Rio Tinto Alcan

Section 15

Noise and Vibration

15 Noise and Vibration

15.1 Introduction

This section outlines the potential noise emissions from the Project and noise related impacts. This information is provided as supporting evidence for conclusions relating to impacts on matters of NES.

Section 15.2 summarises the noise impact assessment undertaken for the terrestrial environment. Additional details on noise are included in Section 10 of the Project's EIS prepared for the Queensland Government (RTA 2011).

Section 15.3 summarises the impact assessment undertaken for underwater noise effects on the marine environment. Additional details are included in the detailed technical report provided in **Appendix 15-A**.

15.2 Terrestrial Noise

15.2.1 Ambient Noise Levels

A noise survey was undertaken over an eight-day period in 2008 to determine the existing ambient noise levels at Evans Landing, located to the north of the Project area. This site was considered to be representative of the residential areas along the Embley River, namely Napranum and the accommodation areas in Evans Landing, which would be the nearest sensitive receptors to the Project area. **Table 15-1** summarises the results of the noise survey for $L_{A90(1hr)}$ (noise level exceeded 90% of the time – a measure of background noise) and $L_{Aeq(1hr)}$ (average noise energy during the one hour measurement period) at the survey site.

Table 15-1 Summary of Median Background Noise Levels at Evans Landing (dB(A))

Noise Level	Day	Evening	Night
$L_{A90(1hr)}$	41	38	38
$L_{Aeq(1hr)}$	53	48	47

The $L_{Aeq(24hr)}$ (average noise energy during the 24 hour measurement period) at Evans Landing was monitored at 51dB(A).

In 2012 additional noise monitoring was conducted at Napranum (Noise Mapping Australia Pty Ltd 2012). Results for $L_{A90(1hr)}$ noise levels matched those measured at Evans Landing. It is therefore concluded that $L_{Aeq(1hr)}$ at Napranum would be similar or equal to those recorded at Evans Landing.

15.2.2 Relevant Impacts

15.2.2.1 Noise Sources

Construction of the mine facilities and beneficiation plants would consist of a number of noise sources including earthworks, erection of buildings and structures, and installation of plant and equipment.

Once mining commences vegetation would be removed and topsoil stripped using front-end loaders or scrapers. Bauxite and overburden are relatively easy to dig and would not require blasting. Overburden would be loaded into haul trucks with front-end loaders and transported to the rehabilitation areas. Typically these activities would take place close to the active mining areas.

Mining activities would include extraction of bauxite by front-end loaders and loading haul trucks. The trucks would then travel to the dump station situated close to the beneficiation plant. In each development area there would be a fleet of loaders and trucks stripping and placing overburden.

The mine industrial area would include numerous noise sources including the beneficiation plant (including crushers), conveyors, power station, stacker/reclaimers and light vehicles.

15.2.2.2 Potential Effects on Terrestrial Fauna

The potential effects of Project related noise on terrestrial fauna include physical damage to hearing, increased energy expenditure or physical injury while responding to noise, interference with normal activities and impaired communication. Ongoing impacts of these effects may include habitat loss, reduced reproductive success and increased mortality.

As with humans, an animal's response to noise can depend on a variety of factors, including noise level, frequency distribution, duration, number of events, variation over time, rate of onset, noise type, existence and level of ambient noise, time of year, and time of day. The animal's location, age, sex, and past experience may also affect their response to noise.

There are no specific Commonwealth or State noise criteria related to terrestrial fauna. The Queensland *Environmental Protection (Noise) Policy 2008* (Qld) (EPP (Noise)) includes acoustic quality objectives for critical habitats (Protected Areas or areas defined in a conservation plan under Queensland's *Nature Conservation Act 1992* and Marine Parks under the *Marine Parks Act 2004* (Qld)).

There have been limited studies on the impacts that noise has on the behaviour and health of birds and mammals. Most studies completed indicate that species (both mammals and birds) may begin to avoid habitats when sound levels reach 70dB(A) to 90dB(A) (FWHA 1994, Dawe and Goosem 2008).

With respect to peak noise levels, the US Department of Transport Federal Highway Administration (FWHA) (1994) studies of various species determined that startled responses of terrestrial fauna occur from around the 80-90dB(A) range. For example, birds may flush from the nest in response to a sudden loud noise, but in most cases they will return within ten minutes. Similar results were found by Dawe and Goosem (2008).

In reference to mammals, Manci *et al*. (1998) state that:

> *Sound levels above about 90dB(A) are likely to be adversive to mammals and are associated with a number of behaviours such as retreat from the sound source, freezing, or a strong startle response. Sound levels below about 90dB(A) usually cause much less adversive behaviour. Laboratory studies of domestic mammals have indicated that behavioural responses vary with noise types and levels, and that domestic animals appear to acclimate to some sound disturbances*.

The potential impacts of Project related noise on terrestrial fauna in the vicinity of the Project area are described in **Section 6**.

15.2.2.3 Modelled Impacts

The noisiest activity during construction would be pile driving. Calculations indicate that noise emissions from pile driving can be expected to return to 62dB(A)$_{LA10}$ (59dB(A)$_{LAeq}$) within 500m of piling activities, which would be well below the startled response and avoidance criteria. As the piling would be undertaken in the marine environment as part of the construction of the wharves and jetties, it is not anticipated that noise from this activity would cause any significant startled response to terrestrial fauna as noise levels would be below 90dB(A)$_{LA10}$ within 20m which would still be over water and not within the terrestrial environment.

Predictive noise modelling for the Project was undertaken for the predicted highest output operational scenario of 50Mdptpa. The noise model considered sound power levels from the plant, equipment and activities carried out during both phases of the Project. A fleet of haul loaders and haul trucks were modelled in several mining areas (including mining areas closest to sensitive human receptors) and on roads simultaneously to reflect the planned operations. Modelling also considered meteorology and terrain within the Project area.

