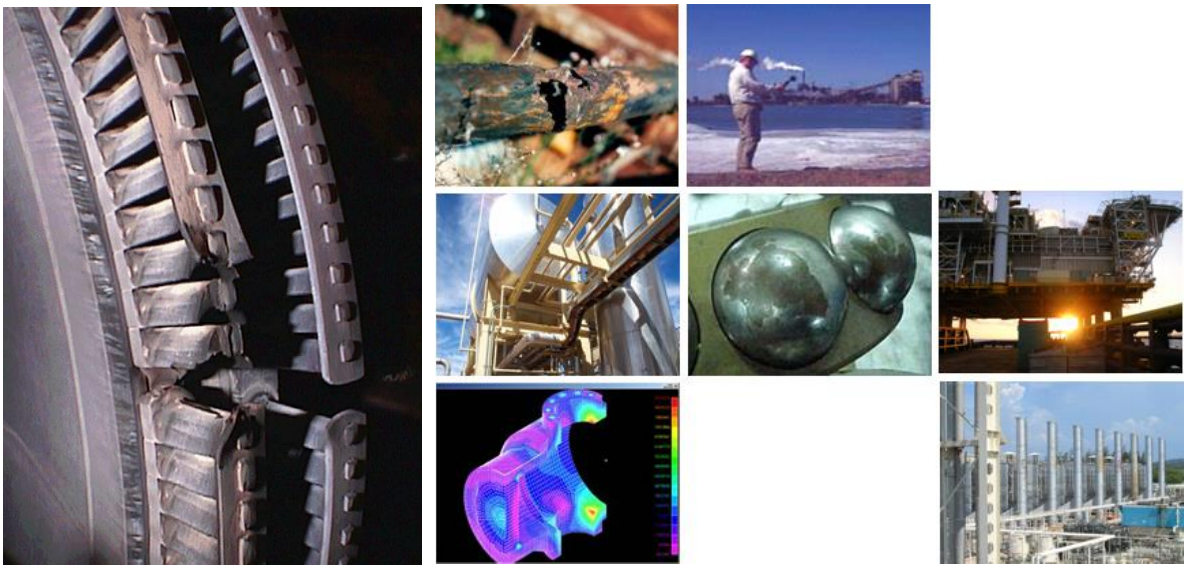
KOOMBANA BAY MARINE STRUCTURES PROJECT: UNDERWATER NOISE ASSESSMENT



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EXECUTIVE SUMMARY

The impacts associated with underwater noise associated with construction at Koombana Bay for the Koombana Bay Marine Structures Project are manageable. The activity will have minimal impact on the marine fauna in the area because:

- The likelihood of impact of injury to marine fauna can be managed with the use of a 500m exclusion zone, consistent with standard best practice.
- This exclusion zone is reasonable as they are within a visual ranges and are typically used by Marine Mammal Observers.

The results are summarised in the following table:

Table A: Calculated Maximum range for effects for various receivers

Species	Range for Effect and Basis		
	Permanent Injury, PTS, or Fatality	TTS	Behavioural Disturbance
Dolphins	14m (2)	144m (2)	519m (2)
Fish	15m (2)	245m (2)	N/A
Turtles	23m (1)	N/A	>2000km (2)

(1) Peak Pressure
(2) Daily Exposure

The use of impact management measures has been investigated and discussed in the study. A 500 m exclusion / shutdown zone has been suggested, based on the largest range for behavioural disturbance of dolphins.

In preparing the assessment:

- The assumptions around the piling activities are considered representative of the worst case based on the previous piling conducted in the Koombana Bay;
- Source data has been drawn from SVT's experience, and cross checked with work conducted by others for consistency;
- The underwater noise model is based on a MMPE algorithm which has been validated for shallow water conditions similar to those in the project area;
- The bathymetry has been supplied for the modelled project area;
- The criteria selected for the assessment of impact on the marine fauna have been peer reviewed and agreed with RPS.

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1. INTRODUCTION

1.1 Overview of the Koombana Bay Marine Structures Project

The South West Development Commission are planning a redevelopment at Koombana Bay. The project includes the following elements relevant to underwater noise:

- Expansion of the existing marina and marine industry facilities at Casuarina Boat Harbour;
- A marina development at Koombana Bay Sailing Club, involving the installation of floating boat pens; and
- The redevelopment of the Dolphin Discovery Centre, including a small passenger loading finger jetty for tour boats.

1.1.1 Casuarina Harbour Development

An overview of the plan for Casuarina Harbour is presented in Figure 1-1. The Casuarina Harbour construction activities at involve:

- the addition of a new breakwater to the north east of the harbour;
- Expansion of the harbour boat facilities, including the construction of pens throughout the harbour area; and
- Earth works around the bay, with the potential to increase the depth of the harbour area, particularly close to shore, by dredging.

Figure 1-1 Overview of development planned at Casuarina Harbour

1.1.2 Koombana Bay Sailing Club Marina

An overview of the proposed works at the Koombana Bay Sailing Club Marina (KBSB) is provided in Figure 1-2, and includes:

- Extension of the existing eastern breakwater further north, with at return extending westwards at the northern extremity;
- The construction of a new breakwater to the west of the existing breakwater was not included in the modelling. Hence this is not included in the assessment; and
- Potential to construct boat pens within the sheltered area.

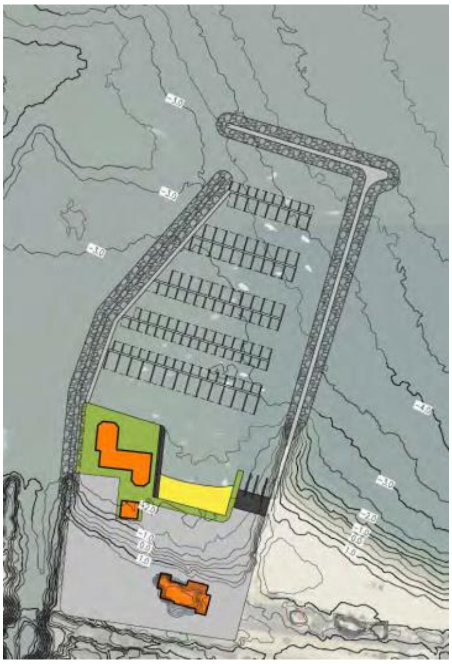

Figure 1-2: Proposed development with breakwater extension at Koombana Bay Sailing club

1.1.3 Dolphin Discovery Centre

At the dolphin discovery centre a small finger jetty to accommodate passenger loading to tour boats is planned. The design of Dolphin Discovery jetty was not available to SVT at the time of carrying out the underwater noise modelling.

1.1.4 Noise Sources

The most significant source of noise from the project is expected to be the pile driving associated with the construction of the boat pens at Casuarina Harbour and Koombana Bay Sailing Club Marina, and the construction of the Dolphin Discovery Centre Finger Wharf.

Other sources of underwater noise associated with the project will be the dredging and rock dumping. RPS has advised SVT that the piling may be replaced with drilling due to the ground type in the area. Numerical modelling of these activities is not included in the scope of this study.

1.2 Scope

The Koombana Bay Project is required to undergo a Strategic Public Environmental Review (SPER). As part of the PER, assessment of underwater noise impacts on sensitive marine species is required. An assessment of potential airborne noise impacts from construction on sensitive residential receptors is also required.

RPS is providing environmental assessment support to the Southwest Development Commission for the Koombana Bay Project. RPS has identified that sensitive marine fauna that occur in the area (dolphins, fish, and turtles) may be adversely affected by underwater noise.

SVT was commissioned by RPS to undertake an underwater noise impact assessment of the construction noise associated with the project. This study assesses the underwater noise due to pile driving activities that are likely to occur at Casuarina Bay, the Koombana Bay Sailing Club Marina and the Dolphin Discovery Centre; and the impact on the sensitive species identified by comparison with established criteria.

The scope of the study includes:

- A determination of the likely worst case conditions for the generation of underwater noise from piling during construction of the Koombana Bay Project;
- Calculation of the underwater noise levels (for four scenarios) from the piling activities expected to be conducted as part of the project, using an appropriate numerical model;
- Assessment of the modelled underwater noise levels against the response criteria; and
- Recommend underwater noise management strategies.

A qualitative underwater noise assessment is also included for the other potential sources of underwater noise associated with the construction activities at Koombana Bay.

1.3 Definition, Acronyms

Table 1-1 List of Acronyms

Acronym	Meaning
AHD	Australian Height Datum
BoM	Bureau of Meteorology
KBSBM	Koombana Bay Sailing Club Marina
MFO	Marine Fauna Observers
MMPE	Monterey Miami Parabolic Equation
PTS	Permanent Threshold Shift
RMS	Root Mean Squared
SEL	Sound Exposure Level
SPL	Sound Pressure Level
SSP	Sound Speed Profile
TTS	Temporary Threshold Shift
WOA	World Wide Atlas

2. METHODOLOGY

2.1 Underwater Noise Modelling

SVT's underwater noise model (see Appendix B-1 for model selection description) predicts the transmission loss of underwater noise with a number of factors including ranges, depth, and bottom type. The model can predict transmission loss from multiple noise sources in both narrowband and broadband frequency ranges. The underlying calculation software kernel has been developed by the universities of Miami and Monterey[1] in the USA, the front end interface has been developed by SVT. The calculation kernel has been validated and is known as the Monterey Miami Parabolic Equation (MMPE) model.

SVT maintains a database of underwater noise sources based on field measurements and published data. This database allows SVT to directly enter the noise source frequency spectrum into the underwater noise model.

2.1.1 Data and Model Limitations

The following data and model limitations need to be noted:

1) **Rough Surface Scattering**. Acoustic wave scattering due to the roughness of the sea surface and seabed is not accounted for in the model, which makes the model more conservative.

2) **Vertical Launch Angles (±40°)**. The launch angle[2] of the model is limited to ±40°. The sound waves predicted at angles close to the noise source outside of this angle are evanescent waves, i.e. strongly decaying[3].

3) **Shear Speed**. As the model is based on a Parabolic Equation (PE), it does not accurately predict the effect of the high shear speed components of some bottom types and therefore makes the model more conservative.

2.1.2 Model Validation

Underwater propagation models use bathymetric data, geo-acoustic[4] information and oceanographic parameters[5] as inputs to produce estimates of the acoustic field at any depth and distance from the source. The quality of the model's estimate is directly related to the quality of the environmental information used. For example, the geo-acoustic parameters of the seabed, such as compressional and shear sound speed, sound attenuation and sediment density, can affect acoustic propagation and can therefore affect the model predictions.

[1] NPS (Naval Post Graduate School) Monterey California.

[2] MMPE implements the Pade equation approximation which gives small phase error angles in the main propagation direction.

[3] It must be noted that PE models are limited in vertical launch angles. For any angles outside of this limit, the model erroneously predicts evanescent waves.

[4] Geoacoustic parameters include material density, and compressional and shear speed.

[5] Oceanographic parameters include sound speed profiles of the water column and tidal heights. It is assumed that the sound speed velocity in the water column is the same for all ranges.

Four general categories of acoustic propagation models are used in underwater acoustics: ray tracing; normal mode; parabolic equation (PE); and finite difference models. Of these model types, PE models are the most capable of making reliable predictions in range dependent shallow water[6] environments with changing bottom types, and with reasonable calculation solution times. The MMPE algorithm has been used as the basis of SVT's underwater noise model, this algorithm was selected because it has been rigorously tested and validated for shallow water environments at the Shallow Water Acoustic Modelling (SWAM 99) Workshop in Monterey California.

2.2 Underwater Noise Generated by Pile Driving

In order to install the upright posts to form the piers, boat pens and finger wharf for the project, piles will be driven into the sea bed by impact piling. Impact piling operations involve the hammering of a pile into the seabed using a mechanically driven or gravity (drop) hammer. The hammering action results in noise radiated from the pile into the atmosphere, water and seabed.

At each strike of the hammer, in addition to the whole displacement of the pile further into the seabed, the pile also bends elastically, and then returns to its original shape. This bending takes the form of flexural waves in the pile (refer Figure 2-1), which propagate along the length of the pile and into the riverbed[7]. The transverse component of the wave creates compression waves in the water and air at the surface of the pile, which will propagate out from the pile as noise. The compressional component of the flexural wave will propagate into the seabed.

