Ports North

CAIRNS SHIPPING DEVELOPMENT PROJECT

PILING ACTIVITY UNDERWATER NOISE

Definition of Project Observation and Exclusion Zones for Marine Fauna Management

September 2019

CAIRNS SHIPPING DEVELOPMENT PROJECT – PILING ACTIVITY – UNDERWATER NOISE REPORT

Definition of Project Observation and Exclusion Zones for Marine Fauna Management

PURPOSE

This document summarises outcomes of an assessment of marine fauna management zones for piling works part of the Cairns Shipping Development Project. The management zones consist of observation and exclusion zones, related to managing underwater noise impacts to marine fauna from piling for the new wharf construction. An assessment of these zones is a part of the approval requirements for the Project.

BACKGROUND

Under Permit EPBC 2012/6538 Ports North are required to establish an exclusion zone and observation zone for piling activities undertaken for the Cairns Shipping Development Project. Condition 15 sets out the following requirements for these zones:

> *The exclusion zone and observation zone must be based on relevant scientific evidence about the impact of noise on marine fauna likely to be present at the time of pile driving operations. A report on the adequacy of the exclusion zone and the observation zone must be published by the approval holder on the website prior to any pile driving operations commencing. The report must include evidence of input and peer review by a suitably qualified person.*

The attached report was developed in response to this condition. It has been prepared by Arup and peer reviewed by Marshall Day Acoustics. This report updates the recommended mitigation measures set out in the Revised Environmental Impact Statement for the Project which includes a 1,000m observation zone and 100m exclusion zone.

An observation zone is one that must be monitored for the occurrence of marine fauna while the buffer between piling and marine fauna that must be maintained; if marine fauna enter this zone, piling must cease.

MANAGEMENT MEASURES

The report sets out a range of observation and exclusion zones based on different species. The two most stringent zones identified were:

- For low frequency cetaceans (whales) when conducting wharf piling works – 1,500m observation zone and 400m exclusion zone.
- For sea turtles when conducting wharf piling works – 1,500m observation zone and 300m exclusion zone.

All other zones are less than these.

The report acknowledges that these zones can be decreased where species occurrence is unlikely. As there have been no known occurrences of whales within the inner port area, Ports North have not adopted this exclusion zone. Instead, the following zones are adopted for *all* piling works:

Observation Zone: 1,500m   **Exclusion Zone**: 300m

The use of these zones will meet or exceed best practice guidelines for all marine fauna species likely to occur in the piling area. The report also sets out other management measures (e.g. soft start procedures) which will also be adopted by Ports North.

Ports North

Cairns Shipping Development Project

Piling Underwater Noise Report

R01

Issue | 27 September 2019

Job number 270492

Arup Australia Pty Ltd ABN 76 625 912 665

Arup
Level 4, 108 Wickham Street
Fortitude Valley
QLD 4006
GPO Box 685 Brisbane QLD 4001
Australia
www.arup.com

ARUP

Document verification

ARUP

Job title		Cairns Shipping Development Project			**Job number** 270492
Document title		Piling Underwater Noise Report			**File reference**
Document ref		R01			
Revision	**Date**	**Filename**	Report_PilingAcousticAssessment_Draft1.docx		
Draft 1	26 Jul 2019	**Description**	First draft		
			Prepared by	Checked by	Approved by
		Name	Marta Galindo Romero	Cameron Hough	Cameron Hough
		Signature			
Draft 2	1 Aug 2019	**Filename**	Report_PilingAcousticAssessment_Draft2.docx		
		Description			
			Prepared by	Checked by	Approved by
		Name	Marta Galindo Romero, Andrea McPherson, and Cameron Hough	Cameron Hough	Cameron Hough
		Signature			
Draft Issue	7 Aug 2019	**Filename**	Report_PilingAcousticAssessment_Draft2.docx		
		Description	Draft issue for client comment / peer review		
			Prepared by	Checked by	Approved by
		Name	Marta Galindo Romero, Andrea McPherson, and Cameron Hough	Cameron Hough	Cameron Hough
		Signature			
Issue	27 Sep 2019	**Filename**	Report_PilingAcousticAssessment_Issue.docx		
		Description	Updated following comments from peer review		
			Prepared by	Checked by	Approved by
		Name	Marta Galindo Romero, Andrea McPherson, and Cameron Hough	Cameron Hough	Kym Burgemeister
		Signature			

Issue Document verification with document ✓

Contents

Appendices

1 Introduction

Arup Australia Pty Ltd (Arup) have been commissioned by Ports North to provide acoustic engineering services for the Cairns Shipping and Development (CSD) Project to conduct an underwater noise assessment for the piling works associated with the CSD project. Arup previously conducted an underwater noise assessment for the project as part of the 2014 Draft EIS for the project.

The required scope for the current assessment has been defined as follows:

- A review and/or summary of the previous noise assessment undertaken for the revised EIS
- Determine an assessment methodology for determining appropriate observation and exclusion zone distances for piling
- Nominate observation and exclusion zone distances that are appropriate to marine fauna likely to be present during piling activity. This should include as a minimum: cetaceans, turtles, fish species.
- Conduct a literature review that addresses why the nominated distances are appropriate for works and minimise underwater noise impacts to marine fauna Best practice guidelines should be referred to where relevant e.g. South Australian Guidelines for Underwater Piling

Note that this report addresses noise from piling activities from the CSD project only. Noise from shipping movements, dredging etc were assessed as part of the draft EIS and impacts are assumed to be unchanged.

This report presents the outcomes of the review and assessment as described above. In addition, Ports North's scope requires:

- A peer review by a suitably qualified expert in underwater noise and marine mammals.

A peer review has been conducted by Marshall Day Acoustics. The comments from the peer review have been included in Appendix B.

2 Background

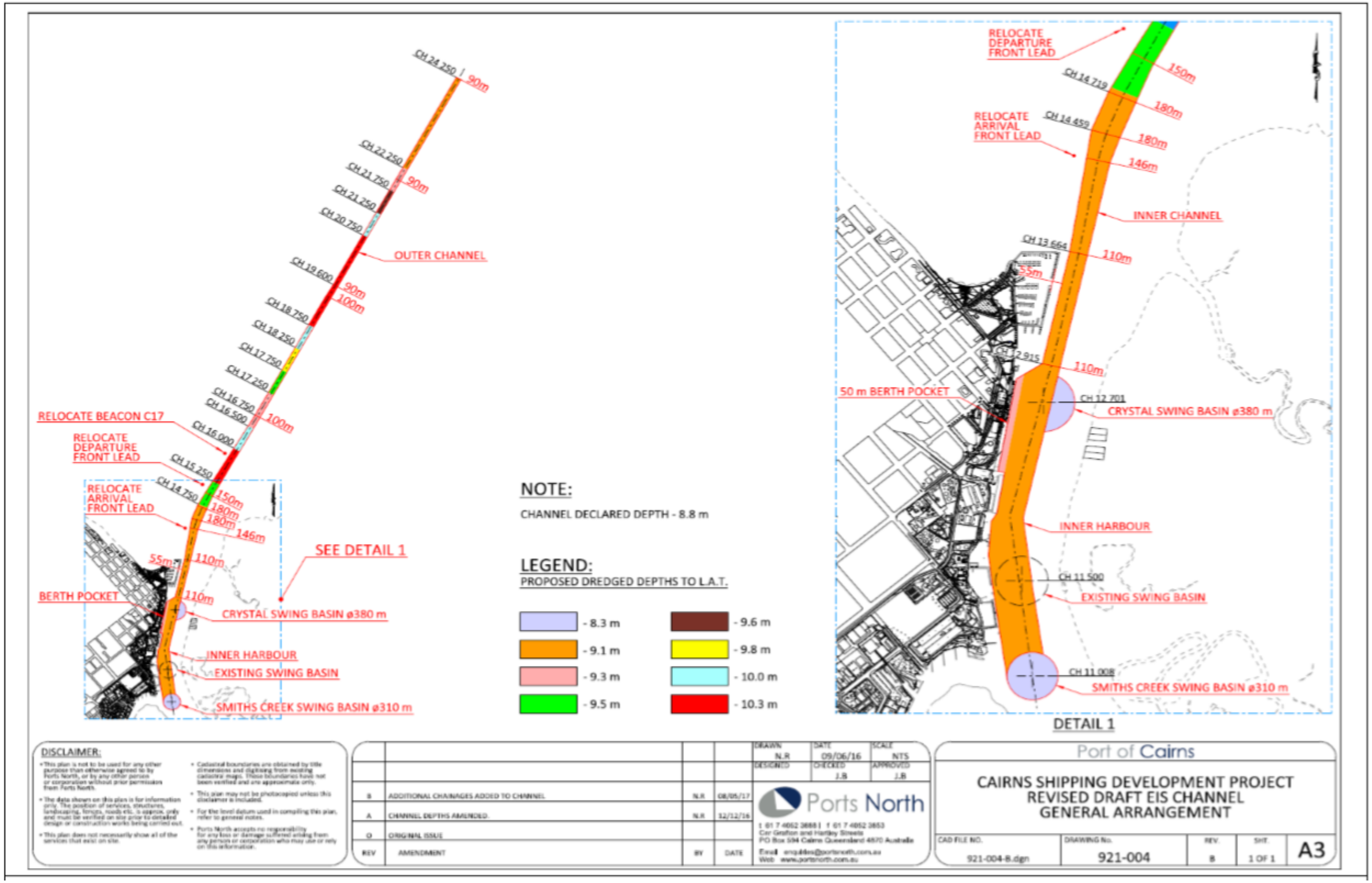
2.1 Project Description

The approved CSD works include:

- Capital dredging of up to 1,000,000 m^3 of marine sediment (measured in situ) to widen and deepen the existing Trinity Inlet shipping channel, deepen the existing Crystal swing basin, establish a new Smiths Creek swing basin, and expand existing berth pockets.
- Capital dredging based on two types of dredge: trailer suction hopper dredge (TSHD) to dredge up to 900,000 m^3 of soft clays, and backhoe dredge (BHD) to dredge the remaining 100,000 m^3 of stiff clays.
- Capital dredging to be limited to the period between March and September.
- Soft clays to be placed in the Northern Sands Dredged Material Placement Area (DMPA) via an onshore dredged material delivery pipeline, with tailwater from the DMPA to be discharged to the Barron River.
- Stiff clays to be placed at the Tingira Street DMPA
- Wharf upgrade works, including piling activity
- Relocation of navigational aids, including piling activity.

An overview of the works is included in Figure 1:

Figure 1: Proposed upgraded channel and swing basins (from revised draft EIS Chapter A3)



2.2 Approvals and management framework

As part of the EIS process, Ports North committed to the following mitigation measures to limit potential impacts to marine animals from underwater noise generated through piling activity (for both wharf construction and relocation of navigational aids:

- adopting a “soft-start” regime at the start of each day’s piling activities to encourage wildlife to move away from the area
- implementing a marine mammal observation zone of one kilometre and an exclusion zone of 100 m during piling activities
- stopping piling activities if marine mammals are spotted within or approaching the exclusion zone

Condition 15 of the EPBC Act approval granted for the project requires the following:

‘The exclusion zone and observation zone must be based on relevant scientific evidence about the impact of noise on marine fauna likely to be present at the time of pile driving operations. A report on the adequacy of the exclusion zone and the observation zone must be published by the approval holder on the website prior to any pile driving operations commencing. The report must include evidence of input and peer review by a suitably qualified person. Within 10 business days after publishing the report, the approval holder must notify the Department of the actual date of publication”.

The EPBC approval did not mandate what the exclusion and observation zone distances should be. This report provides recommended exclusion and observation zone distances based on a review of available guidelines and on recent research into the sensitivity of marine fauna to piling noise.

2.3 Piling details

The following information has been received about the piles and piling process and has therefore used as the basis for the assessment. The information in this section is based on drawing number 724646-B “Cairns – Entrance Channel – Entrance Front Lead (T1), Front Harbour Lead (FHL) and C17 Relocation” dated 26/6/18 and email correspondence from Ports North received on 17 July 2019.

An assessment of driveability has been conducted for the wharf piling, based on the following assumptions:

- Continuous running hammer with no pauses or wait time during driving.
- The hammer has been analysed with a maximum stroke of 2.08m with an impact efficiency of 95%. This requires the hammers to be properly maintained, operated and well aligned during driving;
- Hammer running at full energy/maximum drop height. This assumption will underestimate the number of strikes as the installation will typically use

smaller drop heights during the initial stages of driving, with an increase in drop height as the geotechnical resistance increases. However from the point of view of the cumulative noise impacts there is unlikely to be a significant change in overall cumulative SEL, since any reduction in the SEL from an individual pile strike would be offset by an increase in the number of strikes.

- The effects of setup have not been considered. Should setup occur, the implication would be to reduce geotechnical resistances at end of drive and increase pile penetrations.
- The geotechnical resistance is based on the LB, BE and UB profiles detailed in the pile driveability report 2972MJWS01A.

Navigational Aids

- 3 new aids
- 1 pile/day over 2-week period
- Junttan 7/9 hammer
- 10-11 m penetration in seafloor
- 1.2 m diameter piles
- 16 mm thick

Note that no driveability assessment has been provided for the navigational aids. The representative number of pile strikes has been assumed to be 1000 based on the upper bound of the estimated piling for the 610 mm piles at the wharf.

Wharves

For the wharf upgrade works, piles will be driven from a barge by a piling rig with crane and hammer

Method: initial “soft start” then vibro hammer, and then finished off with a hammer

One tender has proposed vibro hammer then an IHC S-280 hammer, and another will use

- 610mm piles:
  - ICE416 vibro hammer then a
  - Junttan 8s
- 2200mm piles:
  - a) ICE44-50 vibro hammer,
  - b) followed by a Junttan 20S

Wharfs 1-5

- 2200 mm diameter
- From 28/10/19 to early /4/2020
- 30 piles
- 1 pile / day with a blow count of ~1500-3000 blows.

Wharf #6

- 610 mm diameter
- From 30/9/19 to 26/10
- 38 piles
- 1.5-2 piles/day with 500-1000 blows.

3 Previous Assessments

3.1 Revised Draft EIS

The revised draft EIS (Ports North 2017) did not present any significant update to the underwater noise assessment conducted in the draft EIS (Ports North 2014) and largely referred to the findings of the draft EIS for the underwater noise assessment.

As such, although the draft EIS is not an approved document and has been superseded by the revised draft EIS, the previous assessment conducted as part of the draft EIS has been reviewed and revised as part of this report.

A summary of the relevant sections from the draft EIS is included in Section 3.2 below.

3.2 Draft EIS

3.2.1 Source Levels

Source levels for impact pile driving were determined from measurements of peak source levels at 1 m from piles of 4-5 m diameter (by Nehls et al 2008, quoted in Diederichs et al, 2008), which were corrected to a 1.2 m diameter pile size using the relationship between pile diameter and peak sound pressure level presented in the same work (i.e. 3.1 dB / m pile diameter) (Figure 2), with spectra assumed based on the spectra presented in Nedwell et al (2007) for shallow-water piling (Figure 3).

Figure 2: Approximate relationship between pile diameter and peak sound pressure level (normalised to 20 m water depth and 750 m distance from source), Nehls et al (2008), presented in Diederichs et al (2008)

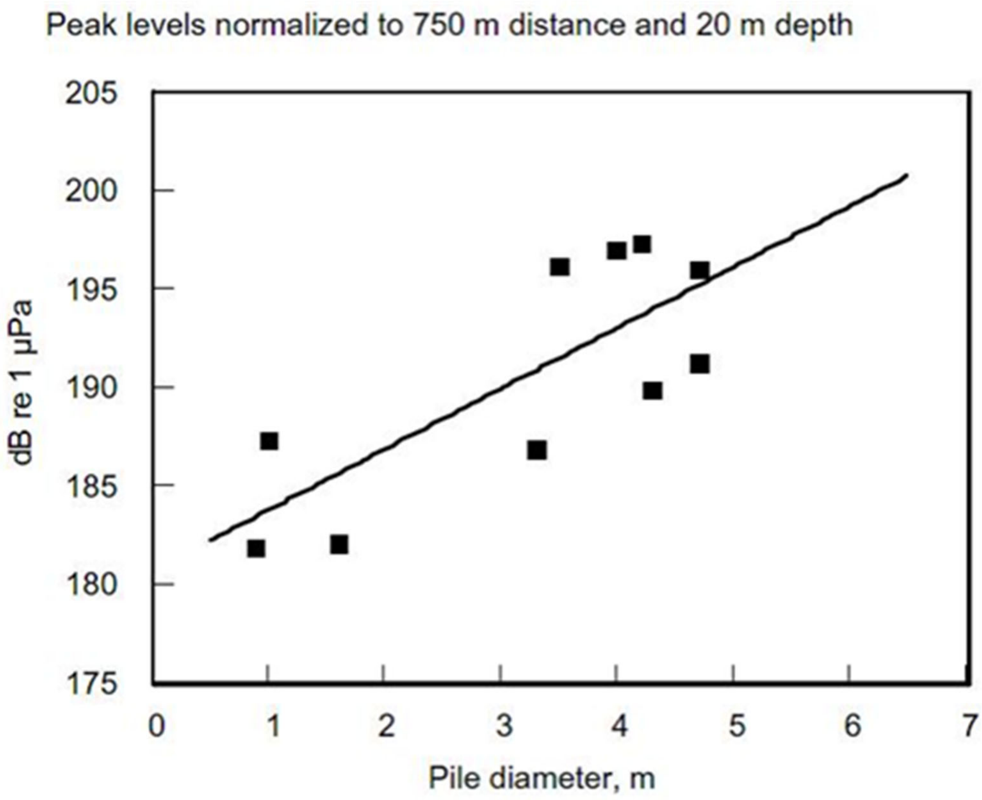
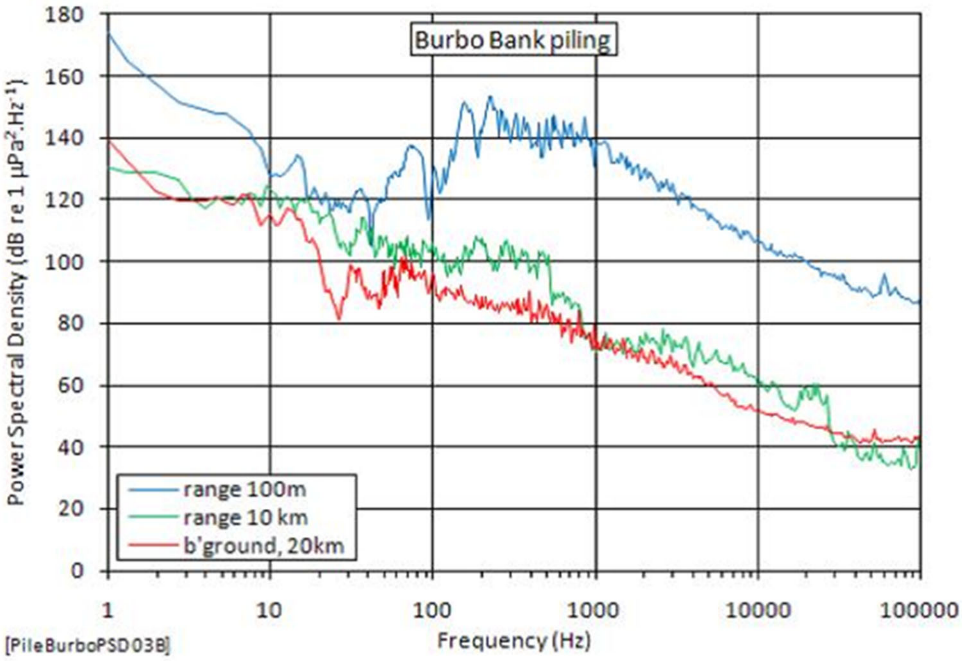
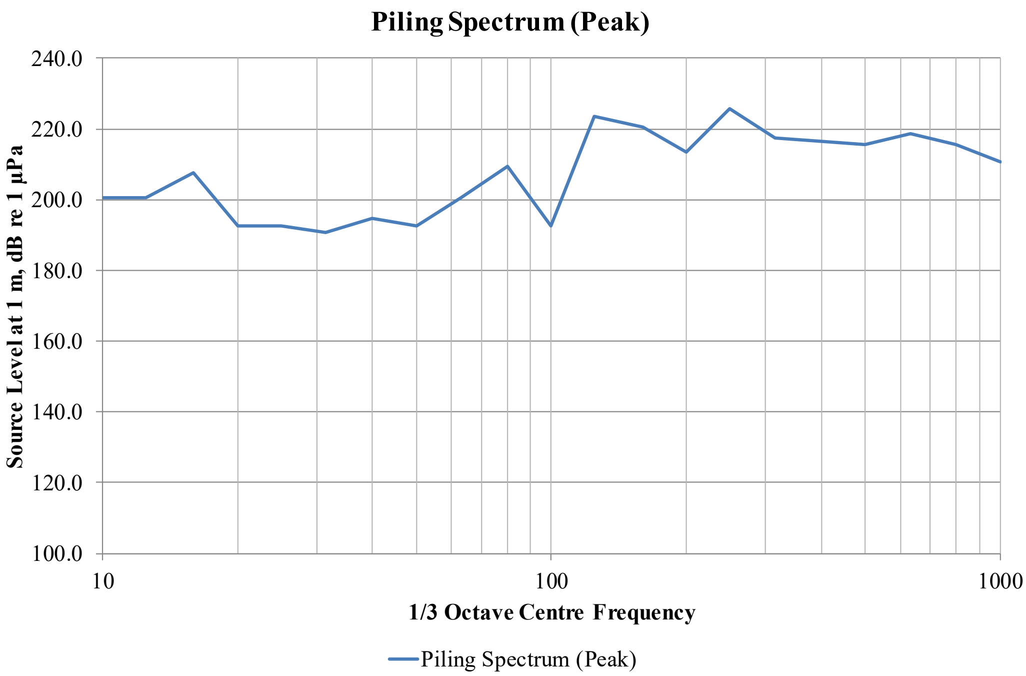


Figure 3: Frequency spectra of impact piling (4.3 m diameter pile) in shallow water, adapted from Nedwell et al (2007). Blue curve is at approximately 100 m from source; green curve is at approximately 10 km from source, red curve is background noise at approximately 20 km from source.