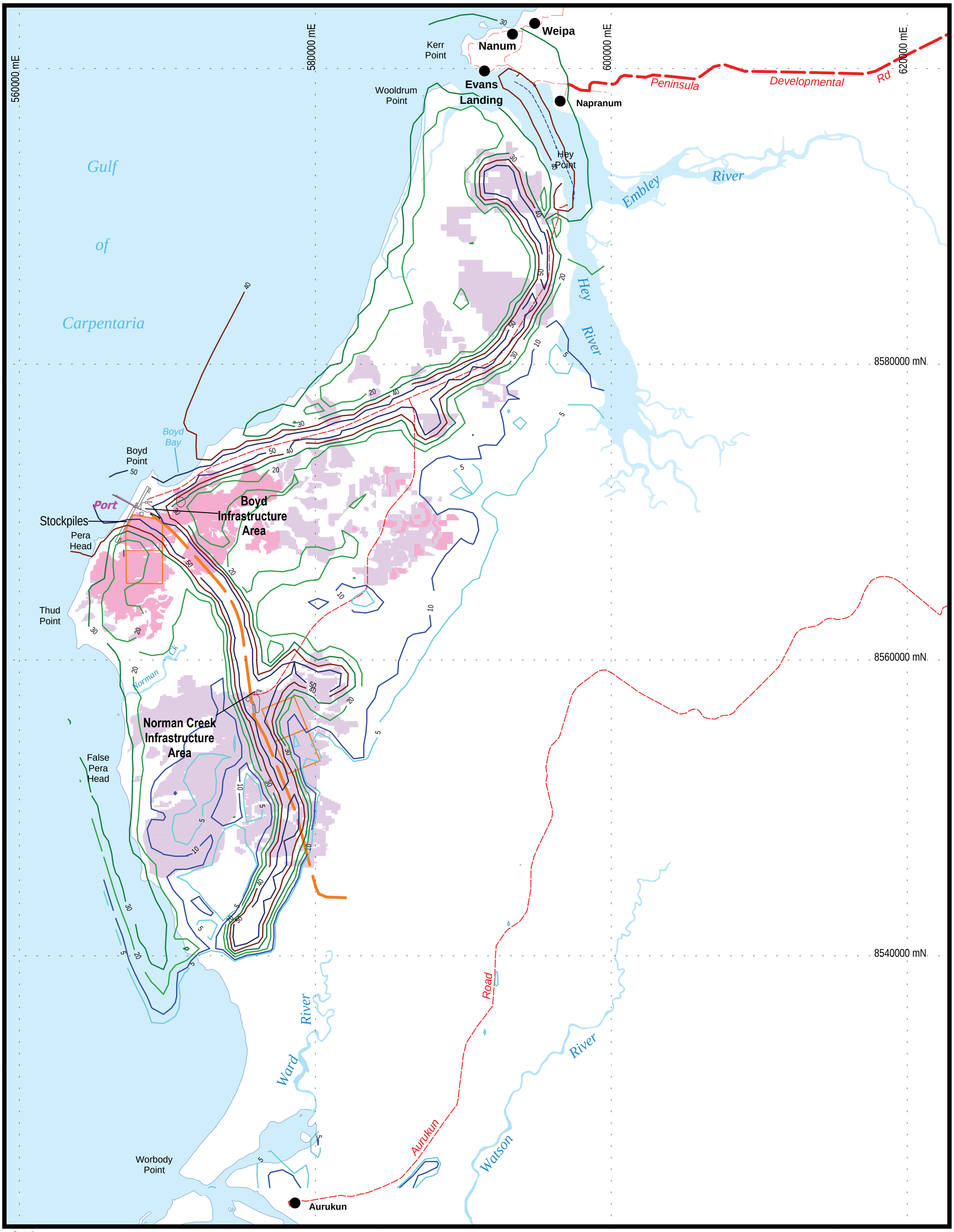
The digital terrain noise model used was the PEN3D General Prediction Model. Details of the model and the modelling results are provided in Section 10 of the EIS prepared for the Queensland Government (RTA 2011).

Blasting is not proposed during either construction or operations, and therefore there would be no impact associated with blasting noise, ground vibration, or flyrock.

Figure 15-1, **Figure 15-2** and **Figure 15-3** show the day, evening and night time $L_{Aeq(1\ hour)}$ noise contours associated with the predicted worst-case operational scenario (50Mdptpa production scenario). The model has assumed a spatial distribution representative of operations likely to cause the highest noise levels at the sensitive receptor residential locations of Napranum and Aurukun. Based on experience, the modelled L_{A10} noise levels can be considered to be approximately 3dB(A) higher than the equivalent L_{Aeq} levels.

The modelling results show that noise associated with the Project would be localised, with higher noise level contours tightly spaced around mining activities and infrastructure areas (such as conveyors and roads). During the worst case scenario (evening), high level noise contours are limited to the immediate mining and infrastructure areas, including noise levels exceeding 50dB(A) L_{Aeq} (or approximately 53dB(A) L_{A10}), a level well below both the startled response rate and avoidance criteria. In addition, the typical noise from the front end loaders and trucks associated with mining activities would not be impulsive, further reducing the risk of startled response. Noise levels would typically reduce to ambient conditions within 1km of mining related activities.

Overall, relevant noise impacts on terrestrial fauna would be minor and would generally be limited to times when mining is occurring close to the mine pit limits and when the wind direction is towards adjacent habitat areas (the prevailing winds are easterly).



- ● Township (Sensitive Receptor)
- Road/track
- Infrastructure corridor
- Barge / Ferry route
- Tailings storage facility
- Mining Years 1 -13
- Mining Years 14 - 40
- 10 Modelled Noise Level ($L_{Aeq1hour}$)

South of Embley Project

Fig 15-1: Modelled Day Period Noise (50Mdptpa)

N

5 0 5km

Datum/Projection: GDA94/MGA Zone 54 Date: 14/08/2012

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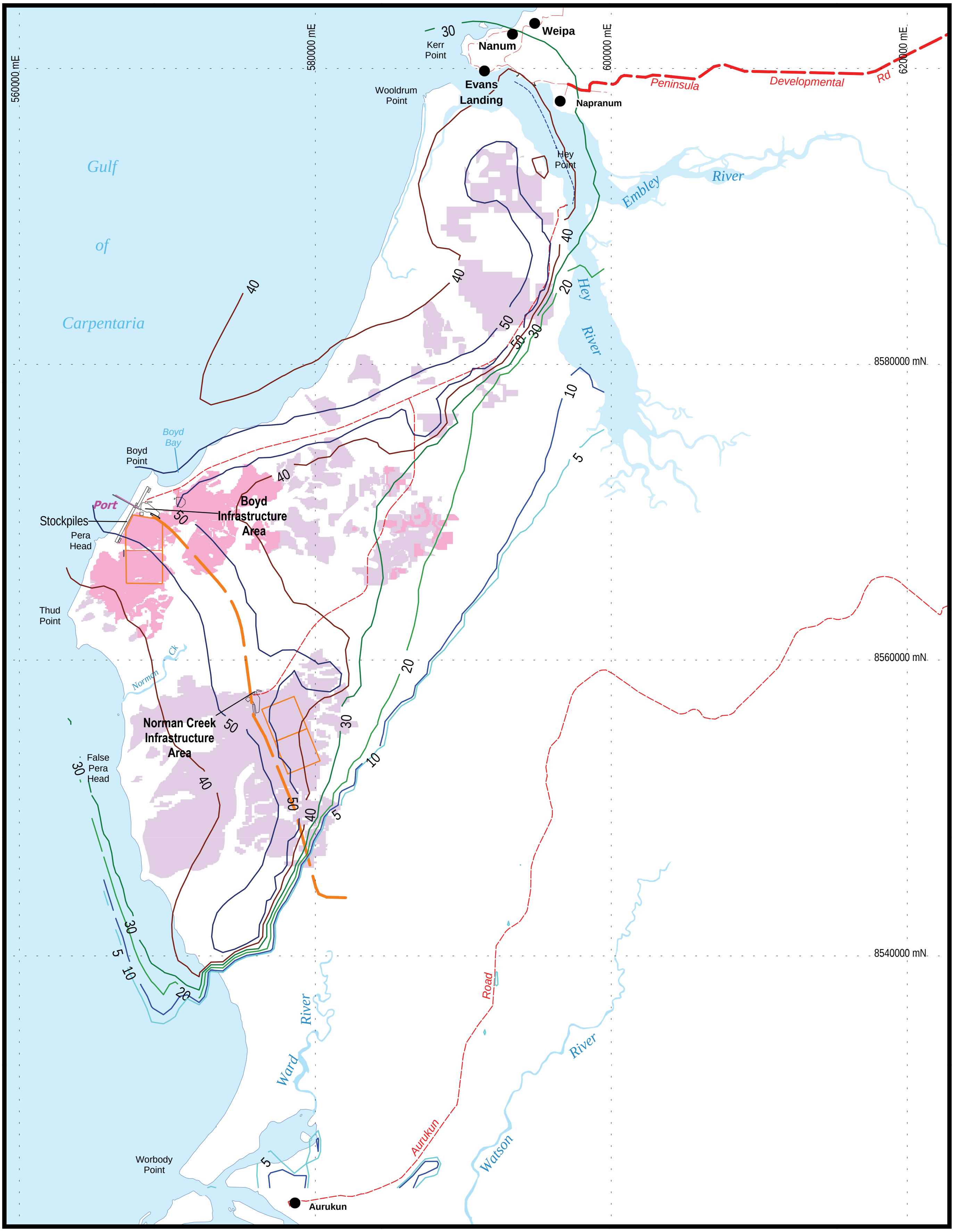


