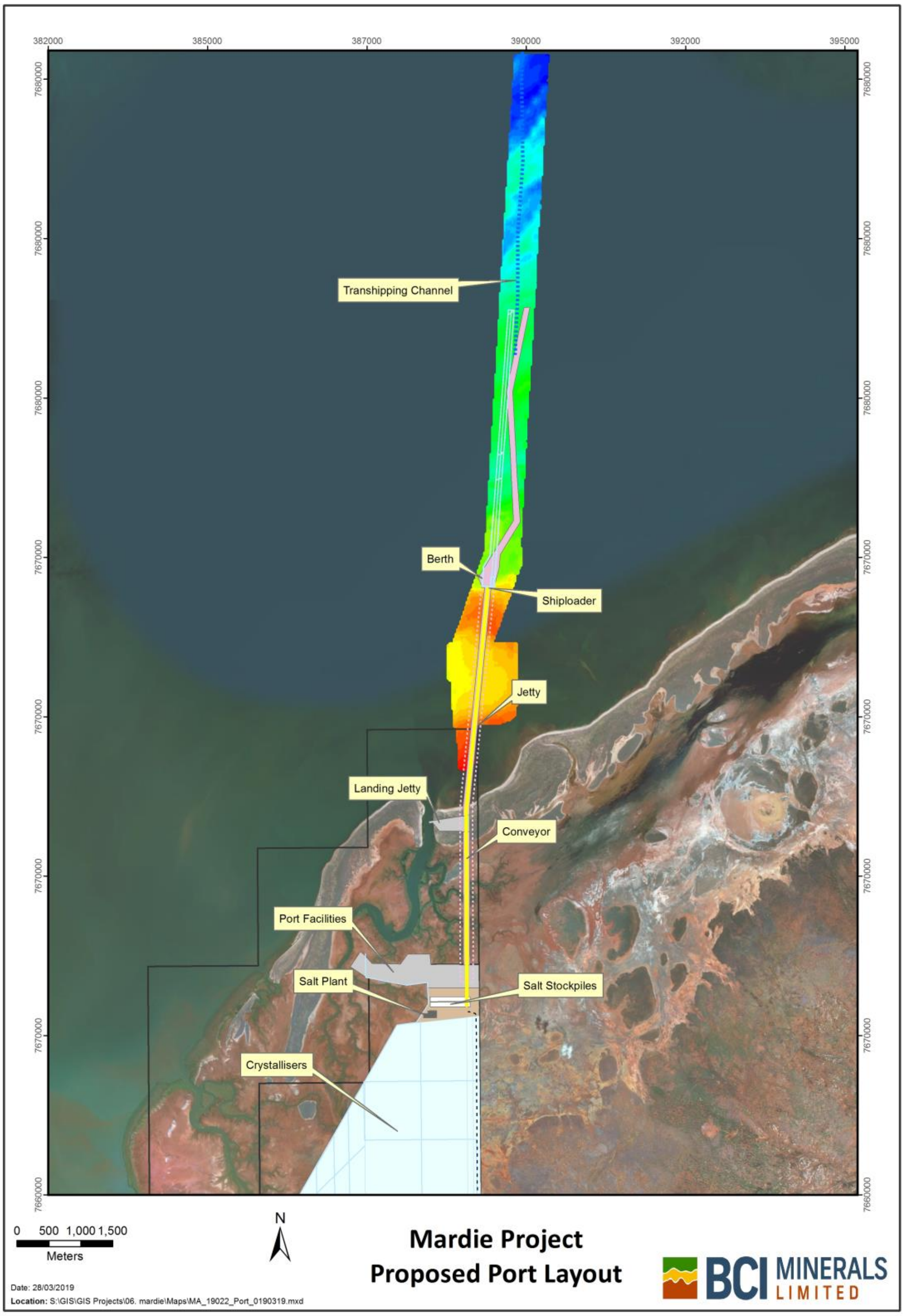

Figure 1-2 : Development Envelope and Indicative Disturbance Footprint (Source: Mardie Project Environmental Scoping Document)

2 Assessment Criteria

2.1 Summary of Recommended Assessment Criteria

Table 2-1 presents the assessment criteria adopted for turtles and dugongs for this study. A more detailed overview of the hearing bandwidths is provided in Appendix A.

Table 2-1 Received noise levels at which there is a possibility of TTS or behavioural response.

Marine Fauna Type	Hearing Bandwidth	Possible Temporary Threshold Shift (TTS)		Possible Behavioural Response [RMS]	
Turtles and Green Sawfish	100 to 800 Hz	Peak	222 dB re1µPa	RMS	166 dB re 1µPa [3]
		SEL	183 dB re 1µPa^2.s[4]	SEL	175 dB re 1µPa^2.s
Humpback Whales and Dugongs	7 Hz to35 kHz W(LF)[5]	Peak	219 dB re 1µPa [6]	RMS	120 re 1µPa[7]
		SEL	179 dB re 1µPa^2.s [8]	SEL	140 re 1µPa^2.s [9]
Australian Humpback Dolphins	150 Hz to 160 kHz W(MF)	Peak	230 dB re 1µPa [10]	RMS	120 re 1µPa
		SEL	185 dB re 1µPa^2.s [11]	SEL	140 re 1µPa2.s [9]

3 McCauley et al, 'Marine Seismic Surveys- A study of Environmental Implications' APPEA Journal 200, pg 692-708 [4] and McCauley RD, et al, 2000,'Marine Seismic Surveys: analysis and propagation of air-gun signals and effects of exposure on humpback whales, sea turtles, fishes and squid'. R99-15, Perth Western Australia.

4 Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals, Science Applications International, May 2000.

5 Low frequency weighting as per NOAA technical guidance.

6 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, National Oceanic and Atmospheric Administration (NOAA), July 2016

7 Based on Southall et al recommended SPL RMS of 120 dB re 1µPa (see Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

8 National Oceanic and Atmospheric Administration (NOAA) 'Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing' Table 6 page 33.

9 Dunlop et al., Determining the behavioural dose-response relationship of marine mammals to air gun noise and source proximity.

10 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, National Oceanic and Atmospheric Administration (NOAA), July 2016

11 National Oceanic and Atmospheric Administration (NOAA) 'Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing'.

3 Methodology

3.1 Overview

The desktop study has been undertaken using a computer noise model to simulate underwater noise emissions. The underwater software calculation kernel utilises the Monterey Miami Parabolic Equation (MMPE), which was developed by the Miami and Monterey universities in the USA. The model can predict transmission loss from multiple noise emission sources simultaneously in both broadband and narrowband frequency ranges.

Underwater propagation models require inputs including bathymetric data, geo-acoustic information and oceanographic parameters to produce 3D estimates of the acoustic field at any depth and distance from the source. The quality of the model prediction is directly related to the quality of the environmental information used in the model.

