Ichthys Gas Field Development Project

Potential Effects of Underwater Blasting, Piledriving and Dredging on Sensitive Marine Fauna in Darwin Harbour

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Prepared for

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Abbreviations

Abbreviation	Description
dB	deciBel
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
EIS	Environmental Impact Statement
EPBC Act	*Commonwealth Environment Protection and Biodiversity Conservation Act 1999*
HE	high explosive
Hz	Hertz
INPEX	INPEX Browse, Ltd
Kg	kilogram(s)
LNG	liquefied natural gas
kHz	kiloHertz
LPG	liquefied petroleum gas
MMbbl	million barrels
M	metre(s)
Mm	millimetre(s)
Ms	millisecond(s)
NEQ	net explosive quantity
NMFS	National Marine Fisheries Service
Pa	Pascal
PCAD	Population Consequences of Acoustic Disturbance
RAN	Royal Australian Navy
RL	received level
RMS	root mean square
SEL	sound exposure level
SPL	sound pressure level
SSDP	Southern Seawater Desalinisation Project
Tcf	trillion cubic feet
TNT	trinitrotoluene
TTS	temporary threshold shift
TPWC Act	*Northern Territory Parks and Wildlife Conservation Act 2005*
URS	URS Australia Pty Ltd
WAWC	Western Australian Water Corporation
µ	micro

Executive Summary

For the Ichthys Gas Field Development Project (the Project), a two train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site zoned for development on Blaydin Point on Darwin Harbour. Construction of facilities in the nearshore development area will disturb areas of seabed and emit noise in Darwin Harbour, and some of the shoreline area of Blaydin Point and Middle Arm Peninsula, as described within the Draft Environmental Impact Statement (Draft EIS).

Darwin Harbour contains an operational port that already generates underwater noise from a variety of sources and activities. Many of the existing facilities were constructed and currently operate in a manner similar to the proposed development of the nearshore Project area by INPEX. The key Project activities that are likely to produce noise emissions significantly different or louder than current port activities are pile driving and drilling and blasting operations.

Blasting in the nearshore development area may be required where high strength rock is encountered that cannot be removed by dredging at Walker Shoal. INPEX is currently investigating the technical feasibility of alternatives to blasting for the removal of hard rock material. If blasting is required for the removal of Walker Shoal, it will be undertaken using the “confined” blasting (i.e. drill-and-blast) method, which involves drilling small holes in the rock with charges placed and connected in the holes for subsequent surface firing. To provide context, a number of alternatives to blasting have also been considered.

Darwin Harbour contains a number of variables that make underwater noise modelling difficult. Each of these listed factors adds a degree of uncertainty to predictions of underwater noise:

- shallow water
- variable water depth caused by the large (8 m) tidal range
- naturally occurring noise generated by the large water flow caused by tidal movements, particularly during spring tides
- variable bottom type, which affects the reflection and absorption of noise
- variable salinity, seasonally and between the arms and main body of the harbour
- proximity and volume of existing anthropogenic noises
- local weather conditions, such as thunderstorms with heavy precipitation, which also produce underwater noise.

Modelling of underwater noise propagation has accommodated the uncertainties in source data and information by; firstly identifying the uncertainties, secondly incorporating conservative assumptions at each stage of the modelling process, and finally by including sensitivity analyses.

This report also presents a synopsis of the latest available, contemporary research, policies and field experiences and present guidance concerning the evaluation and management of blast and in-water noise and its implications for potentially sensitive marine fauna, in the context of the INPEX’s proposed marine construction works in Darwin Harbour.

Several groups of animals or individual species in Darwin Harbour are of particular concern in terms of underwater noise potentially generated by anthropogenic activities. These are species that are of high conservation value, such as protected fauna, and important commercial and recreational fishery species. The key groups and species in Darwin Harbour are:

- three species of coastal dolphin, the Australian snubfin (*Orcaella heinsohni*), the Indo-Pacific humpback (*Sousa chinensis*) and the Indo-Pacific bottlenose (*Tursiops aduncus*)
- dugongs (*Dugong dugon*)

- six species of marine turtle: the green turtle (*Chelonia mydas*), flatback turtle (*Natator depressus*), hawksbill turtle (*Eretmochelys imbricata*), loggerhead turtle (*Caretta caretta*), leatherback turtle (*Dermochelys coriacea*) and the olive Ridley turtle (*Lepidochelys olivacea*)
- fish.

The blasting of Walker Shoal as envisaged by INPEX, will expose potentially sensitive marine fauna to some level of noise and blast-induced risk. Given the size, placement and intended method of employment of the charges, there is unlikely, however, to be any substantive risk, and less so a 'significant' risk of injury. What inherent risk does exist will be attenuated to a significant extent by INPEX's intended risk mitigation measures. The blast effects which may cause injury will be confined to a relatively small zone.

Where risk does exist is more within the realm of behavioural disturbance related to noise from the detonations and pile driving, which would be made more acute as the blasting and pile driving programs may be extended in duration. This may manifest as one of three observed results, or perhaps a combination, namely:

- habituation by fauna of perceived sensitivity
- behavioural modification, possibly including periodic or temporary avoidance of the affected area
- permanent abandonment of the affected area.

The latter is considered the least likely outcome, given that Darwin's history of development as a trading port over the last century or so has seen numerous events and activities, including dredging campaigns, port developments involving extended pile driving programs, intense cyclonic events and other significant incidents which have included in-water explosive detonations. Despite all of these stimuli, dolphins, dugongs and other marine fauna of interest continue to reside within Darwin Harbour. This suggests a degree of tolerance or resilience.

The contention that sensitive fauna in Darwin Harbour are unlikely to be affected to any enduring degree is supported, albeit anecdotally, by observations from other similar harbour environments. For example, Cockburn Sound, near Perth, is also a major port which has been developed via a progressive program of dredging, rock blasting and pile driving. Nevertheless, the Sound supports a viable population of closely studied and monitored dolphins (*Tursiops aduncus*), with no observed impact upon this resident dolphin population evident, either within the available literature or anecdotally.

Introduction

1.1 Background

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field in the Browse Basin at the western edge of the Timor Sea about 200 km off Western Australia's Kimberley coast. The field is about 850 km west south west of Darwin, Northern Territory and encompasses an area of approximately 800 km^2 (out of the 3041 km^2 in the permit area) with water depths ranging from 90 to 340 m (Figure 1-1).

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 million barrels (MMbbl) of condensate. INPEX will process the gas and condensate to produce liquefied natural gas (LNG), liquefied petroleum gas (LPG) and condensate for export to overseas markets.

For the Ichthys Gas Field Development Project (the Project), a two train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site zoned for development on Blaydin Point on Darwin Harbour. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

Construction of facilities in the nearshore development area will disturb areas of seabed and emit noise in Darwin Harbour, and some of the shoreline area of Blaydin Point and Middle Arm Peninsula, as described within the Draft Environmental Impact Statement (Draft EIS).

Darwin Harbour contains an operational port that already generates underwater noise from a variety of sources and activities. Many of the existing facilities were constructed and currently operate in a manner similar to the proposed development of the nearshore Project area by INPEX. The key Project activities that are likely to produce noise emissions significantly different or louder than current port activities are pile driving and drilling and blasting operations.

Modelling of underwater noise by the Project was not undertaken in the Draft EIS by INPEX (2010). Nevertheless, well established principles of underwater noise and impulse propagation were used to assess potential effects on INPEX's proposed activities. As a result of further engineering investigations and analyses, blasting intentions have evolved since the drafting of the supporting literature review (URS 2009) and the Draft EIS public comment period, and again since then.

Blasting in the nearshore development area may be required where high strength rock is encountered that cannot be removed by dredging at Walker Shoal. INPEX is currently investigating the technical feasibility of alternatives to blasting for the removal of hard rock material. If blasting is required for the removal of Walker Shoal, it will be undertaken using the "confined" blasting (i.e. drill-and-blast) method, which involves drilling small holes in the rock with charges placed and connected in the holes for subsequent surface firing. To provide context, a number of alternatives to blasting have also been considered.

Darwin Harbour contains a number of variables that make underwater noise modelling difficult. Each of these listed factors adds a degree of uncertainty to predictions of underwater noise:

- shallow water
- variable water depth caused by the large (8 m) tidal range
- naturally occurring noise generated by the large water flow caused by tidal movements, particularly during spring tides
- variable bottom type, which affects the reflection and absorption of noise

1 Introduction

- variable salinity, seasonally and between the arms and main body of the harbour
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- local weather conditions, such as thunderstorms with heavy precipitation, which also produce underwater noise.

Modelling of underwater noise propagation has accommodated the uncertainties in source data and information by; firstly identifying the uncertainties, secondly incorporating conservative assumptions at each stage of the modelling process, and finally by including sensitivity analyses.

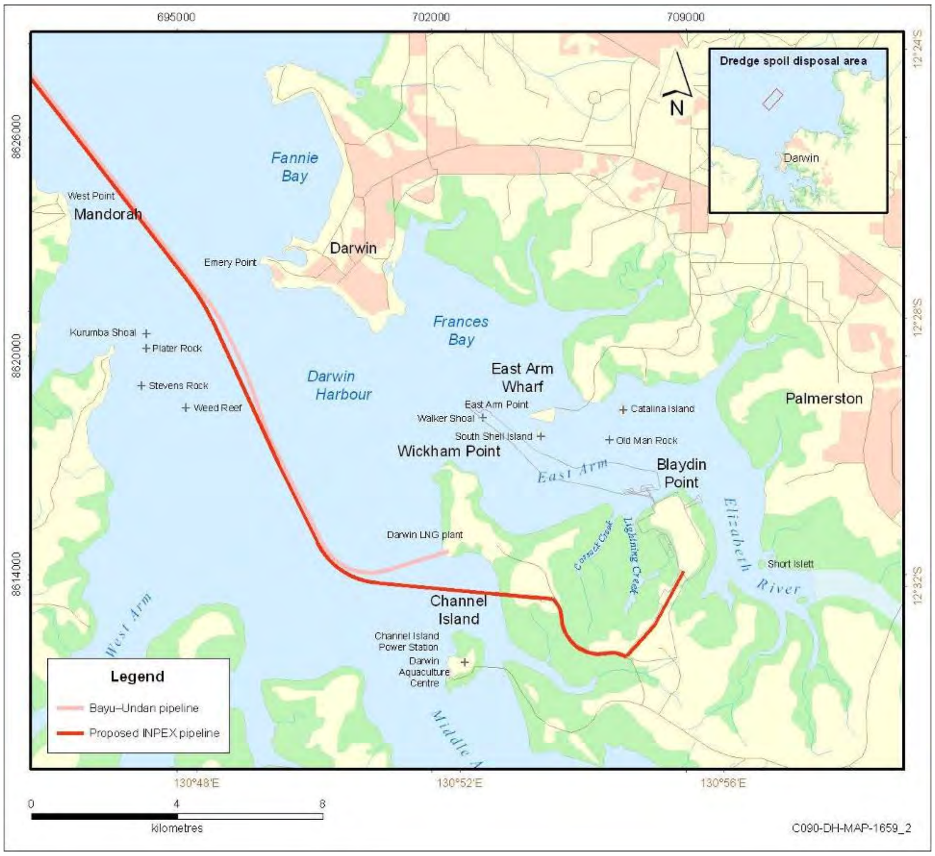

Figure 1-1 Darwin Harbour and the nearshore development area, including Walker Shoal

1.2 Objective and Scope

It is the purpose of this report to present a synopsis of the latest available, contemporary research, policies and field experiences and present guidance concerning the evaluation and management of blast and in-water noise and its implications for potentially sensitive marine fauna, in the context of the INPEX's proposed marine construction works in Darwin Harbour. In parallel with this literature review, the potential impacts of noise from key Project activities in the nearshore development area were subject to underwater acoustic modelling (SVT 2011; Appendix A).

This report does not present a comprehensive review of underwater sound. The physics of underwater sound, characteristics of ambient noise, natural and anthropogenic sources of noise in the ocean and general sensitivities of significant marine fauna have all been addressed and are available in Appendix 15 of the Draft EIS (URS 2009). As such, this report presents an updated companion of more specific focus to that original report.

2

Potential Underwater Noise Generated by the INPEX Project

Activities associated with the nearshore activities including the construction of a product loading jetty and other project associated activities within Darwin Harbour will generate noise, which has the potential to lead to adverse impacts upon marine fauna in the vicinity of these activities. Some noise-generating activities will also continue through the operations and maintenance phases of the project.

Potentially significant sources of noise will include:

- pile driving
- dredging activities
- rock fragmentation operations
- drill and blast operations.

2.1 Marine Drill and Blast

INPEX is currently investigating the technical feasibility of alternatives to blasting for the removal of high strength rock material. If blasting is required for the removal of Walker Shoal, it will be undertaken using the “confined” blasting (drill-and-blast) method, which involves drilling small holes in the rock with charges placed and connected in the holes for subsequent surface firing.

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole in solid materials. A drill bit is a multipoint, end cutting tool. It cuts by applying pressure and rotation to the object, which forms chips at the cutting edge. Underwater drilling noise can be regarded as a continuous (or non-pulse) signal. The source spectrum and the spectrogram of a typical drilling noise from SVT’s database are shown in Figure 2-1 and Figure 2-2 respectively. As can be seen, drilling noise is dominated by very low-frequency noise, with the peak level at around 6 Hertz (Hz).

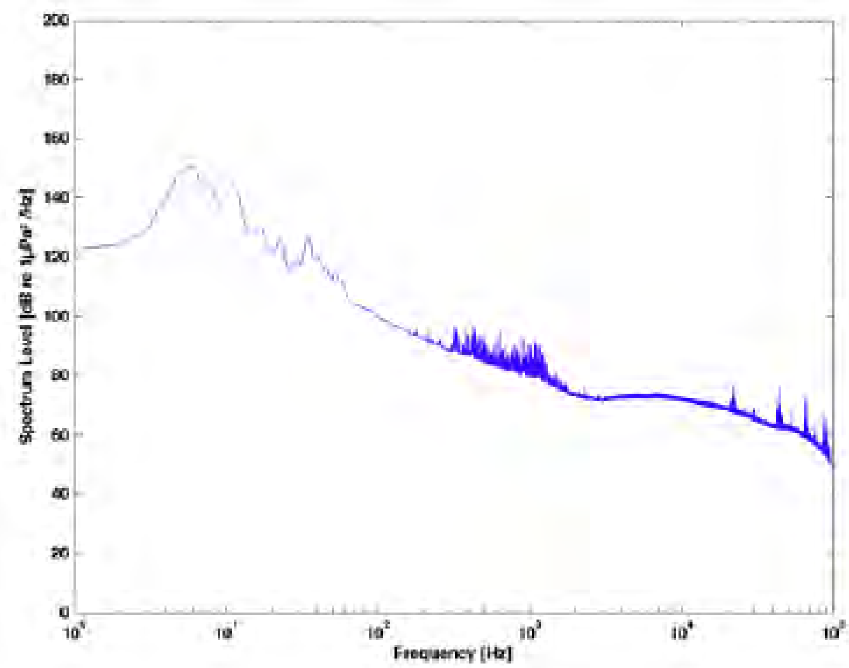

Figure 2-1 Source spectrum level of a typical drilling signal

2 Potential Underwater Noise Generated by the INPEX Project

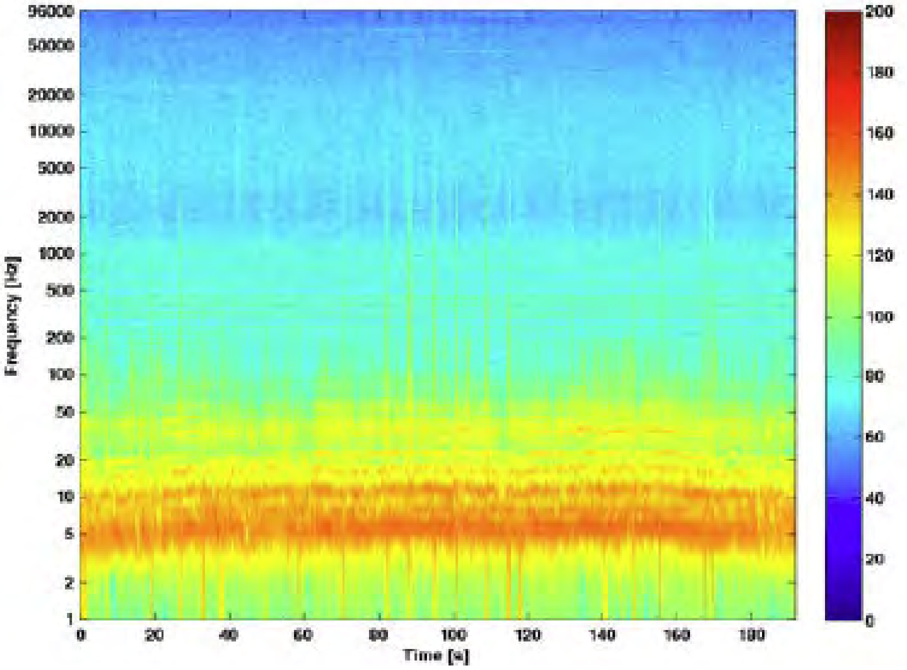

Figure 2-2 Spectrogram showing the variation of the noise from a drilling operation over time

In comparison with surface blasting methods, confined blasting generates reduced effects upon the marine environment. This is primarily because surface blasting requires a larger charge to break up rock material (generally three times larger than for confined blasting), and the explosive energy is dispersed throughout the water column rather than being largely contained within the rock body. Nedwell (1989) showed that the in-water peak pressure for an embedded charge is reduced substantially, to approximately 5%, and the 'impulse' (i.e. a double-sided sound pulse of a relatively high acoustic level and extremely short time interval) to approximately 30% of that for the equivalent unconfined charge. The rise time of the wave is also slowed (as it passes through the rock) resulting in the duration of the blast being increased over that for an equivalent freely-suspended charge, typically to 1–2 ms. The resulting blast wave is therefore likely to contain a high proportion of low frequency energy components (and therefore a low portion of high frequency energy components). It is germane to consider, that it is the fast rise time (i.e. the high frequency components) of impulse waves which are the cause of most physiological damage, so if these are attenuated, then so too is the potential for physiological effects.

The impact of a set of underwater blasts can also be reduced by implementing small timing delays between explosions, through connected fuses. The detonation event therefore comprises a chain of individual subordinate detonations. These produce irregular and less pronounced peak pressure levels than would occur if all the explosives were detonated simultaneously, or if a single aggregate charge of the same net explosive content was detonated (Keevin 1998). For the nearshore development area, it is proposed to use smaller charges (i.e. 50 kg) set on micro-delays, producing lower peak pressure levels than would result from a single blast (i.e. 300 kg). The explosions would be 'stemmed' (i.e. covered) and fired with a successive delay interval of 25 milliseconds (ms) between individual charges. Stemming the explosive with material, instead of water, can have the effect of forcing the explosive gas energy to do more work on the rock mass thereby releasing a slightly lower pressure impulse into the water when the work is completed.

2 Potential Underwater Noise Generated by the INPEX Project

Explosive sources, which are regarded as generating single pulse signals, have two important components that are of interest to underwater noise. They are as follows:

- Shock wave. Important in unconfined explosions (e.g. severing steel, boulder breakage, ordnance testing).
- Gas component. Generally the more useful component for material displacement (e.g. mass demolition by displacement of material).

As can be seen from the above each component is used to perform a different type of mechanical work. Explosives can be designed to release different total energy fractions of shock wave and gas component depending on the mechanical work to be performed. All explosions have some fractions of both. This is an important consideration as the shock wave component of a blast is the most critical component for occasioning any physical injury.

Explosive blasts are typically broadband, non-linear effects with large peak pressures and extremely fast rise and fall times. An analytical formula where m is expressed in kilograms, and r is expressed in metres) can be used (if the net explosive quantity [NEQ], expresses as trinitrotoluene [TNT] equivalent of the explosive is known) to determine the peak sound pressure level (SPL peak)[1] per charge mass, at a range of 1 m from the source (SVT 2011), as shown in Figure 2-3.

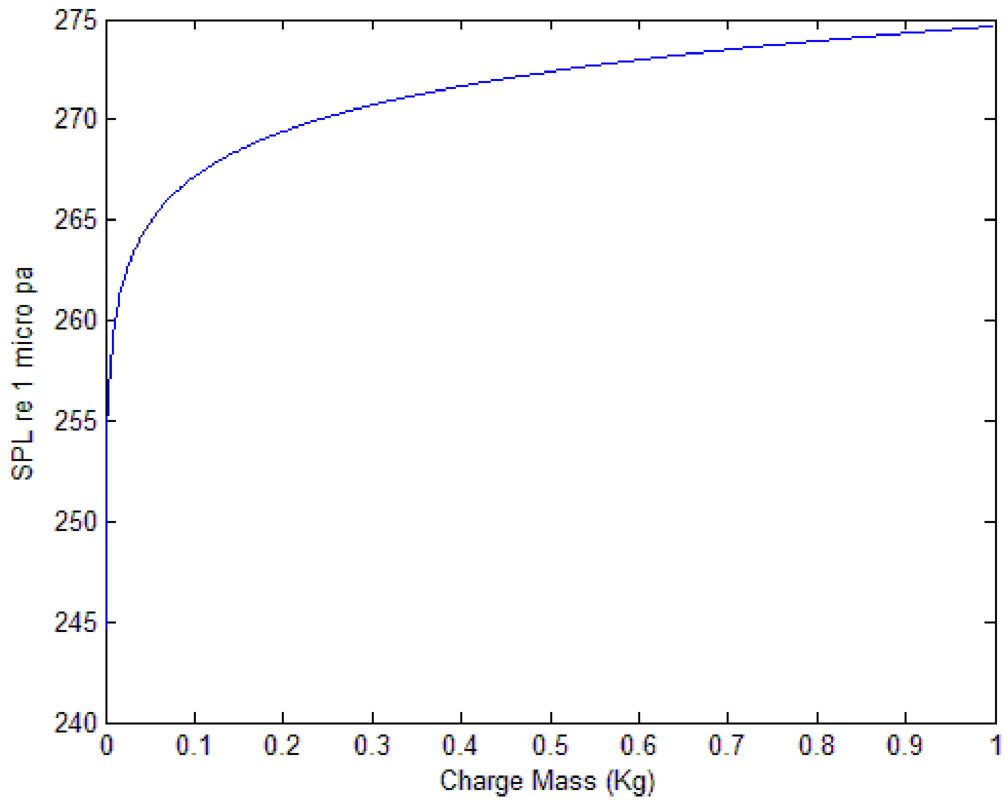

Figure 2-3 Blast sound pressure level achieved per charge mass

Noise emissions from underwater blasting of Walker Shoal in Darwin Harbour may occur under three proposed nominal scenarios which are described below. It is proposed there will be four blasts per

1 Peak pressure is the maximum recorded pressure and is measured from the mean of the signal to the maximum excursion from the mean. SPL peak can be empirically calculated based on SPL RMS as: SPL peak = SPL RMS + 18 dB re 1 uPa.

day. It will be assumed that the emulsions (i.e. explosives) to be used will be similar to those used in analogous developments in the north-west of Western Australia. The three scenarios considered for blasting include:

- 24 holes each with 50 kg
- 12holes each with 25 kg
- 6 holes each with 50 kg.

Detonating 50 kg of emulsion gives a peak value of 108.1 MPa at a distance of 1 m using the formula of Ross (1987). As for underwater confined charges, the peak pressure may be conservatively estimated as 0.4 times the peak pressure of unconfined charges, compared to 0.3 times predicted by Nedwell (1989). This equates to a peak pressure value of 275 deciBel (dB) (re 1 µPa @ 1 m) (or an estimated 258 dB [re 1 µPa @ 1 m] root mean square [RMS]). The duration of the pulse can be calculated to be 24.5 µs which gives a sound exposure level (SEL)[2] of 212 dB (re 1 µPa².s). The discharge of 25 kg emulsion gives a SEL of 209 dB re 1 µPa².s. The source spectrum curve of the blasting is assumed to follow the research outcome from Weston (1960).

For each scenario the following parameters were used:

Micro-delay duration between individual charge detonations: 25 ms.

Tidal height: Constant tide height of 6 m.

Depth/ diameter of hole and depth of stemming: assume 120 mm diameter, drilled to at least 4 m below the design depth (more for larger drill pattern spacing). Stemming is dependent on the amount of overburden present—which should be assumed to be zero if the alternative dredging methods have been attempted to refusal. In this case the stemming length should be kept to a minimum for the effective completion of the blasting works (assume less than 1 m). Further detailed design will be required to assess the required stemming depth and in any case the actual stemming thickness will be determined for each blast during the works.

Type of explosive: Common underwater explosives include: gelatinous nitro glycerine based products and ammonia gelatin-based emulsions. These explosives are high power, waterproof and are often used for underwater and hard rock blasting. For the purpose of modelling, a typical emulsion TNT equivalent of 0.31 was used. Explosives were modelled as a point source. The charge size and emulsion type were used to determine the peak pressure from which the source level was determined.

Table 2-1 Summary of scenario parameters

Parameter	Scenario 1 – 24 holes each with 50 kg	Scenario 2 – 12 holes each with 25 kg	Scenario 3 – 6 holes each with 50 kg
Mass of explosive per hole	50 kg	25 kg	50 kg
Blast Duration	24.5 µs	21.3 µs	24.5 µs
Number of holes	24	12	6
Depth/diameter of hole	120 mm diameter – 4 m depth	120 mm diameter – 4 m depth	120 mm diameter – 4 m depth
Micro-delay	25 ms	25 ms	25 ms

[2] Sound exposure level (SEL) is a measure of energy. Specifically, it is the dB level of the time integral of the squared instantaneous sound pressure normalised to a one second (1 s) period. It is useful in analysing cumulative exposure because it enables sounds of differing duration to be compared and assessed in terms of total energy (Southall et al. 2007).

Parameter	Scenario 1 – 24 holes each with 50 kg	Scenario 2 – 12 holes each with 25 kg	Scenario 3 – 6 holes each with 50 kg
Pressure	108.1 MPa @ 1m	83.43 MPa @ 1m	108.1 MPa @ 1m
SPL peak	275 dB re 1 µPa @ 1 m	272 dB re 1 µPa @ 1 m	275 dB re 1 µPa @ 1 m
SPL RMS	258 dB re 1 µPa @ 1 m RMS	255 dB re 1 µPa @ 1 m RMS	258 dB re 1 µPa @ 1 m RMS
SEL	SEL of 212 dB re 1 µPa²․s	SEL of 209 dB re 1 µPa²․s	SEL of 212 dB re 1 µPa²․s

2.2 Pile Driving

Pile driving operations involve hammering a pile into the seabed. The noise emanating from a pile during a piling 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 hammering a pile into the sea bed (Figure 2-4) will cause vibrations in the pile that will propagate along the length of the pile and then into the seabed. The transverse (i.e. sideways) component of the vibrations will create compressional waves that will propagate into the ocean while the downward component of the vibration 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 compressional 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 proportion of the total wave energy.

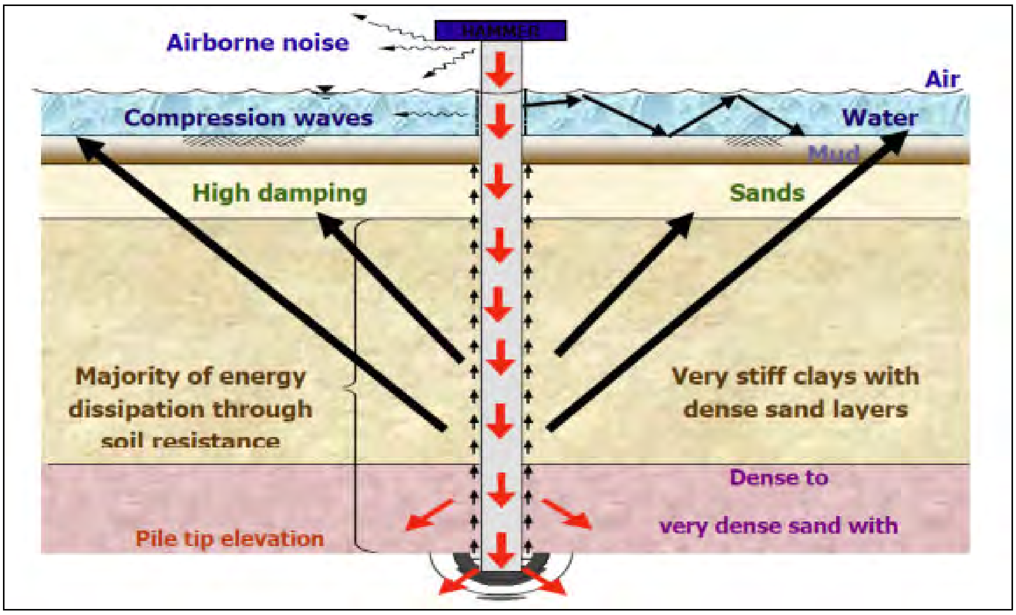

Figure 2-4 Energy transfer modes which occur when a pile is being driven into the seabed (Theiss 2006)

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. It was assumed that hydraulic impact hammers with diameter of 1,500 mm will be used for pile driving operations in this project. This is a conservative assumption as measurements indicate that they transmit the most energy. The pile driving pulses occur roughly once every second. The noise that is generated by an impact hammer hitting the top of the pile is short in duration lasting approximately 90 ms and can therefore be regarded as pulse signal. The pulse duration was used to calculate the SEL of the pile from the SPL RMS value. A measured source spectrum level of a typical piling signal is given in Figure 2-5.

