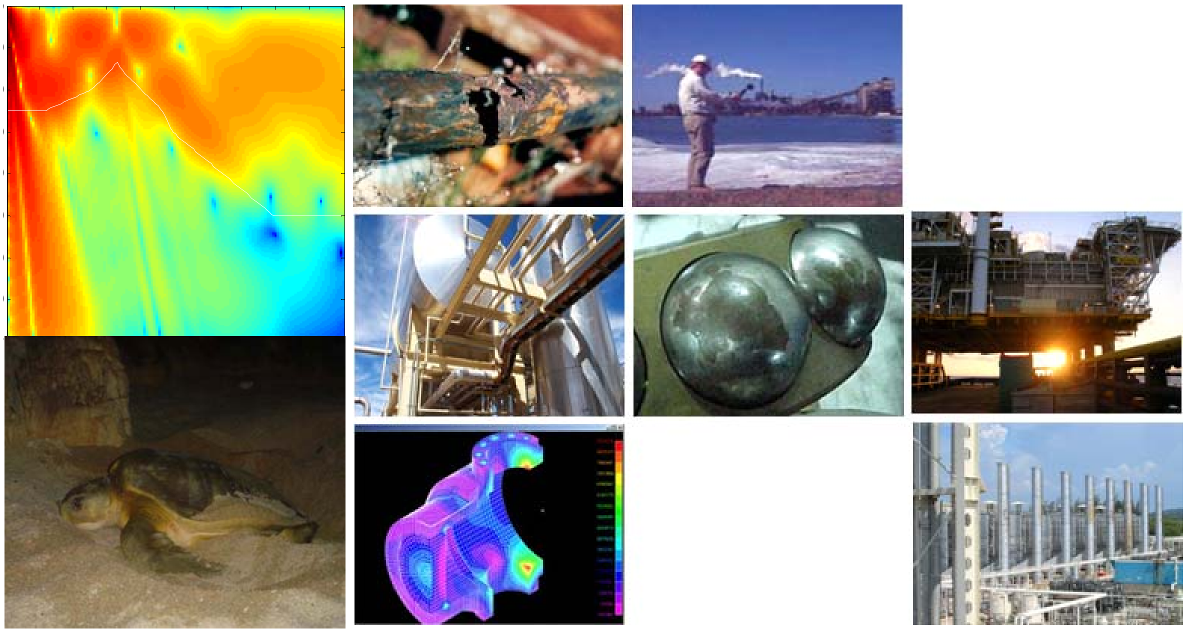
SVT ENGINEERING CONSULTANTS

CAPE LAMBERT PORT B DEVELOPMENT UNDERWATER NOISE ASSESSMENT



RIO-TINTO

Rpt02-075066-Rev2-12 August 2009

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Head Office: Perth, Western Australia

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DOCUMENT CONTROL & REVIEW INFORMATION

Client: **RIO-TINTO**

Client Contact: **Peter Royce**

SVT Contact: **Granger Bennett**

SVT Office: **Perth**

SVT Job No: **075066**

SVT Document No: **Rpt02-075066-Rev2-12 August 2009**

SVT Engineering Consultants ABN: 18 122 767 944		
SVT Perth (HEAD OFFICE)	SVT Kuala Lumpur Office	SVT Melbourne Office
112 Cambridge Street West Leederville WA 6007 Australia Tel: + 61 (0)8 9489 2000 Fax: + 61 (0)8 9489 2088 Email: mailbox@svt.com.au	SVT-Engineering Malaysia Sdn Bhd (Malaysian Office) 62A, Jalan Badminton 13/29, Tadisma Business Centre, 40100 Shah Alam, Selangor, Malaysia Tel: +60 3 5513 6487 (h/p 012 330 1071) Fax: +60 3 5513 6486 Email: mailbox@svt.com.au	Suite 1, 20 Cato Street Hawthorn East, VIC 3123 Australia Tel: +61 (0)3 9832 4406 Fax: +61 (0)3 9917 2204 Email: mailbox@svt.com.au

EXECUTIVE SUMMARY

SVT was commissioned to undertake an assessment of the underwater noise associated with the proposed pile driving activities for the Cape Lambert Port B Development. This report documents the outcomes of that assessment of underwater noise from pile driving activities associated with construction of the proposed access jetty.

Background. The recent Cape Lambert upgrade construction works involved the extension of the Port A wharf by an additional 300 m. Pile driving associated with that construction programme is completed. Construction of the new access jetty and wharf associated with the Cape Lambert B development will involve driving piles into the seabed after which a prefabricated deck and conveyor will then be constructed on top of the piles. It is planned that three different sizes of steel pile will be used in the construction of the access jetty and wharf (1200mm and 1500mm pile diameter for the access jetty; and 1500mm and 1600mm pile diameter for the wharf). At Cape Lambert a large impact hammer, which uses gravity and hydraulics to give inertia to the hammer, is being used to drive the pile into the seabed. The noise that is generated by the hammer hitting the top of the pile is short in duration lasting approximately 90ms and can therefore be described as an impulsive noise. Because the noise is impulsive its frequency spectrum is therefore broadband and does not have any tonal characteristics.

Aim The aim of this document is to assess the impact of underwater noise on turtles, Humpback whales and fish due to pile driving for the Cape Lambert Port B Development.

Legislation. There is no legislation or guidance documentation on the effects of sound on turtles. Some documentation exists for odontocete[1] and fish. From the available guidance documentation for fish, there are three metrics[2], Sound Exposure Level (SEL), peak Sound Pressure Level (SPL) and fish weight that can be used when determining acceptable noise levels.

Biological Noise Parameters. This report considers Flatback and Green turtles, fish and the Humpback whale as the sensitive marine receptors. When evaluating the effect of sound on these marine animals, the following biological parameters need to be considered:

- physical injury
- threshold shift hearing loss
- masking and behavioural change.

Turtles. The following peak pressure and SEL values are of interest with regard to their effects of noise on turtles:

Effect	Pressure Level	SEL
Physical injury	222 dB re 1µPa	198dB re 1µPa^{2}s
Hearing damage	222 dB re 1µPa	
Behavioural and masking	120 dB re 1µPa	

[1] Member of the toothed whale suborder, which includes killer whales, dolphins, belugas and porpoises.

[2] Popper et al, Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper.

Humpback Whales. There is little or no data available for Humpback whales so it is difficult to set quantitative acceptable levels for Humpback whales. It is noted that the whale migration routes and female/calf resting areas are a considerable distance from the pile driving area. The avoidance criteria recommended by both Southall *et al* [3] and the EPBC Act policy statement 2.1 applicable to offshore seismic exploration activities is used:

	Possible Physical Injury	Possible Avoidance
Peak Pressure	230 dB re 1µPa[4]	224 dB re 1µPa[5]
SEL	198 dB re 1µPa^2.s[6]	160 dB re 1µPa^2.s[7]

Fish. It can be expected that reef fish may occur in and around the new jetty area and therefore the pile driving activities. As these fish are usually small and are usually site bound they will suffer some loss due to physical injury. For this assessment the conservative levels of 187 dB re 1µPa^2.s proposed by Popper[8] is used.

Field Data. From the field data obtained from in-situ pile driving for the earlier Cape Lambert upgrade it was determined that the peak source level (SL) pressure was 240 dB re 1µPa @1m. The SEL of a single pile pulse was 220 dB re 1µPa^2.s @1m. This SEL was used in the model to evaluate the area around the pile that would result in possible physical injury and avoidance.

Underwater Model. The Monterey Miami Parabolic Equation (MMPE) model was selected to model the underwater acoustics as it is well suited to shallow water environments. The model was used to predict peak pressure levels and sound exposure levels for the proposed access jetty at Cape Lambert. From the results of the model, zones of physical injury and zones of avoidance were determined for adult and hatchling turtles, Humpback whales and fish. Figure 1-1 shows the zone of possible physical injury and the zone of avoidance for adult and juvenile turtles. Figure 1-2 shows the predicted zone of possible physical injury for hatchling turtles. Figure 1-3 shows the predicted zone of possible physical injury for fish.

Zones of Possible Physical Injury and Avoidance. Pile operations are discrete events and therefore the zones shown in these figures are not continuous zones, but are an accumulation of all the piling events that are to take place in the area. Each pile can therefore be separated into a circle of physical injury and a circle of avoidance. The circles of physical injury or hearing damage for adult and juvenile turtle's ranges from 20m for piling operations close to shore to 30 m for pile driving operations at the end of the jetty and the zone of avoidance ranges from 300m to 400m as shown in Figure 1-1. The following conclusions for adult turtles can be drawn from this figure:

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[3] Southall et al also considers observational data from other transient sources such as explosions.

[4] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[5] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[6] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

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

[8] Popper et al, Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper.

1. It appears that pile operations are unlikely to prevent turtles from nesting on Cooling Water beach as the zone of avoidance does not encroach on the path leading up to the beach.
2. To ensure that no physical injury or hearing damage to the turtles occurs a minimum 30 m circle around each pile needs to be cleared from all turtles before pile driving operations start (once they have started it can be assumed that the turtle will avoid the area).

The circles of potential physical injury or hearing damage for hatchling turtle's ranges from 40 m for piling operations close to shore to 70 m for pile driving operations as shown in Figure 1-2. It is assumed that the hatchling turtles will not avoid any noise sources as their swimming patterns will primarily be dictated by tides and currents. The following conclusion can be drawn from this figure:

1. The tide and current at the time when the hatchlings take to the sea and the location where the piles are being driven in will determine if the hatchlings will enter the zone of possible physical injury.

The circles of potential physical injury or hearing damage for fish ranges from 140 m for piling operations close to shore to 340 m for pile driving operations as shown in Figure 1-3. It must be remembered that these ranges are based on the conservative levels proposed by Popper for very small fish. The ranges will decrease for larger fish.

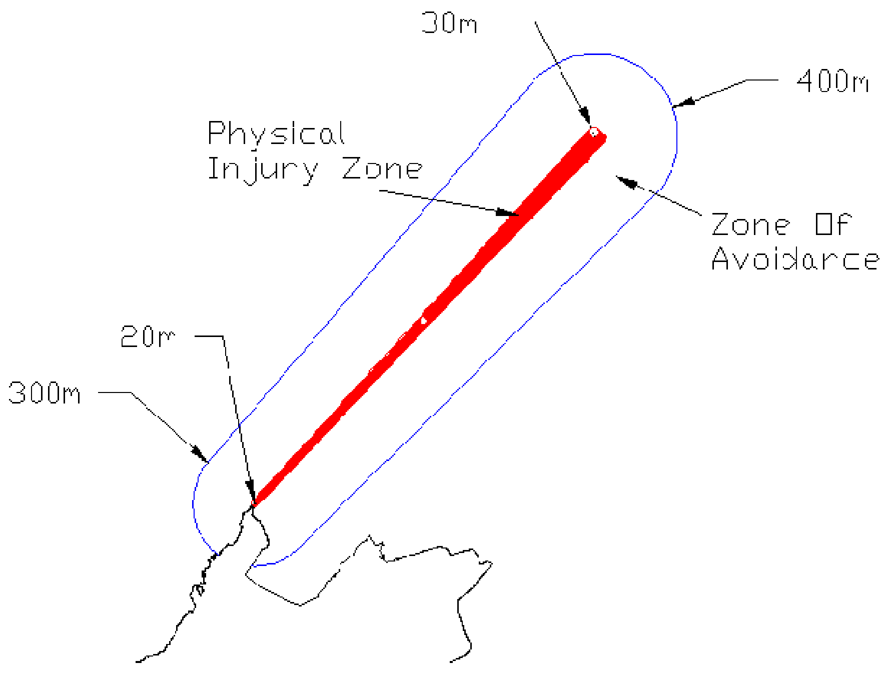

Figure 1-1 Predicted zones of avoidance and possible physical injury for adult turtles and juvenile turtles. Zone of physical injury is a 30 m circle around each pile near the end of the jetty and a 20 m circle around each close in pile. The zone of avoidance is a 400m circle at the end of the jetty and a 300m circle for the close in piles.