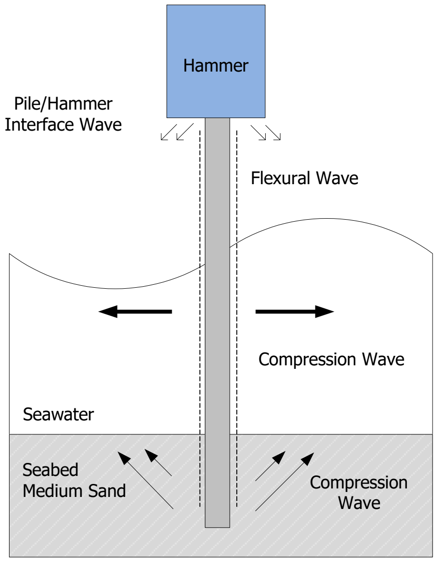

Figure 2-1 Underwater noise associated with piling within a causeway

The dominant underwater noise source from the piling event is the compression wave generated from the surface of the pile in the water column. It has been found that the magnitude of the underwater noise emanating from a pile during piling is a function of the piling method (i.e. impact hammer or vibration), the pile material type (i.e. steel or concrete), the force applied to the pile (usually described by the hammer energy or hammer size), the pile size, and the characteristics of the substrate into which it is being driven.

[6] Shallow water is defined to be depths < 200 m (see Richardson et al, 1995. Marine Mammals and Noise, Academic Press).

[7] Note: Depending on the resistivity of the soil, some of the energy will be reflected back up the length of the pile.

2.3 Piling Assumptions

2.3.1 Pile diameter

The existing piles within Casuarina Harbour have a diameter of 406 mm for boat pens ranging from 10 to 15 m in length. The layout of the proposed Casuarina Harbour development provided by RPS show larger boat pens to the north of up to 35 m in length, indicating the potential for larger vessels. Based on this it is reasonable to expect that larger piles may be required and that pile sizes up to 600 mm diameter could be expected for a 35m vessel.

2.3.2 Hammer Energy

For the noise modelling a 45 kJ hammer energy (which typically comprises a 4 to 4.5 tonne hammer with a drop height of approximately 1.5 to 1 m) has been used in three of the four scenarios on the following basis:

- 45 kJ represents the upper bound of the hammer energy that can be applied to a 406 mm diameter pile without permanently deforming it;
- 45 kJ is sufficient to drive both 406 mm and 600 mm piles in sandy silt ground conditions;
- SVT understands that a 45 kJ hammer energy is near the maximum capability of common small piling rigs and is above the minimum capability of medium to larger rigs, hence at this early stage of the project includes a large proportion of available rigs;
- RPS provided piling logs kept by the Department of Transportation from the piling conducted at Bunbury Port Inner Harbour, which indicated a 47 kJ hammer energy was used to drive 600mm piles, with similar seabed geological properties to those present in the project area (sand and silt over basalt)[8].

There is potential that the finger wharf at the Dolphin Discovery Centre mat not require the same lateral load bearing capacity as the boat pens, and therefore may use a smaller diameter pile, and may be driven with a lower hammer energy. Also, the finger wharf location is 'open' and as a result will result in a broader distribution of underwater noise. Therefore, an additional scenario was modelled for the Dolphin Discovery Centre jetty with a 35 kJ hammer.

2.3.3 Number of strikes

The DOT piling logs for the Bunbury Port Inner Harbour indicate approximately 100 strikes were required to set the piles to a sufficient depth in basalt. Other piling records for the area show an average of approximately 10 strikes were required to set piles into a sandy bottom.

The assessment outcomes and recommendations in this report are based on the assumption of 300 strikes per day. However, to allow flexibility and for further development of impact management methods the results for a range of total strikes per day (from one, 100, 200, 300 and 400 strikes) have been presented in the results.

[8] This may have involved a 'drill and drive' methodology, the piling records do not provide this level of detail.

2.3.4 Piling Locations

The Koombana Bay Project is in a conceptual phase and as such the engineering details of the piling are not confirmed. Using the current design information, worst case piling locations were selected for the piling at Casuarina Harbour, KBSCM and the Dolphin Discovery Centre. These locations were selected to represent expected worst case conditions, for example where propagation would occur through gaps in existing barriers (such as the breakwaters) and for the deepest water conditions.

Table 2-1 Piling coordinates

Piling Locations	Coordinates (Zone 50 H)
Casuarina Bay Piling	373581.00 m E, 6313430.00 m S
Sailing Club Piling	373866.00 m E, 6312849.00 m S
Dolphin Discovery Centre Piling	374302.00 m E, 6312491.00 m S

Figure 2-2 Piling locations

The pile is represented in the underwater noise model by a point source at the underwater acoustic centre of the pile (i.e. midwater depth).

2.3.5 Estimation of Piling Source Noise Level and Spectrum

The piling source level has for hammer energy of 35 kJ and 45 kJ has been determined by scaling using logarithmic energy relationship from measured and published data points for other hammer energies. The resultant source level was then cross-checked with the estimated sources levels for similar piling energies in studies undertaken by others, and found to be consistent. The source SEL used in the study are:

- 45 kJ Hammer: 199 dB re 1μPa^2.s @ 1 m
- 35 kJ Hammer: 198 dB re 1μPa^2.s @ 1 m

The piling source spectrum was extracted from SVTs database of measurement piling driving and scaled to match the overall expected source level. Figure 2-3 shows the piling pulse SEL source spectra used in the underwater noise model.

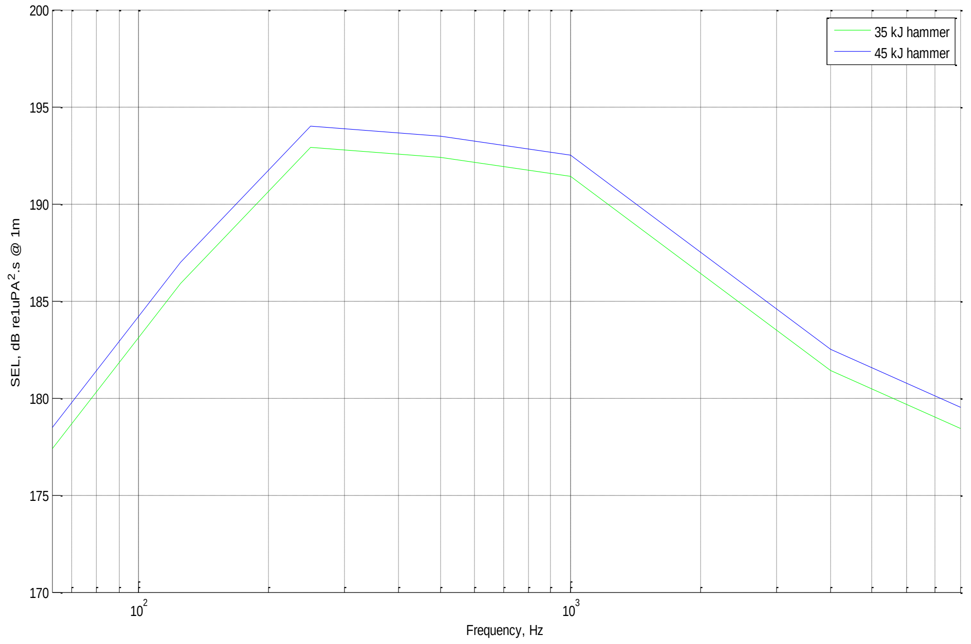

Figure 2-3 Hammer SEL Source Level Spectra

2.3.6 Peak Pressure

SVT conducted an analysis of measured piling data collected during a recent harbour piling campaign, where both SPL and Peak noise levels were determined for each hammer strike. The data, which was collected at multiple distances and bearings from piling activity, demonstrated a crest factor (CF) of between 15 and 20 dB for piling sources. Based on this data, and as a conservative assessment measure, a CF of 20 dB has been applied for the project.

Predicted peak pressure noise levels were calculated from the calculated sound pressure level with range using the crest factor. The relationship is:

L_{peak} = SPL + CF.

2.3.7 Summary of Piling Source Inputs and assumptions

The following table summarises the key information regarding the piling sources presented in the above sections.

Table 2-2 Hammer specifications used in the underwater noise model

Hammer Specifications	
Hammer energy	35 kJ (for Casuarina Bay, Sailing Club and Dolphin Discovery Centre); 45 kJ (for Dolphin Discovery Centre only)
Modelled number of strikes	1, 100, 200, 300 and 400.
Estimated number of strikes per day	300
Piling Scenarios	1. Piling of 306 mm piles at the Casuarina Bay with break wall 2. Piling of 600 mm piles at the Casuarina Bay with break wall 3. Piling of 306 mm piles at the Sailing Club with break wall 4. Piling of 306 mm piles at the Dolphin Discovery Centre

2.4 Environmental Inputs

2.4.1 Important Environmental Factors

The propagation of noise through the water is dependent upon a number of environmental factors. The depth of the water limits the lowest frequency of noise that can propagate, the deeper the water the lower the cut-off frequency. Because of this, propagated noise levels may be higher in deeper water for the same source. This factor is important when conducting underwater noise assessments in shallow water, near shore, or, estuarine locations.

Temperature and salinity changes also affect the propagation of noise in water, causing refraction changes which may result in channelling of noise in the water column and also affect the reflection from the seabed. It is noted that due to the shallow depths, the sound speed profile (SSP) behaves closely to pure isothermal conditions.

The type of sea bed affects the fraction of noise that is reflected and transmitted at the water / sea bed boundary. This is dependent upon the impedance miss-match between the water and the sea-bed, and the acoustic impedance is primarily characterised by the sound speed of the sea bed. Another factor that can affect the propagation of noise, and the transmission of noise generated into the sea bed into the water column is the ability of the sea bed to propagate compression and shear waves. This data is input into the model as an attenuation rate for compression and shear wave types. This data is typically drawn from published research, which lists sound speed and attenuation rates for various ground types.

2.4.2 Model Environmental Data

The following environmental conditions were entered into the model:

1. **<u>Depth</u>**. The bathymetry of the project region and surrounds has been provided by RPS. The bathymetry includes the existing and proposed break-waters at Casuarina Harbour and Koombana Bay Sailing Club.

2. **Tide Levels**. A review of the Bunbury tides from Bureau of Meteorology data indicates a typical maximum tide of 1.2 m, therefore a tide of 1.2 m[9] was modelled as representative of high tide conditions which are worst case for underwater noise propagation.

3. **Seabed Types**. Data provided by SVT by RPS [17] demonstrates that the seabed in the project area is mostly sand with a proportion of fines, and that is overlayed on a basalt bedrock. The geo-acoustic properties of the ground type used in the model are shown in Table 2-3[10], where sand was used to represent the ground type.

Table 2-3 Seabed Geo-acoustic Properties [18]

Seabed Type	Sound Speed	Density	Sound Attenuation
Sand	1650 m/s	1.9 g/cm^3	0.8 dB/m/kHz (Compressional) 2.5 dB/m/kHz (Shear)

4. **Sound Speed Profile.** The water depth in the modelling area is relatively shallow and therefore no significant temperature gradient is expected in the water column. Additionally, as the location is not estuarine the salinity is expected to be homogenous. Therefore no the change in sound speed with depth or range is expected. The underwater sound speed profile (SSP) of 1523 m/s was obtained from the World Ocean Atlas using an annual mean temperature, salinity and pressure, for the project region, and has been entered into the model as isothermal.

[9] The Port of Bunbury lists the highest astronomical tide as 1.4m.

[10] Note: the model uses the geo-acoustic properties to determine the attenuation and reflectivity of the waves as they travel through the seabed.

3. MARINE FAUNA ASSESSMENT CRITERIA

RPS has advised that the sensitive marine fauna in Koombana Bay are fish, turtles and dolphins.

The criteria for the assessment, outlined in the following sections, have been selected based on advice from the marine fauna specialists at RPS. The noise criteria used for assessment of the impact of underwater noise are defined in terms of cumulative sound exposure level (SEL_{cum}), averaged Sound Pressure Level (SPL) and Peak Sound Pressure Levels (L_{peak}). As the criteria are drawn from a number of publications, the noise descriptors used are not always consistent. Appendix B provides a discussion on noise descriptors and their meaning. The following points are a non-technical summary intended to inform readers of the following sections.

- In this report Sound Pressure Level (SPL) means the average sound pressure at a location expressed in dB.
- Sound Exposure Level (SEL) is the cumulative sound energy, expressed in dB, for a discrete event, in the instance of a continuous source, normalised to one second for a defined period. The Cumulative SEL (SEL_{cum}) is the total sound energy for a set number of discrete events, or in the instance of a continuous source, for the total period under consideration.
- Peak pressure level (L_{peak}) is highest instantaneous pressure, expressed in dB, and is typically used to describe impulsive noise sources.

