Assets | Engineering | Environment | Noise | Spatial | Waste

Underwater Noise Modelling – Spoilbank Marina Project

Port Hedland, Western Australia

Prepared for Department of Transport

February 2020

Project Number: TN20003-1

Version	Description	Date	Author	Reviewer
0	Draft - Internal Review	14/2/2020	RK	GB
1	Released to Client	18/2/2020	GB	MS
2	Updated with comments	18/2/2020	GB	

Table of Contents

1 Introduction 2

1.1 Background 2

1.2 Aim 2

1.3 Scope 2

1.4 Applicable Documents 2

2 Assessment Criteria 4

2.1 Marine Fauna 4

2.2 Hearing Threshold Weighting Curves 4

2.3 Summary of Recommended Assessment Criteria 5

3 Methodology 6

3.1 Overview 6

3.2 Seabed Types 6

3.3 Sound Speed Profile 6

3.4 Data and Model Limitations 7

3.5 Noise Sources 7

3.5.1 General 7

3.5.2 Piling 7

3.5.3 Dredging 9

3.5.4 Bulk Carrier 10

3.6 Noise Modelling Source Locations 11

3.6.1 Dredging 11

3.6.2 Piling 11

4 Noise Model Results and Discussion 13

4.1 Dredging 13

4.2 Piling 17

4.2.1 Channel Marker Piling 17

4.2.2 Marina Piling 20

5 Management Approach 24

6 Conclusion 25

Tables

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

Table 3-1 Seabed properties used in the model

Table 3-2 Pile driving specifications

Table 3-3 Piling noise source level

Table 3-4 Dredging noise source

Table 3-5 Dredging Model Scenario

Table 3-6 Piling Scenarios

Table 4-1 TTS and Behavioural Disturbance Ranges for Channel Marker piling.

Table 4-2 TTS and Behavioural Disturbance Ranges for Marina piling

Figures

Figure 1-1 Proposed Project (source: DoT)

Figure 3-1 Pile Driving source characteristics

Figure 3-2 Dredger noise source characteristics

Figure 3-3 Bulk carrier source levels as determined by DSTO.

Figure 3-4 Piling and Dredging Locations Modelled

Figure 4-1 Noise Contour with no hearing thresholds applied– Dredging– SPL RMS

Figure 4-2 Maximum SPL RMS Noise Levels with Range for Turtles and Sawfish – Dredging and Barging Operations

Figure 4-3 Maximum SPL RMS Noise Levels with Range for Humpback Whales (low frequency cetaceans) and Spotted dolphin (mid-frequency cetaceans) – Dredging and Barging Operations

Figure 4-4 Noise Contour – Piling Channel Marker – SEL for a single strike

Figure 4-5 Maximum noise level with range for Turtles and Sawfish – Piling Channel Marker

Figure 4-6 Maximum noise level with range for Humpback Whales – Piling Channel Marker

Figure 4-7 Maximum noise level with range for Spotted Dolphin – Piling Channel Marker

Figure 4-8 Noise Contour – Piling Marina – SEL for a single strike

Figure 4-9 Maximum noise level with range for Turtles and Sawfish – Piling Marina

Figure 4-10 Maximum noise level with range for Humpback Whales – Piling Marina

Figure 4-11 Maximum noise level with range for Spotted Dolphin – Piling Marina

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]

Appendices

Appendix A Hearing Bandwidth Overview

Appendix B Equations Used

1 Introduction

The following report provides a summary of a desktop underwater noise assessment undertaken of construction activities for the development of the Spoilbank Marina in Port Hedland by the Department of Transport (DoT).

1.1 Background

The Project will be undertaken in Port Hedland near Cemetery Beach in Western Australia. The construction of the marina will involve various activities such as piling and dredging to develop the marina and boat channel (see Figure 1-1).

1.2 Aim

The aim of this report is to predict underwater noise levels from construction activities (i.e. piling and dredging) associated with the Spoilbank Harbour Project.

1.3 Scope

This report summarises the method and results of the underwater noise modelling for construction activities only. It also includes the predicted ranges at which the fauna assessed could potentially experience Temporary Threshold Shift and behavioural responses.

1.4 Applicable Documents

1. Southall et al, Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects, Aquatic Mammals 2019, 45(2).
2. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, National Oceanic and Atmospheric Administration (NOAA), July 2016.
3. Casper, B.M. (2006). The hearing abilities of elasmobranch fishes. Graduate Theses and Dissertations, University of South Florida.

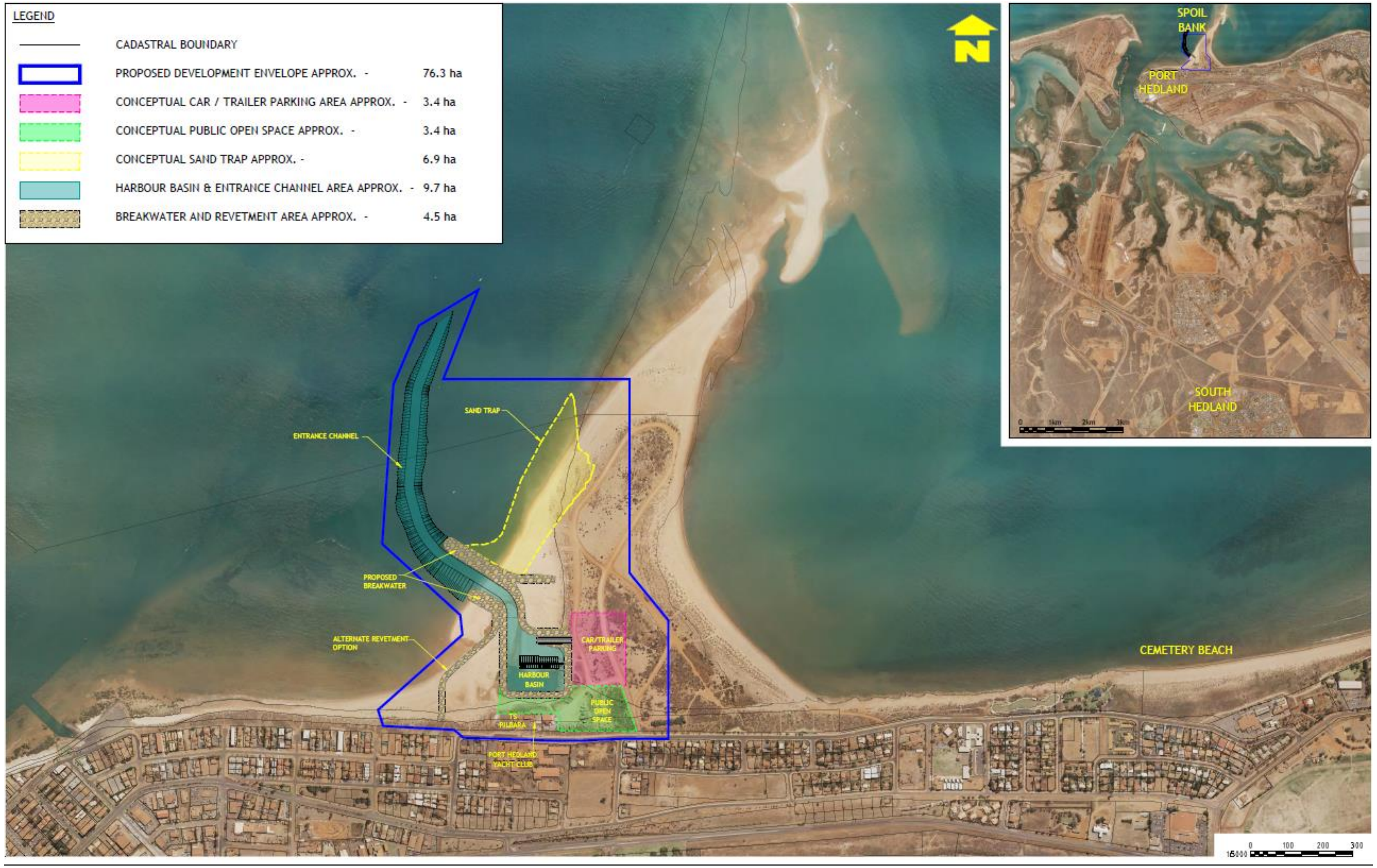

Figure 1-1 Proposed Project (source: DoT)

2 Assessment Criteria

2.1 Marine Fauna

The following fauna have been included in the assessment:

- Turtles (Flatback Turtle).
- Humpback Whales.
- Spotted Dolphins.
- Sawfish.