The model has been setup to assume worst case environmental conditions for all scenarios (i.e. the conditions which result in the greatest propagation of noise from source to receiver) and therefore provides conservative model predictions.

3.2 Noise Source Levels

Construction will involve various noisy activities and equipment. The most significant noise generating activities that have been identified and form the basis for this modelling are piling and dredging.

The noise source levels used for modelling have been calculated based on a combination of client proposed operational data, equipment source levels from Talis' database of underwater noise sources and information available in literature. All source levels include overall and octave band spectral levels.

The source levels and positions of these sources are discussed in detail in section 4.

3.3 Bathymetry

The bathymetry applied to the model for the Mardie area was provided by O2 Marine.

3.4 Seabed Types

A sandy seabed (see Table 3-1 for seabed properties) has been assumed for the study area. This is a conservative assumption because sand is more reflective in shallow water environments (i.e. shallow grazing angles) than limestone and other materials which may be present in the area.

Table 3-1 Seabed properties used in the model

Type	Sound Speed (m/s)	Density (g/cm^3)	Sound attenuation (dB/m/kHz)		Shear Speed (m/s)
			Compression	Shear	
Fine to medium sand	1774	2.05	0.37	0	0

3.5 Sound Speed Profile

The area of interest for the modelling is in very shallow water (maximum bathymetric depth in the data provided is approximately 25 m). As a result, it is expected that the temperature profile through the water column will be isothermal. Therefore, the sound speed profile used for modelling is a constant water temperature of 27°C and a constant salinity of 35 parts per thousand (ppt).

3.6 Data and Model Limitations

The following limitations apply to the noise modelling;

- **Reflection**. Specular reflection due to rough seabed surface and wave action is not accounted for in the model.
- **Airborne Noise**. A small component of the noise generated above the sea surface may transfer into the water column, however this has not been accounted for in the model.
- **Salinity and Sound Speed Profiles**. The water depth in the modelling area is relatively shallow. It has therefore been assumed that the water column is isothermal. Additionally, salinity will have negligible effect on the sound speed profile. Variation in the sound speed profile has been limited to the effects of water column pressure.
- **Bathymetry**. For near shore modelling, both bathymetry and topography were used in the model. The 0 m mark of the bathymetry is based on the Mean Sea Level (MSL) level. A 3 m tide above MSL was used in the model to reflect high tide.
- **Model Contour Depth.** The model is capable of producing horizontal noise contours for any depth and distance, as well as vertical plots showing depth versus range for any bearing. However, it is not practical within the constraints of the study to provide plots for each depth and for each bearing (i.e. 360 outputs for each scenario). As a result, a selected sub-set of graphs for depths and bearings of interest are provided within this report.

4 Modelling Sources

4.1 Dredging and Barge Noise Source Level

Dredging is an underwater excavation activity used to increase the water depth for shipping purposes. This excavation is carried out by gathering up bottom sediment and disposing of this material to a different location.

A backhoe excavator on a barge will be used for dredging. The backhoe dredger is a lower noise alternative to other dredging techniques, as the majority of the noise sources are located on the dredge barge out of the water. As a result, only a small amount of acoustic energy though structure borne noise is expected to be transferred into the water through the backhoe and other ancillary equipment operating on the barge. As there is no available source level data for a backhoe dredge, a conservative approach has been taken where a medium size vessel source level has been used. The Sound Pressure Level (SPL) source level used for modelling of dredging activities is given in Table 4-1 and Figure 4-1.

As the source level used for the dredger is similar to what is expected for a small barge the same source level has been used.

Table 4-1 Dredging and Barge noise source level

Parameter	Noise Level, SPL RMS[12]
SPL Source Level	167 dB re 1µPa @ 1m

[12] Sound Pressure Level Root Mean Square

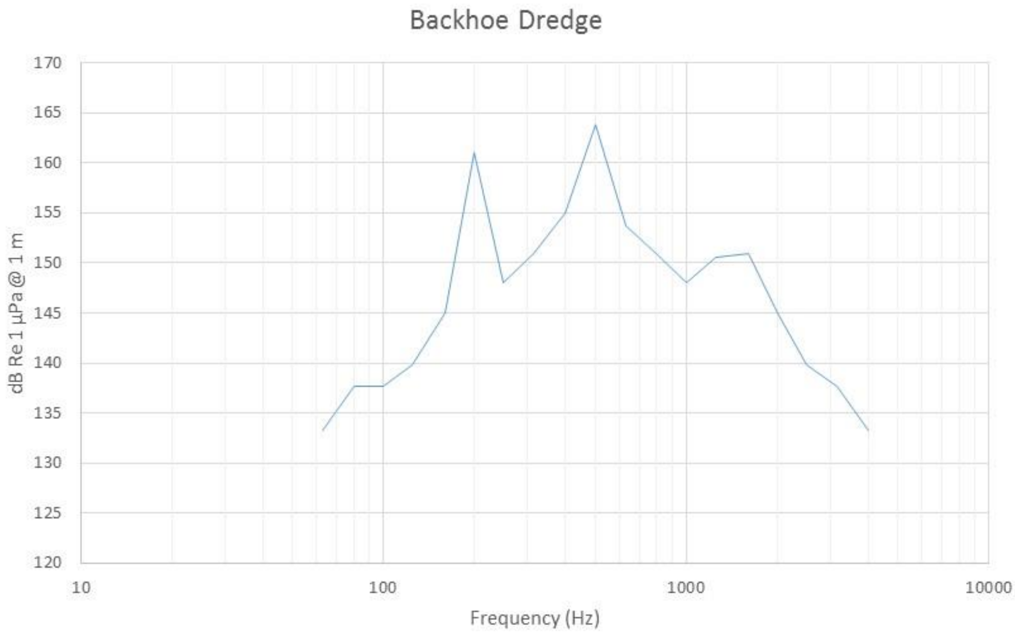

Figure 4-1 Backhoe dredging and barge noise source characteristics

4.2 Piling Noise Source Level

Pile driving involves hammering a pile into the seabed to the point of refusal. The noise emanating from a pile is a function of its material type, its size, the force applied to it and the characteristics of the substrate into which it is being driven.

The action of driving a pile into the seabed excites bendy[13] waves in the pile that propagate along the length of the pile and transfer into the sea and seabed. The transverse component of the wave propagates into the ocean, while the compression component propagates into the seabed. Once in the seabed, the energy will then propagate outwards as compression and shear waves.