3.1 Fish

Table 3-1 outlines the assessment criteria for impact on fish and fish larvae, from Popper [8]. The criteria are defined in terms of SEL_{cum} and L_{peak} noise levels. The fish criteria are separated between fish with or without the swim bladder as the gas filled space increases the fish vulnerability to the changes in sound pressure. Fish eggs and larvae have been separated due to their vulnerability, reduced mobility and small size.

Table 3-1 Fish and larvae noise criteria

Type of Animal	Mortality and Potential Mortal Injury	Recoverable Injury	TTS
Fish: No swim bladder (particle motion detection)	> 219 dB SEL_{cum} or > 213 dB L_{peak}	> 216 dB SEL_{cum} or > 213 dB L_{peak}	>> 186 dB SEL_{cum}
Fish: Swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or > 207 dB L_{peak}	203 dB SEL_{cum} or > 207 dB L_{peak}	> 186 dB SEL_{cum}
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or > 207 dB L_{peak}	203 dB SEL_{cum} or > 207 dB L_{peak}	186 dB SEL_{cum}
Eggs and larvae	210 dB SEL_{cum} or > 207 dB L_{peak}	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low
Note: Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).			

3.2 Turtles

Little is known about the source levels and associated frequencies that cause physical injury to a turtle. Therefore, the value this study takes for physical injury assessment is conservative.

Two trials [10] conducted on the response of a green and loggerhead turtle to impulsive signals (air-gun) showed that at SPLs of 175 dB re 1 µPa the turtle behaviour became more erratic, which was presumed to be an avoidance response. A SPL of 175 dB re 1 µPa is equivalent to a SEL of 164 dB re 1µPa^2.s, where it is assumed that a pulse length of 90ms was used during the experiment. The criteria for turtles are shown in Table 3-2.

Table 3-2 Turtle underwater noise criteria

Receiver	Impact	Criteria
Adult Turtle	Behavioural Impact [10]	175 dB SPL 164 dB SEL
	Possible Physical Injury [14]	207 dB L_{peak}

3.3 Dolphin Criteria

In the NOAA guidelines [7] the bottlenose dolphin is categorised as a *mid-frequency weighted cetacean*. The mid frequency weighting has the highest sensitivity between approximately 300 Hz to 100 kHz tapering off on both sides (a chart of the frequency weighting is shown in Appendix B-5). However, as Figure 2-3 shows the majority of the energy from the piling activity falls into the flat "unweighted" section of the mid-frequency weighting, the results presented in this report are all unweighted.

The NOAA guidelines provided SEL_{cum} and L_{peak} noise levels at which Temporary Threshold Shift (TTS) in hearing sensitivity may occur and a level at which Permanent Threshold Shift (PTS) in hearing sensitivity may occur for mid frequency cetaceans. These are summarised in Table 3-3.

For behavioural disturbance of dolphins, Southall et al. [1] observed a response for the mid frequency cetaceans (captive killer whales) with severity score of 6 (i.e. visible startle response) at 160 dB SPL. This SPL level has been converted to a SEL level, assuming a pulse length of 100 ms. There is limited specific research on dolphin's behavioural response to underwater noise. The South Australian guideline uses 160 dB SEL which is based on NOAA 2011 for behavioural impacts on cetaceans. Therefore a range of 10 dB is used to determine the range of potential behavioural impacts.

Table 3-3 Middle frequency cetacean criteria

Impact	Criteria
Possible behavioural Impact [1]	160 dB SPL (Mid frequency weighted) 160 – 170 dB SEL (Mid frequency weighted)
Temporary Threshold Shift [7]	170 dB SEL_{cum} (Mid frequency weighted) 224 dB L_{peak}
Permanent Threshold Shift [7]	185 dB SEL_{cum} (Mid frequency weighted) 230 dB L_{peak}

Table 3-4 Summary of safety zones for impact piling

4. MODEL RESULTS

4.1 Overall model outputs

The modelled underwater noise levels have been plotted as contours for each piling location and hammer energy. The full results for each scenario are provided in Appendix C and include the noise contours for sound pressure level and a graph of the noise levels with range (SPL, SEL, L_{peak}) and along the worst case bearing.

The sound pressure level charts show the predicted SPL and L_{peak} from a single strike with range. The SEL plots show the SEL for 1, 100, 200, 300 and 400 strikes of the hammer. The range to meet the SEL assessment criteria for 1, 100, 200, 300 and 400 strikes are tabulated in Appendix E. The SPL and L_{peak} are not dependent upon the number of strikes.

4.2 Range to Criteria

Table 4-1 shows a summary of the range to criteria divided into three broad categories of marine fauna impacts:

- Injury or Permanent Impact;
- Temporary or Recoverable Impact: and
- Behavioural Impacts.

The ranges in presented Table 4-1 to meet the SEL criteria are for 300 strikes (3 piles) per day. The table shows that dolphins are the most sensitive fauna (i.e. the longest range to the criteria).

Table 4-1 Ranges at which the marine fauna criteria are met

Marine Fauna Criteria	Casuarina Harbour (45 kJ)	Koombana Bay Sailing Club (45 kJ)	Dolphin Discovery Centre (45 kJ)	Dolphin Discovery Centre (35 kJ)
Injury or Permanent Injury Impact				
Fish Injury (207 - 219 dB SEL_{cum})	0-12m	0-12m	0-14m	0-15m
Fish Eggs and Larvae Injury (207 dB L_{peak})	20m	19m	23m	19m
Adult Turtle Injury (207 dB L_{peak})	20m	19m	23m	19m
Dolphin PTS (185 SEL_{cum}) dB(M)	10m	12m	14m	13m
Dolphin PTS (230 dB L_{peak})	Not Reached	Not Reached	Not Reached	Not Reached
Temporary or Recoverable Injury Impacts				

Marine Fauna Criteria	Casuarina Harbour (45 kJ)	Koombana Bay Sailing Club (45 kJ)	Dolphin Discovery Centre (45 kJ)	Dolphin Discovery Centre (35 kJ)
Fish Recoverable Injury (203 - 216 SEL_{cum})	0-18m	2-17m	3-19m	2-18m
Fish TTS (186 SEL_{cum})	245m	193m	208m	179m
Dolphin TTS (170 SEL_{cum}) dB(M)	138m	117m	144m	114m
Dolphin TTS (224 dB L_{peak})	Not Reached	Not Reached	1m	Not Reached
Behavioural Impacts				
Turtle Adult Behaviour (175 SPL RMS)	162m	129m	135m	118m
Turtle Adults Behavioural Disturbance (164 SEL_{cum})	1806m	1423m	>2000m	>2000m
Dolphin Behavioural (160 SPL) dB(M)	286m	260m	315m	254m
Dolphin Behavioural (160 SEL_{cum}) dB(M)	489m	434m	519m	464m

5. OTHER NOISE SOURCES

5.1 Construction of Breakwaters

To construct the breakwater it is likely that a sand / soil core will first be established along the breakwater alignment. The core may then be covered in a geo-fabric layer to stabilise it and to minimise the chance of fine sediments being released into the marine environment. A sloping rock fill 'batter' or 'armour' would then be installed over the core to provide sufficient stability and strength and protect the core from erosion.

Rock dumping produces underwater noise through the splash, tumble and grinding of falling rocks. This produces low to moderate levels of broadband noise, which would attenuate relatively rapidly due to the shallow water depth in the project area. It is anticipated that rock dumping events, and thus the noise generated, would be intermittent. There is no expectation that the injury criteria would be breached by the activity.

5.2 Drilling

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole in solid materials. The drill bit is a multipoint, end cutting tool. It cuts by applying pressure and rotation force to the material, which forms chips at the cutting edge.

Underwater drilling noise can be regarded as a non-pulse or continuous signal. An example source spectrum of typical percussion drilling noise from SVT's database is shown in Figure 5-1. As can be seen, drilling noise is mid by frequency noise between 100 Hz and 10kHz, this particular measurement produced an SPL of 136 dB at 16m from a jack-up drilling rig (background subtracted).

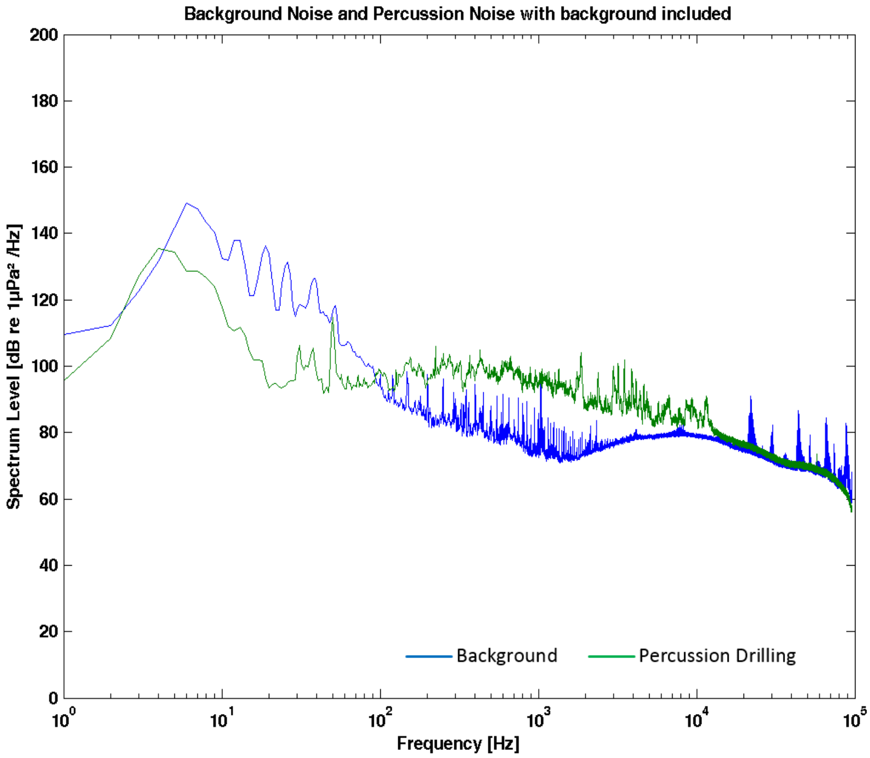

Figure 5-1 Example Drilling Noise Spectrum

Drilling activities (if conducted) are not expected to breach the injury criteria at any distance more than a few metres from the source.

5.3 Excavation and Dredging

The processes that describe the sound sources associated with mechanical backhoe (excavator) dredging activities fall within several categories. Physical removal of sediment from the substrate as the bucket is inserted into the bed, forced through the bed in a "scooping" arc, and removed from the bed produces grinding and scraping sounds. Lifting of the material from the bed up through the water column can produce sounds emanating from hydraulic pumps and the articulated bucket support arm.

Placing the dredged sediment into a barge can produce sounds that are transmitted through the hull of the barge, particularly during the early stages of the barge-filling process. On-board machinery will produce various sounds throughout the dredging process, such as sounds associated with winches, generators, and the power plant. These sources will be similar in character and strength to those generated by the shipping using the channel to the Bunbury Port Inner Harbour.

The US Army Corps of Engineers[11] found that underwater noise levels produced by a backhoe dredge excavating limestone spoil were up to 149 dB at a distance of 60m and depth of 9m. Injury criteria are not expected to be breached by these sources.

[11] Characterization of Underwater Sounds Produced by a Backhoe Dredge Excavating Rock and Gravel, December 2012, US Army Corps of Engineers, Dredging Operations Environmental Research Program.

6. RECOMMENDATIONS

To manage and minimise the impact of the piling activity, a number of approaches and strategies may be adopted. Potential strategies are briefly discussed in the following sections.

Conduct activities in shallow water

The propagation of the noise is affected by the water depth, with deeper water being favourable for propagation of more low frequency noise. The noise modelling exercise has assumed a worst case (maximum tide) situation. If possible, conducting the pile driving during low tide will assist in minimising, the spread of noise throughout the surrounding area. As an extension of this, piling the first pile of the day in shallower water (closer to shore) may provide a warning, similar to a soft start, allowing the sensitive marine fauna time to leave the area before piling moves to deeper water.

Conduct activities outside sensitive periods

Where behavioural changes to dolphins are predicted these may be avoided by conducting works during periods of the year where these specific receivers are not present or these specific activities do not take place.

Use the minimum effective hammer energy

In conducting the assessment SVT has assumed a piling driving energy based largely on practicability considerations and guided by logs of previous piling in the area. It may be possible to drive the pile using a lower energy hammer, and hence reduce the affected area.

Soft start

A soft-start procedures involves beginning with low energy piling gradually increasing to full working energy over a set time period. These approaches allows time for potentially affected animals to flee the immediate area and to avoid injury. Based on industry best practice, a 30 minute soft-start/ ramp up is to be recommended.