The impacts of underwater noise on Flatback Turtles and 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 Spotted 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', are appropriate for this study.

- **Sawfish**. A study of elasmobranch fishes[3] audiograms indicates that their hearing bandwidths range from 10 to 1000 Hz. As the study area is very shallow it is expected that the very low frequencies will only exist as short duration evanescent waves. This implies that frequencies below 100 Hz will attenuate very quickly. With the lower frequencies removed the Sawfish will have a similar hearing bandwidth to that of turtles and it has therefore been assumed that their TTS levels will be similar to that of Turtles.

2.2 Hearing Threshold Weighting Curves

Hearing weighting curves for Low Frequency (LF) and High Frequency (HF) Cetaceans have been applied to all predicted received levels in accordance with *Southall et al* (2019)[4].

[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' and 'Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals for injury'.

[3] Casper, B.M. (2006). The hearing abilities of elasmobranch fishes. Graduate Theses and Dissertations, University of South Florida

[4] Southall et al, Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects, Aquatic Mammals 2019, 45(2).

A flat hearing weighting curve from 100 to 800 Hz has been used for Turtles and Sawfish.

2.3 Summary of Recommended Assessment Criteria

Table 2-1 presents the assessment criteria adopted for cetaceans, Turtles and sawfish 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 Sawfish	100 to 800 Hz	Peak	222 dB re1µPa	RMS	166 dB re 1µPa [5]
		SEL	183 dB re 1µPa^2.s[6]	SEL	175 dB re 1µPa^2.s
Humpback Whales	7 Hz to35 kHz W(LF)[7]	Peak	219 dB re 1µPa [8]	RMS	120 re 1µPa[9]
		SEL	179 dB re 1µPa^2.s [10]	SEL	140 re 1µPa^2.s [11]
Spotted Dolphins	150 Hz to 160 kHz W(MF)	Peak	230 dB re 1µPa [12]	RMS	120 re 1µPa
		SEL	185 dB re 1µPa2.s 13	SEL	140 re 1µPa2.s [11]

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

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

7 Low frequency weighting as per NOAA technical guidance.

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

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

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

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

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

13 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 Bathymetry

The bathymetry applied to the model was obtained from DoT and publicly available data.

3.2 Seabed Types

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

Table 3-1 Seabed properties used in the model

Type	Sound Speed (m/s)	Density (g/cm³)	Sound attenuation (dB/m/kHz)		Shear Speed (m/s)
			Compression	Shear	
Fine to medium sand	1774	2.05	0.37	0	0

3.3 Sound Speed Profile

The area of interest for the modelling is in very shallow water (maximum bathymetric depth in the data provided is approximately 40 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 for a constant water temperature of 27°C and a constant salinity of 35 parts per thousand (ppt).

3.4 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 (e.g. piling) will 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 4 m hightide above MSL was used in the model[14].
- **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.

3.5 Noise Sources

3.5.1 General

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 data, equipment source levels from a database of underwater noise sources and information available in literature. The sources calculated also take account for the proposed parameters and energies applied for piling activities.

All source levels include overall and octave band spectral levels.

3.5.2 Piling

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.

[14] DoT tidal data for Port Hedland indicates that Highest Astronomical Tide (HAT) is 3.72 m above MSL. This has been rounded up to 4 m as a conservative approach.

The action of driving a pile into the seabed excites bendy[15] 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 90ms and can therefore be described as an impulsive noise.

It is expected that both channel marker and marina piles will take a maximum of 1 hour to reach the point of refusal. As a result, the maximum exposure has been assumed to be 1 hour.

The pile driving specifications[16] that have been used to calculate the source levels for modelling of piling are given in Table 3-2.

Table 3-2 Pile driving specifications

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

Table 3-3 and Figure 3-1 present the pile driving source levels used for modelling which has been calculated using the data provided.

Table 3-3 Piling noise source level

Parameter	Value SEL² for a single strike
SEL Source Level (SL)	205 dB re 1µPa².s @ 1m

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

[16] As provided in a pile driving record provided by Dot.

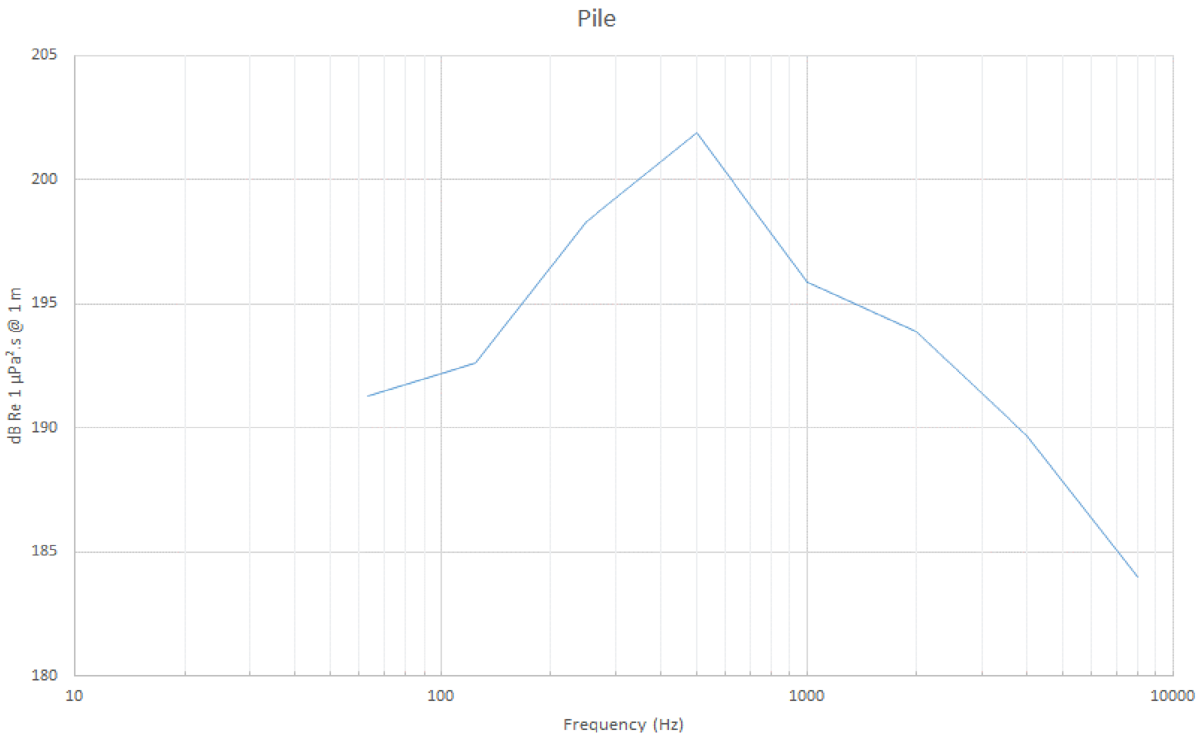

Figure 3-1 Pile Driving source characteristics

3.5.3 Dredging

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.

It is assumed that this project will utilize a Cutter Suction Dredger. A Cutter Suction Dredger is a ship that includes a cutter head used to loosen the material and a suction mouth, inlet and pump used to mobilise the material from the seabed through piping and onto a DMMA (Dredge Material Management Area). Booster pumps may be used to transport the material to the DMMA, but these will be located on land and have not been included in the model.

The source level used for modelling of dredging activities is given in Table 3-4 and Figure 3-2.

