GOVERNMENT OF WESTERN AUSTRALIA

Browse LNG Precinct



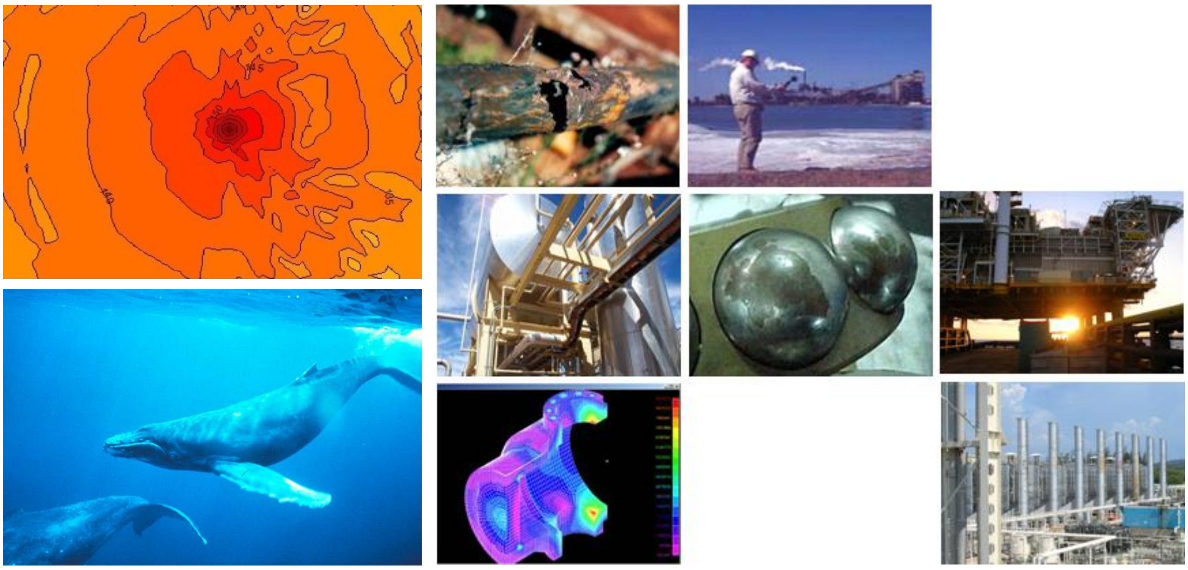

Browse Liquefied Natural Gas Precinct
Strategic Assessment Report

(Draft for Public Review)
December 2010

Appendix C-12

Downstream Browse Underwater Noise Assessment

DOWNSTREAM BROWSE UNDERWATER NOISE ASSESSMENT



WOODSIDE

Rpt01-1052753-Rev4-04 November 2010

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SVT Job No: **1052753**

SVT Document No: **1052753-Rev4-04 November 2010**

Rev	Description	Prepared	Reviewed	Date
4	Revised with Client Comments comments	Binghui Li	Granger Bennett	04 November 2010
3	Revised with Client Comments comments	Binghui Li	Granger Bennett	27 October 2010
2	Changed Zone of Avoidance to Zone of Behavioural Disturbance	Binghui Li	Granger Bennett	18 October 2010

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EXECUTIVE SUMMARY

SVT was commissioned by Woodside to perform an underwater noise assessment for the construction activities associated with the Browse LNG Precinct development. This report documents the outcomes of the underwater noise model and the assessed impact on marine fauna from various construction activities associated with the development, to inform the Strategic Assessment of potential facilities within the proposed Precinct.

The following marine activities were assessed as part of the scope of this report:

- Pile driving on the berths and along the access jetty
- Dredging operations
- Marine blasting
- Vessel movements

Assessment Criteria

Possible physical injury and possible behavioural disturbance by marine fauna are the two environmental impacts of underwater noise that were considered in the assessment. These two effects result in the determination of two areas or zones of interest. These areas or zones are as follows:

1. **Zone of Possible Physical Injury**. In this zone there is a possibility that the animal may suffer physical injury and/or permanent hearing damage.
2. **Zone of Possible Behavioural Disturbance**. In this zone there is a possibility that the animal may experience masking and/or behavioural change and/or avoid the area.

The marine fauna under this study include:

- Whales
- Dolphins
- Dugongs

Table E-1 provides the noise assessment criteria that were used to determine impacts on whales, dolphins and dugongs. The signals from pile driving and marine blasting operations were regarded as pulses, while signals from dredging operations and vessel movements were considered as non-pulses.

Table E-1 Received threshold levels for peak pressure, RMS sound pressure level (SPL) and sound exposure level (SEL) above which there would be a possibility of physical injury or behavioural effect for Cetaceans (whales and dolphins) and dugongs.

Metric	Possible Physical Injury		Possible Behavioural Disturbance	
	Single/Multiple pulses	Non-pulses	Single/Multiple pulses	Non-pulses
Peak Pressure	230 dB re 1µPa [1] (un-weighted)	230 dB re 1µPa [1] (un-weighted)	224 dB re 1µPa [1] (un-weighted)	Not applicable
RMS SPL	Not applicable	Not applicable	Not applicable	120 dB re 1µPa [1]
SEL	198 dB re 1µPa^2.s [1] (M-weighted)	215 dB re 1µPa^2.s [1] (M-weighted)	160 dB re 1µPa^2.s [2] (unweighted)	Not applicable

Modelling Results

Four modelling scenarios were modelled as shown in Table E-2. For each modelled scenario both Mean Sea Level (MSL) and Highest Astronomical Tide (HAT) were considered. Table E-2 summarises the maximum distances between noise sources and the zones of possible behavioural disturbance and possible physical injury for whales, dolphins and dugongs. As can be seen from the table Sound Exposure Levels are time based and therefore the range changes with the length of exposure (as shown for Cutter/Trailer Suction Dredging).

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

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

Table E-2 Furthest distance to zones of possible behavioural disturbance and possible physical injury (see Table 6-1 for more details)

Modelling Scenarios	Furthest Distance from Source to Zone of Potential Behavioural Disturbance (m)	Furthest Distance from Source to Zone of Potential Physical Injury (m)
Pile Driving – Near IMF	250 [3]	60 [4]
Cutter/Trailer Suction Dredging – End of Dredging Channel	550 [5]	- [6]/ 5 [7]/ 15 [8]/ 75 [9]
Cutter/Trailer Suction Dredging – End of Dredging Channel near IMF	500 [5]	- [6]/ - [7]/ 10 [8]/ 50 [9]
Marine Blasting – Near IMF	200 [10]	25 [10]
Fallpipe Rock Dumping Vessel – End of Dredging Channel	450 [5]	–

[3] Based on SEL of a 10 second period.

[4] Based on SEL of a single piling strike of around 90 ms.

[5] Based on SPL rms of 120 dB re 1μPa.

[6] Based on continuous exposure over a 30 minute period.

[7] Based on continuous exposure over an hour period.

[8] Based on continuous exposure over a 3 hour period.

[9] Based on continuous exposure over a 24 hour period.

[10] Based on received peak pressure level of a single blasting pulse.

Modelling Scenarios	Furthest Distance from Source to Zone of Potential Behavioural Disturbance (m)	Furthest Distance from Source to Zone of Potential Physical Injury (m)
Fallpipe Rock Dumping Vessel – End of Dredging Channel Near IMF	400 [5]	–

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1. INTRODUCTION

SVT was commissioned by Woodside to undertake an assessment of the underwater noise associated with the construction activities for the proposed Browse LNG Precinct Development. This report documents the outcomes of the underwater noise model and the expected impact on marine fauna from various construction activities associated with the development, to inform the Strategic Assessment of potential facilities within the proposed Precinct.

1.1 Background

The proposed Browse LNG Precinct development is located in the vicinity of James Price Point in the Kimberley region of Western Australia. The facility forms the downstream component of the Browse gas field development. The facility development will consist of the construction of access jetties and the dredging of a shipping channel as shown in Figure 1-1. These construction activities may involve the use of marine piling, blasting, dredging, rock dumping and various work vessels.

The Browse LNG Precinct will incorporate multiple LNG facilities operated by future proponents. This study considered the potential LNG facilities proposed to be developed and the associated supporting nearshore infrastructure within the Browse LNG Precinct, while noting that specific details of individual facilities are subject to refinement. This underwater noise study informs the Strategic Assessment undertaken by the Department of State Development (DSD) for the Environmental, Social and Health Assessment (ESHA) of impacts related to development of the Browse LNG Precinct.

1.2 Aim

The aim of this study was to assess the impact of underwater noise on certain marine fauna species, i.e. whales, dolphins and dugongs, as a result of the marine construction activities associated with the proposed Browse LNG Development.