Piles can be driven using various methods such as vibration, gravity and hydraulic hammer. The method that is used is dependent on the size of the pile and the substrate into which the pile is being driven. It is planned that hydraulic impact hammers will be used for this piling operation. The noise that is generated by an impact hammer hitting the top of the pile is short in duration lasting approximately 100 ms and can therefore be described as an impulsive noise.

The pile driving specifications that have been used to calculate the source levels for modelling of piling are given in Table 4-2.

[13] Bendy wave is a wave that comprises of a compression wave and a transverse wave.

Table 4-2 Pile driving specifications

Parameter	Value
Pile diameter	~900 mm
Hammer Type and Weight	16t Hydraulic
Hammer Energy	235 kJ
Blow rate	30 bpm

Table 4-3 and Figure 4-2 present the pile driving source levels used for modelling which has been calculated using the data provided.

Table 4-3 Piling noise source level

Parameter	Value SEL^2 for a single strike
SEL Source Level	205 dB re $1\mu Pa^2.s$ @ 1m

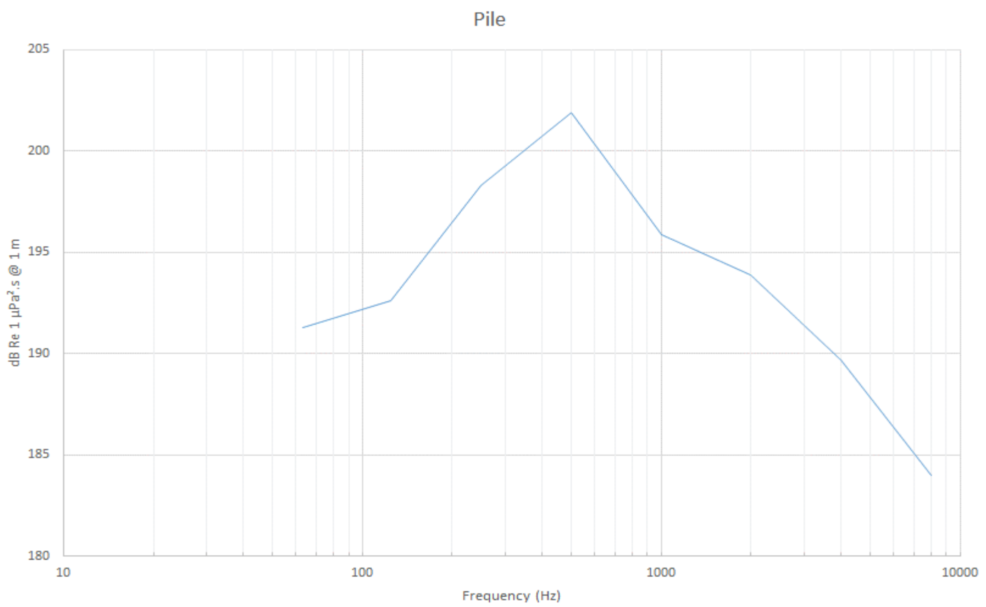

Figure 4-2 Pile Driving source characteristics

4.3 Location of Modelled Noise Sources

Table 4-4 defines the modelled noise source locations for Dredging and Piling activities, which have also been graphically presented in Figure 4-3.

The modelled noise sources were located in the deepest possible position for that noise source and all model scenarios have been run for high tide (i.e. 3m above mean sea level (MSL)) and also at mean tide and low tide for piling scenarios. As the sources have been modelled at the deepest point for all scenarios, the modelling outputs can therefore be considered as conservative and worst case.

Table 4-4 Noise Source Locations

Activity	GPS Location (MGA94, Zone 50K)	
	Eastings	Northings
Dredging	389480 m E	7673750 m N
Piling	389250 m E	7672250 m N

(a)

(b)

Figure 4-3 Noise Source Locations modelled including (a) regional context and (b) nearfield image showing the proposed jetty and dredge channel.

5 Noise Model Results and Discussion

The following sections present noise modelling results for dredging (section 5.1) and piling (section 5.2).

As discussed in section 4, all results are presented based on high tide (except for piling where the results for low and mean tide levels have also been provided).

As the species of interest have different hearing bandwidths and hearing thresholds, their predicted received levels will differ. As a result, the maximum received noise levels with distance have been provided separately for the species of interest.

Noise contour maps are provided with no hearing thresholds applied, representing the highest predicted noise levels from each activity.

5.1 Dredging and Barge

Dredging and Barge is considered as a continuous noise source for the purposed of this study, and therefore the most relevant noise parameter for assessment of dredging impacts is the SPL RMS.

The following results have been provided:

- Figure 5-1 presents the predicted SPL RMS noise contours (with no hearing thresholds applied) for dredging and barge activity.
- Figure 5-2 shows the maximum predicted SPL RMS for Turtles and Green Sawfish (i.e. with hearing thresholds applied between 100 to 800 Hz), and attenuation of the received levels over range. As can be seen from the graph, received noise levels never exceed the threshold level of behavioural response (i.e. 166 dB re 1µ Pa SPL RMS).
- Figure 5-3 shows the maximum predicted SPL RMS for humpback whales and dugongs (i.e. low frequency weighting curve applied as per NOAA technical guidance), and attenuation of the received levels over range. As can be seen from the graph, received noise levels attenuate to below 120 dB re 1µ Pa SPL RMS at ~1500 m from the dredging operations.
- Figure 5-3 also shows the maximum predicted SPL RMS for Australian Humpback Dolphins (i.e. mid-frequency cetaceans), and attenuation over range. As can be seen from the graph, received noise levels attenuate to below 120 dB re 1µ Pa SPL RMS at ~200 m from the dredging operations.

The following can be concluded from the results:

- The dredging and barging operations are not expected to result in any behavioural disturbance of Turtles and Green Sawfish.
- Noise levels from the activities drop to below 120 dB re 1µ Pa SPL RMS at ~1500 m from the vessels. Therefore, the zone of behavioural disturbance is expected to be;
    - 1500m from the dredger and barge for humpback whales and dugongs (low frequency cetaceans).

- 200m from the dredger and barge for Australian Humpback Dolphins (mid frequency cetaceans).