Table 3-4 Dredging noise source

Parameter	Value SPL RMS[17]
SPL Source Level (SL)	182 dB re 1µPa @ 1m

[17] Sound Pressure Level Root Mean Square

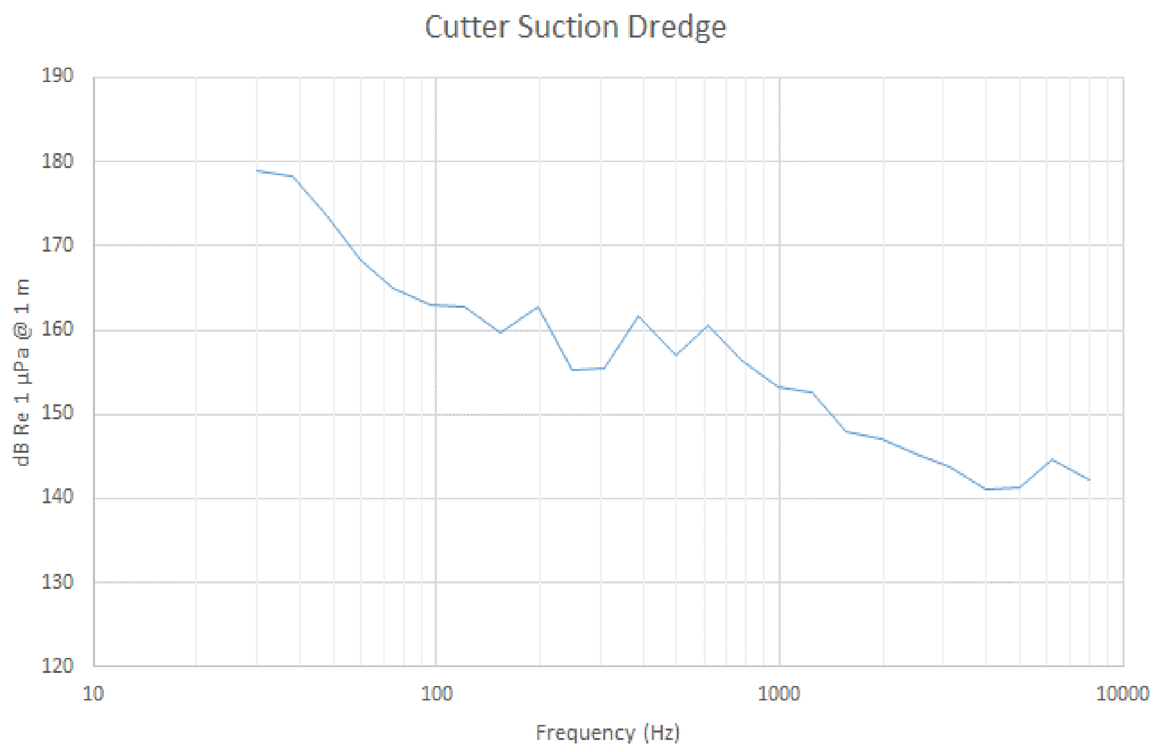

Figure 3-2 Dredger noise source characteristics

3.5.4 Bulk Carrier

Iron Ore carriers which form a large part of the shipping activity in the Port Hedland area have not been included in the model as they form part of the existing background noise. As a result, the expected source levels are included in this section so that they can be compared with that of the dredging activity.

Figure 3-3 shows typical bulk carrier source levels as determined by DSTO. If these levels are compared with those of the dredger shown in Figure 3-2 it can be seen that the dredgers source levels above 50 Hz are very similar to those of the bulk carriers. Below 50 Hz the dredger's source levels become higher. As the dredger is dredging in shallow water it is expected that these lower frequencies will attenuate rapidly. The dredger will therefore likely be indistinguishable from the background noise.

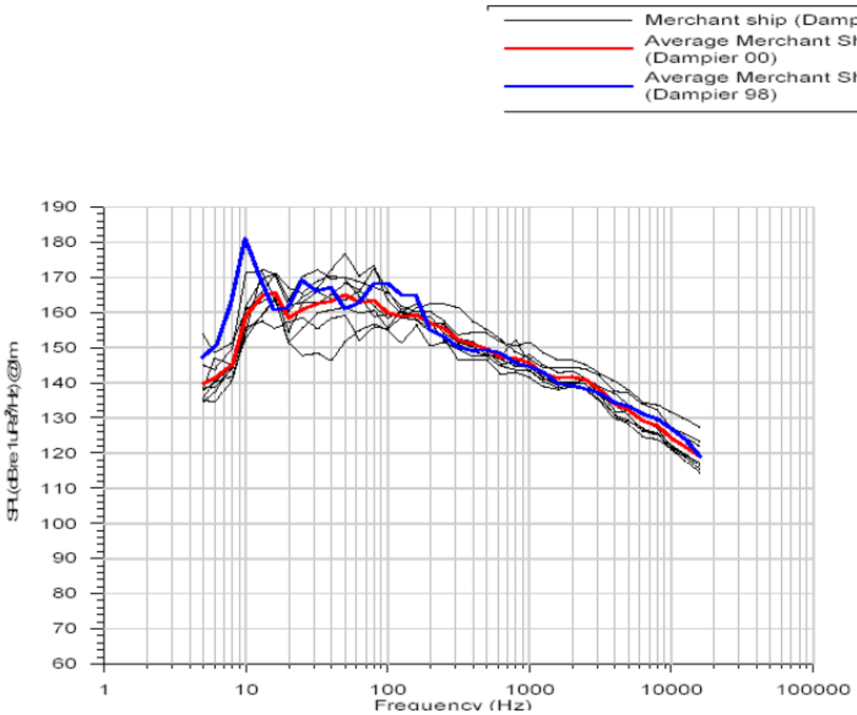

Figure 3-3 Bulk carrier source levels as determined by DSTO.

3.6 Noise Modelling Source Locations

The following sections define the noise model scenarios that have been run for dredging and piling. All scenarios utilise the source levels defined in section 2.

Figure 3-4 shows the locations of each noise source relative to the proposed harbour.

The modelled noise sources were positioned in the deepest possible location for that noise source, and all model scenarios have been run for 4m above Lowest Astronomical Tide (LAT) which has been estimated as high tide. As the sources have been modelled at the deepest point and high tide assumed for all scenarios, the modelling outputs can therefore be considered as conservative and worst case.

3.6.1 Dredging

The dredging noise source was placed at the deepest part of the channel (see Table 3-5). The deepest location was selected because the deeper the water, the better the noise will propagate through the water column. As a result, this location can be considered as a worst-case scenario for the dredger.

Table 3-5 Dredging Model Scenario

Location Name	Dredging Location
Location (MGA Eastings and Northings)	665761.9, 7754663.0

3.6.2 Piling

Table 3-6 presents details of the two pile locations modelled, which includes piling in the marina for the jetties and in the boat channel for the channel markers.

Table 3-6 Piling Scenarios

Location Name	Piling – (Inside Marina)	Piling – (Channel Marker)
Location (Eastings and Northings)	666038.4, 7753708.1	665771.5, 7754743.7