1.3 Scope

The scope of this work covers the prediction of underwater noise impact on whales, dolphins and dugongs for the following anthropogenic noise sources:

- Pile driving
- Blasting
- Dredging
- Various vessel activities

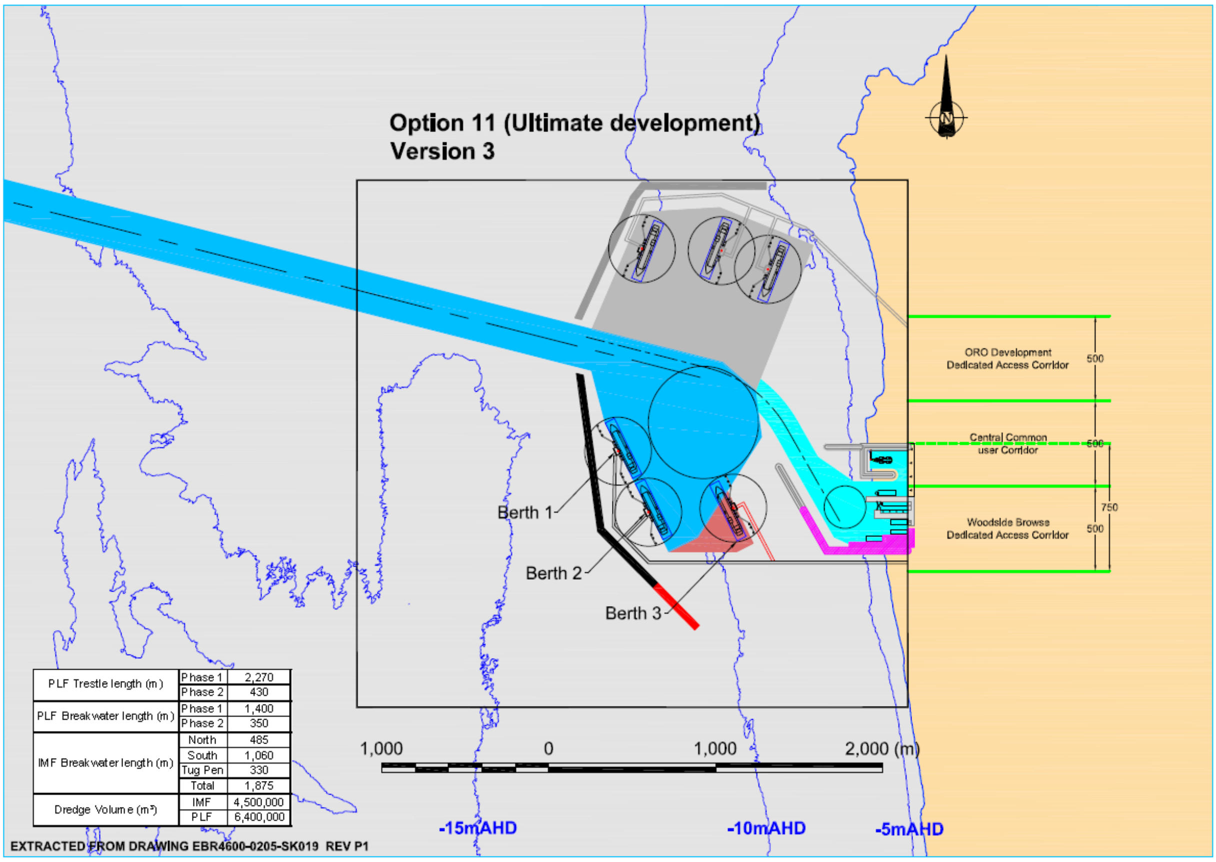

Figure 1-1 Browse LNG Development Precinct Port Area with conceptual port layout.

2. NOISE SOURCES

The noise sources considered in this study are outlined in the following sub-sections. The spectrum characteristics of these sources are listed in Appendix A.

2.1 Pile Driving

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

The action of driving the pile into the sea bed will excite bendy[11] waves in the pile that will propagate along the length of the pile and then into the seabed. The transverse wave component of the wave will create 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 is planned that hydraulic impact hammers of up to 40 tonnes will be used for pile driving operations in this development project, and the pile will have diameters of between 900 mm and 1200 mm. 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 described as impulsive noise.

2.2 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 seabed in the nearshore area of James Price Point, Western Australia is mainly made up of limestone-like material which is to be crushed and loosened by a cutter suction dredger and discharged onto the sea floor behind the cutter head. Once crushed, it will be reclaimed and transported to a disposal area by a trailer suction hopper dredger. The noise from dredging activities is mainly generated by the operating motors and engines of dredging vessels. The Cutter suction dredger and trailer suction hopper dredger are expected to be predominant noise sources during the dredging operation.

2.2.1 Cutter Suction Dredger

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 the earth and transport it to the suction mouth. The cutter can also

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

be used for hard surface materials like gravel or rock. The dredged soil is usually sucked up by a wear-resistant centrifugal pump and discharged through a pipe line or to a barge.

2.2.2 Trailer Suction Hopper Dredger

A trailer suction hopper dredger is a ship that is equipped with one or multiple trailing suction pipes. Material is lifted through the trailing pipes by one or more pumps located on the upper deck and discharged into a hopper contained within the hull. The suction pipe terminates in a dredgehead which may incorporate systems to dislodge compacted material and flow to the suction inlet as efficiently as possible.

2.3 Marine Blasting

If during the dredge program hard rock is encountered blasting will be necessary. As the blasting will be used for material displacement the charges will be drilled and stemmed.

Explosives have two important components that are of interest to underwater noise. They are as follows:

- **Shock wave**. Important in unconfined explosions and it is used for fracturing or cutting structures (e.g. severing steel, seismic, bolder breakage, ordinance testing)

- **Gas component**. Generally the more useful component as it is used 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.

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 sound pressure level (SPL) per charge mass as shown in Figure 2-1.

In order to inform this preliminary noise study, it is assumed that the blasting explosive to be used by future proponents in the Browse LNG Precinct is expected to be an emulsion that is used in the mining industry. This emulsion has a TNT equivalent of 0.31. Detonating 50 kg of Powergel gives a peak value of 8.026766 MPa at a distance of 1 m using D. Ross's formula[12], this translates into a value of 258 dB re 1 μPa @ 1 m. The duration of the pulse can be calculated to be 24.5 μs which gives an SEL of 212 dB re 1 μPa².s

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

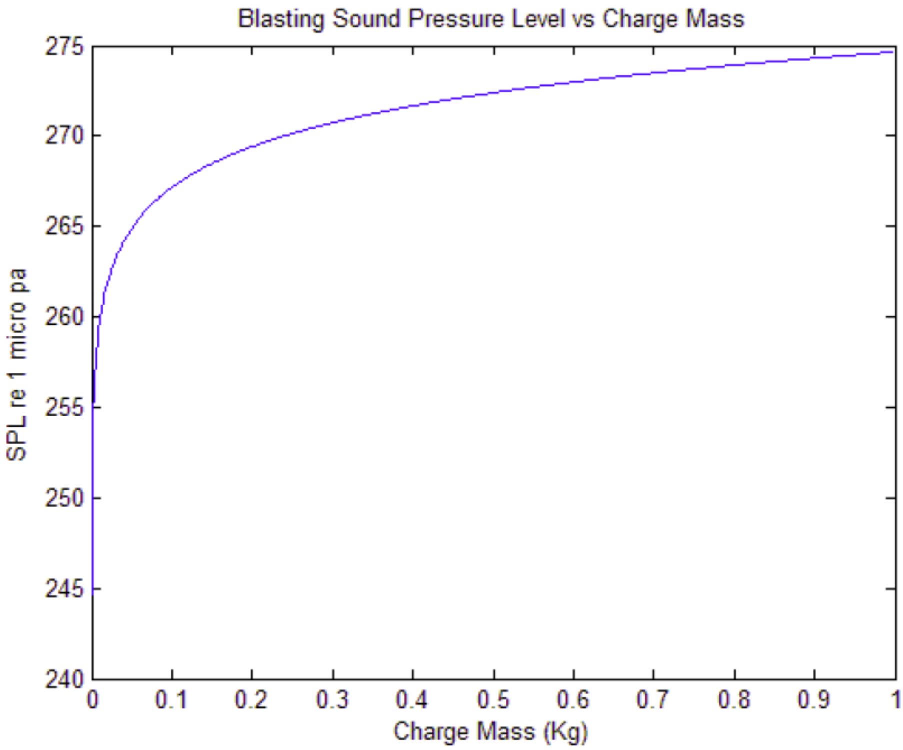

Figure 2-1 Blast sound pressure level achieved per charge mass.

2.4 Vessel Movements

During the construction phase of the facility development, vessel operations are expected to be intensive, and therefore the noise from vessel movements should be taken into account for the noise impact assessment. Offshore marine vessels are involved in almost every development process to support pile driving, dredging, rock dumping, heavy lifting, material importing, pipelaying, etc. Marine vessels will be operating in locations from the main marine facility to the end of the dredging channel. The size of the vessels to be used during construction ranges from 100 t for a survey boat to around 40000 t for a fallpipe rock dumping vessel. The noise energy emitted from vessels depends on a number of factors and generally increases with the size of the vessel. The fallpipe rock dumping vessels (~40000 t) located about 5 km offshore and the sidedump rock dumping vessels (~20000 t) at the marine facility nearshore are expected to be the largest vessels operating during construction and they have therefore been modelled in the assessment.

3. ASSESSMENT CRITERIA

Unlike airborne noise, where impact levels on humans have been regulated, assessment levels for underwater environmental noise impacts have not been defined in regulation except in the case of underwater noise impacts on cetaceans from seismic surveys, where the EPBC Act Policy Statement 2.1[13] applies. As a result, assessment levels in this report are determined from peer reviewed and widely accepted literature.