The result (representing the higher value in the range obtained) was a source level of 235 dB re 1 µPa at 1 m (peak) and 200 dB re 1 µPa²·s at 1m (SEL) as shown in Figure 4.

Figure 4: Piling source level spectrum for 1.2 m piles, draft EIS



3.2.2 Impact Criteria

The draft EIS conducted a literature review of available information regarding the sensitivity of marine fauna to underwater noise and developed impact criteria for assessment of impacts.

Table 1 summarises the impact criteria developed for the draft EIS, including details of the research upon which the criteria were based:

Table 1 Summary of Impact Criteria developed in the draft EIS

Impact	Species	Sound Pressure dB re 1 µPa	Sound Exposure Level dB re 1 µPa™±v	Reference
50% Mortality (all sizes)	Fish		210dB	Hastings and Popper (2005)
	Migratory birds and shorebirds		198dB	Yelverton et al (1973)
Serious Physical Injury	Marine Mammals	$240dB_{peak}$		Parvin, Nedwell and Howland (2007)
	Fish		195dB (onset of mortality)	Hastings and Popper (2005)
	Migratory birds and seabirds (diving)		195dB (onset of mortality)	Yelverton et al (1973)
Permanent Hearing Damage (PHD)	All species	$130dB_{ht}$	$135dB_{ht}$	Nedwell. 2005 Nedwell et al (2007a)
	Whales – Baleen	$230dB_{peak}$	$198dB(M_{lf})$ (impulsive) $215dB(M_{lf})$ (continuous)	Southall et al (2007)
	Whales – Toothed	$230dB_{peak}$	$198dB(M_{mf})$ (impulsive) $215dB(M_{mf})$ (continuous)	Southall et al (2007)
	Dugongs	220 dBpeak	$188dB(M_{mf})$ (impulsive) $205dB(M_{mf})$ (continuous)	Southall et al (2007)
	Seabirds (airborne)	110 dB(A) (continuous) 125 dB(A) (impulsive)		Dooling and Popper (2007)
	Seabirds (diving)		193dB	Yelverton et al (1973)

Impact	Species	Sound Pressure dB re 1 µPa	Sound Exposure Level dB re 1 µPa™£v	Reference
Temporary Hearing Damage (TTS)	All Species	70 dB_{ht} (onset)		Nedwell. 2007a
	Whales – Baleen	224 dB_{peak} 160 dB_{rms} (continuous)	183 $dB(M_{lf})$ (impulsive)	Southall et al (2007) Nachtigal, 2004
	Whales – Toothed	224 dB_{peak} 160 dB_{rms} (continuous)	183 $dB(M_{mf})$ (impulsive)	Southall et al (2007) Nachtigal, 2004
	Dugongs	214 dB_{peak} 150 dB_{rms} (continuous)	173 $dB(M_{mf})$ (impulsive)	Southall et al (2007) Nachtigal, 2004 Modified by 10 dB to account for increased sensitivity of sirenians relative to odontocetes.
	Seabirds (airborne)	93 dB(A) (continuous) 110 dB(A) (impulsive)		Dooling and Popper (2007)
	Seabirds (diving)		190dB (safe level for no injuries)	Yelverton et al (1973)
Disturbance – Strong (>90% avoidance) (SA)	All species	90 dB_{ht}		Nedwell et al, 2005
	Marine Mammals	160dB_{rms} (impulsive) 120dB_{rms} (continuous)		NOAA (2011)
	Fish	140-160dB_{peak} (impulsive)		Mieller-Blenkle et al, 2010
	Chelonians	175 dB_{peak}		McCauley et al (2000)
	Seabirds (airborne)	72 dB(A)		Cutts et al (2013)
Masking	Whales – Toothed and Baleen	115dB_{rms}		Lucke et al (2007)
Detection	Whales - Toothed	90 dB (frequencies below 1 kHz)		Nedwell et al 2004
	Dugongs	80 dB (below 1 kHz)		Nedwell et al 2004

3.3 Previous Nominated observation and exclusion zone

The Draft EIS stated; for CSDP, the SEL from one pile strike is approximately 145-150 dB(M) at 100 m (depending on whether the M_{lf} or M_{mf} weighting is used). Hence for the piling associated with CSDP the recommendation was;

- observation zone of 1 km, and
- exclusion zone (shut-down zone) 100 m.

The Draft EIS observation and exclusion zones were based on and consistent with the requirements of the *South Australian Underwater Piling Noise Guidelines 2012*.

4 Literature Review

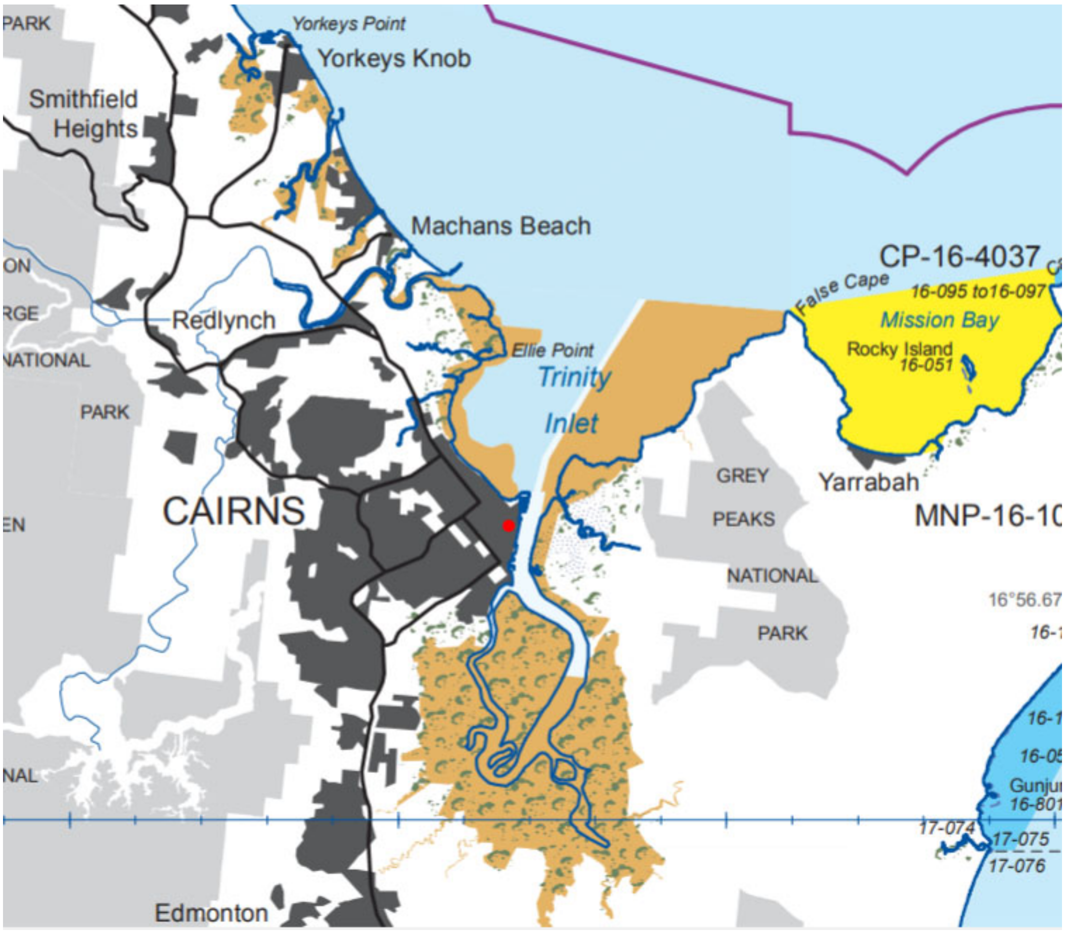
4.1 Relevant Legislation and Policy

4.1.1 Location Context

The CSD project is located within Trinity Inlet which is connected to the Coral Sea. The region of the inlet and the surrounding waters are part of the World Heritage and National Heritage Properties. The Port property, immediate waters and the navigation channel are not zoned within the Great Barrier Reef Coast Marine Park area (State marine waters) and or the Great Barrier Reef Marine Park area (Commonwealth marine waters). However, the surrounding waters of Trinity Inlet are within an Estuarine Conservation Zone of the Great Barrier Reef Coast Marine Park area.

In addition, a number of listed threated species are known within the region including the Humpback whale (*Megaptera novaeangilae*) listed as vulnerable, loggerhead turtle (*Caretta caretta*) listed as Endangered, and Freshwater sawfish (*Pristis pristis*) listed as vulnerable to name a few. With the combination of the locality and the various listed threat and species the works being carried out are considered a controlled action under the EPBC Act (and have been conditioned as per the project approvals summarised in Section 0).

Figure 5. Extract from the Great Barrier Reef Marine Parks Zoning Maps (Map 5- Cairns)



4.1.2 Australian Legislation, Policy and Guidelines

- The Australian Environment Protection and Biodiversity Conservation Act 1999 (EPBC), including the Matters of National Environmental Significance (MNES)
- Great Barrier Reef Underwater Noise Guidelines: Dissuasion and options paper (McPherson, et al 2017)
- Government of South Australia Underwater Piling Noise Guidelines (2012)
- QLD Environment Protection Act 1994 (EP Act)
- QLD Environmental Protection (Noise) Policy 2008
- Nature Conservation Act 1992 of Queensland

International

United States

- Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (NMFS 2018)
- The Marine Mammal Protection Act of 1972 (MMPA)

- The Endangered Species Act 1973 (ESA)

New Zealand

- New Zealand 2013 Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations

European

- European Marine Strategy Framework Directive

International

- International Standard ISO 18405 (2017) Underwater Acoustics - Terminology

4.2 Great Barrier Reef Underwater Noise Guideline and Options Paper

The Great Barrier Reef Marine Park Authority (GBRMPA) commissioned a guidance document (McPherson et al 2017), published in 2017 to inform the process of development for a guideline for considering and managing the impacts of anthropogenic underwater noise on the Great barrier reef's marine fauna. This Guideline and Options Paper document reviewed current understanding of underwater noise and application. It also considered the technical approaches of how underwater noise should be appropriately measured and modelled. It provided a summary of best practice and internationally accepted methodologies. In addition, it reviewed the basic information on soundscapes and hearing of fauna species found within the GBRMPA area.

For the purposes of this report this document was reviewed and applied where relevant.

4.3 Metrics

Due the variable use of terminology in underwater acoustics there has been some ambiguity across different studies in regards to effects on marine mammals. To resolve this, in 2017 the ISO published a standard for underwater noise terminology, ISO 18405 Underwater Acoustics – terminology (ISO 2017).

Previously used and current terminology is summarised in Table 2.

Table 2 Summarised metrics for underwater noise (table replicated from Parnum et al., 2018).

Metric	**Commonly used (before 2017)**	**ISO (2017) / NMFS (2018)**	
		In main text	**In tables/equations**
Sound Pressure Level	SPL_{rms}, SPL_{RMS}	SPL	SPL (L_p)
Peak Pressure	SPL_{pk}	PK	PK (L_{pk})
Sound Exposure Level	SEL_{cum}	SEL_{24h}	SEL_{24h} ($L_{E,24h}$)

4.4 Source Levels for Marine Piling

Source levels for impact pile driving used in the Draft EIS are presented in Section 3.2.1, obtained from the scientific literature available until 2014.

A literature review of publications since that date has been conducted to assess the validity of the source levels previously used and to adapt them to the specific piles used in the planned works.

Where piling works consist of a mix of pile diameters, a conservative approach has been followed where the largest piles are used to model impacts from all piles.

Source levels (i.e. sound levels at 1 m from source) are generally not directly measured but modelled. This can be done solely with a computer model or using measurements of received levels and then calculating the source level based on the modelled propagation loss. The radiation of sound from pile driving is a complex process and assumptions are required, therefore there can exist a range of source levels for similar piling scenarios.

Many works in the scientific literature present values for SEL, SPL and peak levels at 10 m from the pile. By comparison with data from plots presented in works such as Denes et al., 201) and from previous modelling of propagation done for the Draft EIS, spherical propagation has been assumed in the near field of the source allowing source levels at 1 m to be calculated based on the measured level at 10 m assuming a 20 log (d) relationship of level vs distance for the region close to the source. This results in a correction of 20 dB between measured values at 10m to source levels at 1m from the pile. (The assumption of spherical propagation is considered a reasonable assumption provided that the water depth is greater than the propagation distance).

Figure 6 from (Li and McPherson, 2018) shows the modelled one third octave level of received signal with highest SEL @ 10m for 1.2m diameter piles for two hammers (IHC S500 and Junttan HHK 25s) and three sites. The overall SEL range measured was from 190 to 192 dB re 1 µPa^2 s, which is equivalent to approximately 210 to 212 dB re 1 µPa^2 s @ 1m.

Figure 6: Modelled one third octave level of received signal with highest SEL @ 10m for 1.2m diameter piles for two hammers and three sites, from (Li and McPherson, 2018).

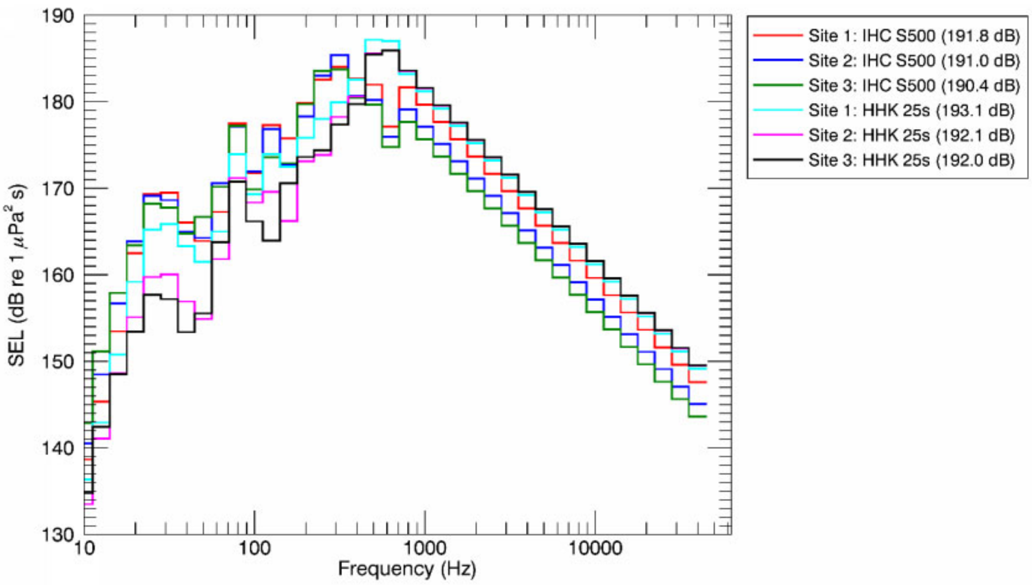


Figure 7 and Figure 8, adapted from (Denes et al., 2016) show the peak level, SPL, and SEL as a function of range during impact pile driving for the refurbishment of the Alaska Marine Highway System ferry terminals. The pile diameters used for the piling were 30" (~0.8m) or 24" (~0.6m) pile diameter. Source measurements were conducted at close distances (within 20 m of the pile) as well at longer range (~1 km). The values summarised here have been based on the close-in measurements corrected to 10 m distance assuming spherical propagation.

For 0.8 m piles, the SEL @ 10m was approximately 170-180 dB re 1 µPa^2 s, and peak level @ 10m was approximately 200- 210 dB re 1 µPa.
The equivalent source levels are SEL @ 1m 190-200 dB re 1 µPa^2 s, peak 220-230 dB re 1 µPa.

For the 0.6 m diameter piles, the piles were installed by a mix of drilling, vibratory piling and impact piling. The total number of strikes for impact piling was small (<10 blows) which means that there is not enough data to present a range of values.
Overall SEL @ 10m was approximately 170 dB re 1 µPa^2 s and peak @ 10m approximately 195 dB dB re 1 µPa.
The equivalent source levels are SEL @ 1m 190 dB re 1 µPa^2 s and peak @ 1m 215 dB re 1 µPa.

Figure 7: Measured peak level, SPL, and SEL vs range during impact pile driving for 30” (~0.8 m) diameter steel piles at Kake (top) and Auke Bay (bottom)
From (Denes et al., 2016).

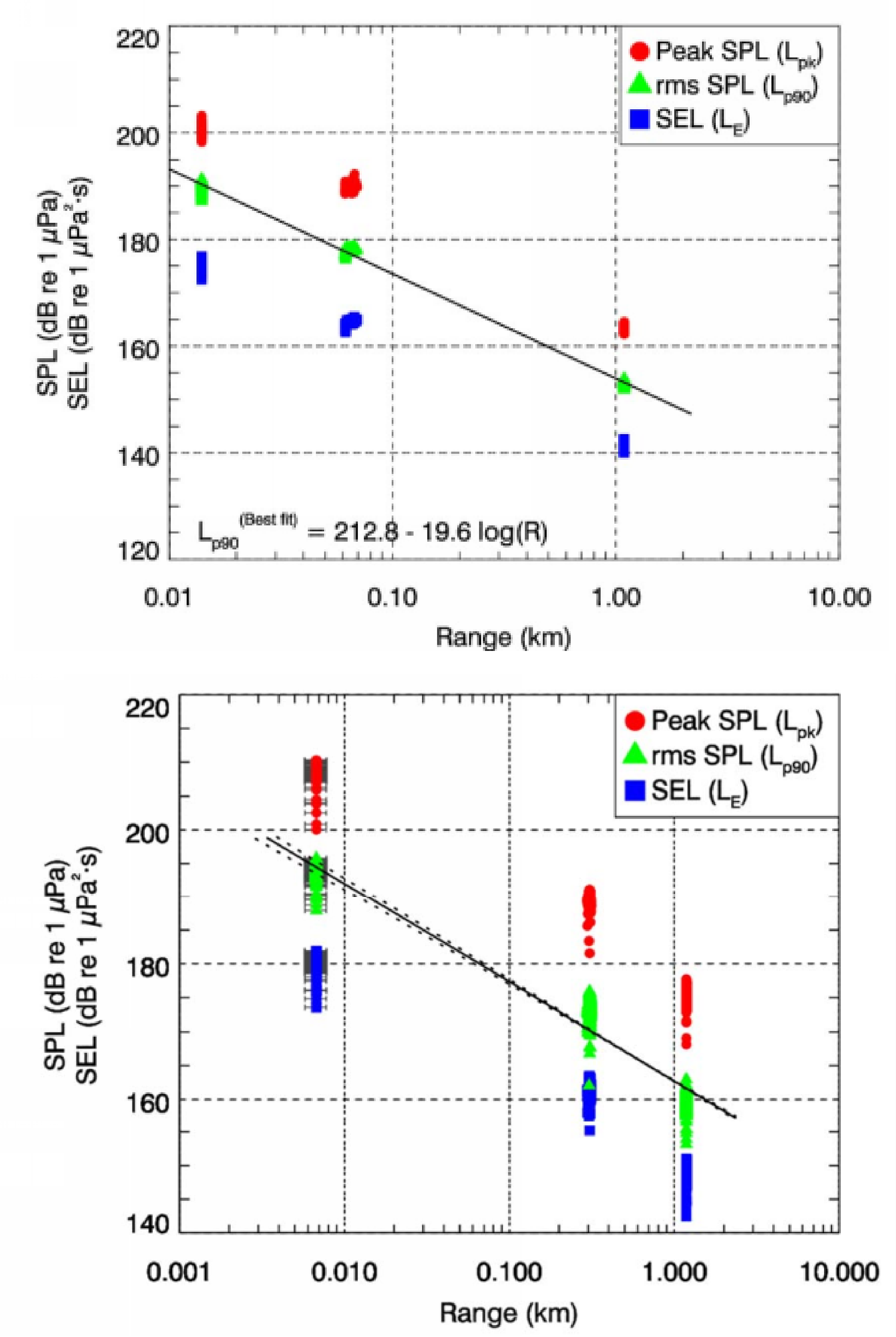
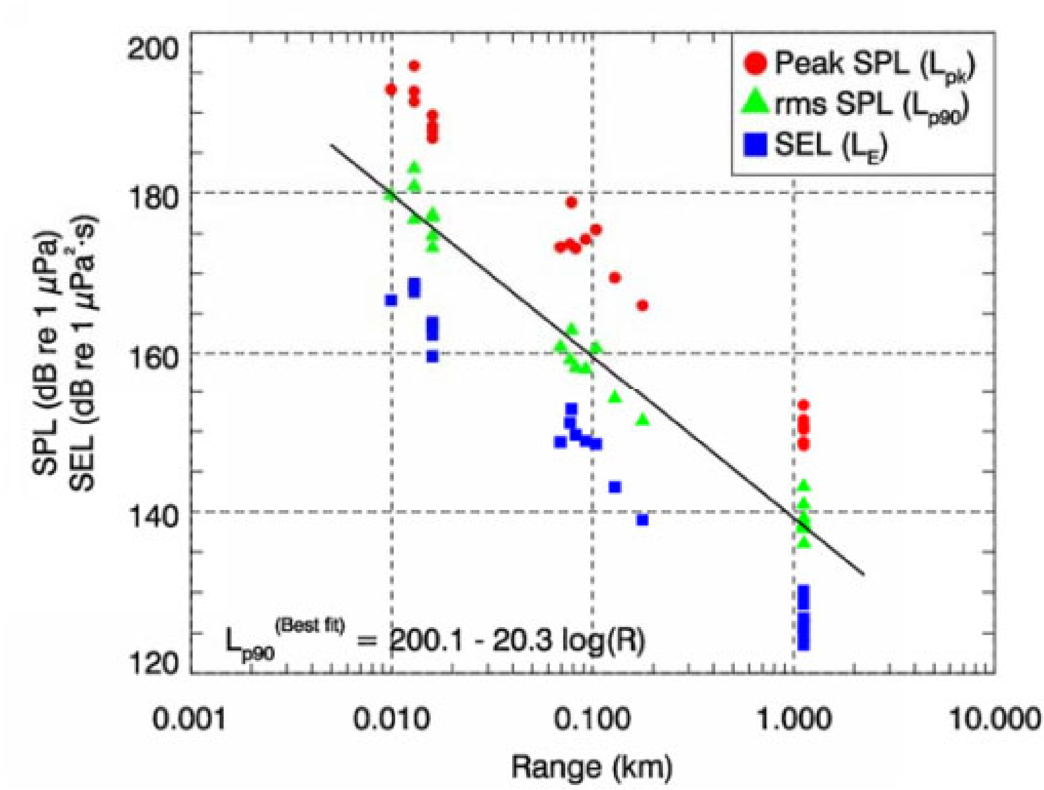


Figure 8: Measured peak level, SPL, and SEL vs range during impact pile driving for 24” (~0.6 m) diameter steel piles, Kodiak, from (Denes et al., 2016).