Bubble Curtain

Bubble curtains have been shown to be effective in attenuating underwater noise. Bubble curtains involve the release of compressed air at the at the sea bed which then rises to the surface as a stream of bubbles. The acoustic impedance miss-match between the bubble and the surrounding water results in high rates of attenuation. Because of the localised nature of the source, bubble curtains can be an effective and practicable control for pile driving. However, bubble curtains only work where the curtain can be continuously maintained, for example where a current does not wash the curtain away. Given the open water beachside project location, this restriction may make bubble curtains ineffective.

Cofferdams

Placing a larger diameter pipe around the intended pile and pumping it clear of water creates an air filled cofferdam around the pile. This creates a high acoustic impedance mismatch between the air filled cofferdam and the surrounding water resulting in high level of sound attenuation. As the seabed is sand over basalt in the project area there is the possibility the cofferdam could be installed without high energy driving by resting the pile hammer on the cofferdam and letting it settle to the basalt layer.

Drill and Drive or Vibration Drive

For smaller pile sizes, particularly for insertion into hard rock, it may be possible to first drill a hole and then drive the pile into the hole. It is anticipated that this methodology would require significantly lower hammer energy, and significantly lower number of blows.

Piles may also be vibration driven into sea bottom types that are soil / sand. This removes the impulsive nature of the task that is potentially injurious to marine fauna. Management of TTS and PTS would still be required but the management zones are likely to be more limited.

Monitor and Manage

As the modelling is based on a number of assumptions, it is recommended that actual levels be measured once piling commences and that these measurements be used to adjust the assessment and inform the management measures.

7. CONCLUSION

An assessment of the underwater noise generated by the piling planned in Koombana Bay as part of the Koombana Bay Marine Structures Project has been undertaken. The results are summarised below.

Permanent Injury or fatality

- The instantaneous permanent injury to dolphins defined by the L_{peak} Criterion, is not reached at any location.
- There is potential for permanent injury to dolphins within a range of up to 14 m based on the daily exposure criterion.
- There is potential for permanent injury to adult turtles at a range of up to 23m from the activity, defined by the L_{peak} Criterion;
- There is potential for permanent fish eggs and larvae injuries at a ranges of up to 11m from the activity, based on the daily exposure criterion;

Recoverable Injury and TTS

- There is potential for TTS in dolphins within a range of up to 1m from the activity, defined by the L_{peak} Criterion;
- There is the potential for TTS in dolphins within a range of 144 m using the daily exposure criterion.
- The range for recoverable injury for fish reaches up to 19 m using the daily exposure criterion.
- Fish within a range of 245 m may experience TTS based on the daily exposure criterion.

Behavioural Disturbance

- The single strike (SPL) criterion for behavioural disturbance to dolphins extends out to a range of 1061 m.
- The zone for dolphin behavioural disturbance extends out to 519 m using the daily exposure criterion.
- The single strike (SPL) criterion for behavioural disturbance to turtles extends out to a range of 162 m.
- The zone for turtle behavioural disturbance extends out to beyond 2km using the daily exposure criterion.

The limiting (longest) ranges for the impact assessment are drawn in each case from the daily exposure criteria. The criteria sum the overall sound energy (from the source) received by the animal for a 24 hour period, and in this case are calculated for 300 pile driving strikes. The calculation does not take account of the potential for the animal to flee outside of the affected area during the course of the activity, and the results are therefore considered conservative.

The use of impact management measures has been investigated and discussed in the study.

Additional mitigation measures for the piling may be considered and a number of these have been briefly discussed in the report.

A qualitative assessment of other activities with the potential to generate underwater noise has been undertaken.

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APPENDIX A UNDERWATER NOISE MODEL

Appendix A-1 Underwater Noise Model Selection

Various numerical techniques are used to develop underwater acoustic propagation models, including wavenumber integration, ray theory, normal modes, parabolic equation (PE) and finite differences/finite elements. When determining which model is to be used for the modelling prediction, it is necessary to define the application for which it is to be used and the type of underwater environment it is going to simulate. For the model applied in this assessment, the underwater environment has the following characteristics:

- strong range dependence
- a deep and shallow water ocean environment
- differing bottom types.

Parabolic Equation (PE) models are capable of making predictions in various conditions: shallow water, areas that have changing bottom types and under environmental conditions that are range dependent. A PE model called the Monterey Miami Parabolic Equation (MMPE) model was selected because it has been benchmark-tested for shallow water environments. The PE model is a well-recognized algorithm for transmission loss prediction and is widely used in the field of underwater acoustics. SVT have validated the model in multiple instances, for example: seismic survey modelling in Bassett Field (SVT for Total, 'Underwater Noise Modelling Validation and Results for 3D Seismic Survey in Bassett Field', 2010, Job Ref: 1052786-3-200).

The MMPE is a broadband model, and makes use of transmission loss calculations at multiple frequencies. With higher frequency comes greater computational overhead, and therefore to speed up the modelling process an upper-bound on frequency must be chosen. SVT chose to model frequencies from 63 Hz to 2 kHz, which is considered as being reasonable since most of the pile energy is in the first 2 kHz. This is a standard approach that has been followed by others such as, for example, the Centre for Marine Science and Technology (CMST) at Curtin University. It should be noted that the model demonstrated that frequencies below 250 Hz do not transmit in the shallow water environment of the project.

Furthermore, the absorption of sound in sea water increases significantly with high frequencies. Jensen et al[12] provide the well-recognised expression for the frequency dependence of attenuation (see equation B.1), where α is the attenuation in dB/km and f is the frequency of the sound in kHz.

$$\alpha = (3.3)(10^{-3}) + \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + (3.0)(10^{-4}) \qquad \text{(B.1)}$$

Using this equation will result in 4.1 dB/km attenuation for a sound wave at 20 kHz, compared to 0.8 dB/km at 8 kHz and 0.1 dB/km at 2 kHz.

[12] Jensen et al. *Computational Ocean Acoustics,* Springer, New York, 2000.

Appendix A-2 Underwater Noise Model Inputs

Table D-1 Underwater noise model inputs

Model Inputs	
Octave Band Frequencies Modelled (Hz)	250, 500, 1000, 2000
Hammer Pulse Length	100 ms
Height of Noise Source	Middle of the water column
Receiver Height	2.0 m below the sea surface
Piling Coordinates: • Casuarina Bay • Sailing Club • Dolphin Discovery Centre	 373581.00 m E, 6313430.00 m S 373866.00 m E, 6312849.00 m S 374302.00 m E, 6312491.00 m S
Source Sound Exposure Source Level: • 45 kJ Hammer • 35 kJ Hammer	 199 dB re 1µPa^2.s @ 1 m 198 dB re 1µPa^2.s @ 1 m
Number of Strikes Modelled	1, 100, 200, 300, 400

APPENDIX B PRINCIPLES OF UNDERWATER NOISE

Appendix B-1 Sound Pressure Level

Sound Pressure Level – The RMS level of sound at the instant (or in practice within one second) of the noise occurring. Since sound travels as a pressure wave, with high and low pressure amplitudes, the sound pressure level is always varying in time. Sound pressure level is expressed in dB, with relation to a reference sound pressure p_{ref}. The mathematical definition of sound pressure level (L_p) is:

$$L_P = 10 \log_{10}\left(\frac{p_{rms}^2}{p_{ref}^2}\right) \qquad \text{(B.1)}$$

(SPL is the commonly used descriptor for sound pressure level, however the official standard descriptor is L_p. For clarity and consistency with reference documents SVT uses SPL in this report.)

Because SPL is a continuously varying value, it is useful to average the SPL over a certain time period, to provide a reliable and meaning full comparison of the amplitude of sound. This averaging is conducted on an energy basis, and because sound pressure is varying about a zero mean pressure, the root mean square (rms) is used. In airborne acoustics, this averaging yields a value commonly referred to as the *Equivalent Level*, or L_{eq}. While L_{eq} is the commonly accepted and used notation, the official standard term and notation for this value is *Time Averaged Level*, L_T.

In a number of publications regarding the impact of underwater noise, SPL has been used as the descriptor for continuous received noise upon which the proposed assessment criteria are based. In these documents the term sound pressure level has been defined as an *averaged* sound pressure. This definition, mathematically, is the same as that for the Time Averaged Level, discussed above.

Additional opportunity for confusion has arisen in the field since the NOAA guidelines (2016) have reverted to the original definition of SPL.

Since SVT is referring in this document to criteria that use the SPL descriptor, and this descriptor was intended to mean an averaged level by the author of the publication, SVT will use SPL in this document to mean a time averaged level of rms sound pressure. This is to aid other readers of the document in understanding and cross-checking the referenced guidelines.

Therefore, for this document, the following definition of Sound Pressure Level is adopted:

Sound Pressure Level (SPL) is defined as the sound pressure, relative to some reference pressure, averaged over the time period T. For underwater acoustics, the reference pressure is generally taken to be p_{ref} = 1 μPa. Mathematically this is expressed as:

$$SPL = 10 \log_{10}\left(\frac{1}{T}\int_0^T \frac{p(t)^2}{p_{ref}^2}\,dt\right) \qquad \text{(B.2)}$$

Appendix B-2 Sound Exposure Level (SEL)

The Sound Exposure Level (SEL), also known as the energy flux density, the constant sound pressure level that if maintained for one second, would deliver the same total sound energy as the original source. It is usually used to describe discrete noise events. SEL is the commonly used descriptor for sound exposure level, however the official standard descriptor is L_E, such as it is used in the NOAA guidelines. For clarity of readership SVT has maintained the SEL notation in this study.

This is especially useful as it can be used in an accumulative context by summing all energy over an extended time period T, or over N discrete events, to find the total received sound energy level. The disturbance and injury criteria for marine life is commonly given in SEL for impulsive noise sources such as pile-driving, and SEL is also used by NOAA for newer criteria even for non-impulsive sources.

$$SEL = 10\ \log_{10}\left(\int_0^T \frac{p(t)^2}{p_{ref}^2} dt\right) \tag{B.2}$$

In deriving the SEL for a continuous source, the time T should be taken as 1 second.

The Cumulative SEL (SEL_{cum}) is the total sound energy for a set number of discrete events, or in the instance of a continuous source, for the total period under consideration.

For *n* pulses, the cumulative SEL can be derived from the single pulse SEL by equation B.3.

$$SEL_{cum} = SEL + 10\log(n) \tag{B.3}$$

For *a continuous source*, the cumulative SEL for a defined exposure time T can be can be derived from the SEL by equation B.4.

$$SEL_{cum} = SEL + 10\log(T) \tag{B.4}$$

Appendix B-3 Other Descriptors of Sound

L_{peak} The absolute maximum peak pressure level (not RMS level) reached at any time within the measurement period. L_{peak} gives a true representation of the actual maximum physical pressure of an acoustic wave.

Crest Factor The peak amplitude of the waveform divided by the RMS value of the waveform. The Crest Factor describes the how the peak of a wave form relates the average (rms) level. The Crest Factor is also sometimes called the Peak to Average Ratio (PAR) when expressed in engineering units (ie for sound when expressed as pressure (Pa). Because sound is typically expressed in dB, (a logarithmic unit) and log(ab) = Log(a) + Log(b), when the crest factor is expressed in dB it is the difference between the peak value and the rms value, i.e. CF = L_{peak} - L_p

Octave Band A 'constant percentage bandwidth' where each successive band centre frequency is double the previous one. International standards define nominal centre frequencies of 16 Hz, 31.5Hz, 63Hz, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, 4kHz, 8kHz, and 16kHz. Each octave band has a bandwidth which is proportional to the frequency so that there are no gaps or overlaps between bands. A separate noise level can be measured for each band, allowing definition of the frequency content of the noise.

Tonality — A qualitative term used to identify when a noticeable tone or series of tones are detectable. In environmental noise this can be used to can be used describe noise that may be more annoying (due to its frequency content), than other noise of a similar overall level – when it is so used, the appropriate authority will usually define a quantitative means for determining when a noise demonstrates 'tonality'.

Appendix B-4 Sound Propagation Effects

Sound propagates both through the water and through the sea bed due to efficient transmission due to their similar acoustic impedances. This is not the case with the air-water boundary at the sea surface. Therefore the effect of airborne propagation can be assumed insignificant, and more importantly the surface will act as a near perfect reflector of underwater sound. Bottom loss must also be considered and is a function of the bottom type and the grazing angle. The limiting frequency f_0 below which no propagation is possible within the sediment is given by equation A.4.

$$f_0 = \frac{c_{water}}{4h}\sqrt{\frac{1}{1-(c_{water}/\ c_{sediment})^2}} \quad \text{(B.4)}$$

Appendix B-5 M Weighting

To account for the different hearing frequency ranges for marine mammals, particularly when criteria are set for cumulative energy exposure (such as SPL or SEL) and for disturbance criteria, weightings have been developed for each species group. The weightings provided by NOAA as applied in this report are presented below.