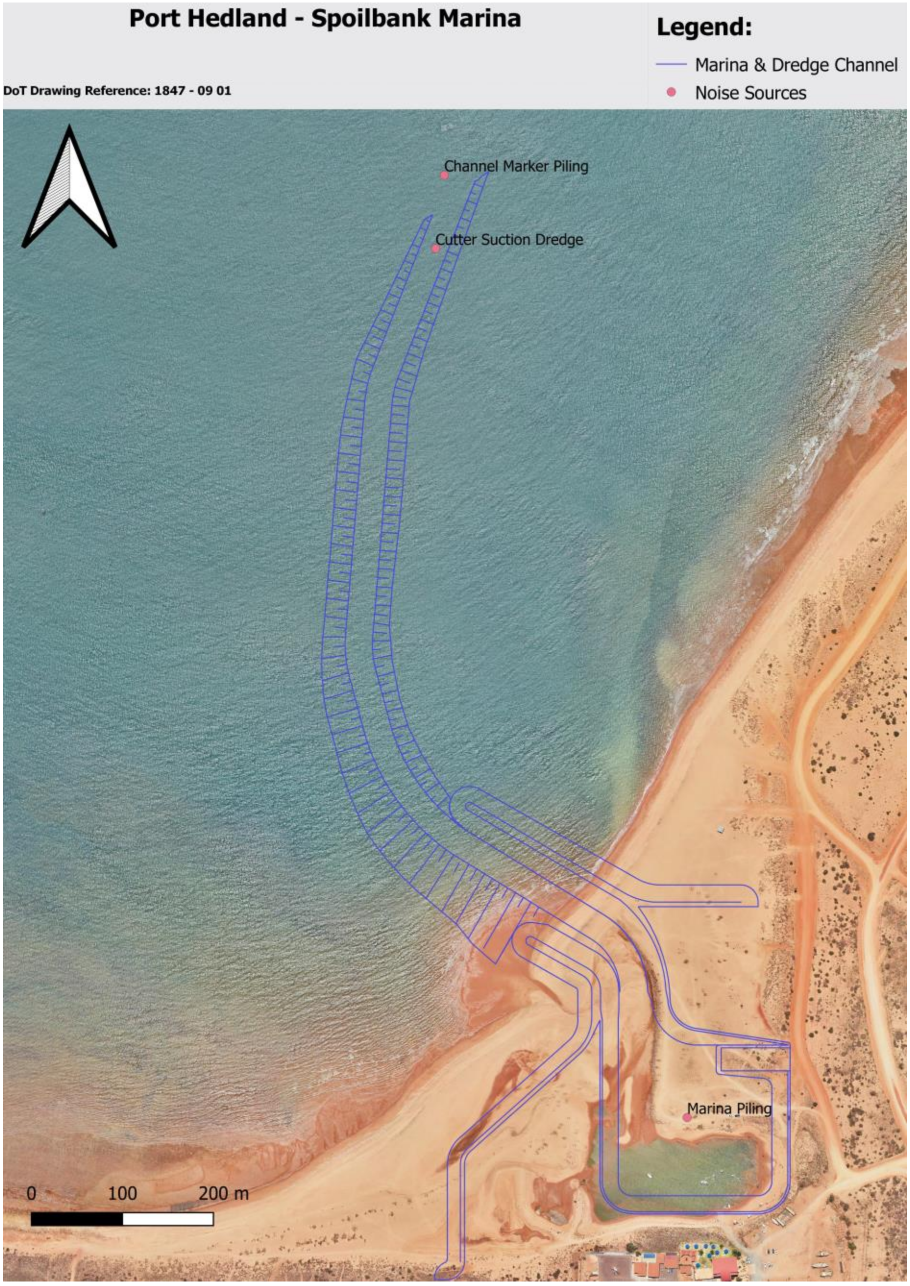

Figure 3-4 Piling and Dredging Locations Modelled

4 Noise Model Results and Discussion

The following sections present noise modelling results for dredging (section 4.1) and piling (section 4.2).

As discussed in section 3.5.4, all results are presented based on high tide.

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.

Graphs showing maximum levels with range are also provided. These graphs show the maximum level predicted at each range regardless of the relative bearing from the source. Considering the bathymetry and as shown in the contour plots it can be determined that most of maximum levels shown in the graphs would be associated with received levels towards the Port Hedland shipping channel to the north of the Marina.

4.1 Dredging

Dredging 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 summary is provided of the modelling outcomes:

- Figure 4-1 presents the predicted SPL RMS noise contours (with no hearing thresholds applied) for dredging activities. As the dredging has been modelled in the deepest part of the boat channel which is also close to the Port Hedland shipping channel the noise in that direction propagates into the deep water and attenuates slower than in shallower water.
- Figure 4-2 shows the maximum predicted SPL RMS for Turtles and Sawfish (i.e. with hearing bandwidths applied between 100 to 800 Hz), and attenuation of the received levels over range. As can be seen from the graph, received noise levels only exceed the threshold level of behavioural response (i.e. 166 dB re 1µ Pa SPL RMS) at the dredger.
- Figure 4-3 shows the maximum predicted SPL RMS for Humpback Whales (i.e. low frequency weighting curve applied as per NOAA technical guidance) and the maximum predicted SPL RMS for Spotted Dolphins (i.e. mid-frequency cetaceans). As can been seen from the graph:
    - The predicted SPL RMS for Humpback whales attenuate to below 120 dB re 1µ Pa SPL RMS at ~5300 m from the dredging operations.
    - The predicted received noise levels for Spotted Dolphins attenuate to below 120 dB re 1µ Pa SPL RMS at ~800 m from the dredging operations.
- As there are no breeding or resting grounds within the area for Humpback Whales dredging is not expected to have any impacts as behavioural impacts will not disturb the whales while breeding and resting.

- For Spotted Dolphins dredging will only have a small noise impact if there are foraging grounds close to where the dredger is dredging. Dredging is therefore considered to be low risk for Spotted Dolphins.
- Dredging noise impacts is very low. Therefore, this activity is low risk for Turtles.