Further examples of source levels were found in (Dahl et al., 2015) for the peak pressure level measured from impact pile driving. They report levels of 220 dB re 1 µPa @ 10 m for a 0.75 m diameter pile (~240 dB re 1 µPa @1m), and 200 dB re 1 µPa @ 300 m for a 5m diameter pile.

The Caltrans Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish (Buehler et al 2015) collates data from a large number of separate shallow water piling projects and presents a summary of source levels. For steel pile sizes relevant to the CSD piling, values of peak level @ 10 m and SEL @ 10 m were:

- 0.6 m piles PK 203-207 dB re 1 µPa, SEL 177-180 dB re 1 µPa^2 s (source levels of 223-227 dB re 1 µPa and 197-200 dB re 1 µPa^2 s)
- 1.0 m piles PK 208-210 dB re 1 µPa, SEL 180-183 dB re 1 µPa^2 s (source levels of 228-230 dB re 1 µPa and 200-203 dB re 1 µPa^2 s)
- 2.4 m piles PK 220 dB re 1 µPa, SEL 195 dB re 1 µPa^2 s (source levels of 240 dB re 1 µPa and 215 dB re 1 µPa^2 s)

A peak level of 206 dB re 1 µPa @ 12 m for a 1.5m diameter pile was measured as described in (Köller et al, 2006).

Levels from 2.4 m diameter piles were measured in (Martin et al., 2012) and compared to a model as described in (MacGillivray, 2015). Peak level @ 10 m was on average 223 dB re 1 µPa and SEL @ 10 m was 194 dB re 1 µPa^2 s (source levels of 243 dB re 1 µPa and 214 dB re 1 µPa^2 s)

Diederichs et al, 2008 presented source values for SEL and peak level of 235-240 dB re 1 µPa for piles of 4-5 m diameter originally obtained from (Nehls et al 2008).

A comparison of the piling levels in the literature vs pile diameter is included in Figure 9 for peak and Figure 10 for SEL. All values presented for distances other than 10 m have been normalised to 10 m distance assuming spherical propagation. The 3.1 dB/m diameter relationship from (Nehls et al 2008) is included (set so that the value for a 5 m pile is equal to the Nehls et al value).

Figure 9: Comparison of peak piling levels vs pile diameter at 10 m

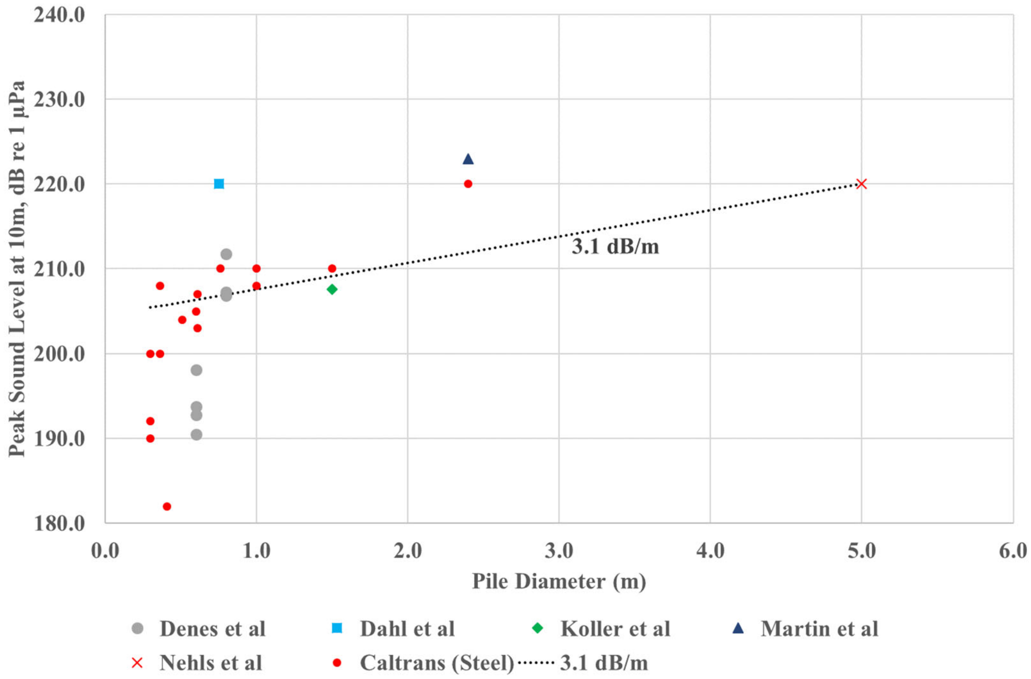
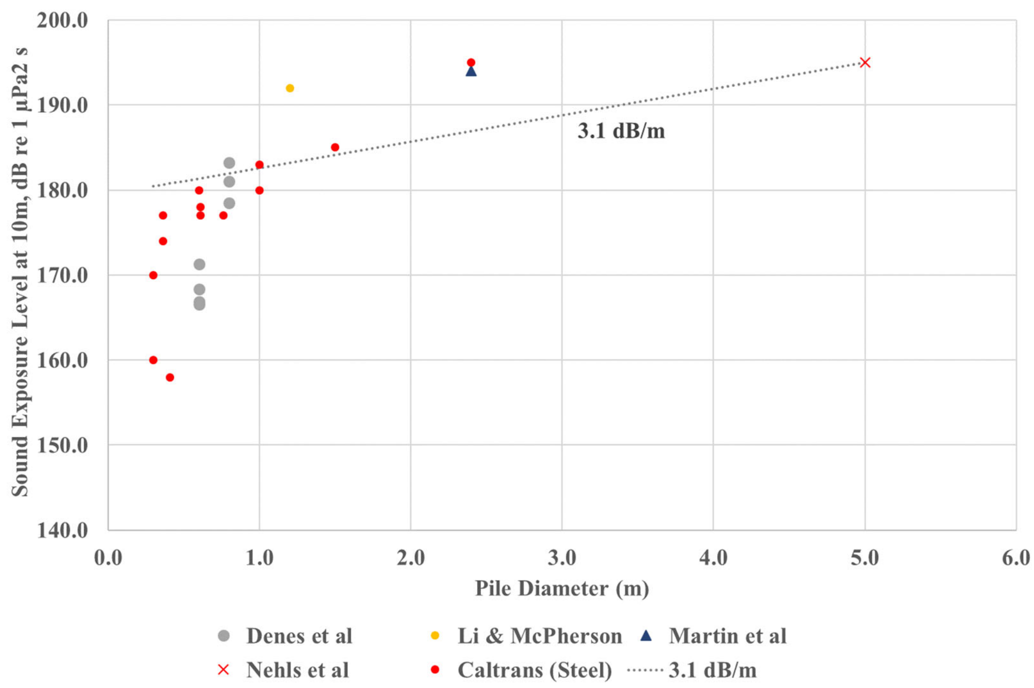


Figure 10: Comparison of SEL piling levels vs pile diameter at 10 m



Comparison of Figure 9 and Figure 10 shows that the 3.1 dB/m diameter relationship from Nehls et al 2008 is broadly accurate, however there can be significant spread in the data. The trendline can be considered to be at the upper end of the representative range for typical piling levels.

Peak and SEL source levels for CSD piling have been determined using the source levels from Nehls et al 2008, corrected for pile diameter using the 3.1 dB/m diameter correlation shown on the same work. SPL values for the piling have been assumed to be 10 dB lower than the peak values based on the measured relationships in Denes et al 2016.

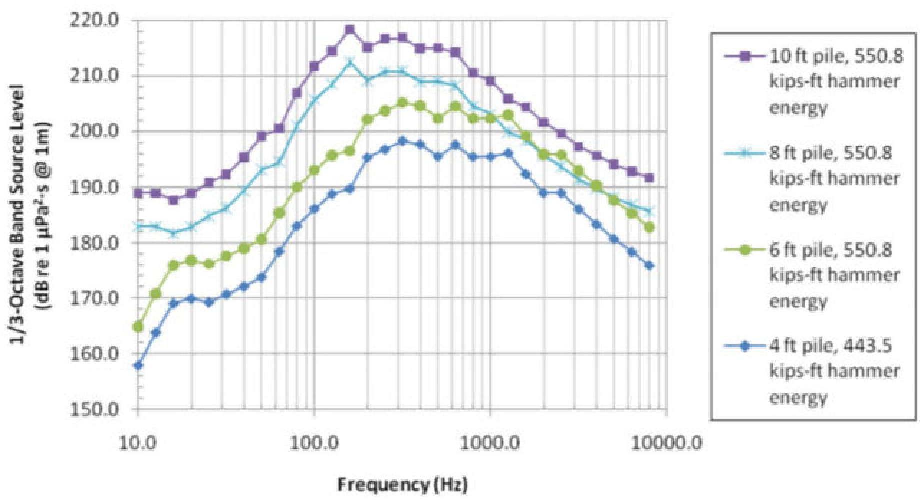
Acknowledging the spread in the data in the literature shown in Figure 9 and Figure 10, it is recommended that early monitoring of actual piling levels within Trinity Inlet be conducted and if necessary the predicted levels (and corresponding impact zones) updated.

For the wharf source, impacts have been assessed for the 2.2 m diameter piles only. This is because the source level for the 2.2 m piles at Wharf 1-5 is ~5 dB higher than the source level for the 610mm piles, and additionally because the number of strikes per pile is higher (1500 vs 500). Even when accounting for the potential for two piles to be installed per day for the 610 mm piles vs one pile per day for 2.2m, the impacts (both in terms of peak level and SEL) from the 2.2 m piles would be higher than for the 610 mm piles (i.e. the cumulative sound exposure from two 610 mm piles is still lower than the cumulative sound exposure from one 2.2 m pile).

The piling spectrum in Figure 3 (from Nedwell et al 2007) used in the draft EIS is quite ‘flat’ at low frequency and the values below 40 Hz may have been affected by ambient noise in the measurements. Examination of other more recent measurements of piling spectra conducted at closer distances to the source, e.g.

the values from Li & McPherson (2018) in Figure 6 and the predicted values from MacGillivray et al (2011) shows a roll-off of piling noise at frequencies below 100 Hz (Figure 11) which is considered to be more appropriate.

Figure 11 Predicted 1/3 octave band impact piling source levels for steel piles, from MacGillivray et al (2011)



The spectrum shape for the 1.2m and 2.2m piles have been assumed based on the MacGillivray et al 2011 spectrum shapes for the 4ft pile (~1.2m) and 8ft pile (~2.4m). Values for 10 kHz have been extrapolated based on the 8 kHz value and the slope of the spectrum at high frequency.

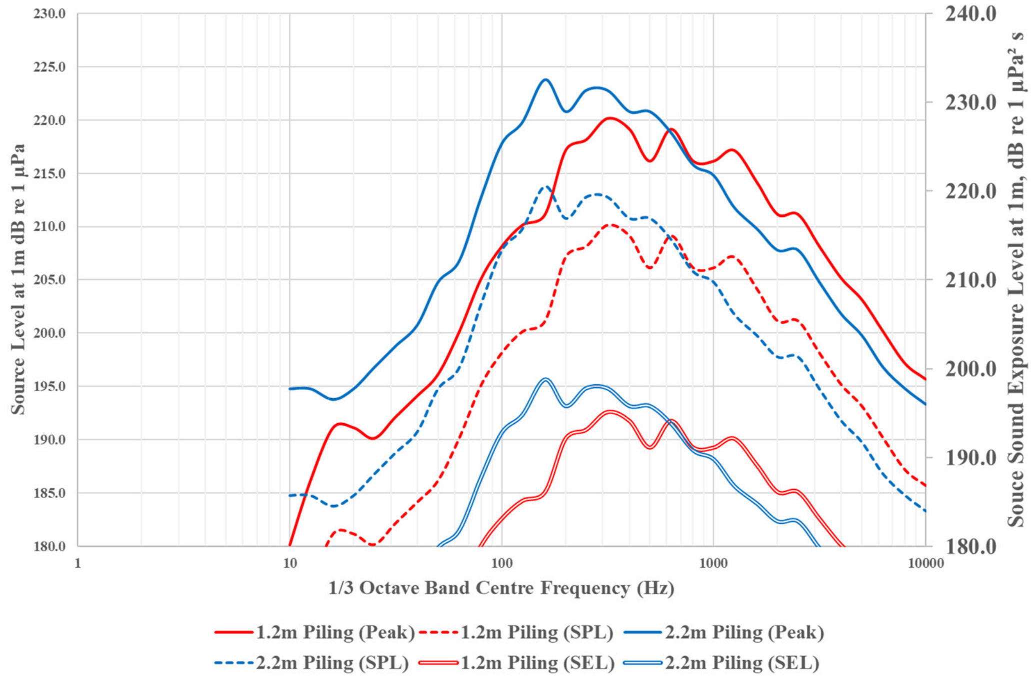
This results in the following source levels:

- 1.2m pile (navigational aids)
  228 dB re 1 µPa @ 1m (peak) / 203 dB re 1 µPa² s @1m (SEL)
- 2.2m pile (Wharf piling)
  231 dB re 1 µPa @ 1m (peak) / 206 dB re 1 µPa² s @1m(SEL)

These values are consistent with previous quoted piling source levels from recent literature. The assumed piling source levels should be confirmed by monitoring during early stages of construction works.

The source spectra for the updated piling source levels are shown in Figure 12.

Figure 12: Updated piling peak, SPL and SEL source levels at 1 m



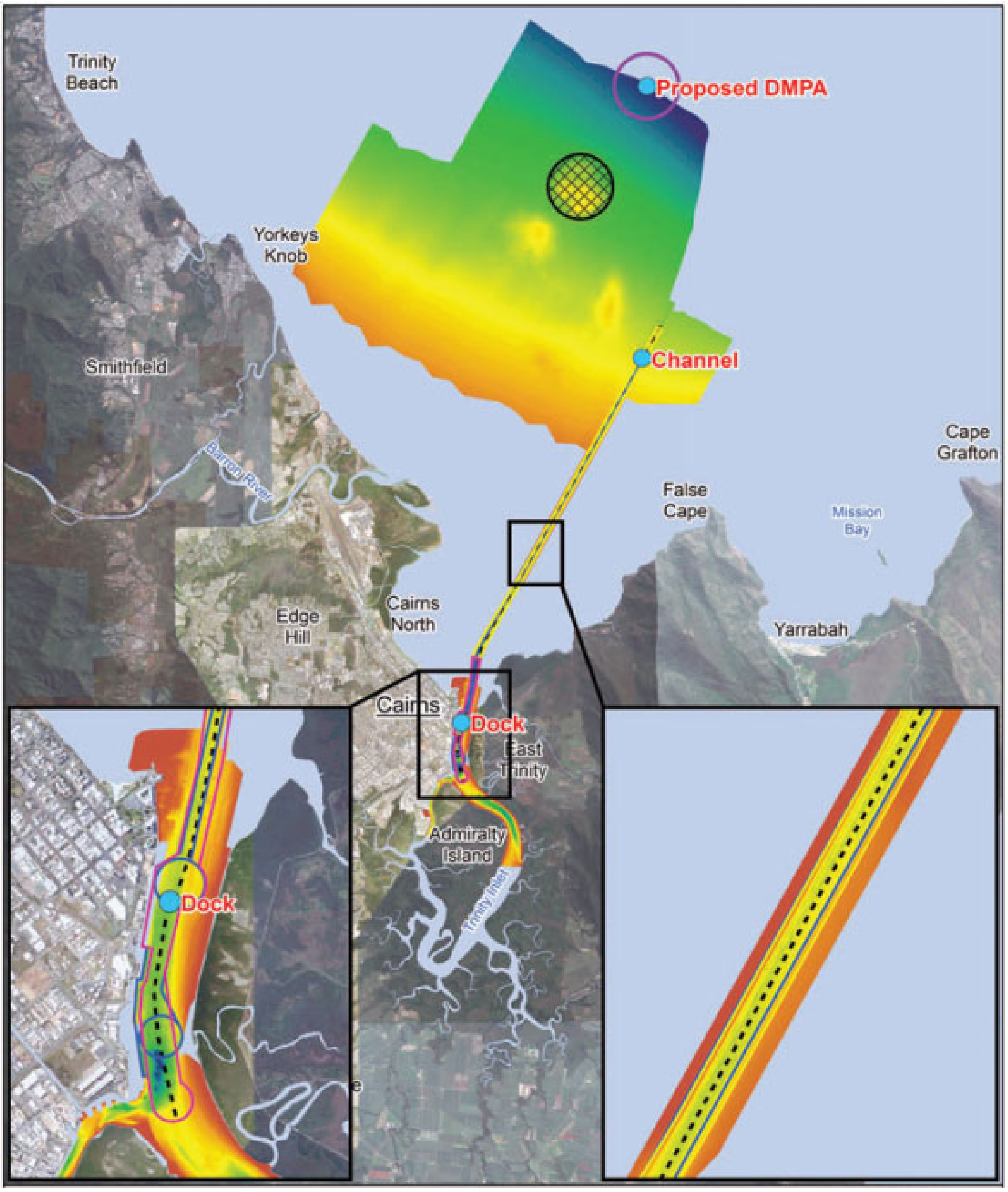
5 Updated Assessment of Impacts

5.1 Assumptions and Limitations

Given the time and scope limitations associated with completing this work we have described the assumptions and limitations in assessing the review of the observational and exclusion zone of the Draft EIS. These include:

- Source locations assumed to be same as per Draft EIS, as shown in Figure 13.

Figure 13: Source locations for piling (from draft EIS)



Bathymetry as per existing bathymetry as provided during the Draft EIS (prior to capital dredging) as shown in Figure 14 and Figure 15.