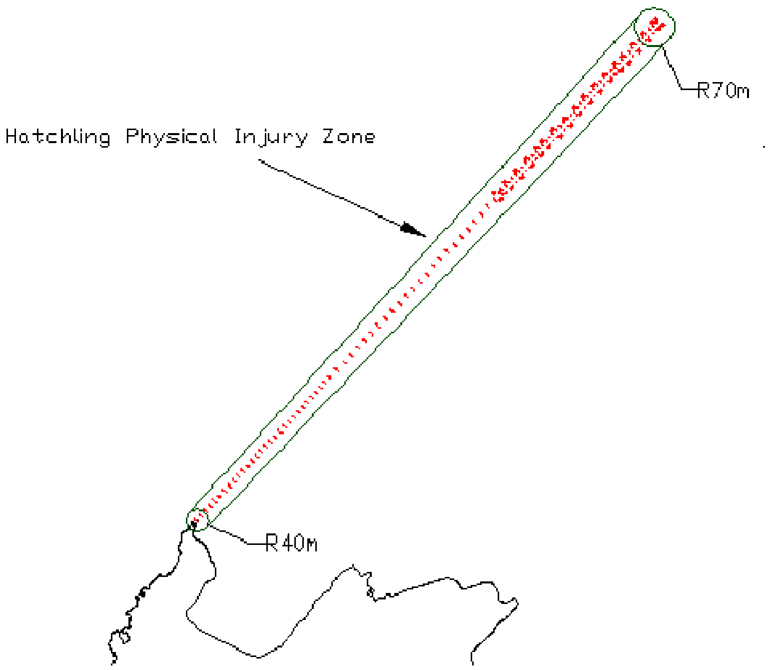

Figure 1-2 Predicted zone of possible injury for hatchlings. Zone of physical injury is a 70 m circle around each pile near the end of the jetty and 40 m for the close in piles.

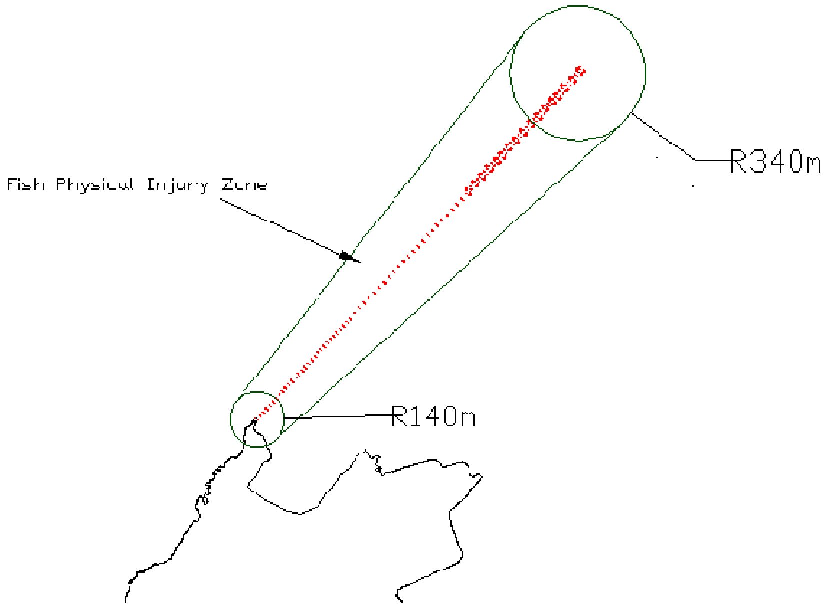

Figure 1-3 A figure showing the predicted zone of potential injury for fish. Zone of potential physical injury is a 340 m circle around each pile near the end of the jetty and a 140 m circle for close in piles.

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1. INTRODUCTION

SVT was commissioned to undertake an assessment of the underwater noise associated with the proposed pile driving activities for the Cape Lambert Port B Development. This report documents the outcomes of that assessment of underwater noise from pile driving activities associated with construction of the proposed access jetty.

1.1 Background

The recent Cape Lambert upgrade construction works involved the extension of the Port A wharf by an additional 300 m. Pile driving associated with that construction programme is completed. The Cape Lambert Port B Development will involve the construction of a new access jetty and wharf structure of approximately 2.8 km as shown in Figure 1-1.

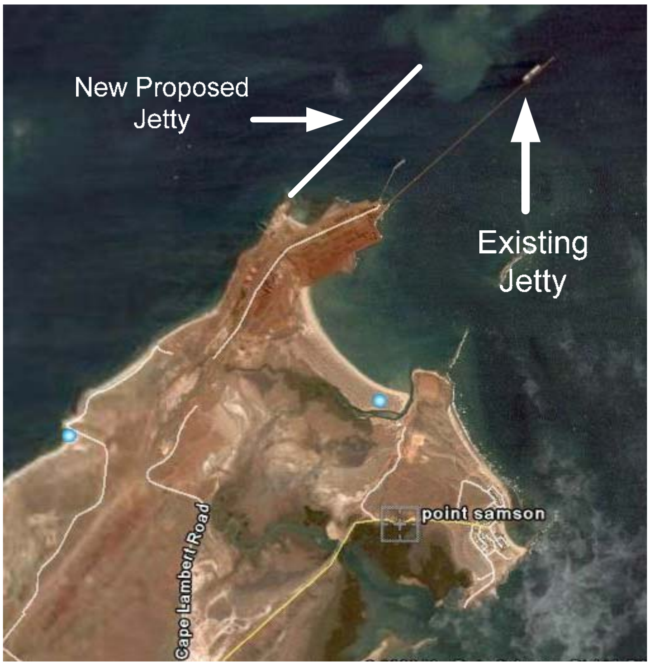

Figure 1-1 Aerial photograph showing Point Samson and the Cape Lambert Jetty

Construction of the new access jetty and wharf will involve driving piles into the seabed after which a prefabricated deck and conveyor will then be constructed on top of the piles. It is planned that three different sizes of steel pile will be used in the construction of the access jetty and wharf (1200mm and 1500mm pile diameter for the access jetty; and 1500mm and 1600mm pile diameter for the wharf).

Piles can be driven using various methods such as vibration, gravity and hammer. The method that is used is dependent on the size of the pile and the substrate into which the pile is being driven. At Cape Lambert, a large impact hammer (see Figure 1-2), which uses gravity and hydraulics to give inertia to the hammer, was used at the existing Port A wharf to drive each pile into the seabed. The noise that is generated by the hammer hitting the top of the pile is short in duration lasting approximately 90ms and can therefore be described as an impulsive noise, therefore the frequency spectrum generated is broadband and hence does not have any tonal characteristics. From field measurements it was found that the hammer strikes the pile approximately every second and it can take up to 4 hours before the pile driving operation is completed.

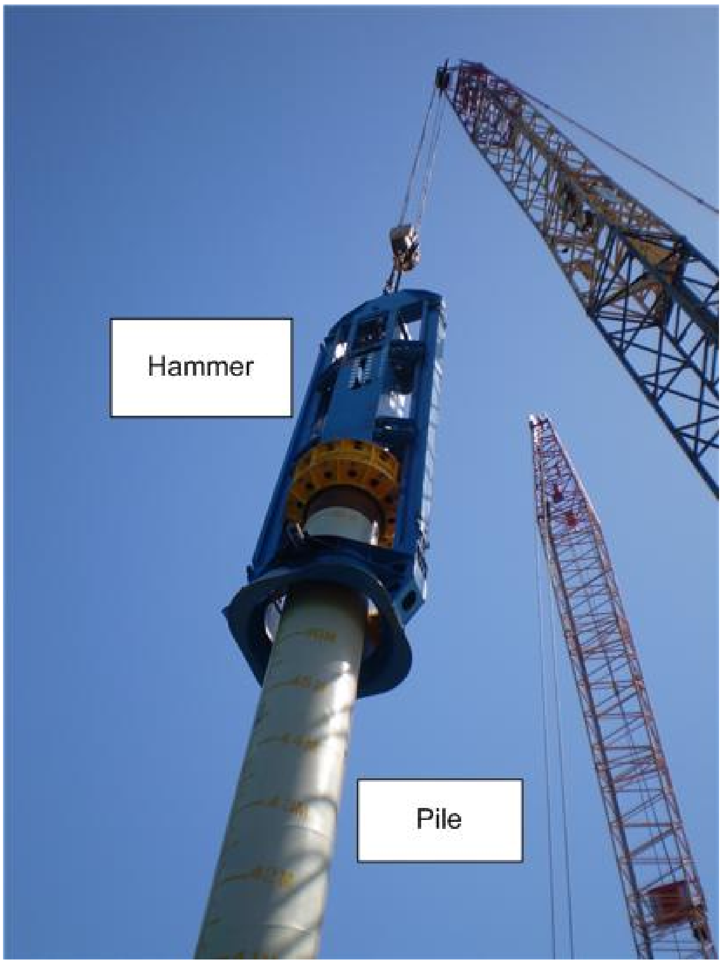

Figure 1-2 A photograph of a pile with a hammer on top (photo taken at Cape Lambert for a 1200mm steel pile).

1.2 Scope

The aim of this document is to assess the impact of underwater noise from pile driving on turtles, Humpback whales and fish associated with the Cape Lambert Port B Development.

1.3 Applicable Documents

Environmental Protection and Biodiversity Conservation Act 1999 Chapter 5, Part 13.

Shallow Water Acoustic Modelling (SWAM 99) Workshop.

2. LEGISLATION AND GUIDANCE DOCUMENTATION

2.1 Marine noise

SVT has undertaken a literature review to identify any legislation or guidance documentation on the effects of sound on turtles. The review failed to find any useful information for turtles; however, the review did find some documentation for marine mammals (Southall *et al* [9]) and fish. From the available guidance documentation for fish, there are three metrics[10], Sound Exposure Level (SEL), peak Sound Pressure Level (SPL) and fish weight that can be used when determining acceptable noise levels.

2.1.1 Peak sound pressure level

The peak sound pressure level (SPL) is defined as the maximum excursion of pressure in the sound field within one pulse. The peak pressure determines whether the ear is exposed to extreme mechanical stress. This value can be obtained from the underwater acoustic model where the transmission loss for range and depth can be estimated from the frequency spectrum entered into the model for the pile driving impulse.

2.1.2 Sound exposure level

The sound exposure level (SEL) is defined as the total energy of a single pulse normalised to 1 sec having the units Pa^2.s. The SEL is the notional level that is maintained constant for 1s and contains the same amount of acoustic energy as varying noise levels. It is used to quantify short duration noise events. This metric is therefore appropriate for impulse (short duration) waveforms such as pile driving pulses. It is expressed in dB re 1µPa^2.s. Because all SEL measurements are normalised to a one second interval, it is possible to compare the energy content of different exposures to sound. SEL is calculated[11] by summing the cumulative pressure squared of the pulse over time. To predict the SEL, knowledge of the pulse shape and spectral content is required.

2.1.3 Weight

The last metric that the guidance documentation[6] points to is the strong correlation between fish mortality from an impulse pressure wave and fish size or weight (Figure 2-1); the smaller the fish, the more susceptible it is to an impulse pressure. It can be inferred from this that turtle hatchlings will be more susceptible than adult turtles to impulse pressure waves.

Flatback[12] turtle hatchling weights can vary between 30 – 51 g (mean of 40g) which implies a no injury SEL level of 198dB re 1µPa^2s is applicable[13], where it is assumed that hatchlings will suffer the same effects as fish would when exposed to the same impulsive pressure wave.

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[9] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[10] Popper et al, Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper.

[11] $SEL = 10Log\left(t_{sample\_rate}\sum_{n=PulseBegin}^{N_{PulseEnd}}\frac{P_n^2}{P_0^2}\right)$ or $SEL = 10Log\left(\int_{t_{PulseBegin}}^{t_{PulseEnd}}\frac{P_t^2}{P_0^2}dt\right)$

[12] Flatback turtles are the dominant user of the rookeries present at Bells Beach and Cooling Water Beach at Cape Lambert.

[13] The 30 g was taken as the worst case scenario weight and the SEL is therefore based on this weight.

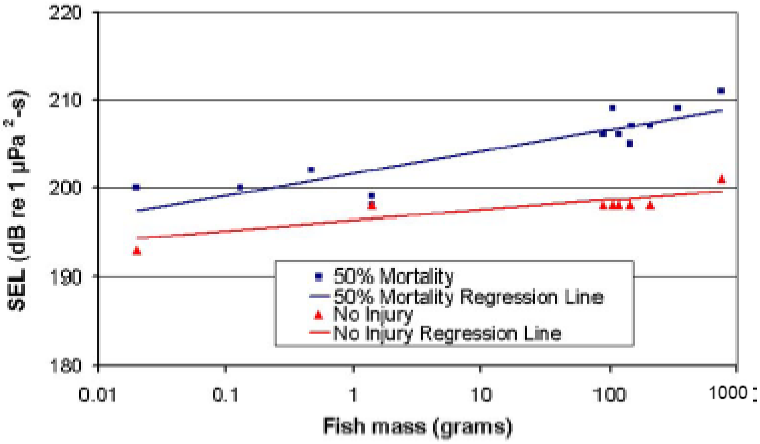

Figure 2-1: Fish mortality regression line plotted against SEL and fish mass

2.2 Conservation Status

Both the Green and Flatback turtles are classified as endangered, while the Humpback whale is classified as vulnerable according to the IUCN[14] red list.