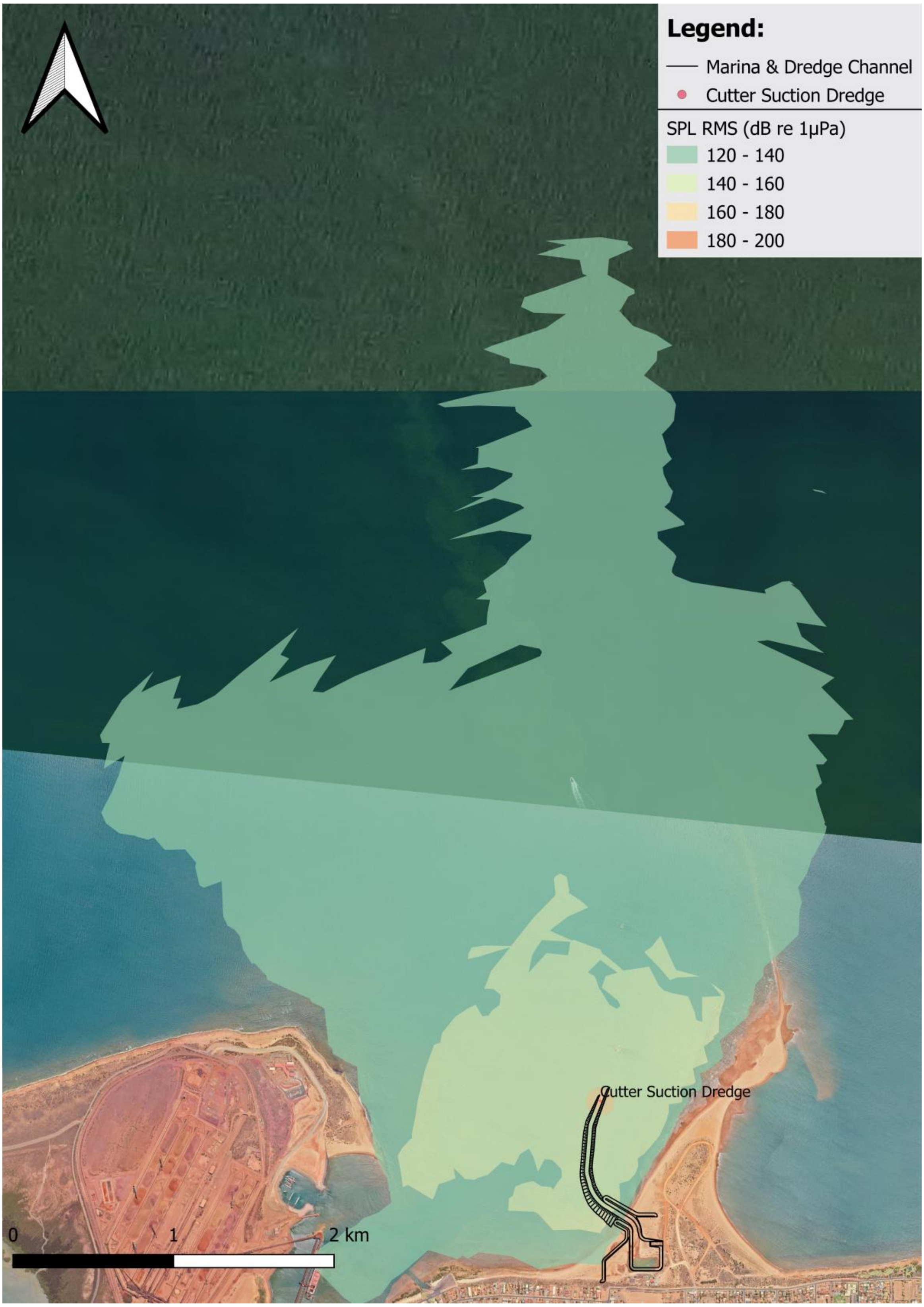

Figure 4-1 Noise Contour with no hearing thresholds applied– Dredging– SPL RMS

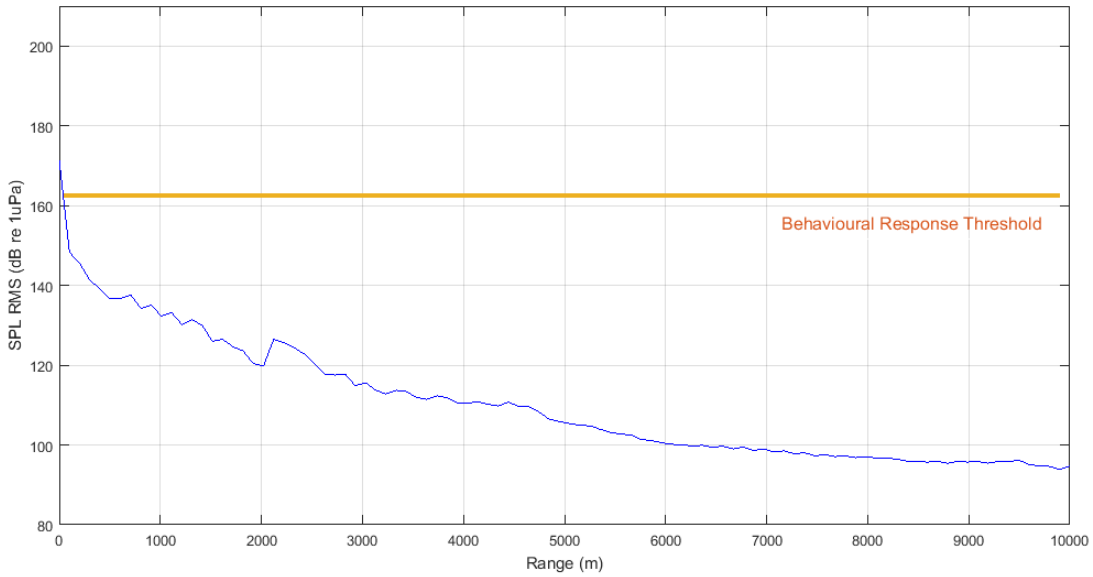

Figure 4-2 Maximum SPL RMS Noise Levels with Range for Turtles and Sawfish – Dredging and Barging Operations

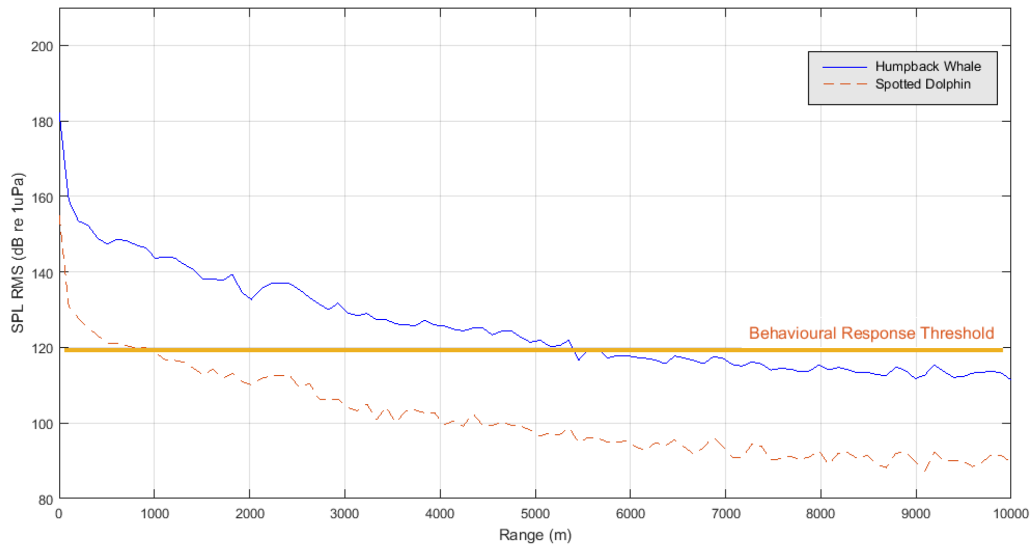

Figure 4-3 Maximum SPL RMS Noise Levels with Range for Humpback Whales (low frequency cetaceans) and Spotted dolphin (mid-frequency cetaceans) – Dredging and Barging Operations

4.2 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.

Highest Astronomical Tide (HAT) has been used for piling. It must be noted that at low tide the water depth will be up to 4m shallower (i.e. LAT). This implies that during low tide conditions less acoustic energy will be transmitted into the water column and low frequency waves are not formed.

The following summarises the model results for piling:

4.2.1 Channel Marker Piling

- Figure 4-4 presents the SEL predicted high tide noise contours (with no hearing thresholds applied) for a single pile strike. As the channel marker pile has been modelled in the deepest part of the boat channel which is also close to the Port Hedland shipping channel the noise propagates into the deep water and as a result attenuates slower in that direction than in shallower water.
- Figure 4-5 shows the maximum predicted SEL for a single pile strike and for multiple pile strikes (equating to a continuous exposure time of 1 hour) for Turtles and Sawfish (i.e. with hearing thresholds applied).
- Figure 4-6 shows the maximum predicted SEL for a single pile strike for Humpback Whales (i.e. low frequency weighting curve applied as per NOAA technical guidance).
- Figure 4-7 shows the maximum predicted SEL for a single pile strike for Spotted Dolphins (i.e. mid frequency cetacean weighting curve applied) with range for hightide.
- Table 4-1 shows the maximum ranges at which thresholds are predicted to exceed TTS thresholds for a single strike and for multiple strikes (i.e. 1-hour continuous exposure). It also includes the maximum range at which behavioural disturbance thresholds are exceeded.
- The ranges at which TTS levels are exceeded for Turtles, Sawfish and Australian Humpback Dolphin are less than those of the Humpback Whales. This is due to the hearing bandwidths of Humpback Whales being wider.
- There are only a small number (9 in total) of Channel Marker Piles that will be piled. Most of these piles will be placed in shallower water further away from the Port Hedland shipping channel. The noise from the shallower piles will therefore attenuate faster than the deeper ones located close to the shipping channel. As a result, the threshold ranges in Table 4-1 for the shallower piles will be a lot closer.
- Additionally, if piling takes place at low tide then the amount of energy radiated by the pile into the water will be a lot less and, in some cases, it will be negligible. In these cases, the threshold levels will only be exceeded very close to the pile or not at all. It is therefore

recommended that piling as far as reasonably practicable only take place at low tide and that for the shallower piles (i.e. < 3 m water depth[18]) the exclusion zones are not applicable.

Table 4-1 TTS and Behavioural Disturbance Ranges for Channel Marker piling.

Description	TTS Ranges		Behavioural Disturbance Ranges	
	Single Strike	Multiple Strikes Continuous Exposure (1 hour)	Single Strike	Multiple Strikes Continuous Exposure (1 hour)
Turtles and Sawfish	80 m	1 km	2.7 km	7.9 km
Humpback Whales	101 m	2.3 km	6.3 km	>10 km
Spotted Dolphin	Only at pile	101 m	1.4 km	6.2 km