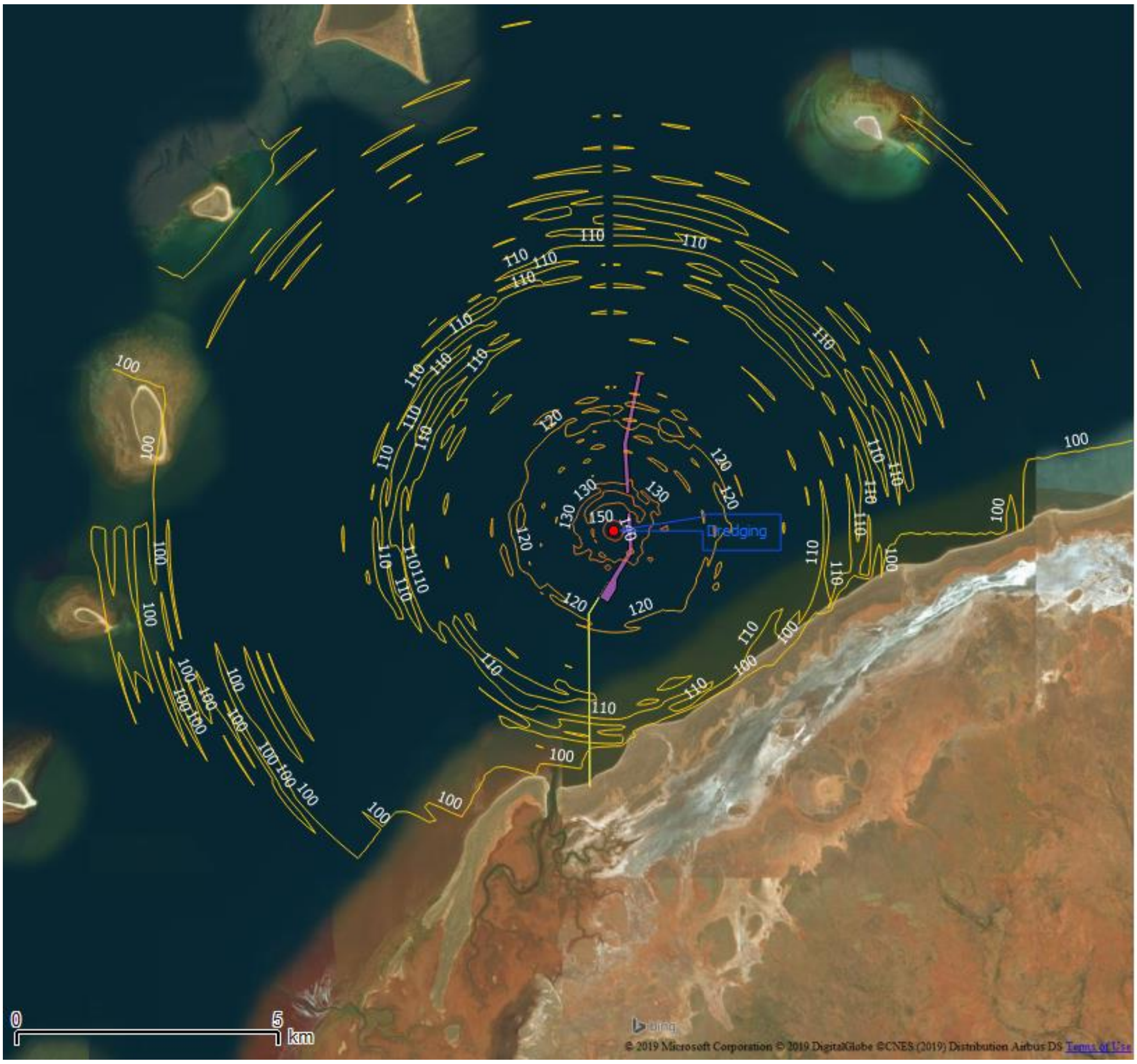

Figure 5-1 Noise Contour with no hearing thresholds applied– Dredging and Barging Operations – SPL RMS

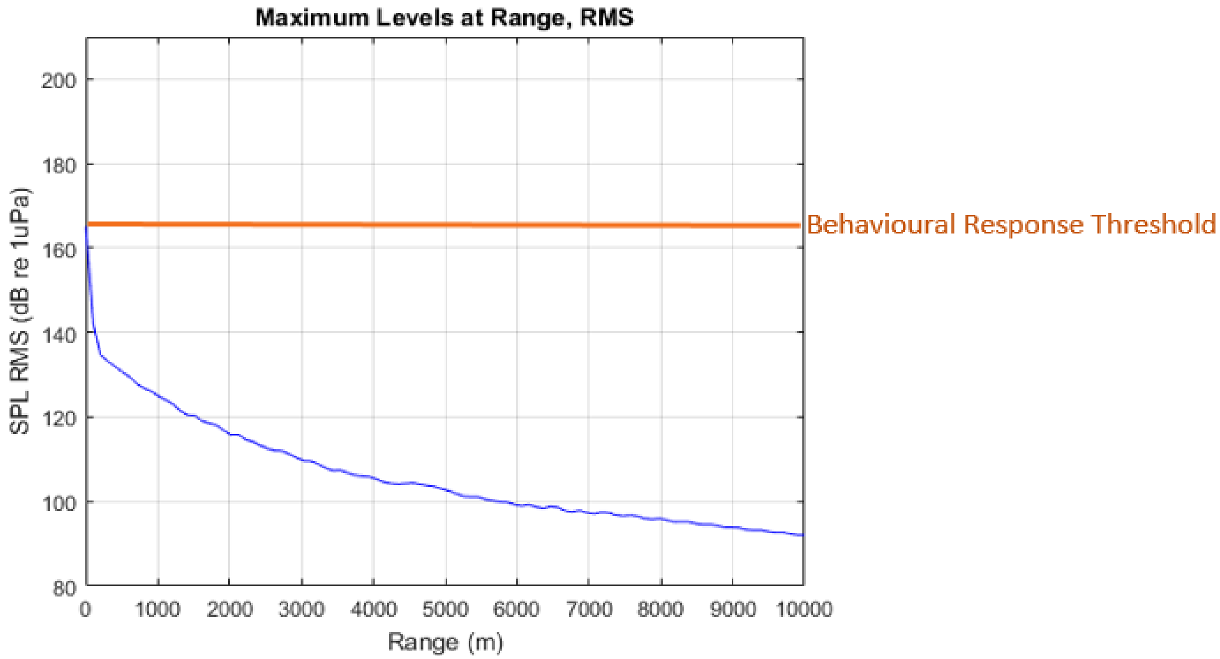

Figure 5-2 Maximum SPL RMS Noise Levels with Range for Turtles and Green Sawfish – Dredging and Barging Operations