[14] International Union for the Conservation of Nature and Natural Resources

3. BACKGROUND NOISE ASSESSMENT

3.1 Marine noise

The discussion on noise sources necessarily includes ambient noise. Ambient noise is an important feature of any underwater environment because it inherently implies acceptable levels of noise for marine animals and therefore provides some guidance as to what anthropogenic[15] noise levels might be acceptable. The ambient noise levels presented in this report are for the deep ocean.

The ocean is a noisy environment and the noisy background must be considered when evaluating the various noise sources and their impacts on the marine environment. Figure 3-1 shows that ambient noise levels are frequency dependent, with natural seismic[16] activity being in the first 10 Hz, shipping and meteorological effects like rain and wind dominate the spectrum from 10 to 100 Hz, while wave action, rain and wind dominate the spectrum up to almost 100 kHz. Above 100 kHz ambient noise is dominated by molecular thermal effects. Figure 3-1 also shows that, in the 100 to 1000 Hz band, the ambient noise for the deep ocean is estimated to be a maximum 90 dB re 1µPa/Hz, [17]. It is proposed that this noise level be accepted as a guideline for the level at which noise is expected to have little impact on a turtles hearing threshold, communications and behavioural patterns.

[15] Man made noise.

[16] Natural seismic activity refers to activities such as earthquakes and submarine volcanoes.

[17] Wenz, JASA, 34, 1936. 90 dB re 1µPa/Hz was taken as the highest ambient noise within the turtles auditory bandwidth.

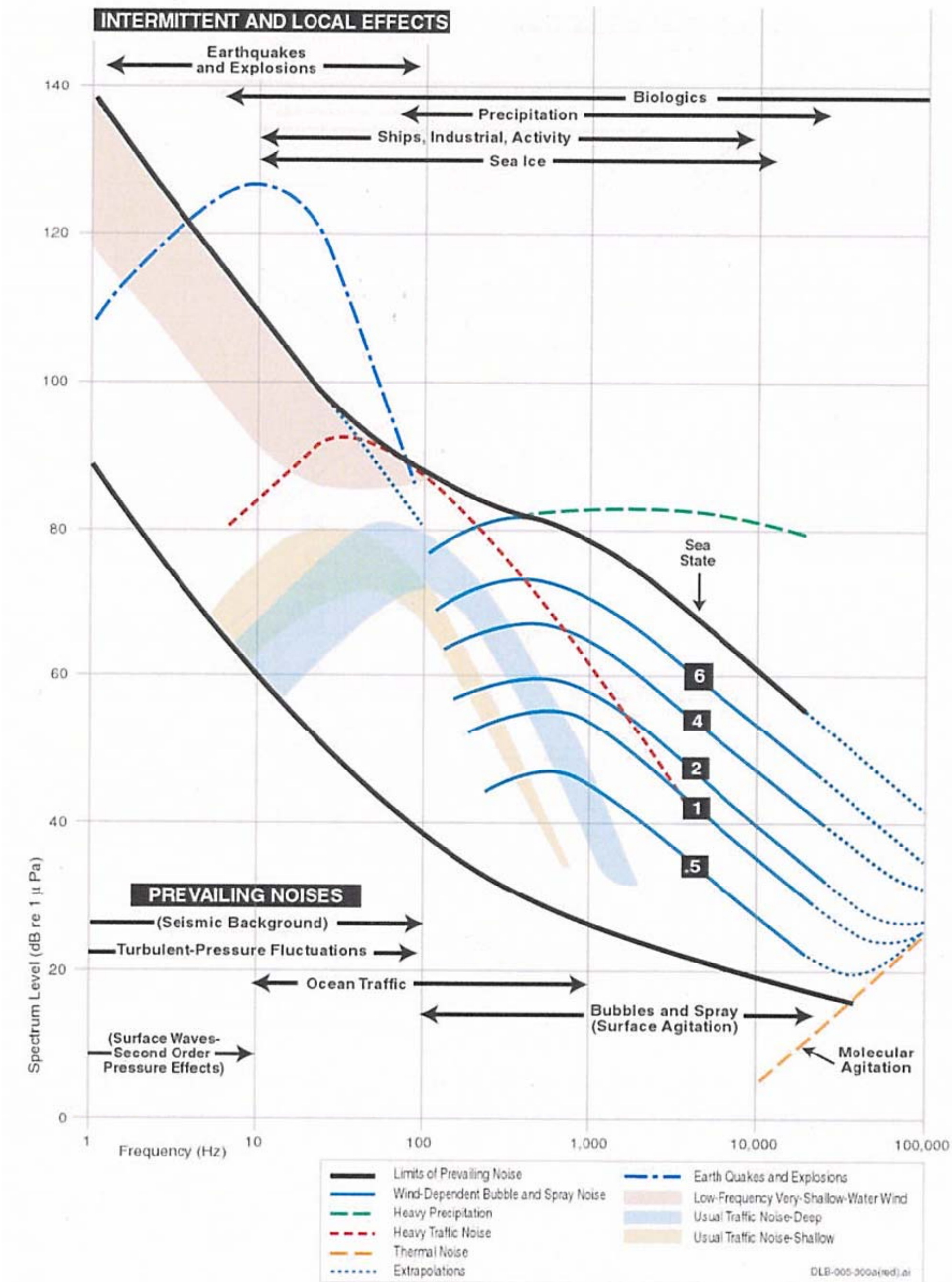

Figure 3-1 Typical deep ocean noise levels and frequencies with all noise levels given re 1m from the noise source[18].

[18] Adapted from Wenz. G.M. 1962. 'Acoustic ambient noise in the ocean: Spectra and sources'. Journal of the Acoustics Society of America 34:1936-1956.

4. UNDERWATER NOISE SOURCES FROM PILE DRIVING

4.1 Pile driving operations overview

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

The action of driving the pile into the sea bed (Figure 4-1) will excite bendy[19] waves in the pile that will propagate along the length of the pile and then into the seabed. The transverse wave component of the wave will create compression waves that will propagate into the ocean while the compression component of the bendy wave will propagate into the seabed. There will also be some transmission of the airborne acoustic wave into the sea.

It can be expected that most of the energy from the hammering action of the pile driver will transfer into the seabed. Once in the seabed, the energy will then propagate outwards as compression and shear waves. Some of the energy may be transferred into Rayleigh waves, which are seismic waves that form on the water/seabed interface, but it is expected that this will be a small portion of the total energy.

The waveform generated from a pile driving operation shows significant peak SPL. It is important to note, however, that the pulse duration and pulse rise time is longer than that of an explosion[20]. As a result, the effect of a pile driving pulse on a marine animal will not be as damaging as a pulse from an explosion of equal peak SPL.

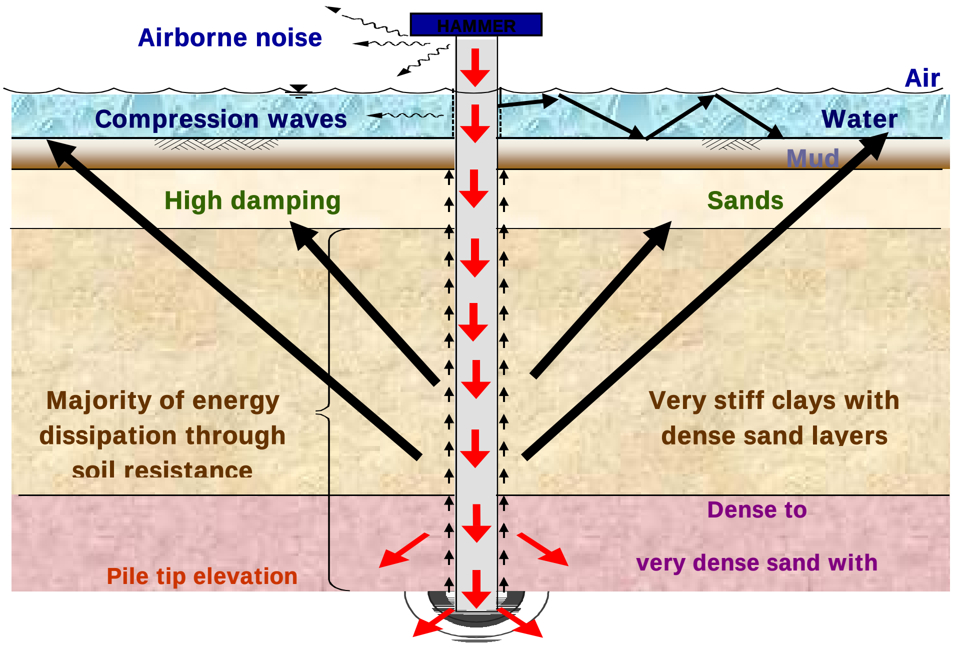

Figure 4-1: Energy transfer modes which occur when a pile is being driven into the seabed [21]

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

[20] From testing done on land animals (as well as some references to underwater explosions) it appears that most tissue damage from an explosion is as a result of the shock wave. Different tissue densities (such as muscle and bone for example) and especially air filled cavities expand and contract at different rates. This expansion and contraction can result in physical injury due to overextension of the organ or due to tearing of the tissue. This can be directly coupled to the rate of change of the pressure wave. A pile driving pulse does not have the same properties as shock wave and therefore it can be assumed that even though the peak pressure may be similar, the resulting physical injury will not be as severe.

[21] S. Theiss, “Development of Guidance on the effects of Pile Driving on Fish’, TRB ACD40, 2006

5. NOISE-SENSITIVE RECEPTORS

5.1 Marine receptors

This report considers Green and Flatback turtles, fish and the Humpback whale as the sensitive marine receptors. When evaluating the effect of sound on these marine animals, the following biological parameters need to be considered:

- physical injury
- threshold shift hearing loss
- masking and behavioural change.

It must be noted that it is difficult to evaluate the sound levels at which all these biological effects will occur. The limited research that has been done on these animals with regard to their responses to noise is insufficient to allow accurate predictions of any but the grossest impacts by noise.

5.2 Physical injury

Physical injury is defined as an injury to an animal caused by an acoustic pressure field that results in either mortality or damage to an organ of the animal. Physical injury normally occurs in a marine animal when it is exposed to a rapidly changing acoustic field. The injury is normally a result of the animal being exposed to a high peak pressure followed by a sudden drop in pressure which causes a rapid contraction and expansion of the tissue within the animal. Any change in tissue density could therefore result in physical injury when the animal is exposed to a rapidly changing pressure wave. Typically this implies that air filled cavities within the animal will be the most susceptible, while areas where tissue density changes more gradually, such as between muscle and bone will be less susceptible. Physical injury includes permanent hearing damage. Instantaneous permanent hearing damage is defined as "The complete loss of hearing due to structural damage of the animal's hearing organ". This could occur when the peak pressure is high enough to result in the hearing organ being damaged.

5.3 Threshold Shift Hearing loss

Threshold shift hearing loss can be divided into two categories namely:

- **Temporary threshold shift (TTS)**. Noise induced TTS is the reversible elevation in auditory threshold due to exposure to loud sound. The magnitude and duration of TTS is related to the level, duration, spectral distribution and temporal pattern of the stimulus[22].
- **Permanent threshold shift (PTS)**. Noise induced PTS is defined as a significant, irreversible loss of hearing threshold due to the continuous exposure to sound which may also be caused by repeated TTS's over a long period of time. PTS cannot be predicted from the degree of TTS induced in single exposure events.

[22] Kastak *et* al, 'Underwater temporary threshold shift induced by octave band noise in three species of pinniped', JASA 106(2) Aug 1999.

5.4 Masking and behavioural change.

Behavioural responses of marine animals to noise are highly variable and dependent on a suite of internal and external factors. Some internal factors can include:

- past exposure of the animal to noise
- individual noise tolerance
- demographic factors such as age and sex.

External factors can include:

- non-acoustic characteristics of the source (i.e. stationary or moving)
- environmental factors that influence sound transmission
- habitat characteristics (i.e. confined location)
- location and proximity to the shore line.