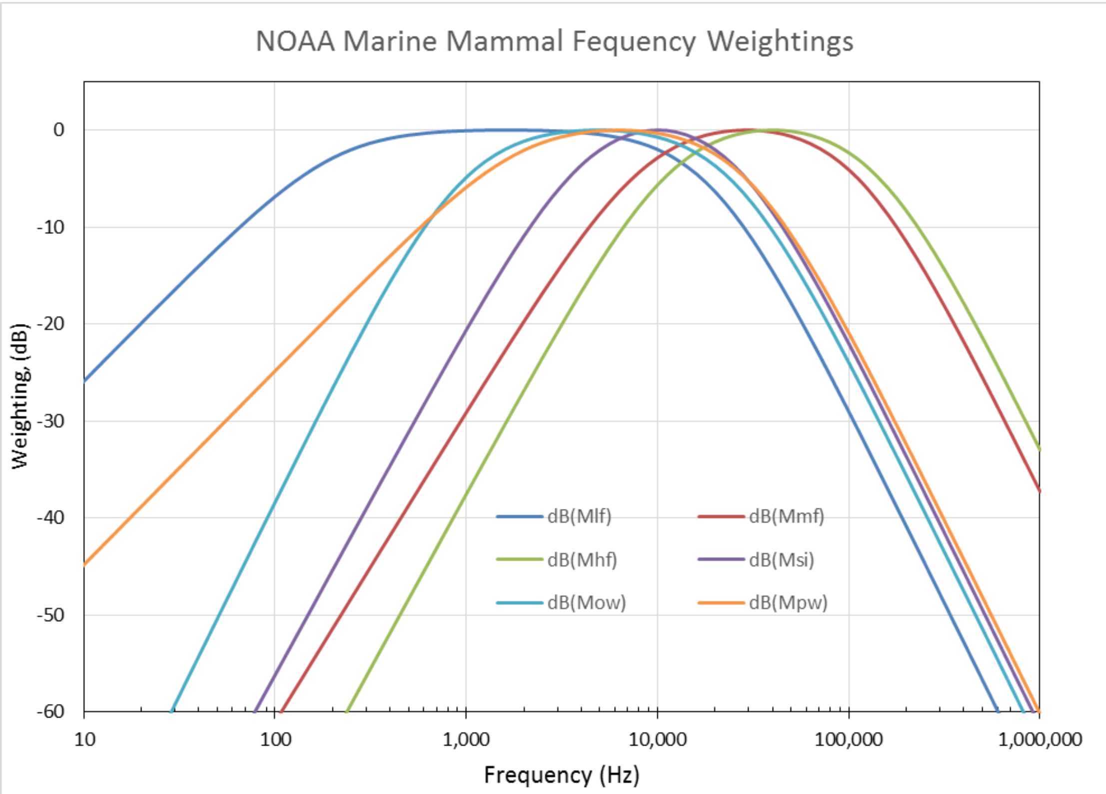

Fig. B-1 NOAA Marine Mammal Frequency Weightings

APPENDIX C MAXIMUM NOISE LEVELS VERSUS RANGE (UNWEIGHTED)

Appendix C-1 Casuarina Harbour Piling (45 kJ)

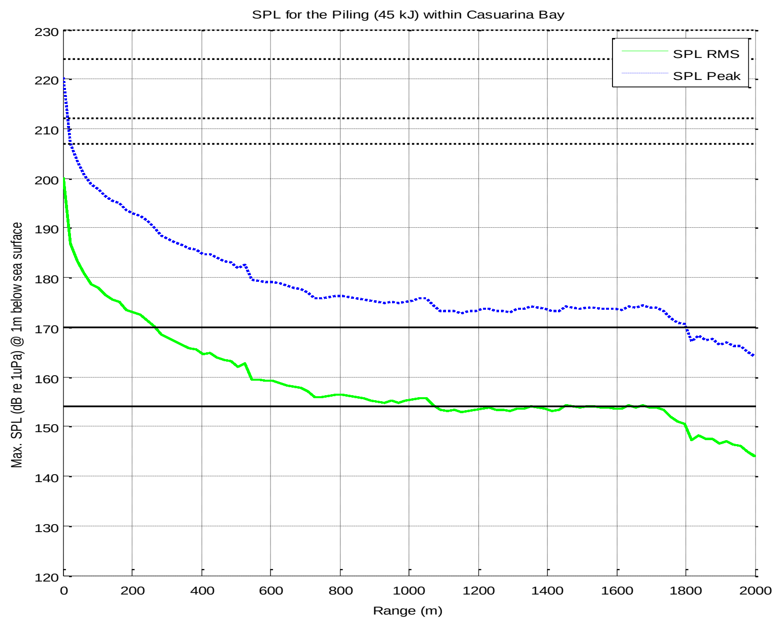

Fig. C-1 Maximum sound pressure level for piling at Casuarina Harbour versus range

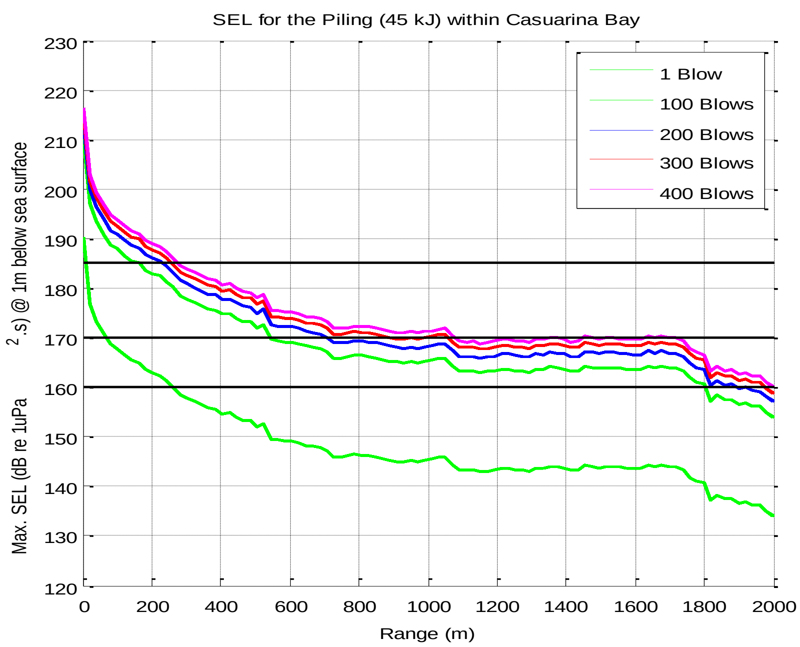

Fig. C-2 Maximum sound exposure level for piling at Casuarina Harbour versus range

Appendix C-2 Koombana Bay Sailing Club Piling (45 kJ)

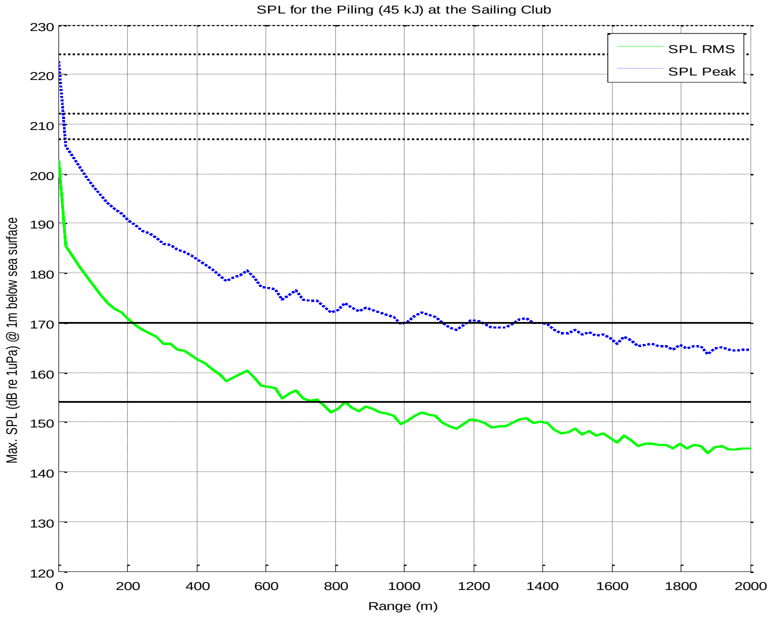

Fig. C-3 Maximum sound pressure level for piling at Koombana Bay Sailing Club versus range

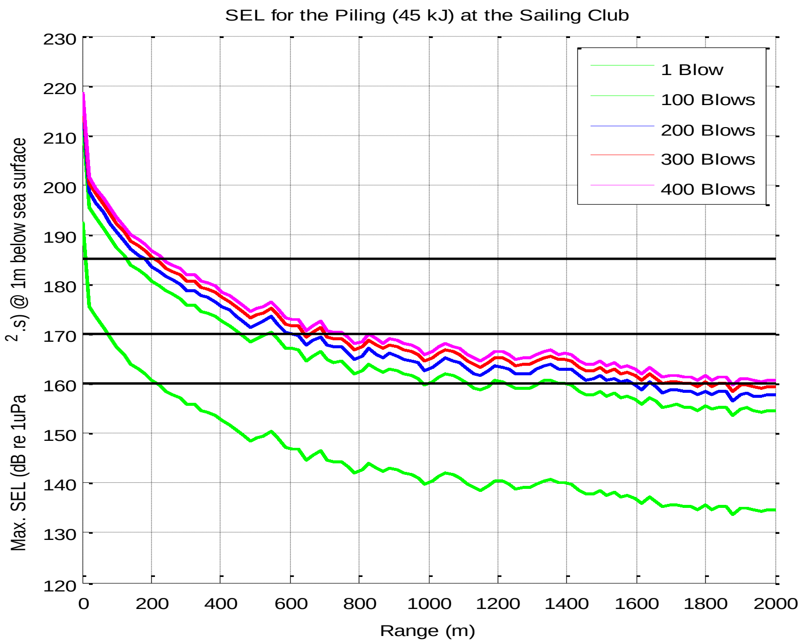

Fig. C-4 Maximum sound exposure level for piling at Koombana Bay Sailing Club versus range

Appendix C-3 Dolphin Discovery Centre (45 kJ)

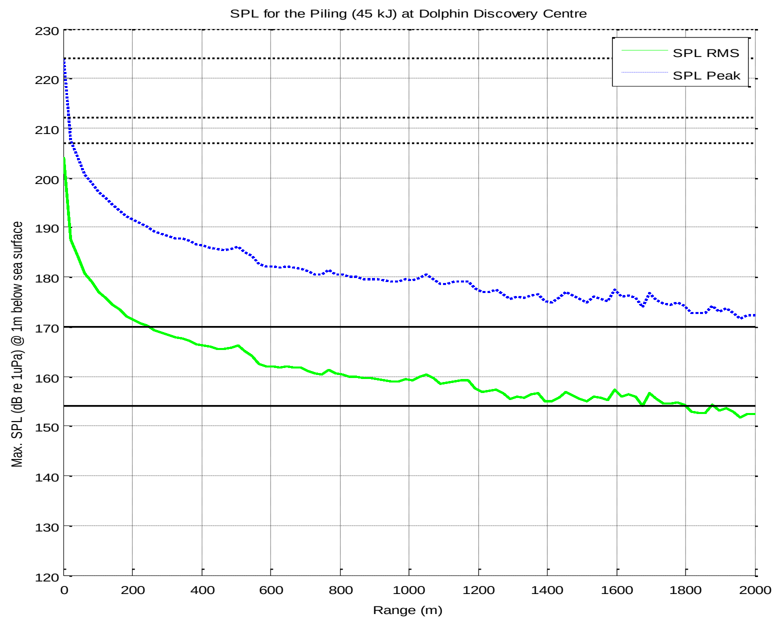

Fig. C-5 Maximum sound pressure level for 45 kJ piling at Dolphin Discovery Centre versus range