Figure 14: Bathymetry for wharf piling

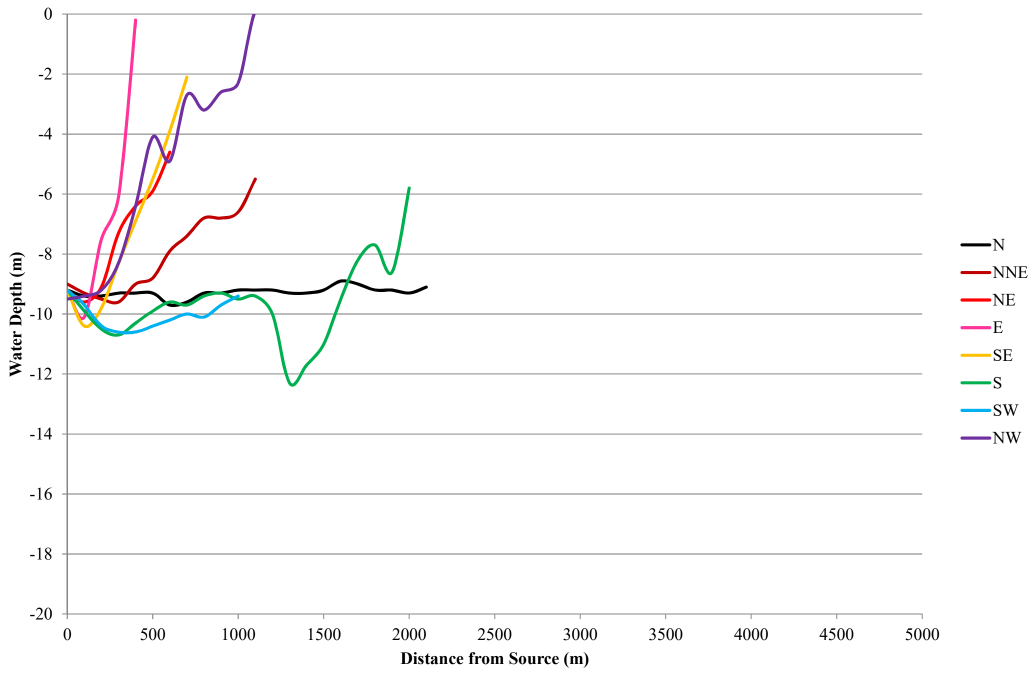
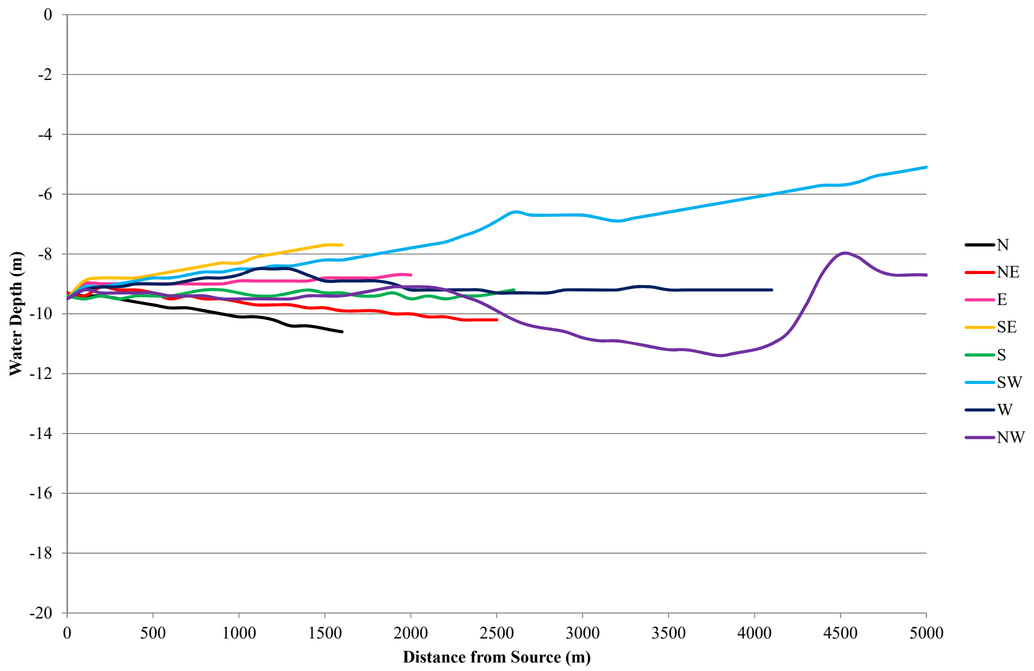


Figure 15: Bathymetry for channel piling



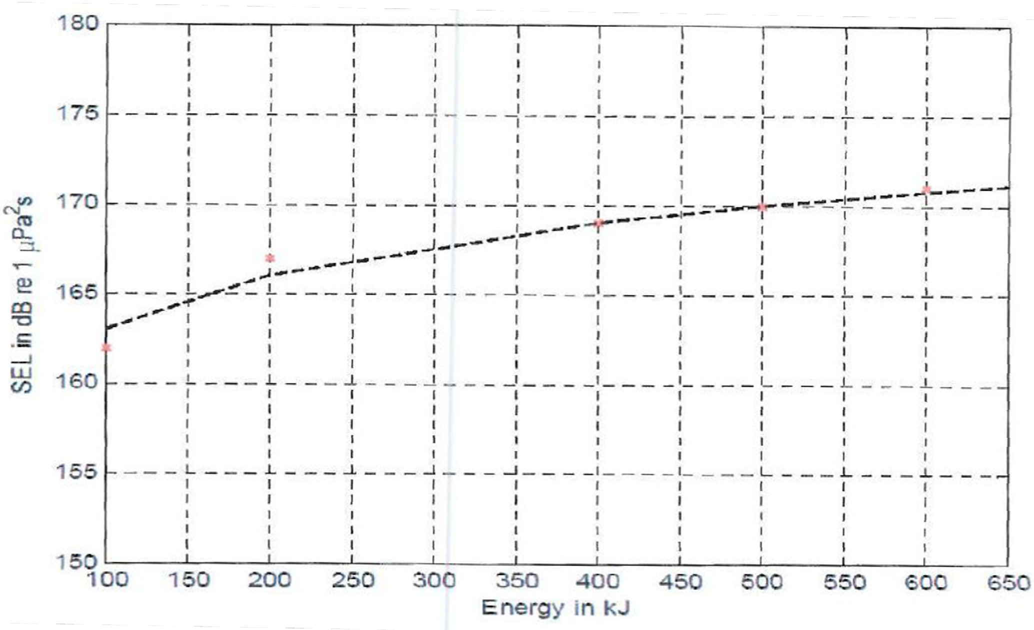
- Propagation (transmission loss) predictions were assumed as per the Draft EIS, which conducted predictions using the Acoustic Toolbox (ActUP) developed by the Centre for Marine Science and Technology at Curtin University, implementing the RamGEO model with a "slow bottom" seafloor with speed of sound less than that of the water column, to model the muddy clay seafloor of Trinity Inlet with relatively high bottom loss over an underlying rock substrate.
- Transmission loss predictions are for a 5 m receiver depth which is considered to be representative of a submerged marine mammal.
- The predicted transmission loss at 200 Hz (the dominant frequency for the piling spectra in Figure 12) exhibits a 10 log relationship in the close zone near the source with a higher rate of propagation as distance increases. This is attributable to losses at the seafloor which are prominent considering the muddy seabed.
- Modelling is based on single strike results, and assuming one pile is being driven at a time. SEL Cumulative levels are than calculated based on number of strikes assuming that all strikes have same noise generation. This assumes that the receiver is stationary, which is a conservative assumption and neglects the effect of any animals moving away from the source to escape the noise exposure (which would decrease the cumulative noise exposure).
- Piling predictions at the wharf locations has been conducted for the largest pile diameter, 2.2 m diameter, used for Wharves 1-5. Impacts for the smaller piles for Wharf 6 (610 mm diameter) will be reduced by approximately 5 dB.
- Piling predictions for the channel location are based on 1.2 m diameter piles.
- For the SEL cumulative calculations, the following assumptions for pile strikes within a 24-hour period have been assumed, based on the driveability assessment (2.2m piles) and on the guidance from Caltrans (Buehler et al 2015) (for 1.2 m piles; no driveability assessment was provided for the 1.2m piles):
    - 1.2m piles 600 strikes
    - 2.2m piles 1500 strikes

  These values are based on the lower bound of the expected range from the driveability assessment. This is considered appropriate because all pile strikes in the noise predictions are assumed to be full power strikes, and also because the assumption assumes a stationary animal that is exposed to every pile strike and ignores any avoidance behaviour. Assuming that an animal would remain stationary for thousands of pile strikes is an overconservative assumption.

  The predicted zones would be subject to change based on the selected piling contractor's equipment and applications methods. Any changes to the assumed number of strikes will change the outcome of the level of cumulative noise at a particular distance by a factor of $10 \log_{10} \left(N / N_0 \right)$ dB, where N is the number of pile strikes used by the contractor and N_0 is the number of pile strikes assumed in this report.

- Although the number of pile strikes would increase if lower-power pile strikes were used, the cumulative SEL would be essentially unchanged, because there is an approximately linear (10 log) relationship between hammer impact energy and the sound exposure level (acoustic energy), as shown in Figure 16. In other words, the increased number of pile strikes is offset by the decreased energy of each blow and the total noise dose associated with the piling is essentially constant. Reducing the pile energy would, however, reduce the peak sound levels associated with piling; however impacts from piling are typically governed by noise-dose (sound exposure level) metrics rather than peak level metrics.

Figure 16: Approximate relationship between piling impact energy and Sound Exposure Level, from IHC Merwede)



- Noise predictions were conducted for impact piling only. Although some vibropiling is proposed to be used as part of piling works, the sound level from vibropiling is significantly lower than impact piling (Approximately ~25 dB lower in terms of PK level, ~15 dB lower in terms of SEL (comparing SEL from single strike to 1 s SEL from vibropiling, based on the data presented in the Caltrans report (Buehler et al 2015)).
  For the 1.2 m piles at CSD, the cumulative SEL from 600 strikes of impact piling is equivalent to vibropiling for 3.3 hours.
  For the 2.2 m piles at CSD, the cumulative SEL from 1500 strikes of impact piling is equivalent to vibropiling for 16.7 hours.

  Provided that vibropiling does not occur for longer than these calculated durations, the impacts from any vibropiling works would be less than the predicted impact piling impacts.

5.2 Updated Assessment Criteria

Within the last five years since the draft EIS there have been further developments of knowledge throughout the underwater acoustic community. As such several of the impact criteria obtained from the literature review conducted for the draft EIS have required adjustment. The referenced injury and behavioural levels adopted in this study have been selected as the most widely accepted and applied criteria. Additionally, several resources have become more standardised in the use of terminology with the release of the ISO 18405 Underwater Acoustics – terminology (ISO 2017).

The main resources utilised to update the marine animal threshold criteria include but are not limited to:

- Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific) (Finneran et al 2017).
- Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts (2014, 2016 & 2018) National Marine Fisheries Service (NMFS)(U.S.).
- 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts (NMFS, 2018)
- Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report (Popper et al. 2014)
- Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects (Southall et al. 2019).

This literature review has also included a review of the public documentation of the Cape Lambert Port a Marine Structures Refurbishment Project EIS, by Parnum et al (2018). These documents have succinctly compiled a number of these guidance references for application to pile driving. These documents and assessments undertaken are very applicable to the application and outcomes of the reviewed Draft EIS observation and exclusion zones.

For clarity, criteria referring to a peak sound level have been written in plain text, criteria referring to SPL in <u>underlined text</u> and criteria referring to cumulative SEL24hr in **bold text**.

5.2.1 Marine mammals (cetaceans, dugongs, and other)

The information currently available suggests a more refined understanding of hearing, hearing thresholds and behavioural responses than was available at the time of writing of the draft EIS. This increased knowledge also includes a better understanding of the auditory capabilities of marine mammals. In addition, there has been a change in the approach of how hearing is represented, i.e. through updated weighting functions that are adjusted for the animal's frequency sensitivity, and in the use of cumulative SEL criteria.

Temporal (TTS) and Permanent (PTS) threshold shifts have been better refined and suggest generally lowered thresholds for peak, SEL and SPL that indicate potential for the onset of changes in hearing. For the most part, cetaceans have been referred to low, mid, and high frequency hearing (Table 3). This is based on several overarching documents and guidelines and provides a generalised assessment approach for several species within each category, as a more conservative approach and to protect the hearing of a wider range of species. For the purposes of this review, it is considered extremely unlikely for high-frequency cetaceans to be present in the Cairns area and for this reason they are not included in the review of criteria and impacts will not be predicted for high-frequency cetaceans.

Table 3 presents behavioural and injury criteria for marine mammals.

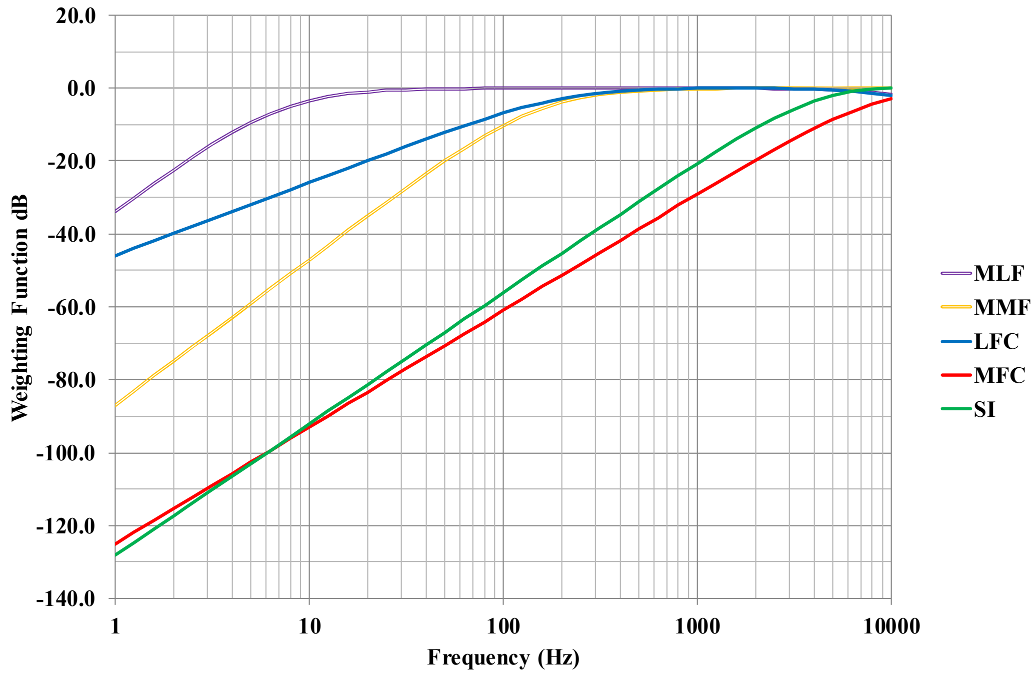
Table 3. Commonly applied behavioural and injury criteria for marine mammals

Effect	Low- frequency cetaceans	Mid-frequency cetaceans	Dugongs
Behavioural Response	160 dB SPL re 1 µPa for impulsive noise, U.S. National Marine Fisheries Service (NMFS) criterion (NMFS 2018))		
TTS	213dB PK **168 dB SEL24hr (weighted)**	224 dB PK **170 dB SEL 24hr (weighted)**	220 dB PK **175 dB SEL24hr (weighted)**
PTS	219 dB PK **183 dB SEL24hr (weighted)**	230 dB PK **185 dB SEL24hr (weighted)**	226 dB PK **190 dB Weighted SEL24hr**
Injury	237 dB PK	237 dB PK	237 dB PK
References	Finneran et al (2017)	Finneran et al (2017)	Finneran et al (2017)

The applicable frequency ratings for use with the weighted criteria will differ for different criteria. The SEL24hr criteria from NFMS 2018 (based on Finneran (2016) are intended to be used with new "Phase 3" weighting functions which replace the older M_{mf}, M_{lf}, M_{pw} weighting functions from Southall et al (2007) and are based on more recent research regarding the hearing sensitivity of marine mammals.

These functions, labelled "LFC", "MFC" and "SI" for low-frequency cetaceans, mid-frequency cetaceans and sirenians, respectively, are compared against the older M_{lf}, M_{mf} functions in Figure 17.

Figure 17: Comparison of NMFS 2018 and Southall et al 2007 weighting curves



The older M_{mf} etc criteria were based on assumptions regarding the low-frequency hearing of marine mammals which were overly conservative and assumed that low-frequency hearing sensitivity was the same as the most sensitive frequency range. More recent research (summarised in Southall et al 2018) has shown that low-frequency hearing of marine mammals is less sensitive than previously assumed. This is why the new functions are less flat (i.e. attenuate low-frequencies more) than the older M-weighting functions.

5.2.2 Fish (including eggs and larvae)

There are multiple groups of hearing sensitivities for fish. Fish hearing is a combination of auditory function, presence of swim bladder and sensitivity to pressure and particle motion (Popper & Hawkins 2019).

It will be difficult to determine the location of fish species prior to and during pile driving. It is recommended that mitigation measures as described in section 5.4.1 be considered to reduce likelihood of mortality (Table 4).

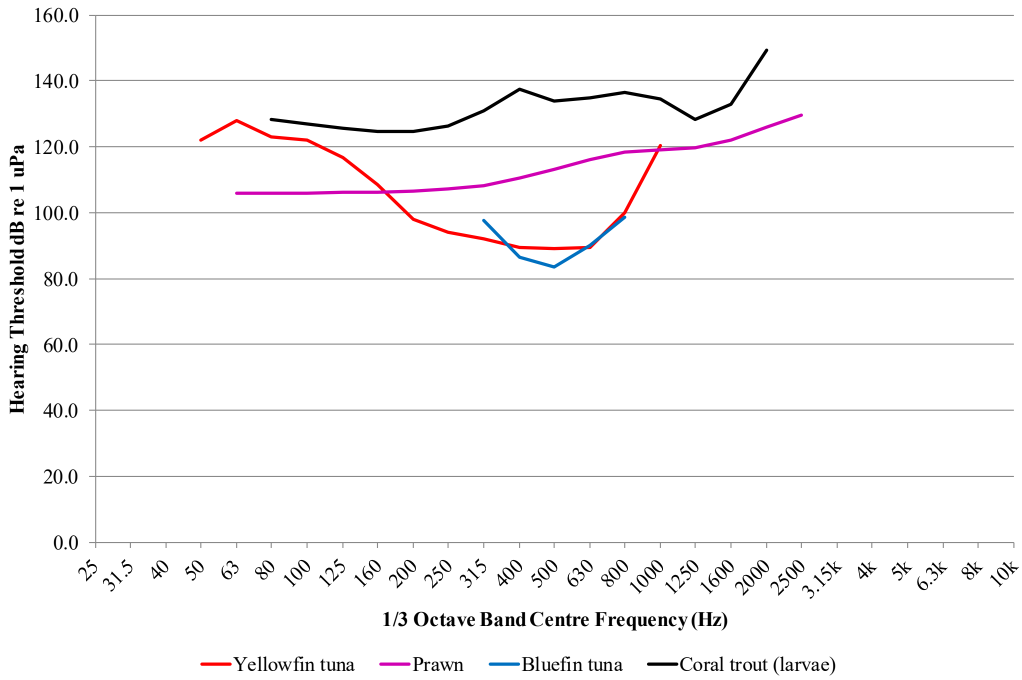
The revised draft EIS chapter B7 (Marine Ecology) identifies three species of threatened shark that could occur within the study area. No listed species of fish were noted as being present.

Major commercial fishery species for the Port of Cairns include barramundi, coral trout, tuna, Spanish mackerel and prawns. Within the inshore Trinity Inlet environment, barramundi is likely to be the only species regularly present.

No audiometric data is available in the literature for barramundi, however a study of an existing barramundi fish farm (Petersen and Jurevicius 2009) indicates that barramundi tolerate high noise levels (up to 130 dB re 1 µPa). No data is available for Spanish mackerel, however the species does not have a swimbladder and is therefore unlikely to be particularly noise-sensitive. A study of coral trout larvae (Wright et al 2008) indicates that the hearing sensitivity (at least at larval stage) is relatively low, with thresholds over 120 dB re 1 μPa and hearing being most sensitive at low frequencies (around 100-200 Hz). Audiograms are available for Pacific bluefin tuna (Dale et al 2015) and for yellowfin tuna (Nedwell et al 2004). Tuna has much more sensitive hearing than the other important fishery species at Cairns, with thresholds of approximately 80 dB re 1 μPa and maximum sensitivity occurring at ~500 Hz. Thresholds for prawn species associated with the Cairns fishery are not available, but an audiogram for the common prawn is available (Lovell et al 2005), which indicates a hearing threshold above 105 dB re 1 μPa.

A summary of the hearing thresholds of relevant species is included below in Figure 18.

Figure 18: Hearing thresholds of commercially-significant fish and prawn species (from Nedwell et al 2004, Lovell et al 2005, Dale et al 2015 and Wright et al 2008).



For evaluating behavioural impacts on fish, a hybrid tuna audiogram has been defined as the more stringent of the Yellowfin and Bluefin tuna audiograms.

Sharks and rays

There is still little information available on the effects of anthropogenic noise on elasmobranchs, however as these animals have a dependence on pressure changes (and particle motion) more than actual pressure hearing, they are inherently more sensitive to low frequency (McPherson et al. 2017). For the purposes of this literature review we have assumed sharks will fall into a similar category as fish with no swim bladder (particle motion detection).

Table 4. Fish injury criteria due to pile driving, information reproduced from (Popper et. al. 2014).

Type of animal	Mortality Potential mortal injury Non-recoverable injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	**>219 dB SEL24h** or >213 dB PK	**>216 dB SEL24h** or >213 dB PK	**>186 dB SEL24h**	(N)Moderate (I) Low (F) Low	(N)High (I)Moderate (F)Low
Fish: Swim bladder not involved in hearing (particle motion detection) "Hearing generalists"	**210 dB SEL24h** or >207 dB PK	**>203 dB SEL24h** or >207 dB PK	**>186 dB SEL24h**	(N) Moderate (I) Low (F) Low	(N)High (I)Moderate (F)Low
Fish: Swim bladder involved in hearing (primarily pressure detection) "Hearing specialists"	**207 dB SEL24h** or >207 dB PK	**>203 dB SEL24h** or >207 dB PK	**>186 dB SEL24h**	(N) High (I) High (F) Moderate	(N)High (I)High (F)Moderate
Fish: Eggs and larvae	**>210 dB SEL24h** or >207 dB PK	(N) Moderate (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Peak sound pressure level dB re 1 µPa; SEL24h dB re 1µPa2·s.
All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist.
Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

5.2.3 Sea turtles and marine reptiles

The revised draft EIS chapter B7 (Marine Ecology) identifies five species of threatened turtle that could occur within the study area.