5.5 Turtles

5.5.1 Auditory sensitivity

The sea turtle's auditory canal consists of cutaneous plates underlain by fatty material 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. The extracolumella has a mushroom-shaped head which is loosely attached to the outer middle ear cavity. The extracolumella has a long shaft-like shape which extends through the middle ear and is responsible for transmitting the sound to the stapes in the auditory canal. The footplate of the stapes in turn 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 to be approximately 2 kHz and their maximum sensitivity is between 300 and 400 Hz [23]. Studies using auditory brainstem responses[24] of juvenile Green and Ridley's turtles and sub-adult Green turtles showed that juvenile turtles have a 100 to 800 Hz (Figure 5-1) bandwidth, with best sensitivity between 600 and 700 Hz,

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

[24] Some issues regarding Auditory Brainstem Response (ABR) and behavioural audiograms are as follows. The 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. SVT is unable to confirm if the sound field is measured at the head of the subject. Some other issues concerning ABR are that the subjects are often drugged. From the 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 the statistics of the sample size are not stable. Considering all the above, and knowing that there are inaccuracies in the ABR technique, SVT 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 and that there was no attenuation). This is equivalent to taking a linear weighting and not an A-weighting for the human case. This is considered a conservative approach and it is felt that it is reasonable under the circumstances.

while adults have a bandwidth of 100 to 500 Hz (Figure 5-2), with the greatest sensitivity between 200 and 400 Hz [25,26]. This indicates that a turtle's frequency and sensitivity bandwidth decreases with age.

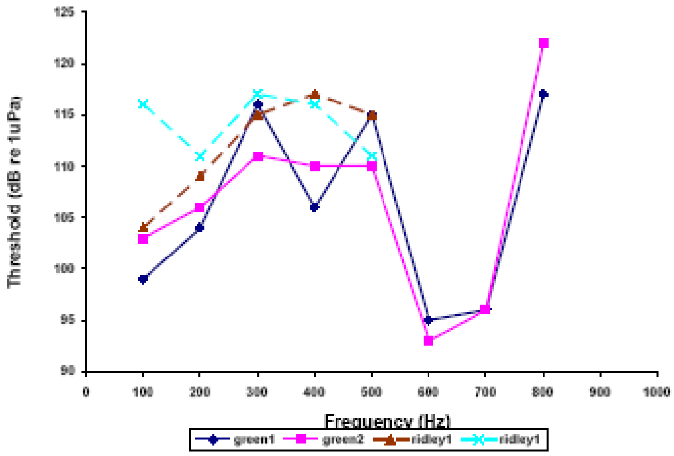

Figure 5-1: Audiograms of two juvenile green turtles and two juvenile Ridley's turtles[27]

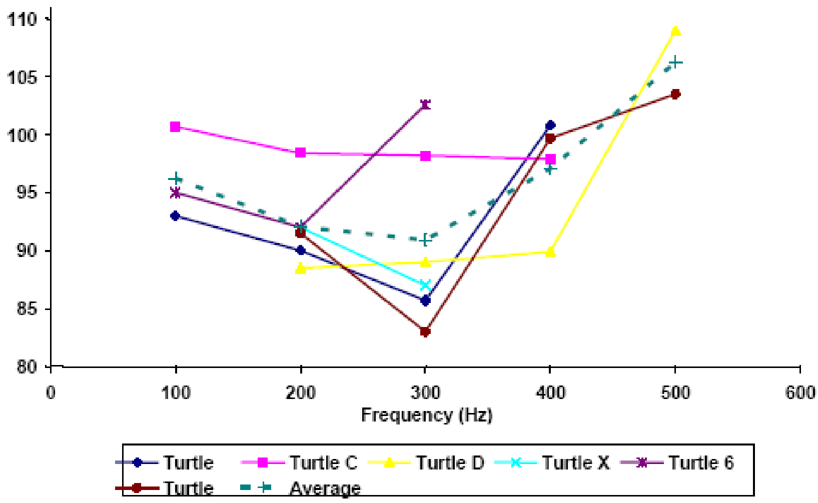

Figure 5-2: Audiograms of six sub-adult Green turtles[28]

5.5.2 Physical injury

Little is known about the source levels and associated frequencies that cause physical injury to a turtle. Some studies on the effects of explosions on turtles recommend that an empirically-based safety range be

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

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

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

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

used for guidance[29]. Using the safety range formula as noted[30] and converting back to peak SPL using Ross[31] formula, a value of 222 dB re 1µPa is obtained. Based on this SPL, a value of 222 dB re 1µPa that should not be exceeded is applied for adult turtles to avoid physical injury to the turtle.

Hatchlings will be evaluated using the SEL values for fish. As Flatback hatchling weights can vary between 30 and 51g, the SEL value for hatchlings will be taken as 198 dB re 1µPa^{2}s, assuming that hatchlings will suffer the same effects as fish exposed to a similar impulsive pressure wave. This is based on the no injury regression line in Figure 2-1[32].

5.5.3 Instantaneous permanent hearing damage

Measurements taken in 1973[33], reveal that blast pressures of 138 kPa at 26m caused damage to the eardrums of various land animals. If this pressure is extended to animals underwater, the 138 kPa level relates to an SPL of approximately 223 dB re 1µPa.

5.5.4 Threshold Hearing Loss

No supporting literature could be found to determine acceptable noise levels to prevent threshold shift in turtles.

5.5.5 Masking and behavioural change

Only limited literature could be found that shows what SPL will affect the turtles' behavioural patterns or mask their communications. Tests done on two Green and two Loggerhead turtles showed that at levels of between 166 and 175 dB (rms) re 1 µPa there was a noticeable increase in swimming behaviour which was presumed to be avoidance response[34]. As the data is very limited, it is proposed that the noise targets for TTS, PTS, masking and behavioural changes should be based on the ambient noise levels to which these animals are routinely exposed. They could be described as being habituated to at least these levels of noise. It is therefore proposed that the maximum deep ocean ambient noise level in the 100 to 1000 Hz bandwidth be used as a level of exposure at which masking and behavioural change will not occur. Using the curves in Figure 3-1 the maximum ambient noise level within the bandwidth is 90dB re 1µPa/Hz, which implies a total received noise of 120dB re 1µPa for the auditory bandwidth of a turtle. This level can be considered conservative and will be used to assess the probability of behavioural changes in turtles.

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[29] Young, G.A. 1991. Concise methods for predicting the effects of underwater explosions on marine life. NAVSWC No. 91-22. Naval Surface Warfare Centre, Silverspring, Maryland, USA.

[30] Keevan and Hempen,' THE ENVIRONMENTAL EFFECTS OF UNDERWATER EXPLOSIONS WITH METHODS TO MITIGATE IMPACTS, U.S. Army Corps of Engineers, Aug 1997.

31 D. Ross. Mechanics of underwater noise. Penisula Publishing. Los Altos. California, USA

[32] Popper *et al* (Interim Criteria for Injury of Fish to Pile Driving Operations: A White Paper) suggest a 187 dB re 1µPa2s criterion for fish. This is based on the 50% mortality line and testing done on 0.01 g fish. Considering the rationale behind the criteria it was decided to use the no mortality regression line and the weight of the turtle hatchlings.

[33] Young, G.A. 1991. Concise methods for predicting the effects of underwater explosions on marine life. NAVSWC No. 91-22. Naval Surface Warfare Centre, Silverspring, Maryland, USA.

[34] 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.

5.5.6 Correlating noise levels to biological sound effects

Based on information in the preceding sections, the following peak pressure and SEL values are of interest with regard to the effects of noise on turtles:

Effect	Pressure Level	SEL
Physical injury	222 dB re 1µPa	198dB re 1µPa^{2}s[35]
Hearing damage	222 dB re 1µPa	No Data Available
Behavioural and masking	120 dB re 1µPa	No Data Available

5.6 Humpback Whales

5.6.1 Auditory sensitivity

Whales have typical mammalian ears that consist of a middle ear and cochlea. Ears are the organs most sensitive to pressure and, therefore, to injury. Severe damage to the ears can include damage of the tympanic, fracture of the ossicles, cochlear damage, haemorrhage, and cerebrospinal fluid leakage into the middle ear.

The effects of anthropogenic noise on Baleen[36] whales is a topic of intense interest not only to marine mammalogists but also to a variety of commercial interests, the military, oceanographers, and researchers that use sound in the ocean. One issue in setting standards for noise exposure levels is the absence of knowledge of the auditory properties of Baleen whales.

Humpback whales produce a complex set of vocalised song patterns. The spectrum of the patterns has been measured to be between 20 and 24000 Hz with maximum peak to peak source level of 184dB re 1µPa @ 1m [37]. It can be assumed that this bandwidth and source level is indicative of the whales auditory bandwidth and auditory sensitivities.

5.6.2 Humpback Migration Routes and Resting Areas

The whale resting areas and migration route distances from the new jetty in Cape Lambert are given in Figure 5-3. As can be seen from the figure the closest migration route is approximately 28 km from the wharf while the resting area for females and calf's is approximately 42 km from the wharf. The resting area is also well shielded (as shown in Figure 5-3) by the Burrup peninsula.

[35] This level will be used for turtle hatchlings.

[36] The baleen whales, also called whalebone whales or great whales, form the Mysticeti, one of two suborders of the Cetacea (whales, dolphins, and porpoises).Baleen whales are characterized by having baleen plates for filtering food from water, rather than having teeth. This distinguishes them from the other suborder of cetaceans, the toothed whales or Odontoceti. The scientific name derives from the Greek word mystidos, which means "unknowable". The Humpback whale is a Baleen whale.

[37] Whitlow *et al*, 'Acoustic properties of humpback whale songs', JASA, 120(2), Aug 2006.

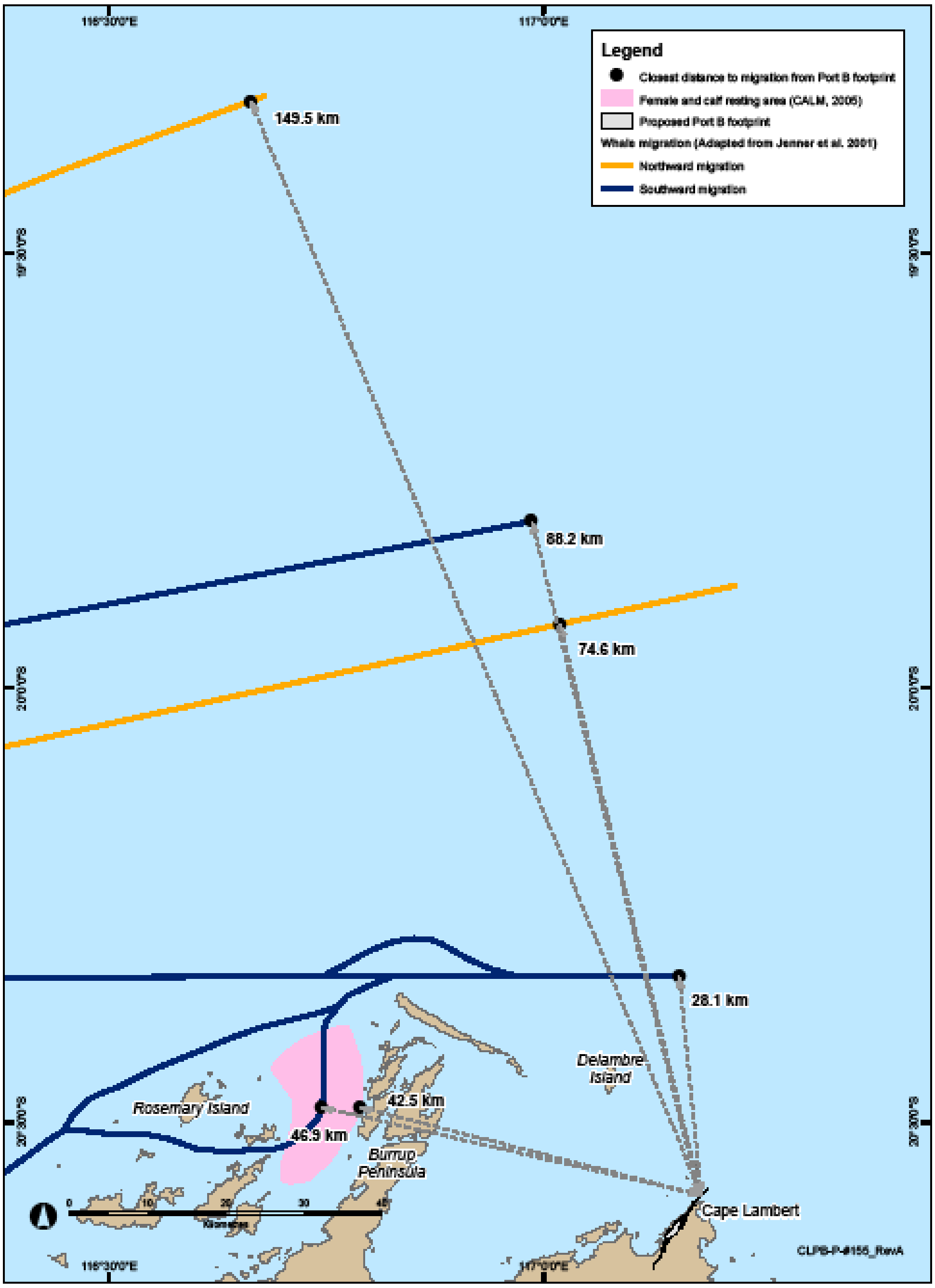

Figure 5-3: Whale resting areas and migration route distances from the new jetty

5.6.3 Assessment of Noise Impacts on Whales

The criteria that will be used for the assessment of Humpback whales are given in Table 1. They are based on the criteria recommended by Southall *et al* [38] and the EPBC Act policy statement 2.1 applicable to offshore seismic exploration activities. The following technical notes should be considered regarding the assessment criteria.