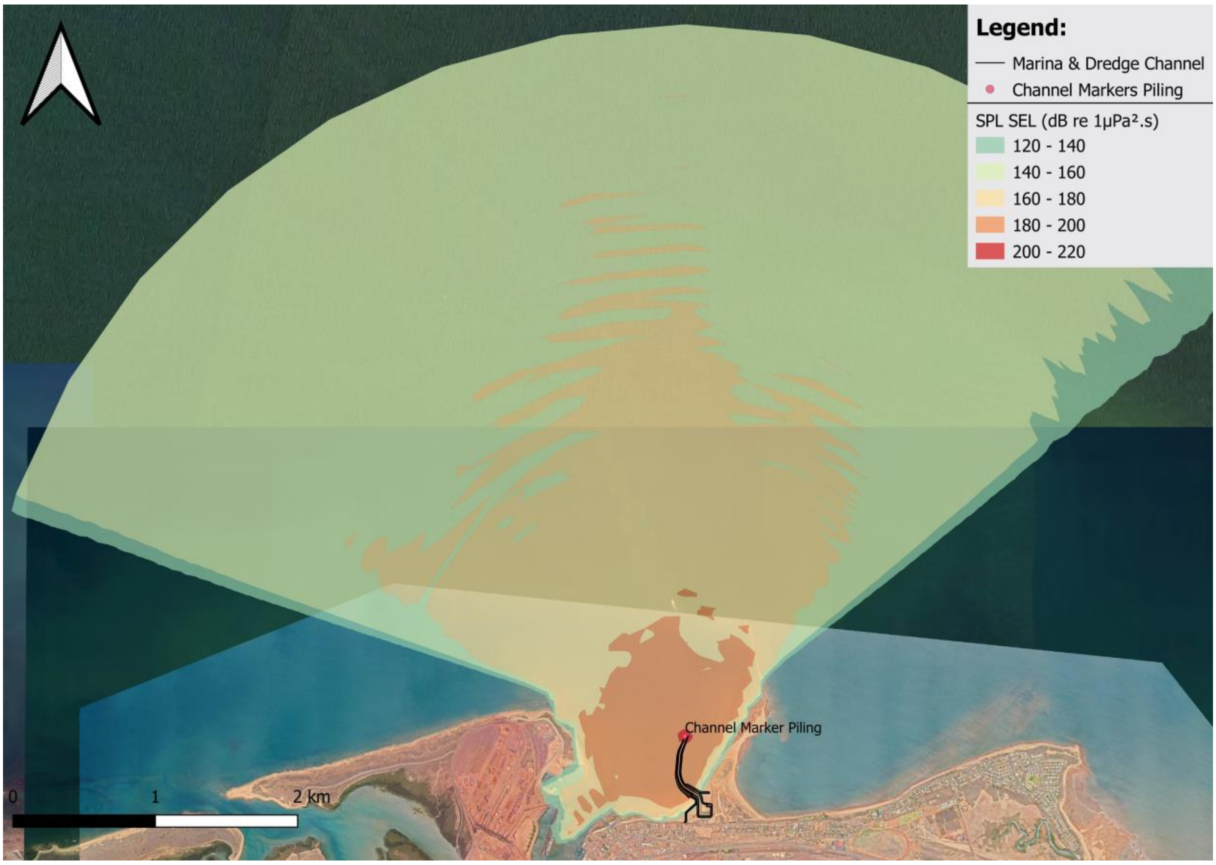

Figure 4-4 Noise Contour – Piling Channel Marker – SEL for a single strike

[18] 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.

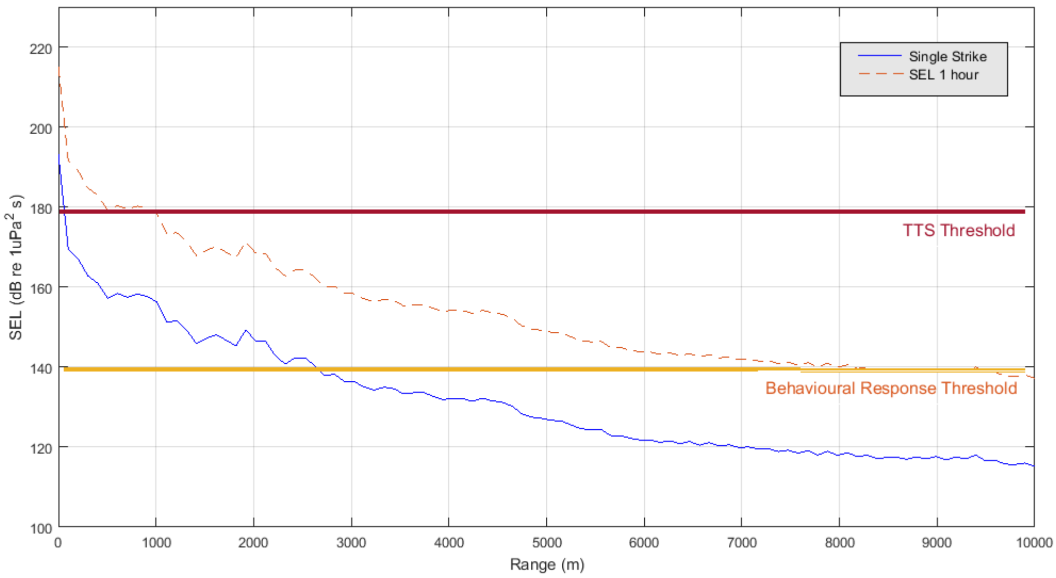

Figure 4-5 Maximum noise level with range for Turtles and Sawfish – Piling Channel Marker

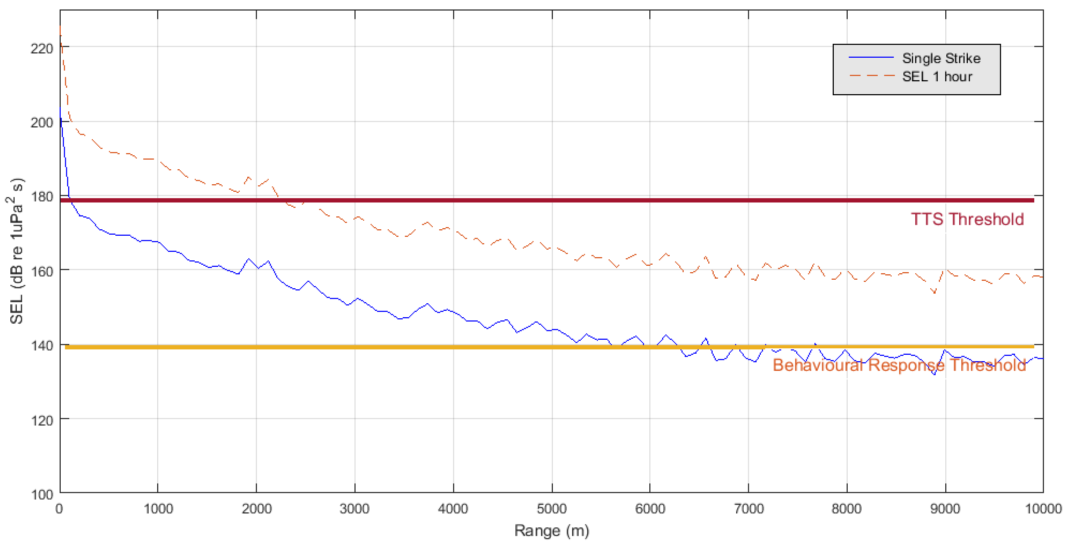

Figure 4-6 Maximum noise level with range for Humpback Whales – Piling Channel Marker

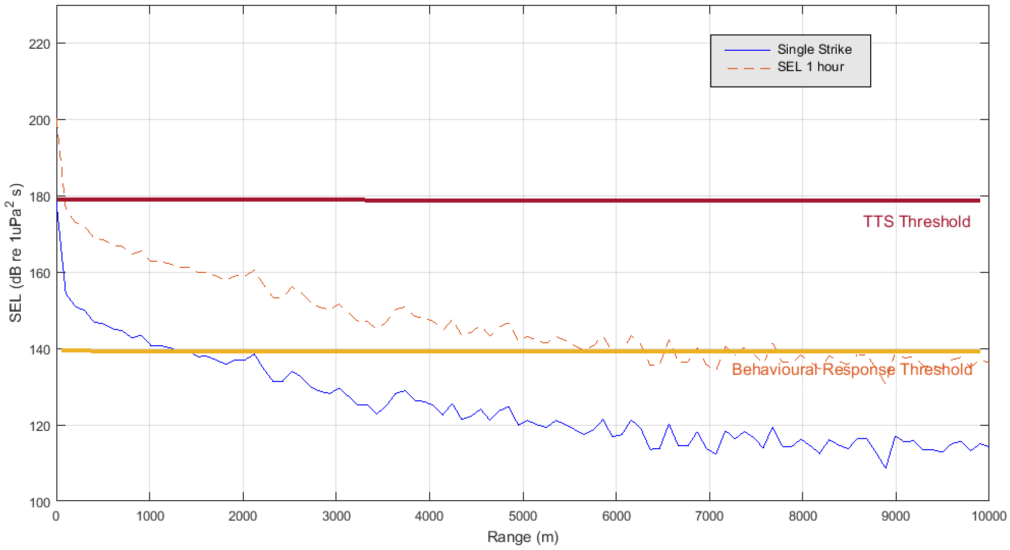

Figure 4-7 Maximum noise level with range for Spotted Dolphin – Piling Channel Marker

4.2.2 Marina Piling

- Figure 4-8 presents the SEL predicted hightide noise contours (with no hearing thresholds applied) for a single pile strike. As can be seen from this figure the noise is constrained by the marina and therefore attenuates rapidly before reaching deeper water.
- Figure 4-9 to Figure 4-11 shows the maximum ranges at which TTS and behavioural thresholds are exceeded.
- Table 4-1 shows the maximum ranges at which thresholds are predicted to exceed TTS thresholds for single and for multiple strikes (1 hour continuous exposure). It also includes the maximum range at which behavioural disturbance thresholds are exceeded.