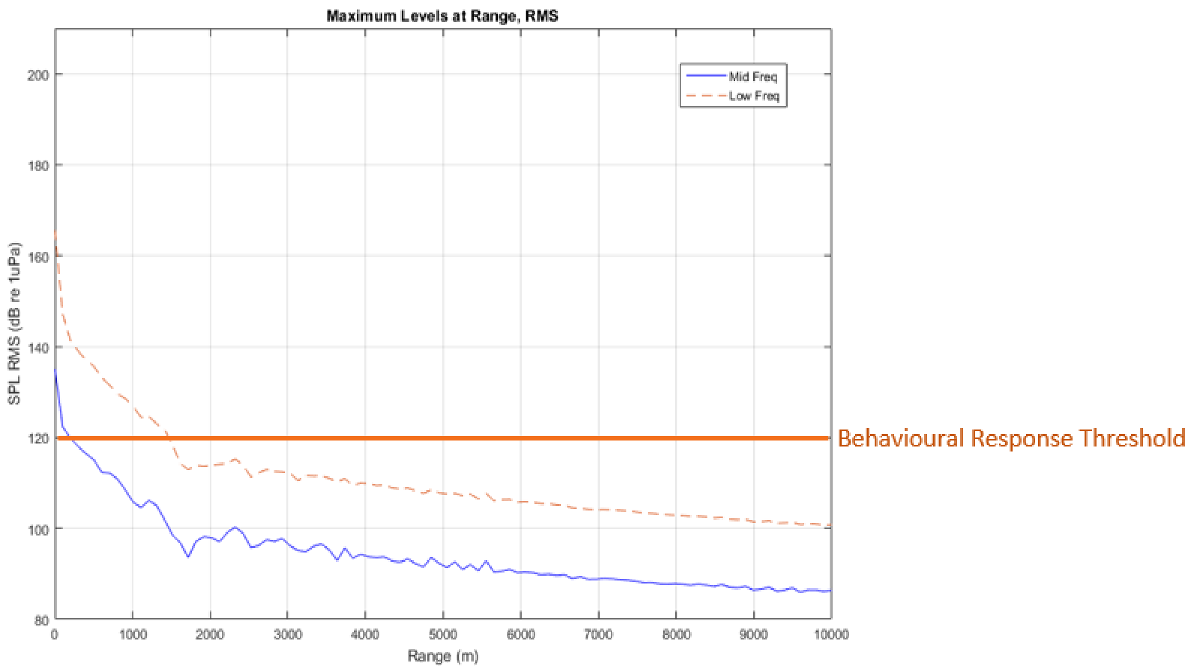

Figure 5-3 Maximum SPL RMS Noise Levels with Range for Humpback Whales and Dugongs (low frequency cetaceans) and Australian Humpback dolphin (mid-frequency cetaceans) – Dredging and Barging Operations

5.2 Piling

Piling is an impulsive noise source involving multiple pile strikes. Therefore, the SEL is the most relevant parameter for assessing the impacts of piling on marine fauna.

High, mean and low tide have been considered for piling. It must be noted that at low tide the water depth at the modelled source location is less than 3 m. At these depths, not much of the pile is immersed in the water and the cut-off frequency is 130 Hz. This implies that less acoustic energy is transmitted into the water column and low frequency waves are not formed. The model also becomes less accurate at these depths.

The following results have been provided:

- Figure 5-4 presents the SEL predicted high tide noise contours (with no hearing thresholds applied) for a single pile strike.
- Figure 5-5 shows the maximum predicted SEL for a single pile strike for turtles and Green Sawfish (i.e. with hearing thresholds applied) with range for high, mean and low tide. As can be seen from the graph received noise levels attenuate to below TTS (i.e. 183 dB re 1µ Pa^2.s) at the following distances;
    - **High Tide -** ~101 m.
    - **Mean Tide**. ~101 m.
    - **Low Tide**. Never exceeds TTS.
- Figure 5-6 shows the maximum predicted SEL for a single pile strike for Humpback Whales and Dugongs (i.e. low frequency weighting curve applied as per NOAA technical guidance) with range for high, mean and low tide. As can be seen from the graph, received noise levels attenuate to below TTS (i.e. 179 dB re 1µ Pa^2.s) at the following distances;
    - **High Tide -** ~500 m.
    - **Mean Tide**. ~300 m.
    - **Low Tide**. Only at pile.
- Figure 5-7 shows the maximum predicted SEL for a single pile strike for Australian Humpback Dolphins (i.e. mid frequency cetacean weighting curve applied) with range for high, mean and low tide. As can be seen from the graph, received noise levels attenuate to below TTS (i.e. 185 dB re 1µ Pa^2.s) at the following distances;
    - **High Tide -** Only at pile.
    - **Mean Tide**. Only at pile.
    - **Low Tide**. Never exceeds TTS.
- Figure 5-5 to Figure 5-7 also shows range at which behavioural thresholds are exceeded. As can be seen from the graphs the behavioural thresholds exceeded at the following ranges for high and mean tides:
    - **Turtles and Sawfish ~ 500 m.**
    - **Humpback Whales and Dugongs ~ 10 km.**
    - **Australian Humpback Dolphin ~ 4 to 5 km.**

    Low tide exceedance of behavioural disturbance levels only occurs in close proximity of the pile for Humpback Whales, Dugongs Australian Humpback Dolphin.

The following can be concluded from the results:

- The water levels associated with tides has a significant effect on the received noise levels.
- The ranges at which TTS levels are exceeded for turtles, Green Sawfish and Australian Humpback Dolphin are a lot less than those of the Humpback Whales and Dugongs. This is due to the hearing bandwidths of Humpback Whales and Dugongs being significantly wider.
- At low tide, the received levels are predicted to be below the TTS threshold for all assessed marine fauna, while at mean and high tides the TTS threshold levels are exceeded at ranges less than 100 m for turtles, Green Sawfish, Australian Humpback Dolphin and at 500 m for Humpback Whales and Dugongs.