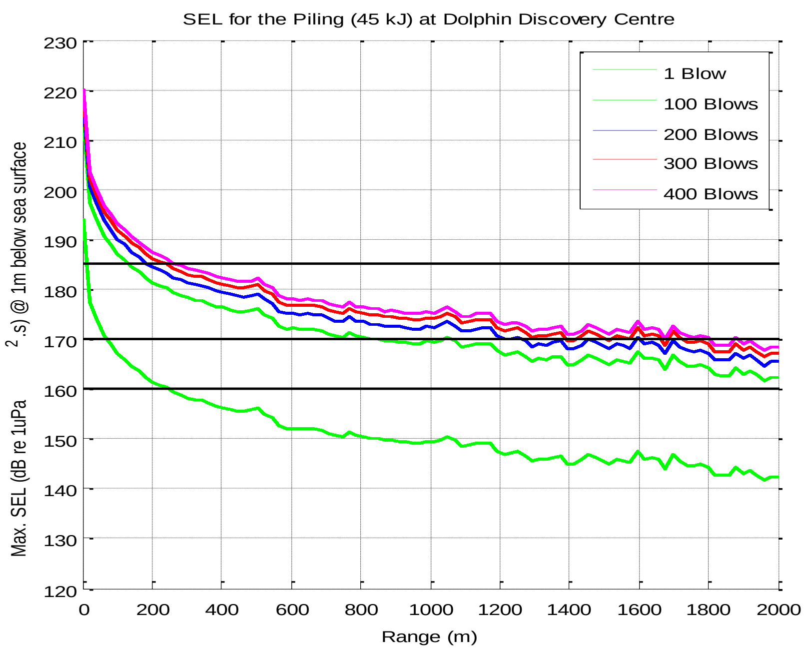

Fig. C-6 Maximum sound exposure level for 45 kJ piling at Dolphin Discovery Centre versus range

Appendix C-4 Dolphin Discovery Centre (35 kJ)

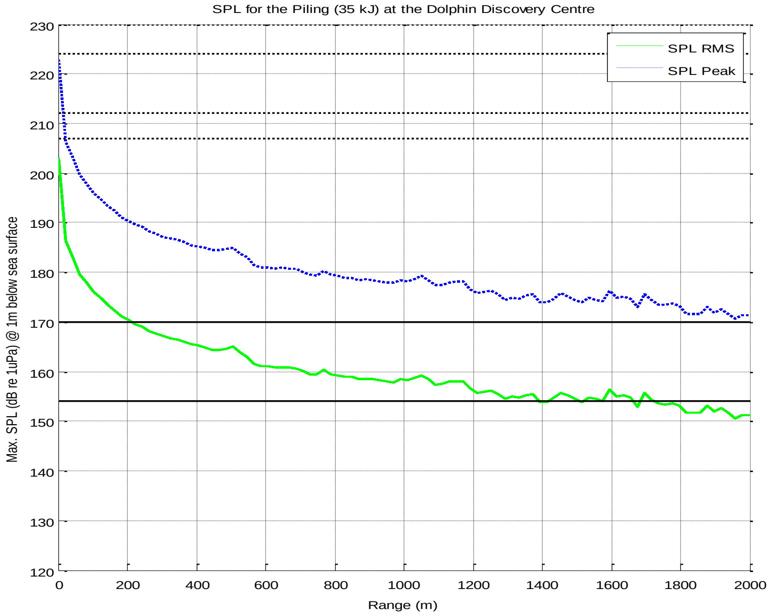

Fig. C-7 Maximum sound pressure level for 35 kJ piling at Dolphin Discovery Centre versus range

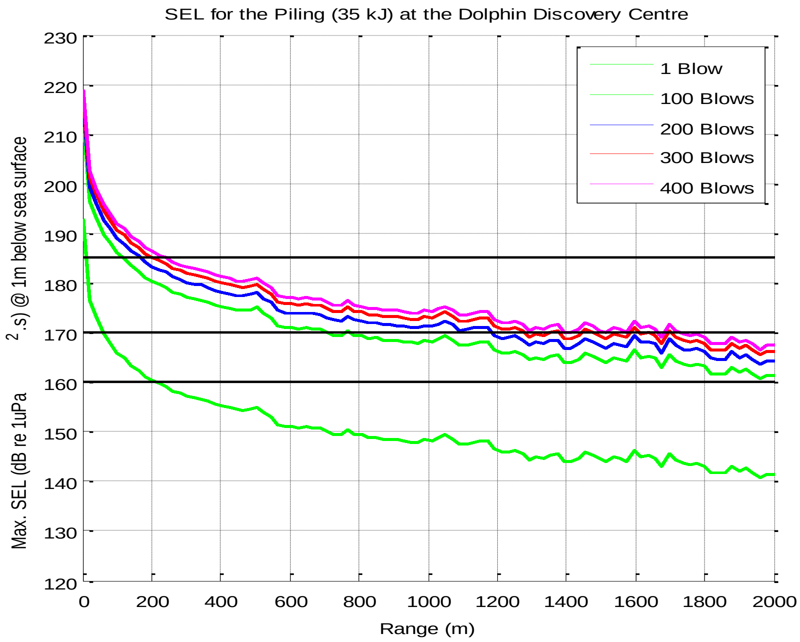

Fig. C-8 Maximum sound exposure level for 35 kJ piling at Dolphin Discovery Centre versus range

APPENDIX D MAXIMUM NOISE LEVELS VERSUS RANGE: NOAA M-WEIGHTED

Appendix D-1 Casuarina Harbour Piling (45kJ)

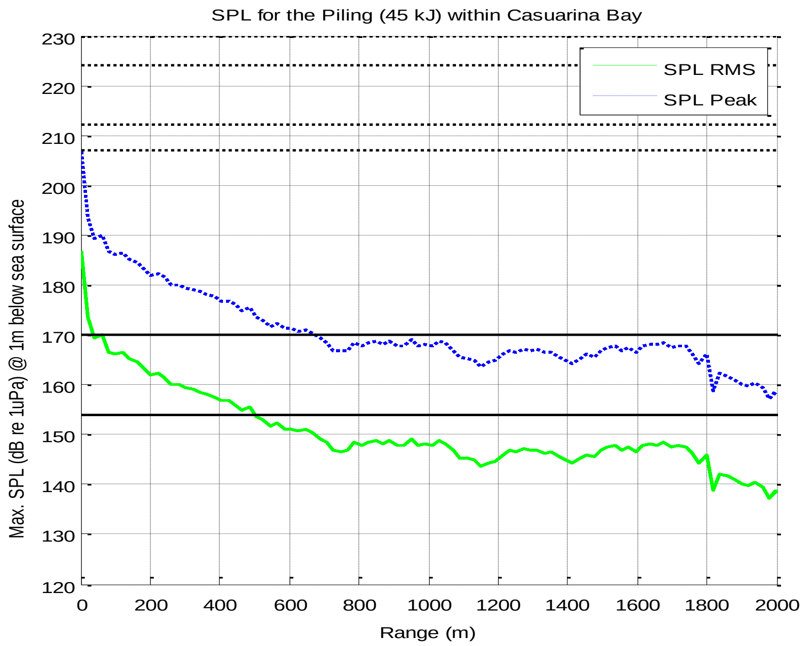

Fig. D-1 Maximum M-weighted sound pressure level for 45kJ piling at Casuarina Bay versus range

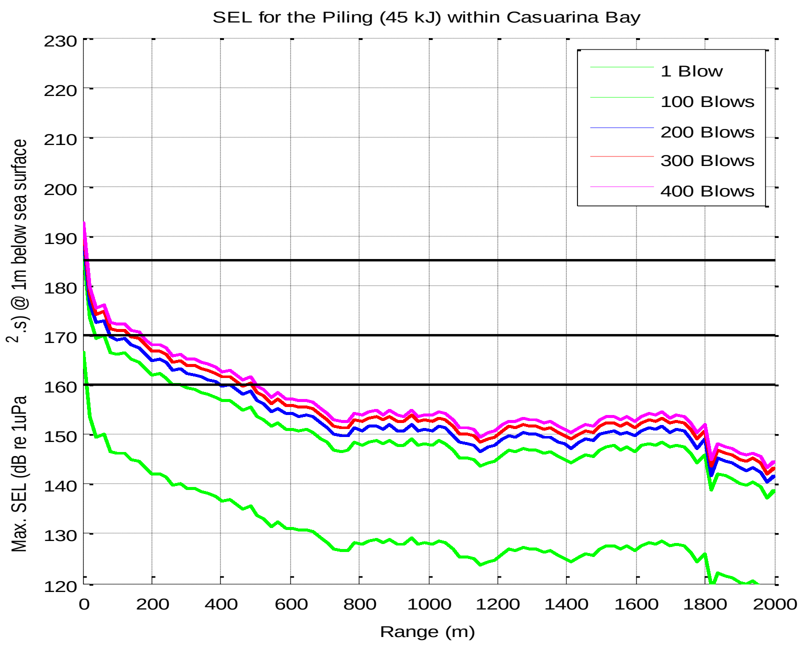

Fig. D-2 Maximum M-weighted sound exposure level for 45kJ piling at Casuarina Bay versus range

Fig. D-3 Noise contour showing the Dolphin PTS (185 dB SEL), TTS (170 dB SEL) and behavioural (160 dB SEL) Ranges (300 strikes), at Casuarina Bay

Appendix D-2 Koombana Bay Sailing Club (45kJ)

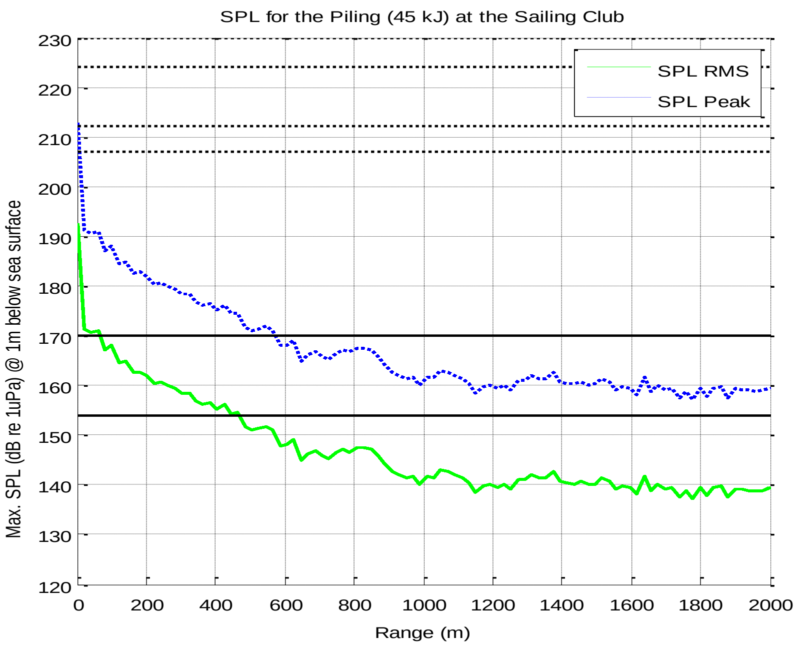

Fig. D-4 Maximum M-weighted sound pressure level for 45kJ piling at Sailing Club versus range

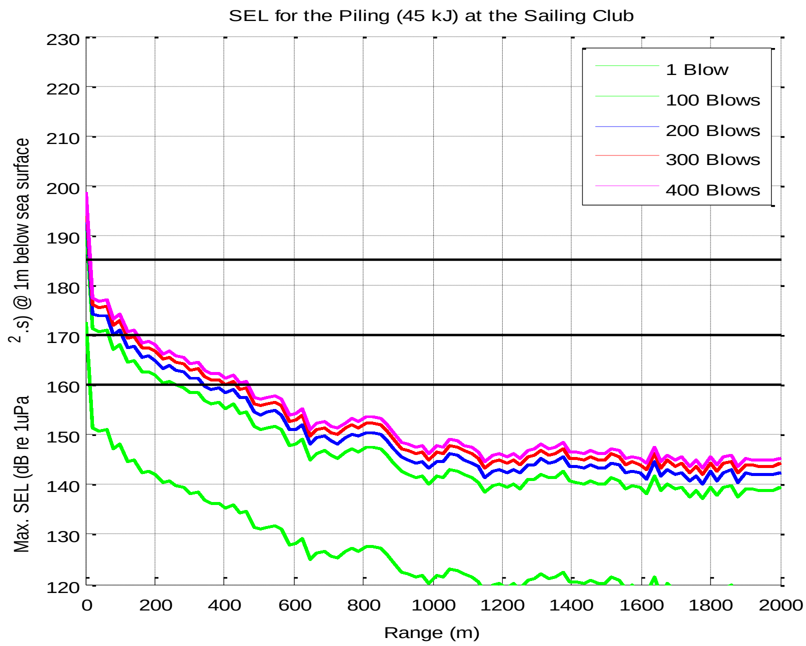

Fig. D-5 Maximum M-weighted sound exposure level for 45kJ piling at Sailing Club versus range