Table 4-2 TTS and Behavioural Disturbance Ranges for Marina piling

Description	TTS Ranges		Behavioural Disturbance Ranges	
	Single Strike	Multiple Strikes (1 hour)	Single Strike	Multiple Strikes (1 hour)
Turtles and Sawfish	~80 m	~202 m	~80 m	~202 m
Humpback Whales	~101 m	~180 m	~404 m	~1.4 km
Spotted Dolphin	Only at pile	~101 m	~300 m	~400 m

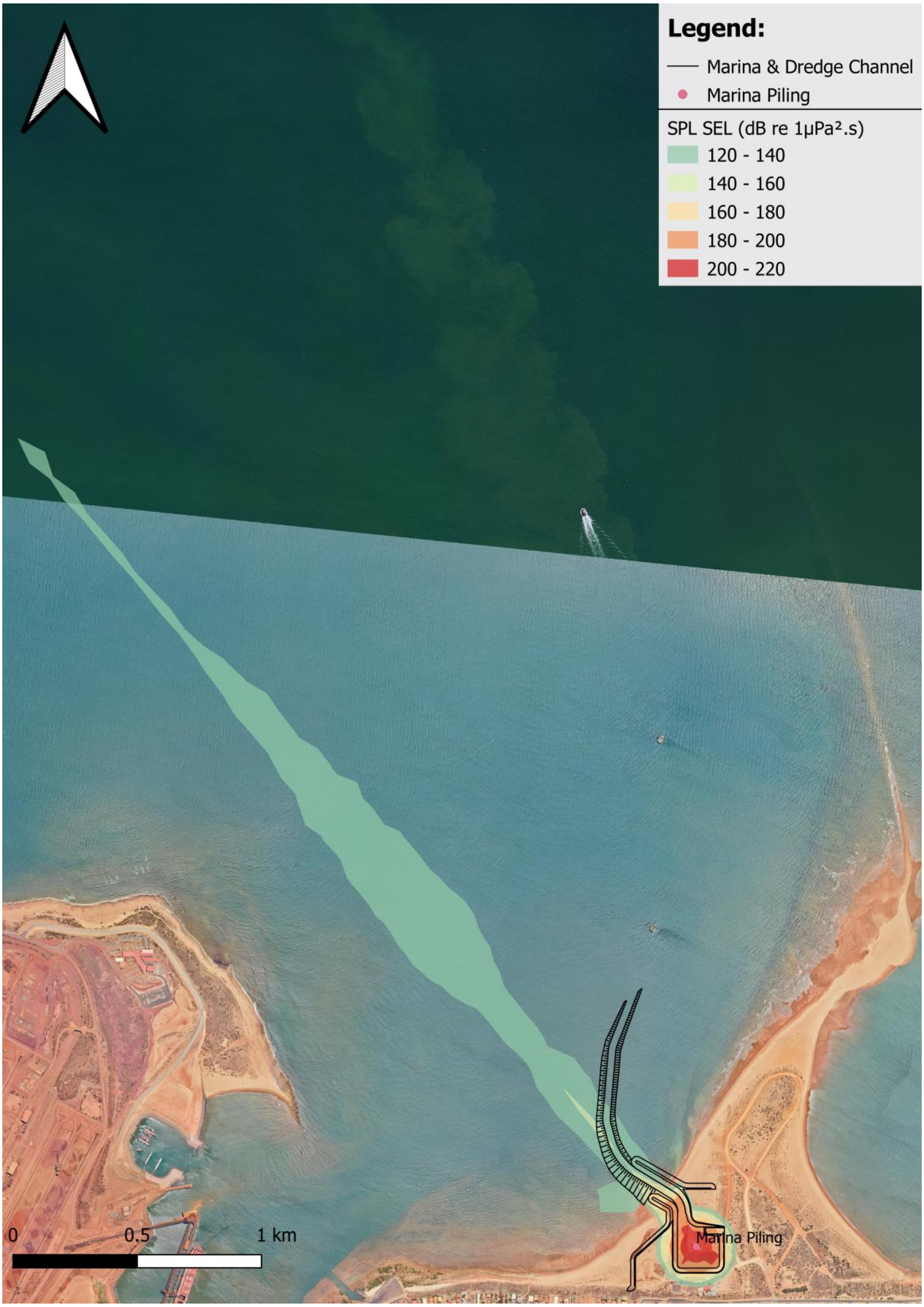

Figure 4-8 Noise Contour – Piling Marina – SEL for a single strike

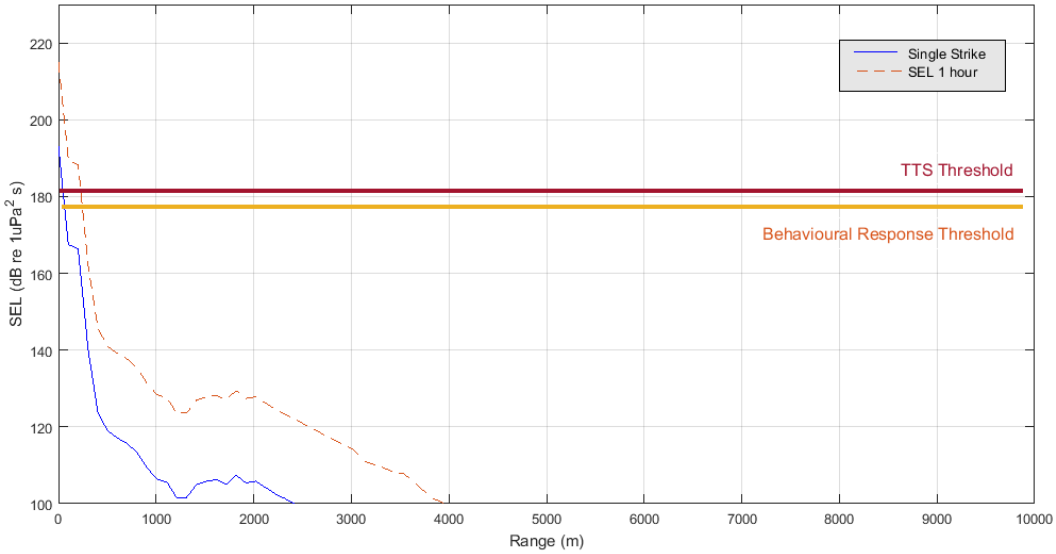

Figure 4-9 Maximum noise level with range for Turtles and Sawfish – Piling Marina