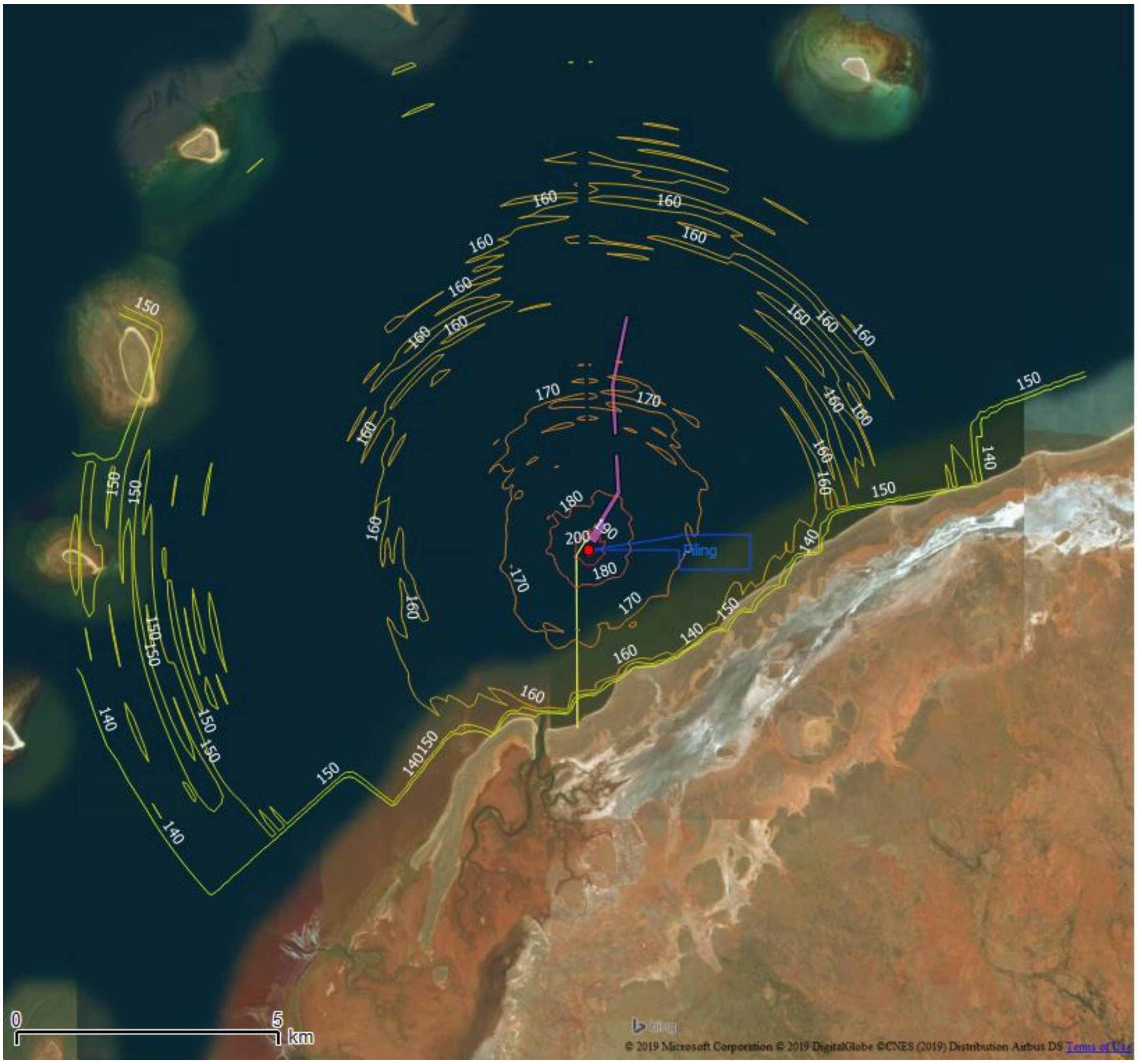

Figure 5-4 Noise Contour – Piling – SEL for a single strike at 5 m below water surface

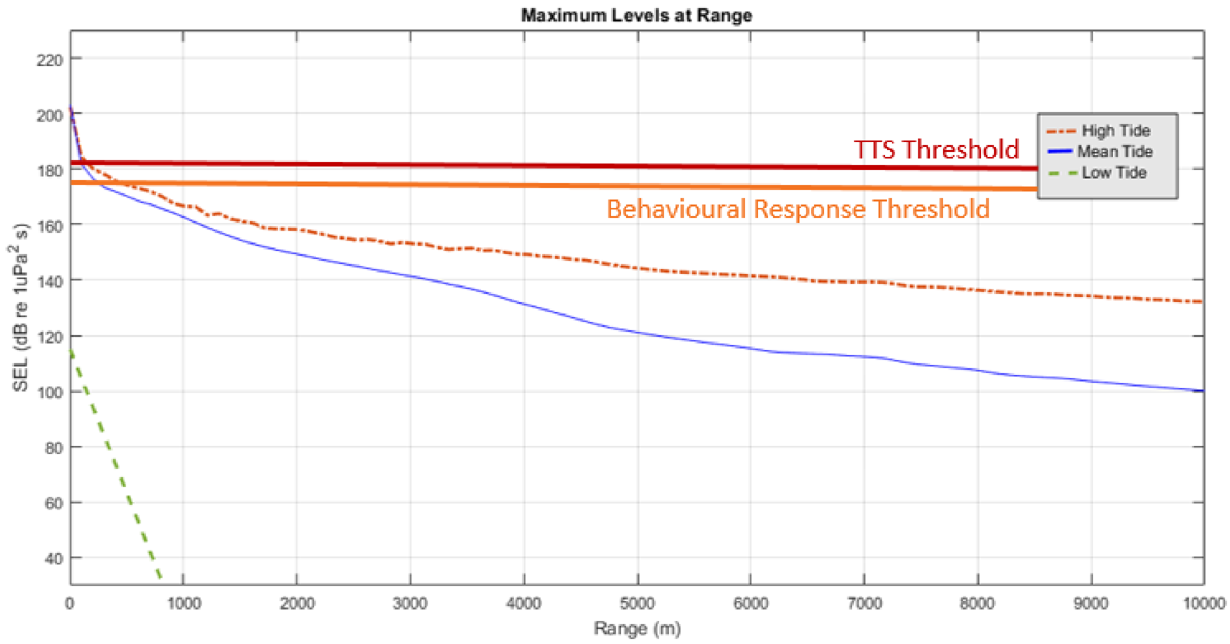

Figure 5-5 Maximum noise level with range for turtles and Green Sawfish – Piling – SEL for a single strike