- Township (Sensitive Receptor)
- Road/track
- Infrastructure corridor
- Barge / Ferry route
- Tailings storage facility
- Mining Years 1 -13
- Mining Years 14 - 40
- 10 Modelled Noise Level ($L_{Aeq1hour}$)

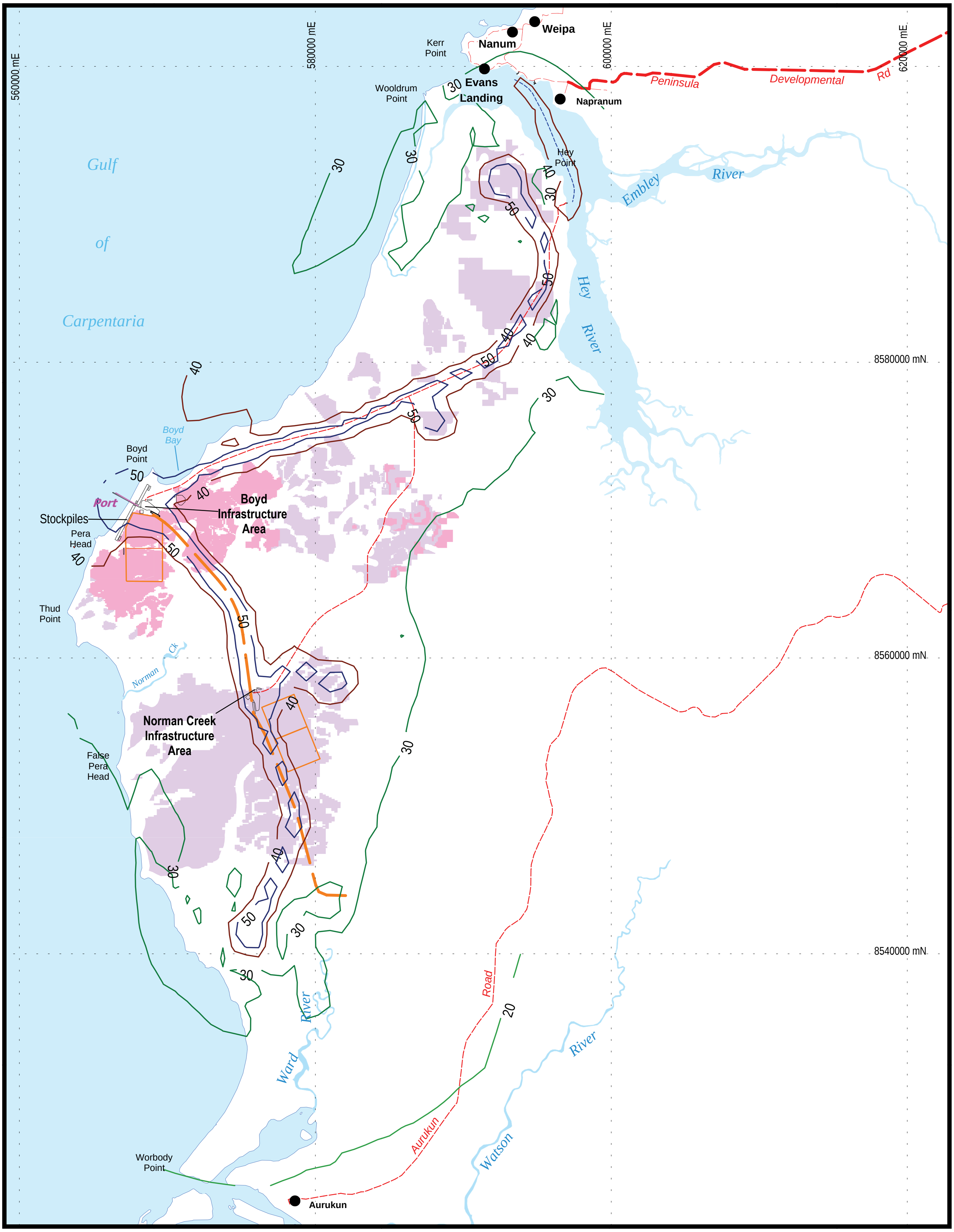
South of Embley Project

Fig 15-2: Modelled Evening Period Noise (50Mdptpa)

N

5 0 5km

Datum/Projection: GDA94/MGA Zone 54 Date: 14/08/2012



●	Township (Sensitive Receptor)
	Road/track
	Infrastructure corridor
	Barge / Ferry route
	Tailings storage facility
	Mining Years 1 -13
	Mining Years 14 - 40
30	Modelled Noise Level ($L_{Aeq1hour}$)

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South of Embley Project

Fig 15-3: Modelled Night Period Noise (50Mdptpa)

N 5 0 5km

Datum/Projection: GDA94/MGA Zone 54 Date: 14/08/2012

15.2.3 Avoidance, Mitigation, Enhancement Measures and Residual Impacts

There are no specific noise avoidance measures associated with the Project, however the following mitigation measures would be implemented:

- the manufacturer's sound power level specifications for major equipment items would be used as guidance when purchasing equipment;
- pile driving activities for the ferry terminal would be undertaken in the day so as not to cause nuisance at sensitive receptors;
- a noise monitoring program, including attended monitoring at Napranum, would be implemented after operation commences to compare to baseline noise monitoring at Evans Landing and Napranum and to validate the noise model. In the event that measured noise levels exceed applicable noise limits, appropriate action would be taken to reduce noise levels;
- adaptive management measures to reduce noise would be implemented where effects of increased noise are found to be occurring; and,
- noise monitoring would be carried out in accordance with the requirements of the Project's Environmental Authority issued by the Queensland Government.

The application of these noise control measures has been included in the modelled results shown in **Figure 15-1** to **Figure 15-3**, which therefore illustrate that the residual noise impacts on terrestrial fauna are predicted to be minor.

15.3 Underwater Noise

15.3.1 Ambient Noise Levels

The background underwater noise environment must be considered when evaluating the various noise sources and their impacts on the marine environment (SVT 2009). Underwater noise levels from different sources are frequency dependent, as follows (SVT 2009):

- seismic activity is in the first 10Hz;
- shipping and meteorological effects, including rain and wind, dominate the spectrum from 10 to 100Hz;
- wave action, rain and wind dominate the spectrum up to almost 100kHz; and,
- molecular thermal effects dominate the spectrum above 100kHz.

15.3.2 Relevant Impacts

15.3.2.1 Noise Sources

Underwater noise would occur as a result of construction of the proposed Port (refer to **Section 3.7.2**), barge/ferry terminals and navigation aids (refer to **Section 3.6.2**) and temporary seaborne access infrastructure (refer to **Section 3.6.5**). Underwater noise during construction would be due to pile driving activities, Project-related shipping activities (refer to **Section 3.9.1.1**) and capital dredging (refer to **Section 3.8.1.1**). Pile driving activities would closely follow the completion of capital dredging activities. Underwater noise during operations would be due to Project-related shipping activities (refer to **Section 3.9**) and maintenance dredging (refer to **Section 3.8.1.2**).

Appropriate parameters used to assess the impacts of underwater noise on marine fauna include sound pressure and sound exposure (Southall *et al.* 2007). Sound pressure is assessed in terms of both peak sound pressure level, and mean-square sound pressure level (referred to here as sound pressure). Sound exposure level is a measure of the energy of the sound to which an animal would be exposed. To model the propagation of noise within the underwater environment, the source levels of noise emitted from the activity are determined as peak sound pressure at 1m and sound exposure at 1m.