[38] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

The Southall *et al* physical injury criteria are based on experiments conducted on mid frequency mammals (i.e. beluga whales and bottlenose dolphins). Due to the lack of data for low frequency mammals (i.e. humpback whales) the data for mid frequency mammals is recommended by Southall *et al* to be used for low frequency mammals.

The avoidance criteria recommended by both Southall *et al* [39] and the EPBC Act policy statement 2.1 are based on observational data from seismic surveys. It must be noted that observational data is by no means conclusive. Additionally seismic pulses on which the criteria are based are different both in spectrum and time to that of a pile driving pulse. However, as there is no data available that can be used to determine the criteria for pile driving, the criteria for seismic surveys will be used.

Table 1 Estimated received levels at which there is a possibility of physical injury or behavioural effect for Humpback Whales.

	Possible Physical Injury	Possible Avoidance
Peak Pressure	230 dB re 1µPa[40]	224 dB re 1µPa[41]
SEL	198 dB re $1\mu Pa^2.s$[42]	160 dB re $1\mu Pa^2.s$[43]

5.7 Fish

As shown in Figure 2-1 there appears to be a correlation between noise, fish weight and possible physical injury (i.e. the smaller the fish the more susceptible they are to injury). It is therefore important to know what fish and their relatively sizes that are found within the area. It can, however, be expected that reef fish will be the most susceptible to pile noise as they are usually site bound and they will therefore suffer some loss. For assessment purposes it should therefore also be determined if any of the reef fish are endangered. The following paragraphs provide some background to the various biological factors that need to be considered when assessing the impact on fish.

5.7.1 Auditory sensitivity

Most marine fish, including seahorses and pipefish, are considered to be hearing generalists, i.e. they do not have any auditory specialisations that confer more sensitive hearing abilities upon them. As such, hearing generalist fishes are relatively poor hearers. They only hear up to approximately 1,500 Hz (as opposed to 20,000 Hz for humans) and have relatively high hearing thresholds at these low frequencies (i.e., sounds must be reasonably loud before they become audible to these fishes). By contrast, other fishes that have developed hearing specialisations (e.g. goldfish), are termed “hearing specialists.” These fishes can hear up

[39] Southall et al also considers observational data from other transient sources such as explosions.

[40] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[41] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[42] Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

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

to 4,000 Hz and have lower hearing thresholds (they are more sensitive hearers). Most hearing specialists are freshwater fish.[44]

5.7.2 Physical injury and Instantaneous permanent hearing damage

Most fish possess a swim bladder which is a gas-filled organ that is used for both communication and buoyancy. A rapidly changing acoustic field can cause the swim bladder to contract and expand suddenly, resulting in physical injury which can result in death. Limited studies by Enger, Hastings et al., and McCauley et al. have examined other 'hearing generalists'. The most relevant research was by McCauley et al[45,] which showed that pink snapper, approximately 230 mm in length, suffered permanent hearing loss when exposed to SPL of approximately 180 dB re 1µPa from an air gun.

5.7.3 Assessment of the effects on fish as a result of pile noise

It can be expected that reef fish may be found in and around the new jetty area and therefore the pile driving activities. As these fish are usually small it can be expected that they will suffer some loss due to physical injury. For this assessment the conservative levels of 187 dB re 1µPa^2.s proposed by Popper[46] will be used.

[44] Hastings, Popper,' Report on Hydro-acoustics, Bioacoustics, and noise thresholds for fish "Best Available Science", CLATRANS, Draft final report 6 Sept 2004.

[45] Robert D. McCauley, R. D., Fewtrell, J., Popper, A. N., 'High intensity anthropogenic sound damages fish ears'; JASA,, 113(1), Jan 2003.

[46] Popper et al, Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper.

6. CAPE LAMBERT UNDERWATER MEASUREMENTS

Underwater pile noise measurements were taken during pile driving activities at Cape Lambert from the 23rd to 25th April 2008. Both near field and far field measurements (see Figure 6-1) were taken of a 1600mm diameter steel pile being driven in with a Menck hammer. Near field measurements were taken on the piling barge at the pile position while a work boat was used to take the far field measurements which are indicated as buoy 1, 2, 3 and mooring buoy in Figure 6-1. The measurements were taken using a calibrated Reson TC 4032 hydrophone attached to a 30m cable. A Bruel and Kjaer Pulse system was used to record the hydrophone data with the sampling rate set at 8 kHz.

Figure 6-1 Photograph showing the pile measurement positions.

Figure 6-2 shows the measured near field pressure levels taken approximately 15.7m from a 1600mm pile. Using spherical spreading loss, Table 6-1 shows the estimated Source Level (SL) and SEL for the pile driving operation measured at Cape Lambert.

Table 6-1 Estimated Source Level (SL) and SEL values for a single pile pulse

Source Level	Estimated Value
SL_{Peak}	240 dB re 1µPa @1m
$SL_{Peak\ to\ Peak}$	242 dB re 1µPa @1m
SL_{RMS}	221 dB re 1µPa @1m
SEL for one pulse	220 dB re 1µPa^2.s @1m
SL (Turtle Bandwidth 100 to 1000Hz)	138 dB re 1µPa @1m

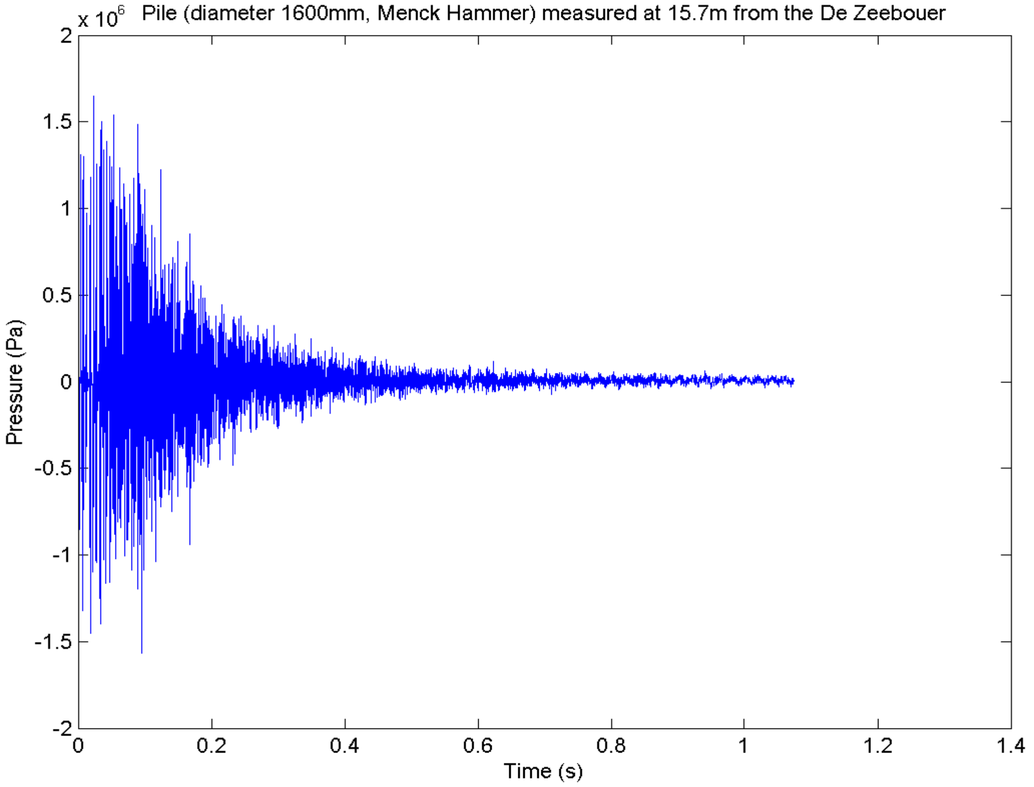

Figure 6-2 Near field measurement of a 1600mm pile.

Figure 6-3 shows the spectrogram[47] display of a received pulse at 15.7m from the pile driving operation. As can be seen from the figure, most of the acoustic energy is received within the first couple of milliseconds of the pulse.

[47] Also referred to as a waterfall time-frequency display.

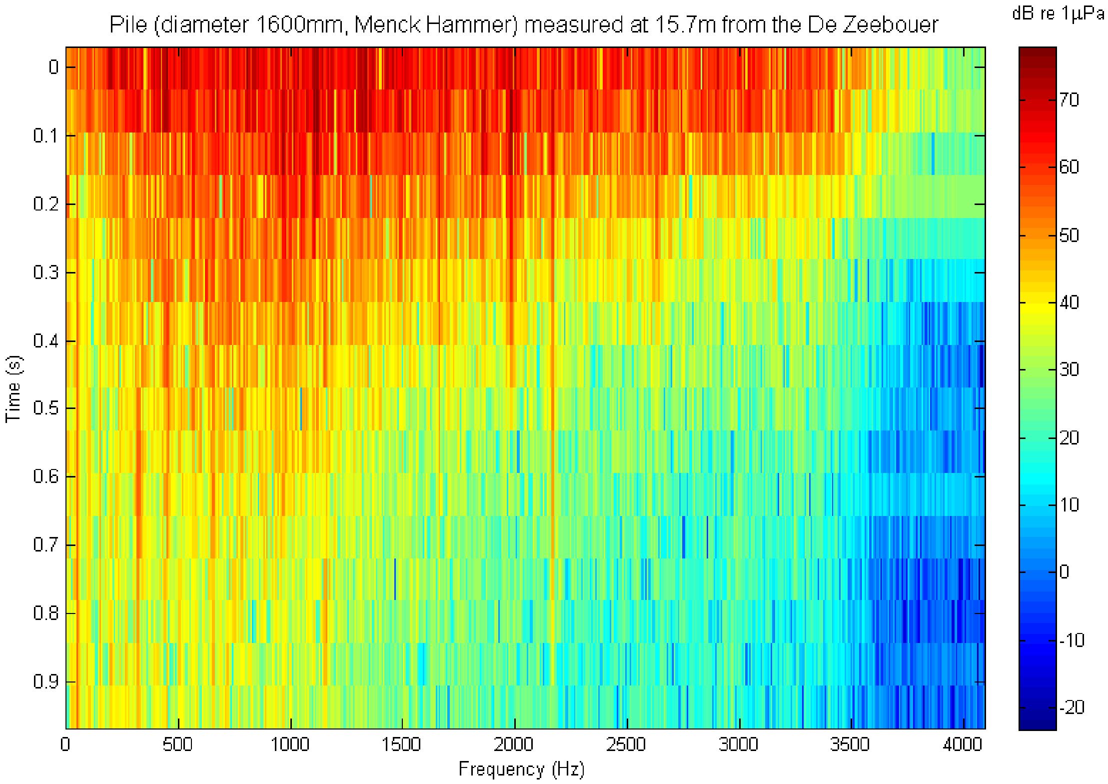

Figure 6-3 Spectrogram display showing the change of frequency content in the signal with time.

7. MODELLING METHODOLOGY

7.1 Marine noise

Underwater propagation models use bathymetric data, geoacoustic information and oceanographic parameters as inputs to produce estimates of the acoustic field at any depth and distance from the source. The quality of the model estimate is directly related to the quality of the environmental information used in the model. For example, the geoacoustic parameters of the seabed, such as compressional sound speed, sound attenuation, and sediment density, can significantly affect the acoustic propagation and can therefore affect model predictions. The seabed parameters entered into the Cape Lambert model were based on estimates obtained from core samples and seismic surveys.