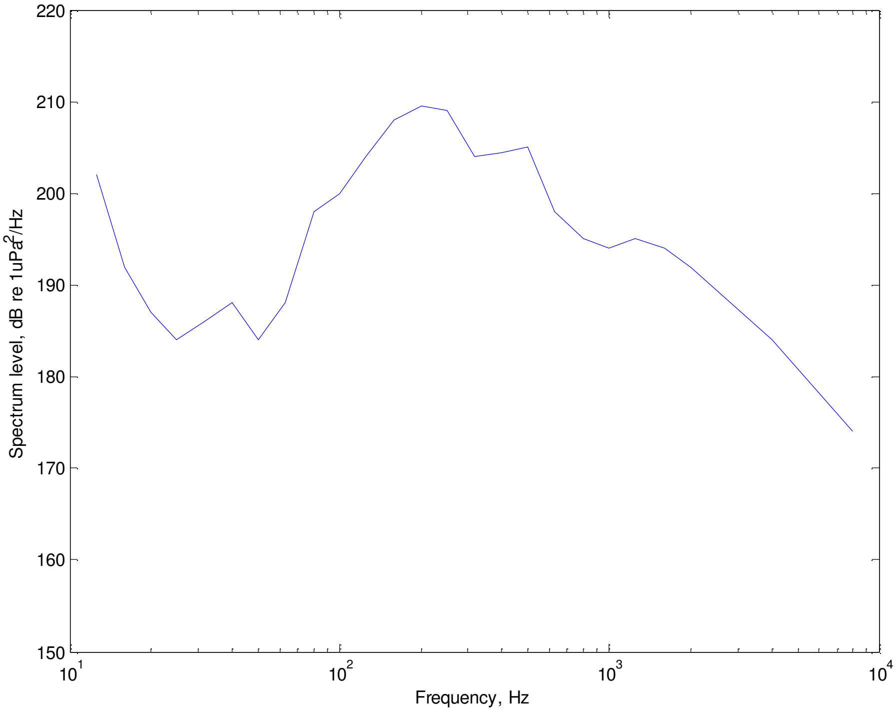

Figure 2-5 Measured source spectrum level of a typical piling signal for a steel pile

2.3 Dredging

Dredging is an excavation operation carried out at least partly underwater, with the purpose of gathering up bottom sediments and disposing of them at a different location. The noise from dredging activities is mainly generated by the operating motors and engines of dredging vessels and has non-pulse characteristics. It is expected that cutter suction dredgers are going to be used to undertake the dredging operation in Darwin Harbour. A cutter suction dredger is a vessel that employs a suction tube with a cutter head at the suction inlet, which is used to loosen the earth and transport it to the suction mouth. The cutter can also be used for hard surface materials like gravel or rock. The dredged material is usually vacuumed up by a wear-resistant centrifugal pump and discharged through a pipe line or to a barge. Figure 2-6 gives the source spectrum level of a cutter section dredger that was measured by SVT.

Specialised cutter suction dredgers are considered as an alternative to the drilling and blasting operation at Walker Shoal. As the source spectrum data for specialised cutter suction dredger is not available, its spectrum curve was assumed as the same as that of normal cutter suction dredger (see Figure 2-6) with a 6 dB higher spectrum level than that of normal cutter suction dredging.

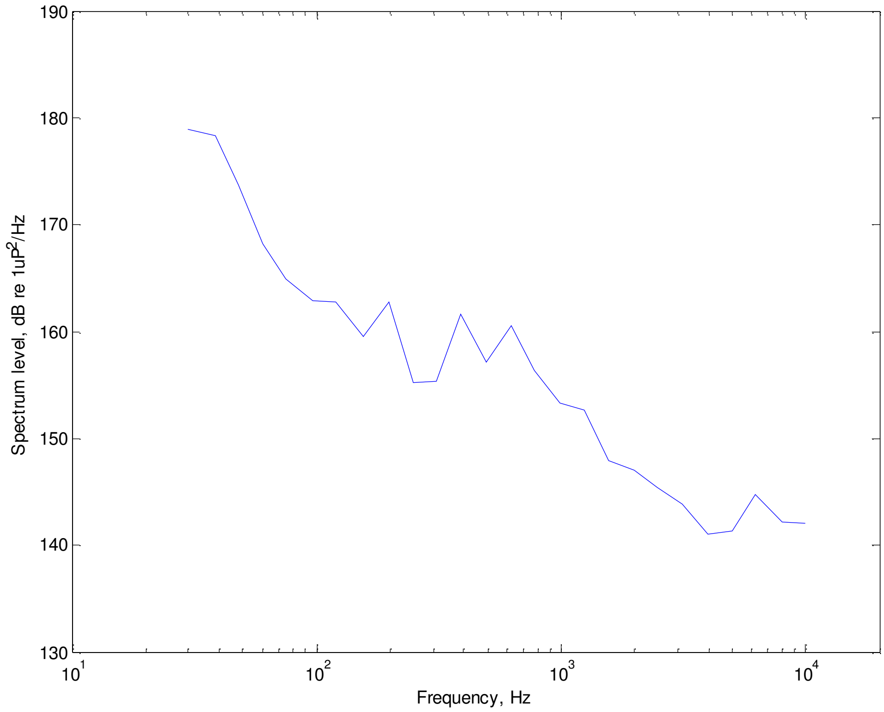

Figure 2-6 Source spectrum level of a normal cutter suction dredger measured by SVT

2.4 Hydro-hammer

The hydraulically operated hydro-hammer has a solid one-piece ram with a fully enclosed hammer housing. The hammer operating cycle repeats itself automatically, controlled by the pressure valve. The ram is guided by oil lubricated upper and lower bearings which eliminate wear on the ram.

The hydro-hammer is suitable for all types of piling and foundation works ranging from impact sensitive concrete piles, to large and long offshore caisson piles, and also includes underwater rock breaking at full energy.

Signals generated from hydro-hammering operation are regarded as pulses, with a maximum source level of around 165 dB (re 1 µPa at 1 m) at 200 Hz. Figure 2-7 shows the spectrum level of the hydro-hammer, provided by INPEX. It is assumed that the blow rate of the hammer is roughly equal to the pile driving, i.e. 60 blows per minute, with the duration of each hammering impulsive signal as approximately 90 ms. The duration was used to calculated the SEL of the hammer.

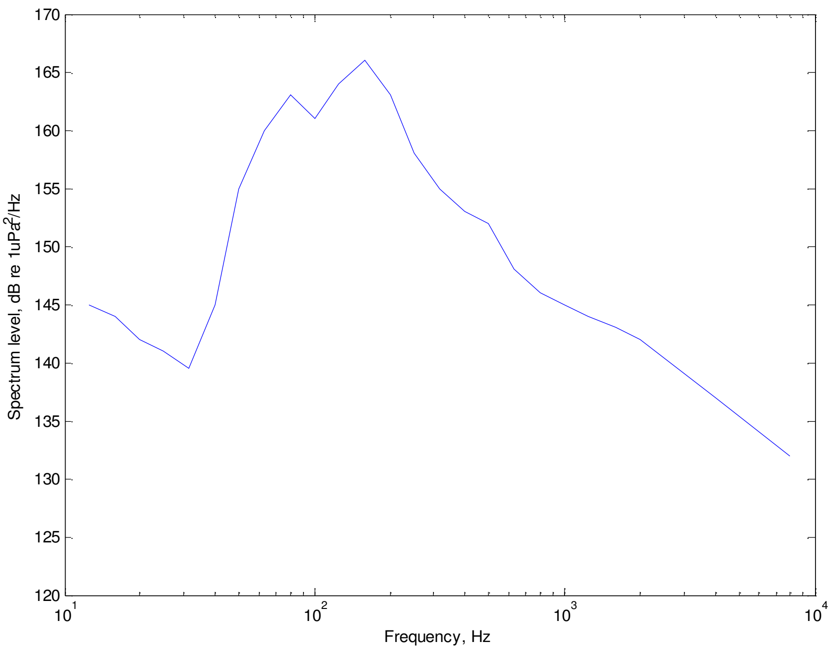

Figure 2-7 Source spectrum level of a hydro-hammer operation

2.5 Cumulative Impacts

Noise modelling was undertaken by SVT (2011) for dredging and piling. The modelling included locating the dredge position near to Walker Shoal. This placed the dredge in relatively close proximity to the marine blast and drill activities and piling works, to account for and enable an assessment of worst case "cumulative impacts" (i.e. through reinforcement of sound from multiple activities).

Note that there is a certain community appeal and interest in the assessment and modelling of cumulative sound exposures. This, however, is a fraught undertaking. This is mainly attributable to the inherent uncertainties and unknowns regarding noise propagation of single sources, let alone multiple ones, which would require the would-be modeller to make numerous assumptions and estimates. Furthermore, even two separate sources with exactly the same frequency and signal (i.e. tonal) characteristics would add together differently in different locations, varying between being complementary and hence additive to being antagonistic and hence cancelling each other out, dependent upon distance from sources and the relative phase differences between the two signals at the point being measured. In addition, the reality of cumulative noise effects can be counter-intuitive, as a 'doubling' of received noise would result in a 3 dB increase in noise: for example, two exactly synchronous 200 dB signals when combined, would double the effective signal strength to a level of 203 dB.

Sensitive Marine Species in Darwin Harbour

Several groups of animals or individual species in Darwin Harbour are of particular concern in terms of underwater noise potentially generated by anthropogenic activities. These are species that are of high conservation value, such as protected fauna, and important commercial and recreational fishery species. Appendix 15 (Section 2.4) of the Draft EIS discusses the key groups and species in Darwin Harbour, therefore only a summary of these species has been provided below.

3.1 Cetaceans

Three coastal species of dolphins, the Australian snubfin (*Orcaella heinsohni*), the Indo-Pacific humpback (*Sousa chinensis*) and the Indo-Pacific bottlenose (*Tursiops aduncus*) are the most common cetacean species in Darwin Harbour (Palmer 2008). All three are listed and are considered to be migratory under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The three species are considered to be of ‘least concern’ under the *Territory Parks and Wildlife Conservation Act 2005* (TPWC Act). The snubfin dolphin is a recently described species, having been separated as a distinct species from the Irrawaddy dolphin (*O. brevirostris*).

These species of dolphin are generally considered to have hearing acuity across the range of 150 Hz to 160 kiloHertz (kHz) (Southall et al. 2007), with greatest sensitivity in the range of around 5 kHz to 80 kHz. Their range of vocalisations and echolocation has been reported in the literature as:

- Indo-Pacific bottlenose dolphins whistle between 2 and 22 kHz (Hawkins 2010). No record of their echolocation clicks was found in the literature.
- Indo-Pacific humpback dolphins whistle between 1 and >22 kHz (Shultz & Corkeron 1994, Van Parijs & Corkeron 2001a), click between 2 and 200 kHz (Goold & Jefferson 2004) and emit burst-pulse sounds between 0.5 and > 22 kHz (Van Parijs & Corkeron 2001b).
- Snubfin dolphins whistle at 3-4 kHz; clicks exceed 22 kHz (Van Parijs, Parra & Corkeron 2000).

Other cetaceans that have been recorded in Darwin Harbour include the sperm whale (*Physeter macrocephalus*), the pygmy sperm whale (*Kogia simus*) and the humpback whale (*Megaptera novaeangliae*). False killer whales produce whistles between 4 and 10 kHz (Murray, Mercado and Roitblat 1998), and clicks between 30 and 100 kHz with source levels of 201–225 dB re 1 µPa @ 1 m (Madsen, Kerr & Payne 2004). However, recordings of these species are rare and represent vagrant individual sightings. Occasional pods of false killer whales (*Pseudorca crassidens*) are known to visit the harbour but little research has been conducted into their utilisation of the area (Whiting 2003).

3.2 Dugongs

Dugongs (*Dugong dugon*) are listed marine and migratory species under the EPBC Act, but they are not listed under the TPWC Act. Dugongs occur in low numbers in Darwin Harbour, where they forage on the rocky reef flats between Channel Island and the western end of the Middle Arm Peninsula. Dugongs have been observed in this area during most months of the year, except from September to December. No seagrass occurs on the reef flat in this area; instead, the dugongs were likely to have been feeding on macroalgae (Whiting 2003, 2008).

Dugongs produce a variety of calls between 500 Hz and 18 kHz (Anderson & Barclay 1995).

3.3 Turtles

Six species of marine turtles occur in the waters of the Northern Territory: the green turtle (*Chelonia mydas*), flatback turtle (*Natator depressus*), hawksbill turtle (*Eretmochelys imbricata*), loggerhead turtle (*Caretta caretta*), leatherback turtle (*Dermochelys coriacea*) and the olive Ridley turtle (*Lepidochelys olivacea*). Three species of turtles (loggerhead, leatherback and olive Ridley) are listed as endangered under the EPBC Act; the remaining three species (green, hawksbill and flatback) are listed as vulnerable. Under the TPWC Act the loggerhead turtle is listed as endangered, the leatherback turtle as vulnerable and the remaining four species are not listed as threatened. Green, hawksbill and flatback turtles occur in Darwin Harbour regularly; olive Ridley and loggerhead turtles are suspected to be infrequent users; and the leatherback turtle is an oceanic species that is unlikely to occur in Darwin Harbour (Whiting 2001).

Thus, the most common species of turtles in Darwin Harbour are the green turtle and hawksbill turtle, but the flatback turtle is also included in the present study. As a general rule, marine turtles are considered to display hearing acuity in the range 250 Hz to 1 kHz (URS 2009).

3.4 Fish

Darwin Harbour waters support a high diversity of both resident benthic and transient pelagic fish species. Larson and Williams (1997) recorded 415 species of fish in Darwin Harbour, including 31 new records for the Northern Territory. However, little is known about the basic requirements of fish living in the harbour, such as habitat preferences, food habits, breeding periodicity and locations and lifespan (Larson 2003).

Fish inhabit a considerable range of habitats within the harbour. Most harbour fish are small, and are difficult to distinguish taxonomically. The most diverse group in Darwin Harbour is the gobies (approximately 70 species), followed by cardinal fish (20 species) and, unusually for the tropics, the pipefishes (19 species), which are listed marine species under the EPBC Act (Larson 2003).

Mangroves provide juvenile habitat for most fish species commonly harvested by recreational and indigenous fishers, such as trevallies (*Caranx* spp.), mackerel (*Scomberomorus* spp.), salmon (*Eleutheronema tetradactylum* and *Polydactylus macrochir*), grunter (*Pomadasys kaakan*) and barramundi (*Lates calcarifer*) (McKinnon et al. 2006). During high spring tides the mangrove forest is used extensively by a wide range of fish. At low tide only resident species appear to remain in pools (Martin 2003).

With respect to hearing, fish have been informally split into two groups; ‘hearing generalists’ and ‘hearing specialists’. The former are considered able to discern sounds up to around 1 kHz, while the latter can detect sounds at around 2 kHz or more (URS 2009). Barramundi are hearing specialists.

Updated Review of Potential Environmental Effects and Management of Underwater Noise and Impulse from Proposed Underwater Construction Activities

As previously noted, activities associated with the nearshore activities including the construction of a product loading jetty and other project associated activities within Darwin Harbour will generate noise, which has the potential to lead to adverse impacts upon marine fauna in the vicinity of these activities. Only blasting (and associated drilling), pile driving and dredging are expanded upon in the following sections. Information on, and evaluation of, the other sources is presented in Appendix 15 (Section 6) of the Draft EIS.

4.1 Marine Drill and Blast

The most damaging component of an underwater shock wave is the initial fast rise in pressure; the 'impulsive' element. The area over which this has a significant effect is limited however due to the rapid loss of the component frequencies which form the sharp leading edge of the pulse. After propagating through the water column these higher frequency components diminish such that the initial shockwave rapidly attenuates into a broad spectrum of frequencies with most energy in the sub 1 kHz range.

Various explosive devices are occasionally used for research, removal of navigational hazards, removal of rocky outcrops during capital dredging programs, deconstruction of abandoned structures, scuttling hulks for artificial reefs, military exercises and (rarely) for ship shock trials.. Charges used for ship scuttling or minor underwater rock blasting are typically small (0.1 to 5 kg TNT). Use of explosive discharges by the research community has declined in recent decades, partly because of environmental and safety concerns but also because of the lack of control and the non reproducible nature of the source waveform and the precise detonation depth.

There are a number of marine construction projects within Australia that have been approved by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) in the use of underwater blasting in shallow waters and others conducted in overseas jurisdictions. Examples of these and their management stipulations are summarised below:

Western Australian Water Corporation - Alkimos Wastewater Treatment Plant

The Western Australian Water Corporation (WAWC) developed an ocean outlet pipeline associated with the Alkimos Wastewater Treatment Plant at Quinns Rocks, Western Australia. Underwater noise was generated from rock fragmentation required in advance of dredging. It was proposed to use 10 kg charges at approximately 3 m hole-depth along the ocean outlet route. An exclusion zone of 1000 m for marine megafauna was implemented in addition to the need for a blast management plan.

Western Australian Water Corporation - Southern Seawater Desalinisation Project

The WAWC developed a desalinisation plant at Binningup, Western Australia as part of the Southern Seawater Desalinisation Project (SSDP). Potential sources of underwater noise included underwater blasting during construction of the intake and outlet pipelines for the SSDP, to approximately 800 m offshore. Whales, dolphins and sharks are regularly sighted along the coastline of WA and may also be infrequent visitors near the SSDP at Binningup. Anecdotal reports indicate that little penguins (*Eudyptula minor*), a listed marine species under the EPBC Act, also occur periodically in the Binningup area. In the case of any explosive blasting, an exclusion zone of 2,000 m radius was proposed around detonation sites. From one hour before the planned time of detonation this zone was to be checked to be clear of large marine fauna such as whales, dolphins, sharks and turtles. If any were observed to be within the zone then detonation was to be delayed until such time as the observed fauna moved outside the zone.

BM Alliance Coral Operations Pty Ltd - Hay Point Coal Terminal Expansion

BM Alliance Coral Operations Pty Ltd proposed to dredge and blast as part of the Berth 3 pocket and apron Hay Point Coal Terminal Expansion (BMA 2010). The establishment of the proposed Berth 3 pocket and apron area would result in the removal of up to 275,000 m^3 of dredge material, comprising approximately 185,000 to 245,000 m^3 of alluvial and weathered rock material and 30,000 to 90,000 m^3 of bedrock requiring pre-treatment by drill and blast. The blasting would be undertaken with delayed detonation of blast holes using non-electric or electric delays between blast holes (MIC 10 kg to 50 kg per delay), employing a maximum of 24 blast holes in a shot. Establishment of an initial 2 km exclusion zone around drilling and blasting operations was proposed for cetaceans, and an 1,150 m exclusion zone for dugongs, marine turtles and large schools of fishes, subject to review during initial blasting on the basis of ongoing acoustic monitoring.

Channel Dredging – Miami, Florida, US

Underwater blasting was undertaken at the Port of Miami-Dade, Florida as a component of a dredging program to deepen a channel and turning basin at the port to over 12 m. This involved 40 blasts, each of up ~60 kg, over a 37 day period. The program was cognisant of potential effects upon dolphins, manatees, marine turtles and fish which occurred in the project area. During this program 186 individual animals were observed in the immediate area, before, during or after blasting events. A 750 m radius significant marine fauna safety zone was stipulated by regulatory authorities, overseen by a minimum of six observers. No injuries of any kind to marine mammals were observed as a result of the blasting program (Port of Miami 2005; Hempen, Keevin & Jordan 2007).

Ship Shock Trials – US Atlantic Coast

Explosive shock trials of the US Navy destroyer, *USS Winston S. Churchill*, were conducted offshore of northern Florida in May and June 2001 in water greater than 200 m deep. The shock trials consisted of three underwater detonation tests, spaced approximately one week apart using 10,000 lb (4,536 kg) unconfined charges. Mitigation measures to minimise the potential impact of the shock trials on marine mammals and sea turtles were based on a safety range of 3700 m radius around the detonation site, with an additional 1850 m buffer zone. Approximately 1,200 marine mammals, including dolphins, and 32 sea turtles were sighted during pre-detonation monitoring. No injured or dead marine mammals or turtles were detected during approximately 185 hours of post-detonation aerial and vessel visual monitoring following the three detonations (Clarke & Norman 2005).

Explosive Demolition of Marine Petroleum Infrastructure – United States

A review was performed by CSA (2004) of the environmental issues associated with the removal of fixed platforms and installations by the use of underwater blasting. In 1995 and 2002, the US National Marine Fisheries Service (NMFS) issued guidelines on the use of explosives to remove offshore oil and gas structures in the Gulf of Mexico. The safety exclusion radius for bottlenose and spotted dolphins was determined to be 914 m. The NMFS document does not specify the source of this number, but it is apparently based on record of turtle death/injury observations available to the reviewers (Kilma, Gitschlag & Renaud 1988) rather than any modelling. Anecdotal observations (using the 914 m monitoring range) suggest that it has been effective in preventing deaths or serious injuries of marine mammals. However the review noted that the scientific basis for this specific number is weak, as it was not developed specifically for marine mammals, but it was nevertheless assessed as being effective in practice in avoiding marine mammal injury and mortality as a result of blasting. The implication of this finding of 'weak' scientific basis is that the authors indicated that the 'safe' distances were conservative and could be reduced. CSA (2004) noted that whilst dolphin mortality has been reported in the literature (e.g. Klima, Gitschlag & Renaud 1988; Jefferson 2000), no details on the circumstances of these incidents were available.

Explosive Demolition of a Pier – Florida, US

Apart from the potential evidence of injury and mortality discussed above, there are numerous studies on the behavioural change and temporary threshold shift (TTS) as a low level, very conservative surrogate for the threshold of potential onset of physical injury of bottlenose dolphins in relation to marine blasting. Moore et al. (2006) investigated the effects upon bottlenose dolphins, *T. truncatus,* from demolition and construction of underwater structures (bridge foundations) in Sarastoa Bay, Florida. Two piers were demolished simultaneously using 18 kg charges, with 25 ms delays between charges placed in boreholes, for a total blast duration of 1 second. Charges were placed at 5.1 m depth in waters of 4.5 m deep. A steel coffercell was placed around the area to aid containment of debris and abate sound. Smaller charges were used than originally planned to reduce safety radius from ~600 m to ~300 m in line with the granted permit. They concluded that dolphins at 730 m and 1830 m away from the blast site did not exhibit any short term response to the explosions at mean received noise levels of 76 dB and 62 dB (re 1 μPa) at 25Hz to 20kHz, respectively, which represented an increase above mean ambient noise levels of 54 dB (re 1 μPa) at 25Hz to 20kHz.

Mine Warfare Training – Australia

In Australia, the Department of Defence undertook an environmental assessment of the conduct of countermine warfare training by Royal Australian Navy (RAN) *Huon* class minehunters. The training required detonation of the Danish Mine Disposal Charges. The activity would continue indefinitely with a charge of 65 kg for an average of 12 firings per year, in an unconfined detonation sitting on top of the sediment. Defence indicated that for a 65 kg unconfined charge detonated at a depth of ~45 m in open water, marine mammals greater than 1,500 m from the detonation were unlikely to be exposed to pressure damage. Thus, a conservative buffer of 3,600 m was adopted for the firings. The Commonwealth assessment and subsequent approval was predicated on the prediction that up to eight marine species classified as 'Threatened', six as 'Migratory' and 33 as 'Marine Protected Species' inhabited the waters intended for the mine warfare activities (PPK 2002).

The RAN undertakes underwater demolition and mine disposal training areas at Triangular Island, in Shoalwater Bay, Queensland. This involves up to 240 firings per annum of charges ranging from 10 kg to over 100 kg, with one recorded detonation comprising a total charge of around 186 kg, mostly conducted during intensive six week and two week training periods. Shoalwater Bay supports a population of turtles and dugongs, the latter reputedly due to the extensive shallow-water seagrass communities. Defence undertook an extensive review of the potential effects upon marine fauna of the impulse and noise arising from these activities. The most salient finding was that for a charge of 186.1 kg, peak pressures measured at varying distances from the source (compared with modelled estimates in parentheses) (Box, Marian & Wiese 2000) were as follows:

- 246 m, actual 21.1 kPa (*cf.* modelled 750 kPa)
- 360 m, actual 6.9 kPa (*cf.* modelled 490 kPa)
- 926 m, 2.2 kPa (*cf.* modelled 170 kPa).

Note, the discrepancy between modelled as opposed to actual measured results is an artefact of the characteristic limitations of attempting in-water acoustic propagation modelling in shallow water environments. The need for models to generally assume constant conditions for multiple variables, particularly depth and bottom type, imposes systemic deficiencies in environments where no such constant conditions exist, such as muddy, shallow, tidal, coastal and estuarine areas. As such, there is often a tendency for modellers to adopt a conservative approach and assume acoustic propagation conditions more favourable and more constant than what actually exist. As a result, modelled levels for shallow water scenarios often over-state actual levels due to the need to assume constant conditions in what are highly variable, heterogeneous settings.

In conclusion, Box, Marian & Wiese (2000) opined that the detonations of explosives with net explosive quantities (NEQs) at Triangular Island of up to 186 kg produced no significant pressure levels at distances over 1 km from the source. They further postulated that the safe distances for dugongs and turtles would be ‘much less’ than 1 km.

Summary

A comparative summary of the blasting programs outlined above is presented in Table 4-1.

Table 4-1 Comparative summary of blasting programs and their approved regulatory requirements

Blasting Program	Location	Blasting Methods	Environmental conditions (depth, distance from shoreline etc.)	Regulatory Requirements
Port of Miami-Dade channel deepening, Florida	Port of Miami-Dade, Florida, USA	40 blasts, each of up ~60 kg, over a 37 day period.	12 m depth.	A 750 m significant marine fauna safety was stipulated by regulatory authorities, overseen by a minimum of six observers.
Explosive shock trials of *USS Winston S. Churchill*	Offshore Northern Florida, USA	Three underwater detonation tests, spaced approximately one week apart using 4,536 kg unconfined charges.	Unconfined detonation in open water.	Safety range of 3,700 m radius around the detonation site, with an additional 1,850 m buffer zone around the safety zone.

4 Updated Review of Potential Environmental Effects and Management of Underwater Noise and Impulse from Proposed Underwater Construction Activities

Blasting Program	Location	Blasting Methods	Environmental conditions (depth, distance from shoreline etc.)	Regulatory Requirements
Department of Defence – RAN *Huon* Class Minehunters		65 kg charge for an average of 12 firings per year.	Unconfined detonation at a depth of ~45 m in open water.	Marine mammals greater than 1,500 m from the detonation were unlikely to be exposed to pressure damage.
Department of Defence – RAN Underwater Demolition and Mine Disposal Training	Triangular Island, Shoalwater Bay, Queensland	Up to 240 firings of up to 10 kg over a 6 week period and 30 firings of 150 kg during a two week period.	Shallow mudbanks.	For submerged birds and mammals, 20 m was considered a safe distance from a 0.5 kg charge detonated at a depth of 3 m, and 1 km was more than sufficient for the largest charges.