A variety of units are used in underwater acoustics to define steady-state and impulsive signals. Some of the important definitions are as follows:

- 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 (0-Pk). Peak pressure is the maximum recorded pressure and is measured from the mean of the signal to the maximum excursion from the mean.
- Sound Pressure Level Peak to Peak units dB re 1 µPa (Pk-Pk). Peak to Peak sound pressure is the algebraic difference between the maximum positive and maximum negative instantaneous peak pressure.
- Sound Exposure Level (SEL) units dB re 1 µPa^2.s. Sound exposure level is a measure of energy with the dB level of the time integral of the squared-instantaneous sound pressure normalized to a 1-s period. For impulsive signals, such as pile driving noise and marine blasting noise, the averaging time is a significant consideration. Impulsive signals are better described by a measure of Sound Exposure Level (SEL) and a measure of the signal peak pressure.

3.1 Zones of Interest

For underwater noise impacts on marine fauna, two effects are of interest, namely physical injury and behavioural disturbance. These two effects result in the determination of two areas or zones of interest for underwater noise assessments. These areas or zones are as follows:

1) **Zone of Possible Physical Injury**. In this area there is a possibility that the animal may suffer physical injury and/ or permanent hearing damage.

2) **Zone of Possible Behavioural Disturbance**. In this area there is a possibility that the animal may experience masking and/or behavioural change and/or avoid the area.

3.2 Cetaceans and Dugongs

3.2.1 Auditory Sensitivity

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

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[13] EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales. Australian Government, Department of the Environment, Water, Heritage and the Arts. September 2008.

As low-frequency cetaceans, humpback whales produce a complex set of vocalised song patterns. The spectrum of the patterns has been measured to be between 20 and 24000 Hz with maximum peak to peak source level of 184 dB re 1 μPa @ 1m [14]. In the absence of more detailed information on the hearing of humpback whales from the literature, it can be assumed that this bandwidth and source level is indicative of the whales' auditory bandwidth and auditory sensitivities.

Dolphins are mid-frequency cetaceans, which have hearing over a wide range of low to very high frequencies. According to combined available research results, mid-frequency cetaceans have lower and upper frequency limits of nominal hearing at approximately 150 Hz to 160 kHz respectively[15].

Dugongs are also mid-frequency marine species. The hearing frequency range for dugongs is from 1 kHz to 180 kHz[16], with the most sensitive range between 1 kHz and 8 kHz.

3.2.2 Assessment of Noise Impacts

There is lack of scientific data specific to sirenians (i.e. dugongs) for determining injury and behavioural disturbance as a result of underwater noise, therefore the criteria for cetaceans were applied to dugongs in this assessment study. The criteria that will be used for the assessment of cetaceans and dugongs are given in Table 3-1. A dual-criterion approach was used for both zones of physical injury and behavioural disturbance. The following technical notes should be considered regarding the assessment criteria:

- The injury criteria for marine mammal groups and signal types (i.e. single pulses, multi-pulses and non-pulses) are divided into received peak pressure level and sound exposure level. These criteria mark the expected onset of permanent threshold shift (PTS). The onset of PTS was derived by Southall *et al*[17] from measured or assumed onset of temporary threshold shift (TTS) levels and expected TTS growth range estimates for each marine mammal group[18] [19]. Accordingly, Southall *et al*[20] defined physical injury criteria based on experiments conducted on mid frequency cetaceans (i.e. beluga whales and bottlenose dolphins). Due to the lack of data for low frequency cetaceans (i.e. humpback whales), the data for mid frequency mammals is recommended by Southall *et al* to be used for low frequency cetaceans.

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

[15] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[16] Anderson and Barclay, Acoustic signals of solitary dugongs: physical characteristics and behavioural correlates. Journal of Mammology 76, 1226-37.

[17] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[18] Southall *et al* determined PTS from TTS levels based on a 40 dB expected increase that will result in PTS. This calculation was based on an extrapolation of estimated growth of TTS in terrestrial mammals. The injury criteria are considered to be conservative.

[19] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

[20] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

- The SEL criteria in Table 3-1 for possible physical injury are M-weighted based on M-weighting functions for low-, mid-, and high-frequency cetaceans shown in Figure 3-1[21]. As most of the energy of the noise sources considered in this assessment (as shown in Appendix B) are within the frequency range of both low and mid frequency cetaceans where the response curve is flat (i.e. are most sensitive), this study took a conservative approach by considering the SEL criteria for possible physical injury as un-weighted.
- For behavioural disturbance *Southall et al* states: '*The available data on behavioral responses do not converge on specific exposure conditions resulting in particular reactions, nor do they point to a common behavioral mechanism. Even data obtained with substantial controls, precision, and standardized metrics indicate high variance both in behavioral responses and in exposure conditions required to elicit a given response. The inability to identify broadly applicable, quantitative criteria for behavioral disturbance in response to multiple-pulse and nonpulse sounds is an acknowledged limitation.*'
- Due to the lack of data and uncertainty in the data for behavioural disturbance and for the purposes of this assessment TTS will be classed as behavioural disturbance for pulses. The onset of TTS criteria for single pulses and multi-pulses recommended by both Southall *et al*[22] and the EPBC Act Policy Statement 2.1 are based on data predominately from seismic surveys[23]. This criterion will be used as the criteria for possible behavioural disturbance.
- It is noted that the SEL value 160 dB re 1 μPa^2.s for possible behavioural disturbance obtained from the EPBC Act Policy Statement 2.1 is based on a seismic pulse made once every ten seconds. As pile driving pulses occur once every second it is assumed that 10 pile driving pulses will be equal to the same time period of one seismic pulse. An addition 10 dB will be added to the pile driving SEL to compensate for this difference. The SEL values for non-pulses for possible physical injury assessment are based on expected sound exposure levels for a 24 hour period.
- It must be noted that observational data is by no means conclusive. Additionally, seismic pulses on which the criteria are based are different both in spectrum and time to that of a pile driving pulse. However, as there is no data available that can be used to determine the criteria for pile driving, the criteria for seismic surveys will be used. For non-pulse signals such as vessel movements, the criteria was taken as a SPL of 120 dB re 1μPa (RMS) from the literature[24].

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[21] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

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

[23] Southall et al references work where 120 dB re 1μPa (RMS) has been shown to result in behavioural disturbance of Bowhead Whales during seismic surveys. However Southall et al does not recommend these levels as no single value is recommended. As a result the EPBC Act Policy Statement 2.1 has been taken as reference,

[24] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

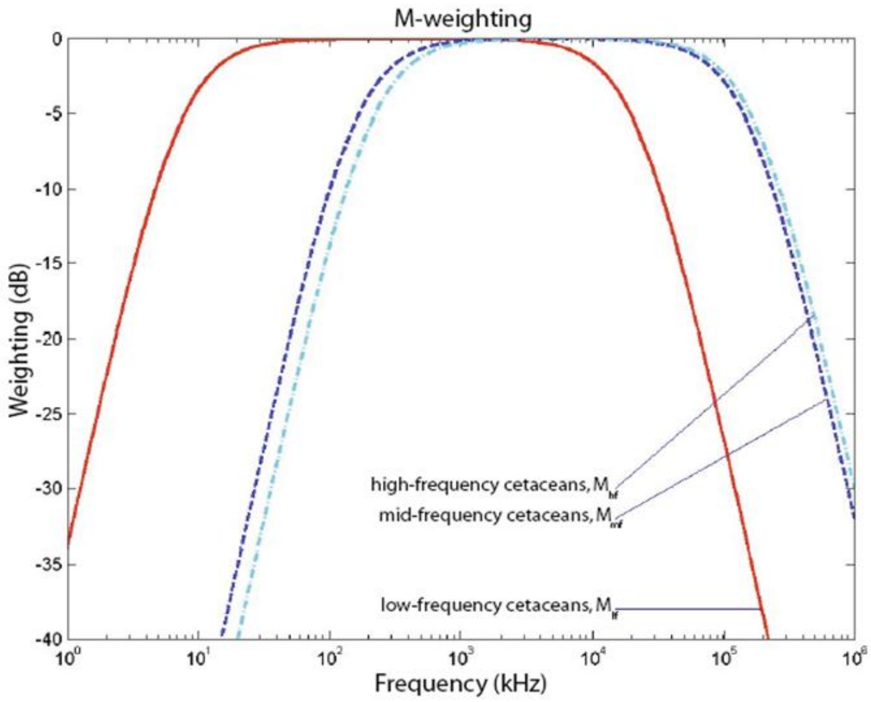

Figure 3-1 The M-weighting functions for low-, mid-, and high-frequency cetaceans.

Table 3-1 Received threshold levels for peak pressure, RMS sound pressure level (SPL) and SEL above which there would be a possibility of physical injury or behavioural effect for cetaceans and dugongs.

Metric	Possible Physical Injury		Possible Behavioural Disturbance	
	Single/Multiple pulses	Non-pulses	Single/Multiple pulses	Non-pulses
Peak Pressure	230 dB re 1µPa [25] (un-weighted)	230 dB re 1µPa [25] (un-weighted)	224 dB re 1µPa (un-weighted)	Not applicable
RMS SPL	Not applicable[26]	Not applicable	Not applicable	120 dB re 1µPa [27]

[25] Southall *et al* recommends the criteria for injury from exposure to single/multiple pulses and non-pulses in terms of peak pressure are TTS-onset levels (224 dB re 1µPa) plus 6 dB of additional exposure

[26] RMS values are not recommended by *Southall et al* as injury from underwater noise is related to peak pressure and the amount of acoustic energy the marine fauna are exposed to over a period of time (energy exposure over time is calculated in the Sound Exposure Level).