7.1.1 Model selection

Four categories of acoustic propagation models are used in underwater acoustics: ray, normal mode, parabolic equation (PE) and finite element models. When determining which to use, it is necessary to define the application for which it is to be used and the type of underwater environment it is going to be modelling. For Cape Lambert, the underwater environment has:

- strong range dependence
- shallow water
- differing bottom types[48].

PE models[49] are by nature capable of making predictions in environments that are range dependent, shallow water and have changing bottom types. As a result a PE model called the Monterey Miami Parabolic Equation (MMPE) model was selected. This model was selected because it has been rigorously tested for shallow water environments[50].

7.1.2 Model Environmental Inputs

In all cases, the worst case scenario was chosen i.e. the conditions which would produce the greatest propagation of noise. As a result, all depths used in the model assume spring tide conditions (i.e. Lowest Astronomical Tide (LAT) + 6 m).

7.1.3 Model Contour Depth

As marine animals use the entire water column, the entire water column should be considered. However the acoustic pressure waves that are created in water that is restricted in depth, are complex by nature, and as

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[48] The MMPE model is a parabolic model. Shear waves are compensated for as an additional loss mechanism. This loss is compensated for no matter what the shear speed.

[49] It must be noted that PE models are limited in vertical launch angles. The launch angles of the source are limited to ±40° from the horizontal. For any angles outside of this limit, the model erroneously predicts evanescent (i.e. strongly decaying) waves. This phenomenon is due to the fact that the model predicts an imaginary propagation vector.

[50] Shallow Water Acoustic Modeling (SWAM 99) Workshop

a result the pressure values change with depth and frequency as shown in Figure 7-1 and Figure 7-2. As can be seen from Figure 7-1 the pressure fluctuates within the vertical component of the column as well as with range. If this figure is compared to Figure 7-2 (which is the same bathymetry but at 910Hz, which is within the auditory bandwidth of a juvenile turtle) it can be seen that the pressure fluctuations are different to those of Figure 7-1.

To minimise the amount of data to be presented, the following approach has been taken. The highest pressure levels can be expected to be close to the seabed as the seabed forms a reflective surface and therefore an anti-node, while the sea surface is a pressure release boundary and therefore a node. A contour taken near the seabed will therefore be the worst case scenario. It is further assumed that the turtle spends most of its time when dived at approximately 2m above the seabed. This depth has been taken as the worst case scenario for turtles. All contour plots shown are therefore for this depth above the seabed.

7.1.4 Source Levels and SEL's.

As the noise from pile driving operations is impulsive, there are two metrics that can be used in the evaluation. The first metric is the received peak pressure levels from which an assessment can be made with regards to received auditory noise by the turtle and physical injury for an adult turtle. The second metric will be Sound Exposure Level (SEL) by which the impact of the impulse on hatchlings can be assessed. Peak pressure was estimated using an empirical formulae[51].

7.1.5 Model Accuracy.

The model accuracy was determined using the far field measurements taken at the buoys marked in Figure 6-1. From the far field measurements it was found that the model is on average 12 dB accurate. The model inaccuracy can probably be attributed to error in measurement position, error in model bottom types, error in measurement position depth and error in tidal height at time of measurement. Underwater models can be between 5 and 15 dB accurate.

[51] $SPL_{peak}=SEL+10*\log(T_1/T_2)+6$ where $T_1=1s$ and $T_2=$ duration of pile pulse

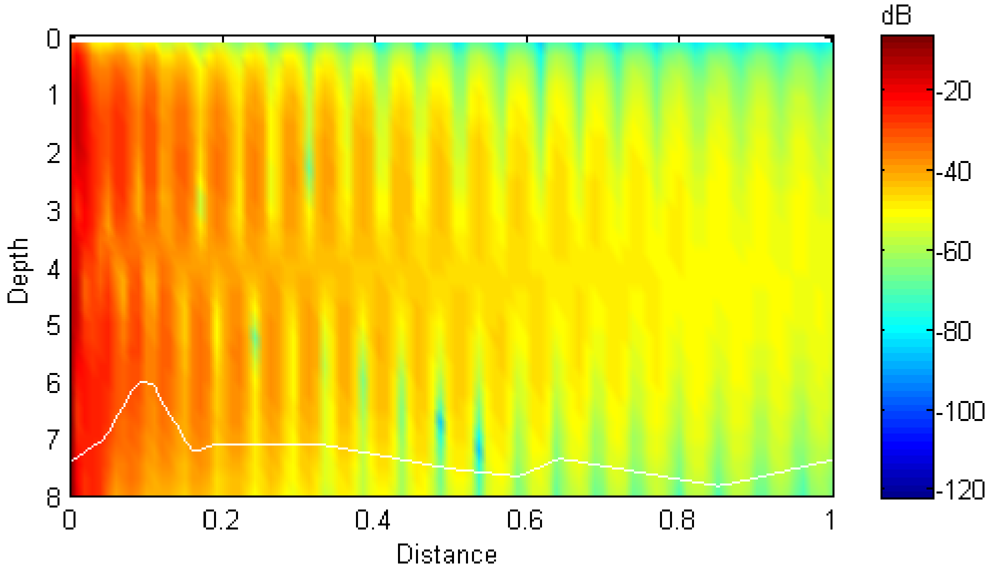

Figure 7-1 Pressure transmission loss[52] in dB's over the water column with range (0 to 1km) at 310 Hz, at Cape Lambert with relatively flat bathymetry

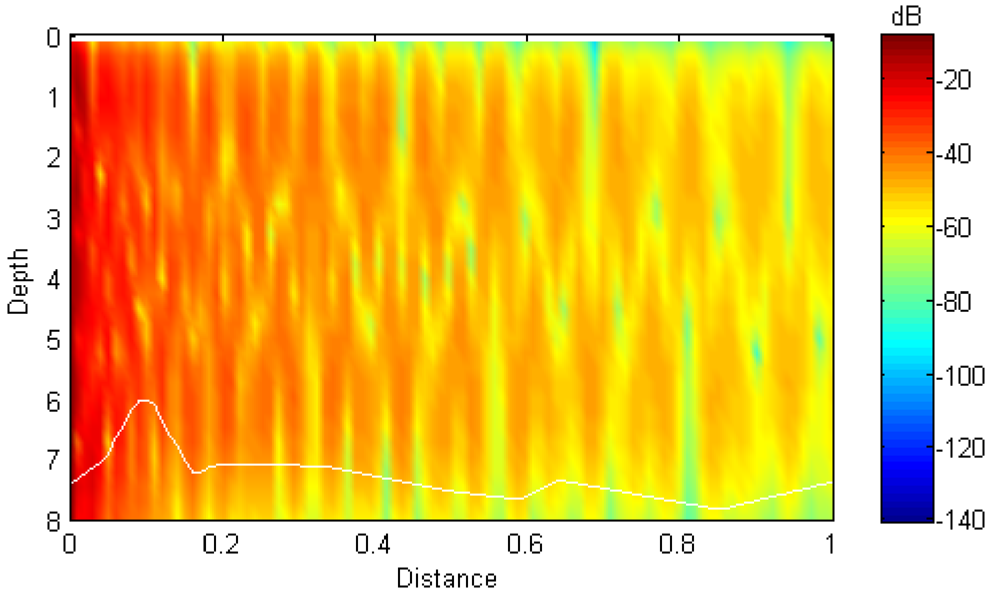

Figure 7-2 Pressure transmission loss in dB's over the water column with range (0 to 1km) at 910 Hz, at Cape Lambert with relatively flat bathymetry

[52] Transmission Loss (TL) is defined as: $TL = 10Log\left(\frac{I_{receiver}}{I_{SL@1m}}\right)[dB]$

8. MODELLING RESULTS

The model was run for various pile positions. A sample of these positions (i.e. one close to the shore, one half-way along the new access jetty and one near the end of the new access jetty at the wharf end) is provided. The seabed entered into the model was based on geotech data taken in close proximity to the proposed new wharf. From this data the seabed was found to consist of predominantly fine sand, course sand and Calcanerite and coral. The estimated geoacoustic properties of the seabed are shown in Table 8-1. Small rocky outcrops were also evident. As the water depth is relatively shallow and no CTD data was available it was assumed that the waters in the area are isothermal.

Table 8-1 Geoacoustic properties of the seabed at Shark Bay

Seabed Type	Sound speed ($m\ s^{-1}$)	Density ($g\ cm^{-3}$)	Attenuation ($dB\ m^{-1}\ kHz^{-1}$)	Shear Speed ($m\ s^{-1}$)
Calcanerite	1650	2.001	1.581	1500
Gravely Sand	1708	2.008	1.01	
Medium Sand	1774	2.05	0.374	

Pile driving operations are relatively discrete events. This implies that normally one or two piles are driven in simultaneously. This is dependent on the number of barges that are available for construction. In reality even if there are multiple barges they will seldom drive a pile in at exactly the same time and if they do, the overlap is generally short. As a result, pile operations are modelled as discrete events and their cumulative sum is not considered.

8.1.1 Close In Pile Operation

Figure 8-1 and Figure 8-2 show the predicted sound exposure level (SEL) for a single pile pulse from a close-in pile driving operation. As can be seen from Figure 8-2 the 160 dB re 1µ Pa^2.s contour is well outside the whale migration routes.

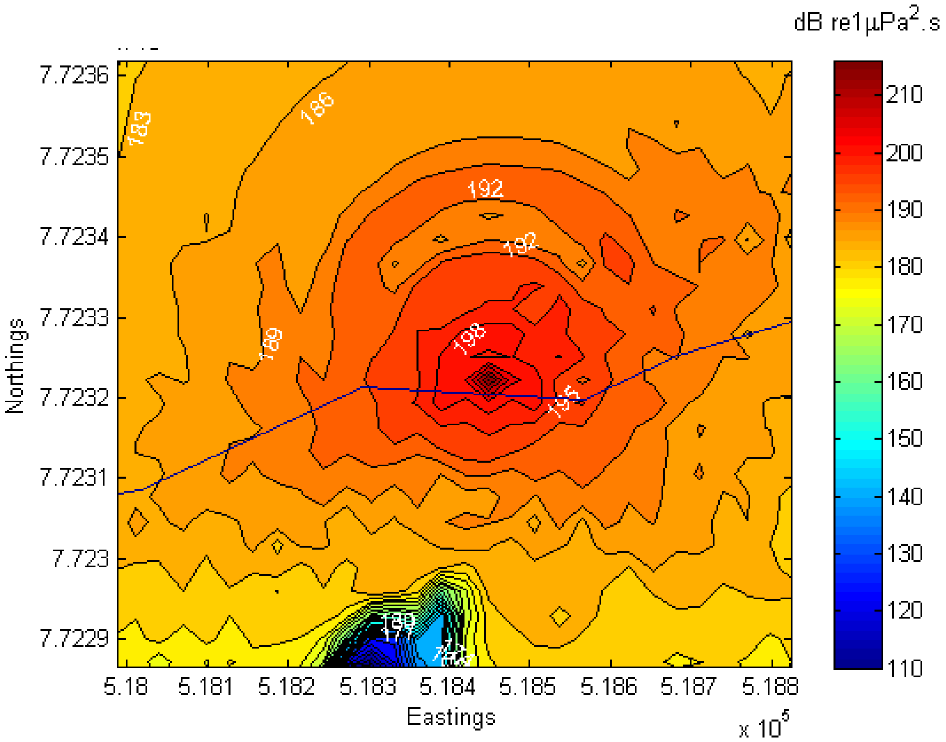

Figure 8-1 Contours showing a zoomed in view of the received SEL at 2m above the seabed of a close in pile driving operation.