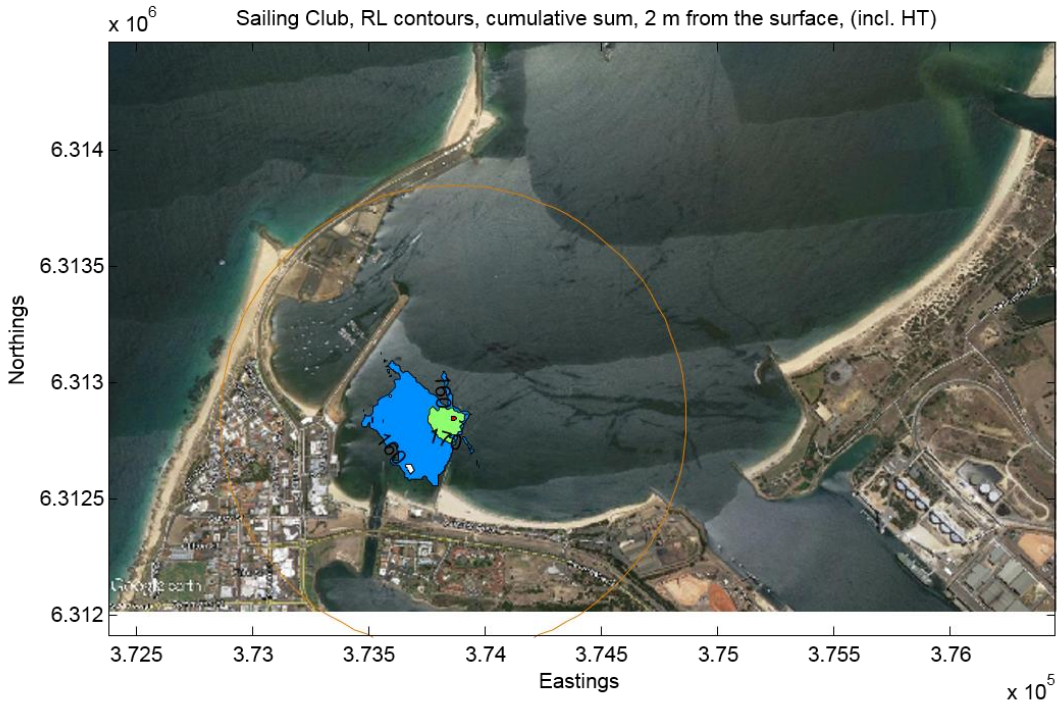

Fig. D-6 Noise contour showing the Dolphin PTS (185 dB SEL), TTS (170 dB SEL) and behavioural (160 dB SEL) Ranges (300 strikes), at Koombana Bay Sailing Club

Appendix D-3 Dolphin Discovery Centre (45kJ)

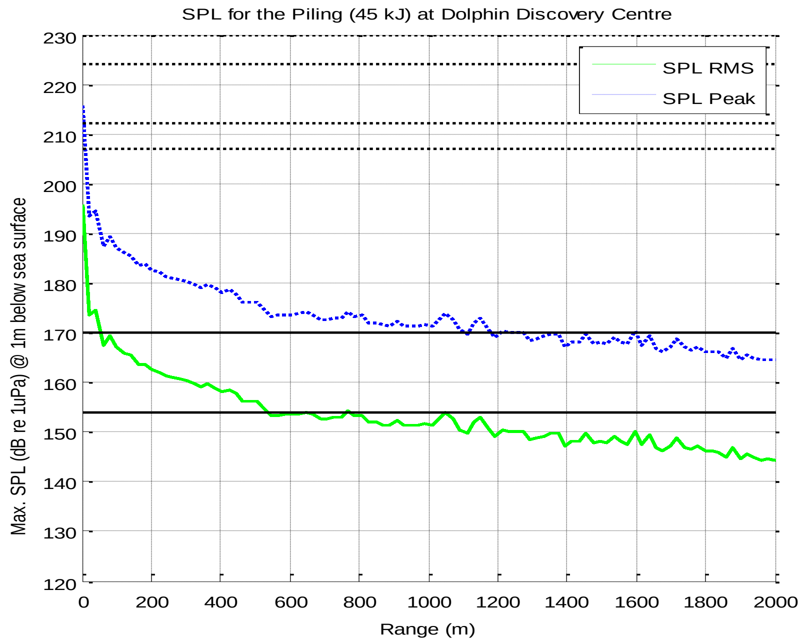

Fig. D-7 Maximum M-weighted sound pressure level for 45kJ piling at Dolphin Discovery Centre versus range

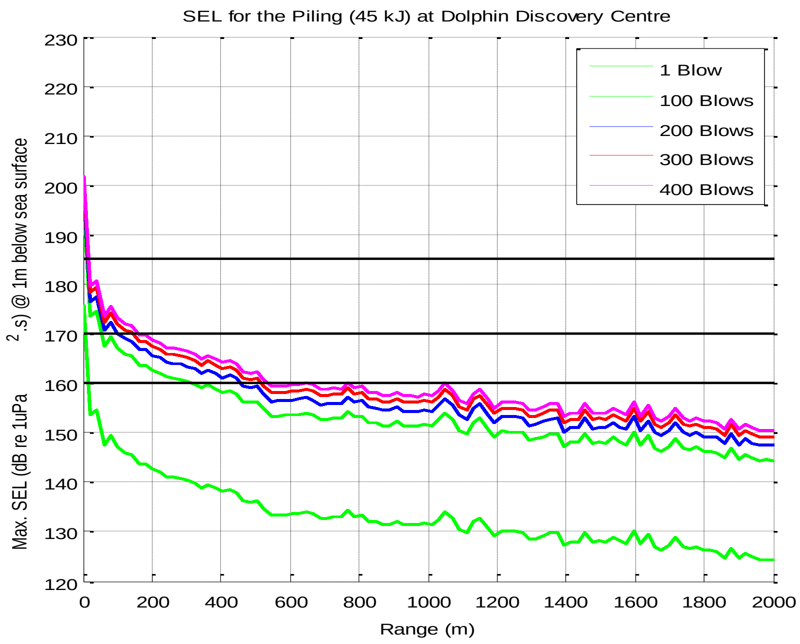

Fig. D-8 Maximum M-weighted sound exposure level for 45kJ piling at Dolphin Discovery Centre versus range

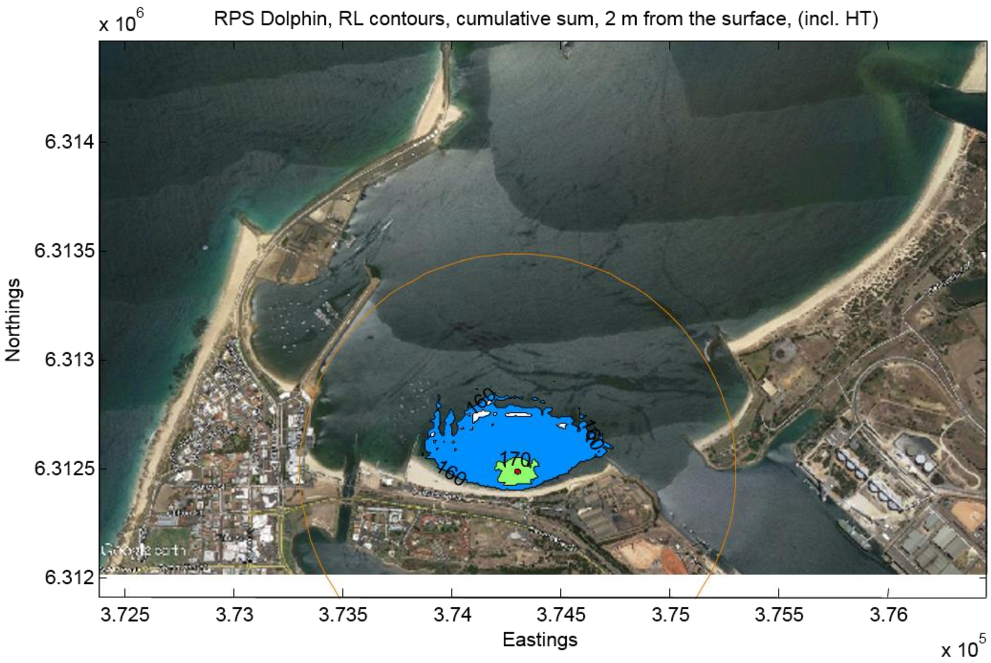

Fig D-9 Noise contour showing the Dolphin PTS (185 dB SEL), TTS (170 dB SEL) and behavioural (160 dB SEL) Ranges (300 strikes, 45 kJ hammer), at Dolphin Discovery Centre

Appendix D-4 Dolphin Discovery Centre (35kJ)

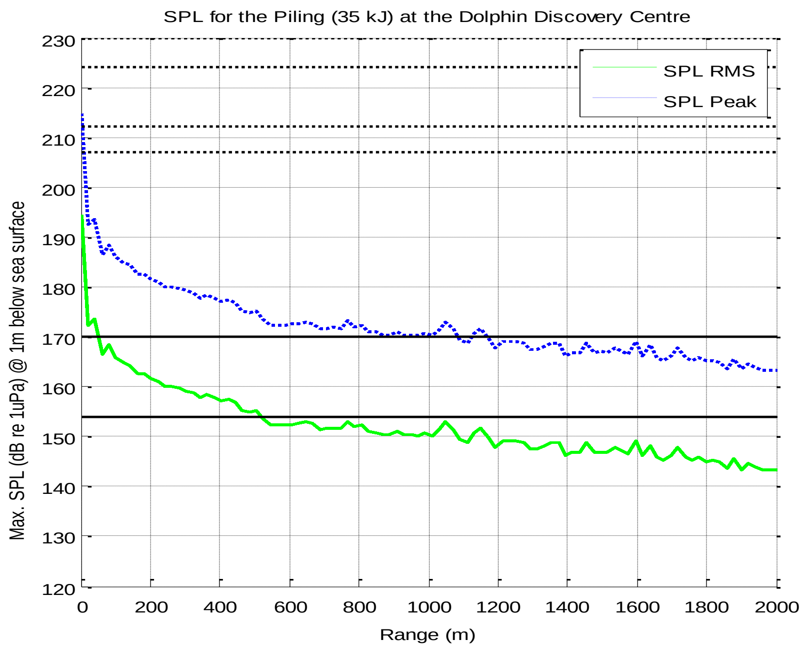

Fig. D-10 Maximum M-weighted sound pressure level for 35kJ piling at Dolphin Discovery Centre versus range

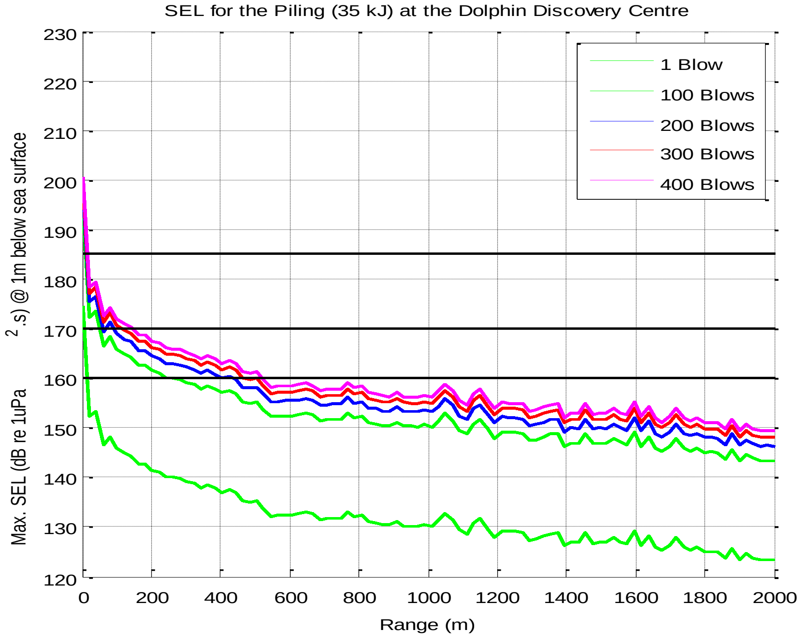

Fig. D-11 Maximum M-weighted sound pressure level for 35kJ piling at Dolphin Discovery Centre versus range