[27] Southall *et al*, Marine mammal noise exposure criteria: initial scientific recommendations, Aquatic Mammals, Volume 33, Number 4, 2007, ISSN 0167-5427

Metric	Possible Physical Injury		Possible Behavioural Disturbance	
	Single/Multiple pulses	Non-pulses	Single/Multiple pulses	Non-pulses
SEL	198 dB re 1μPa^2.s[28] (M-weighted)	215 dB re 1μPa^2.s [29] (M-weighted)	160 dB re 1μPa^2.s [30] (unweighted)	Not applicable

[28] Southall *et al* recommends the criteria for injury from exposure to single/multiple pulses in terms of SEL are TTS-onset levels (183 dB re 1μPa^2.s) plus 15 dB of additional exposure

[29] Southall *et al* recommends the criteria for injury from exposure to non-pulses in terms of SEL are TTS-onset levels (195 dB re 1μPa^2.s) plus 20 dB of additional exposure

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

4. METHODOLOGY

4.1 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.

4.1.1 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[31].

4.1.2 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.
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. 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.

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

4.1.3 Model Environmental Inputs

The following environmental conditions were inputted into the model:

Tide level

Tides near the James Price Point coastal area are semi-diurnal (two highs and two lows each day), with tidal sea-surface height variability in excess of plus or minus (±) 4 meters. In all cases for this study, Mean Sea Level (MSL) and the Highest Astronomical Tide (HAT) were used.

Seabed Types

Based on geophysical survey results supplied to SVT by Woodside, the seabed features in the nearshore survey area off James Price Point are mainly limestone base, uncemented shelly sandy silts of various thickness as sediment, and small patches of hard rock with random distribution in the area. 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 nearshore shallow water region of James Price Point, the reflection coefficient of sand is higher than that of limestone. For the small patches of hard rock and inland area, basalt was selected to represent the seabed type. The geoacoustic properties of the seabed types used in the model are as described in Table 4-1.

Table 4-1 Geoacoustic properties used in the model for each seabed type

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
Bassalt	5250.0	2.700	0.1	0.2	1500

Sound Speed Profile

Shallow water in the Pilbara area has been found to have a constant temperature for the entire water column, as a result the sound speed profile in the nearshore of James Price Point is assumed to be isothermal with a constant temperature of 23 ºC and a constant salinity of 35 ppt.

4.1.4 Model Contour Depth

The model produces horizontal contours for any depth as well as vertical plots showing depth versus range for any bearing. It is not practical to provide plots for each depth (up to 250 depending on the scenario) and for each bearing (i.e. 360 for each scenario). As a result only a selected number of graphs are provided in this report.

5. MODEL INPUT

5.1 Noise Source Locations

As presented in Section 2, four different categories of noise sources are considered for the Browse LNG facility development, i.e. pile driving, dredging, marine blasting, and vessel movements.

Pile driving barges are expected to be operating at berths and access jetties in the integrated marine facility (IMF), and three piling barges are assumed to be operating simultaneously. Dredging operations will be both near the IMF and at the end of dredging channel. Marine blasting is assumed to occur near the IMF, around 1 km offshore. For the predominant noise sources from vessel movements, fallpipe rock dumping vessels are assumed to be operating near the end of the dredging channel, around 5 km offshore and sidedump rock dumping vessels are at the rock load facility at the IMF.

The noise sources and their locations are listed in detail in Table 5-1.

Table 5-1 Noise sources and their locations

Source	Easting	Northing
Pile Driving 1 – Near IMF	406952 m	8064457 m
Pile Driving 2 – Near IMF	407069 m	8064082 m
Pile Driving 3 – Near IMF	407285 m	8064849 m
Cutter/Trailer Suction Dredging 1 – End of Dredging Channel	403287 m	8065176 m
Cutter/Trailer Suction Dredging 2 – Near IMF	406658 m	8064887 m
Marine Blasting – Near IMF	407911 m	8064142 m
Fallpipe Rock Dumping Vessel – End of Dredging Channel	403797 m	8065176 m

Source	Easting	Northing
Sidedump Rock Dumping Vessel – Near IMF	406772 m	8064713 m

5.2 Modelling Source Depths and Characteristics

The depths of different noise sources were determined by estimating their acoustic centre, as listed in Table 5-2. The source spectrum levels of each source used in the model are given in Appendix A. The frequency range used in the model was from 63 Hz to 8 kHz, which covers the expected frequency range of the major noise energy produced by the construction activities which might impact cetaceans and dugongs.

Table 5-2 Noise source depths and characteristics.

Source	Source Depth	Source Characteristics
Pile Driving 1 – Near IMF	7.5 m above seabed	See Figure A-1 in Appendix A
Pile Driving 2 – Near IMF	7 m above seabed	See Figure A-1 in Appendix A
Pile Driving 3 – Near IMF	6.7 m above seabed	See Figure A-1 in Appendix A
Cutter/Trailer Suction Dredging 2 – Near IMF	1 m below sea surface	See Figure A-3 and A-4 in Appendix A
Cutter/Trailer Suction Dredging 1 – End of Dredging Channel	1 m below sea surface	See Figure A-3 and A-4 in Appendix A
Marine Blasting – Near IMF	1 m below sea surface	See Figure A-2 in Appendix A

Source	Source Depth	Source Characteristics
Fallpipe Rock Dumping Vessel – End of Dredging Channel	1 m below sea surface	See Figure A-5 in Appendix A
Sidedump Rock Dumping Vessel – Near IMF	1 m below sea surface	See Figure A-5 in Appendix A

6. MODELLING RESULTS

The contour plots shown in this section are for a receiver depth of 2 m below the sea surface. The scenarios under both Mean Sea Level (MSL) and Highest Astronomical Tide (HAT) were modelled. Only the results for HAT are presented as it represents the worst case scenario.

6.1 SEL Contours for Different Noise Sources

6.1.1 Pile Driving

It is expected that 3 pile barges will be operating simultaneously on berths and access jetties in the IMF, with a maximum of 3 hours operation in a 24 hour period. Pile barges are assumed to be approximately 800 m apart.

Error! Not a valid bookmark self-reference. and Figure 6-2 show the predicted SEL noise contours for 10 seconds of piling (i.e. 10 pulses) for 3 pile driving operations occurring simultaneously at three locations. Figure 6-3 and Figure 6-4 present the SEL noise contour for 3 hours of continuous pile driving operation in 24 hours using 3 pile barges simultaneously. As can be seen from these figures the longer that a marine mammal is exposed to pile driving pulses the higher the SEL value will be. As a result the time of exposure must be taken into consideration when determining the zones of possible injury and behavioural disturbance.

Table 6-1 shows the predicted SPL peak, SEL for a single piling strike and SEL for a 10s period (10 pulses), against the distance from the source.

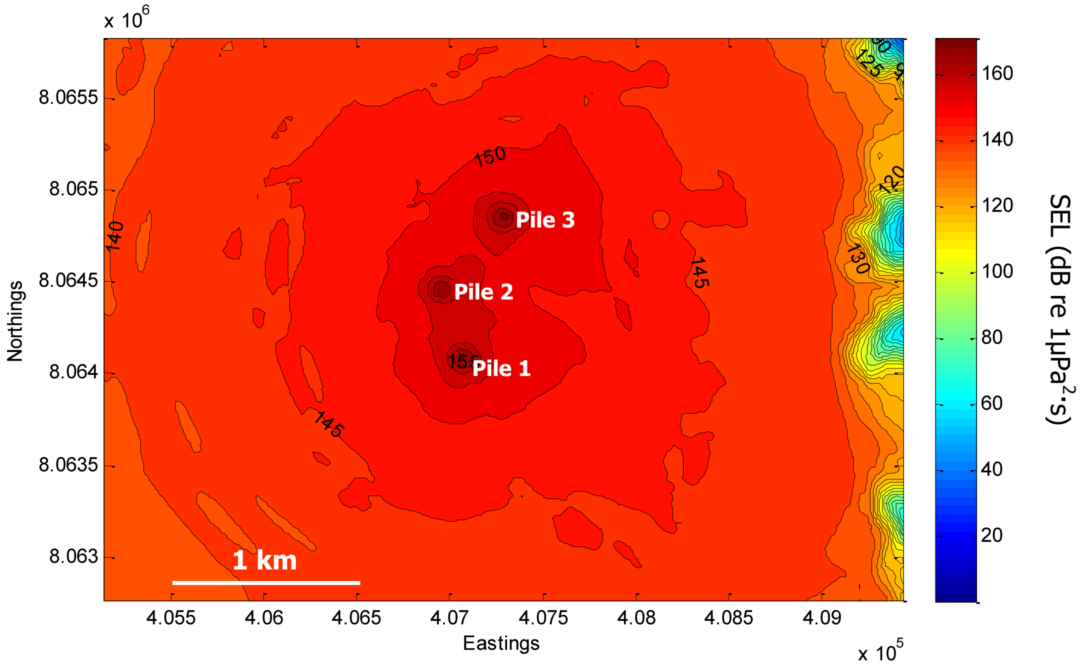

Figure 6-1 Contours showing predicted SEL with 3 piling barges operating simutaneously for a 10 s period. The noise contour is 2 m below the sea surface