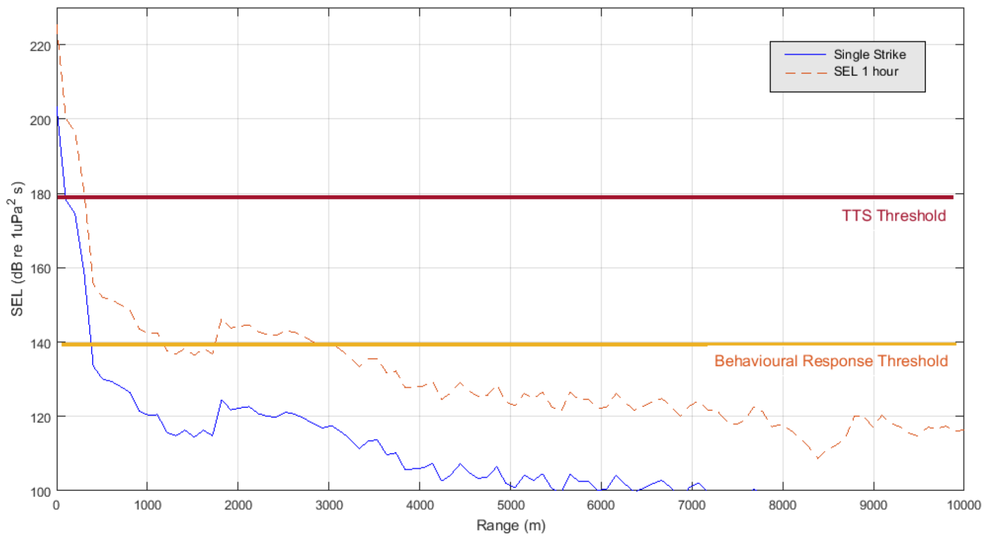

Figure 4-10 Maximum noise level with range for Humpback Whales – Piling Marina

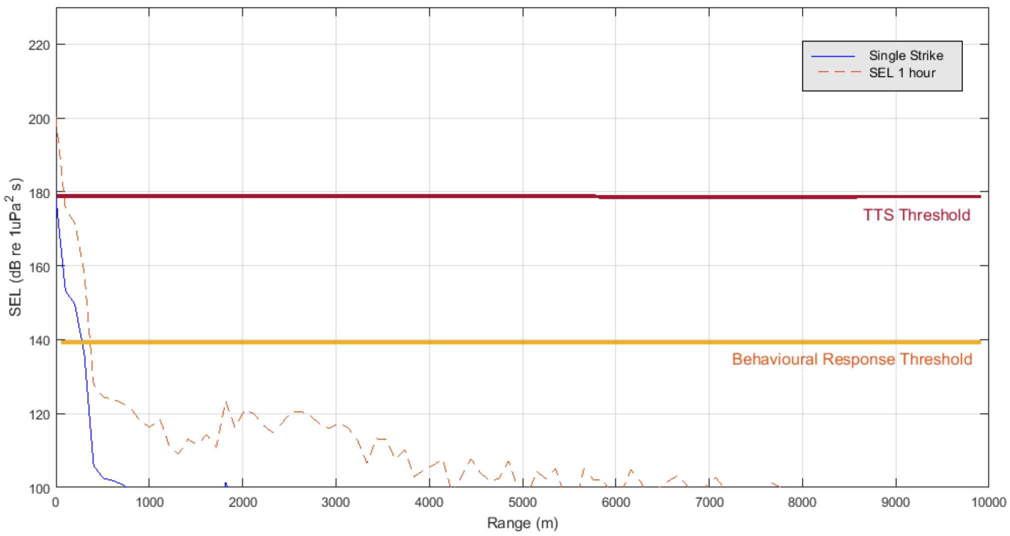

Figure 4-11 Maximum noise level with range for Spotted Dolphin – Piling Marina

5 Management Approach

Based on the outcomes of the modelling, a noise management approach based on water depth should be considered for Piling. The following is proposed:

1. As far as practical, piling should be scheduled for low tide.
2. **Marina piles.** For Marina Piling, observations should be made before piling commences to make sure that the Marina area is clear of megafauna. If the area is clear, then piling can commence.
3. **Channel Marker Piles Water depth < 3 m**. Where water depths at the pile are < 3m and only as a precautionary measure, an observation should be made before piling commences to make sure that there are no megafauna are in close proximity of piling operations (i.e. within ~50 m) before piling commences. If megafauna are in close proximity, piling should only commence when they have moved outside the area.
4. **Channel Marker Piles Water depth > 3 m**. For water depths > 3 m it is proposed that a noise management zone be used to manage noise impacts in the following way:
    a. **Before Piling Commences**: Marine Observers should confirm that a noise management zone out to ~300 m is clear of Humpback Whales and clear of dolphins and Turtles out to ~100 m. Once the management zone is clear, piling can commence.
    b. **During Piling**. If Humpback Whales or Turtles move within 500 m and dolphins within 100 m of the piling moving towards the piling activity, then piling should stop within 5 minutes of the observation being made. Once the animals have moved out of their respective management zones piling can recommence.

6 Conclusion

Based on the modelling results, the following can be concluded:

- **Dredging** – Noise emissions from dredging are low risk, and therefore are not expected to result in any behavioural disturbance for Turtles and Dolphins and minimal behavioural disturbance for Humpback Whales.
- **Piling General**. As far as reasonably practicable it is recommended that piling be scheduled for low tide.
- **Marina Piling** – As the Marina is in an enclosed space the piling noise is contained within the Marina. Marina piling is therefore considered to be low risk. As a result, the only recommendation is that observations should be made before piling commences to make sure that the Marina area is clear of megafauna.
- **Channel Marker Piles.** There are only a small number (9 in total) of Channel Marker Piles. Most of these piles will be placed in shallower water further away from the Port Hedland shipping channel. The noise from the shallower piles will therefore attenuate faster than the deeper ones located close to the shipping channel. As a result, a water depth management approach, as described in Section 5, with associated noise management zones is recommended for the Channel Marker piles.

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[19]. Studies using auditory brainstem responses[20] 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[21,22]. 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.

---

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

20 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

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

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

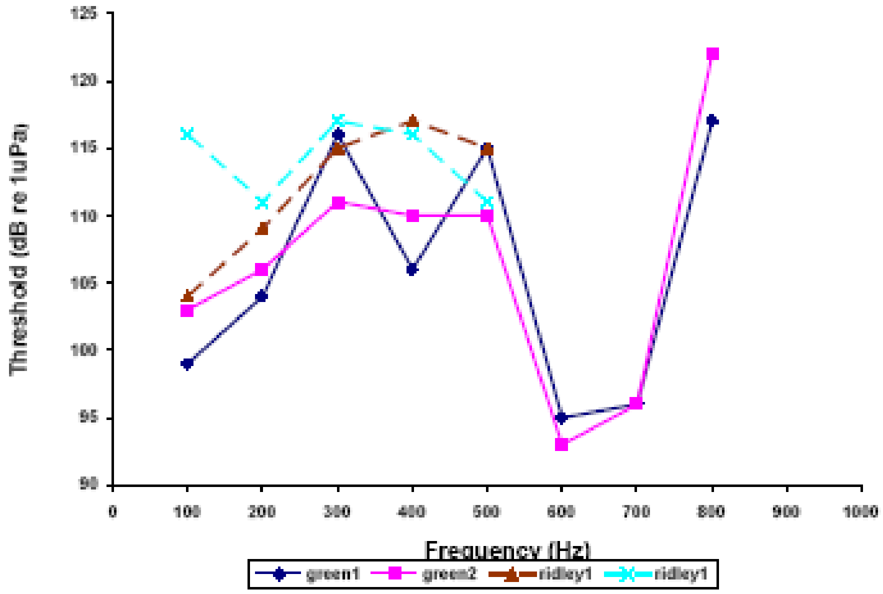

Figure 6-1 Audiograms of two juvenile Green Turtles and two juvenile Ridley's Turtles[7]

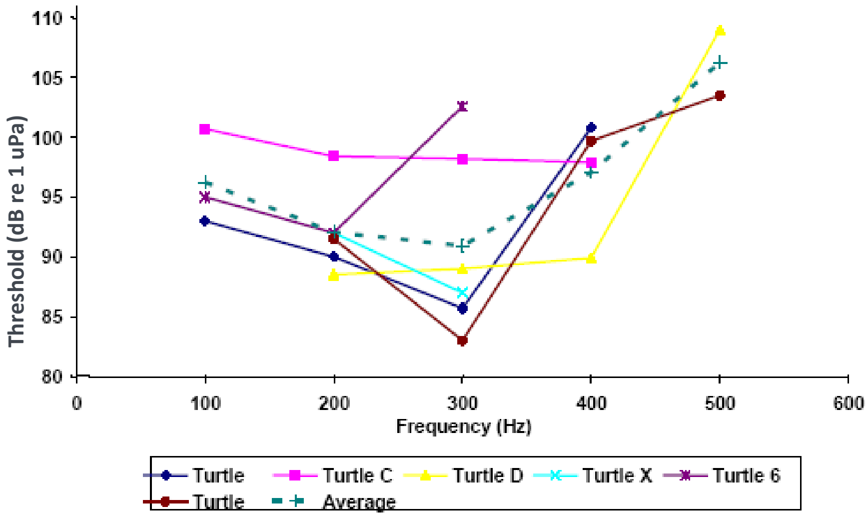

Figure 6-2 Audiograms of six sub-adult Green Turtles[4]

Appendix B Equations 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).

The following equations include the following units of measurement; Pascals (Pa), Metres (m), Seconds (s), kilograms (kg).

Talis Consultants

Level 1, 660 Newcastle Street,
Leederville,
Western Australia 6007

PO Box 454,
Leederville,
Western Australia 6903

Phone: 1300 251 070
Email: info@talisconsultants.com.au