It should be noted that underwater noise is converted to the decibel (dB) ratio using a reference pressure of one micro-Pascal (µPa). In air the reference pressure is 20µPa. Using this air pressure reference, the equivalent sound pressure underwater would appear to be 26dB greater than the pressure in air due to the difference in the reference pressures (1µPa underwater versus 20µPa in air). Underwater sound pressure levels are therefore reported as dB re 1µPa and underwater sound exposure level is reported as dB re $1\mu Pa^2.s$.

Pile Driving

Noise emitted during pile driving operations is a function of pile type, pile driving method, the pile's material type, 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 floor would create a mixture of compression and transverse waves within the pile which would transfer from the pile into the air, ocean and sea floor. Once in the sea floor, the waves would then move outwards with some transmission of waves between the air/ocean and ocean/sea floor along the noise propagation pathway. Most of the energy from pile driving activities would normally transfer into the sea floor.

Steel pipe piles would be used for the construction of the majority of marine and river facilities for the Project. The pipe piles would be driven with hydraulic impact hammers (impact pile driving). The typical hammer for driving piles larger than 1200mm has a mass of 25 tonnes, yielding typical hammer energy of 368kJ. Smaller piles would typically be driven by a 16 tonne hammer, with typical hammer energy of 235kJ. Steel sheet piles may be used in addition to the pipe piles at the Humbug and Hey River terminals. The sheet piles would be installed using a vibratory driver (vibratory pile driving), with a typical maximum frequency of 1800 vibrations per minute (30Hz) and a driving force of 1844kN (188 tonnes weight).

At the Port, two or three hammers would be in use simultaneously for pile driving activities (one 25 tonne, and one or two 16 tonne). At the river facilities up to two 16 tonne hammers would be in use for pile driving activities, however the two impact hammers and vibratory driver would not operate simultaneously at the same facility. Proposed pile sizes for each facility and the predicted source levels for each pile size and type are summarised in **Table 15-2**. The proposed piling schedule for the Project facilities is presented in **Table 15-3**, which indicates the duration of pile driving at each facility. Piling may be undertaken 24 hours a day.

The source levels of the Project pipe piles in **Table 15-2** were predicted based on existing published measurements of similar piling method, pile rig configuration and material to those which would be used at the Project (Bailey *et al.* 2010, Carlson *et al*. 2007, Duncan *et al.* 2010, Erbe 2009, ICF Jones and Stokes 2009, Laughlin 2007). An expert review of the modelling methods identified that source levels should be estimated at worst case (95^{th} percentile) in order to not underestimate potential underwater noise impacts on listed threatened estuarine and marine fauna and non-avian migratory species (A. Duncan pers. comm.). Therefore worst case source levels were adopted in the underwater noise model.

Previously measured underwater impact pile driving noise (pipe piles) has been shown to be very broadband (40Hz to >40kHz) near the source. Peak frequencies from pile driving generally lie between 200Hz and 400Hz (Bailey *et al*. 2010, Erbe 2009, Nehls *et al.* 2007, Reinhall and Dahl 2011). Due to the large absorption over distance at higher frequencies, at long ranges (approximately greater than 1000m) only sound energy at frequencies less than 1kHz remain (Bailey *et al*. 2010, Nehls *et al.* 2007).

If required, the drive-drill-drive method would be used in more challenging ground conditions. This means that if impact pile driving cannot penetrate the substrate to the target depth, the remaining substrate would be drilled to the target depth from inside the pile. A final re-drive into the drill hole would then achieve pile penetration to the target depth. It is unlikely that rock socket drilling (to penetrate hard rock) would be required. No measurements of noise source levels for similar drilling activities were available. Only measurements of louder drilling activities within harder rock (rock-socket drilling) and larger piles (4.25m diameter) were available. The loudest of these measurements were used to produce a conservative estimate of source peak sound pressure of no greater than 163dB re 1μPa (Nedwell *et al.* 2003, Ward 2012).

Vibratory pile driving of a 600mm wide sheet pile was determined to produce a peak source sound pressure of 202dB re 1μPa, and a source sound pressure level of 185dB re 1μPa (ICF Jones and Stokes 2009).

Table 15-2 Pile Sizes and Source Levels

Facility	Pipe Pile Diameter (mm)	Sheet Pile Size Width (mm) / Length (m)	Number of Piles	Source Sound Exposure Level at 1m (dB re 1 µPa)	Source Peak Sound Pressure Level at 1m (dB re 1 µPa
Port Facility	1,500		36	211	242
	1,200		80	210	241
	1,050		107	208	239
	750		46	206	238
	600		2	206	235
	355.6		3	203	236
Humbug terminal	750		12	206	236
	900		6	207	236
		600 / 12.5	160	185*	202
Humbug terminal (temporary berthing facility)	600		4	205	235
Hornibrook ferry and tug terminal	750		13	206	237
	1,050		8	207	237
River Navigation Aids	1,050		3	208	238
Hey River terminal	750		11	206	236
	900		6	207	236
	1,050		1	208	237
		600 / 12.5	160	185*	202
Hey River terminal (temporary berthing facility)	600		16	205	235

* It is inappropriate to determine the source sound exposure level of vibratory pile driving which is a continuous sound. Sound pressure level was used instead given known relationships between the two parameters.

Table 15-3 Pile Schedule

Facility	Pile Type	Duration
Port Facility	Pipe	12 - 15 months
Humbug terminal	Pipe	3 – 4 weeks
	Sheet	1 – 2 weeks
Hornibrook ferry and tug terminal	Pipe	3 – 4 weeks
River Navigation Aids	Pipe	1 – 2 weeks
Hey River terminal	Pipe	3 – 4 weeks
	Sheet	1 – 2 weeks

Due to differences in sound signals generated from the various methods, underwater noise levels were assessed as multi-pulse signals for impact pile driving and as non-pulse (continuous) signals for vibratory pile driving and drilling as described in Southall *et al*. (2007). The multi-pulse/non-pulse distinction is important because the different signals typically have a different potential to cause physical effects, particularly on hearing of marine and estuarine fauna. Since drilling and vibratory pile driving would be continuous sounds, it is inappropriate to assign a source sound exposure level. However, the source sound pressure level can be utilised to assess impacts on marine fauna, given known relationships between these parameters. No source sound pressure was available for drilling; however, comparison of drilling to vibratory pile driving indicates that drilling is at least 39dB quieter. As drilling is much quieter than other methods the peak sound pressure was used to calculate a conservative sound exposure levels for drilling.

Dredging

Project-related dredging activities are described in detail in **Section 3.8**. The dredging at the Port would be carried out by a cutter suction dredge (CSD). This would either be pumped to several spilt hopper barges (SHB) or re-deposited on the sea bottom and retrieved by a trailing suction hopper dredge (TSHD). Dredged spoil, which is suitable for sea disposal, would be transported by the TSHD or SHB to a proposed new offshore spoil disposal ground located approximately 17km west of Boyd Point (refer **Figure 3-8** for location). Dredging and offshore spoil disposal would be conducted 24 hours a day, seven days a week.

Dredging at the river facilities is anticipated to be undertaken using either a barge-mounted backhoe/dipper dredge, with a bucket up to approximately $13m^3$ or a CSD. Dredge spoil would be transferred to either a SHB or TSHD for transport to the Albatross Bay spoil ground. Subsequent capital and maintenance dredging would be undertaken as required (refer **Section 3.8.12**).

Dredging is at the lower end of the scale with regards to emitted sound pressure levels in aquatic environments (CEDA 2011). The main noise anticipated during dredging operations would be the noise from TSHD and CSD, which are reported to create higher underwater noise than the noise associated with grab dredges (CEDA 2011, Nedwell and Howell 2004). The source sound pressure of underwater noise from a TSHD ranges from 186 to 188dB re 1µPa with peak intensity between 100 to 500Hz. The source sound pressure of underwater noise from a CSD ranges from 172 to 185dB re 1µPa, with peak intensity between 100 and 500Hz (CEDA 2011). These levels are comparable to that of vibratory pile driving.