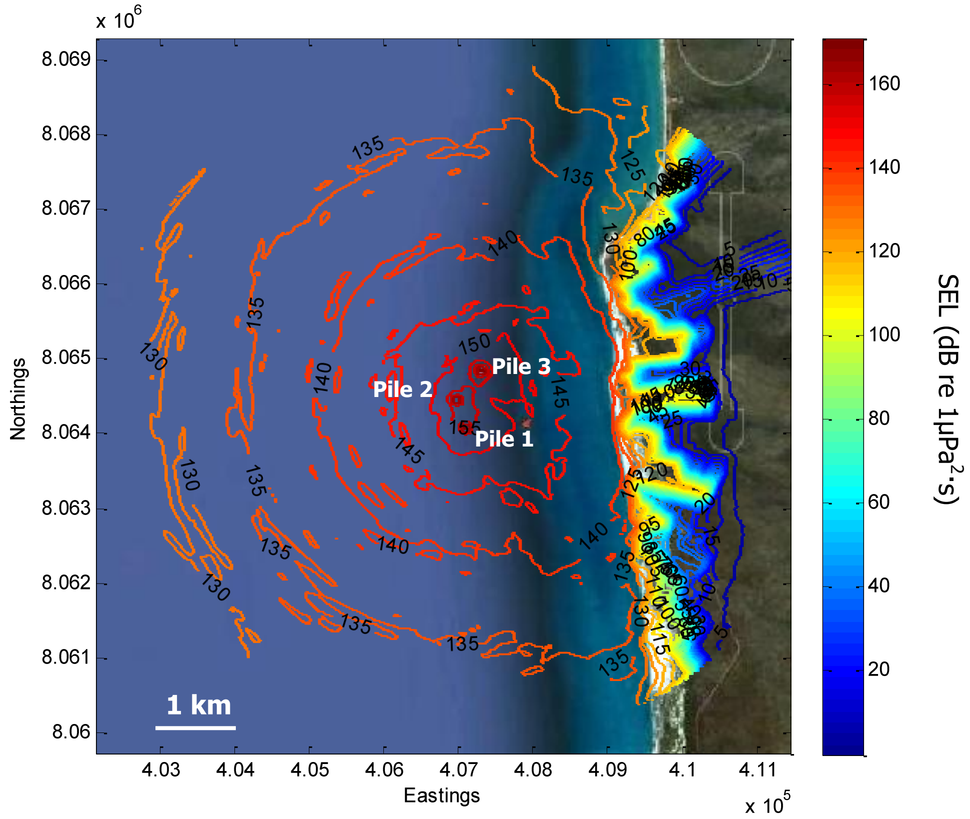

Figure 6-2 Overview of the pile driving SEL noise contour 2 m below the sea surface, with 3 piling barges operating simutaneously for a 10 s period.

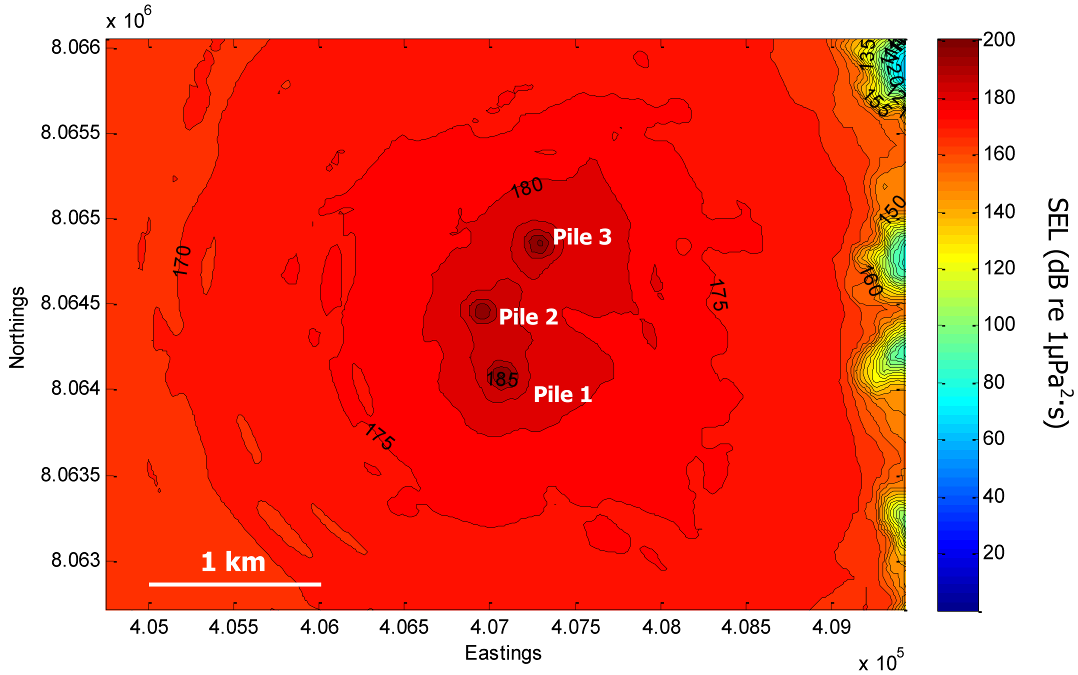

Figure 6-3 Contours showing predicted SEL with 3 piling barges operating simutaneously for 3 hours in a 24 hour period. The noise contour is 2 m below the sea surface

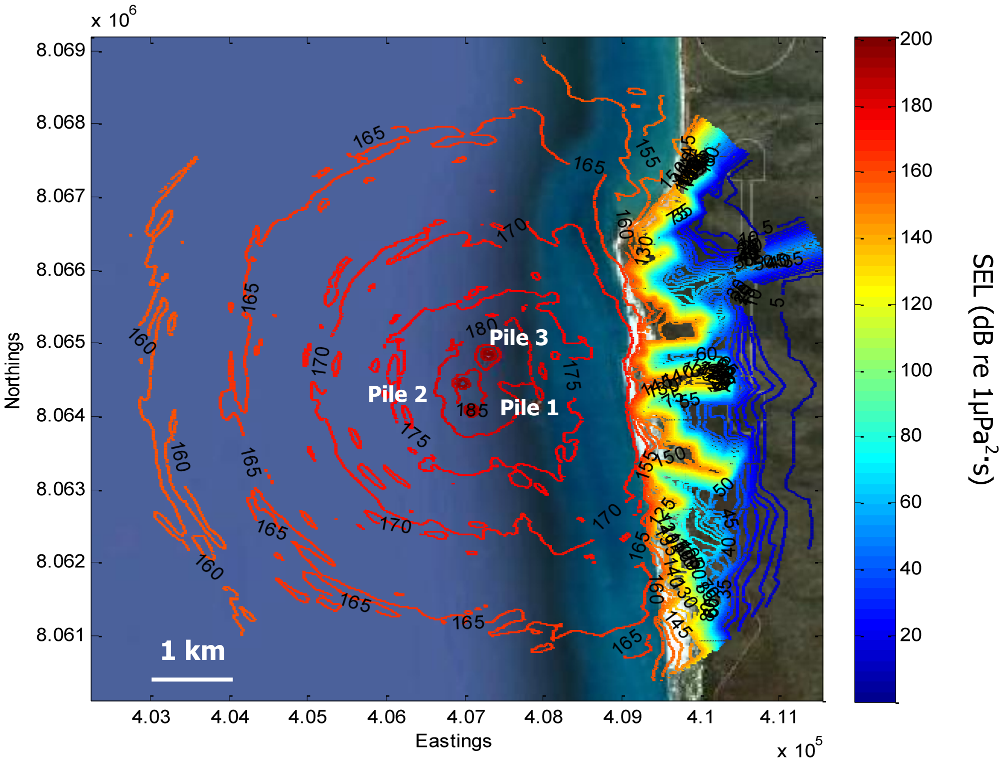

Figure 6-4 Overview of the pile driving SEL noise contour 2 m below the sea surface, with 3 piling barges operating simutaneously for 3 hours in a 24 hour period.

Table 6-1 The predicted SPL peak, SEL for a single piling strike and SEL for a 10s period (10 pulses), against the distance from the source.

Distance from Source (km)	Peak SPL (dB re 1 µPa)	SEL (dB re 1 1µPa2·s) for a single piling strike	SEL (dB re 1 1µPa2·s) for a 10 s period (10 pulses)
0.05	213	196	207
0.1	190	173	184
0.2	172	155	166
0.5	160	143	154
1	151	134	145
2	143	126	137
5	131	114	125

6.1.2 Dredging

Cutter and trailer suction dredging will be occurring near the end of the dredging channel. Trailer suction dredging operations are expected to operate continuously. Cutter suction dredging operations are expected to operate only 15% of time. As a result only the trailer suction dredging operation was considered in the model due not only to its continuous operation but also because it is a relatively higher noise source (see Appendix A). Figure 6-5 and Figure 6-6 present the SEL noise contours for two trailer suction dredger operating simutaniously over a 24 hour[32] period near the IMF and at the end of the dredging channel respectively.