It is pertinent to note that the shock trials and offshore structure removal using explosions, as described above, were conducted in deeper waters than that proposed for Walker Shoal, with deep open water often acting to increase the peak pressure and impulse at distances from the source. For charges jetted into rock, peak pressure can be reduced to 5% of that in open water and impulse by 30% (Nedwell & Edwards 2002).

4.1.2 Potential Effects on Significant Marine Fauna

This section reviews the known effects on important marine fauna from likely noise sources associated with the proposed marine drill and blast program. It reports on recorded observations and analyses from around the globe and does not specifically focus upon Darwin Harbour, or even Australia. It is intended to provide a general background to the literature on the effects of anthropogenic noise upon sensitive or charismatic marine fauna.

Cetaceans

Available information on the impacts of blasting on marine mammals has been obtained from experimental studies using animal carcasses, from extrapolations of experiments on terrestrial mammals and, to a much less extent, marine mammals as well as from opportunistic post-mortem examinations of stranded animals following detonations. This information is however considered very limited (CSA 2004), but has nevertheless been supplemented by field experience and associated anecdotal evidence of the general non-occurrence of discernible adverse outcomes. It should be considered, however, that the ‘weakness’ in the literature is more of an academic interest, as opposed to any deficiencies in the practices of practicable mitigation. This is because the science is uncertain as to what constitutes an acceptable ‘safe’ level of exposure, so mitigation measures proposed and adopted are, arguably universally, precautionary and conservative in their approach. CSA (2004) postulated that if there was greater certainty in the science, it is more likely that what are currently considered as 'safe' mitigation distances would be reduced.

The extent of mortality and injury from blasting depends on a range of interplaying variables. These include the size and depth of charge, composition of explosive used, water depth, bottom composition, distance and depth of individual from explosion centre and size and type of species concerned.

Richardson et al. (1995) reported on observed effects of explosives upon the behaviour of marine mammals. Humpback whales in the vicinity of explosives being detonated near Bermuda displayed no interruption to their vocalisations. Similarly, humpbacks within 2 km of explosions in sub-bottom rocks off Newfoundland displayed no obvious reactions when 200 kg to 2,000 kg charges were detonated. Gray whales within a 'few' kilometres of detonations of 9 kg to 36 kg charges used during seismic survey have been observed to alter swimming behaviour, while other observers (Fitch & Young 1948, in Richardson et al. 1995) report the whales "were seemingly unaffected and in fact were not even frightened from the area".

Toothed whales show a tolerance for impulsive acoustic disturbances, although the initial reaction may be one of avoidance. Captive false killer whales showed no obvious reaction to small charges, and other odontocetes have been found to be attracted to the location of detonations (Richardson et al. 1995), presumably in search of dead, injured or disoriented fish as prey.

Risk of physical injury or mortality does exist for large fauna, but these are only realistic probabilities in the immediate zone around the point of detonation; these risks are ameliorated by standard marine fauna observation and clearance procedures of no more than a few hundred metres (Lewis 1996).

Although the noise from any use of explosives during construction of the Project will be detectable over a wide area by potentially sensitive fauna, this risk is considered minimal when it is noted that use of explosives will be confined, and only extend for a relatively limited period. This conclusion is consistent with Richardson et al. (1995), who summarised that while some odontocetes, in particular, display short-term avoidance reactions to explosive impulses, overall, marine mammals show considerable tolerance of noise pulses from explosions. This conclusion is further reinforced by observed reactions to explosives used singly or repetitively. The observed tolerance of marine mammals may be linked to their experience of the intense, impulsive nature of many acoustic events of natural origin, such as lightning and whale breaching and tail slapping.

A generally accepted, conservative threshold value of SEL for causing TTS in marine mammals is 183 dB re $\mu Pa^2.s$, which can be expressed as 224 dB (re 1 µPa [peak]) SPL for pulses (as reported in Southall et al. 2007). TTS is often employed as a surrogate threshold value for the onset of potential physical injury, as it represents physical effects, albeit transient and reversible, to, generally, the most sensitive physiological feature of biota to be protected (URS 2010).

Sirenians

The data for sirenians are limited. Noting this, criteria developed for cetaceans are often applied as proxy measures.

Marine Turtles

In the case of shockwave effects, there are very little definitive data available on the types and extent of turtle tissue damage due to underwater detonations, and most workers assume that turtle lungs, ear drums and other gas-containing organs would be affected to the same degree as their counterparts in marine mammals (Lewis 1996).

Due to the lack of specific injury response curves for turtles, Young (1991) followed US NMFS criteria for sea turtles in the Gulf of Mexico and provided safe distance ranges plots for sea turtles based on cube root scaling, where:

$$\text{Turtle Safe Range (feet)} = 560 \times \text{NEQ TNT}_{(lbs)}^{1/3}$$

Three specific predictions listed by Lewis (1996) support Young's (1991) prediction plot; namely that organ tissue damage in sea turtles may occur at distances less than 750 m from a 100 kg high explosive charge, with hearing damage at range distances less than 1500 m from charge weights exceeding 90 kg (net explosive quantity kg TNT) (Lewis 1996).

These predictions match limited aerial monitoring observations obtained during a Defence training exercise in Shoalwater Bay, where an apparently healthy green turtle was spotted in shallow water seagrass beds within 800 m from a site where, less than 40 minutes previously, a large detonation of ~100 kg NEQ TNT ordnance had been conducted. No drifting or disoriented turtles were seen by a low-level aerial survey crew or by on-site observers (URS 2002).

Lewis (1996) also describes an incident involving three sea turtles in the vicinity of an underwater shock trial involving detonation of a 545 kg TNT charge at 37 m depth off Florida in 1981. A large adult turtle (182 kg) that was between 153-214 m from the detonation was killed, a ~120 kg turtle that was 366 m away was slightly injured, while the third turtle (~120 kg) that was at a range of 908 m was uninjured. From these data it was considered that a conservative safety range for turtles could be predicted by the formula of 80 m per $kg^{1/3}$ of high explosives (HE) (O'Keefe & Young, in Lewis 1996), although it should be noted that there is a difference between the method of O'Keefe and Young (1984) and the method of Young (1991) (see above).

The results of the Florida test are in agreement with the aerial observations in Shoalwater Bay in 2001 (i.e. uninjured adult green turtle at 700-800 m from a shallow water [~3 m] detonation of 100 kg TNT; URS 2002). While there are no observations or data on the range thresholds for either acoustic injury or behavioural responses for the five other marine turtle species found in Australian waters, there is no anatomical evidence to suggest these species should be any more sensitive than either green or loggerhead turtles.

Fish

The main cause of damage to fish as a result of the explosives detonated for marine blasting operations (WBM Oceanics 1993) relates to the high peak pressure, rapid rise times and rapid decay to below ambient hydrostatic pressure. Injuries sustained to fish from marine blasting operations include haemorrhaging, gross damage to the kidney, and rupture to the swim bladder and/or body cavity. Fish mortality is predominantly caused by rupture of the swim bladder.

Popper et al. (2006) report on the detailed review by Hastings and Popper (2005) for which they converted data collected by Yelverton et al. (1975) to sound exposure levels. This resulted in the prediction of no injuries occurring from blasts to the smallest fish (0.01 g) at RLs up to 193 dB (re $1\mu Pa^2.s$).

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Sharks may be less susceptible to blast and impulse effects than are many fish. This is due to the absence of a swim bladder, their physical size and arguably also due to their general morphology. While fish without swim bladders are much less sensitive to blast pressure damage than swim bladder fish, it is worthy of note that fish with a cylindrical body shape (e.g. barracuda, queenfish, kingfish) have been found less vulnerable than laterally compressed fish with thin-walled bladders (Lewis 1996).

Modelling of Underwater Noise Generated by the Project

Underwater noise propagation models use bathymetric data, geoacoustic information and oceanographic parameters as inputs to produce estimates of the acoustic field in the water column at any depth and distance from the source. The accuracy of the environmental information used in the model is critical for the modelling prediction. For example, the geoacoustic parameters of the seabed, particularly the seabed layer structure, the compressional and shear sound velocities for each layer material, and the corresponding sound attenuation coefficients can significantly affect the acoustic propagation and can therefore affect the accuracy of the model predictions (SVT 2011, Appendix A).

For model selection, data and model limitations and model inputs please refer to Appendix A for detail (SVT 2011).

For each modelling scenario, the received RMS SPL, the corresponding SPL peak and corresponding SEL, for different ranges from the receiver to the noise sources, were modelled. Three frequency weightings, i.e. mid-frequency cetacean weighting, 100–1k Hz flat frequency weighting and 100–2k Hz flat frequency weighting, were applied to the SEL estimates, along with various exposure durations. For modelling scenarios, their corresponding locations and noise sources refer to Appendix A for detail (SVT 2011).

Two salient issues relating to conservative assumptions in the modelling need to be borne in mind when reviewing the outputs of the studies. The first is that the model has assumed uniform, homogeneous conditions for the water surface, water column and seafloor which suggest acoustic propagation ranges in excess of that which would be actually expected. This is because those aspects of the environment have invariably been assumed to be in a condition most conducive to acoustic propagation, when in reality this is unlikely to be the case. Furthermore, the heterogeneity of these conditions which would actually be encountered would further diminish acoustic propagation potential, due to the effects of absorption and scattering of energy which does not occur to the same extent when uniform, advantageous conditions are assumed. In addition, unless otherwise stated, the model has assumed constant peak tidal conditions in Darwin Harbour, which acts to significantly increase the intensity and extent of the spread of acoustic energy from a given point source compared with any condition less than high tide, particularly when compared with low tide conditions.

Secondly, the models of cumulative exposure are based upon a convenient but undeniably unrealistic scenario which assumes that any given individual animal will not alter either it position or orientation in relation to the modelled sound source for the entire duration of the assumed acoustic exposure. The whole premise of cumulative exposure modelling is founded upon human workplace occupational acoustic exposures. Although a useful tool for marine fauna exposures in the prevailing absence of anything better, the reader is cautioned against too literal an interpretation of the cumulative modelling results.

5.1 Marine Drill and Blast

The relevant contour plots of SPL RMS were provided following the respective modelling operations.

5 Modelling of Underwater Noise Generated by the Project

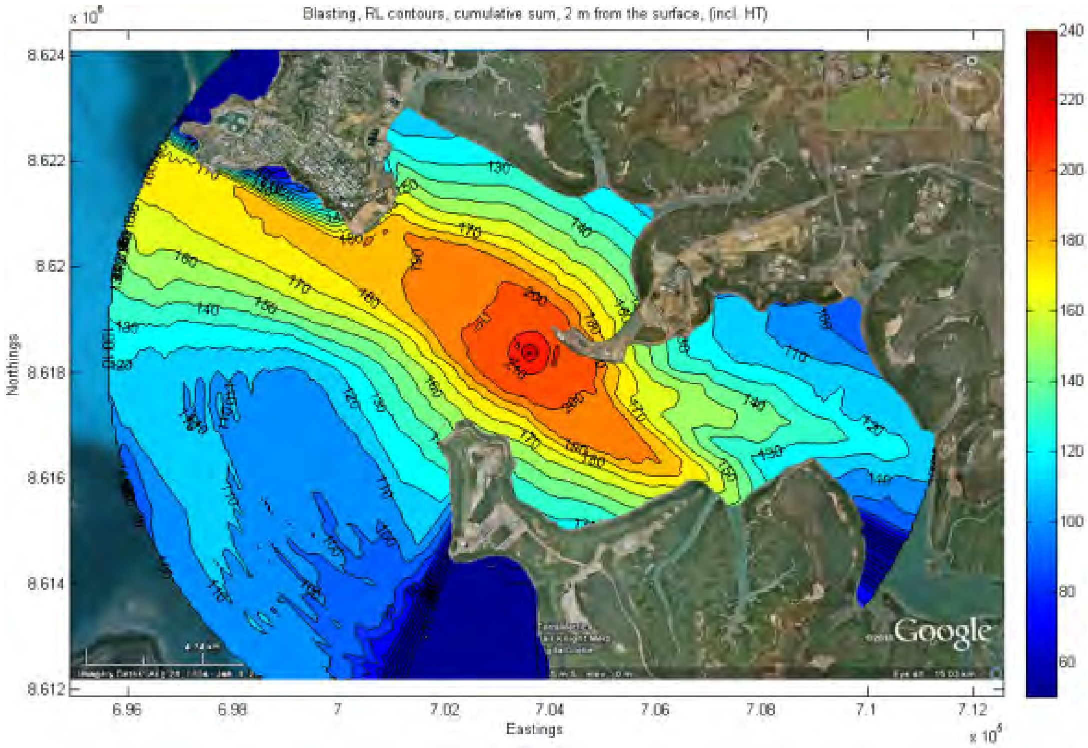

Figure 5-1 Received SPL RMS contour under the scenario of blasting operation at Walker Shoal. The blasting operation has 24 holes with 50 kg charge mass each hole

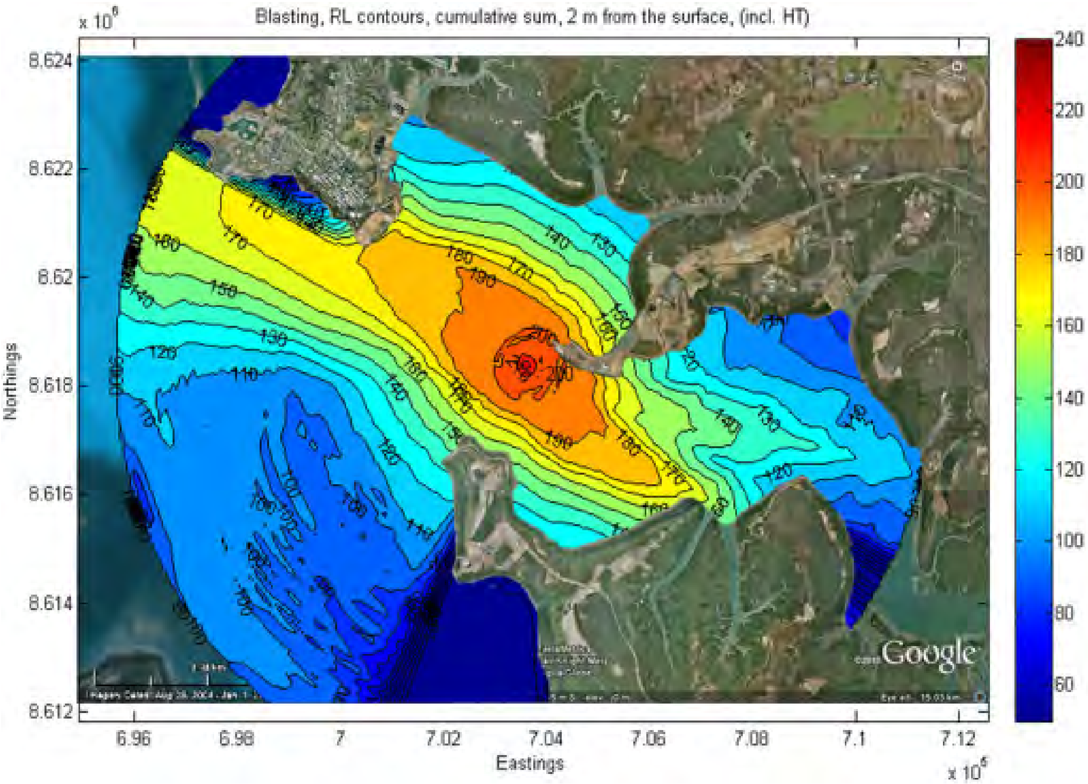

Figure 5-2 Received SPL RMS contour under the scenario of blasting operation at Walker Shoal. The blasting operation has 12 holes with 25 kg charge mass each hole

5 Modelling of Underwater Noise Generated by the Project

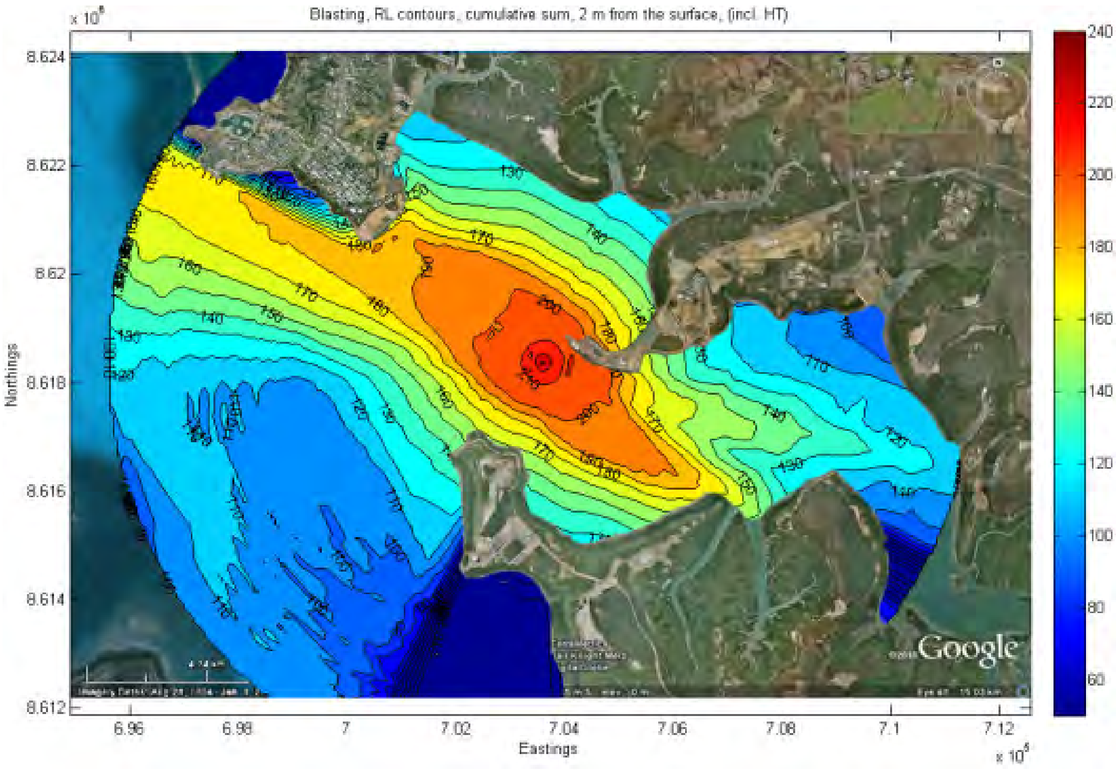

Figure 5-3 Received SPL RMS contour under the scenario of blasting operation at Walker Shoal. The blasting operation has 6 holes with 50 kg charge mass each hole

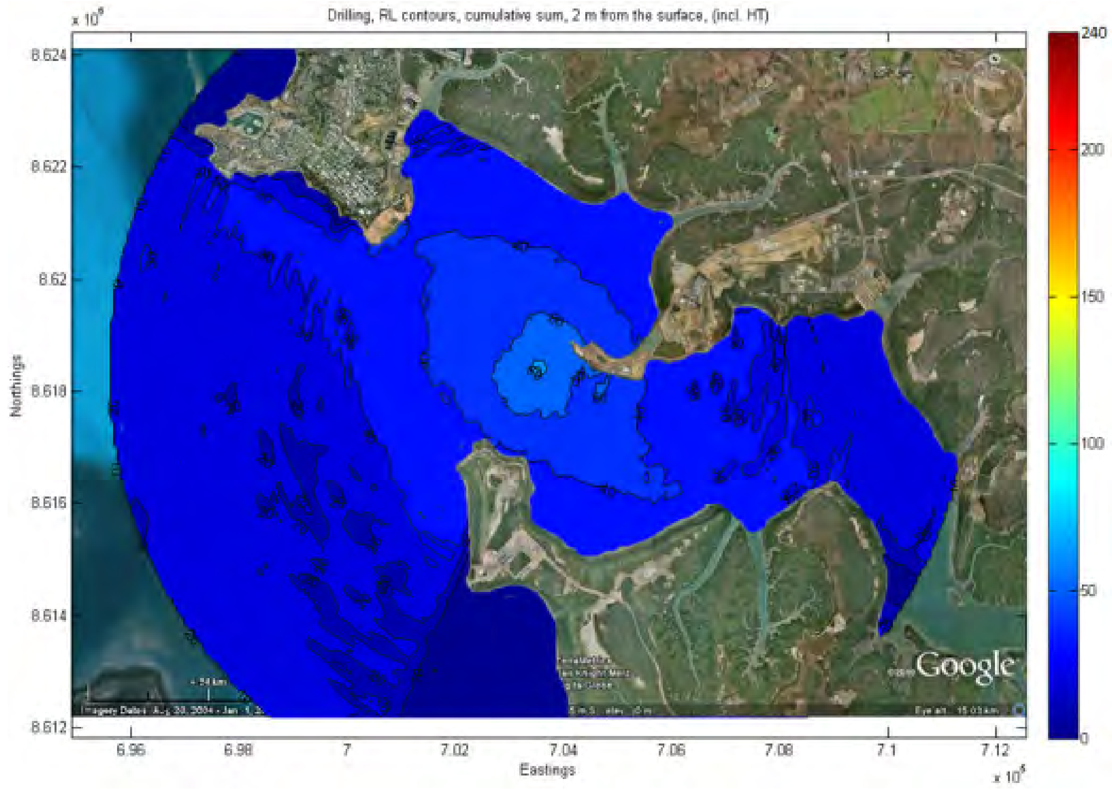

Figure 5-4 Received SPL RMS contour under the scenario of drilling operation at Walker Shoal

5.2 Pile Driving

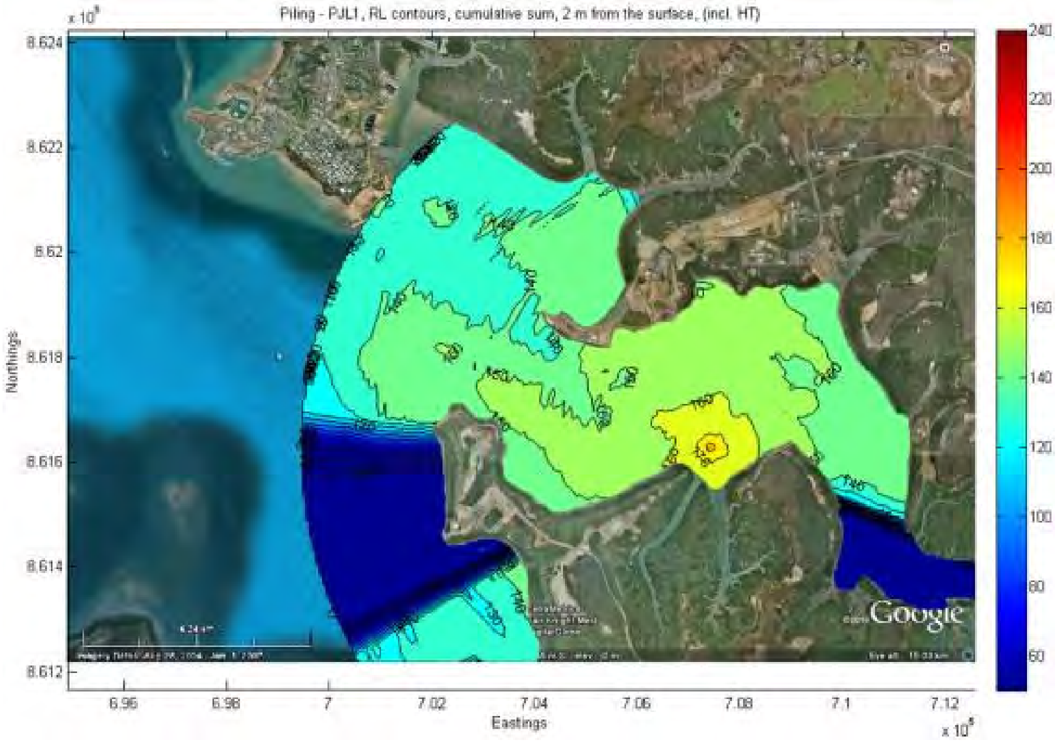

Figure 5-5 Received SPL RMS contour under the piling operation of Piling – PJL1 (6 m tidal height and sandy seabed type as model input)

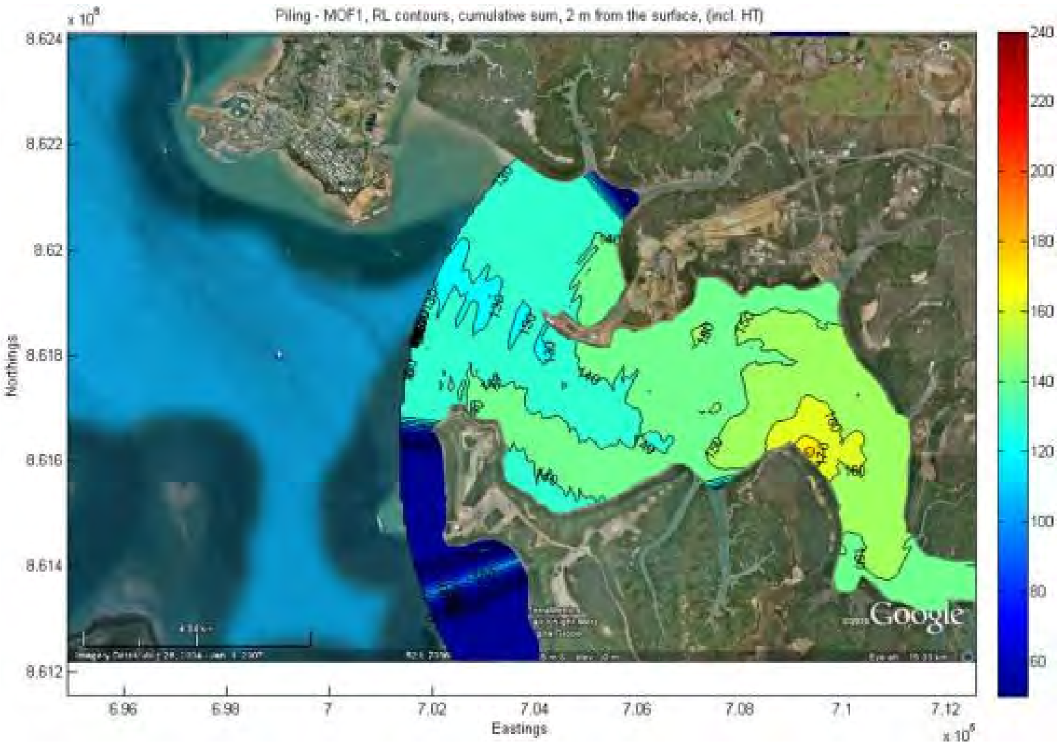

Figure 5-6 Received SPL RMS contour under the piling operation of Piling – MOF1 (6 m tidal height and sandy seabed type as model input)

5.3 Dredging

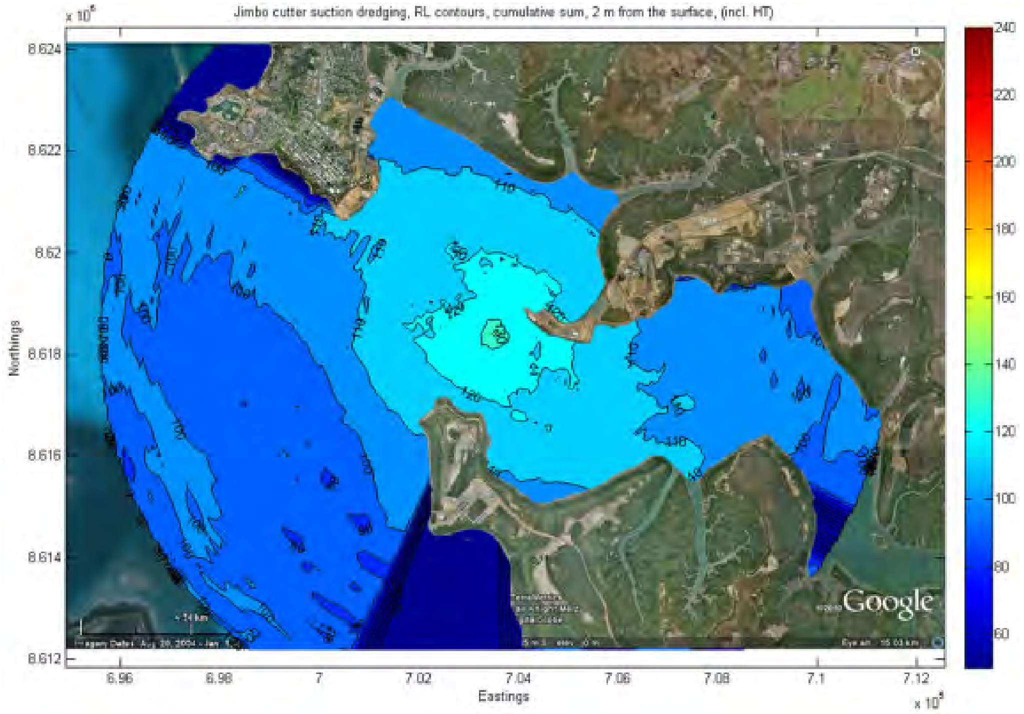

Figure 5-7 Received SPL RMS contour under the scenario of Specialised Cutter Suction Dredging operation at Walker Shoal

5.4 Hydro-hammer

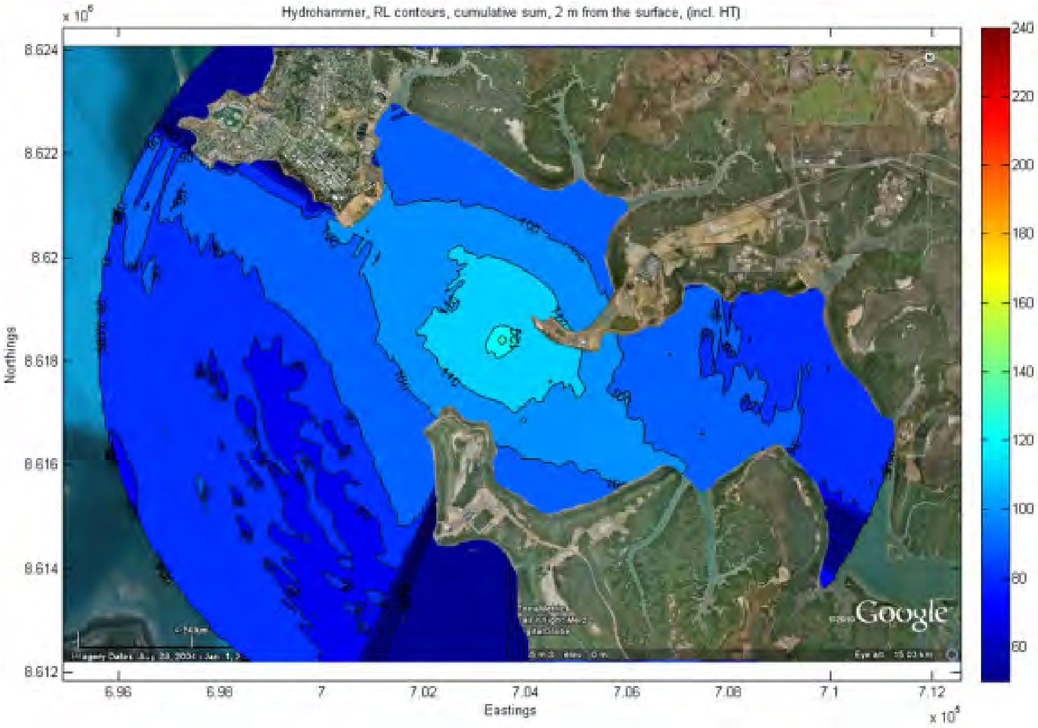

Figure 5-8 Received SPL RMS contour under the scenario of hydro-hammer operation at Walker Shoal

Recommended Exposure Criteria for Marine Fauna and Proposed Risk Mitigation Measures

6.1 Proposed INPEX Blast and Noise Exposure Criteria

No definitive models are available to predict the precise nature of, and potential for, injury. A broad range of variables relating to bathymetric and environmental conditions and the characteristic of the organisms influence the impact. As a result, ‘safe’ distances cannot be predicted with certainty, however the most recent literature has presented what may be considered conservative methodologies for making estimates of the spatial extent of the ‘area of damage’ for a range of fauna. These methodologies are based upon the most current research and analysis, amassed experience, and contemporary policy and regulatory objectives and practices.