In 2014, Popper et. al. in addition to reviewing the injury criteria for fish, assessed sea turtles. Data on the effects of pile driving on sea turtles are lacking. However, Popper et. al. (2014) adopts the levels for fish that do not hear well since it is likely these would be conservative for sea turtles. Because of their rigid external anatomy, it is possible that sea turtles are highly protected from impulsive sound effects, at least with regard to pile driving (Table 5).

Criteria for sea turtles were sourced from Popper et al 2014, and Finneran et al 2017 and are summarised in Table 5.

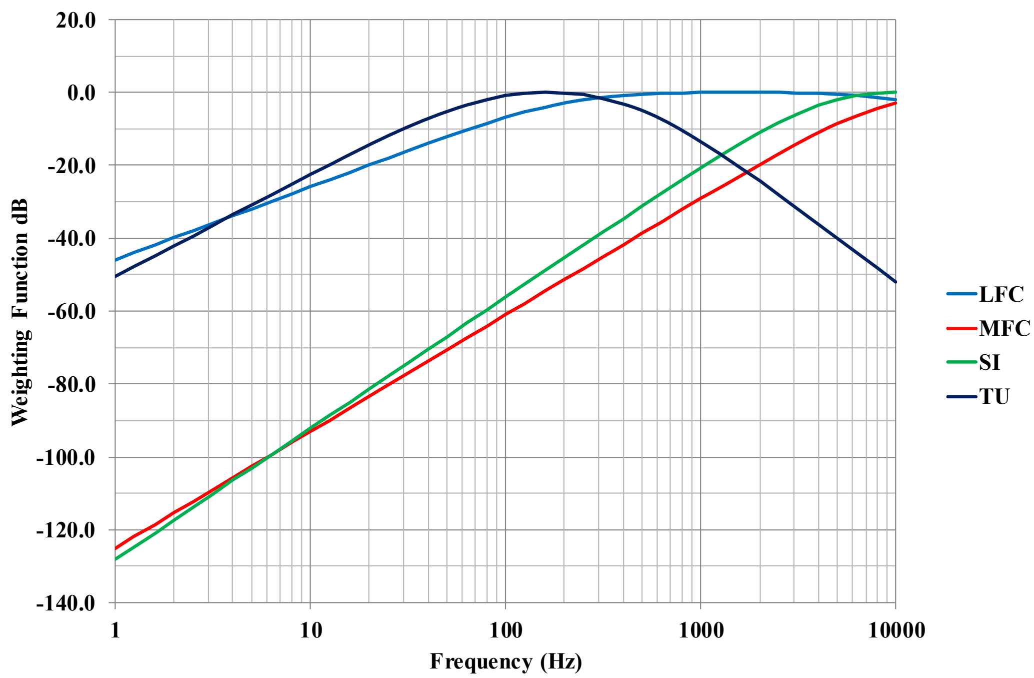
Table 5. Sea turtle injury and behavioural criteria.

Type of animal	Mortality Potential mortal injury Non-recoverable injury	Impairment			Behaviour	Reference
		Recoverable injury	TTS	Masking		
Turtles	**210 dB SEL24h** or >207 dB PK	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I)Moderate (F) Low	Popper et at. 2014
	PTS **204 dB Weighted SEL24h** 232 dB PK Injury: 237 dB PK	-	**189 dB Weighted SEL24h** 226 dB PK	-	175 dB SPL	Finneran et al. (2017)

Note that the peak level criteria from Popper et al 2014 for injury are more stringent than the Finneran et al 2017 criteria for temporary hearing damage. This relates to the different methodologies used for deriving criteria from these two studies; the more stringent of the two values has been used as a conservative assessment.

Finneran et al (2017) define a 'TU' weighting function for turtles for use with weighted SEL criteria, which is shown in Figure 19 below (with the criteria for marine mammals for reference to show relative sensitivity).

Figure 19: Weighting functions for turtles compared to marine mammals



Sea snakes

There is still little information available on sea snakes on how they hear and how susceptible they might be to underwater noise (McPherson et al 2017). It is suspected that they may respond in a similar way to turtles, such as exhibiting behavioural avoidance of the sound sources (Parnum et al., 2018).

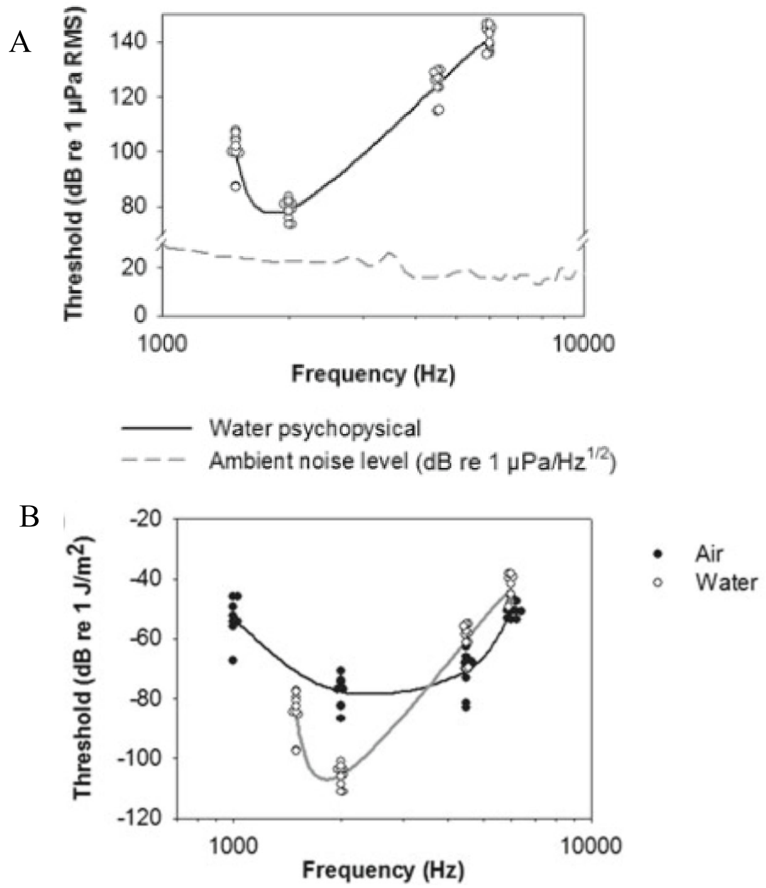
5.2.4 Birds

There is still little information available on birds (while diving) as far as the impact on hearing and behaviour due to in water pile driving.

A brief review of in air and underwater hearing of four diving species was reviewed on the Lesser scaup (*Aythya affinis*), Long-tailed ducks (*Clangula hyemalis*), Red-throated loons (*Gavia stellata*) and the Northern gannets (*Morus bassanus*). Overall, they found Peak amplitude increased and peak latency decreased with increasing stimulus sound pressure level. Hearing sensitivity peaked between 1,500 and 3,000 Hz. (Crowell, 2016).

Another study recently reviewed the in air and underwater hearing of the great cormorant (*Phalacrocorax carbo sinensis*) as part of a piolet study. The results suggest they have a narrower band of hearing but have a lower threshold to noise energy levels. The hearing range sits between >1 kHz and 6 kHz (Figure 4) (Johansen et al., 2016).

Figure 20. Hearing threshold in water in SPL(figure A) and hearing in air and water in energy density (B) of the great cormorant in Johansen et al. (2016).



Both these studies would suggest birds could hear the pile being driven however their range of most hearing sensitivity of hearing (> 1 kHz) is above the frequency range containing the greatest energy from pile driving (< 1 kHz).

The previous reference in the Draft EIS to hearing injury and mortality from an proximity explosion (Yelverton et al. 1973) which has a different acoustic energy composition. However as there is still a lack of understanding of the hearing and behavioural impacts of impulse noise on marine birds (diving) a few assumptions will be made to provide estimated thresholds (Table 6).

Table 6. Estimated thresholds for Bird injury and behaviour.

Species*	**Onset of injury**
Birds (diving)	190 dB SEL (Yelverton et al. 1973)

5.3 Updated Underwater Noise Predictions

Using the revised source levels as per Section 4.4, the predicted underwater noise levels from piling operations at the wharf and within the shipping channel have been updated using the propagation transmission losses predicted for the draft EIS. Revised predicted underwater noise levels for piling at the wharf and in the shipping channel are presented in Appendix A

A summary of the revised predicted underwater noise levels have been provided in Table 7. The levels have been calculated based on single strike levels at set distances for establishing the levels at which the marine animal criteria threshold would be achieved.

In addition to the single strike levels, the cumulative SEL (denoted SEL_{cum} or SEL_{24hr}) was calculated based upon the equation in Popper et al., 2014:

$SEL_{cum} = SEL_{ss} + 10log10(N)$, where SEL_{ss} is the single strike SEL.

This has been explained clearly in Parnum et al (2018):

> *"SEL_{24h} is a cumulative metric that reflects the dosimetric impact of noise levels within the driving period, and it assumes that an animal is consistently exposed to such noise levels at a **fixed position**. The distances that correspond to SEL_{24h} typically represent an unlikely worst-case scenario for SEL-based exposure since, more realistically, marine fauna (mammals, fish, or turtles) would not stay at the same location or at the same range for an extended period. Therefore, a reported distance for an SEL_{24h} criterion does not mean that any animal travelling within this distance of the source will be injured, but rather that the animal could be injured if it remained within that range for the entire period of operation."*

The SEL and SEL cumulative (SEL_{24h}) levels have been calculated with weighting functions to correct for low and mid frequency cetaceans. The more recent NMFS weighting functions (NMFS 2018) have been used in addition to the Mmf, and Mlf functions from (Southall et al 2007) which were used in the draft EIS and which are referenced in the SA Underwater Piling Guidelines.

In addition, unweighted levels have been presented for comparison to criteria for impacts on fish, sea turtles and (where applicable) marine birds (diving).

Table 7 and Table 3summarise the predicted underwater noise levels at set distances from the piling at the wharf and channel, respectively. Values that are above behavioural response thresholds have been formatted in <u>underline</u>. Values that are above damage (TTS) criteria are formatted in **bold**.

Data for the older Southall et al 2007 parameters M_{lf} and M_{mf} are presented for single strike SEL only. This is because for assessment of impacts on animals these metrics have been superseded; they are included for SEL_{ss} only because the SA Underwater Piling Noise Guidelines references exclusion zones based on the value of the single strike SEL for these parameters.

Graphs with predicted piling noise levels vs distance are included in Appendix A.

Table 7. Updated underwater noise level prediction from pile driving at wharf (2.2 m pile diameter)

Metrics	**Relative dB at specified distances from pile**				
	50m	**100m**	**300m**	**500m**	**1km**
SPL dB re 1 µPa (rms) *single strike*					
Unweighted	178	173	156	145	135
Peak dB re 1 µPa *single strike*					
Unweighted	188	183	166	155	136
dB_{ht} (Dolphin)	108	102	67	51	19
dB_{ht} (Dugong)	114	108	74	63	43
Sound Exposure Level dB re 1 µPa²·s *single strike (not cumulative)*					
Cetaceans Low-frequency (LFC)	162	157	139	127	107
Cetaceans Low-frequency (M_{lf})	162	157	141	130	111
Cetaceans Mid-frequency (MFC)	142	136	101	85	57
Cetaceans Mid-frequency (M_{mf})	152	147	128	116	95
Sirenians	149	143	108	92	63
Chelonians	156	151	139	130	111
Unweighted#	163	158	141	130	111
SEL_{24hrs} *(SEL_{ss}+10log_{10}(N))** *N= 1500 strikes^*					
Cetaceans Low-frequency (LFC)	**194**	**189**	**170**	159	139
Cetaceans Mid-frequency (MFC)	**173**	167	132	117	89
Sirenians	**181**	**175**	139	124	95
Chelonians	**189**	184	172	163	144
Unweighted#	**194**	**189**	172	162	143

For impacts to fish or birds

* Popper et al 2014, for SEL_{cum} = SEL_{24h}

^if the number of strikes increases the cumulative sound level will increase, this will increase the energy/pressure level at the same distance, if there are less strikes the inverse relationship will happen.

Table 8. Updated underwater noise level prediction from pile driving in channel (1.2 m pile diameter)

Metrics	Relative dB at specified distances from pile				
	50m	100m	300m	500m	1km
SPL dB re 1 µPa (rms) *single strike*					
Unweighted	180	174	151	137	115
Peak dB re 1 µPa *single strike*					
Unweighted	190	184	161	147	125
dB_{ht} (Dolphin)	118	111	78	61	32
dB_{ht} (Dugong)	111	105	72	54	15
Sound Exposure Level dB re 1 µPa²·s *single strike (not cumulative)*					
Cetaceans Low-frequency (LFC)	165	158	135	120	96
Cetaceans Low-frequency (M_{lf})	165	158	136	122	100
Cetaceans Mid-frequency (MFC)	145	139	105	88	50
Cetaceans Mid-frequency (M_{mf})	165	158	135	120	95
Sirenians	152	146	113	95	57
Chelonians	155	148	134	121	99
Unweighted#	165	159	136	122	100
SEL_{24hrs} *($SEL_{ss}+10log_{10}(N)$)** *N= 600 strikes^*					
Cetaceans Low-frequency (LFC)	**193**	**186**	163	148	124
Cetaceans Mid-frequency (MFC)	**173**	166	133	116	78
Sirenians	**180**	174	141	123	85
Chelonians	183	176	162	149	127
Unweighted#	**193**	**186**	164	150	127

other – for impacts to fish or birds

* Popper et al 2014, for $SEL_{cum} = SEL_{24h}$

^if the number of strikes increases the cumulative sound level will increase, this will increase the energy/pressure level at the same distance, if there are less strikes the inverse relationship will happen.

5.4 Recommended Safety Zones

Recommended safety zones (i.e. observation and exclusion zones) have been defined based on the following approach:

The observation zone has been defined based on the greater of:

- The predicted distance at which behavioural response is predicted to occur
- The observation zone from the SA Underwater Piling Noise Guidelines

By including as a minimum the zone of expected behavioural impacts in the observation zone, this means that animals that enter the observation zone may be expected to experience an avoidance reaction and turn away from the pile before entering the zone where actual injury to the animal could occur.

The exclusion zone has been defined based on the greatest of:

- The predicted distance at which any injury (i.e. TTS, PTS or physical injury) would occur from a single pile strike (either peak or single strike SEL)
- For cetaceans, sirenians or chelonians: the predicted distance at which TTS may occur from cumulative piling (SEL_{24hr})
- The exclusion zone from the SA Underwater Piling Noise Guidelines.

This approach is essentially defining the exclusion zone as being the zone within which injury to an animal would be expected from a single pile strike or within which it would be possible for an animal to experience auditory injury should it stay within the zone for the entire duration of the piling activity (which is unlikely). Marine mammals and sea turtles have been considered in setting observation and exclusion zones since these animals are air-breathing and will need to come up for air periodically, making tracking of animal movements with trained observers possible (albeit difficult in the turbid waters of Trinity Inlet).

Safety zones for fish or diving seabirds have not been provided due to the impracticality of detecting/monitoring these animals within safety zones (fish) or because of the mobility of these animals which allows them to avoid the area of the pile easily by taking flight (birds). However, impact distances are provided (for single strike impacts) which will help to provide context around the expected zone of impacts e.g. for animals that happen to be in the vicinity of the pile when operations commence.

Because the modelling has not been updated for the change in bathymetry that will result from the capital dredging within the swing basin and shipping channel, and accounting for the degree of variation in the source levels, a conservative approach has been adopted to determine safety zones so that any changes to bathymetry that may occur from the dredge works do not make the safety zones inadequate. A safety factor of 10% has been applied in determining safety zones (which are rounded to the nearest 10 m).

A modified approach for determining the standard observation and exclusion zone distances has been adopted. This uses the approach of the SA Underwater Piling

Noise Guidelines but uses the updated LFC/MFC/SI/TU weightings for a single pile strike in place of the superseded M-weightings.

The SA Underwater Piling Noise guidelines define three categories of observation and exclusion zones based on the values of the weighted single strike SEL at 100 m distance or 300 m distance, as follows (coloured for 'low', 'medium' and 'high' categories):

- Where the weighted SELss ≤ 150 dB at 100 m, safety zones of 100 m (exclusion) / 1 km (observation) would apply.
- Where the weighted SELss > 150 dB at 100 m but is ≤ 150 dB at 300 m, safety zones of 300 m (exclusion) / 1.5 km (observation) would apply.
- Where the weighted SELss > 150 dB at 300 m, safety zones of 1 km (exclusion) / 2 km (observation)would apply.

The predicted single strike SEL values for piling at the wharf and channel are presented in Table 9 and Table 10 respectively, colour-coded to show the applicable category.

Table 9 Predicted weighted single strike SEL levels at 100 m and 300 m distance from wharf piling.

Species Group	Weighted SELss Level at 100 m	Weighted SELss Level at 300 m
Low-Frequency Cetaceans	**157.1 dB(LFC)**	**138.6 dB(LFC)**
Mid-Frequency Cetaceans	**135.6 dB(MFC)**	**100.5 dB(MFC)**
Sirenians	**142.7 dB(SI)**	**107.7 dB(SI)**
Chelonians	**151.2 dB(TU)**	**139.5 dB(TU)**

This would result in the following standard safety zones for wharf piling:

- Low-Frequency Cetaceans 300 m (exclusion) / 1.5 km (observation)
- Mid-Frequency Cetaceans 100 m (exclusion) / 1.0 km (observation)
- Sirenians 100 m (exclusion) / 1.0 km (observation)
- Chelonians 300 m (exclusion) / 1.5 km (observation)

Table 10 Predicted weighted single strike SEL levels at 100 m and 300 m distance from piling in the channel.

Species Group	Weighted SELss Level at 100 m	Weighted SELss Level at 300 m
Low-Frequency Cetaceans	**158.4 dB(LFC)**	**135.0 dB(LFC)**
Mid-Frequency Cetaceans	**148.5 dB(MFC)**	**115.4 dB(MFC)**
Sirenians	**145.8 dB(SI)**	**112.7 dB(SI)**
Chelonians	**148.4 dB(TU)**	**134.2 dB(TU)**

This would result in the following standard safety zones for channel piling:

- Low-Frequency Cetaceans 300 m (exclusion) / 1.5 km (observation)
- Mid-Frequency Cetaceans 100 m (exclusion) / 1.0 km (observation)
- Sirenians 100 m (exclusion) / 1.0 km (observation)
- Chelonians 100 m (exclusion) / 1.0 km (observation)

Note that the weighted levels are slightly higher for channel piling due to the different frequency spectrum of the smaller pile source and also the different transmission loss within the shipping channel compared to the wharf. This means that the weighted levels from the 1.2 m pile are higher than for the 2.2 m pile even though the unweighted levels are ~3 dB lower.

By comparison with Table 7, Table 8 and the graphs in Appendix A it can be seen that the recommended exclusion zones from the SA Underwater Piling guidelines are below the most conservative (SEL24 hr TTS impact) distances except for:

- Low-frequency cetaceans for piling at the wharf, where the predicted distance at which the SEL_{24hr} noise level exceeds the LFC weighted TTS threshold is approximately 330 m. Applying a safety factor, the exclusion zone for piling at the wharf is recommended to be 400 m for low-frequency cetaceans.

The developed observation and exclusion zones are considered to provide adequate protection of the various marine animals reviewed, during the described works, based on the information provided along with the assumptions and limitations as described in Section 5.1. The observation and exclusion zones are summarised in Table 11 and Table 12. All impact zone distances are rounded up to the nearest 5 m (except for distances within 10 m of the pile).

As discussed previously, no safety zones are defined for fish or diving birds however the typical impact zones (for injury) have been calculated to be ~15 m from the pile for impacts to fish and ~7 m from the pile for impacts to birds, based on single strike levels (i.e. injuries to fish/birds would be expected for any individuals located within these distances from the pile). Hearing specialist fish are likely to exhibit strong avoidance behaviour within approximately 100 m of the pile. Given the small zone of impacts relative to the size of Trinity Inlet and the short-term duration of the piling works, impacts to commercial fisheries from the piling activities are expected to be insignificant.

In addition to the recommended zones, potential mitigation measures are provided in Section 5.4.1 to further reduce impacts to the marine mammals, fish, sea turtles and birds likely found in the region.

Wharf

Table 11. Recommended observational and exclusion zones summary – Piling at wharf.