The predicted SPL RMS and SEL for a period of 0.5h, 1h, 3h and 24h, against the distance from the source, is shown in Table 6-2.

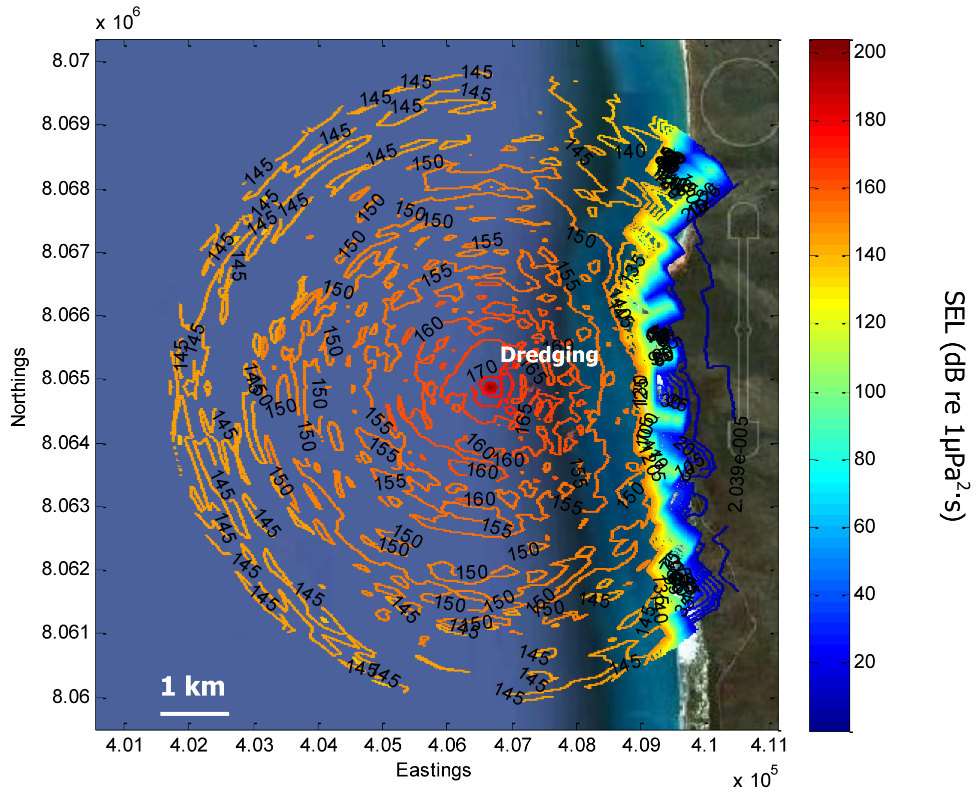

Figure 6-5 Overview of SEL contour 2 m below the sea surface for 2 continous Trailer Suction Dredging operations over a 24 hour period at the IMF.

[32] The SEL for dredging was calculated over a 24 hour period. It therefore assumes that an animal will be continuously exposed to the dredging noise over that time (i.e. 24 hours).

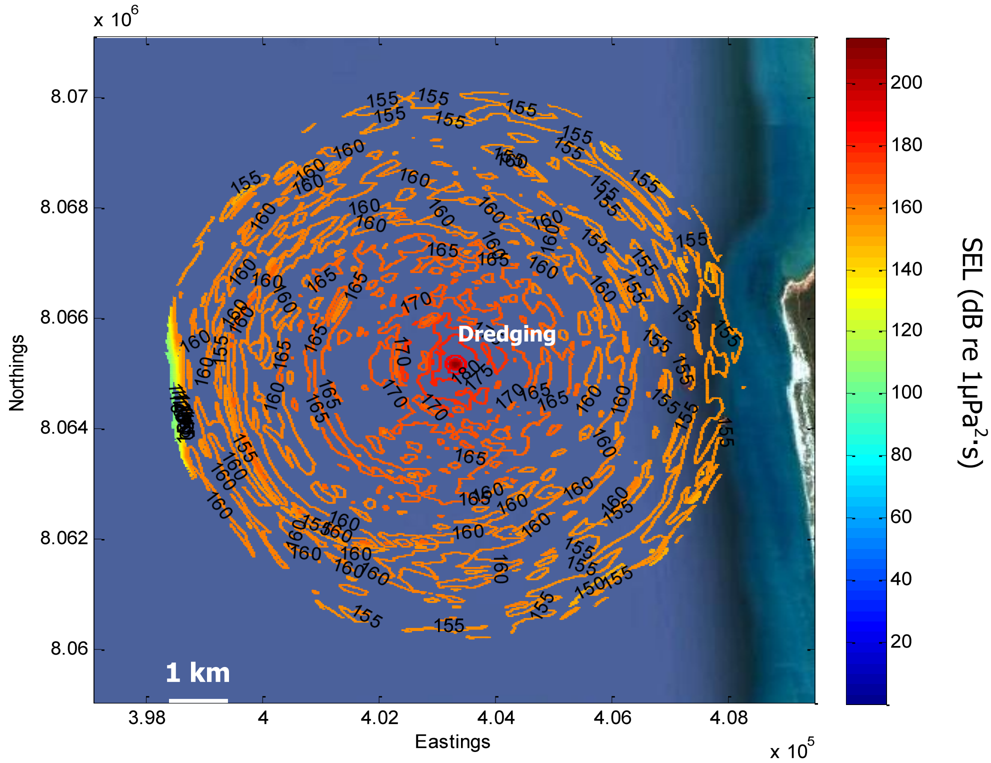

Figure 6-6 Overview of SEL contour 2 m below the sea surface for 2 continuous Trailer Suction Dredging operations over a 24 hour period at the end of the dredging channel.

Table 6-2 The predicted SPL RMS and SEL for a period of 0.5h, 1h, 3h and 24h, against the distance from the source.

Distance from Source (km)	RMS SPL (dB re 1 μPa)	SEL (dB re 1 μPa²·s) for a period of			
		0.5h	1h	3h	24h
0.05	166	198.5	201.5	206.3	215.3
0.1	150	182.5	185.5	190.3	199.3
0.2	136	168.5	171.5	176.3	185.3
0.5	121	153.5	156.5	161.3	170.3
1	113	145.5	148.5	153.3	162.3
2	108	140.5	143.5	148.3	157.3
5	94	126.5	129.5	134.3	143.3

6.1.3 Marine Blasting

The marine blasting noise source was taken to have a charge size of 50 kg of emulsion. It must be noted that this emulsion has a very slow velocity of detonation which implies that it has a relatively small shock wave component, with lots of gas manufactured during the detonating process. It is therefore used for material displacement.

Figure 6-7 and Figure 6-8 present the predicted noise contour for a single blasting pulse. The noise contours are 2 m below the sea surface.

Table 6-3 shows the predicted SPL peak and SEL for a single blast, against the distance from the source.

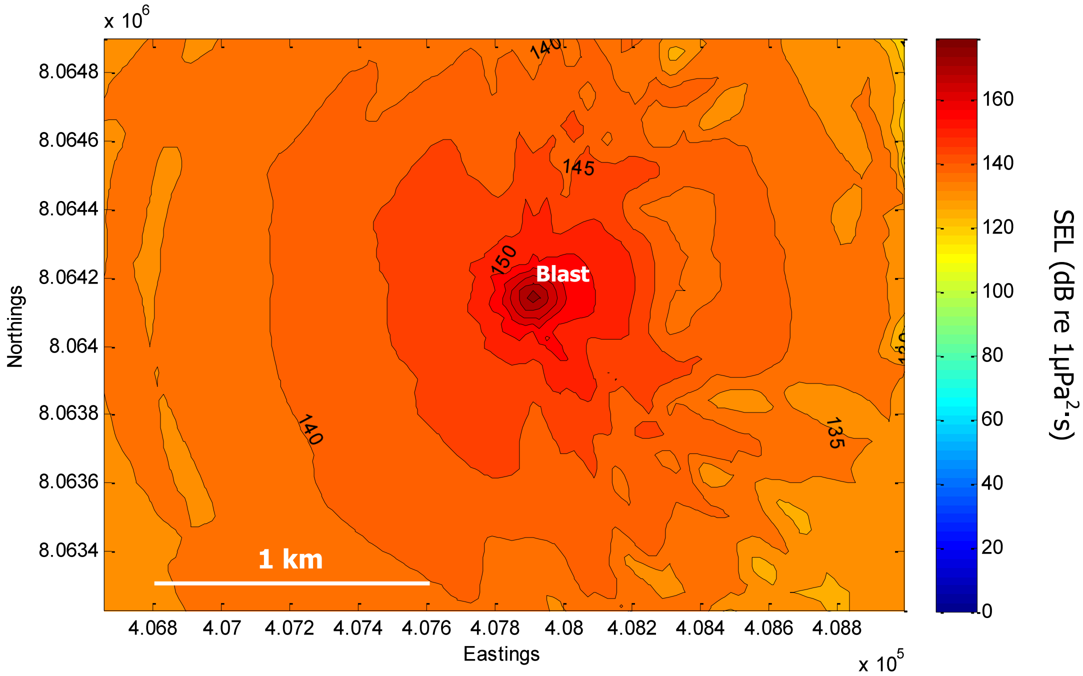

Figure 6-7 Contour showing predicted SEL for a single blast pulse near the IMF. The noise contour is 2 m below the sea surface.