For marine mammals the assessment adopted the exposure criteria developed by Southall et al. (2007), a panel of international experts in acoustics and marine mammal science. The Southall et al. (2007) criteria were developed for cetaceans and pinnipeds based primarily on the levels at which Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) have been found to occur. Induced PTS represents tissue injury, but TTS does not. Although TTS involves reduced hearing sensitivity following exposure, it results primarily from the fatigue (as opposed to loss) of cochlear hair cells and supporting structures and is, by definition, reversible (Nordmann, Bohne & Harding 2000). As such, PTS is considered as a reliable, conservative indicator of the onset of permanent, albeit slight, irreversible physical injury, while TTS serves as a similar, although more cautious, indicator of the possible onset of reversible physiological effects. Southall et al. (2007) also developed exposure criteria for potential adverse behavioural response by cetaceans and pinnipeds exposed to single pulses.

The conservative criteria arrived at by Southall et al. (2007) for possible injury or adverse behavioural action from exposure to a single pulse are:

- In terms of SPL peak pressure: PTS onset levels (unweighted peak levels of 224 dB [re 1 μPa]) plus 6 dB of additional exposure; that is 230 dB (re 1 μPa).
- In terms of SEL: TTS onset levels (mid frequency weighted SEL exposure of 183 dB [re 1 μPa^2-s]) plus 15 dB of additional exposure; that is 198 dB (re 1 μPa^2-s).
- In terms of behavioural response, exposure to a single pulse at a received level SPL of 224 dB (re 1 μPa) (peak), and SEL value of 183 dB (re 1 μPa^2-s).

It is noted that the DSEWPaC EPBC Act Policy Statement 2.1 applies criteria based on TTS onset; limiting exposure to an SEL of 183 dB re 1 μPa^2-s for protection of whales from exposure to the continuous pulses of a seismic survey source. This criterion is included for completeness however it is not considered to be appropriate for single pulses from individual blasts separated by several hours. For multiple exposures the DSEWPaC EPBC Act Policy Statement 2.1 assumes an exposure time of 33 minutes. The criterion, SEL of 183 dB (re 1 μPa^2-s) over a 30 minute exposure, is presented for piling noises.

As noted, the Southall et al. (2007) criteria were developed for cetaceans and pinnipeds. There are no established criteria for sound exposures for dugongs and turtles. When proposing exposure assessment criteria for turtles and fish, Broner & Huber (2010) extrapolated from existing data, particularly Southall et al. (2007) and other work by Popper and colleagues. The derived criteria proposed by Broner & Huber (2010) were used by Commonwealth authorities under the EPBC Act for the assessment of the expansion of port facilities at Hay Point (BMA 2010).

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Table 6-1 Proposed INPEX blast and noise exposure criteria for marine animals

Criterion	Metric	Type of Impact	Reference
MARINE MAMMALS			
230 dB (re 1 µPa) peak	SPL (peak unweighted)	Blast injury (PTS)	Southall et al. (2007) p. 443
198 dB (re 1 µPa^2-s)	SEL (mid frequency weighted)	Instantaneous exposure (PTS)	Southall et al. (2007) p. 443
224 dB (re 1 µPa) peak	SPL	Instantaneous exposure, behavioural response, single blast	Southall et al. (2007) p. 451
183 dB (re 1 µPa^2-s)	SEL	Instantaneous exposure, behavioural response, single blast	Southall et al. (2007) p. 451
183 dB (re 1 µPa^2-s)	SEL (mid frequency weighted)	TTS onset	DSEWPaC Seismic guidelines
TURTLES			
224 dB (re 1 µPa) peak	SPL	Blast (possible TTS)	Broner & Huber (2010) p. 2
198 dB (re 1 µPa^2-s)	SEL	Blast	Broner & Huber (2010) p. 2
183 dB (re 1 µPa^2-s)	SEL	Instantaneous exposure, behavioural response, single blast	Broner & Huber (2010) p. 2
FISH			
195 dB (re 1 µPa^2-s)	SEL	Blast - 0.1 kg fish	Broner & Huber (2010) p. 2
200 dB (re 1 µPa^2-s)	SEL	Blast - 1.0 kg fish	Broner & Huber (2010) p. 2

NOTE: These are all expressed as RLs not source levels.
It should be noted that, for calculation of safe ranges for fish, a method is available that is based upon an observed empirical correlation between pressure and mortalities (Yelverton et al 1975). However, in this instance the method of Broner and Huber (2010) is preferred in this instance as it has already been employed in Commonwealth assessments and approvals under the aegis of the EPBC Act.

6.1.1 Exposure Criteria for Behaviour

A key challenge in the development of behavioural criteria is being able to distinguish a significant behavioural response from an insignificant, momentary alteration in behaviour. To assess and quantify significant behavioural effects to noise exposure it is necessary to understand the impact such changes might have on critical biological changes, including growth, survival and reproduction.

Southall et al. (2007) noted that most behavioural response studies to date have focused on short term and localised behavioural changes whose relevance to individual effects, let alone population factors, is considered low. As an example, it is believed unlikely that a startle response to a brief, transient event would persist long enough to create any response which could be deemed significant. In addition, even strong behavioural responses to single pulses would be expected to dissipate sufficiently rapidly to have limited long term effect on individuals, let alone populations.

In respect of behavioural responses to sound exposure, it is also evident that many more factors affect behaviour than just simple acoustic metrics. These include animal activity at the time of exposure, habituation or sensitisation to the sound, as well as the presence or absence of acoustic similarities between the anthropogenic sound and biologically relevant signals in the animal's environment (e.g. calls of conspecifics, predators or prey).

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When considering information regarding behavioural responses, it is also worth considering information presented by Wartzok and Tyack (2007), who have elaborated on the Population Consequences of Acoustic Disturbance (PCAD) Model developed by the US National Research Council. Wartzok and Tyack (2007) supported the findings of Southall et al. (2007) and reported that behavioural dose-response variability is greater than physiological dose response variability. In addition, they report that behavioural variability can also be dependent on age, sex, reproductive status, season and behavioural state.

Single Pulses

Noting the lack of available data for behavioural thresholds, Southall et al. (2007) propose that following exposure to a single pulse, significant behavioural disturbance should be considered to occur at the lowest level of noise exposure that has a measurable transient effect on hearing (i.e. TTS onset). It is recognised that TTS is not technically a behavioural effect, but is used because it is believed that any loss of hearing functions, even if temporary, has the potential to affect vital rates and therefore behaviour.

The recommended behavioural disturbance criteria for all cetaceans exposed to single pulses have been developed based on the results for TTS onset in a beluga whale exposed to a single pulse. Proposed unweighted SPL criteria have been set at 224 dB (re 1 µPa). The weighted SEL criteria for mid frequency cetaceans have been set at 198 dB (re 1 µPa^2.s). Through extrapolation the same criteria have also been set for low and high frequency cetaceans, the only difference being the influence of the respective frequency weighting functions for sound exposure criteria (see Southall et al. (2007: p. 439).

Multiple Pulses and Nonpulses

In the case of multiple pulses and nonpulses, Southall et al. (2007) report that it is not currently possible to derive explicit criteria for behavioural disturbance. This conclusion is based on the large degree of variability in responses between groups, species and individuals. However, it is highlighted that most research in respect of low frequency cetaceans and nonpulses indicates no or very limited responses at a received level range of 90 to 120 dB (re 1 µPa) and an increasing probability of avoidance and other behavioural effects, albeit generally minor, at a range of 120 to 170 dB (re 1 µPa) SPL.

In the absence of data necessary to develop behavioural based criteria, Southall et al. (2007) undertook a severity scaling analysis of available observational data. This analysis was undertaken for the three cetacean groups, and includes a list of response scores from 0 to 9 with a corresponding behavioural reaction for each score (see Table 6-2). These scores are based on either individual and/or independent group behaviour.

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Table 6-2 Functional marine mammal hearing groups, auditory bandwidth (estimated lower to upper frequency hearing cut-off); genera represented in each group, and group specific (M) frequency-weightings (Southall et al. 2007)

Response score	Corresponding behaviours (Free-ranging subjects)	Corresponding behaviours (Laboratory subjects)[ii]
0	No observable response	No observable response
1	Brief orientation response (investigation/visual orientation)	No observable response
2	Moderate or multiple orientation behaviours Brief or minor cessation/modification of vocal behaviour Brief or minor change in respiration rates	No observable negative response; may approach sounds as a novel object
3	Prolonged orientation behaviour Individual alert behaviour Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Moderate change in respiration rate Minor cessation or modification of vocal behaviour (duration< duration of source operation), including the Lombard Effect	Minor changes in response to trained behaviours (e.g., delay in stationing, extended inter-trial intervals)
4	Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Brief, minor shift in group distribution Moderate cessation or modification of vocal behaviour (duration ≈ duration of source operation)	Moderate changes in response to trained behaviours (e.g., reluctance to return to station, long inter-trial intervals)
5	Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Moderate shift in group distribution Change in inter-animal distance and/or group size (aggregation or separation) Prolonged cessation or modification of vocal behaviour (duration > duration of source operation)	Severe and sustained changes in trained behaviours (e.g., breaking away from station during experimental sessions)
6	Minor or moderate individual and/or group avoidance of sound source Brief or minor separation of females and dependent offspring Aggressive behaviour related to noise exposure (e.g., tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds) Extended cessation or modification of vocal behaviour Visible startle response Brief cessation of reproductive behaviour	Refusal to initiate trained tasks
7	Extensive or prolonged aggressive behaviour Moderate separation of females and dependent offspring Clear anti-predator response Severe and/or sustained avoidance of sound source Moderate cessation of reproductive behaviour	Avoidance of experimental situation or retreat to refuge area (> duration of experiment) Threatening or attacking the sound source

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Response score	Corresponding behaviours (Free-ranging subjects)	Corresponding behaviours (Laboratory subjects)[ii]
8	Obvious aversion and/or progressive sensitization Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms Long-term avoidance of area (> source operation) Prolonged cessation of reproductive behaviour	Avoidance of or sensitization to experimental situation or retreat to refuge area (> duration of experiment)
9	Outright panic, flight, stampede, attack of conspecifics, or stranding events Avoidance behaviour related to predator detection	Total avoidance of sound exposure area and refusal to perform trained behaviours for greater than a day

It should be noted that in the context of behavioural responses in respect to the assessment of risk from noise, a response score of 0 to 6 would in most occurrences be considered a minor or transitory impact. A score of 7 would represent the threshold of onset of significant behavioural response, while a score of 8 to 9 would most likely be considered significant, as it is likely to affect vital rates.

The protection of cetaceans is regulated at two levels: individuals and populations. Population based management clearly allows for some impact on the individuals as long as the impact does not cause, or is likely to cause, significant impact to the species. This means that while injury to individuals should be minimised wherever possible, the level of behavioural impact tolerated from a particular activity should depend on the status of the relevant species (Tougaard et al. 2010).

One of the acknowledged difficulties of assessing behavioural effects is that they can only rarely be observed directly. Even if and when a behavioural reaction can be quantified, any real impacts may often only manifest themselves later in the life of the affected individuals through changes in their individual survival and reproductive success and ultimately the size, vigour and resilience of their population. A conceptual model (Figure 6-1) of these possible linkages has been developed by Tougaard et al. (2010). They postulate that in most cases the impact must thus be inferred indirectly from behavioural observations, which of itself requires a thorough understanding of the links between individuals' behaviours and population-level parameters.

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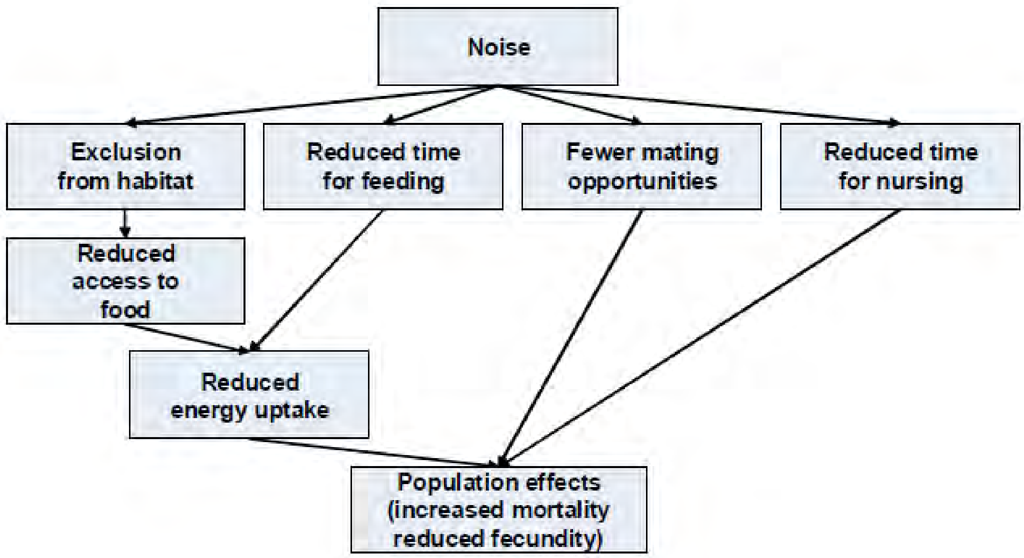

Figure 6-1 Behavioural reactions to noise can have effects on population parameters directly and indirectly (Tougaard et al. 2010)

The PCAD model (see Figure 6-2) was developed as framework to describe and assess acoustic stimuli in relation to population level effects. It is a first attempt at tracing acoustic disturbance through the entire life history of a marine mammal and determining the final consequences for a population (NRC 2005). Additional information on the interpretation and use of the conceptual model has been provided in Section 7 of the Draft EIS Appendix 15 (URS 2009).

The PCAD model requires an understanding of normal behaviour and use of sound and involves five different variables (sound, behaviour change, life function, vital rate and population effect) that are linked by four transfer steps. The first step relates the acoustic source to a behavioural response. The second defines the behavioural disruption in terms of potential effects on critical life functions (e.g. feeding and breeding). The third step aims to integrate these functional outcomes of responses over daily and seasonal cycles, and link them to vital rates in life history. The final step then relates the changes in vital rates of individual animals to overall population effects. However, it should be noted that the PCAD model is intended to serve as a conceptual model only (NRC 2005). It should also be recognised that insufficient data and understanding of applicable population ecological processes prevent actual application of the PCAD model to any discrete species or situation of acoustic exposure. Nevertheless, it provides a functional conceptual construct within which to frame assessments.

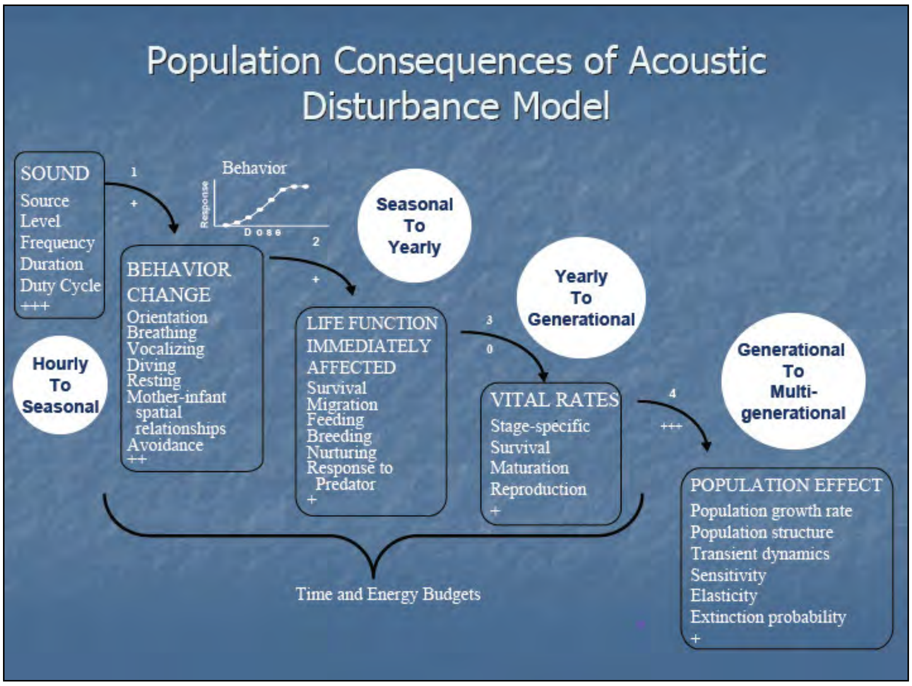

Figure 6-2 PCAD model (Wartzok & Tyack 2007)

The PCAD model complements and supports the information on behavioural disturbance presented by Southall et al. (2007). It should be noted that response scores presented by Southall et al. (2007) up to a score of 6 are most likely to fall within the first two consequence stages of the PCAD model. This supports the conclusion that responses at these levels are unlikely to be significant unless sustained over an extended period of time, as they are otherwise unlikely to affect vital rates or result in population effects.

6.2 Application of PCAD Conceptual Framework

The PCAD model is a useful conceptual tool for exploring any potential nexus between marine anthropogenic noise effects upon individuals of a species, and their translation into population level effects. Application of the PCAD model, however, is hampered by a paucity of data. Assessment of the spatial scale of biological effects requires good information on the distribution and abundance of marine life. Challenges to fill in gaps can come in many ways, due to uncertainties in population estimates for species, difficulties in weighting noise against and accumulating with other stressors, and difficulties in quantifying noise impacts. The PCAD model should be thought of as a framework that clarifies where different kinds of information fit and from within which the most plausible effect can be hypothesised.

The PCAD conceptual framework has been applied to three alternate blasting programs on Walker Shoal below. The commonly recorded cetacean species in Darwin Harbour, the Australian snubfin (*Orcaella heinsohni*) and the Indo-Pacific humpback (*Sousa chinensis*), have been used as indicator species to ascertain what likely effects may arise due to blasting.

6.2.1 Four Week Blasting Program

It is reasonable to expect that some form of behavioural response may occur during a four week blasting program on Walker Shoal. It would be expected that blasting, for any length of time, would possibly induce a change in spatial orientation and some evidence of avoidance by marine megafauna. The Indo-Pacific humpback and the Australian snubfin dolphin appear to be opportunistic generalist feeders, eating a wide variety of fish both on the seabed and within the water column (Parra 2006). No calving areas have been identified in Australian waters for either species and little is known of their reproductive biology or population structure (Ross 2006; Parra, Schick & Corkeron 2006). On the balance of probabilities, it is unlikely that a four week blasting program would coincide with any critical phase of the life history of these odontocetes within Darwin Harbour, such as feeding or breeding, even if there was a spatial overlap. Coastal dolphins within Darwin Harbour have evolved to live in a seasonally dynamic environment, so it is reasonable to assume that they have some ability to respond to environmental perturbation.

6.2.2 Sixteen Week Blasting Program

Using the PCAD model as a framework, it is plausible to surmise that marine megafauna may experience 'life function immediately affected' as a consequence of a 16 week blasting program, although it is equally likely that no such adverse effects would be experienced. It may be considered that adverse effects would only occur if the feeding, breeding or migration of marine megafauna within the harbour were affected to some significant effect. This also assumes that the potentially affected area was the only available habitat of its type, and that any species deleteriously affected could not overcome the disturbance by the simple expedient of moving to another location, even if sub-optimal. As previously stated, little is known about the feeding, breeding, movement, habitat preferences and needs, and life cycles of the Indo-Pacific humpback and the Australian snubfin dolphins in Darwin Harbour. Nevertheless, no data have been presented which suggest that the potentially affected area around Walker Shoal represents critical, unique Darwin area habitat to these species.

6.2.3 Fifty-seven Week Blasting Program

It is reasonable to expect that 'vital rates to population effect' may occur during a 57 week blasting program on Walker Shoal. The area of occupancy of the Australian snubfin dolphin cannot be deduced due to the paucity of sighting records for a large proportion of the range. However, the area of occupancy is likely to include the majority of the area of Darwin Harbour (approx. 1,000 km^2) and its contiguous waters (approx. 1,600 km^2). Population sizes of the Australian snubfin dolphin are estimated to be low, thus making population changes extremely difficult to detect within the span of one year unless changes are extreme (e.g. >20% pa) (Parra 2006).

A blasting program extending over a 57 week period could have a negative effect on a population of Darwin Harbour dolphins if:

- it induced disturbance which had a tangible negative effect upon life functions and life cycle; and
- it coincided spatially with habitat areas critical to the population, for which no substitute alternative was available as a refuge; and
- the life cycle and population were of such sensitivity that one sub-optimal year would lead to a critical negative effect upon population structure and/or vitality.

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A hypothetical construct can illustrate a plausible, but by no means certain, mechanism by which these linkages may happen to combine antagonistically to cause an adverse outcome at the population level. In this postulated scenario, a population level effect could arise from a 57 week blasting program if:

- the area around East Arm was unique and critical as an irreplaceable feeding location; and
- the blasting program resulted in the feeding behaviours of individuals being disturbed to the extent that they did not obtain sufficient nutrition, and/or they expended extra foraging time and effort which inhibited mating; and
- any resultant reduction of reproductive success of the population for a single year was at such a level that it had an adverse effect upon the viability of the population for a period extending beyond that single year.

Although little is known about Australian coastal dolphins in general, or those which inhabit Darwin Harbour in particular, it must be assumed that there is limited likelihood of all three conditions being concurrent. Furthermore, one sub-optimal season as a result of disturbance due to harbour development activities would reasonably be expected to lie within the range of natural perturbations which also detracted from population viability, and thus would be less likely to be significant in its own right. For example, natural events such as severe storms, poor seasons for prey species, and similar natural variations and cyclical events would also detract from population recruitment success, and it is axiomatic that any sustainable population must be able to demonstrate sufficient resilience to matural cycles and perturbations in order to sustain itself.

No study has found a population (or stock) level change in marine mammals as a result of noise exposure (Tasker et al. 2010), and in fact many observations indicate that populations display resilience to or such disturbance, if any discernible effect at all. A detailed review by Thomsen et al. (in prep., as cited in Tasker et al. 2010) found little response by cetacean populations to human acoustic disturbance in four case study areas. Tasker et al. (2010) postulated that if there are any adverse population effects, there are at least three explanations for a lack of correlation between noise exposure and negative population trends, as follows:

1. It is difficult to count many marine mammal species accurately.
2. Often a relatively subtle change in individual behaviour does not scale well to higher levels of aggregation (see PCAD model), or that individuals are able to adapt and thereby compensate for negative effects.
3. The benefits that come with staying in an area of high value (for example a spawning ground) might outweigh any costs caused by human disturbance.

It is likely that no factor alone is harmful enough to cause a decline directly in marine life, yet, together they may create conditions leading to reduced productivity and survival in some cases. Tasker et al. (2010) concluded that it is evident that potential impacts of sound have to be placed in a wider context, addressing the consequences of acoustic disturbance on populations in conjunction with other factors.

In summary, although a 57 week blasting program would be more likely to have some negative effect compared with one of 16 weeks or four weeks, it is by no means certain that any such effect would be critical or significant in terms of its potential effect upon a population of dolphins.

6.3 Mitigation Measures

6.3.1 Marine Drill and Blast

The outcomes of modelling of blast noise exposure have been compared to the exposure criteria referred to above and the predicted safe ranges for marine mammals, turtles and fish are given in Table 6-3.

Table 6-3 Proposed INPEX blast and noise exposure criteria and predicted safe ranges

Criterion	Metric	Type of Impact	Safe Range (m)
MARINE MAMMALS			
230 dB (re 1 µPa) peak	SPL (peak unweighted)	Blast injury (PTS)	< 1,000
224 dB (re 1 µPa) peak	SPL (peak unweighted)	Adverse behavioural reaction	1,000
198 dB (re 1 μPa^2-s)	SEL (mid frequency weighted)	Instantaneous exposure (PTS)	<50
183 dB (re 1 μPa^2-s)	SEL (mid frequency weighted)	TTS onset and adverse behavioural reaction	40–80*
TURTLES			
224 dB (re 1 µPa) peak	SPL	Blast (possible TTS)	1,000
198 dB (re 1 μPa^2-s)	SEL	Blast	<50
183 dB (re 1 μPa^2-s)	SEL	Instantaneous exposure, behavioural response, single blast	40–80*
FISH			
195 dB (re 1 μPa^2-s)	SEL	Blast - 0.1 kg fish	<50
200 dB (re 1 μPa^2-s)	SEL	Blast - 1.0 kg fish	<50

NOTE: These are all expressed as RLs not source levels.
* Variation in range is due to difference in scenarios considered.