Shipping

Project-related shipping activities are described in detail in **Section 3.9**. During the construction phase, an estimated 30 international chartered ship voyages (annual average of 11 shipments) are currently planned to offload at Port of Weipa or at the Boyd Port area. Cargo deliveries required for construction would result in a predicted annual average of 43 additional barge deliveries between Cairns and the Port of Weipa during the 30 to 36 month construction period. Some construction material may be shipped from other domestic ports.

Once operations commence, the Port of Weipa would continue to receive deliveries of cargo, and equipment for the Project at the Humbug and Evans Landing wharves by the existing Cairns-Weipa barge service or from other domestic ports. Fuel would be delivered from Darwin to the Port of Weipa; however, the origin of fuel deliveries may change in future to another port depending upon arrangements managed by the supplier.

Deliveries to the Port of Weipa would be transferred to the Project area via barge, initially to the temporary barge landing area near the proposed Port and, once commissioned, to the Hey River terminal. The workforce would also be transferred from Weipa to the Project area via ferry or boat on a daily basis, initially to the temporary seaborne access facilities near the proposed Port (if required) or the Hey River temporary berthing facility and, once commissioned, to the Hey River terminal.

Bauxite shipping for the Project would be expected to commence in or about 2016 (or approximately three years after the commencement of construction) subject to the grant of relevant environmental or other regulatory approvals, the determination of internal investment approvals for the Project by Rio Tinto, and the construction schedule. The volume of bauxite shipping using the Port of Weipa would over time decrease as reserves north of the Embley River are depleted and bauxite shipping from the proposed Port replaces much of this demand.

Under the maximum production scenario (50Mdptpa) up to 700 bauxite ships per year are predicted to be loaded at the proposed Port and approximately 400 of these would be bound for export markets, not passing through the GBR. The remaining balance of a predicted average of 300 shipments per year (600 ship movements) is required to supply bauxite to two existing alumina refineries in Gladstone. The bauxite shipments through the GBR following commencement of production would continue to be the shipments required to meet the needs of the existing Gladstone refineries and would use the same inner GBR Designated Shipping Area as is used at present. If the maximum production scenario (50Mdptpa) was reached, the potential fluctuation in bauxite shipment numbers beyond that occurring prior to the commencement of the Project would be an average of 60 bauxite ship movements through the GBR annually, which includes possible fluctuations in the future of shipment numbers due to variation in bauxite grade quality and in alumina production at the Gladstone refineries, within the scope of the existing approvals for the refineries.

Underwater noise from shipping principally originates from propeller action and cavitation, movement of the water across the hull, and the transmission of on-board machinery noise as vibration through the hull of the vessel (IMO 2009, Southall 2005). Underwater noise from shipping varies between different classes of vessels, and the speed, design and condition of the vessel will further influence noise generation. In general, the source sound pressure of underwater noise from small to mid-size vessels (recreational vessels up to barges and workboats) is in the range of 165 – 180dB re 1μPa, and for large vessels such as bulk carriers is 180 – 190dB re 1μPa (CEDA, 2011, OSPAR 2009). The predominant sound frequencies associated with large vessels are in the range of 10Hz to 1kHz (OSPAR 2009), with main sound energy less than 0.2kHz (CEDA 2011).

15.3.2.2 Potential Effects on Threatened Estuarine and Marine Fauna and Non-Avian Migratory Species

Pile Driving

There are no designated Marine Parks or Protected Areas in the vicinity of the Project area, and therefore the objectives provided by the EPP (Noise) are not relevant to the Project.

There are no other regulatory criteria relating to noise impacts on marine animals from piling activities. Sensitivities to noise vary among species and potential effects also depend on a number of factors including the type of noise, whether or not the noise source is stationary or moving, or if it is constant or sporadic. Sound propagation in water also varies with depth, sediment type, temperature and salinity, as well as repeated reflections off the surface and bottom (Bailey *et al*. 2010).

Low frequency sound is critical to various aspects of marine mammal life. Marine mammals use sound for many reasons such as communication, navigation, predator avoidance and prey capture (McCauley and Cato 2003, Marine Mammal Commission 2007). Marine mammals, such as whales and dolphins, are known to be sensitive to underwater noises that are louder (greater intensity) than normal background levels.

Underwater noise is not identified as a potential impact on Estuarine Crocodiles (Leach *et al.* 2009) nor is it identified as a threat to the species in the DSEWPaC SPRAT database (DSEWPaC 2012q). Estuarine Crocodiles are known to occur within the vicinity of the existing port facilities within the Embley River, where similar construction and operational activities have been conducted. Similarly, the species would be expected to continuing utilising environments surrounding the Project marine facilities.

Currently, underwater noise criteria have not been developed specifically for Dugong to manage potential temporary threshold shift or behaviour disturbance. However, previous anatomical studies of Dugong suggest that their overall hearing sensitivity would likely to be less than that of dolphins. Therefore adopting the same underwater noise criteria for Dugongs as for dolphins would provide a conservative management basis for Dugongs.

Very little is known about the underwater noise source levels and associated frequencies that cause physical injury or behavioural responses in marine turtles. Available data on marine turtle hearing suggests a highest auditory sensitivity at frequencies of 250 – 700Hz, and some sensitivity to frequencies at least as low as 60Hz (Moein-Bartol *et al.* 1999, Ridgeway *et al*. 1969). Hearing measurements made for a limited range of species indicate that marine turtles generally hear best at low frequencies and that the upper frequency limit of their hearing is likely about 1kHz.

Casper (2006) identified that while elasmobranchs can detect sounds, they do not have sensitive hearing compared to other marine animals or the ability to detect most natural sounds they encounter in the far field.

Many acoustic metrics (including sound pressure, peak sound pressure or sound energy) could be considered in relation to noise impacts on animals. Southall *et al.* (2007), and more recently Erbe (2012), both identify that impact assessment in regards to behaviour disturbance should be multi-variate. However, Southall *et al.* (2007) identified sound pressure level as the best metric with which to assess the available behavioural response data, given it had most often been measured or estimated during disturbance studies. There are limitations associated with this method including that sound pressure level fails to account for the duration of exposure, whereas sound exposure level does, and that many other contextual variables may affect behaviour disturbance. However, more recent or relevant data on the listed threatened or migratory marine and estuarine species that are known, likely or possibly occur within the Project area are not available and therefore it is concluded that sound pressure level is still currently the best metric with which to assess available behavioural response data.

To assess behaviour disturbance Southall *et al.* (2007) developed an ordinal ranking of behavioural response severity (on a scale of zero to nine) for cetaceans. It is important to identify that from the perspective of behavioural ecology, an effect (e.g. a short term avoidance behaviour) does not necessarily equate to a negative impact on the animal (including its welfare) (Beale 2007). That is, undertaking an avoidance behaviour is only important if it alters the fitness of an individual through changing foraging rates or reproductive output. Therefore the assessment approach undertaken reflected the need to focus on impacts that are ecologically meaningful. A response score of six was associated with the upper range of behavioural impacts associated with increased potential to affect short-term behaviour, including foraging or reproduction, but below levels considered likely to affect vital rates of these behaviours. The sound pressure levels that would produce a response score of six were deemed to be acceptable behaviour disturbance criteria levels for cetaceans from underwater noise generated by Project piling activities (**Table 15-4**).