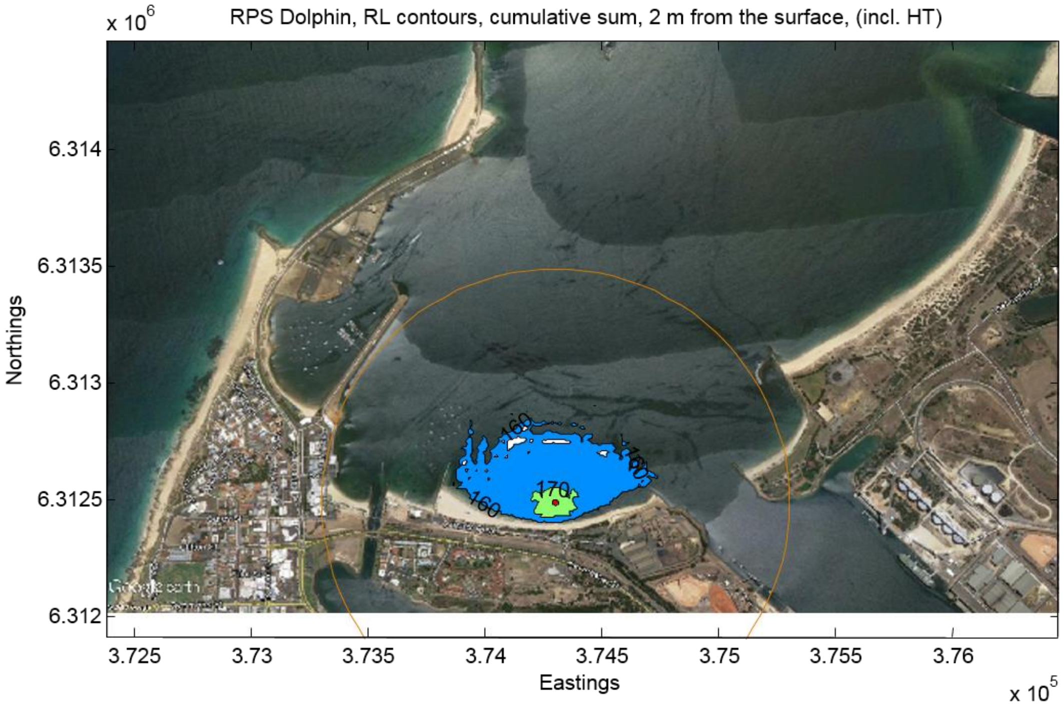

Fig. D-12: Noise contour showing the Dolphin PTS (185 dB SEL), TTS (170 dB SEL) and behavioural (160 dB SEL) Ranges (300 strikes, 45 kJ hammer), at Dolphin Discovery Centre

APPENDIX E SOUND EXPOSURE LEVEL RESULTS

Appendix E-1 Casuarina Harbour Piling

Table 8-1 Maximum ranges at Casuarina Harbour for the marine fauna sound exposure criteria

Criteria	1 Strike	100 Strikes	200 Strikes	300 Strikes	400 Strikes
Fish Injury Max (219 SEL)	Not Reached	Not Reached	Not Reached	Not Reached	Not Reached
Fish Injury Min (207 SEL)	Not Reached	5m	10m	12m	14m
Fish Recoverable Injury Max (216 SEL)	Not Reached	Not Reached	Not Reached	Not Reached	1m
Fish Recoverable Injury Min (203 SEL)	Not Reached	11m	16m	18m	20m
Fish TTS (186 SEL)	6m	132m	203m	245m	265m
Adult Turtle Injury (210 SEL)	Not Reached	1m	5m	8m	9m
Turtle Adults Behavioural Disturbance (164 SEL)	176m	1690m	1777m	1806m	1845m
Dolphin PTS (185 SEL) (M)	Not Reached	3m	7m	10m	12m
Dolphin TTS (170 SEL (M)	Not Reached	61m	78m	138m	170m
Dolphin Behavioural (160 SEL) (M)	10m	285m	398m	489m	502m

Appendix E-2 Koombana Bay Sailing Club Piling

Table 8-2 Maximum ranges at Koombana Bay Sailing Club for the marine fauna sound exposure criteria

Criteria	1 Strike	100 Strikes	200 Strikes	300 Strikes	400 Strikes
Fish Injury Max (219 SEL)	Not Reached	Not Reached	Not Reached	Not Reached	Not Reached
Fish Injury Min (207 SEL)	Not Reached	7m	10m	12m	14m
Fish Recoverable Injury Max (216 SEL)	Not Reached	Not Reached	Not Reached	2m	3m
Fish Recoverable Injury Min (203 SEL)	Not Reached	11m	15m	17m	18m
Fish TTS (186 SEL)	8m	117m	160m	193m	215m
Adult Turtle Injury (210 SEL)	Not Reached	3m	7m	9m	10m
Turtle Adults Behavioural Disturbance (164 SEL)	142m	829m	1093m	1423m	1539m
Dolphin PTS (185 SEL) (M)	Not Reached	7m	10m	12m	13m
Dolphin TTS (170 SEL) (M)	3m	66m	107m	117m	149m
Dolphin Behavioural (160 SEL) (M)	12m	260m	341m	434m	468m

Appendix E-3 Dolphin Discovery Centre (45 kJ)

Table 8-3 Maximum ranges at Dolphin Discovery Centre for the marine fauna sound exposure criteria

Criteria	1 Strike	100 Strikes	200 Strikes	300 Strikes	400 Strikes
Fish Injury Max (219 SEL)	Not Reached	Not Reached	Not Reached	Not Reached	1m
Fish Injury Min (207 SEL)	Not Reached	9m	12m	14m	16m
Fish Recoverable Injury Max (216 SEL)	Not Reached	Not Reached	1m	3m	5m
Fish Recoverable Injury Min (203 SEL)	Not Reached	13m	17m	19m	23m
Fish TTS (186 SEL)	10m	120m	169m	208m	247m
Adult Turtle Injury (210 SEL)	Not Reached	5m	9m	11m	12m
Turtle Adults Behavioural Disturbance (164 SEL)	151m	1882m	>2000m	>2000m	>2000m
Dolphin PTS (185 SEL) (M)	Not Reached	10m	13m	14m	15m
Dolphin TTS (170 SEL) (M)	5m	53m	102m	144m	158m
Dolphin Behavioural (160 SEL) (M)	14m	315m	455m	519m	772m

Appendix E-4 Dolphin Discovery Centre (35 kJ)

Table 8-4 Maximum ranges at Dolphin Discovery Centre for the marine fauna sound exposure criteria

Criteria	1 Strike	100 Strikes	200 Strikes	300 Strikes	400 Strikes
Fish Injury Max (219 SEL)	Not Reached	Not Reached	Not Reached	Not Reached	Not Reached
Fish Injury Min (207 SEL)	Not Reached	7m	11m	13m	15m
Fish Recoverable Injury Max (216 SEL)	Not Reached	Not Reached	Not Reached	2m	4m
Fish Recoverable Injury Min (203 SEL)	Not Reached	12m	16m	18m	19.4m
Fish TTS (186 SEL)	8m	101m	149m	179m	212m
Adult Turtle Injury (210 SEL)	Not Reached	4m	7m	10m	11m
Turtle Adults Behavioural Disturbance (164 SEL)	133m	1726m	1971m	>2000m	>2000m
Dolphin PTS (185 SEL) (M)	Not Reached	9m	11m	13m	14m
Dolphin TTS (170 SEL) (M)	4m	50m	92m	114m	146m
Dolphin Behavioural (160 SEL) (M)	13m	254m	438m	464m	521m

APPENDIX F CASUARINA HARBOUR BATHYMETRY

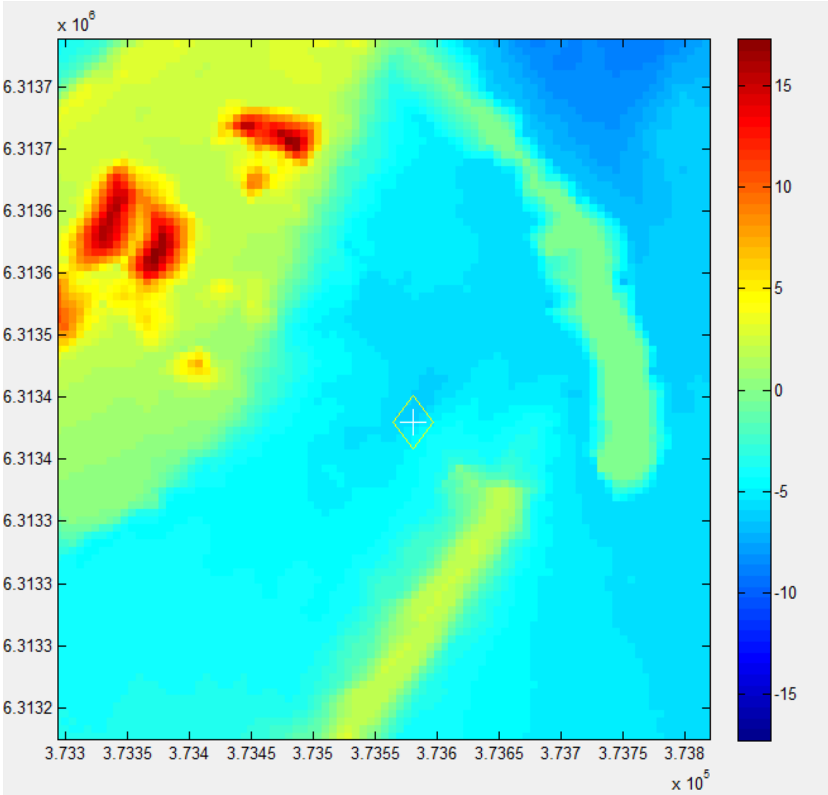

Fig. F-1 Bathymetry used in the underwater noise model

Fig. F-2 Casuarina Harbour Modelled Noise Source Location

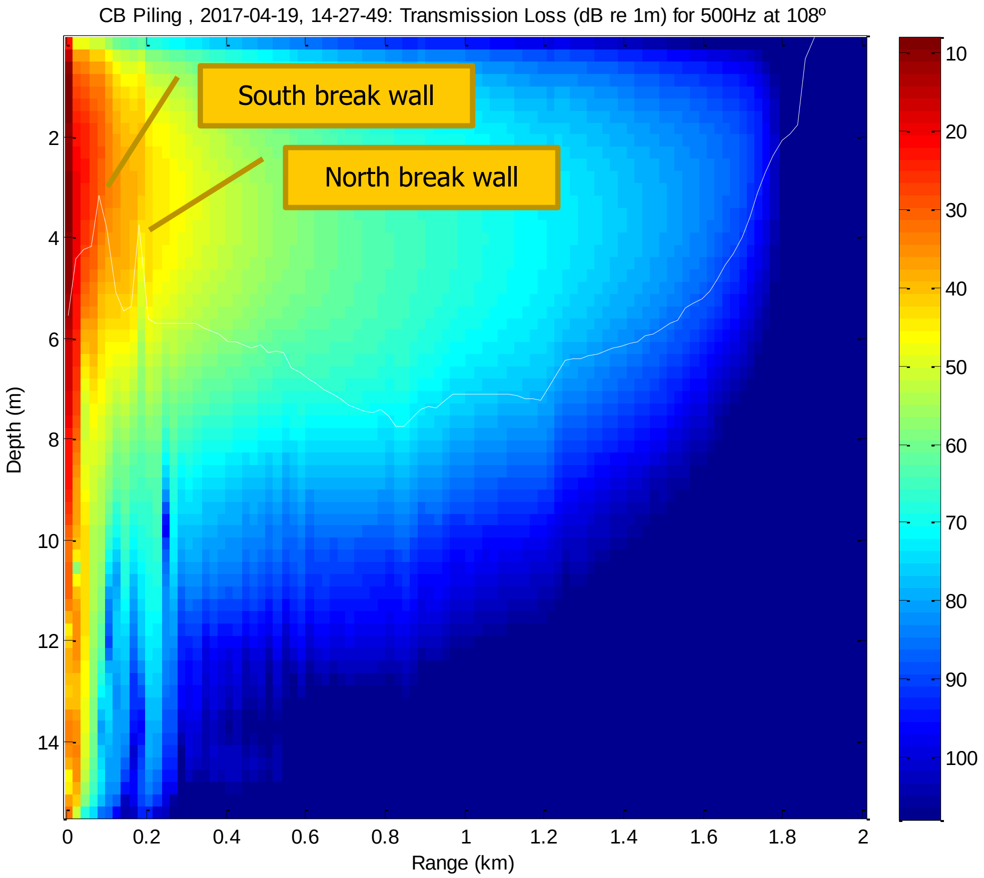

Fig. F-3 Noise prediction cross-section at Casuarina Harbour