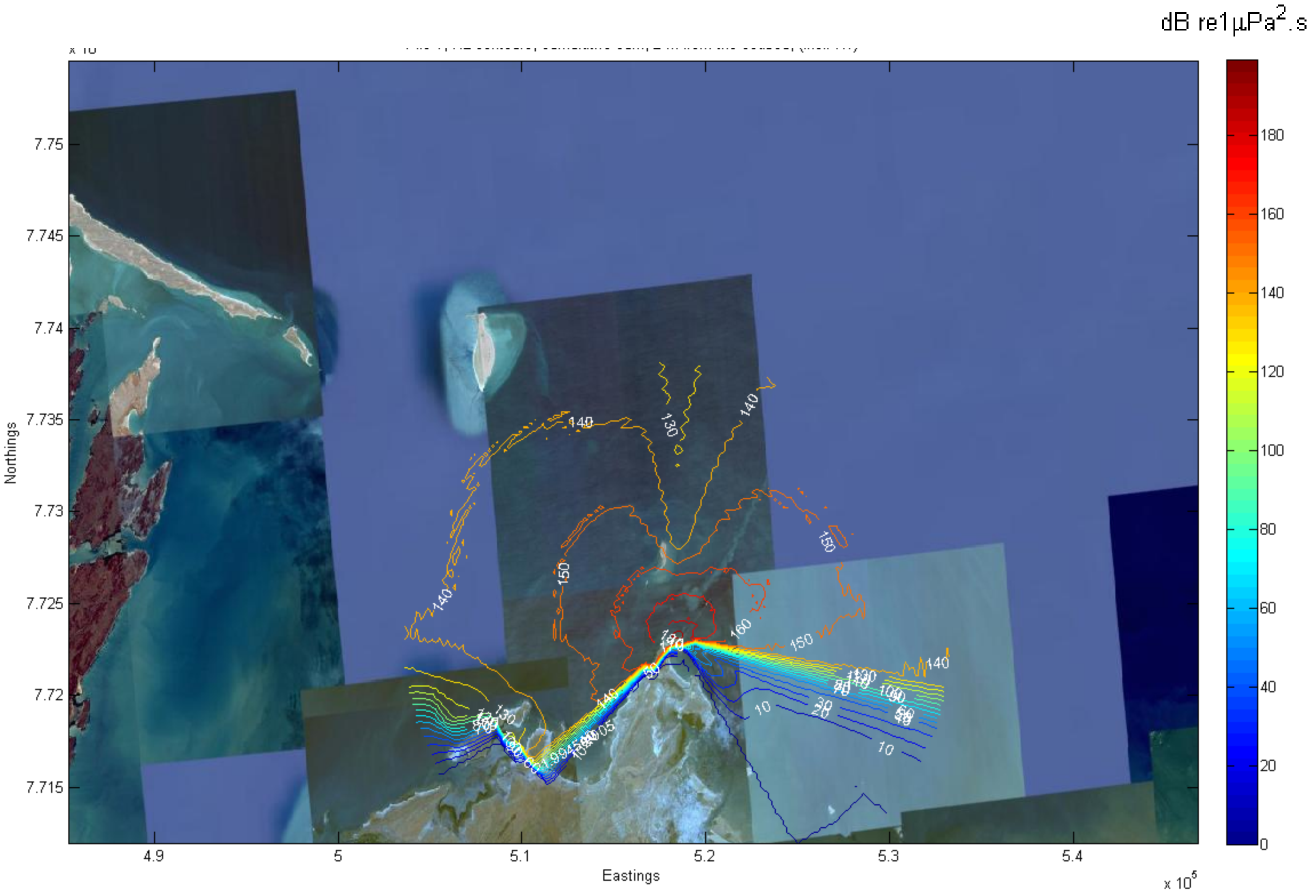

Figure 8-2 Contours showing the predicted SEL at 2m above the seabed for a single pile pulse from a close in pile driving operation

8.1.2 Pile driving operation midway along the jetty.

Figure 8-3 and Figure 8-4 show the predicted sound exposure level (SEL) for a single pile pulse from a midway pile driving operation. As can be seen from Figure 8-4 the 160 dB re 1µ Pa^2.s contour is well outside the whale migration routes.

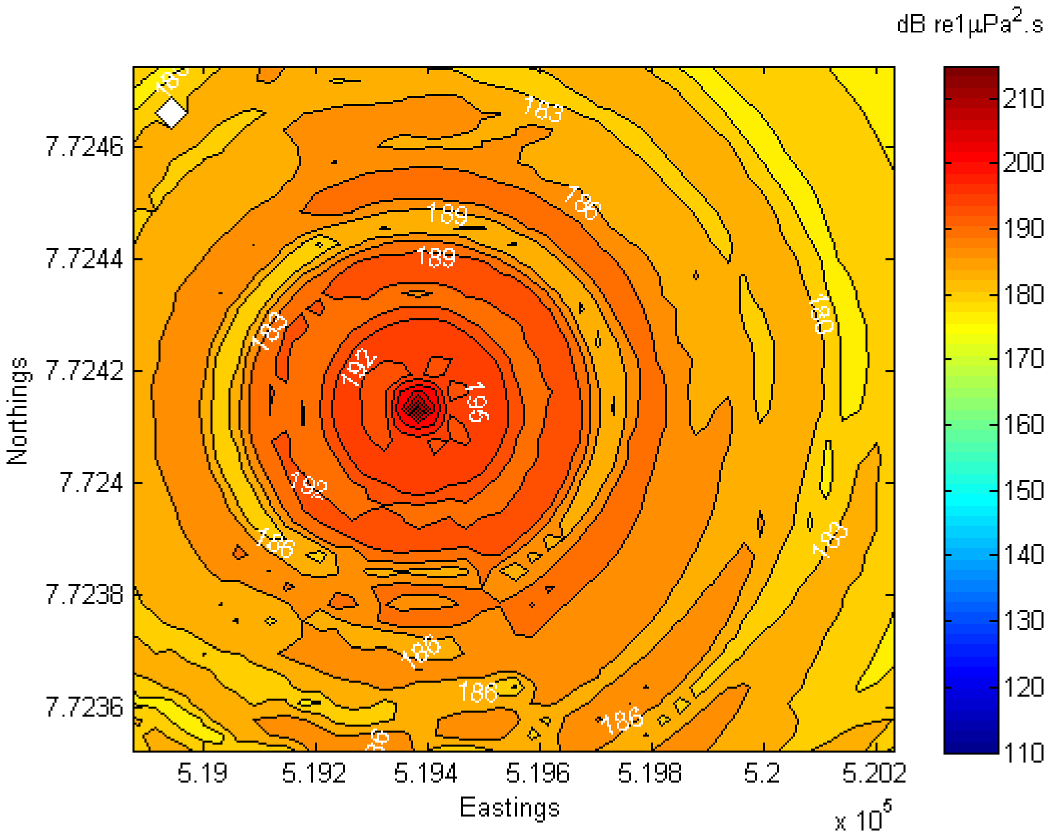

Figure 8-3 Contours showing the received SEL at 2m above the seabed from a midway pile driving operation

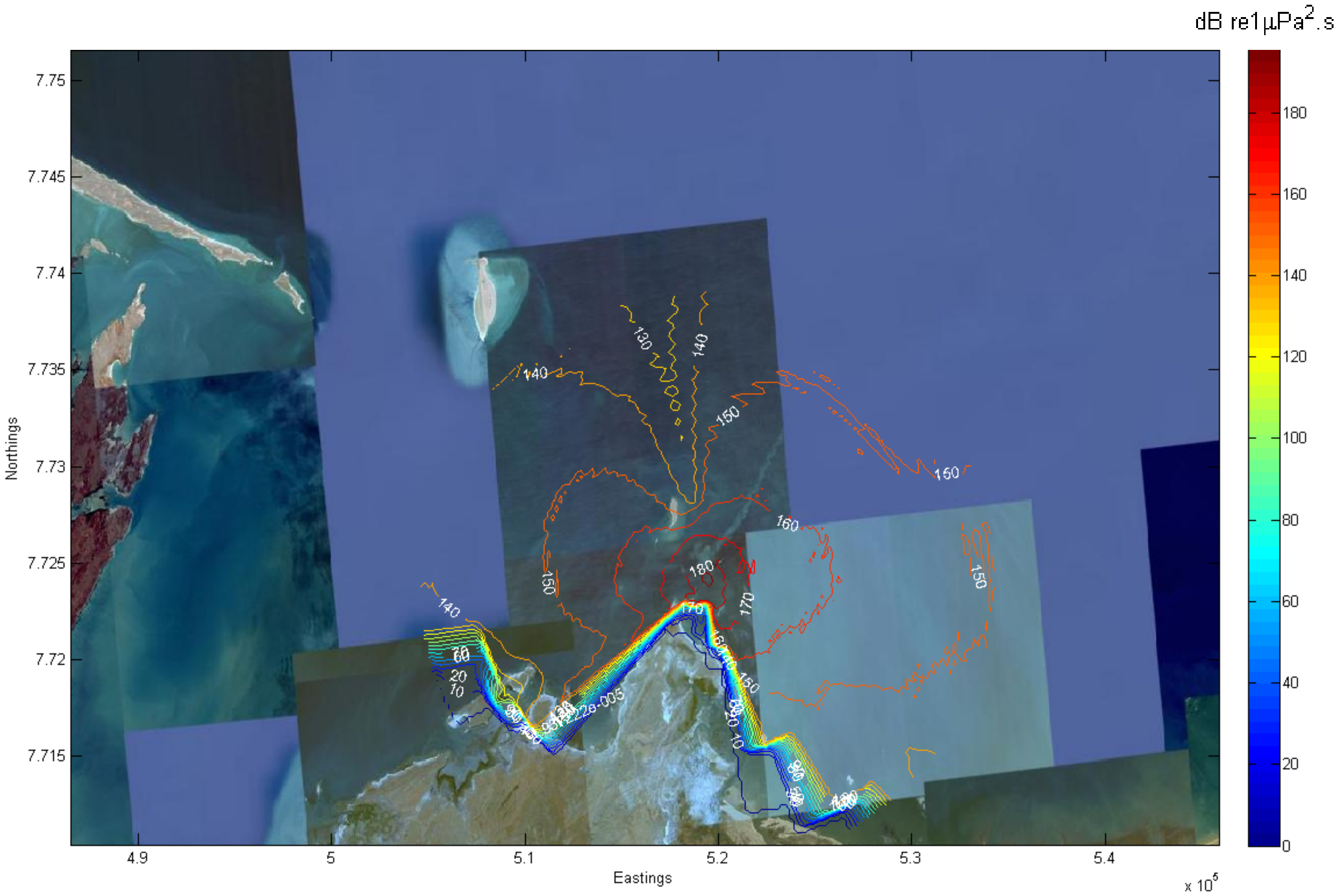

Figure 8-4 Contours showing the predicted SEL at 2m above the seabed from a midway pile driving operation

8.1.3 Pile driving operation at the end of the jetty.

Figure 8-5 and Figure 8-6 show the predicted sound exposure level (SEL) for a single pile pulse from an end of the jetty pile driving operation. As can be seen from Figure 8-6 the 160 dB re 1µ Pa^2.s contour is well outside the whale migration routes.

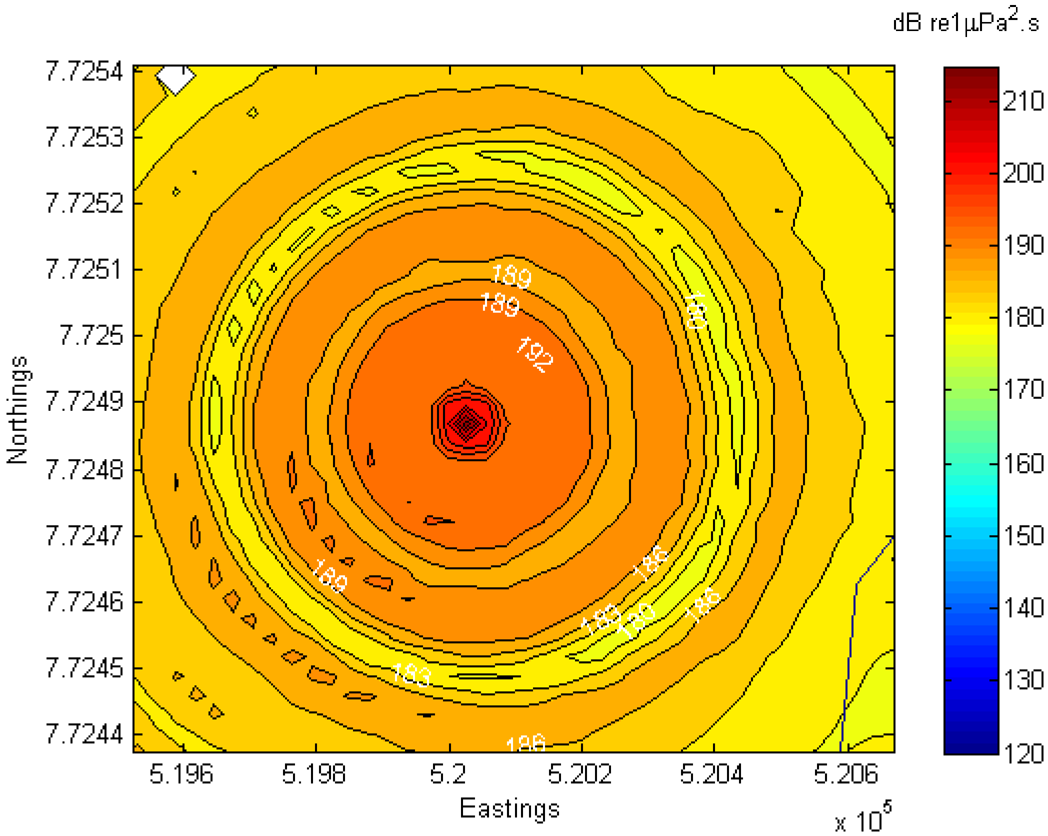

Figure 8-5 Contours showing the received SEL levels at 2 m above the seabed of a end-of-jetty pile driving operation.