It is crucial to balance the demands of the blasting operations with the overall safety of the species. A marine fauna monitoring and safety radius that is excessively large can result in a significant number of unnecessary project suspensions, resulting in the counter-productive prolonging of the duration of blasting and marine construction activities, vessel traffic and overall disturbance within the area. Conversely, a monitoring zone that is too small may put the animals at too great of a risk should one go undetected by the observers and move into the blast area. As a result of these factors, the goal is to establish the optimal size monitoring zone without compromising animal safety, and to provide adequate observer coverage for this zone.

The noise modelling and the associated impact assessment indicate that the proposed drill-and-blast program can be managed so that it is not likely to result in unacceptable impacts on marine fauna. The modelling indicates that the desired SPL RL threshold of 230 dB (re 1 µPa) (peak) would be realised at range of no more than 1000 m, even with the 'worst case' derived from the optimal acoustic propagation conditions assumed for the model. Similarly, the RL thresholds for SEL of 198 dB (re 1 μPa^2-s) would be attained at ranges of around 100 m or so. Consequently, the proposed 1000 m blasting Exclusion Zone will minimise the likelihood of TTS and other injury to marine mammals and turtles. Provisions will be made to monitor the Exclusion Zone for the presence of potentially sensitive fauna and to delay blasting whenever they are inside the Exclusion Zone until they exit the area.

The 1000 m mitigation range derived from the (conservative) modelling and the Southall et al. (2007) exposure criteria compares favourably with the predictions from first principles drawn from Yelverton et al. (1973) of low incidence of ‘trivial’ injuries at a range of 854 m from the blast source, and a ‘safe’ range of 1,248 m. This suggests that the work of Yelverton et al. (1973) is robust and provides a useful foundation for the development of pragmatic risk assessments and mitigation measures on the basis of the principles of physics and vertebrate anatomy.

Although the detonations would be audible to dolphins at or above the derived threshold for possible individual animal behavioural disturbance of 170 dB (re 1 μPa) (RMS) over a wider area, review and rational analysis of likely effect within the contextual framework provided by the PCAD model indicates that the likelihood of population-level effects is less likely. This of itself does not take account of possible habituation, further diminishing the likelihood and severity of any population-level effects.

6.3.2 Pile Driving

A sensitivity analysis of the predicted received levels from piling due to tidal fluctuation was undertaken. For this study one pile driving operation at the product loading jetty was used to determine the variation of predicted received noise levels due to tidal fluctuations. Three different tidal heights, 2 m, 4 m and 6 m above LAT were considered. Medium sand was used as the seabed type.

The change in predicted received levels as a result of tidal fluctuations is illustrated in Figure 6-3 which shows that tidal height fluctuation in shallow water does significantly affect the predicted received levels, particularly in the far field where acoustic propagation has more interaction with the seafloor under the lower tidal heights. By comparison, the data presented in Table 6-4 were calculated assuming a constant tidal height of 6 m (highest astronomical tide).

For a single pulse noise (such as blasting) the use of maximum tide height provides for the ‘worst-case’ scenario. Whereas for multiple exposures over an extended period the use of a constant maximum tide height overstates the actual SEL that would be received because the tide height falls and rises twice over a daily cycle and, as illustrated by Figure 6-3, the received sound level at any given location would rise and fall in unison. However because the computational power required to calculate the variation in SEL dB re 1 μPa^2-s over time for the area affected is so great it is not possible to model SEL with natural tidal fluctuations. Hence we can only note that there is an overstatement in the model that is additional to the influences of the other ‘worst-case’ assumptions made.

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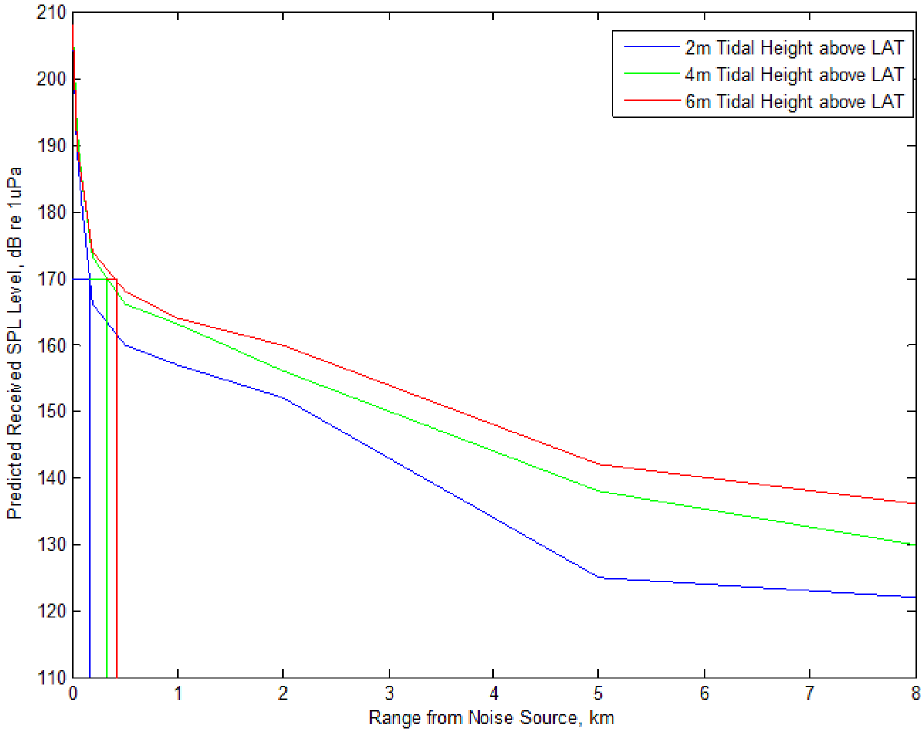

Figure 6-3 Predicted received SPL level against range from piling operation at product loading jetty under three tidal conditions (2 m (blue), 4 m (green) and 6 m (red) above LAT) and with medium sand seabed type

The outcomes of modelling of piling noise exposure have been compared to the exposure criteria referred to above and the predicted safe ranges for marine mammals, turtles and fish are given in Table 6-4.

Table 6-4 Proposed INPEX piling noise exposure criteria for marine animals and predicted safe ranges

Criterion	**Metric**	**Type of Impact**	**Safe Range (m)**
MARINE MAMMALS			
230 dB (re 1 μPa) peak	SPL (peak unweighted)	Injury (PTS) from single or multiple blows	<50
198 dB (re 1 μPa^2-s)	SEL (mid frequency weighted)	Injury (PTS) from 24 hour exposure time	500 - 1,000
183 dB (re 1 μPa^2-s)	SEL (mid frequency weighted)	TTS onset from 30 minute exposure time	2,000*
170 dB (re 1 μPa) RMS	SPL (RMS mid frequency weighted)	Adverse behavioural response to multiple pulses	500 or less
TURTLES			
224 dB (re 1 μPa) peak	SPL (peak unweighted)	Injury from single or multiple blows	<50
198 dB (re 1 μPa^2-s)	SEL (100 to 1kHz flat weighting)	Injury from single or multiple blows	500–1,000

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Criterion	Metric	Type of Impact	Safe Range (m)
183 dB (re 1 μPa^2-s)	SEL (100 to 1kHz flat weighting)	Behavioural response to multiple blows	~ 2,000
FISH			
195 dB (re 1 μPa^2-s)	SEL (100 to 2kHz flat weighting)	No injury from single or multiple blows – 0.1 kg fish	< 50–100
200 dB (re 1 μPa^2-s)	SEL (100 to 2kHz flat weighting)	No injury from single or multiple blows – 1.0 kg fish	< 50

* Requiring the animal to remain consistently within 2000 m or less of the pile driving activity within the confined zone of greatest noise exposure (see Figures 5-5 and 5-6), and the pile driving to continue without pause, and for tidal height to remain constant at maximum modelled height over this period.

The conservative, 'worst case' noise modelling and the associated impact evaluation indicate that the proposed pile driving program can be managed so that it is unlikely to have unacceptable impacts on marine fauna, and particularly any beyond a distance of around 500 m of a pile being driven into the substrate. To minimise the risk of adverse effects upon significant marine fauna, it is intended that pile driving activities will be undertaken only during daylight hours. A watch will be established and maintained for cetaceans, dugongs and turtles, commencing 30 minutes before the "soft start" of pile driving activities. If any animal is observed to be within the "fauna observation zone", that is, within a radius of 500 m of the pile driving location, the "soft start" will not proceed until the animal has been observed to have moved outside the zone or is not sighted for 10 minutes.

Pile driving will commence each day with the "soft start" procedure, where pile driving impact force is gradually scaled up over a five minute period. This will provide an opportunity for any sensitive marine animals to leave the area before full activity is realised. Once commenced, pile driving would be suspended if any dolphins were observed to come within 500 m of the active pile, although this of itself is conservative noting that the desired threshold RL of 198 dB (re 1 μPa^2-s) would generally exist at much shorter ranges and indicate that a dolphin would need to loiter within that immediate location for a period approaching one hour, as a minimum. Precaution inherent in the intended management approach is a result of the adoption of the criterion for safe range predicated on 24 hour exposure, rather than that for lesser exposures.

6.3.3 Dredging

Outcomes of noise exposure modelling been compared to the exposure criteria referred to above and the predicted safe ranges for marine mammals, turtles and fish. At no point is it predicted that noise from jumbo cutter suction dredge operations would exceed the underwater noise criteria.

6.3.4 Hydro-hammer

Outcomes of noise exposure modelling for hydraulic hammer operations at Walker Shoal have been compared to the exposure criteria referred to above and the predicted safe ranges for marine mammals, turtles and fish. At no point is it predicted that noise from hydraulic hammer operations would exceed the underwater noise criteria, primarily due to the low source level, with a peak of around 165 dB (re 1 μPa) at around 200 Hz.

Conclusions and Recommendations

The blasting of Walker Shoal as envisaged by INPEX, will expose potentially sensitive marine fauna to some level of noise and blast-induced risk. Given the size, placement and intended method of employment of the charges, there is unlikely, however, to be any substantive risk, and less so a 'significant' risk of injury. What inherent risk that does exist will be attenuated to a significant extent by INPEX's intended risk mitigation measures. The blast effects which may cause injury will be confined to a relatively small zone, further ameliorated in some directions by a degree of shielding by (remaining) portions of Walker Shoal itself.

Where risk does exist is more within the realm of behavioural disturbance related to noise from the detonations and pile driving, which would be made more acute as the blasting and pile driving programs may be extended in duration. This may manifest as one of three observed results, or perhaps a combination, namely:

- habituation by fauna of perceived sensitivity
- behavioural modification, possibly including periodic or temporary avoidance of the affected area
- permanent abandonment of the affected area.

The latter is considered the least likely outcome, given that Darwin's history of development as a trading port over the last century or so has seen numerous events and activities, including dredging campaigns, port developments involving extended pile driving programs, intense cyclonic events and other significant incidents which have included in-water explosive detonations. Despite all of these stimuli, dolphins, dugongs and other marine fauna of interest continue to reside within Darwin Harbour. This suggests a degree of tolerance or resilience.

The contention that sensitive fauna in Darwin Harbour are unlikely to be affected to any enduring degree is supported, albeit anecdotally, by observations from other similar harbour environments. For example, Cockburn Sound, near Perth, is also a major port which has been developed via a progressive program of dredging, rock blasting and pile driving. Nevertheless, the Sound supports a viable population of closely studied and monitored dolphins (*Tursiops aduncus*), with no observed impact upon this resident dolphin population evident, either within the available literature or anecdotally.

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of INPEX Browse, Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 13 October 2010.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

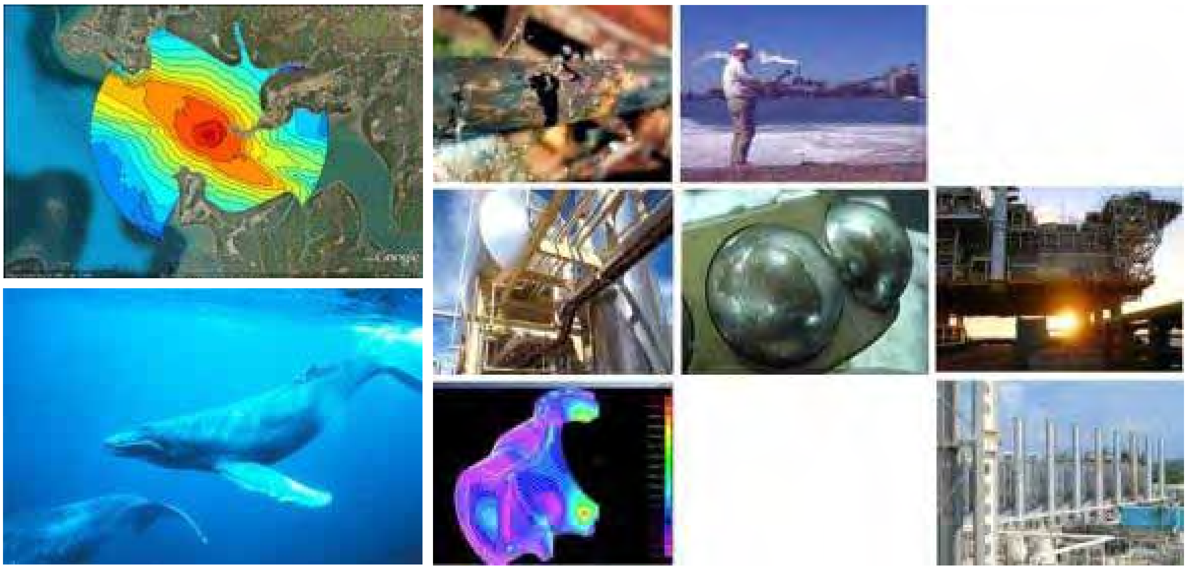
This report was prepared between December 2010 and March 2011, and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Appendix A SVT (2011) Underwater Noise Modelling Report

SVT ENGINEERING CONSULTANTS

INPEX UNDERWATER NOISE MODELLING - DARWIN HARBOUR



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EXECUTIVE SUMMARY

The work undertaken in this report covers the underwater noise modelling for the construction activities associated with the development of the LNG infrastructure in Darwin Harbour, Northern Territory, Australia. The construction activities include underwater percussion drilling and blasting, and their alternative techniques such as a Jumbo Cutter Suction dredge and hydro-hammering, as well as piling and channel dredging activities. The report documents the outcomes of the underwater noise model for these activities associated with the development.

The following scenarios as shown in Table E- 1 were modelled.

Table E- 1 Modelling scenarios, their corresponding locations and noise sources

Scenario	Location [E (m), N (m)]	Noise Source
Blasting and drilling operation and their alternative techniques – Walker Shoal		
Blasting 1 - 24 holes with 50 kg charge mass each hole	[703584, 8618374]	Blasting noise
Blasting 2 - 12 holes with 25 kg charge mass each hole	[703584, 8618374]	Blasting noise
Blasting 3 – 6 holes with 50 kg charge mass each hole	[703584, 8618374]	Blasting noise
Percussion Drilling	[703584, 8618374]	Drilling barge and equipment noise
Jumbo Cutter Suction Dredging	[703584, 8618374]	Dredging vessel noise

Scenario	Location [E (m), N (m)]	Noise Source
Hydro-hammering	[703584, 8618374]	Hammering noise
Piling operation (at PJL and MOF)		
Piling 1 – Simultaneous piling operations at PLJ1 and PLJ2	PLJ1 - [707419, 8616274] PLJ2 - [707550, 8616115]	Piling noise
Piling 2 – Simultaneous piling operations at PLJ1, PLJ2 and PLJ3	PJL1& PJL2 - as above. PLJ3 - [707677, 8615972]	Piling noise
Piling 3 – MOF1	MOF1 - [709331, 8616169]	Piling noise
Piling 4 – Simultaneous piling operations at MOF1 and MOF2	MOF1 – as above. MOF2 – [709331, 8615969]	Piling noise
Dredging operation		
Dredging 1 – right of Walker Shoal	[703856, 8618078]	Dredging vessel noise
Dredging 2 - left of Walker Shoal	[703118, 8618598]	Dredging vessel noise
Dredging 3 - Midway	[704619, 8617487]	Dredging vessel noise
Dredging 4 – MOF Berth	[709593, 8616084]	Dredging vessel noise

Modelling Results

For each modelling scenario, the received Root Mean Square (RMS) Sound Pressure Levels (SPL), the corresponding peak pressure levels (SPL peak) and Sound Exposure Levels (SEL[1]), for different ranges from the receiver to the noise sources, were modelled. Three frequency weightings, i.e. mid-frequency cetacean weighting[2], 100 – 1k Hz flat frequency weighting for turtles and 100 – 2k Hz flat frequency weighting for barramundi, were applied to the SEL estimates. Section 5 of this report details the modelling results for all modelling scenarios.

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[1] SEL is dependent on the length of exposure. The SEL levels in this report are therefore shown for different exposure durations for each range.

[2] *Southall, et al*, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

1. INTRODUCTION

SVT was commissioned by URS to model the expected underwater noise associated with the construction activities for the development of the LNG infrastructure in Darwin Harbour, Northern Territory, Australia. The report documents the outcomes of the underwater noise model for these activities associated with the development.

1.1 Background

Inpex proposes to develop the natural gas and associated condensate resources contained in the Ichthys Field situated about 220 km off Western Australia's Kimberley coast and about 820 km west-south-west of Darwin. For this project (i.e. Ichthys Project), Inpex plans to install offshore extraction facilities at the gas field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour. The infrastructure development in Darwin Harbour, which consists of an onshore component (a two-train LNG fractionation plant and a condensate stabilisation plant) and an offshore component (a product loading jetty and a facilitating channel) will also be constructed.

The construction activities associated with the offshore component of the infrastructure development in Darwin Harbour include underwater blasting, and their alternative techniques such as Jumbo Cutter Suction dredging and hydro-hammering, as well as piling and channel dredging activities. The construction area of the offshore component in the harbour is shown in Figure 1-1. The underwater noise associated with these activities may have a potential impact on marine fauna existing in the harbour (such as dolphins, dugongs, turtles and fish). The possible impacts include physical/auditory injury and behavioural disturbance.

1.2 Aim

The aim of this study is to provide the modelling outcomes of the underwater noise as a result of the proposed construction activities associated with the development of the Ichthys LNG infrastructure in Darwin Harbour, Northern Territory, Australia.

1.3 Scope

The scope of this work covers the prediction of underwater noise from the construction activities associated with the Ichthys LNG infrastructure development for various scenarios. The modelling scenarios, the corresponding locations and noise sources are listed in Table 1-1.

Table 1-1 Modelling scenarios, their corresponding locations and noise sources

Scenario	Location [E (m), N (m)]	Noise Source
Blasting and drilling operation and their alternative techniques – Walker Shoal		
Blasting 1 - 24 holes with 50 kg charge mass each hole	[703584, 8618374]	Blasting noise
Blasting 2 - 12 holes with 25 kg charge mass each hole	[703584, 8618374]	Blasting noise
Blasting 3 – 6 holes with 50 kg charge mass each hole	[703584, 8618374]	Blasting noise
Percussion Drilling	[703584, 8618374]	Drilling vessel and equipment noise
Jumbo Cutter Suction Dredging	[703584, 8618374]	Dredging vessel noise
Hydro-hammering	[703584, 8618374]	Hammering noise
Piling operation (at PJL and MOF)		
Piling 1 – Simultaneous piling operations at PLJ1 and PLJ 2	PLJ1 - [707419, 8616274] PLJ 2 - [707550, 8616115]	Piling noise

Scenario	Location [E (m), N (m)]	Noise Source
Piling 2 – Simultaneous piling operations at PLJ1, PLJ2 and PLJ3	PLJ1& PLJ2 - as above. PLJ3 - [707677, 8615972]	Piling noise
Piling 3 – MOF1	MOF1 - [709331, 8616169]	Piling noise
Piling 4 – Simultaneous piling operations at MOF1 and MOF2	MOF1 – as above. MOF2 – [709331, 8615969]	Piling noise
Dredging operation		
Dredging 1 – right of Walker Shoal	[703856, 8618078]	Dredging vessel noise
Dredging 2 - left of Walker Shoal	[703118, 8618598]	Dredging vessel noise
Dredging 3 - Midway	[704619, 8617487]	Dredging vessel noise
Dredging 4 – MOF Berth	[709593, 8616084]	Dredging vessel noise

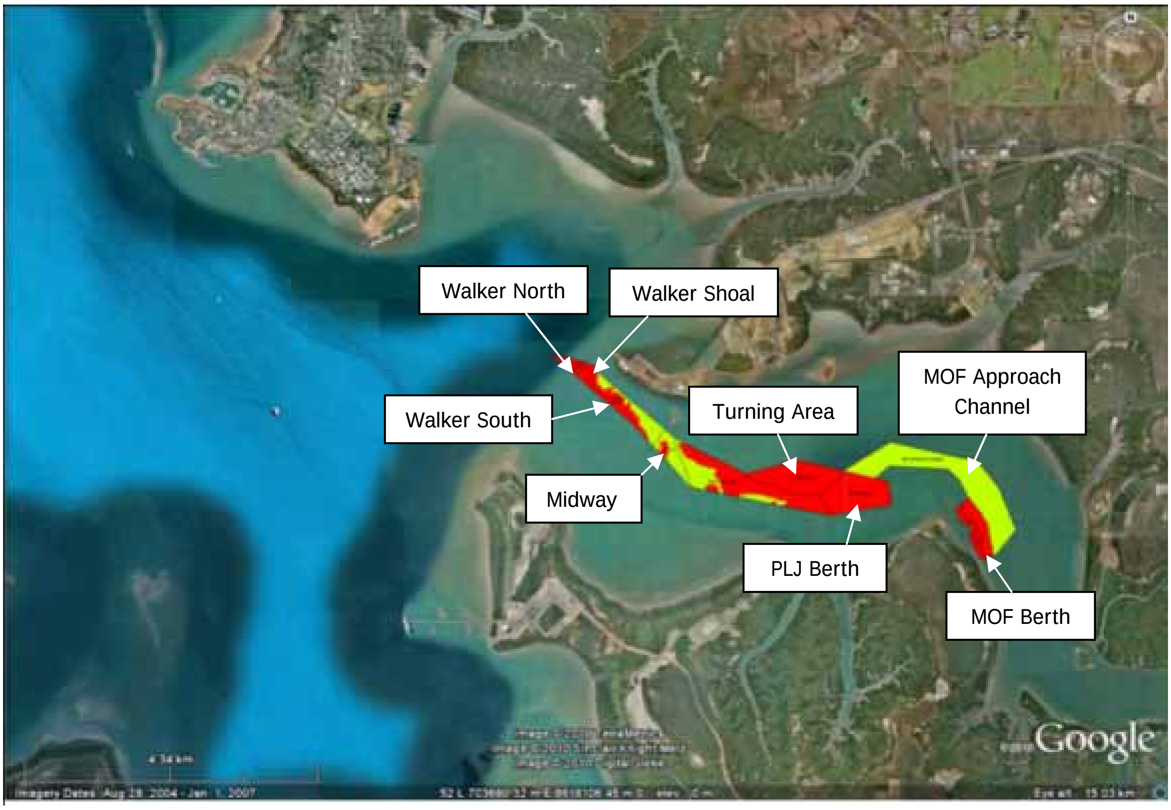

Figure 1-1 The proposed construction area in Darwin Harbour for the LNG infrastructure development. Red: area to be dredged; Green: area at/below required level.

2. NOISE SOURCES

2.1 Definitions

Some of the important definitions associated with underwater noise units and signal categories are as follows:

- **Decibel (dB).** An underwater acoustics pressure level P can be denoted as a ratio value in terms of logarithmic (base 10) scale 20log10(P/P_{ref}), with the reference pressure level P_{ref} as a micropascal (1 µPa). For example, the pressure level of 1 Mpa equals a level of 10log10(10^9) = 90 dB re 1 µPa.
- **Sound Pressure Level (SPL) Root Mean Square (RMS) units dB re 1 µPa**. The RMS pressure is the decibel value of the root mean of the squared pressure over a defined period of a signal.
- **Sound Pressure Level Peak units dB re 1 µPa (SPL peak)**. Peak pressure is the maximum recorded pressure and is measured from the mean of the signal to the maximum excursion from the mean. SPL peak can be empirically calculated based on SPL RMS as: SPL peak = SPL RMS + 18 dB re 1 uPa.
- **Sound Exposure Level (SEL) units dB re 1 µPa^2.s**. Sound Exposure Level is a measure of total energy of a signal over a certain period (e.g. the time integral of the squared-instantaneous sound pressure) normalized to a 1-s period. SEL can be calculated from the SPL RMS as: SEL = SPL RMS + 10log(T), T is the duration of the noise in seconds. As a result the longer the duration of the noise the higher the SEL will be.
- **Pulse signal.** A pulse is defined as brief, broadband, atonal, transients. Examples of pulses are explosions, gunshots, sonic booms, piling and seismic airgun pulses.
- **Non-pulse signal**. Non-pulses can be tonal, broadband, or both. Some non- pulse sounds can be transient signals of short duration but without the essential properties of pulses (e.g. rapid rise time). Examples of sources producing non-pulses include vessels, machinery operations, Floating Platform Storage and Offloading (FPSO's), Drill Rigs, Oil Rigs and Wind Turbines.

2.2 Blasting

Explosives, which are regarded as pulse signals, have two important components that are of interest in underwater noise assessments. They are as follows:

- **Shock wave**. Important in unconfined explosions (e.g. Severing steel, Seismic, bolder breakage, ordinance testing)
- **Gas component**. Generally the more useful component for material displacement (e.g. mass demolition by displacement of material with stemming)

As can be seen from the above each component is used to perform a different type of mechanical work. Explosives can be designed to release different total energy fractions of Shock wave and gas component depending on the mechanical work to be performed. All explosions have some fractions of both. This is an important consideration as the shock wave component of a blast is the most critical component for physical injury.

A delay of 25 ms between charges is planned for each confined blast.

Explosive blasts are typically broadband, non-linear effects with large peak pressures and extremely fast rise and fall times. An analytical formula can be used (if the TNT equivalent of the explosive is known) to determine the peak SPL per charge mass as shown in Figure 2-1.

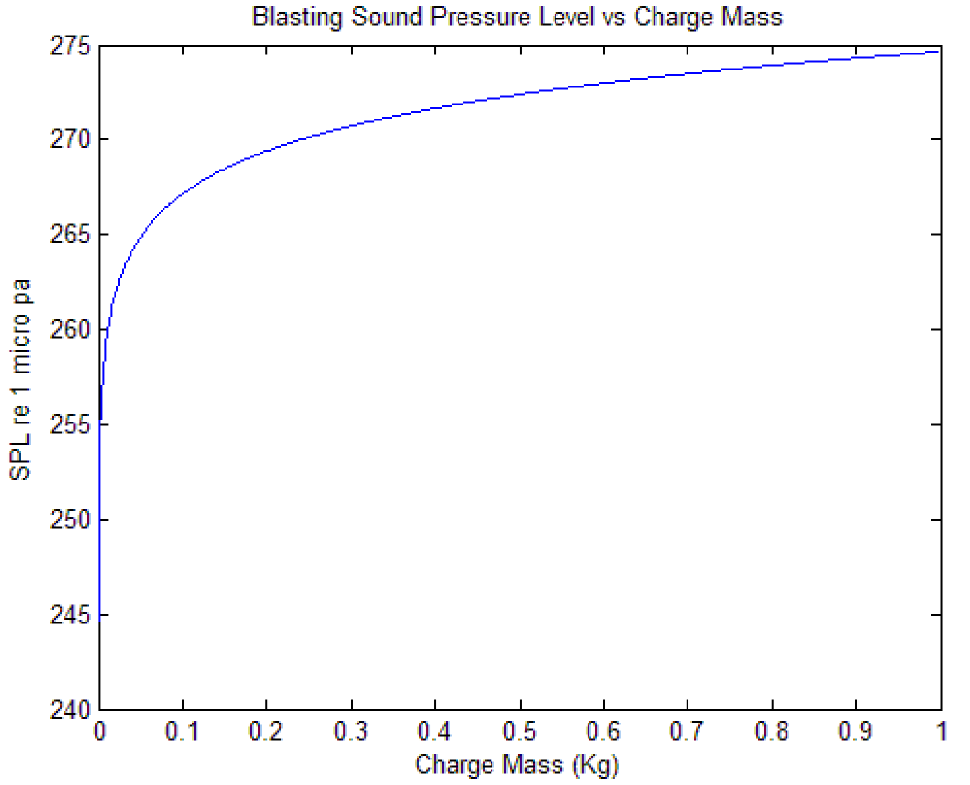

Figure 2-1 Blast Sound pressure level achieved per charge mass.