Species	**Impact Thresholds and Distance of Greatest Impact**			**Recommended Estimated updated safety zones**	
	Physical Injury	**Auditory Injury**	**Behavioural**	**Shut down zone (m)**	**Observation zone (m)**
Cetaceans (low-frequency)	237 dB PK At distance <1 m from pile	PTS 219 dB PK 183 SEL* (LFC weighted) At distance ~15 m from single strike. At distance ~125 m from 24-hour exposure. TTS 213 dB PK 168 dB SEL* (LFC weighted) At distance ~30 m from single strike. At distance ~335 m from 24-hour exposure.	160 dB SPL At distance ~235 m 90 dB_{ht} N/A (no audiogram available for mysticetes)	400 m	1.5 km

<table>
<tr><th rowspan="2">Species</th><th colspan="3">Impact Thresholds and Distance of Greatest Impact</th><th colspan="2">Recommended Estimated updated safety zones</th></tr>
<tr><th>Physical Injury</th><th>Auditory Injury</th><th>Behavioural</th><th>Shut down zone (m)</th><th>Observation zone (m)</th></tr>
<tr><td>Cetaceans (mid-frequency)</td><td>237 dB PK
At distance <1 m from pile</td><td>PTS
230 dB PK
185 SEL* (MFC weighted)
At distance <1 m from single strike.
At distance ~20 m from 24-hour exposure.
TTS
224 dB PK
170 dB SEL* (MFC weighted)
At distance ~5 m from single strike.
At distance ~80 m from 24-hour exposure.</td><td>160 dB SPL
At distance ~235 m
90 dB_{ht}
At distance ~125 m (dolphins)</td><td>100 m</td><td>1.0 km</td></tr>
</table>

Species	**Impact Thresholds and Distance of Greatest Impact**			**Recommended Estimated updated safety zones**	
	Physical Injury	**Auditory Injury**	**Behavioural**	**Shut down zone (m)**	**Observation zone (m)**
Dugong	237 dB PK At distance <1 m from pile	PTS 226 dB PK 190 dB SEL* (SI weighted) At distance ~2 m from single strike. At distance ~20 m from 24-hour exposure. TTS 220 dB PK 175 dB SEL* (SI weighted) At distance ~6 m from single strike. At distance ~100 m from 24-hour exposure.	160 dB SPL At distance ~235 m 90 dB_{ht} At distance ~190 m	100 m	1.0 km
Fish	207 dB PK 203 dB SEL* (unweighted) At distance ~15 m from single strike.	TTS 186 dB SEL* (unweighted) At distance ~20 m from single strike.	90 dB_{ht} At distance ~100 m (Tuna) At distance ~20 m (Prawn) At distance ~5 m (Coral Trout larvae)	-	-

Species	Impact Thresholds and Distance of Greatest Impact			Recommended Estimated updated safety zones	
	Physical Injury	Auditory Injury	Behavioural	Shut down zone (m)	Observation zone (m)
Sea turtles	207 dB PK 210 dB SEL* (unweighted) At distance ~15 m from single strike. At distance ~20 m from 24-hour exposure.	PTS 232 dB PK 204 SEL* (TU weighted) At distance ~2 m from single strike. At distance ~20 m from 24-hour exposure. TTS 226 dB PK 189 dB SEL* (TU weighted) At distance ~7 m from single strike. At distance ~50 m from 24-hour exposure.	175 dB SPL At distance ~85 m	300 m	1.5 km
Birds (diving)	190 dB SEL* (unweighted) At distance ~7 m from single strike.	-	-	-	-

*Note SEL criteria here apply to either single strike SEL (i.e. entire noise dose delivered by single strike) or cumulative SEL24hr (i.e. noise dose delivered over multiple strikes).

Channel

Table 12. Recommended observational and exclusion zones summary – Piling in channel.

Species	Impact Thresholds and Distance of Greatest Impact			Recommended Estimated updated safety zones	
	Physical Injury	**Auditory Injury**	**Behavioural**	**Shut down zone (m)**	**Observation zone (m)**
Cetaceans (low-frequency)	237 dB PK At distance <1 m from pile	PTS 219 dB PK 183 SEL* (LFC weighted) At distance ~15 m from single strike. At distance ~115 m from 24-hour exposure. TTS 213 dB PK 168 dB SEL* (LFC weighted) At distance ~35 m from single strike. At distance ~240 m from 24-hour exposure.	160 dB SPL At distance ~190 m 90 dB_{ht} N/A (no audiogram available for mysticetes)	300 m	1.5 km

Species	**Impact Thresholds and Distance of Greatest Impact**			**Recommended Estimated updated safety zones**	
	Physical Injury	**Auditory Injury**	**Behavioural**	**Shut down zone (m)**	**Observation zone (m)**
Cetaceans (mid-frequency)	237 dB PK At distance <1m from pile	PTS 230 dB PK 185 SEL* (MFC weighted) At distance <1 m from single strike. At distance ~20 m from 24-hour exposure. TTS 224 dB PK 170 dB SEL* (MFC weighted) At distance ~7 m from single strike. At distance ~60 m from 24-hour exposure.	160 dB SPL At distance ~190 m 90 dB_{ht} At distance ~180 m (dolphins)	100 m	1.0 km

Species	Impact Thresholds and Distance of Greatest Impact			Recommended Estimated updated safety zones	
	Physical Injury	**Auditory Injury**	**Behavioural**	**Shut down zone (m)**	**Observation zone (m)**
Dugong	237 dB PK At distance <1 m from pile	PTS 226 dB PK 190 dB SEL* (SI weighted) At distance ~2 m from single strike. At distance ~20 m from 24-hour exposure. TTS 220 dB PK 175 dB SEL* (SI weighted) At distance ~8 m from single strike. At distance ~100 m from 24-hour exposure.	160 dB SPL At distance ~190 m 90 dB_{ht} At distance ~240 m	100 m	1.0 km
Fish	207 dB PK 203 dB SEL* (unweighted) At distance ~15 m from single strike.	TTS 186 dB SEL* (unweighted) At distance ~10 m from single strike.	90 dB_{ht} At distance ~110 m (Tuna) At distance ~15 m (Prawn) At distance ~10 m (Coral Trout larvae)	-	-

Species	**Impact Thresholds and Distance of Greatest Impact**			**Recommended Estimated updated safety zones**	
	Physical Injury	**Auditory Injury**	**Behavioural**	**Shut down zone (m)**	**Observation zone (m)**
Sea turtles	207 dB PK 210 dB SEL* (unweighted) At distance ~15 m from single strike. At distance ~15 m from 24-hour exposure.	PTS 232 dB PK 204 SEL* (TU weighted) At distance <1 m from single strike. At distance ~10 m from 24-hour exposure. TTS 226 dB PK 189 dB SEL* (TU weighted) At distance ~10 m from single strike. At distance ~25 m from 24-hour exposure.	175 dB SPL At distance ~100 m	100 m	1.0 km
Birds (diving)	190 dB SEL* (unweighted) At distance ~7 m from single strike.	-	-	-	-

*Note SEL criteria here apply to either single strike SEL (i.e. entire noise dose delivered by single strike) or cumulative SEL24hr (i.e. noise dose delivered over multiple strikes).

5.4.1 Additional management and mitigation recommendations

There is no published Commonwealth guidance on underwater noise from pile driving. However, the Government of South Australia (SA) published the Underwater Piling Noise Guidelines in 2012, which are adapted from EPBC Policy Statement 2.1 (DEWHA 2008). The Guidelines provide practical management and mitigation measures for the purpose of minimising the risk of injury to occur in marine mammals within the vicinity of piling activities, consistent with international good practice (DPTI 2012).

Standard management and mitigation procedures outlined in the DPTI (2012) Guidelines include:

- Safety zones, including observation and exclusion zones (sized by comparing expected received noise levels with defined noise exposure thresholds)
- 30-minute pre-start-up visual observations
- 10-minute soft-start procedures
- Standby and shut-down procedures
- Compliance and sighting reports.

Additional management and mitigation measures are recommended if the piling work may have, or is likely to have, a significant impact on any Matters of National Environmental Significance (MNES) under the Commonwealth EPBC Act. Example additional measures include:

- Noise monitoring during early piling works to validate/calibrate predictions
- Increased safety zones
- Use of qualified marine mammal observers
- Operational procedures during night time or poor visibility
- Use of a spotter vessel or aircraft if clear observations cannot be made from land or the piling rig
- Passive acoustic monitoring.
- Bubble curtains to reduce the severity of the energy of the sounds caused by the driving of the piles.

6 Peer Review Comments

Peer review comments are provided in Appendix B.

7 References

Buehler D, Oestman R, Reyff J, Pommerenck K, Mitchell B (2015) Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. Caltrans Report No CTHWANP-RT-15-306.01.01

Crowell, S. (2016) Measuring In-Air and Underwater Hearing in Seabirds. The Effects of Noise on Aquatic Life II, Advances in Experimental Medicine and Biology 875, DOI 10.1007/978-1-4939-2981-8_144

Dahl, P. H., de Jong, C. A. F., and Popper, A. N. 2015. The Underwater Sound Field from Impact Pile Driving and Its Potential Effects on Marine Life. Acoustics Today, Spring 2015, vol 11(2), pp 18-25.

Dale JJ, Gray MD, Popper AN, Rogers PH and Block BA (2015) Hearing thresholds of swimming Pacific bluefin tuna Thunnus orientalis. J Comp Physiol A DOI 10.1007/s00359-015-0991-x

Denes, S. L., G.J. Warner, M.E. Austin, and A.O. MacGillivray. 2016. Hydroacoustic Pile Driving Noise Study – Comprehensive Report. Document 001285, Version 2.0. Technical report by JASCO Applied Sciences for Alaska Department of Transportation & Public Facilities.

Diederichs, A., G. Nehls, M. Dähne, S. Adler, S. Koschinski, U. Verfuß. 2008. Methodologies for measuring and assessing potential changes in marine mammal behaviour, abundance or distribution arising from the construction, operation and decommissioning of offshore windfarms. BioConsult SH report to COWRIE Ltd.

DPTI SA (2012) Underwater Piling Noise Guidelines, Government of South Australia Department of Transport and Infrastructure.

Finneran JJ (2016) Auditory Weighting Functions and TTS/PTS Exposure Functions for Marine Mammals Exposed to Underwater Noise. SSC Pacific Technical Report 3026.

Finneran, J.J., E. Henderson, D.S. Houser, K. Jenkins, S. Kotecki, and J. Mulsow. 2017. Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 p. https://apps.dtic.mil/dtic/tr/fulltext/u2/a561707.pdf.

Hastings MC and Popper AN (2005) Effects of Sound on Fish, California Department of Transportation Contract No. 43A0139

Johansen, S. Larsen, O. N., Christensen-Dalsgaard, J. Huulvej, T. K., Jensen, K., Wahlber, M. (2016) In-Air and Underwater Hearing in the Great Cormorant (Phalacrocorax carbo sinensis). The Effects of Noise on Aquatic Life II, Advances in Experimental Medicine and Biology 875, DOI 10.1007/978-1-4939-2981-8_61

Köller J. et al., 2006 Offshore Wind Energy, Research on Environmental Impacts. Springer Science & Business Media.

Li, Z., and C.R. McPherson. 2018. Rio Tinto Cape Lambert Port A Marine Structures Refurbishment Project: Acoustic Modelling of Impact Pile Driving for Assessing Marine Fauna Sound Exposures. Document 01699, Version 1.0. Technical report by JASCO Applied Sciences for Environmental Resources Management.

Lovell et al (2005) The hearing abilities of the prawn Palaemon serratus. Comparative Biochemistry and Physiology Part A 140 pp89-100

MacGillivray A, Warner GR, Racca R and O'Neill C (2011) Tappan Zee Bridge Construction Hydroacoustic Noise Modelling: Final Report. Report by JASCO Applied Sciences for AECOM 63 pp.

MacGillivray, A. O. 2015. A model for underwater sound levels generated by marine impact pile driving, Proceedings of Meetings on Acoustics, Vol. 20 045008 (2015).

Martin, B., MacGillivray, A., MacDonnell, J., Vallarta, J., Deveau, T., Warner, G., Zeddies, D., Mouy, X., and Krebs, J. (2012). "Underwater Acoustic Monitoring of the Tappan Zee. Bridge Pile Installation Demonstration Project: Comprehensive Report," (Technical report for AECOM by JASCO Applied Sciences), p. 139.

McPherson, C., H. Yurk, G. McPherson, R. Racca, and P. Wulf (2017) Great barrier Reef Underwater Noise Guidelines: Discussion and options paper. Document 001130, version 1.0. Technical report by JASCO Applied Sciences for the Great Barrier Reef marine park Authority, Townsville.

Nedwell JR, Edwards B, Turnpenny AWH and Gordon J (2004) Fish and Marine Mammal Audiograms: A summary of available information. Subacoustech Report ref: 534R0214.

Nedwell JN, Lovell J and Turnpenny AWH (2005) Experimental validation of a species-specific behavioural impact metric for underwater noise.

Nedwell J. R., Parvin S. J., Edwards B., Workman R., Brooker A. G. and Kynoch J. E., Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters. Subacoustech Report No. 544R0738 to COWRIE Ltd. ISBN: 978-0-9554279-5-4.

Nehls, G., K. Betke, S. Koschinski, and K. Lüdemann (2008). Sources of underwater noise and their implications on marine wildlife - with special emphasis on the North Sea and the Baltic Sea. UBA FKZ 206 25 2021. German Federal Environment Agency (Umweltbundesamt - UBA). Dessau, Germany. 126 pp.

Parnum, B., Colman, J., Lucke, K. (2018) Potential Impact of Pile-driving Noise at Cape Lambert: A Review of the Literature and International Regulations, 2018 Addendum (version 2.0) Rio Tinto Services Ltd, Doc no: 0478023

Petersen D and Jurevicius D (2009) Environmental noise impact of a major transport corridor on a barramundi fish farm. ACOUSTICS 2009 Adelaide.

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, et al. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/SC1.4 TR-2014. SpringerBriefs in Oceanography. ASA Press and Springer. https://doi.org/10.1007/978-3-319-06659-2.

Popper AN and Hawkins AD (2019) An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of Fish Biology 2019 pp1-22

Ports North (2014) Cairns Shipping Development Project Draft Environmental Impact Statement

Ports North (2017) Cairns Shipping Development Project Revised Draft Environmental Impact Statement

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33(4): 411-521. https://doi.org/10.1080/09524622.2008.9753846.

Southall, B.L., J.J. Finneran, C. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 45(2): 125-232. https://doi.org/10.1578/AM.45.2.2019.125.

Wright KJ, Higgs DM, Belanger AJ and Leis JM (2008) Auditory and olfactory abilities of larvae of the Indo-Pacific coral trout Plectropomus leopardus (Lacepede) at settlement. Journal of Fish Biology 72 2543-2556. doi:10.1111/j.1095-8649.2008.01864.x

Yelverton JT, Richmond DR, Fletcher ER, and Jones RK (1973) Safe Distances from Underwater Explosions for Mammals and Birds. Defense Nuclear Agency Washington DC.

National Marine Fisheries Service. 2018. 2018 Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

Appendix A

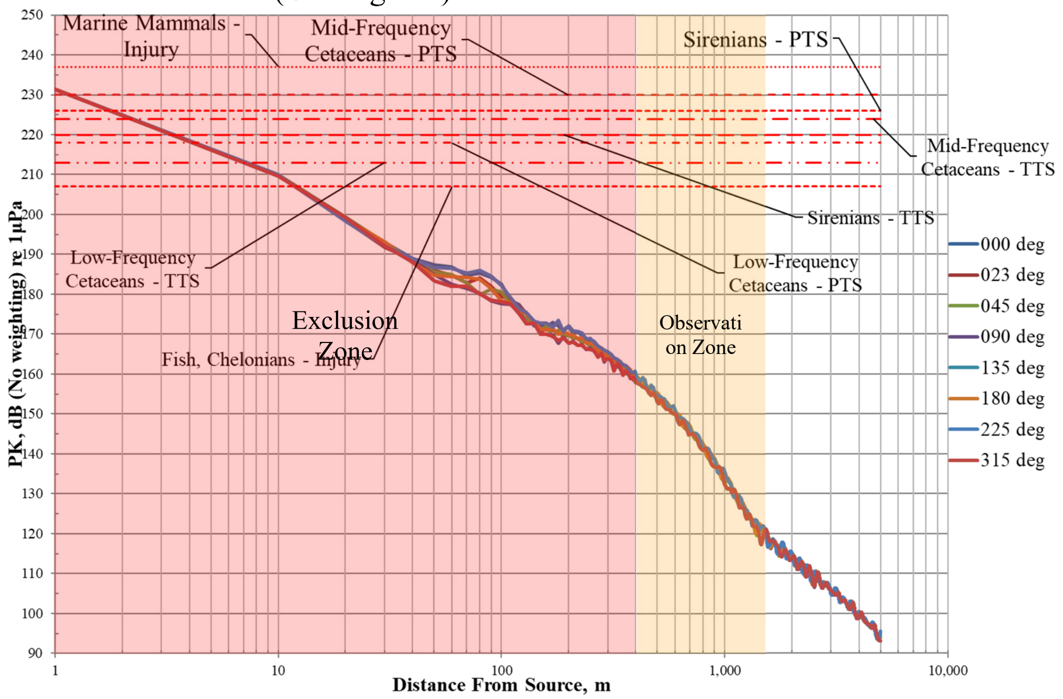
Underwater Noise Predictions

A1 Wharf Piling

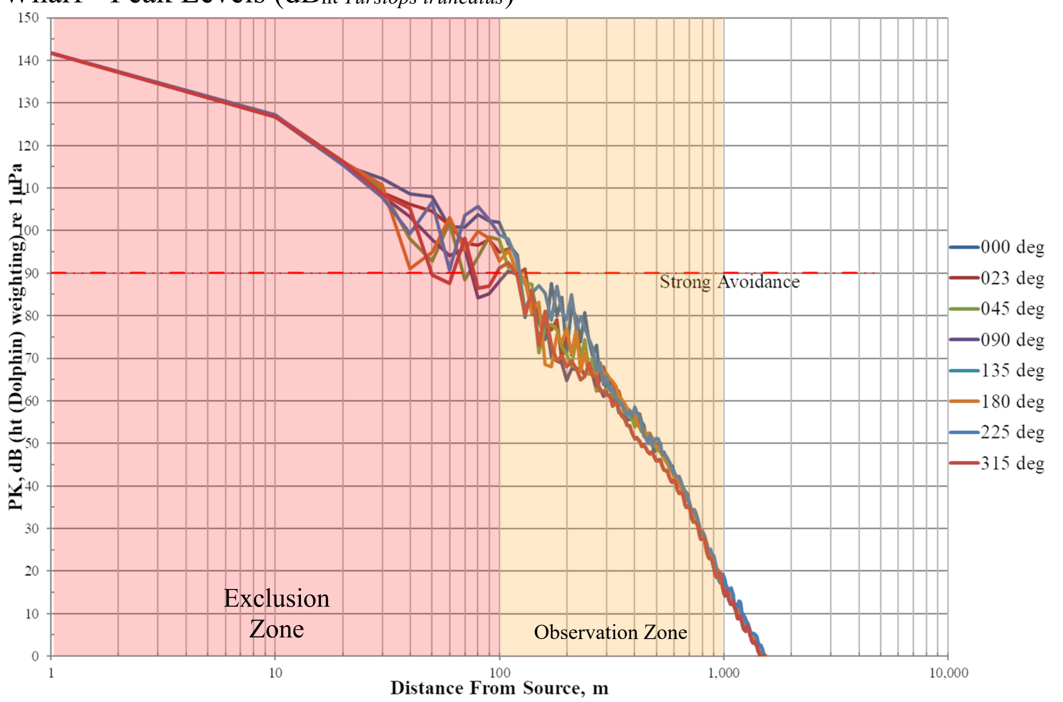
Revised predicted underwater noise levels for piling at the wharf are presented in Figure 21. The exclusion and observation zones are shown on each plot. For each plot the most stringent (i.e. largest) zones relative to the species criteria on the plot are shown.