Comparable criteria for listed threatened estuarine and marine fauna and non-avian migratory species were determined by comparison of the hearing threshold of the species to that of the Bryde's Whale (**Table 15-4**). Where hearing threshold of the species were not available (dugong, sawfish and Speartooth Shark), hearing threshold for similar species were utilised. The response level for these species was determined to exceed that of the Bryde's Whale by the difference in their hearing threshold over the spectrum of the animals hearing bandwidth, as well as hearing threshold over the bandwidth of intense pile driving noise. For marine turtles, a sound pressure associated with ecologically meaningful behaviour response from a multi-pulse source was also obtained from a published study (McCauley *et al.* 2000) with the average of the published study and hearing threshold comparison method used as the behaviour disturbance criteria. Dugongs hearing and sensitivity to underwater noise was compared to cetaceans by using the hearing threshold of the most similar species (manatee) (Gerstein *et al.* 1999). This overlaps with the frequency range of Dugong vocalisations identified by Anderson and Barclay (1995) and is therefore considered representative of the optimal hearing range of the Dugong.

Table 15-4 Behaviour Disturbance Criteria

Species group	Multiple pulse Behaviour Disturbance Criteria (Sound Pressure, dB re 1μPa)	Non-pulse Behaviour Disturbance Criteria (Sound Pressure, dB re 1μPa)
Bryde's Whale	165	135
Dolphins and Dugong	177	177
Marine Turtle	175	150
Sawfish	215	185
Speartooth Shark	202	180

In the context of underwater noise, injury to listed threatened estuarine and marine fauna and non-avian migratory species may include partial deafness, whether temporary or permanent as well physiological injury or death. Southall *et al.* (2007) used a dual-criterion approach to determine the recommended injury criteria. That is, any received noise exposure that exceeds either a peak pressure or a sound exposure criterion for injury is assumed to cause tissue injury in an exposed marine mammal. The more precautionary of the two outcomes is used to determine the criteria. Criteria are provided for both parameters for cetacean species to prevent the onset of a small temporary threshold shift.

The peak sound pressure criteria for cetaceans was determined to be 230dB re 1μPa (Gausland 2000, Southall *et al.* 2007), which is only 12dB and 5dB below the source levels for the loudest pipe piles (refer to **Table 15-2**). Underwater noise would attenuate 12dB over a distance of approximately four meters and injury to listed threatened estuarine and marine fauna and non-avian migratory species is unlikely on the basis of peak sound pressure (as assessed below). Hearing threshold comparison indicates that for the remaining species the peak sound pressure criteria would be higher.

Sound exposure is a measure of the energy of the sound to which an animal would be exposed. In estimating injury it is necessary to consider the cumulative noise an animal would be exposed to over the duration of exposure. The cumulative sound exposure criteria for cetaceans from Southall *et al.* (2007) and from comparison of hearing thresholds for the remaining species are presented **Table 15-5**. For impact pile driving, sound exposure criteria relative to the source level per blow are required for management of the activities. This can be calculated from an expected duration of exposure for each species. The expected duration of exposure was determined from the travelling speed of each species (at a cruising pace) on the basis that animals will avoid loud sound sources. Peer reviewed literature has established that, for mobile marine animals, avoidance behaviour is the common response to underwater noise which occurs when that noise reaches a certain threshold (Janik and Thompson 1996, Nowacek *et al.* 2001, Ng and Leung 2003, Hodgson and Marsh 2007, DeRuiter and Doukara 2012). The exact nature of the avoidance behaviour may vary between species. As an animal moves away from the sound source the perceived sound exposure per blow would gradually decrease with each succeeding blow until the animal reaches a distance where it no longer seeks to avoid the sound source. The gradual decrease has not been taken into account, producing a conservative estimate. The sound exposure criteria per blow are presented in **Table 15-5**.

Table 15-5 Injury Criteria

Species group	Multi-pulse		Non-pulse
	Cumulative sound exposure criteria (dB re 1 $\mu Pa^2.s$)	Sound exposure per blow criteria (dB re 1 $\mu Pa^2.s$)	Cumulative sound exposure criteria (dB re 1 $\mu Pa^2.s$)
Bryde's Whale	198	182	215
Dolphins and Dugong	198	184	215
Marine Turtle	213	193	230
Sawfish	248	225	265
Speartooth Shark	243	228	260

Modelling of noise levels and associated impacts on the relevant listed threatened estuarine and marine fauna and non-avian migratory species from piling are detailed in **Section 15.3.2.3** below.

Dredging

CEDA (2011) reviewed expected impacts of dredging on marine fauna and concluded that it is very unlikely that underwater sound from dredging operations can cause injury. Temporary loss of normal hearing capabilities might happen if individuals are in the immediate vicinity of a dredge and are exposed for a long time, which is unlikely. As was conducted for pile driving, comparison of hearing thresholds indicates that injury to other listed threatened estuarine and marine fauna and non-avian migratory species from dredging operations would also be unlikely.

Underwater noise has the potential to impact listed threatened estuarine and marine fauna and non-avian migratory species feeding, transiting, or nesting (marine turtles) in the vicinity of dredging operations. There may be some behavioural responses for some species to avoid the area of dredging operations although this is expected only at close range to the source (Nedwell and Howell *et al.* 2003). There is also a possibility that many species will become habituated to the noise and remain within the vicinity (Smolowitz and Weeks 2006).

At the Port avoidance behaviour due to underwater noise from dredging could impact foraging or nesting behaviour of marine turtles in the immediate area. Additional details on specific potential impacts to marine turtles are included in **Section 7.3.5.1**.

Dredging operations within the river facilities would be of short duration and any impacts from underwater noise generated by dredging would be temporary. At the Hey River, Humbug and Hornibrook terminals dredging would be conducted for a maximum of fourteen consecutive days with a pause of three days between dredging periods at each site.

As behavioural impacts from underwater noise would be temporary and only occur at close range to the dredge operations the potential unmitigated impacts on listed threatened estuarine and marine fauna and non-avian migratory species would be negligible from dredging operations at the Port and in the Hey and Embley River estuaries.

Shipping

Underwater noise levels from larger vessels (bulk carriers) while travelling at modest speed (between 8 knots and 16 knots) are generally in line with underwater noise levels from TSHD (CEDA 2011). Bauxite shipping and barges would generally be operating at a maximum speed of approximately 14 knots. Noise levels from small to mid-size vessels (including the Project barges, passenger vessels and tugs) are expected to be equal to or less than the lower range of noise levels from larger vessels (CEDA 2011). Due to similarities between underwater noise levels from shipping and dredging, injury to listed threatened estuarine and marine fauna and non-avian migratory species from shipping activities would be unlikely.

As identified in regards to pile driving noise, elasmobranchs do not have sensitive hearing compared to other marine animals or the ability to detect most natural sounds they encounter in the far field (Casper 2006). Impacts to elasmobranch species from Project shipping activities would be unlikely.

Some marine turtles, Dugongs and cetacean species may show behavioural responses and avoid the shipping operations. Given similarities of underwater noise levels from shipping activities to those of dredging activities it is likely that any behavioural impacts would only occur at close range to the source.

Vessels operating in the rivers and further offshore would generally be transitory, except when waiting at anchor or the terminal at which time they would not be running propellers and hull cavitation would not occur, making any impact of underwater noise transitory. Therefore, the potential unmitigated impact of noise from shipping in the river and further offshore would also be negligible. There is also a possibility that listed threatened estuarine and marine fauna and non-avian migratory species may become habituated to the noise and remain within the vicinity (Smolowitz and Weeks 2006), noting shipping operations from Humbug and Hornibrook terminals would be located within an existing operating port.