For this study, it is assumed that the blasting explosive to be used in the Walker Shoal will be an emulsion, which is the same as that is used in the mining industry. A typical emulsion has a TNT equivalent of 0.31. Detonating 50 kg of emulsion gives a peak pressure value of 108.1 MPa at a distance of 1 m using D. Ross's formula[3]. For underwater confined charges, which are expected to be used in this project, the peak pressure may be estimated as 0.4 times the peak pressure of unconfined charges[4], this translates into a peak pressure value of 276 dB re 1 µPa @ 1 m (or an estimated 258 dB re 1 µPa @ 1 m rms). The duration of the pulse can be calculated to be 24.5 µs using D. Ross's formula[1] which gives a SEL of 212 dB re 1 µPa².s. The discharge of 25 kg emulsion gives a SEL of 209 dB re 1 µPa².s. The source spectrum curve of the blasting follows the research outcome from Weston[5].

2.3 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 to the object, which

[3] Donald, Ross, 2002: Mechanics of Underwater Noise. Peninsula Publishing, Los Altos California, USA.

[4] AS 2187.2-2006 Explosives - Storage and use - Use of explosives

[5] Weston, D.E.: Underwater Explosions as Acoustic Sources, *Proc. Phys. Soc.* London, 76(pt.2):233 (1960)

forms chips at the cutting edge. Underwater drilling noise can be regarded as a non-pulse or continuous signal. The source spectrum and the spectrogram of a typical percussion drilling noise from SVT's database are shown in Figure 2-2 and Figure 2-3 respectively. As can be seen, drilling noise is dominated by very low-frequency noise, with the peak level at around 6 Hz.

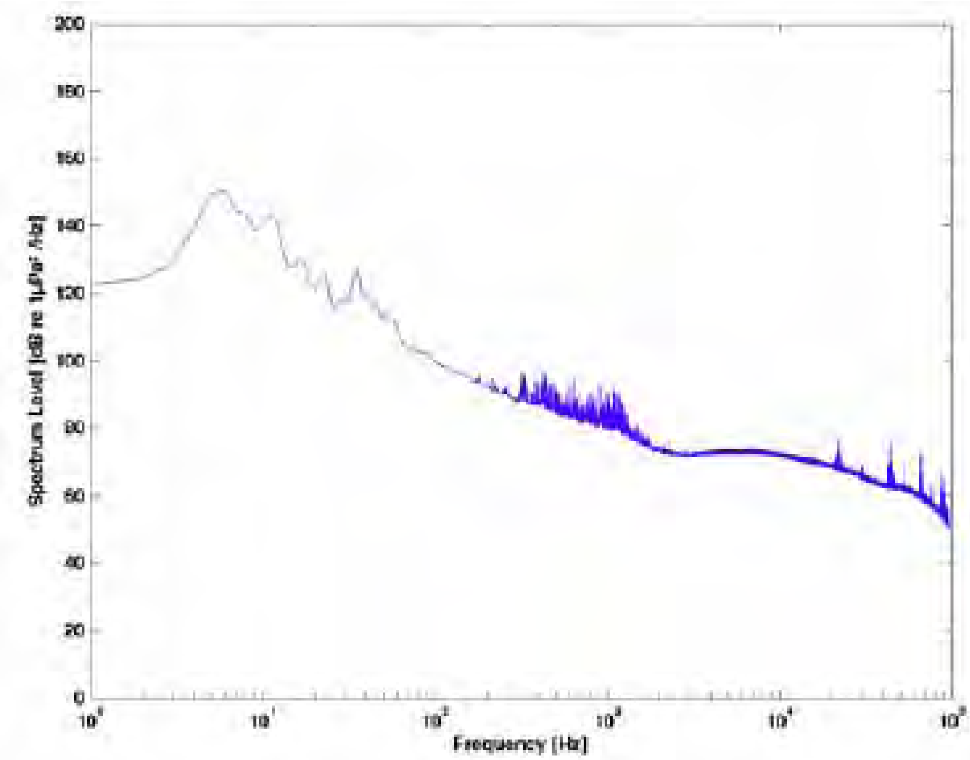

Figure 2-2 Source spectrum level of a typical percussion drilling signal.

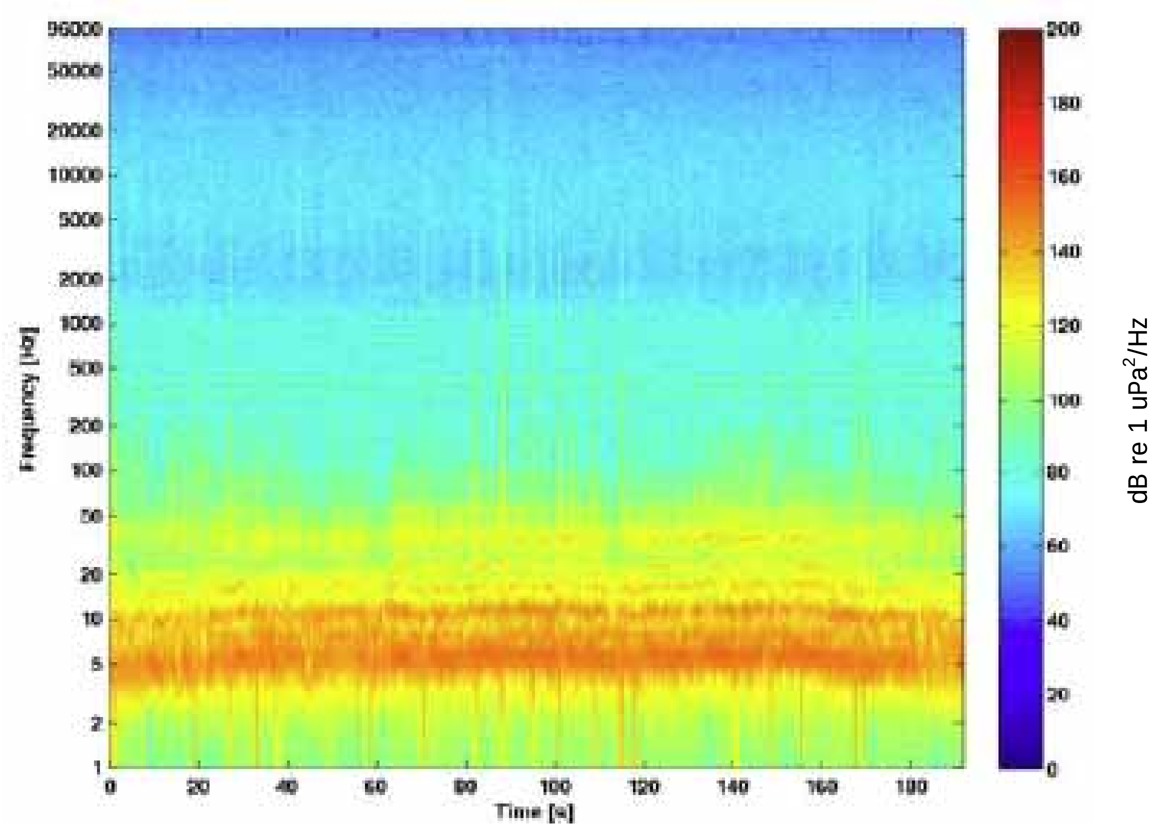

Figure 2-3 Spectrogram showing the variation of the noise from a percussion drilling operation over time.

2.4 Pile driving

Pile driving operations involve hammering a pile into the seabed. The noise emanating from a pile during a piling 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 hammering a pile into the sea bed (Figure 2-4) will excite bendy waves[6] in the pile that will propagate along the length of the pile and then into the seabed. The transverse component of the wave will create compressional waves that will propagate into the ocean while the compressional 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 compressional 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 wave energy.

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. It was assumed that hydraulic impact hammers with diameter 1500 mm will be used for pile driving operations in this project. The pile driving pulses occur roughly once every second. The noise that is generated by an impact hammer hitting the top of the pile is short in duration lasting

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

approximately 90 ms and can therefore be regarded as pulse signal. The pulse duration was used to calculate the SEL of the pile from the SPL RMS value A measured source spectrum level of a typical piling signal is given in Figure 2-5.

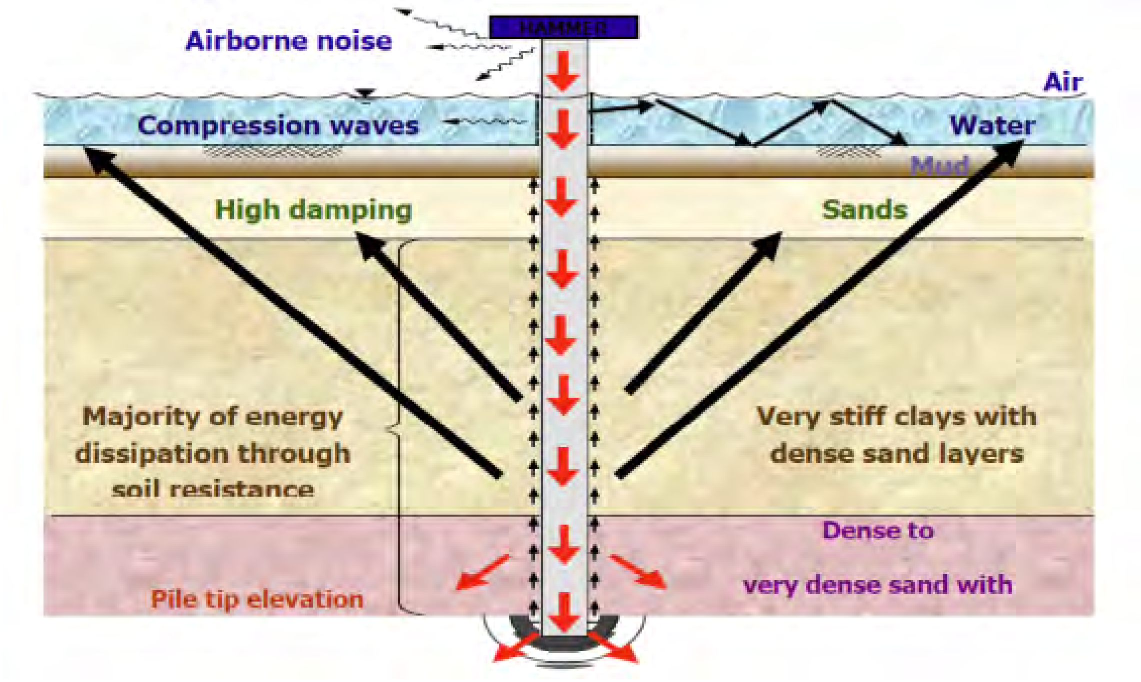

Figure 2-4 Energy transfer modes which occur when a pile is being driven into the seabed [7]

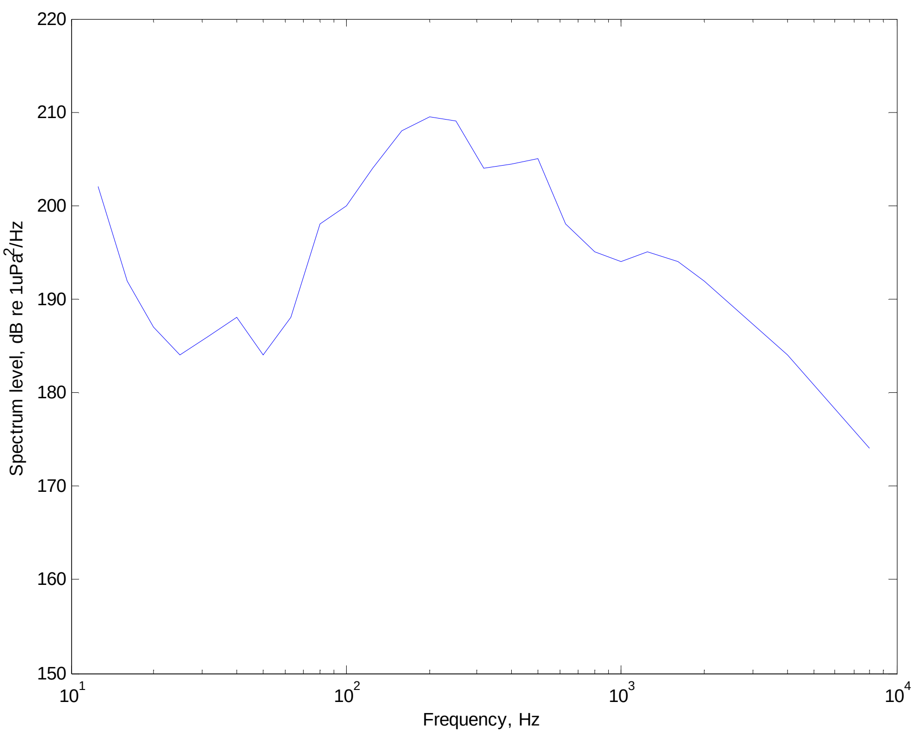

Figure 2-5 Measured source spectrum level of a typical piling signal.

[7] S. Theiss, "Development of Guidance on the effects of Pile Driving on Fish', TRB ACD40, 2006

2.5 Dredging

Dredging is an excavation operation carried out at least partly underwater, in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and disposing of them at a different location. The noise from dredging activities is mainly generated by the operating motors and engines of dredging vessels and has non-pulse characteristics. It is expected that cutter suction dredgers are going to be used to remove harder material (that trailing suction hopper dredges cannot remove) from shipping channel. A cutter suction dredger is a ship that employs a suction tube with a cutter head at the suction inlet, which is used to loosen consolidated sediment and transport it to the suction mouth. The cutter can also be used for hard surface materials like gravel or rock. The dredged material is usually sucked up by a wear-resistant centrifugal pump and discharged through a pipe line or to a barge. Figure 2-6 gives the source spectrum level of a cutter section dredger that was measured by SVT.

Jumbo Cutter Suction Dredgers are considered as an alternative to the drilling and blasting operation at Walker Shoal. As the source spectrum data for Jumbo Cutter Suction Dredger is not available, its spectrum curve was assumed as the same as that of normal cutter suction dredger (see Figure 2-6) with a 6 dB higher spectrum level than that of normal cutter suction dredging based on a conservative consideration.

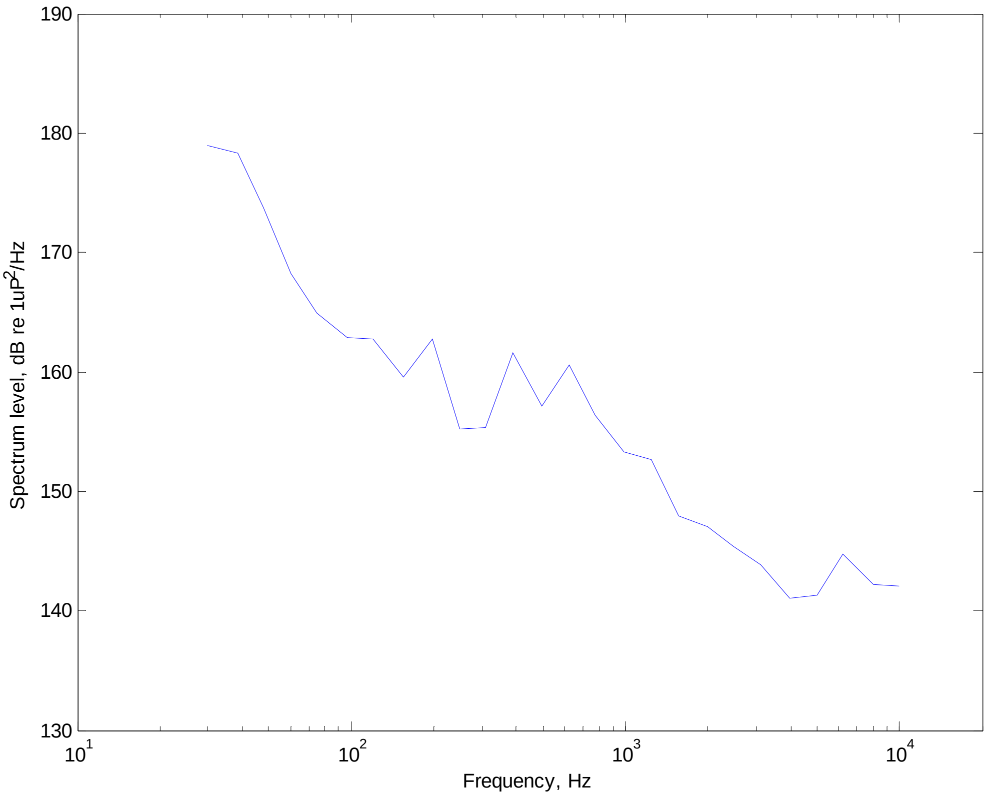

Figure 2-6 Source spectrum level of a normal cutter suction dredger measured by SVT

2.6 Hydro-hammer

Hydrohammer is a proprietary piece of kit manufactured by IHC and hydraulically operated hydro-hammer has a solid one-piece ram with fully enclosed hammer housing. The hammer operating cycle repeats itself automatically controlled by the pressure valve. The ram is guided by oil lubricated upper and lower bearings which eliminate wear on the ram.

The hydro-hammer is suitable for all types of piling and foundation works ranging from impact sensitive concrete piles, to large and long offshore caisson piles, and also includes underwater rock breaking at full energy.

Signals generated from hydro-hammering operation are regarded as pulses. Figure 2-7 shows the spectrum level of the hydro-hammer provided by Inpex. It is assumed that the blow rate of the hammer is roughly equal to the pile driving, i.e. 60 blows per minute, with the duration of each hammering impulsive signal as approximately 90 ms. The duration was used to calculated the SEL of the hammer.

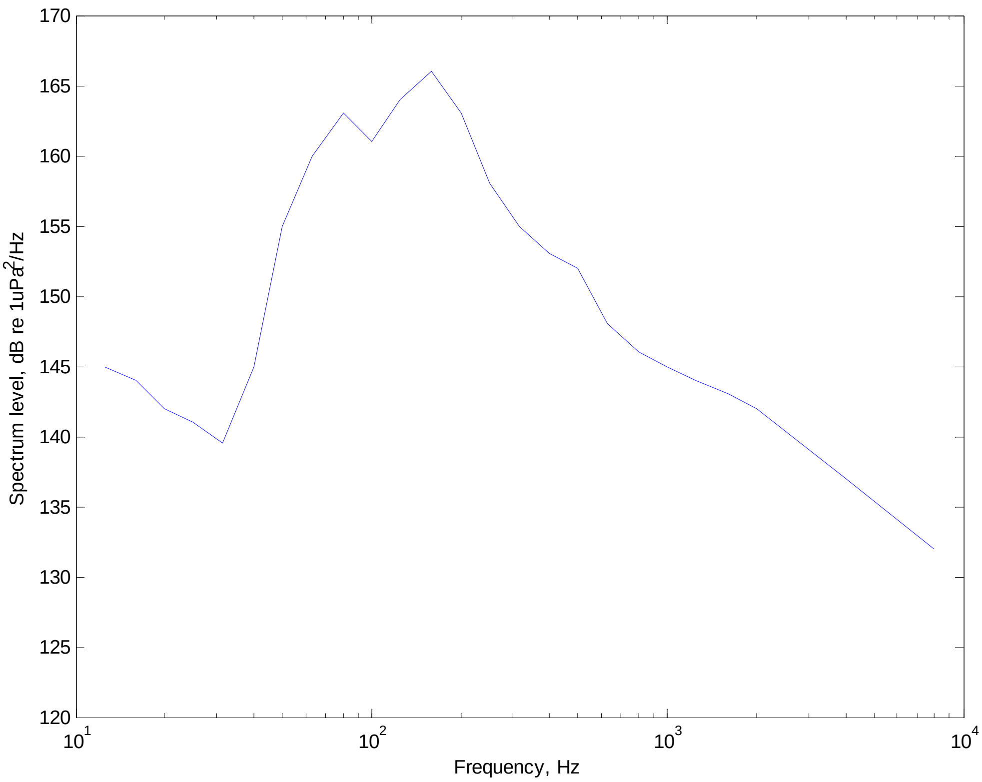

Figure 2-7 Source spectrum level of a hydro-hammer operation

3. METHODOLOGY

3.1 Underwater Noise Modelling

Underwater noise propagation models use bathymetric data, geoacoustic information and oceanographic parameters as inputs to produce estimates of the acoustic field in the water column at any depth and distance from the source. The accuracy of the environmental information used in the model is critical for the modelling prediction. For example, the geoacoustic parameters of the seabed, particularly the seabed layer structure, the compressional and shear sound velocities for each layer material, and the corresponding sound attenuation coefficients can significantly affect the acoustic propagation and can therefore affect the accuracy of the model predictions.

3.1.1 Model Selection

Various numerical techniques are used for the development of 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 model. For this model, the underwater environment has the following characteristics:

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

Parabolic Equation (PE) models are by nature capable of making predictions in environmental conditions that are range dependent, in 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 benchmark tested for shallow water environment[8].

3.1.2 Data and Model Limitations

The following data and model limitations need to be noted:

1. **Rough Surface Scattering**. Acoustics wave scattering due to the roughness of sea surface and seabed is not accounted for in the model. This is a worse case scenario as there is no acoustic energy loss due to the rough surface scattering.
2. **Salinity and Sound Speed Profiles**. The water depth in the modelling area is relatively shallow. It can therefore be assumed that the water column is isothermal. This assumption has been supported by CTD drop data that supplied to SVT by Inpex. Additionally, salinity will have negligible effect on the sound speed profile. Variation in the model's sound speed profile has been limited to the effects of water column pressure.

[8] Shallow Water Acoustic Modelling (SWAM 99) Workshop

3.1.3 Model Environmental Inputs

The following environmental conditions were inputted into the model:

Tide level

In all cases for this study, the Highest Astronomical Tide (HAT) of 6 meters in the region of Darwin Harbour was used as it represents the worst case scenario.

Seabed Types

Based on geophysical survey data supplied to SVT by Inpex, the seabed features in the region of Darwin Harbour can be interpreted predominantly as fine to medium and coarse gravelly sands with limestone base of up to 50 m below the seabed. In terms of the seabed types for the modelling, the worst case scenario, i.e. the conditions under which the greatest propagation of noise would be produced, was chosen by inputting the sandy seabed type. At small grazing angles which apply to the propagation of sound in the shallow water region, the reflection coefficient of sand is higher than that of limestone. The geoacoustic properties of the seabed types used in the model are as described in Table 3-1.

Table 3-1 Geoacoustic properties of the seabed type used in the model.

Type	Sound speed (m/s)	Density (g/cm^3)	Compressional Attenuation (dB/m/kHz)	Shear Attenuation (dB/m/kHz)	Shear Speed (m/s)
Fine to medium sand	1774.0	2.050	0.374	0	0

Sound Speed Profile

The sound speed profile in Darwin harbour was assumed to be isothermal with a constant temperature of 27 ºC and a constant salinity of 35 ppt. This also represents the worst case scenario as the surface duct in the isothermal environment allows longer acoustic propagation in the water column.

3.1.4 Model SPL RMS Contour and Depth

The model can produce horizontal contours of SPL RMS, SPL peak and SEL for any depth as well as vertical plots showing depth versus range for any bearing. It is not practical to provide contour plots of all the various parameters (i.e. SPL RMS, SPL peak and SEL) for each depth. As a result only a selected number of SPL RMS contour plots with the depth of 2 m below the sea surface are provided in this report.

4. MODEL INPUT

Modelling scenarios involves a number of noise sources, as shown in Table 1-1. The noise sources, their locations and source depths for blasting, piling and dredging operation scenarios are listed in Table 4-1, Table 4-2 and Table 4-3 respectively.

The model was run for the octave bands from 64 Hz to 8 kHz as this is within the auditory bandwidth of the marine fauna species in Darwin Harbour and it is the bands in which the noise sources have most of their energy.

Table 4-1 Noise source locations and depths for blasting, drilling and alternative technique operation scenarios

Noise Sources for Blasting, Drilling and alternative techniques scenario	Location [Easting (m), Northing (m)]	Source Depth (m) (below sea surface)
Blasting	[703584, 8062876]	14 [9]
Drilling	[703584, 8062876]	8
Alternative – Jumbo Cutter Suction Dredging	[703584, 8062876]	2
Hydo-hammering	[703584, 8062876]	8

Table 4-2 Noise source locations and depths for piling operation scenarios

Noise Sources for Piling Operation Sceanrio	Location [Easting (m), Northing (m)]	Source Depth (m) (below sea surface)
Piling – PJL1	[707419, 8616274]	3
Piling – PJL2	[707550, 8616115]	3

[9] The explosion was assumed as 4m below seabed.

Noise Sources for Piling Operation Sceanrio	Location [Easting (m), Northing (m)]	Source Depth (m) (below sea surface)
Piling – PJL3	[707677, 8615972]	3
Piling – MOF1	[709331, 8616169]	3
Piling – MOF2	[709331, 8615969]	3

Table 4-3 Noise source locations and depths for dredging operation scenarios

Noise Sources for Dredging Operation Scenario	Location [Easting (m), Northing (m)]	Source Depth (m) (below sea surface)
Dredging 1 – Walker South	[703856, 8618079]	2
Dredging 2 – Walker North	[703118, 8618598]	2
Dredging 3 - Midway	[704619, 8617487]	2
Dredging 4 - MOF	[709593, 8616084]	2

5. MODELLING RESULTS

For each modelling scenario, the received Root Mean Square (RMS) Sound Pressure Levels (SPL), the corresponding peak pressure levels (SPL peak) and corresponding Sound Exposure Levels (SEL), for different ranges from the receiver to the noise sources, were modelled. Three frequency weightings, i.e. mid-frequency cetacean weighting[10], 100 – 1k Hz flat frequency weighting and 100 – 2k Hz flat frequency weighting, were applied to the SEL estimates, along with various exposure durations.

SEL values for 30 minutes, 1 hour, 3 hours and 24 hours have been calculated for each scenario for each range. The times were selected because the level of exposure (i.e. the SEL) is dependent on the length of time the animal is exposed to the noise. As *Southal et al*'s criteria are based on a 24 hour period the maximum SEL has been calculated for a 24 hour period (i.e. the animal is exposed continuously for 24 hours at a specific range). If an animal is only exposed for a portion of that time then the calculated SEL for that portion will be its exposure for the full 24 hour period[11].

Table 5-1, Table 5-2 and Table 5-3 provide the modelled received levels of SPL RMS, SPL peak and SEL for blasting, piling and dredging operation scenarios respectively. The relevant contour plots of SPL RMS were provided following the respective modelling operations.

5.1.1 Sensitivity study on tidal fluctuation

A sensitivity study of the predicted received levels due to tidal fluctuation was undertaken. For this study one pile driving operation at PLJ1 was used to determine the sensitivities of predicted received noise levels to tidal fluctuations. Three different tidal heights, i.e. 2m, 4m and 6m above LAT were considered. Medium sand was used at the seabed type.

The change in predicted received levels as a result of tidal fluctuations can be seen in Figure 5-1. As can be seen from this figure tidal height fluctuation in shallow water does affect the predicted received levels, particularly in the far field where acoustic propagation has more interaction with seafloor under the lower tidal height. The more interactions with the seabed results in lower predicted received levels. It can also be noted that there is a larger drop between predicted received levels for a 6 m and 4 m tide than that between a 4m and 2m tide.

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[10] *Southall, et al*, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[11] For example if an animal is exposed to 30 minutes of pile driving at a range of 500 m and then moves far away from the pile driving then its exposure from pile driving will be 194 dB re 1µPa2.S for a 24 hour period. If the animal is exposed to another noise source over a 24 hour period the exposure levels will then add cumulatively.