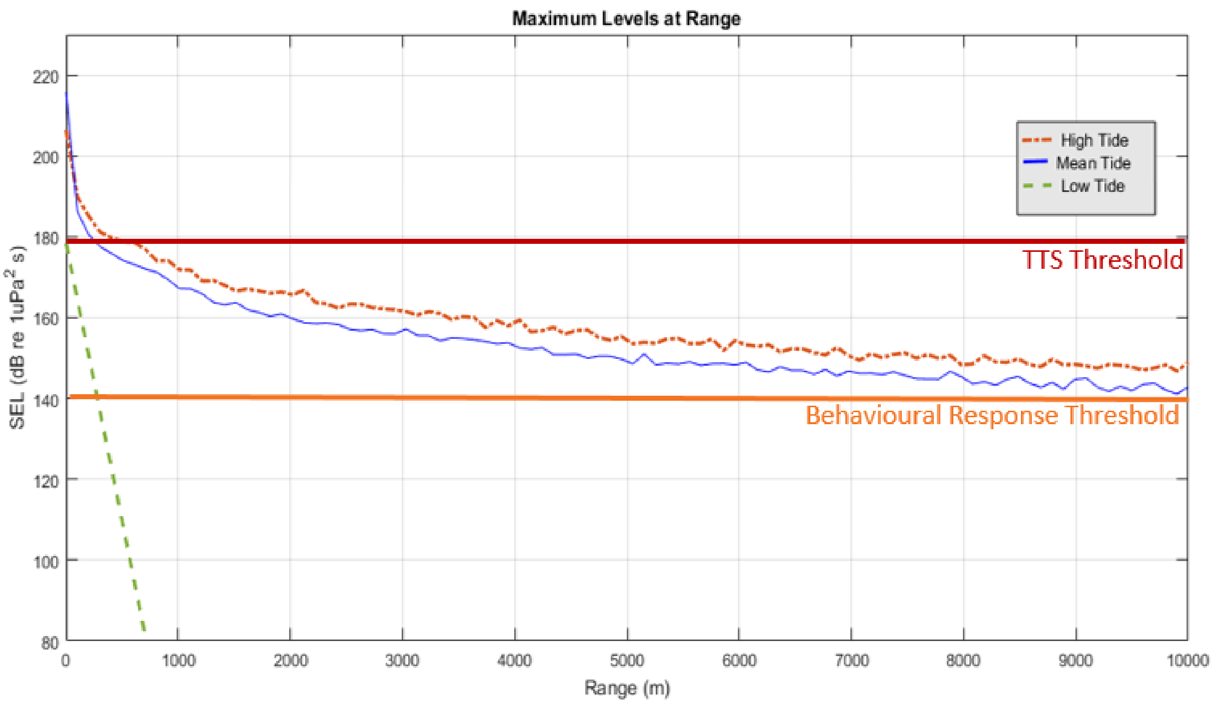

Figure 5-6 Maximum noise level with range for Humpback Whales and Dugongs – Piling – SEL for a single strike

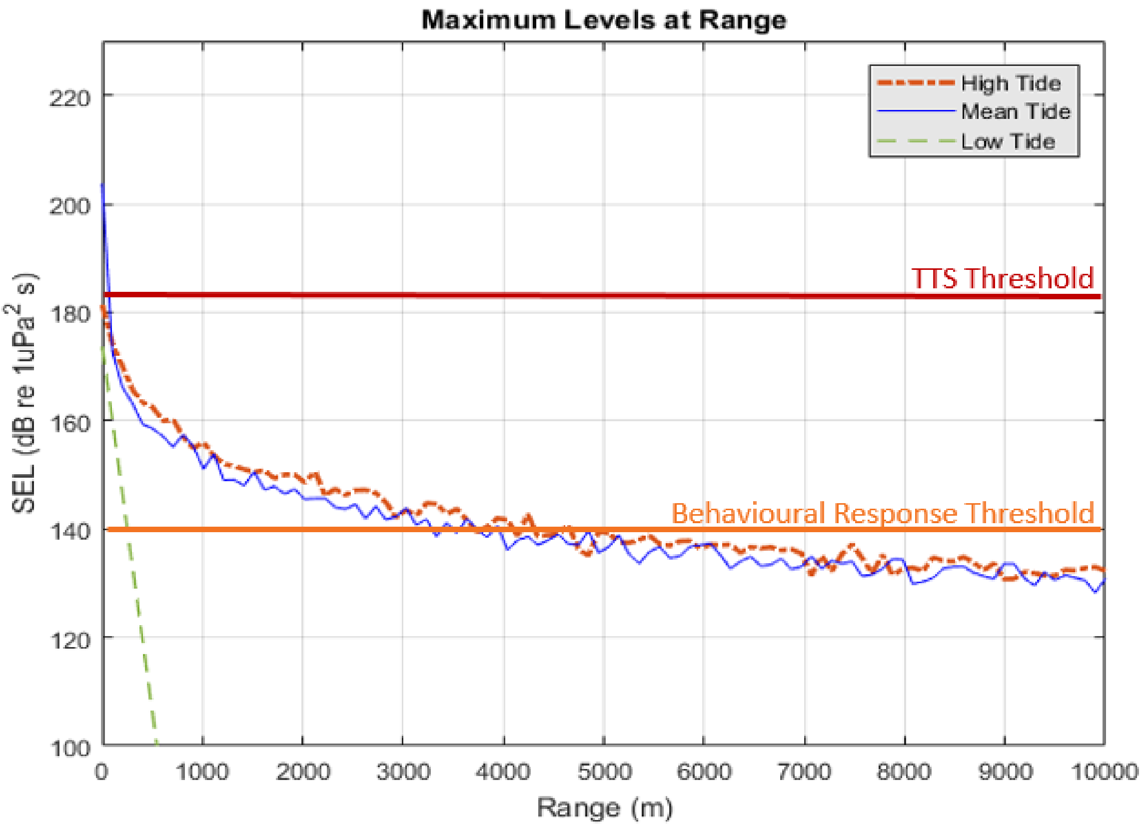

Figure 5-7 Maximum noise level with range for Australian Humpback Dolphin – Piling – SEL for a single strike

6 Conclusion

Based on the results of modelling predictions for the Project, the following can be concluded;

- **Dredging and Barging Operations** – Noise emissions from dredging are not expected to exceed TTS threshold levels for any assessed marine fauna, however, are expected to result in the following ranges of behavioural disturbance;
  - Turtles and Green Sawfish = no behavioural disturbance
  - Australian Humpback Dolphins = 200m from dredging
  - Humpback Whales and Dugongs = 1500m from dredging

- **Piling** – Noise emissions for piling have been predicted for varying water depths (i.e. high, mean and low tides), which has shown that received noise levels vary significantly for the different tide depths. The modelling has predicted that TTS levels are exceeded at the following ranges for piling;
  - Turtles and Green Sawfish = 100m from piling at high and mean tides.
  - Turtles and Green Sawfish = not exceeded at low tide.
  - Australian Humpback Dolphins = 100m from piling at high and mean tides.
  - Australian Humpback Dolphins = not exceeded at low tide.
  - Humpback Whales and Dugongs = 300m to 500m from piling at high and mean tides.
  - Humpback Whales and Dugongs = only at the pile for low tide.

- For predicted exceedances of the TTS threshold levels for high and mean tides (>3m), a management approach should be implemented to prevent TTS exceedances.

Appendix A Hearing Bandwidth Overview

Appendex A1 Hearing Bandwidths - Turtles

The turtle's auditory canal consists of cutaneous plates underlain by fatty tissue at the side of the head which serves the same function as the tympanic membrane in the human ear. Vibrations are transmitted through the cutaneous plates and underlying fatty tissue to the extracolumella, which has a mushroom-shaped head loosely attached to the outer middle ear cavity and a long shaft-like shape which extends through the middle ear and transmits sound to the stapes in the auditory canal. In turn, the footplate of the stapes is responsible for transmitting the acoustic energy through the oval window into the otic cavity, which performs a similar function to that of the human cochlea.