It is suspected that changes in the local marine acoustic environment due to shipping noise have the potential to elevate ambient noise levels and mask communication signals and impact on biology and behaviour of marine and non-avian migratory species. The predominant sound frequencies associated with large vessels are in the range of 10Hz to 1kHz (OSPAR 2009), with main sound energy less than 0.2kHz (CEDA 2011). The range of whale vocalisations (15Hz - 5kHz) is at low frequencies that overlap with shipping noise. The range of dolphin vocalisations is at higher frequencies (0.2 to 150kHz) than whales, and is mostly outside the primary range of shipping noise. However, dolphin species may experience masking of communication when vessels are in close proximity (Okeanos 2008). Nevertheless dolphins commonly ride the bow waves of ships at sea and dolphin species are commonly present in port areas, suggesting they are not disturbed by underwater sound from vessels. Minimal data are available relating to the sensitivity of Dugongs to shipping noise. Dugongs are reported to produce relatively low-level underwater vocalisations, producing sounds quantified by Anderson and Barclay (1995) within the range of 3 to 18kHz for chirp-squeaks and between 0.5 and 2.2kHz for barks. Dugong barks may overlap with shipping noise; however, these are at frequencies which are above the main sound energy of shipping noise.

Additional details on specific potential impacts from shipping noise are presented in **Section 7.3.5.3** for marine turtles, **Section 9.4.4.3** for Dugong, **Section 9.5.4.3** for cetacean species, **Section 11.4.2** for Great Barrier Reef Marine Park, **Section 12.4.4** for World Heritage property and **Section 13.4.1** for National Heritage place.

15.3.2.3 Modelled Impacts

Pile Driving

Sound exposure propagation from pile driving activities was modelled using the normal-mode underwater acoustic propagation model "Adiabatic Modes Based on ORCA" (AMBO). Peak sound pressure level was modelled using spherical spreading with correction for propagation in shallow water.

Underwater noise propagation was modelled separately for piling activities at the Port, Humbug terminal, Hornibrook ferry and tug terminal and Hey River terminal over the horizontal plane. River depth and bathymetry at the river navigation aids is similar to that at the proposed Port and therefore modelling at the Port is considered representative of the river navigation aids.

Modelling was conducted for the largest pile at each facility and potential distances of injury and behaviour disturbance for the smaller piles at each facility have been determined from the estimated difference in the source levels. At the river facilities, modelling was conducted for a range of pile sizes between 600mm to 1,050mm.

The source depth was set at half the depth of the seafloor (10.6m) and the receiver depth was set at 3m. Expert review of the modelling methods identified that the use of a single receiver depth of 3m may have resulted in some under-estimation of received levels and in particular may have resulted in some under-estimation of impacts for animals foraging on or near the seabed (A. Duncan pers. comm.). An assessment was conducted to determine the change in received noise levels at varying depths along the deepest modelled noise propagation path at each facility. At the Port, received levels were predicted to increase up to 5dB at a depth of 12m along the dredge channel (bearing of 298^{o}). Sound propagation was greatest along the dredge channel, due to the depth of the dredge channel relative to the surrounding sea floor in the vicinity of the Port. Received levels were predicted to increase up to 1dB at the Humbug terminal, up to 4.5dB at the Hornibrook terminal, up to 1.5dB at the Hey River terminal and up to 4.0dB at the river Navigation Aids. Modelling was repeated to account for the higher received levels at each facility. Additionally, it was determined that bottom-foraging animals would be subjected to perceived sound exposure between 2 and 7dB lower than those that are predicted for a receiver depth of 3m.

Since the modelling produced results for sound exposure but not sound pressure, previous measurements of noise from impact pile driving activities were used to approximate that sound pressure is typically 13dB higher than sound exposure for impact pile driving (Duncan *et al.* 2010, Erbe 2009, ICF Jones and Stokes 2009) and vibratory pile driving (ICF Jones and Stokes 2009). The same relationship was assumed to be applicable to drilling activities.

The distance at which unmitigated ecologically meaningful behavioural impacts may occur were determined (**Table 15-6** to **Table 15-10**) where modelled noise propagation from piling activities, at the highest predicted received levels, equalled the behaviour disturbance criteria in **Table 15-4**. The results indicate that the propagation distance is greater for pipe piles than sheet piles. **Table 15-6** does not include unmitigated disturbance based impact distances for the Speartooth Shark as the Port area is not considered habitat for this species. Similarly, **Tables 15-7** to **15-10** do not include unmitigated disturbance based impact distances for the Bryde's Whale as the Hey/Embley River estuary is not considered habitat for this species.

An assessment was conducted to determine a likely worst case scenario for underwater noise impacts from piling activities, for more than one piling rig operating at the Port. The likely worst case scenario would occur in the event that the 25t piling rig would be driving the 1,500mm pile and the two 16t piling rigs would each be driving a 1,050mm pile simultaneously. In this event, there is a potential that received sound pressure levels may increase by up to 2.8dB. The behaviour disturbance impact may therefore be greater during this event as presented in **Table 15-6**.

The impact assessments of unmitigated underwater noise from pile driving activities are discussed in detail in **Section 7.3.5.2** for marine turtles, **Section 9.4.4.2** for Dugongs, **Section 9.5.4.2** for the Australian Snubfin Dolphin, Indo-Pacific Humpback Dolphin and the Bryde's Whale. Potential unmitigated impact distances for sawfish species and the Speartooth Shark would all be less than or equal to 10m. Disturbance of behaviour for sawfish species and the Speartooth Shark is therefore negligible during Project piling activities. Behaviour disturbance to listed threatened estuarine and marine fauna and non-avian migratory species from drilling activities would only occur in the immediate vicinity of the piling activity at all locations. Night time drilling activities would therefore be expected to have a negligible impact to behaviour of listed threatened estuarine and marine fauna and non-avian migratory species.

Distances from the pile driving source at which injury impacts are likely to occur were therefore able to be determined on the basis of sound exposure and peak sound pressure at the point where modelled noise propagation from piling activities meet the injury criteria in **Table 15-5**. It has been verified whether, for any of these species, if the distance of potential injury impact exceeds the distance of potential behaviour disturbance. The peak sound pressure injury criteria for cetacean species is 230dB re 1μPa. The maximum value of the source peak sound pressure for pile driving activities for the Project would be 242dB re 1μPa. Modelling determined that the corresponding distance within which injury to cetaceans may occur would be 4m.

The largest source sound exposure level was determined to be 217dB re 1μPa^2.s for vibratory pile driving which is considered to be equivalent to the sound exposure injury criteria of the Indo-pacific Humpback Dolphin, Australian Snubfin Dolphin or Dugong (215dB re 1μPa^2.s). Sound exposure injury criteria increase for all other species and therefore no injury to any species assessed would be expected to occur due to vibratory pile driving or drilling. The smallest sound exposure injury criteria for impact pile driving activities was 182dB re 1μPa^2.s (Bryde's Whale) and the source sound exposure level for the largest pile was 211dB re 1 μPa^2.s. Modelling indicates that the injury criteria would be exceeded within a distance of approximately 31 metres. Injury to cetaceans is predicted to only occur immediately adjacent to piling activities for the largest piles. No injury would be expected to occur for the remainder of the species assessed or for smaller piles.

Table 15-6 Unmitigated Potential Behaviour Disturbance Distance (Port)

Species	Behaviour Disturbance Criteria (Sound Pressure, dB re 1µPa)		Direction of Noise Propagation	Drilling	Pipe pile diameters					
					1500mm	1200mm	1050mm	750mm	355.6mm	1 x 1500mm and 2 x 1050mm
	Multiple Pulse Noises	Continuous Noises		Potential Behaviour Disturbance Distance (m)						
Bryde's Whale	165	135	Towards shore	30	ESL	ESL	ESL	ESL	570	ESL
			Away from shore (all other directions)	30	1330	1210	930	790	570	1580
Dolphins and Dugong	177	177	n.r.	<1	400	360	270	230	170	500
Marine Turtle	175	150	n.r.	<10	470	430	350	280	210	630
Sawfish	215	185	n.r	<1	<10	<10	<10	<10	<10	<10

Note: ESL = Extends to shoreline from the end of the Stage 1 wharf; n.r.= not relevant

Table 15-7 Unmitigated Potential Behaviour Disturbance Distance (Humbug terminal)

Species	Drilling	Sheet Pile	Pipe Piles			
		600mm width	1,050mm	900mm	750mm	600mm
	Potential Behaviour Disturbance Distance (m)					
Dolphins and Dugong	<1	<10	170	160	140	130
Marine Turtles	<10	60	210	200	180	160
Sawfish	<1	<10	<10	<10	<10	<10
Speartooth Shark	<1	<10	<10	<10	<10	<10

Note: The distances here have their maximum values in a westerly direction.