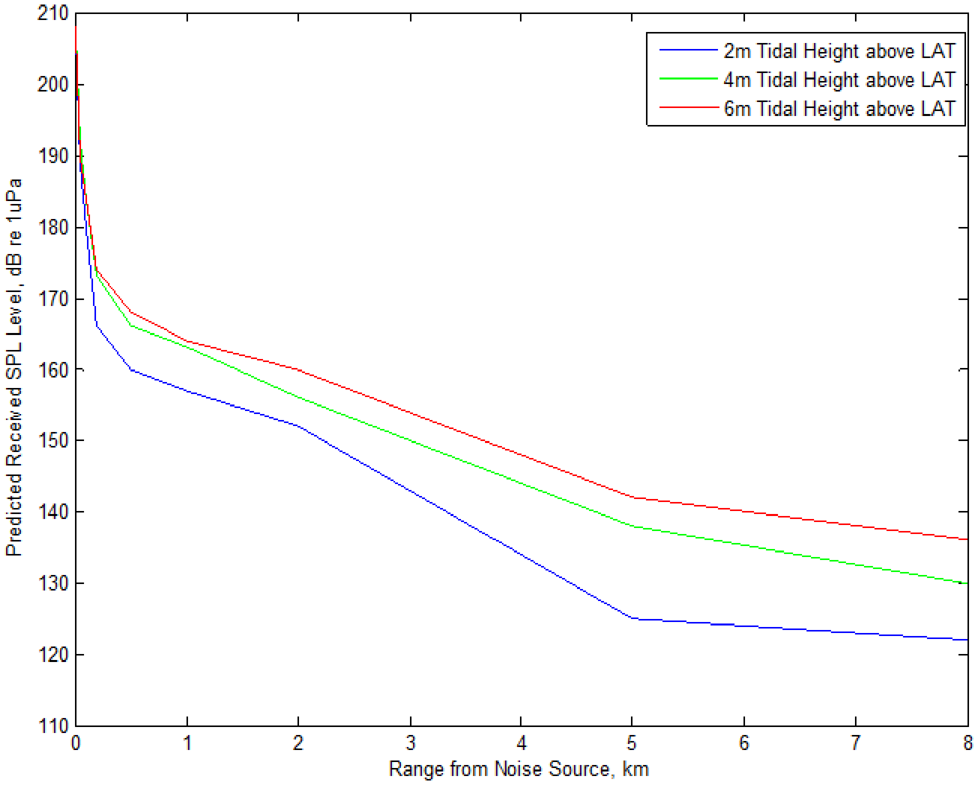


Figure 5-1 Predicted received SPL level against range from piling operation at location of PLJ1, under three tidal conditions (2m (blue), 4m (green) and 6m (red) above LAT) and with medium sand seabed type.

Table 5-1 Received levels of SPL RMS, SPL peak and SEL against different ranges from receivers to the noise source location under the tidal height of 6 m and sandy seabed type. SEL was estimated under various exposure durations and frequency weightings.

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re 1μPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
Blasting[12]– 24 holes with 50 kg charge mass each hole	0.05	231	249	185	185	185	191	185	185	185	191	185	185	185	191
	0.1	226	244	180	180	180	186	179	179	179	185	179	179	179	185
	0.2	218	236	172	172	172	178	171	171	171	177	171	171	171	177
	0.5	214	232	166	166	166	172	166	166	166	172	166	166	166	172
	1.0	206	224	160	160	160	166	159	159	159	165	159	159	159	165

[12] Inpex has indicated that it is expected that there will be up to 4 blasts per day. It was therefore assumed that each blast will be interspaced by 3 hours.

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1µPa) (unweighted)	SPL peak (dB re 1µPa) (unweighted)	SEL (dB re 1µPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	2.0	198	216	153	153	153	159	152	152	152	158	152	152	152	158
	5.0	185	203	137	137	137	143	137	137	137	143	137	137	137	143
	8.0	174	192	126	126	126	132	126	126	126	132	126	126	126	132
Blasting[11] – 12 holes with 25 kg charge mass each hole	0.05	226	244	180	180	180	186	180	180	180	186	180	180	180	186
	0.1	226	244	175	175	175	181	174	174	174	180	174	174	174	180
	0.2	218	236	167	167	167	173	166	166	166	172	166	166	166	172
	0.5	214	232	161	161	161	167	161	161	161	167	161	161	161	167

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1µPa) (unweighted)	SPL peak (dB re 1µPa) (unweighted)	SEL (dB re 1µPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	1.0	206	224	155	155	155	161	154	154	154	160	154	154	154	160
	2.0	198	216	148	148	148	154	147	147	147	153	147	147	147	153
	5.0	185	203	132	132	132	138	132	132	132	138	132	132	132	138
	8.0	174	192	121	121	121	127	121	121	121	127	121	121	121	127
Blasting[13] – 6 holes with 50 kg charge	0.05	231	249	180	180	180	186	180	180	180	186	180	180	180	186
	0.1	226	244	175	175	175	181	174	174	174	180	174	174	174	180

[13] Inpex has indicated that it is expected that there will be up to 4 blasts per day. It was therefore assumed that each blast will be interspaced by 3 hours.

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re 1μPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
mass each hole	0.2	218	236	167	167	167	173	166	166	166	172	166	166	166	172
	0.5	214	232	161	161	161	167	161	161	161	167	161	161	161	167
	1.0	206	224	155	155	155	161	154	154	154	160	154	154	154	160
	2.0	198	216	148	148	148	154	147	147	147	153	147	147	147	153
	5.0	185	203	132	132	132	138	132	132	132	138	132	132	132	138
	8.0	174	192	121	121	121	127	121	121	121	127	121	121	121	127
Drilling	0.05	70	88	103	106	110	119	103	106	110	119	103	106	110	119

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re 1μPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	0.1	64	82	96	99	103	112	96	99	103	112	96	99	103	112
	0.2	57	75	91	94	98	107	92	95	99	108	92	95	99	108
	0.5	54	72	88	91	95	104	88	91	95	104	88	91	95	104
	1.0	51	69	84	87	91	100	84	87	91	100	84	87	91	100
	2.0	45	63	78	81	85	94	79	82	86	95	79	82	86	95
	5.0	34	52	67	70	74	83	68	71	75	84	68	71	75	84
	8.0	29	47	63	66	70	79	63	66	70	79	63	66	70	79

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1µPa) (unweighted)	SPL peak (dB re 1µPa) (unweighted)	SEL (dB re $1\mu Pa^2.S$) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
Jumbo Cutter Suction Dredger	0.05	148	166	175	178	182	191	175	178	182	191	175	178	182	191
	0.1	137	155	165	168	172	181	164	167	171	180	164	167	171	180
	0.2	134	152	161	164	168	177	161	164	168	177	161	164	168	177
	0.5	130	148	157	160	164	173	157	160	164	173	157	160	164	173
	1.0	126	144	152	155	159	168	153	156	160	169	153	156	160	169
	2.0	120	138	147	150	154	163	146	149	153	162	146	149	153	162
	5.0	109	127	137	140	144	153	137	140	144	153	137	140	144	153

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re 1μPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	8.0	103	121	129	132	136	145	127	130	134	143	127	130	134	143
Hydro-Hammer	0.05	135	153	158	161	165	174	158	161	165	174	158	161	165	174
	0.1	128	146	151	154	158	167	151	154	158	167	151	154	158	167
	0.2	124	142	147	150	154	163	146	149	153	162	146	149	153	162
	0.5	120	138	142	145	149	158	143	146	150	159	143	146	150	159
	1.0	116	134	138	141	145	154	138	141	145	154	138	141	145	154
	2.0	110	128	133	136	140	149	134	137	141	150	134	137	141	150

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1µPa) (unweighted)	SPL peak (dB re 1µPa) (unweighted)	SEL (dB re 1µPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	5.0	96	114	118	121	125	134	119	122	126	135	119	122	126	135
	8.0	91	109	113	116	120	129	115	118	122	131	115	118	122	131

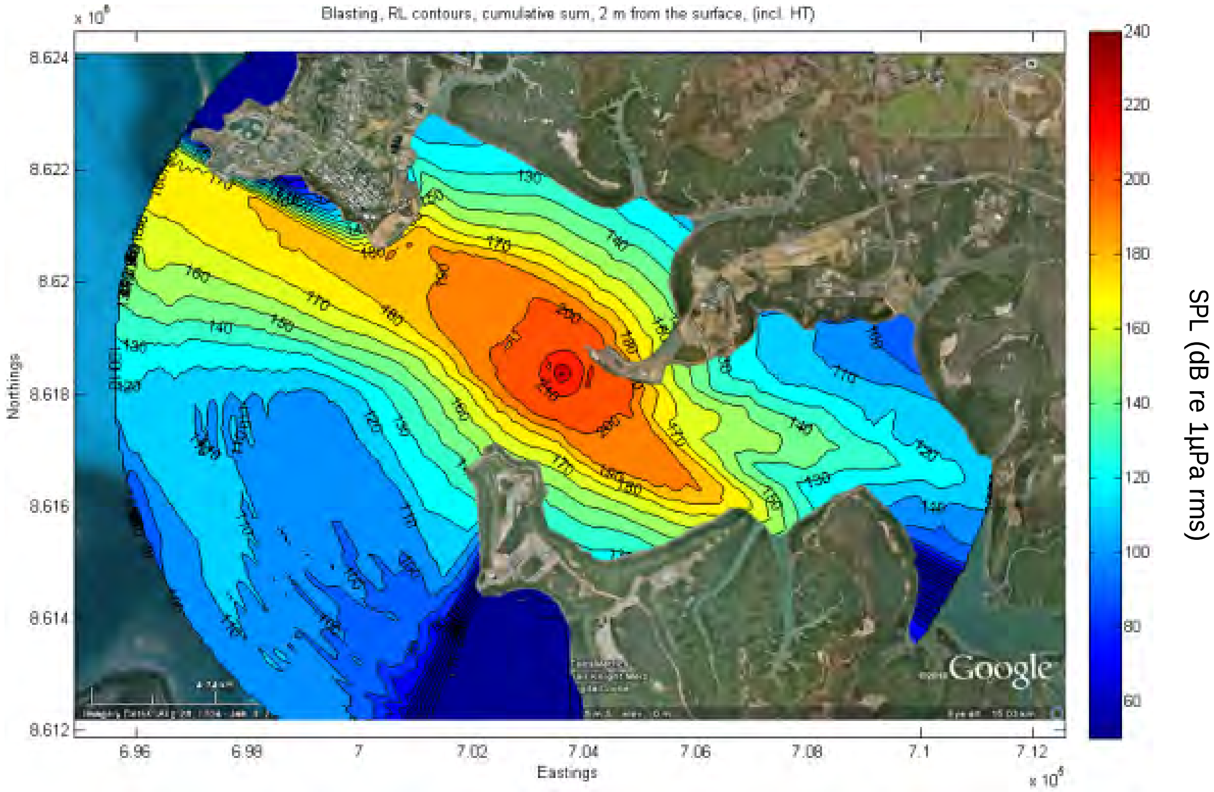


Figure 5-2 Received SPL RMS contour under the scenario of blasting operation at Walker Shoal. The blasting operation has 24 holes with 50 kg charge mass each hole.

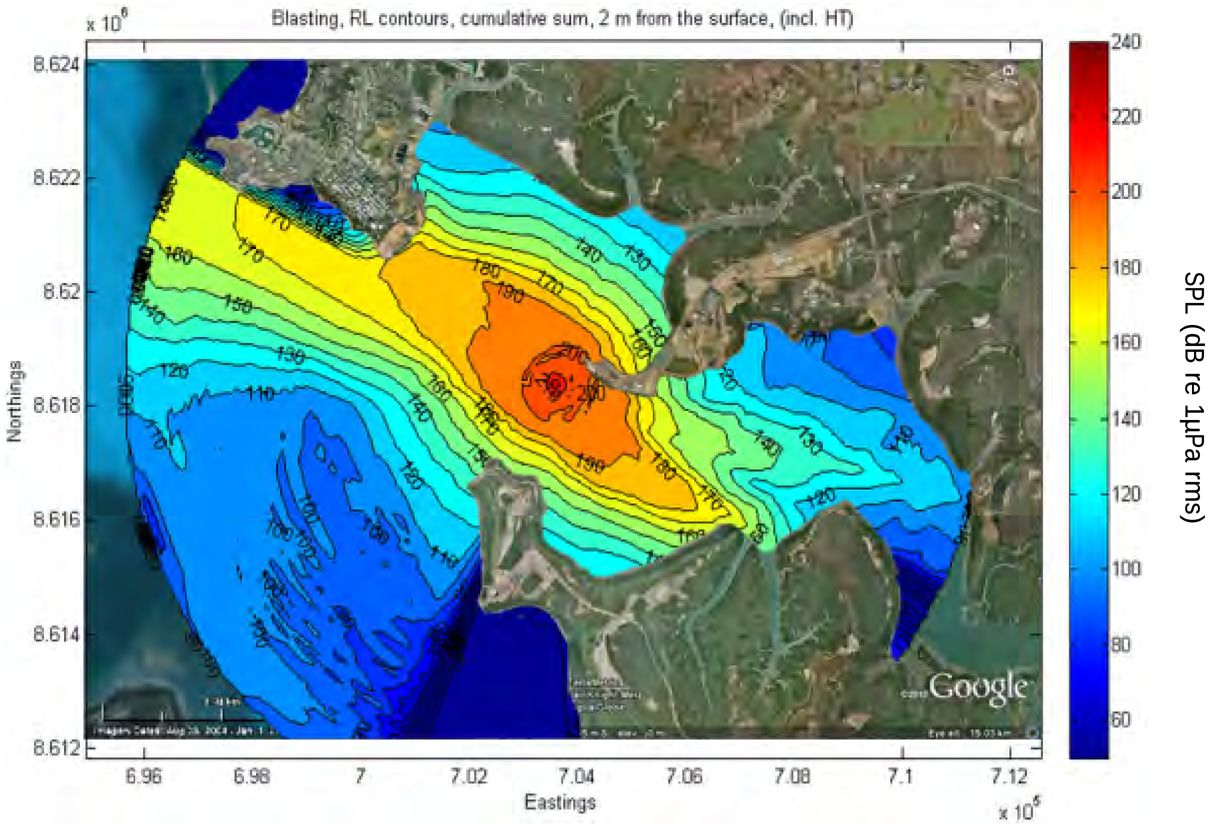


Figure 5-3 Received SPL RMS contour under the scenario of blasting operation at Walker Shoal. The blasting operation has 12 holes with 25 kg charge mass each hole.

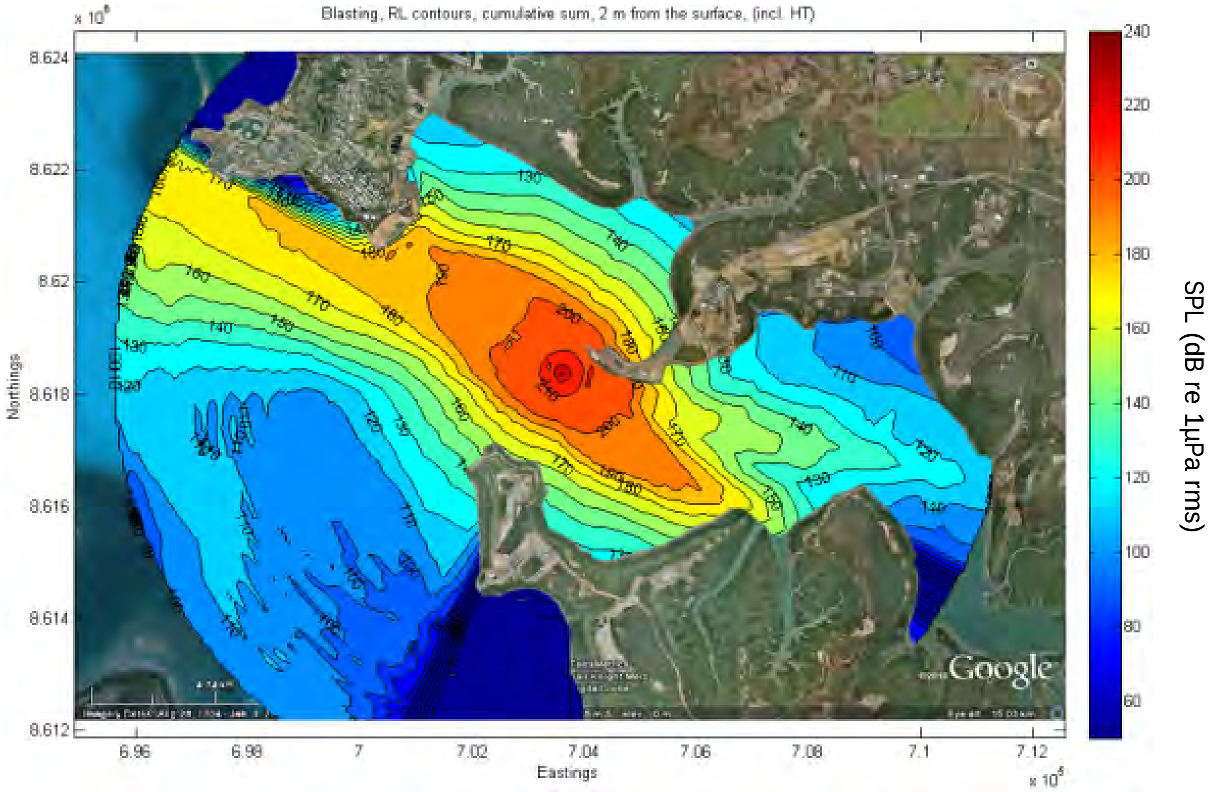


Figure 5-4 Received SPL RMS contour under the scenario of blasting operation at Walker Shoal. The blasting operation has 6 holes with 50 kg charge mass each hole.

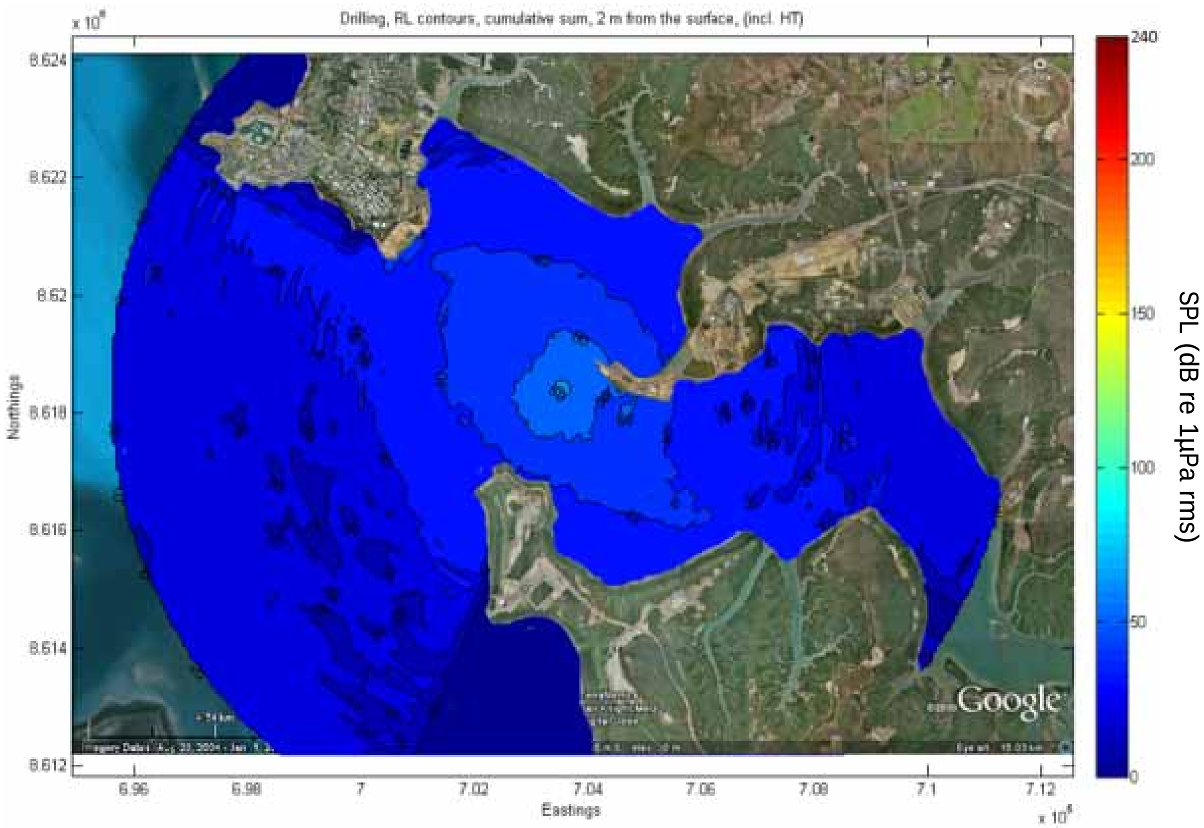


Figure 5-5 Received SPL RMS contour under the scenario of drilling operation at Walker Shoal.

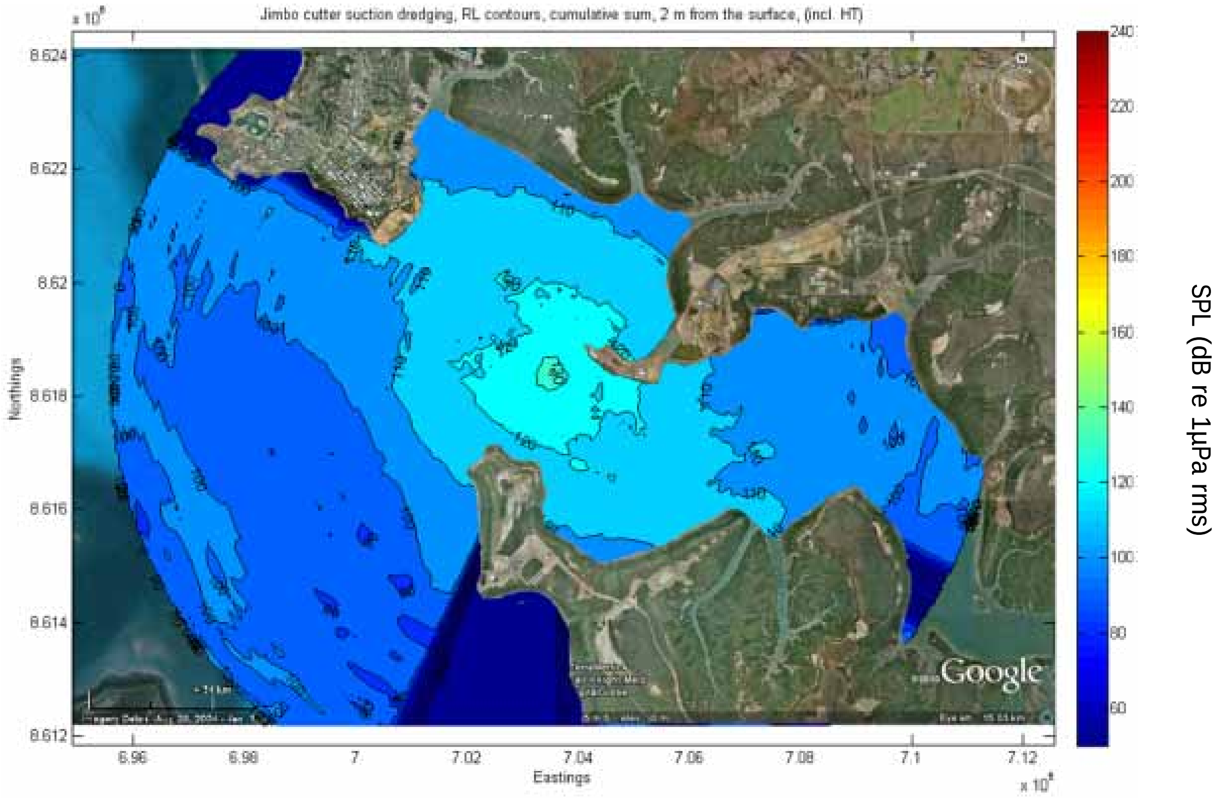


Figure 5-6 Received SPL RMS contour under the scenario of Jumbo Cutter Suction Dredging operation at Walker Shoal.

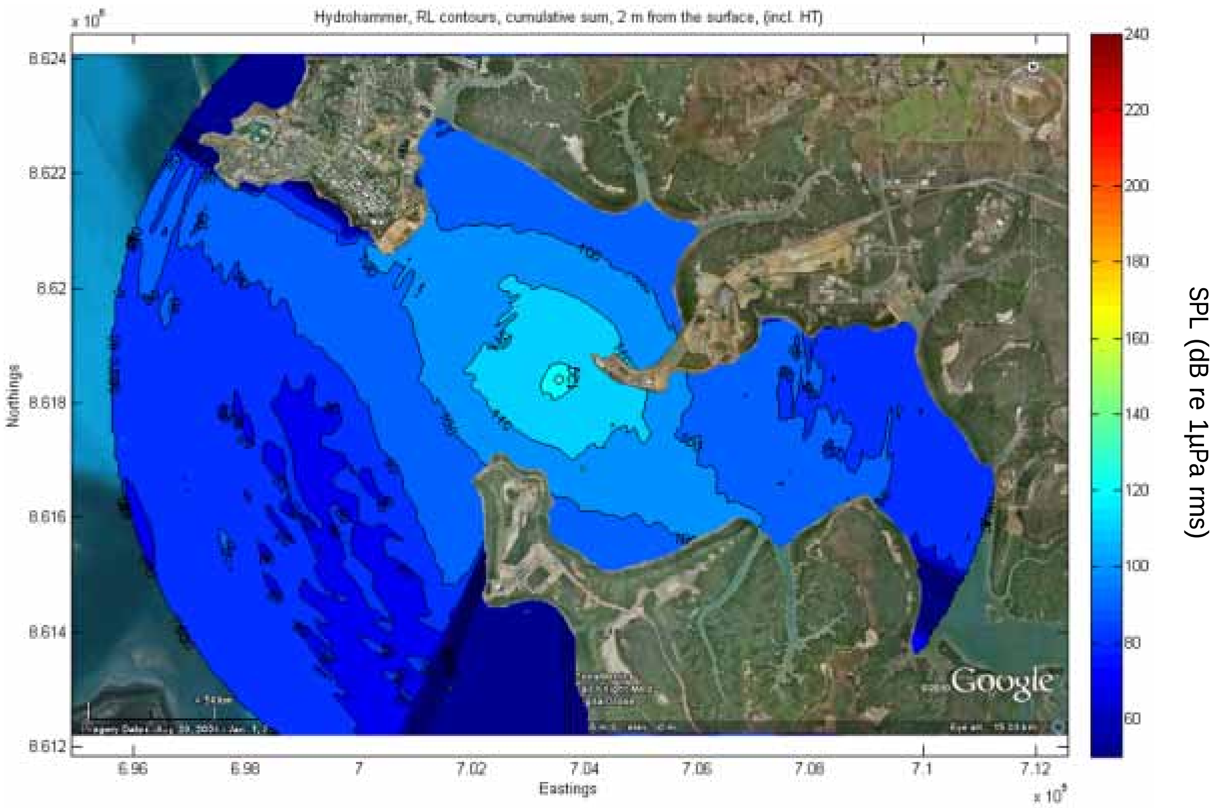


Figure 5-7 Received SPL RMS contour under the scenario of hydro-hammer operation at Walker Shoal

Table 5-2 Received levels of SPL RMS, SPL peak and SEL against different ranges from receivers to the piling locations under the tidal height of 6 m and sandy seabed type. SEL was estimated under various exposure durations and frequency weightings.

Modelling Scenario	Range, km	Received Levels															
		SPL RMS (dB re 1μPa) (unweighted)		SPL peak (dB re 1μPa) (unweighted)		SEL (dB re 1μPa^2.S) with the following frequency weightings and durations [14]											
						Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
		PLJ	MOF	PLJ	MOF	0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
Piling 1 – Simultaneous operation at PLJ1 and PLJ2	0.05	188	N/A	206	N/A	213	216	220	220	213	216	220	220	213	216	220	220
	0.1	180		198		206	209	213	213	206	209	213	213	206	209	213	213
	0.2	175		193		201	204	208	208	201	204	208	208	201	204	208	208
	0.5	168		186		194	197	201	201	194	197	201	201	194	197	201	201
	1.0	164		182		189	192	196	196	189	192	196	196	189	192	196	196

[14] SEL levels were based on an assumption that of 1 pulse per second and that each piling evolution will last 3 hours.