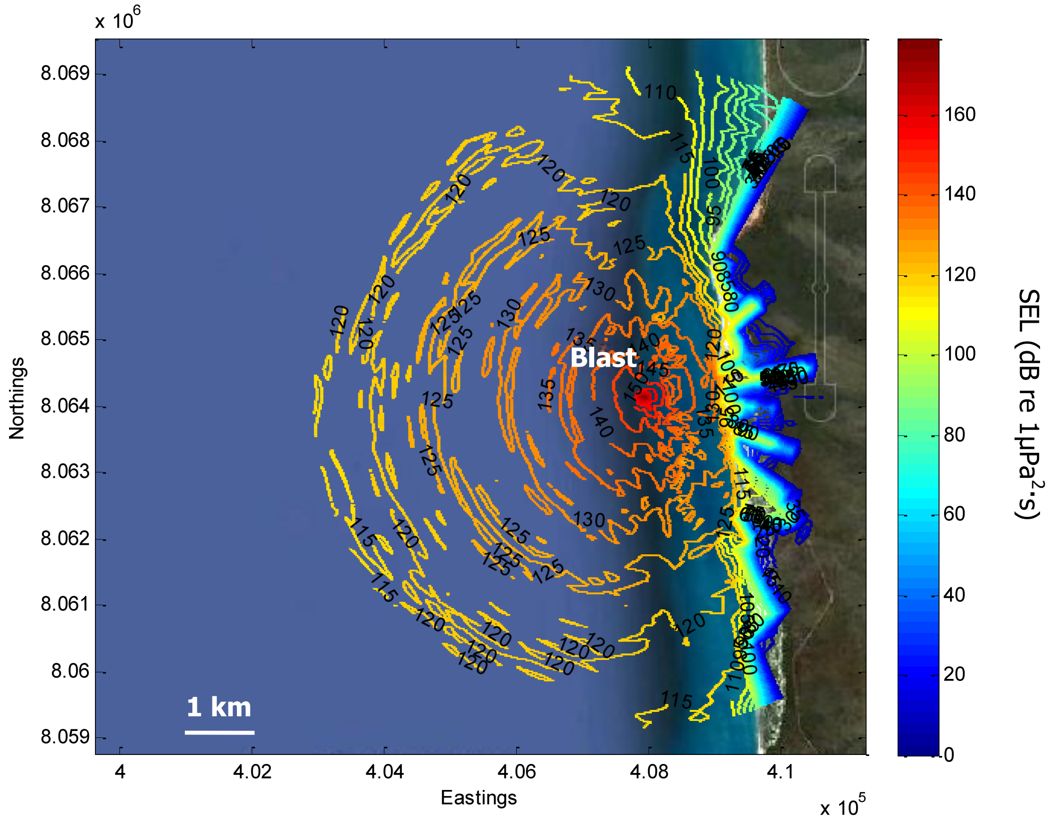

Figure 6-8 Overview of SEL contour 2 m below the sea surface for a single marine blast near the IMF.

Table 6-3 The predicted SPL peak and SEL for a single blast, against the distance from the source.

Distance from Source (km)	Peak SPL (dB re 1 μPa)	SEL (dB re 1 μPa²·s) for a single blast
0.05	232	186
0.1	228	182
0.2	221	175
0.5	202	156
1	189	143
2	176	130
5	160	114

6.1.4 Vessel Movements

It was assumed that two rock dumping vessels, a fallpipe rock dumping vessel at the end of dredging channel and a sidedump rock dumping vessel near the IMF, are operating simultaneously over a 24 hour[33] period. Figure 6-9 shows the SEL noise contour for the two vessel operations.

Table 6-4 gives the predicted SPL RMS and SEL for a period of 0.5h, 1h, 3h and 24h, against the distance from the source.

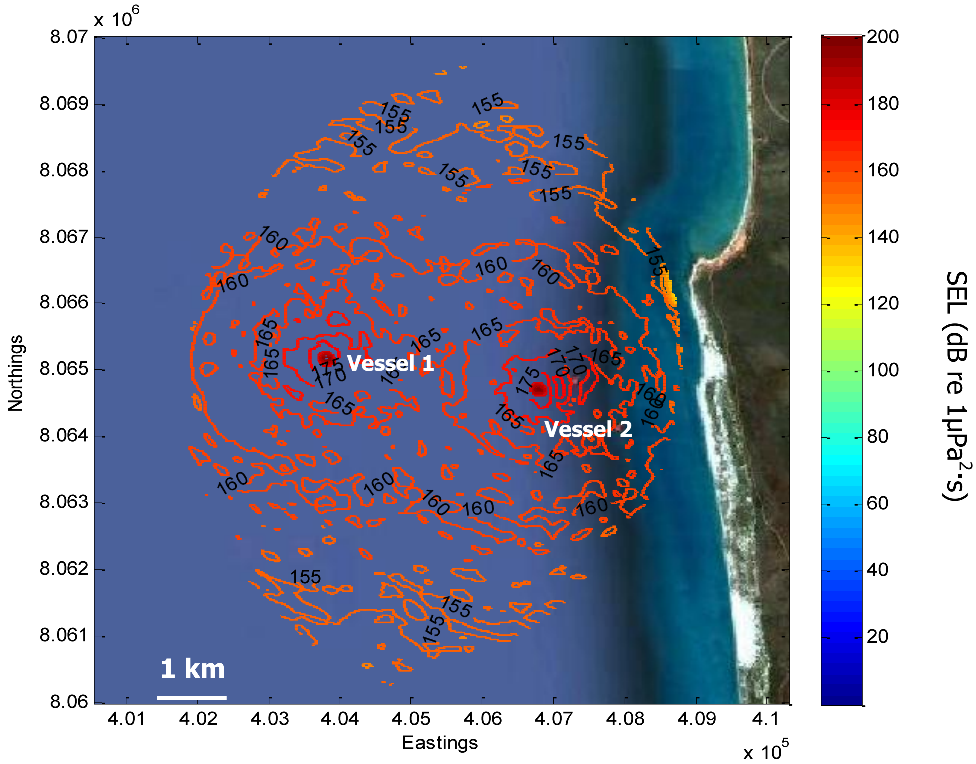

Figure 6-9 Overview of SEL contour 2 m below the sea surface for two operating rock dumping vessels, one at the end of the dredging channel and another one near the IMF, over a 24 hour period.

[33] The SEL for vessel movements was calculated over a 24 hour period. It therefore assumes that an animal will be continuously exposed to the vessel noise over that time (i.e. 24 hours).

Table 6-4 The predicted SPL RMS and SEL for a period of 0.5h, 1h, 3h and 24h, against the distance from the source.

Distance from Source (km)	RMS SPL (dB re 1 μPa)	SEL (dB re 1 μPa²·s) for a period of			
		0.5h	1h	3h	24h
0.05	142	174.5	177.5	182.3	191.3
0.1	129	161.5	164.5	169.3	178.3
0.2	123	155.5	158.5	163.3	172.3
0.5	118	150.5	153.5	158.3	167.3
1	115	147.5	150.5	155.3	164.3
2	106	138.5	141.5	146.3	155.3
5	95	127.5	130.5	135.3	144.3

6.2 Zones of Possible Behavioural Disturbance and Possible Physical Injury

Zones of possible behavioural disturbance and possible physical injury were assessed based on Table 3-1. Peak pressure levels for pile driving noise and marine blasting noise were estimated using an empirical formula[34].

Table 6-5 summarises the maximum distances for the four scenarios modelled and the zones of possible behavioural disturbance and possible injury for whales, dolphins and dugongs. Where applicable, time of exposure, has been included in the zone of physical injury.

For rock dumping vessel movements, it is unlikely that they would induce physical injury or hearing damage to the three groups of marine mammals. The dredging and rock-dumping operations will induce behavioural disturbance to the three marine species in a larger region than pile driving and marine blasting operations.

[34] SPL_{peak}=SEL+10*log(T_1/T_2)+6, where T_1=1s and T_2=duration of impulsive signal.

Table 6-5 Furthest distance to zones of possible behavioural disturbance and possible injury at sea level of HAT.

Modelling Scenarios	Furthest Distance from Source to Zone of Potential Behavioural Disturbance (m)	Furthest Distance from Source to Zone of Potential Physical Injury (m)
Pile Driving – Near IMF	250 [35]	60 [36]
Cutter/Trailer Suction Dredging – End of Dredging Channel	550 [37]	- [38]/ 5 [39]/ 15 [40]/ 75 [41]
Cutter/Trailer Suction Dredging – End of Dredging Channel near IMF	500 [37]	- [38]/ - [39]/ 10 [40]/ 50 [41]
Marine Blasting – Near IMF	200 [42]	25 [42]
Fallpipe Rock Dumping Vessel – End of Dredging Channel	450 [37]	–

[35] Based on SEL of a 10 second period.

[36] Based on SEL of a single piling strike of around 90 ms.

[37] Based on SPL rms of 120 dB re 1µPa.

[38] Based on continuous exposure over a 30 minute period.

[39] Based on continuous exposure over an hour period.

[40] Based on continuous exposure over a 3 hour period.

[41] Based on continuous exposure over a 24 hour period.