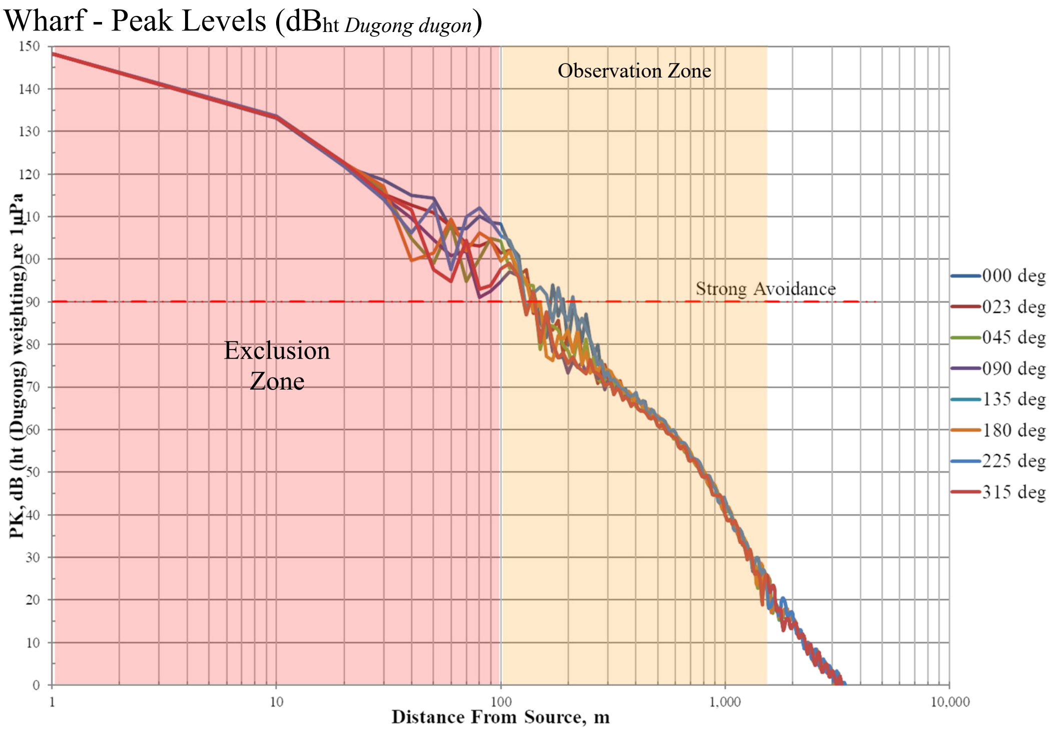
Figure 21: Revised underwater noise predictions – piling at wharf

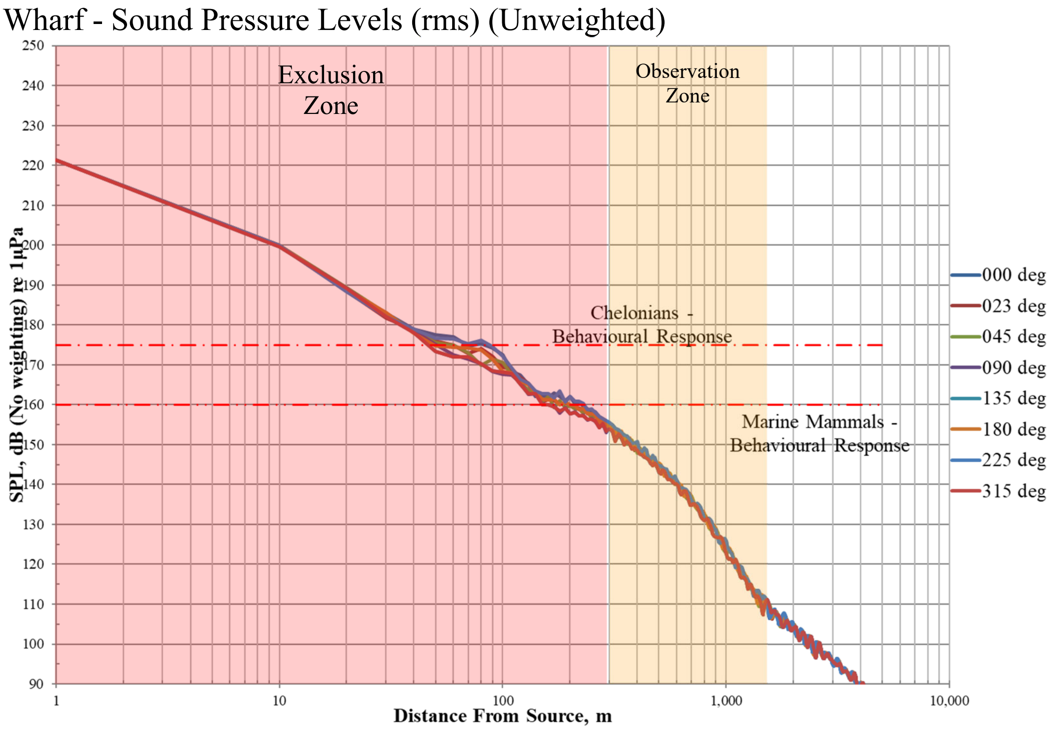
Wharf - Peak Levels (Unweighted)

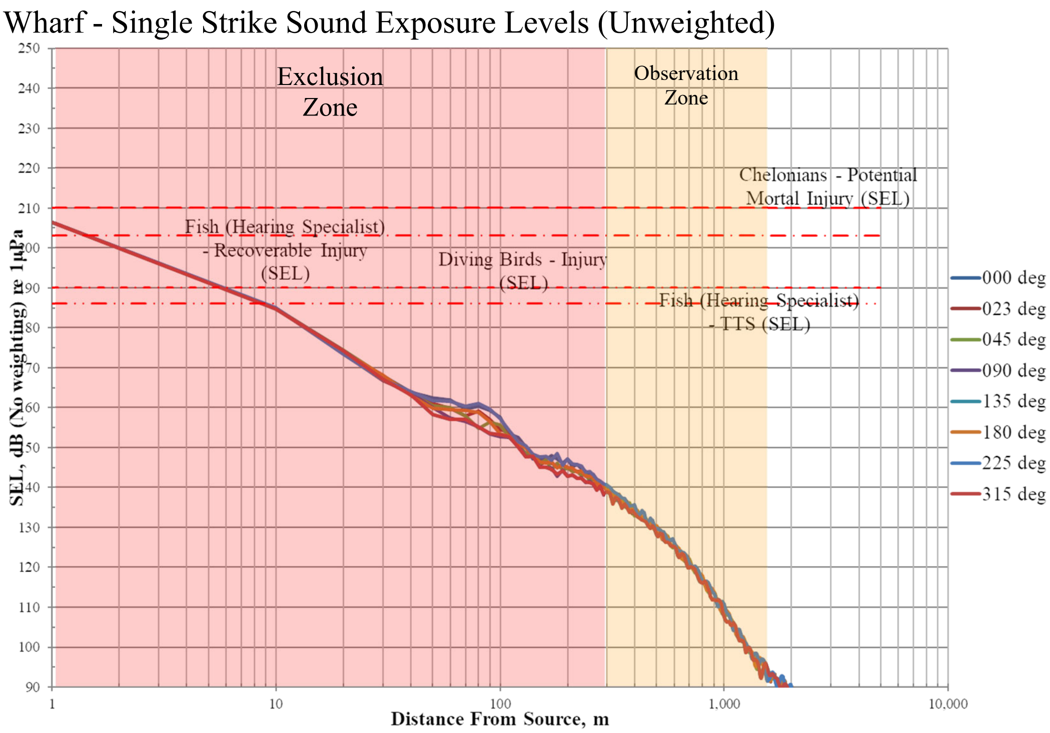


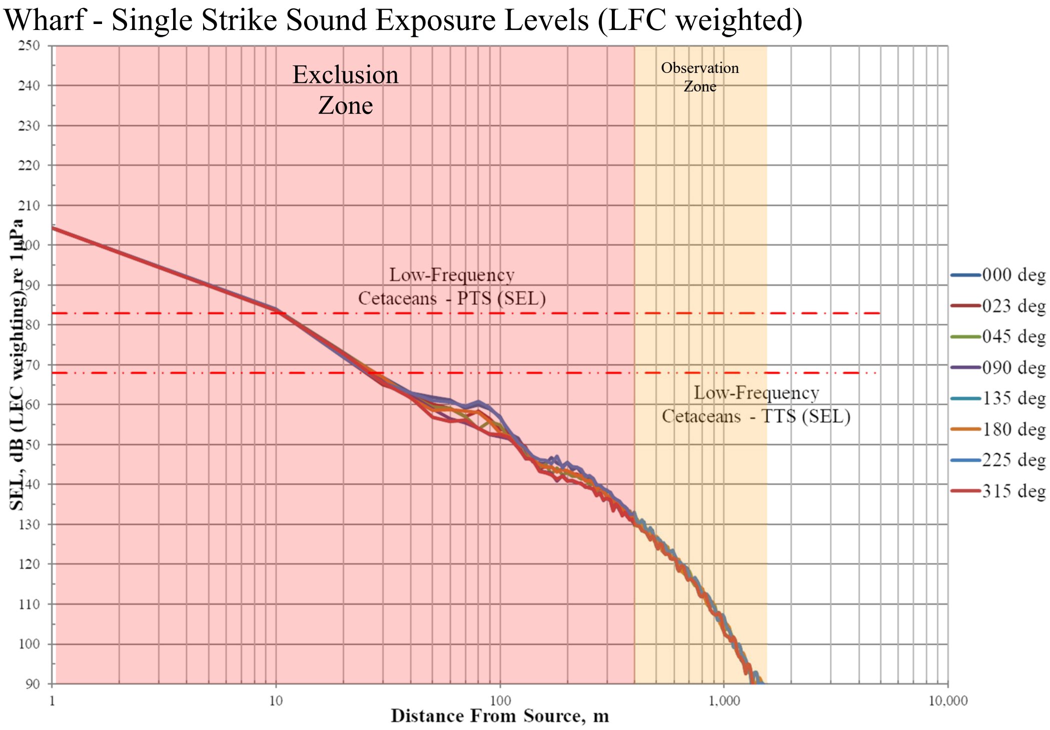
Wharf - Peak Levels (dBht *Tursiops truncatus*)

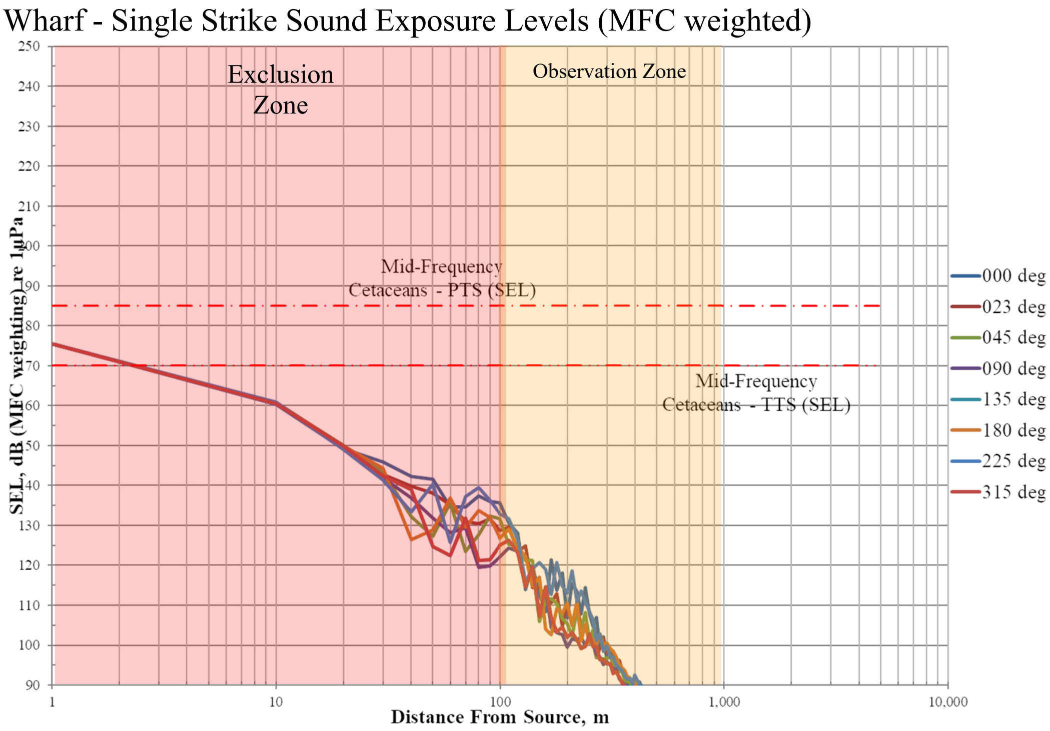


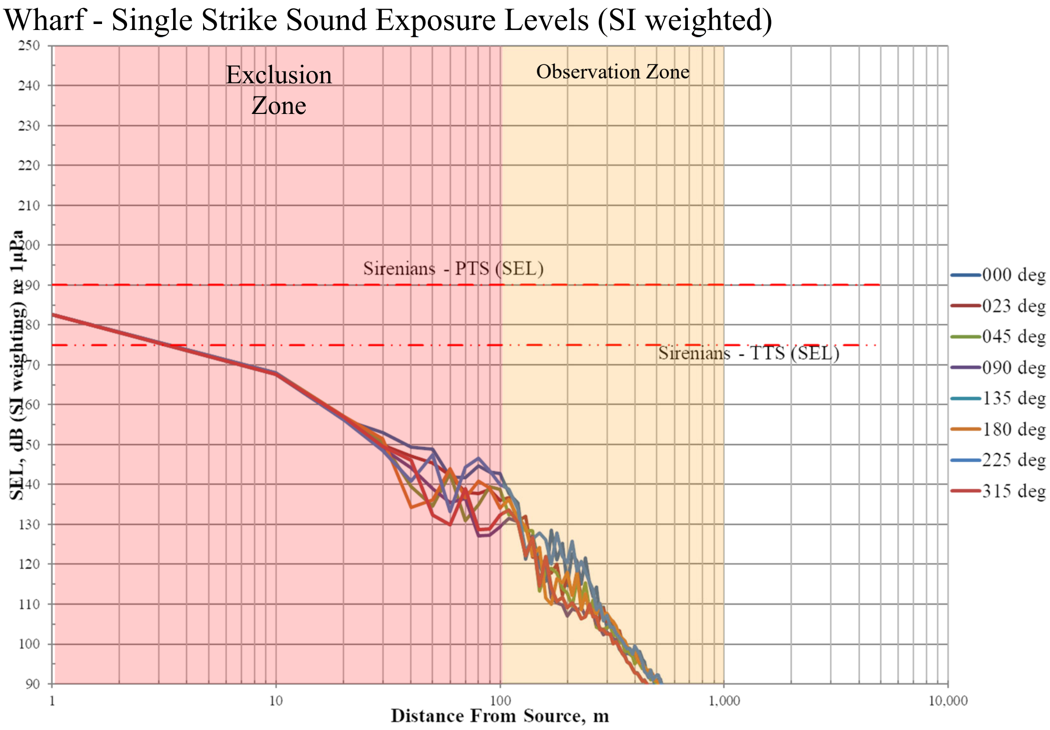

Wharf - Peak Levels (dBht *Dugong dugon*)
Observation Zone
Strong Avoidance
Exclusion Zone
PK, dB (ht (Dugong) weighting) re 1µPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

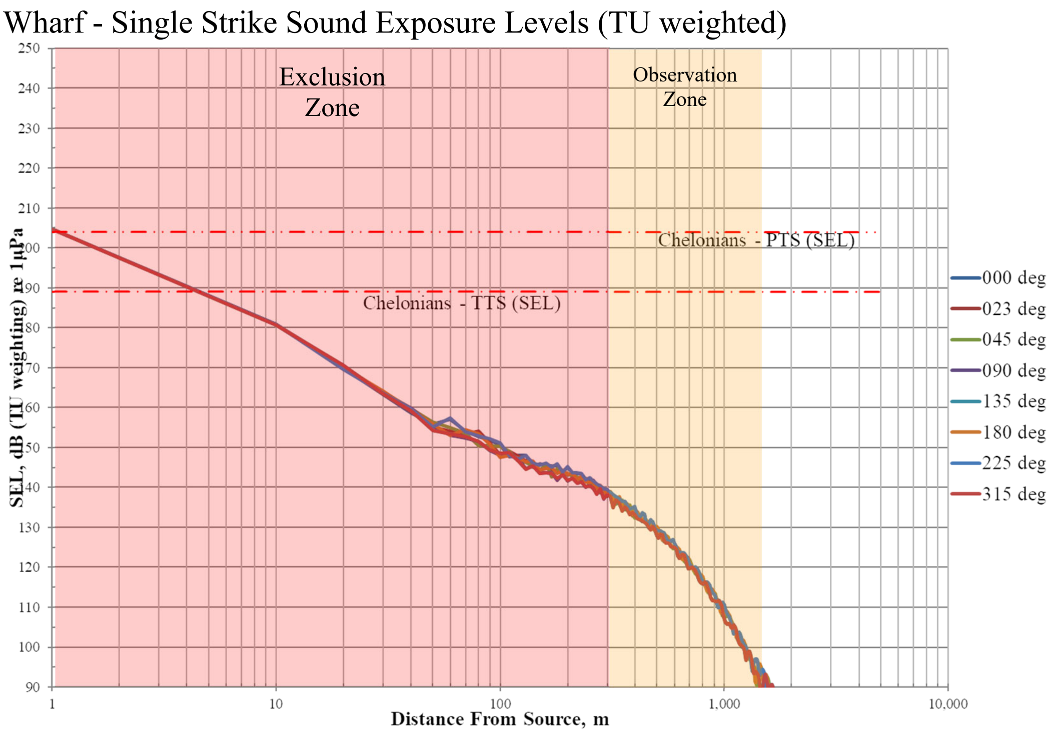

Wharf - Sound Pressure Levels (rms) (Unweighted)
Exclusion Zone
Observation Zone
Chelonians - Behavioural Response
Marine Mammals - Behavioural Response
SPL, dB (No weighting) re 1µPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

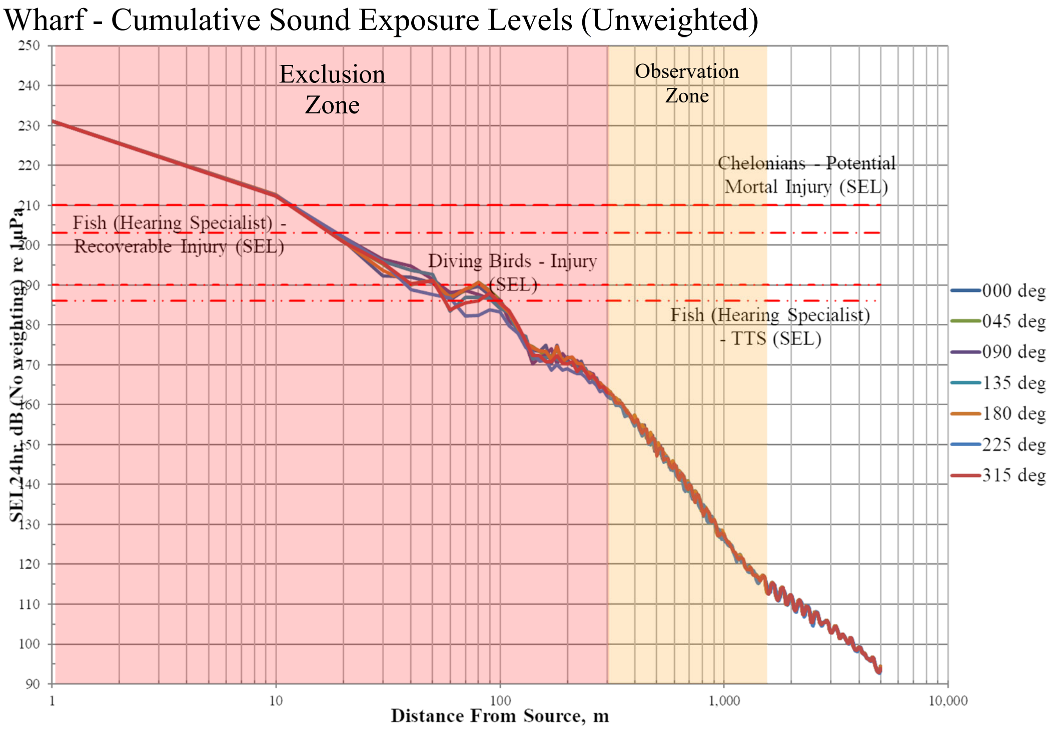

Wharf - Single Strike Sound Exposure Levels (Unweighted)
Exclusion Zone
Observation Zone
Chelonians - Potential Mortal Injury (SEL)
Fish (Hearing Specialist) - Recoverable Injury (SEL)
Diving Birds - Injury (SEL)
Fish (Hearing Specialist) - TTS (SEL)
SEL, dB (No weighting) re 1μPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

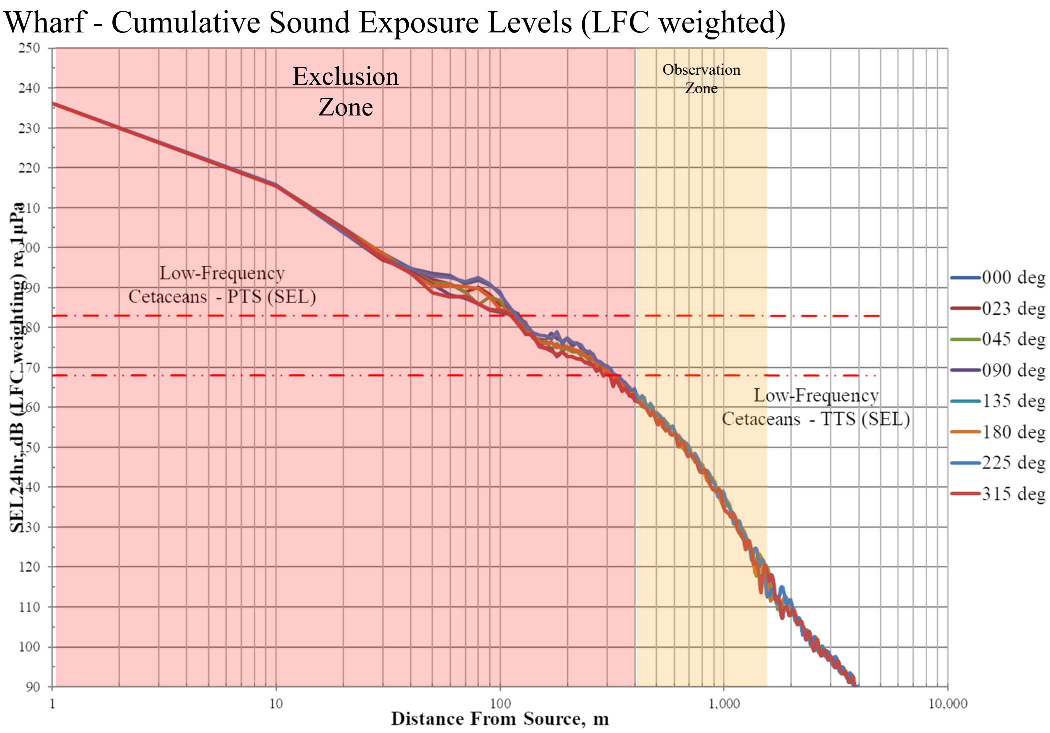

Wharf - Single Strike Sound Exposure Levels (LFC weighted)
Exclusion Zone
Observation Zone
Low-Frequency Cetaceans - PTS (SEL)
Low-Frequency Cetaceans - TTS (SEL)
SEL, dB (LFC weighting) re 1μPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