Table 15-8 Unmitigated Potential Behaviour Disturbance Distance (Hornibrook ferry/tug terminal)

Species	Drilling	Pipe Piles			
		1,050mm	900mm	750mm	600mm
	Potential Behaviour Disturbance Distance (m)				
Dolphins and Dugong	<1	250	230	210	190
Marine Turtles	<10	340	310	280	240
Sawfish	<1	<10	<10	<10	<10
Speartooth Shark	<1	<10	<10	<10	<10

Note: The distances here have their maximum values in the south-easterly to south-westerly directions.

Table 15-9 Unmitigated Potential Behaviour Disturbance Distance (Hey River terminal)

Species	Drilling	Sheet Piles	Pipe Piles			
		600mm width	1,050mm	900mm	750mm	600mm
	Potential Behaviour Disturbance Distance (m)					
Dolphins and Dugong	<1	<10	380	360	330	300
Marine Turtles	<10	110	470	440	400	370
Sawfish	<1	<10	<10	<10	<10	<10
Speartooth Shark	<1	<10	<10	<10	<10	<10

Note: The distances here have their maximum values in Northerly and Southerly directions.

Table 15-10 Unmitigated Potential Behaviour Disturbance Distance (Navigation Aids)

Species	Drilling	Pipe Pile - 1050mm diameter
	Potential Behaviour Disturbance Distance (m)	
Dolphins and Dugong	<1	280
Marine Turtles	<10	360
Sawfish	<1	<10
Speartooth Shark	<1	<10

Note: The distances are equal in all directions

The potential for increased underwater noise levels from piling activities at the Port during the worst case scenario was considered. Given distances within which injury may occur are small (distance of 3m for peak sound pressure and 31m for sound exposure), and the proposed piling rigs cannot operate any closer than 150m, impacts from simultaneous operation of all three rigs would not be likely to cause any significant increase in injury over that which may be caused by single-rig pile driving.

15.3.3 Avoidance, Mitigation, Enhancement Measures and Residual Impacts

15.3.3.1 Pile Driving

The following mitigation measures would be implemented to reduce the impacts on listed threatened estuarine and marine fauna and non-avian migratory species related to underwater noise associated with pile driving:

- for marine and river pile driving activities, the soft start-up approach (assessed below) would be used to disperse marine and non-avian migratory fauna (including marine turtles, cetaceans and Dugongs) prior to normal pile driving activities commencing;
- continual marine fauna observations would be conducted for whales, marine turtles, dolphins and Dugongs for 30 minutes prior to and during marine and river pile driving activities;
- observation zones would be maintained over the distances shown in **Table 15-6** to **Table 15-10** with a minimum observation distance of 300m maintained at all times; The observation zone for the likely worst case scenario (1 x 1,500mm and 2 x 1,050mm pipe piles at the Port) would be the largest zone required if three piling rigs are utilised simultaneously. If a different combination is used which may result in a lower impact an appropriate observation zone may be determined in consultation with DSEWPaC;
- marine and river pile driving activities would be stopped if marine turtles, cetaceans and/or Dugongs enter within an exclusion zone of 100m and remain within the zone for greater than five minutes. Piling activities would not re-commence until the animal/s are observed to move outside the exclusion zone or 30 minutes have passed since last sighting;
- no piling activities would commence if marine turtles, cetaceans and/or Dugongs are observed within the exclusion zone during visual observations prior to soft start-up. Piling activities would not commence until the animal/s are observed to move outside the exclusion zone or 30 minutes have passed since last sighting; and,
- all equipment and machinery would be maintained in accordance with manufacturer's recommendations and excessive underwater noise would be investigated and remedied.

With the implementation of these mitigation measures, residual impacts to listed threatened estuarine and marine fauna and non-avian migratory species from underwater noise associated with pile driving activities would be negligible.

Exclusion Distance

Modelling determined that injury to whales would only likely occur within four metres due to peak sound pressure and 31m due to sound exposure, from the largest piles (1,500mm). The distance of injury impact for all other species would be less. Therefore the proposed 100m exclusion zone is a conservative distance to prevent injury from underwater noise to marine turtles, cetaceans and Dugongs.

Assessment concluded that an animal would have to remain at a distance of 10m from the largest piles for five minutes before they would experience injury due to sound exposure (M. Hall, pers. comm.). Given that for mobile marine animals, the common disturbance response would be for an animal to avoid loud sound sources and move away from the piling activity (Janik and Thompson 1996, Nowacek *et al*. 2001, Ng and Leung 2003, Hodgson and Marsh 2007, DeRuiter and Doukara 2012), the five minute period would be sufficient time for any listed species to move out of the zone of injury impact. Continual observations would be conducted of the 100m exclusion zone which would identify any listed species in the zone of injury impact.

Soft Start-up

Previous studies identified that marine mammals may be deterred from pile driving activity by a soft start procedure (Bailey *et al.* 2010, Robinson *et al.* 2007, Nehls *et al.* 2007). A soft start-up involves progressively increasing hammer energy and therefore noise levels to alert animals to the commencement of the operations. The zone of potential injury to an animal is therefore reduced while deterring animals from the operations outside of this zone. Examples of soft start-up procedures reviewed included piling commencing with hammer energy levels reduced by 1/8th and 1/10th. These examples would result in a 9dB and 10dB reduction of source levels respectively. Through reduction of source levels, the use of a soft start up procedure provides the potential to decrease the zones of injury (determined by sound exposure and peak sound pressure) and behaviour disturbance (determined by sound pressure) for estuarine, marine and non-avian migratory fauna.

15.3.3.2 Dredging

The following mitigation measures would be implemented to reduce the impacts on listed threatened estuarine and marine fauna and non-avian migratory species related to underwater noise associated with dredging activities and offshore spoil disposal:

- all vessels would operate in accordance with appropriate industry and equipment noise and vibration standards;
- regular maintenance of vessels would be conducted to the manufacturers' specifications; and,
- where possible, leaving engines, thrusters and auxiliary plants in stand-by or running mode unnecessarily would be avoided.

Additionally, the marine turtle and marine mammal management procedure (see **Section 7.3.6.1**) provides observation and exclusion distances to prevent injury and ecologically meaningful behaviour disturbance to marine turtles and marine mammals from underwater noise from dredging activities.

With the implementation of these mitigation measures, residual impacts on listed threatened estuarine and marine fauna and non-avian migratory species in the vicinity of the Project from underwater noise associated with dredging activities and offshore spoil disposal would be negligible.

15.3.3.3 Shipping

The following mitigation measure would be implemented to reduce the impacts on listed threatened estuarine and marine fauna and non-avian migratory species related to underwater noise associated with Project-related bauxite shipping activities:

- Bauxite vessels, including on board machinery and equipment, would be maintained to a high standard and any source of excessive underwater noise would be investigated and remedied.

With the implementation of this mitigation measure, residual impacts on listed threatened estuarine and marine fauna and non-avian migratory species from underwater noise associated with Project-related bauxite shipping activities would be negligible.