[42] Based on received peak pressure level of a single blasting pulse.

Modelling Scenarios	Furthest Distance from Source to Zone of Potential Behavioural Disturbance (m)	Furthest Distance from Source to Zone of Potential Physical Injury (m)
Fallpipe Rock Dumping Vessel – End of Dredging Channel Near IMF	400 [37]	–

APPENDIX A : NOISE SOURCE SPECTRUM LEVEL DATA

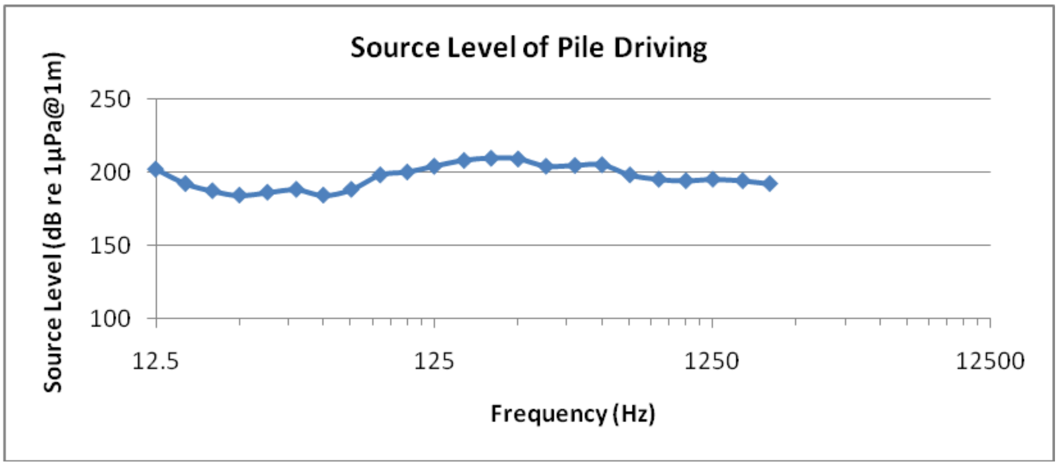

Figure A-1 Source characteristics of Pile Driving.

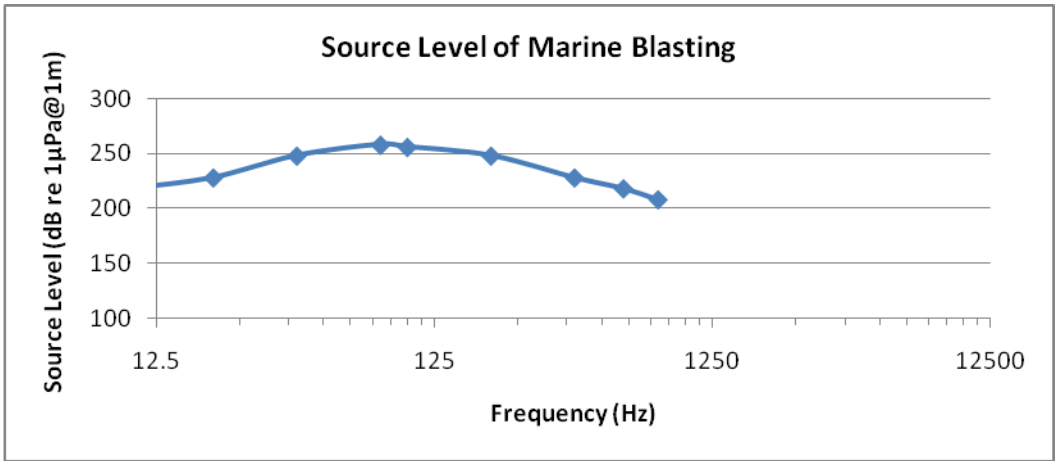

Figure A-2 Source characteristics of Marine Blasting.

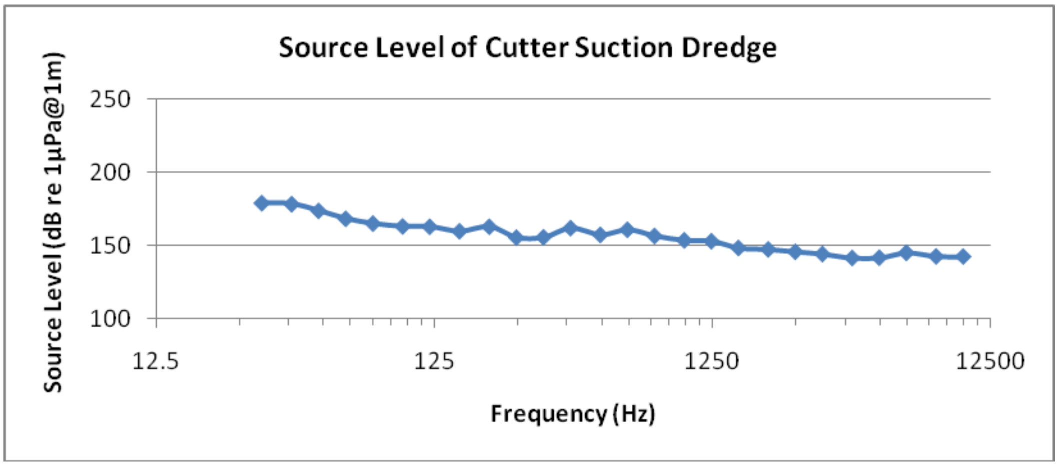

Figure A-3 Source characteristics of Cutter Suction Dredge.

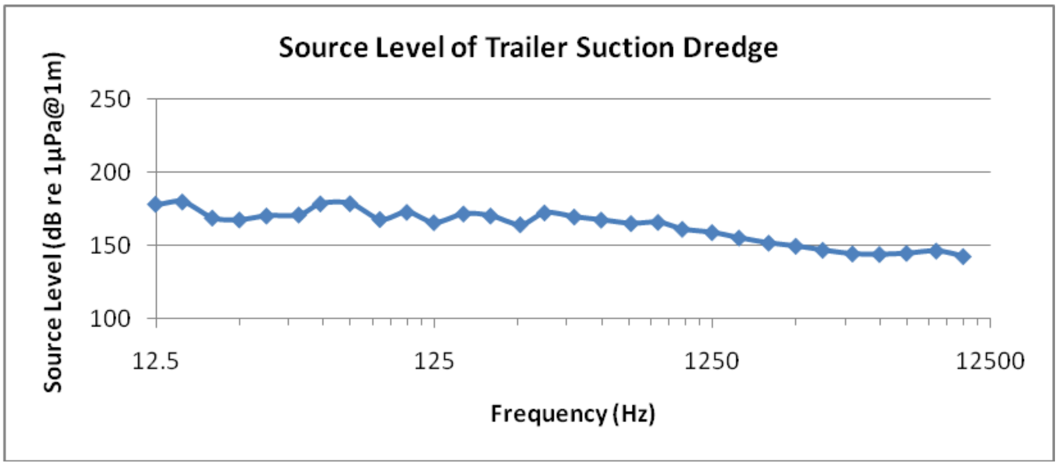

Figure A-4 Source characteristics of Trailer Suction Dredge.

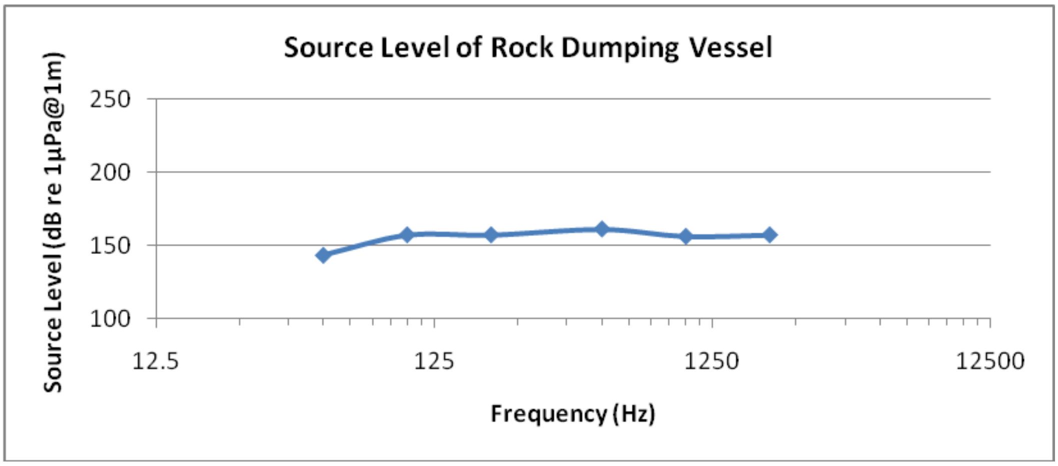

Figure A-5 Source characteristics of rock dumping Vessel.

APPENDIX B : ACRONYMS

Acronym	Definition
DSD	Department of State Development
ESHA	Social and Health Assessment
HAT	Highest Astronomical Tide
IMF	Integrated Marine Facility
LNG	Liquefied Natural Gas
MMPE	Monterey Miami Parabolic Equation
MSL	Mean Sea Level
PE	Parabolic Equation
PTS	Permanent Threshold Shift/Permanent Hearing Damage
RMS	Root Mean Square
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift/Temporary Hearing Damage