Measurements on the cochlea potentials of Giant Sea Turtles have shown their upper auditory limit is ≈2 kHz and their maximum sensitivity is between 300 and 400 Hz[14]. Studies using auditory brainstem responses[15] of juvenile Green and Ridley Turtles and sub-adult Green Turtles showed that juvenile turtles have a bandwidth of 100 to 800 Hz (Figure 6-1), with greatest sensitivity between 600 and 700 Hz, while adults have a bandwidth of 100 Hz to 500Hz (Figure 6-2), with the greatest sensitivity between 200 and 400Hz[16,17]. This indicates a turtle's frequency and sensitivity bandwidth decreases with age.

As a result a flat hearing response threshold between 100 and 800 Hz has been applied to the predicted levels for turtles in order to estimate the acoustic energy levels that they will be exposed to.

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14 Ridgway et al, 'Hearing in the Giant Sea Turtle, Chelonia mydas', Proc N.A.S, Vol 64, 1969

15 There is some potential uncertainty and issues regarding Auditory Brainstem Response (ABR) and behavioural audiograms, including that temporal summation influences sensitivity to sound (i.e. sounds shorter than some critical value are generally less detectable than longer signals). For mammals, this may vary between 30 and 800ms.These long pulse lengths cannot be created in a tank that is limited in size without reverberation. If a reference hydrophone is not placed in close proximity to the subjects head then the received levels will be unknown as reverberation has not been considered. Talis is unable to confirm if the sound field was measured at the subject head. Some other issues with the ABR technique is that the subjects are often drugged. From reviewed papers, it appears that some of the drugs may affect hearing. Another issue is that the number of subjects tested is small and therefore statistics of the sample size are not stable. Considering all the above, and inaccuracies in the ABR technique, Talis determined the optimum approach was to take the widest bandwidth of the known audiogram with no weighting added to it (i.e. it was assumed that the audiogram frequency response was flat

16 Ketten and Bartol,' Functional Measures of Sea Turtle Hearing', doc no. 20060509038, Sept 2005.

17 S Bartol. "Turtle and Tuna Hearing", Woods Hole Oceanographic Institute, MA, USA, as part of NOAA Technical Memorandum NMFS-PIFSC-7, December 2007

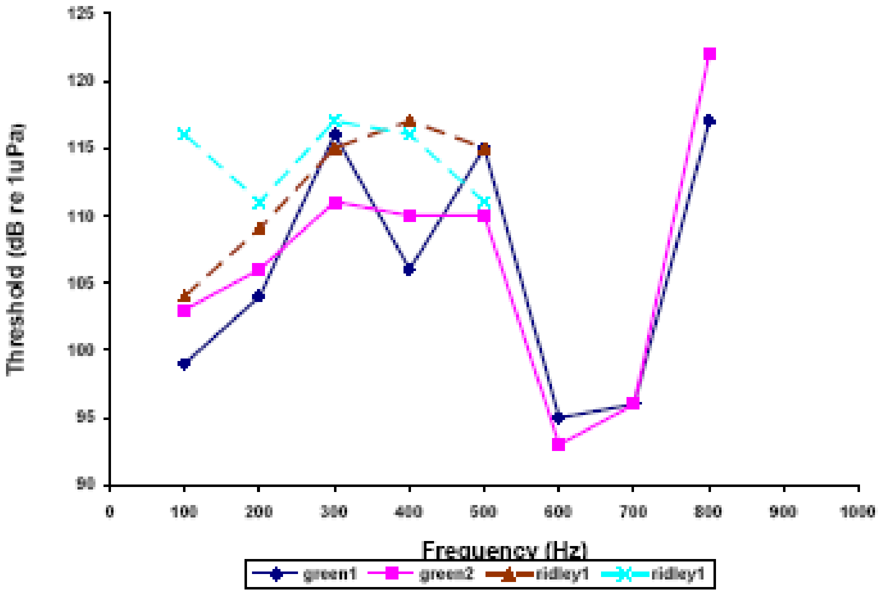

Figure 6-1 Audiograms of two juvenile Green Turtles and two juvenile Ridley's Turtles[7]

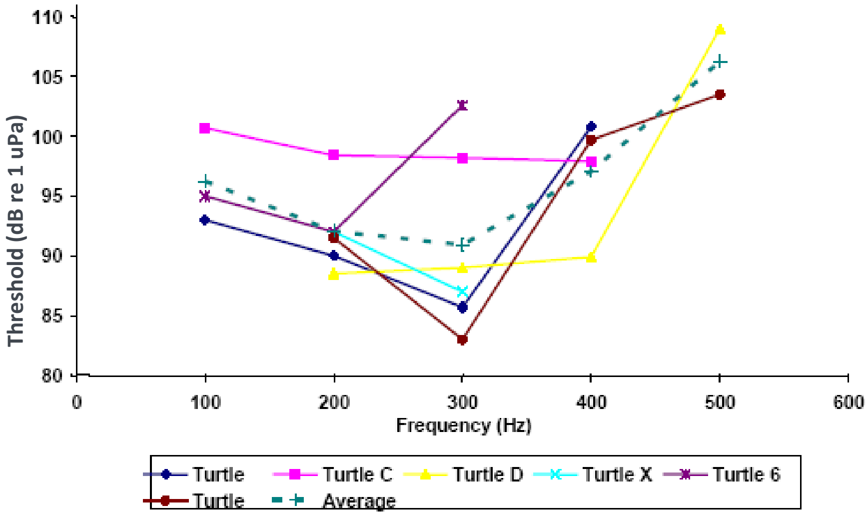

Figure 6-2 Audiograms of six sub-adult Green Turtles[4]

Appendix A2 Hearing Bandwidths - Dugongs

Dugongs, similar to cetaceans, have typical mammalian ears that consist of a middle ear and cochlea. Little is known of these mammals hearing bandwidth apart from one electrophysiological audiogram which found the hearing bandwidth to be between 4 to 32 kHz. This is a similar bandwidth to low frequency cetaceans and as a result the hearing thresholds as proposed in the NOAA guidance document has been applied to the predicted received levels for dugongs.

Appendix B Metrics Used

A variety of units are used in underwater acoustics to define steady-state and impulsive signals, which can include;

- mean square pressure (dB re 1 μ Pa)
- peak pressure (dB re 1 μ Pa)
- equivalent energy or sound exposure level (SEL) (dB re 1 μ Pa^2.s SEL)

The mean squared pressure is the decibel value of the mean of the squared pressure over a defined period of a signal. For steady signals the averaging time is not applicable, however for impulsive signals the averaging time is a significant consideration. Impulsive signals such as piling are better described by a measure of the amount of energy (Sound Exposure Level (SEL) in units of dB re 1 μ Pa^2.s) and measure of the signal peak amplitude (positive and/or negative).

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