Modelling Scenario	Range, km	Received Levels															
		SPL RMS (dB re 1µPa) (unweighted)		SPL peak (dB re 1µPa) (unweighted)		SEL (dB re 1µPa^2.S) with the following frequency weightings and durations [14]											
						Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
		PLJ	MOF	PLJ	MOF	0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	2.0	157		175		183	186	190	190	183	186	190	190	183	186	190	190
	5.0	149		167		176	179	183	183	176	179	183	183	176	179	183	183
	8.0	144		162		173	176	181	181	173	176	181	181	173	176	181	181
Piling 2 – Simultaneous operation at PLJ1, PLJ2 and PLJ3	0.05	188	N/A	206	N/A	215	218	222	222	215	218	222	222	215	218	222	222
	0.1	180		198		208	211	215	215	208	211	215	215	208	211	215	215
	0.2	175		193		203	206	210	210	203	206	210	210	203	206	210	210
	0.5	168		186		196	199	203	203	196	199	203	203	196	199	203	203

Modelling Scenario	Range, km	Received Levels															
		SPL RMS (dB re 1μPa) (unweighted)		SPL peak (dB re 1μPa) (unweighted)		SEL (dB re $1\mu Pa^2.S$) with the following frequency weightings and durations [14]											
						Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
		PLJ	MOF	PLJ	MOF	0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	1.0	164		182		191	194	198	198	191	194	198	198	191	194	198	198
	2.0	157		175		185	188	192	192	185	188	192	192	185	188	192	192
	5.0	149		167		178	181	185	185	178	181	185	185	178	181	185	185
	8.0	144		162		173	176	181	181	173	176	181	181	173	176	181	181
Piling 3 – MOF1	0.05	N/A	187	N/A	205	211	214	218	218	211	214	218	218	211	214	218	218
	0.1		180		198	203	206	210	210	203	206	210	210	203	206	210	210
	0.2		175		193	198	201	205	205	198	201	205	205	198	201	205	205

Modelling Scenario	Range, km	Received Levels															
		SPL RMS (dB re 1µPa) (unweighted)		SPL peak (dB re 1µPa) (unweighted)		SEL (dB re 1µPa².S) with the following frequency weightings and durations [14]											
						Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
		PLJ	MOF	PLJ	MOF	0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	0.5		167		185	190	193	197	197	190	193	197	197	190	193	197	197
	1.0		163		181	185	188	192	192	185	188	192	192	185	188	192	192
	2.0		156		174	181	184	188	188	181	184	188	188	181	184	188	188
	5.0		145		163	167	170	174	174	167	170	174	174	167	170	174	174
	8.0		138		156	160	163	167	167	160	163	167	167	160	163	167	167
Piling 4 – Simultaneous operation at MOF1 and	0.05	N/A	187	N/A	205	214	217	221	221	214	217	221	221	214	217	221	221
	0.1		180		198	206	209	213	213	206	209	213	213	206	209	213	213

Modelling Scenario	Range, km	Received Levels															
		SPL RMS (dB re 1μPa) (unweighted)		SPL peak (dB re 1μPa) (unweighted)		SEL (dB re 1μPa^2.S) with the following frequency weightings and durations [14]											
						Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
		PLJ	MOF	PLJ	MOF	0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
MOF2	0.2		175		193	201	204	208	208	201	204	208	208	201	204	208	208
	0.5		167		185	193	196	200	200	193	196	200	200	193	196	200	200
	1.0		163		181	188	191	195	195	188	191	195	195	188	191	195	195
	2.0		156		174	184	187	191	191	184	187	191	191	184	187	191	191
	5.0		145		163	170	173	177	177	170	173	177	177	170	173	177	177
	8.0		138		156	163	166	170	170	163	166	170	170	163	166	170	170

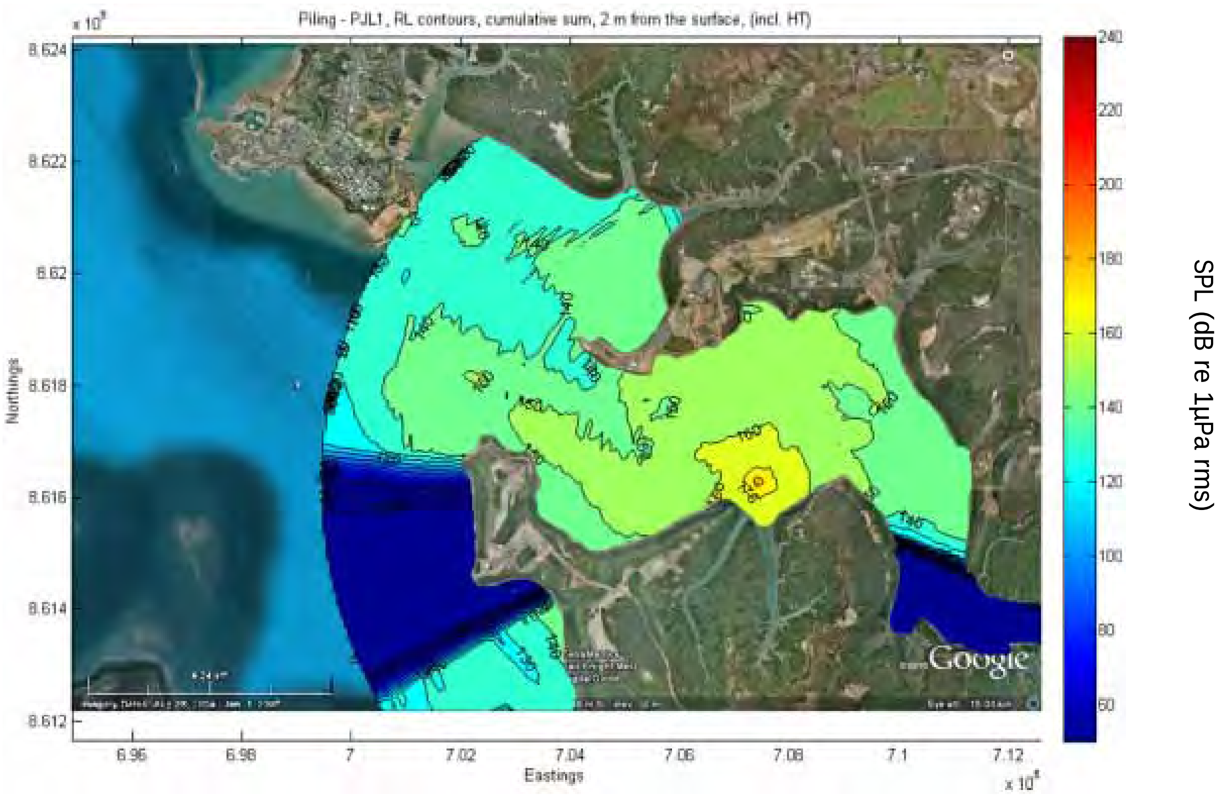


Figure 5-8 Received SPL RMS contour under the piling operation of Piling – PJL1 (6m tidal height and sandy seabed type as model input).

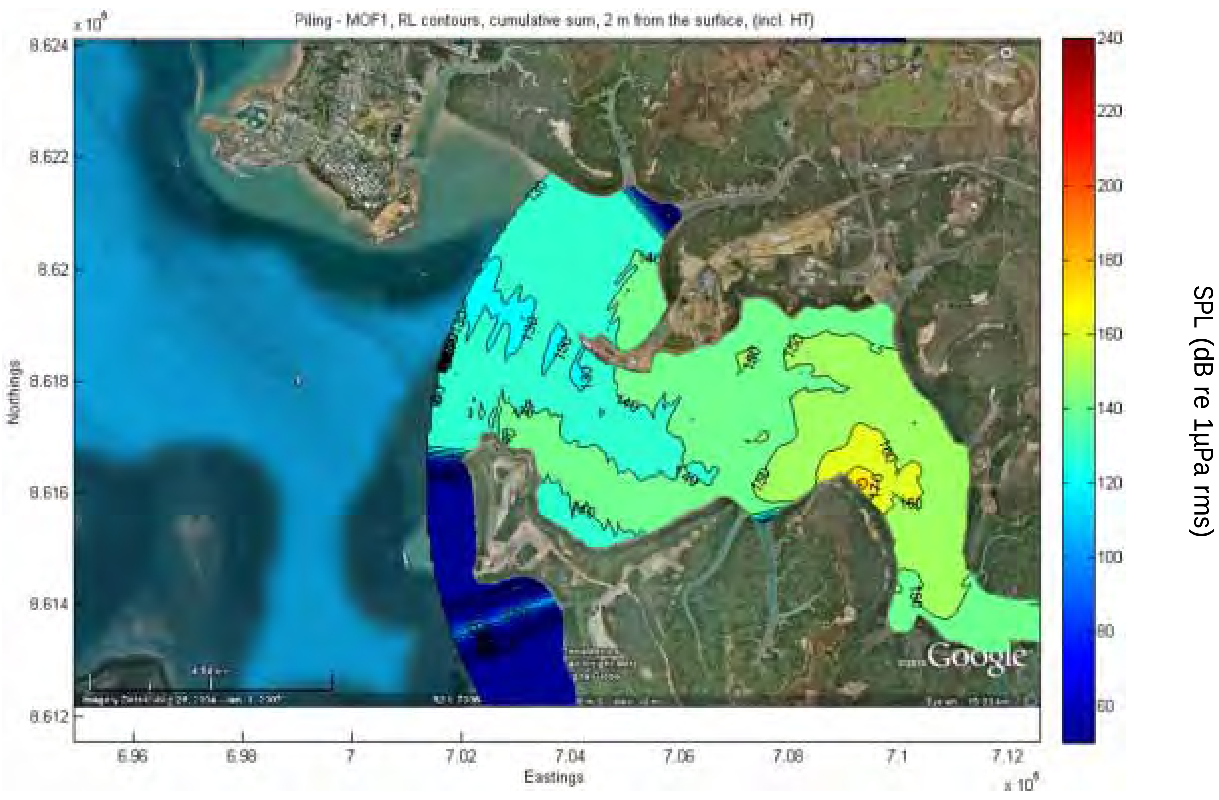


Figure 5-9 Received SPL RMS contour under the piling operation of Piling – MOF1 (6m tidal height and sandy seabed type as model input).

Table 5-3 Received levels of SPL RMS, SPL peak and SEL against different ranges from receivers to the dredging locations under the tidal height of 6 m and sandy seabed type. SEL was estimated under various exposure durations and frequency weightings.

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re $1\mu Pa^2.S$) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
Dredging 1 – Walker South	0.05	141	159	164	167	171	180	164	167	171	180	164	167	171	180
	0.1	129	147	152	155	159	168	152	155	159	168	152	155	159	168
	0.2	128	146	150	153	157	166	150	153	157	166	150	153	157	166
	0.5	125	143	146	149	153	162	146	149	153	162	146	149	153	162
	1.0	120	138	139	142	146	155	139	142	146	155	139	142	146	155
	2.0	114	132	135	138	142	151	135	138	142	151	135	138	142	151

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1µPa) (unweighted)	SPL peak (dB re 1µPa) (unweighted)	SEL (dB re 1µPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	5.0	102	120	120	123	127	136	120	123	127	136	120	123	127	136
	8.0	95	113	116	119	123	132	116	119	123	132	116	119	123	132
Dredging 2 – Walker North	0.05	140	158	164	167	171	180	164	167	171	180	164	167	171	180
	0.1	128	146	151	154	158	167	151	154	158	167	151	154	158	167
	0.2	127	145	150	153	157	166	150	153	157	166	150	153	157	166
	0.5	125	143	147	150	154	163	147	150	154	163	147	150	154	163
	1.0	120	138	143	146	150	159	143	146	150	159	143	146	150	159

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re 1μPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	2.0	114	132	137	140	144	153	137	140	144	153	137	140	144	153
	5.0	104	122	126	129	133	142	126	129	133	142	126	129	133	142
	8.0	98	116	120	123	127	136	120	123	127	136	120	123	127	136
Dredging 3 - Midway	0.05	140	158	163	166	170	179	163	166	170	179	163	166	170	179
	0.1	129	147	151	154	158	167	151	154	158	167	151	154	158	167
	0.2	128	146	150	153	157	166	150	153	157	166	150	153	157	166
	0.5	124	142	147	150	154	163	147	150	154	163	147	150	154	163

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1µPa) (unweighted)	SPL peak (dB re 1µPa) (unweighted)	SEL (dB re 1µPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	1.0	118	136	141	144	148	157	141	144	148	157	141	144	148	157
	2.0	113	131	133	136	140	149	133	136	140	149	133	136	140	149
	5.0	104	122	126	129	133	142	126	129	133	142	126	129	133	142
	8.0	93	111	117	120	124	133	117	120	124	133	117	120	124	133
Dredging 4 - MOF	0.05	145	163	168	171	175	184	168	171	175	184	168	171	175	184
	0.1	136	154	159	162	166	175	159	162	166	175	159	162	166	175
	0.2	130	148	153	156	160	169	153	156	160	169	153	156	160	169

Modelling Scenario	Range, km	Received Levels													
		SPL RMS (dB re 1μPa) (unweighted)	SPL peak (dB re 1μPa) (unweighted)	SEL (dB re 1μPa^2.S) with the following frequency weightings and durations											
				Mid-frequency weighting				100- 1k Hz flat weighting				100 – 2k Hz flat weighting			
				0.5h	1h	3h	24h	0.5h	1h	3h	24h	0.5h	1h	3h	24h
	0.5	126	144	149	152	156	165	149	152	156	165	149	152	156	165
	1.0	120	138	143	146	150	159	143	146	150	159	143	146	150	159
	2.0	114	132	137	140	144	153	137	140	144	153	137	140	144	153
	5.0	102	120	126	129	133	142	126	129	133	142	126	129	133	142
	8.0	96	114	120	123	127	136	120	123	127	136	120	123	127	136

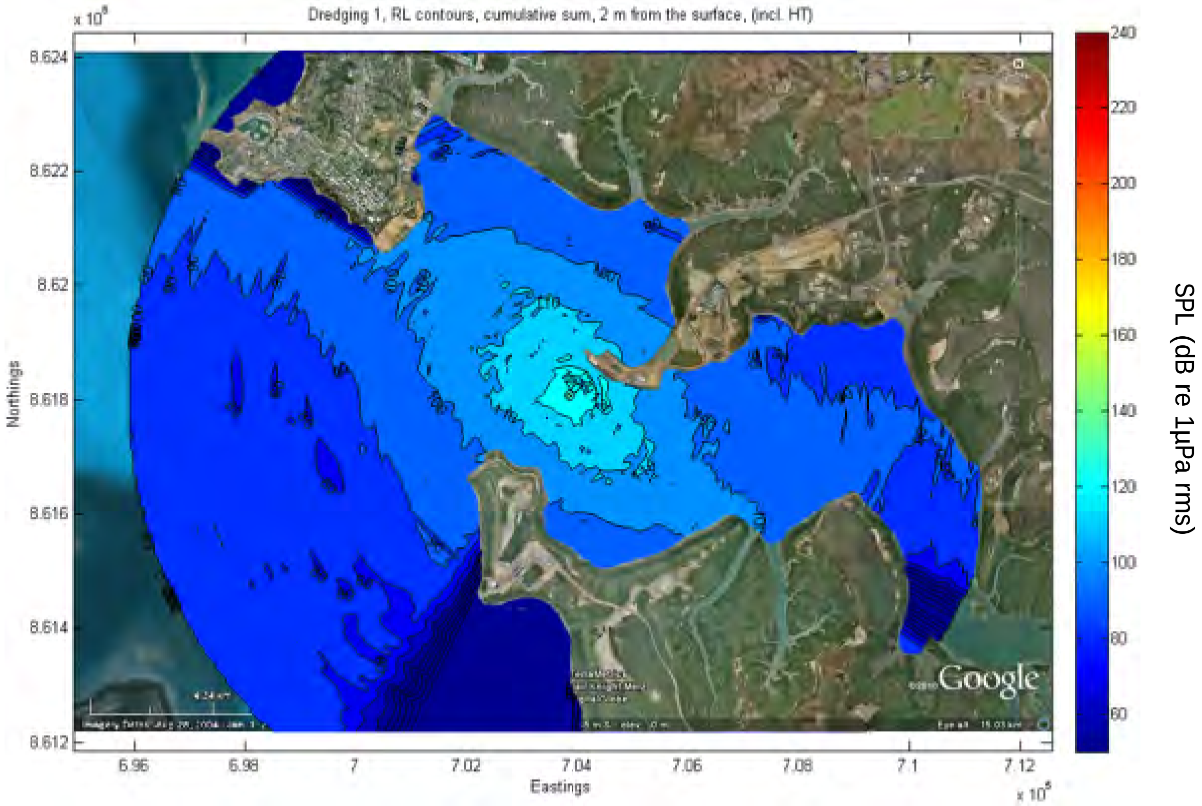


Figure 5-10 Received SPL RMS contour under the dredging scenario of Dredging 1 – Walker South

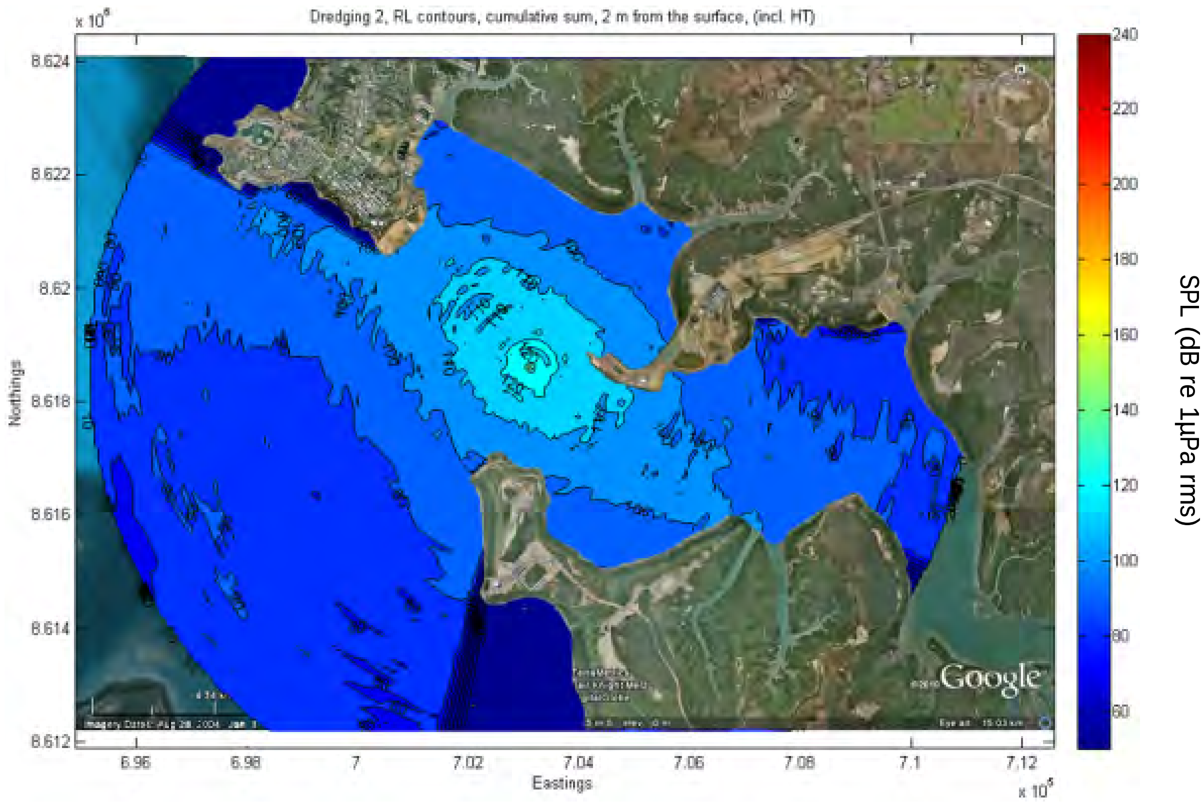


Figure 5-11 Received SPL RMS contour under the dredging scenario of Dredging 2 – Walker North

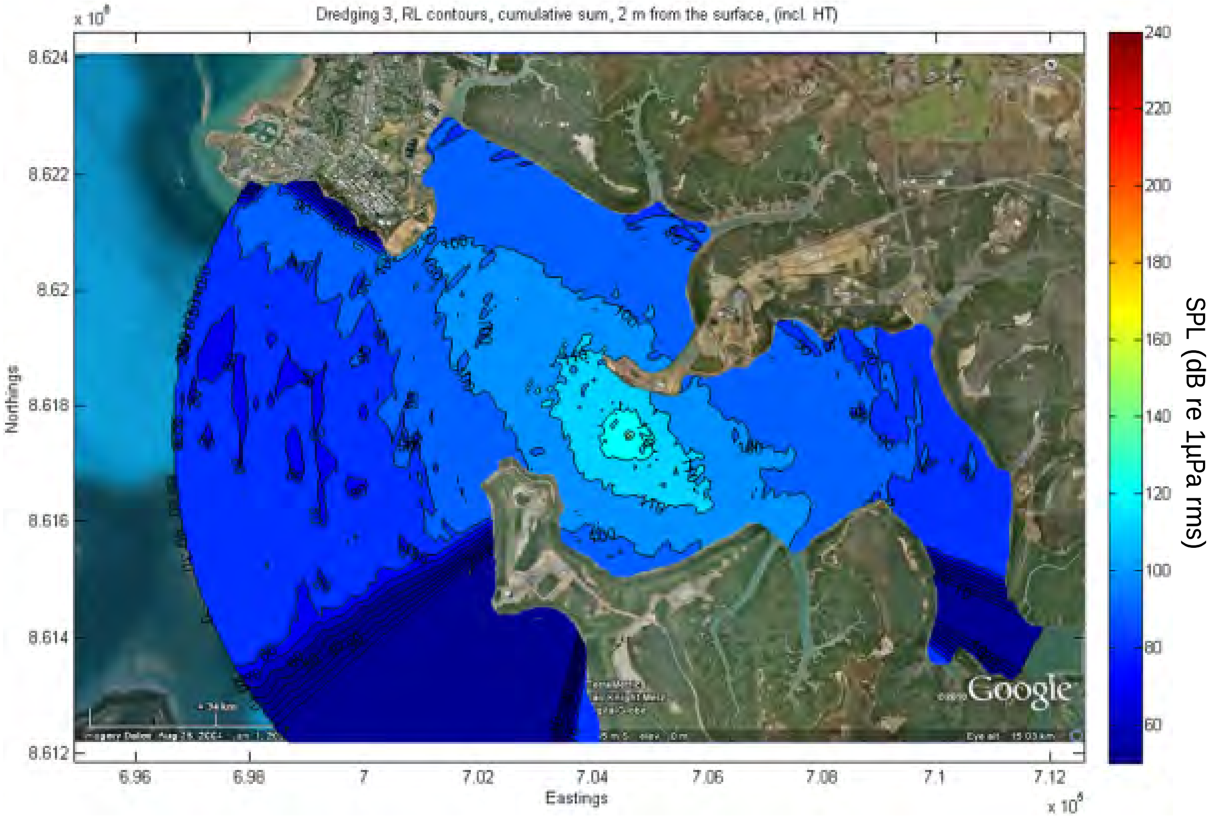


Figure 5-12 Received SPL RMS contour under the dredging scenario of Dredging 3 – Midway

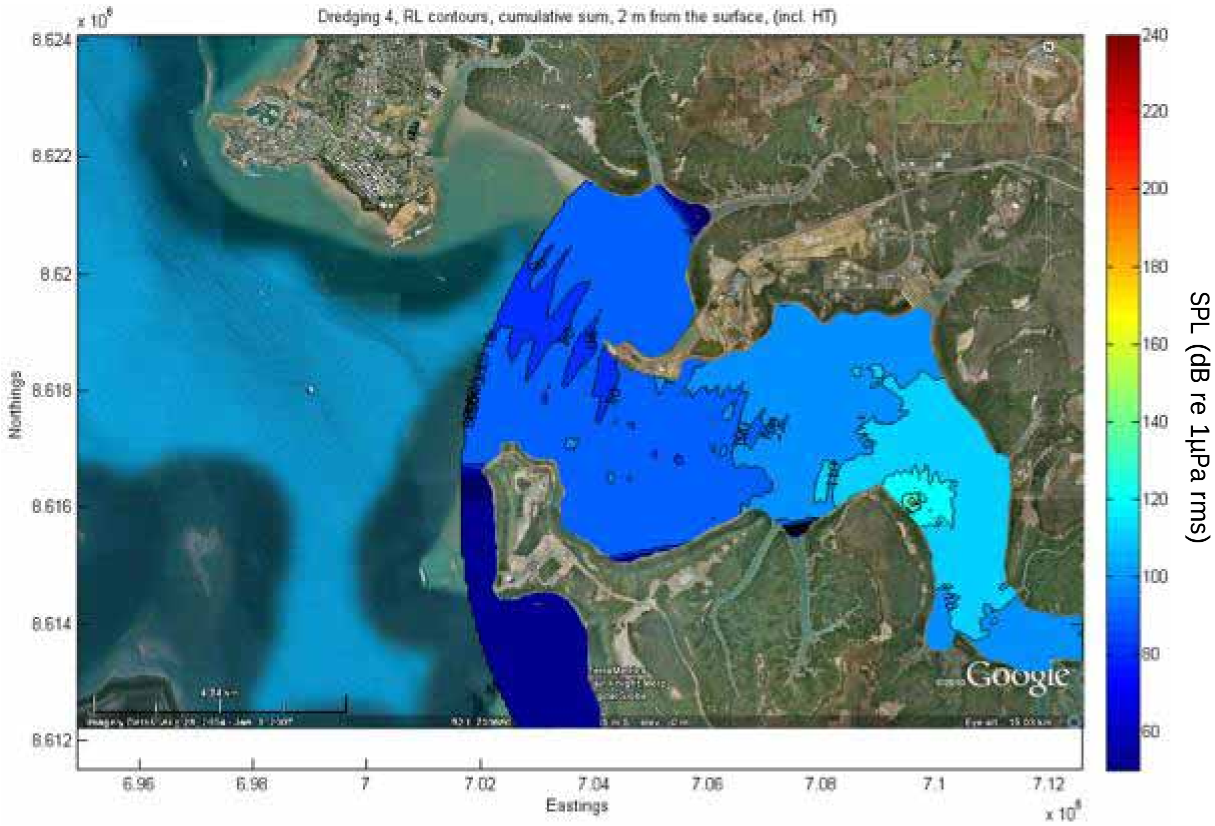
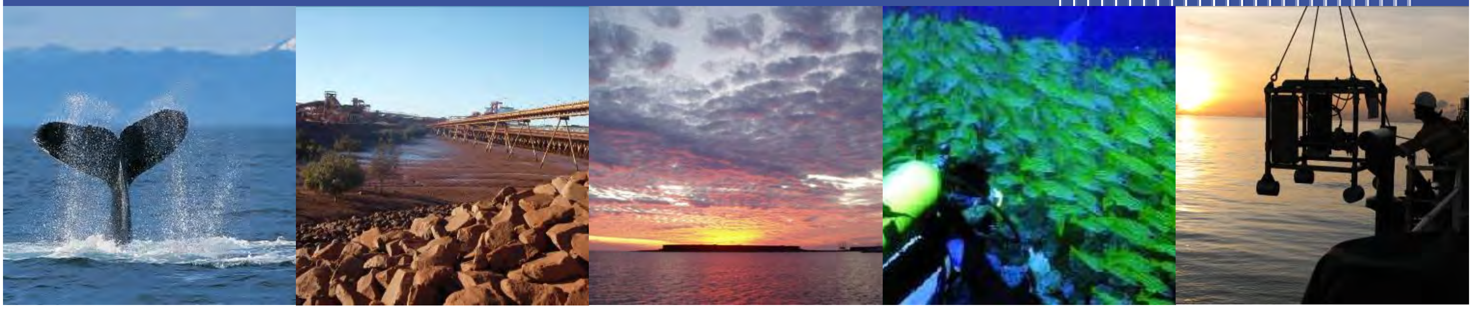


Figure 5-13 Received SPL RMS contour under the dredging scenario of Dredging 4 - MOF

APPENDIX A : ACRONYMS

Acronym	Definition
HAT	Highest Astronomical Tide
LNG	Liquefied Natural Gas
MMPE	Monterey Miami Parabolic Equation
MOF	Maritime Offloading Facility
PE	Parabolic Equation
PLJ	Product Loadout Jetty
RMS	Root Mean Square
SEL	Sound Exposure Level
SPL	Sound Pressure Level



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