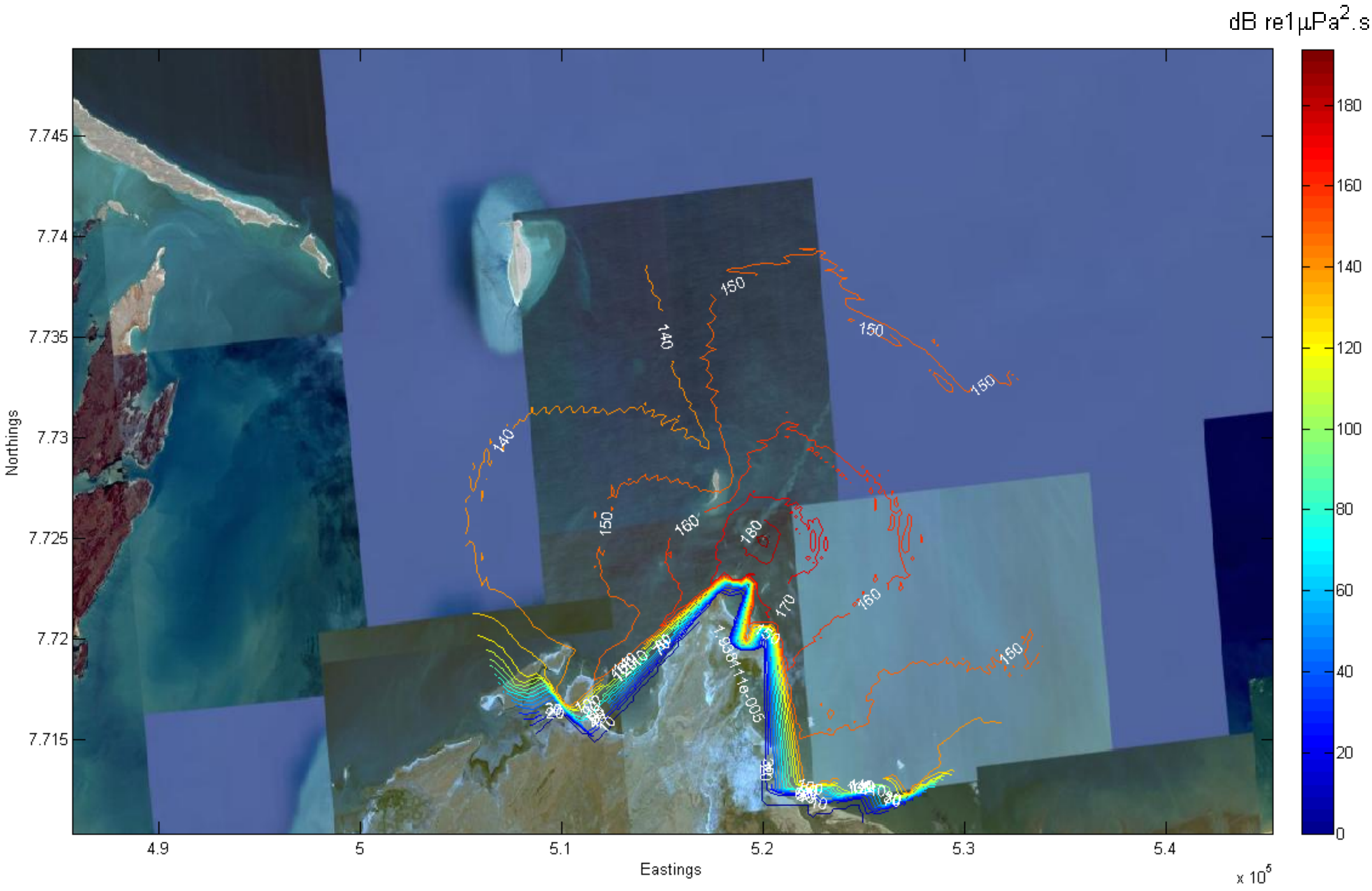

Figure 8-6 Contours showing the predicted SEL at 2m above the seabed from a end-of-jetty pile driving operation

8.1.4 Zones of physical/hearing damage and avoidance

Figure 8-7 shows the zone of potential physical damage and the zone of possible avoidance for adult turtles. Figure 8-8 shows the predicted zone of potential physical injury for hatchling turtles. These zones are based on the 222 dB re 1µPa for physical injury and 120 dB re 1µPa (at 300 Hz) for behavioural and masking levels for adult turtles and the 198 dB re 1µPa^{2}s for potential physical damage for turtle hatchlings. The zone for physical injury is based on a SEL of 187 dB re 1µPa^{2}s.

Pile operations are discrete events and therefore the zones shown in these figures are not continuous zones, but are an accumulation of all the piling events that are to take place in the area. Each pile can therefore be separated into a circle of physical injury and a circle of avoidance.

The circles of potential physical injury for adult turtles ranges from 20 m for piling operations close to shore to 30 m for pile driving operations at the end of the jetty and the zone of avoidance ranges from 300m to 400m as shown in Figure 8-7. The following conclusions can be drawn from this figure for adult turtles:

1. It is assumed that pile operations will not prevent turtles from nesting on Cooling Water Beach.
2. A 30 m circle around each pile needs to be cleared from all turtles before pile driving operations start (once they have started it can be assumed that the turtle will avoid the area).

The circles of potential physical injury or hearing damage for hatchling turtle's ranges from 40 m for piling operations close to shore to 70 m for pile driving operations as shown in Figure 8-8. It is assumed that the hatchling turtles will not avoid any noise sources as their swimming patterns will primarily be dictated by tides and currents. The following conclusion can be drawn from this figure:

1. The tide and current at the time when the hatchlings take to the sea and the location where the piles are being driven in will determine if the hatchlings will enter the zone of possible physical injury.

The circles of potential physical injury or hearing damage for fish ranges from 140 m for piling operations close to shore to 340 m for pile driving operations as shown in Figure 8-9. It must be remembered that these ranges are based on the conservative levels proposed by *Popper*[53] for very small fish. The ranges will decrease for larger the fish.

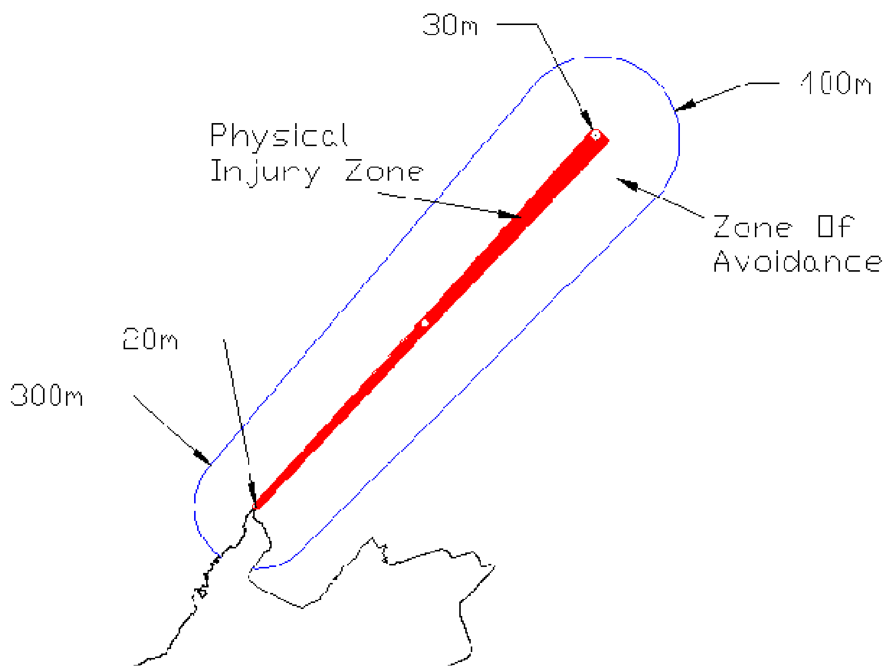

Figure 8-7 A figure showing the adult turtles and juvenile turtles predicted zones of avoidance and potential physical injury. Zone of potential physical injury is a 25m circle around each pile near the end of the jetty and a 10m circle around each close in pile. The zone of avoidance is a 400m circle at the end of the jetty and a 300m circle for the close in piles.

[53] Popper et al, Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper.

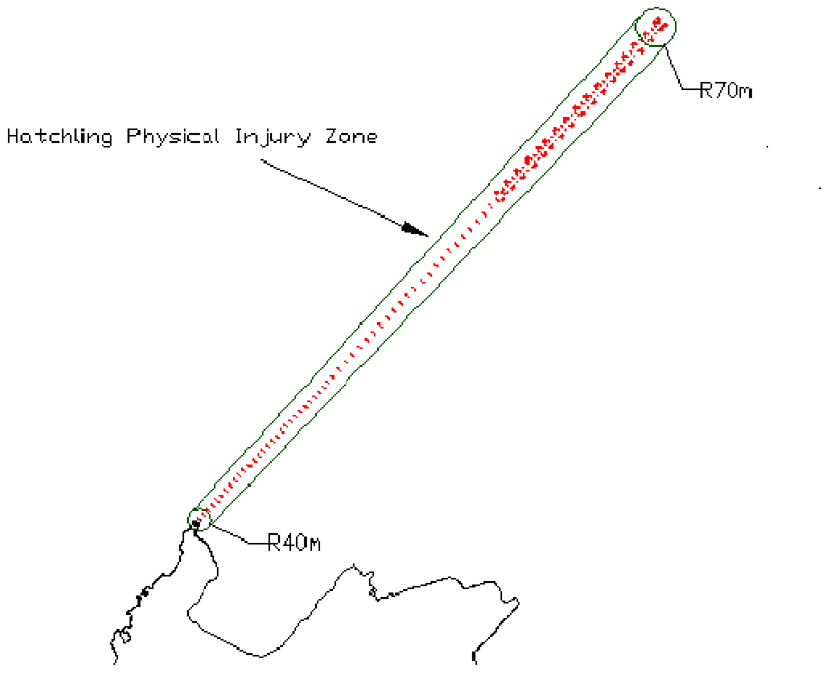

Figure 8-8 A figure showing the hatchling predicted zone of potential injury. Zone of potential physical injury is a 70 m circle around each pile near the end of the jetty and a 40 m circle for close in piles.

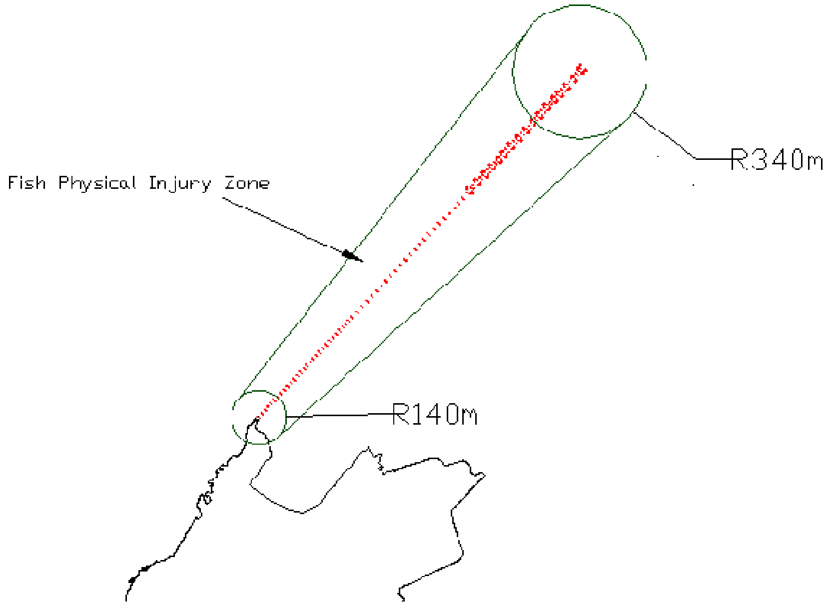

Figure 8-9 A figure showing the predicted zone of potential injury for fish. Zone of potential physical injury is a 340 m circle around each pile near the end of the jetty and a 140 m circle for close in piles.