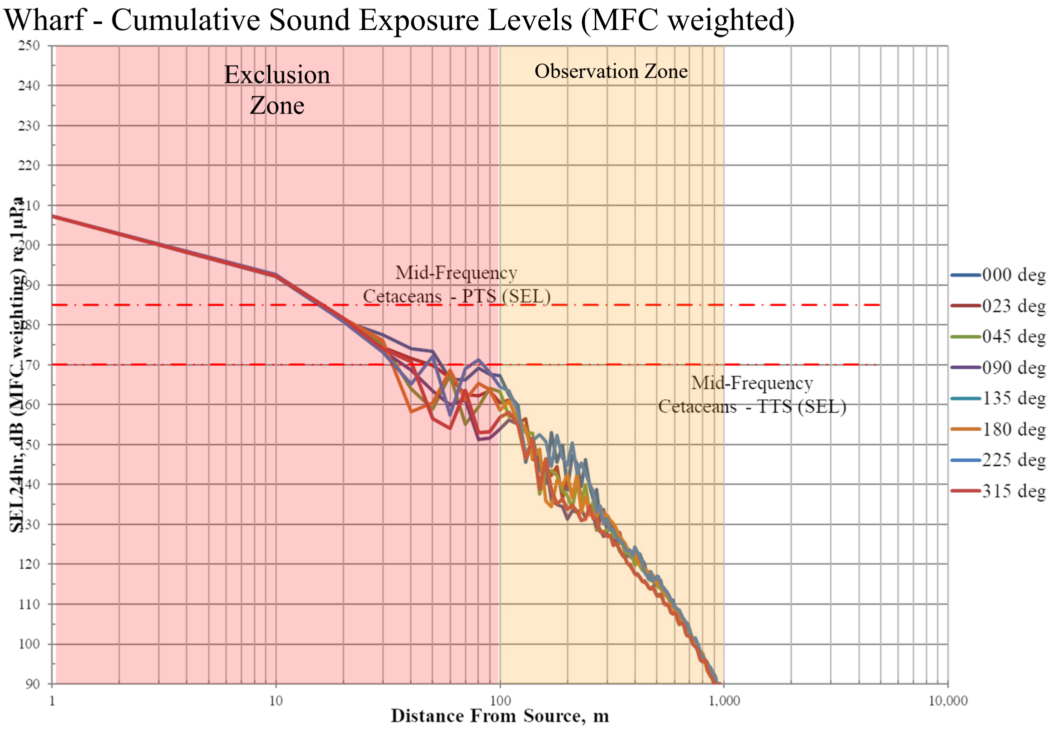

Wharf - Single Strike Sound Exposure Levels (MFC weighted)
Exclusion Zone
Observation Zone
Mid-Frequency Cetaceans - PTS (SEL)
Mid-Frequency Cetaceans - TTS (SEL)
SEL, dB (MFC weighting) re 1μPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg


Wharf - Single Strike Sound Exposure Levels (SI weighted)
Exclusion Zone
Observation Zone
Sirenians - PTS (SEL)
Sirenians - TTS (SEL)
SEL, dB (SI weighting) re 1μPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

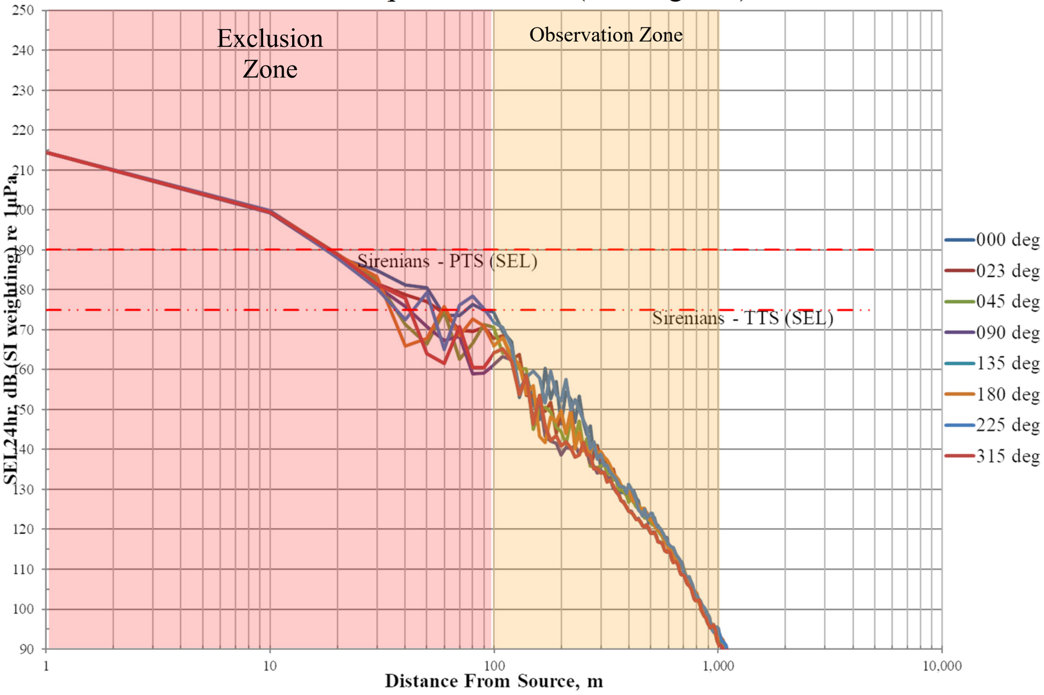

Wharf - Single Strike Sound Exposure Levels (TU weighted)
Exclusion Zone
Observation Zone
Chelonians - PTS (SEL)
Chelonians - TTS (SEL)
SEL, dB (TU weighting) re 1µPa
Distance From Source, m
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg


Wharf - Cumulative Sound Exposure Levels (Unweighted)
Exclusion Zone
Observation Zone
Chelonians - Potential Mortal Injury (SEL)
Fish (Hearing Specialist) - Recoverable Injury (SEL)
Diving Birds - Injury (SEL)
Fish (Hearing Specialist) - TTS (SEL)
SEL24hr, dB (No weighting) re 1µPa
Distance From Source, m
000 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

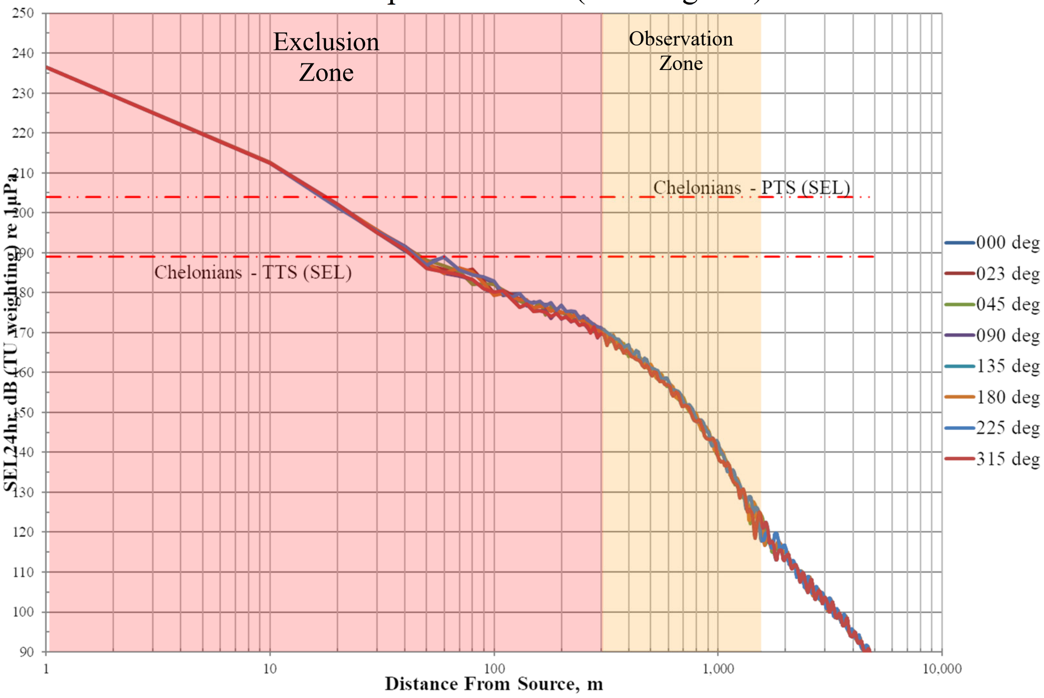

Wharf - Cumulative Sound Exposure Levels (LFC weighted)
Exclusion Zone
Observation Zone
Low-Frequency Cetaceans - PTS (SEL)
Low-Frequency Cetaceans - TTS (SEL)
SEL24hr, dB (LFC weighting) re 1µPa
Distance From Source, m
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
1
10
100
1,000
10,000
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg


Wharf - Cumulative Sound Exposure Levels (MFC weighted)
Exclusion Zone
Observation Zone
Mid-Frequency Cetaceans - PTS (SEL)
Mid-Frequency Cetaceans - TTS (SEL)
SEL24hr, dB (MFC weighting) re 1µPa
Distance From Source, m
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
1
10
100
1,000
10,000
000 deg
023 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

Wharf - Cumulative Sound Exposure Levels (SI weighted)



Wharf - Cumulative Sound Exposure Levels (TU weighted)

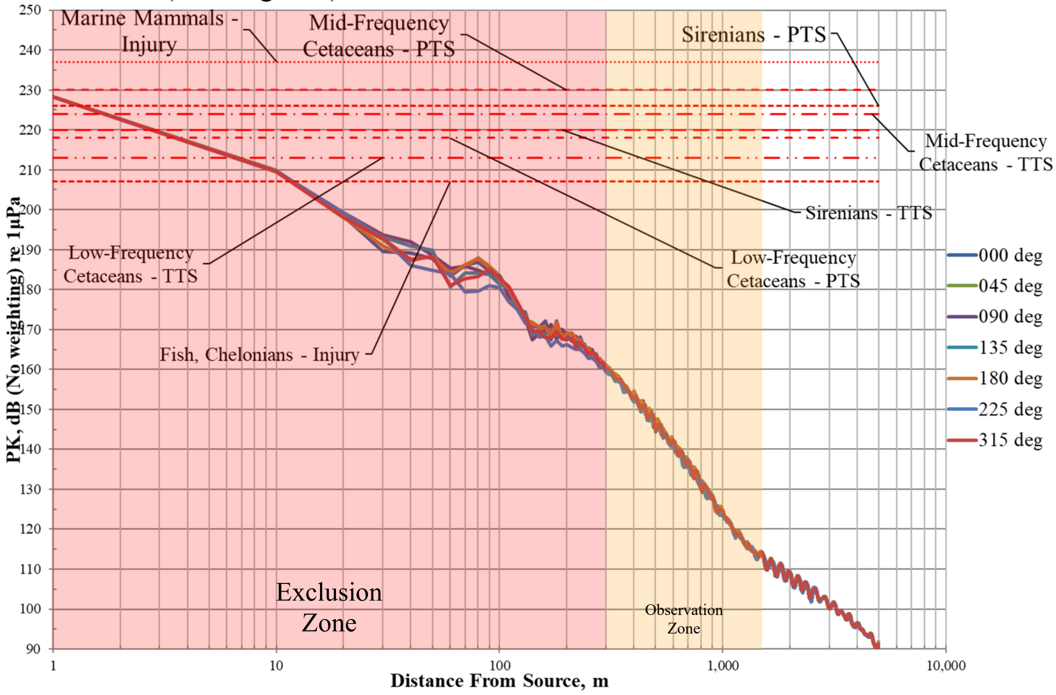


A2 Channel Piling

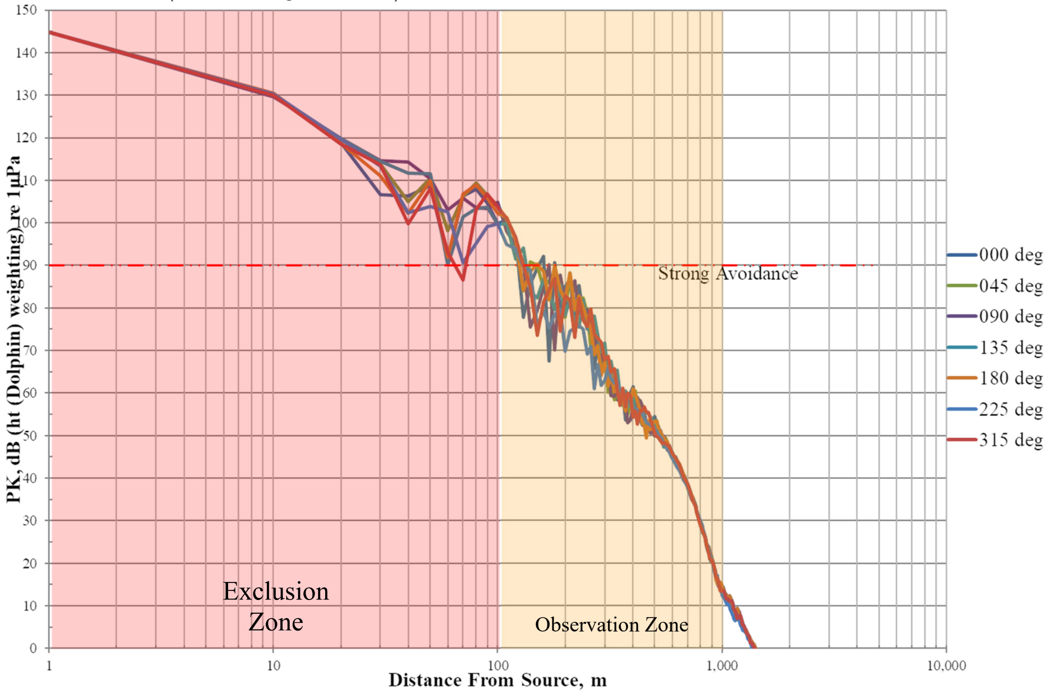
Revised predicted underwater noise levels for piling within the shipping channel are presented in Figure 22. The exclusion and observation zones are shown on each plot. For each plot the most stringent (i.e. largest) zones relative to the species criteria on the plot are shown.

Figure 22: Revised underwater noise predictions – piling in shipping channel (relocation of navigational aids)

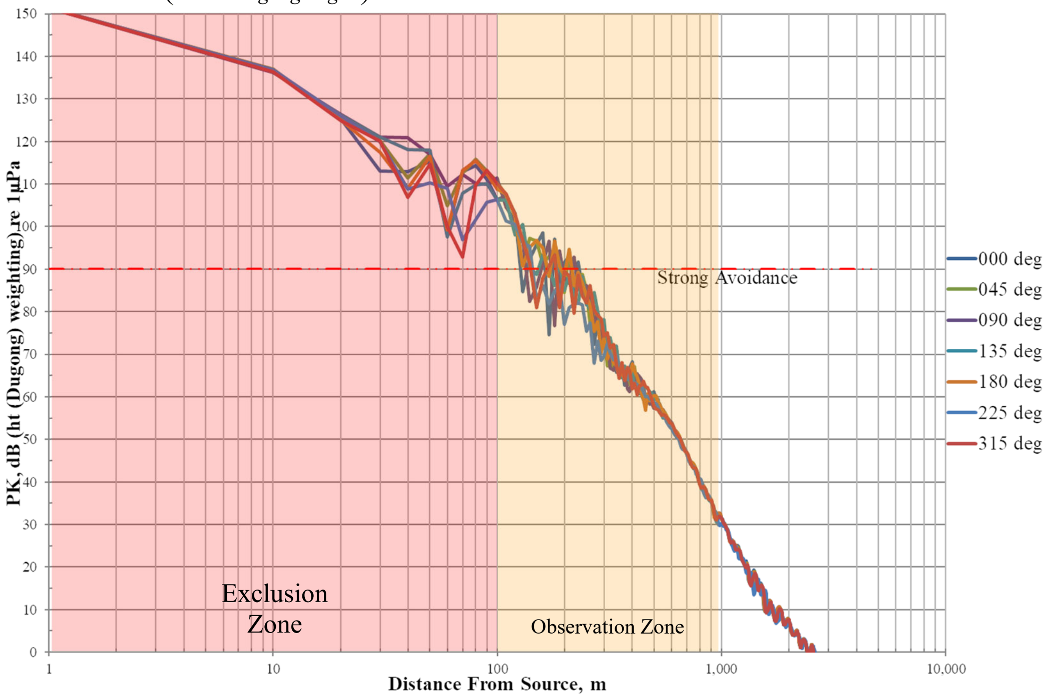
Peak Levels (Unweighted)



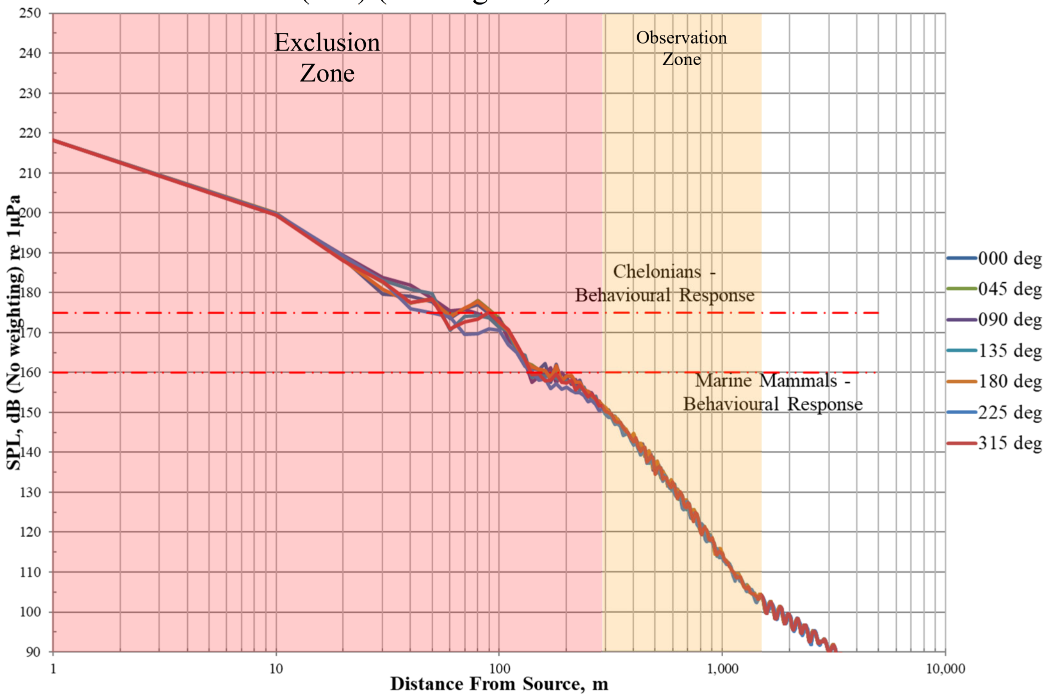
Peak Levels (dBht *Tursiops truncatus*)

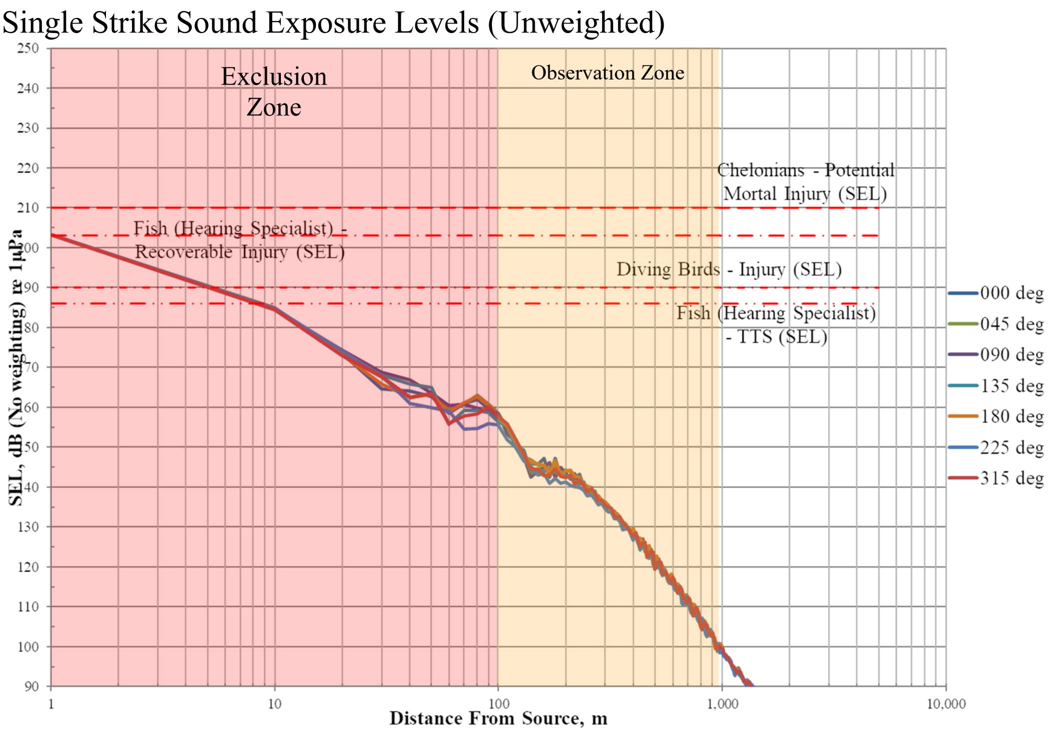


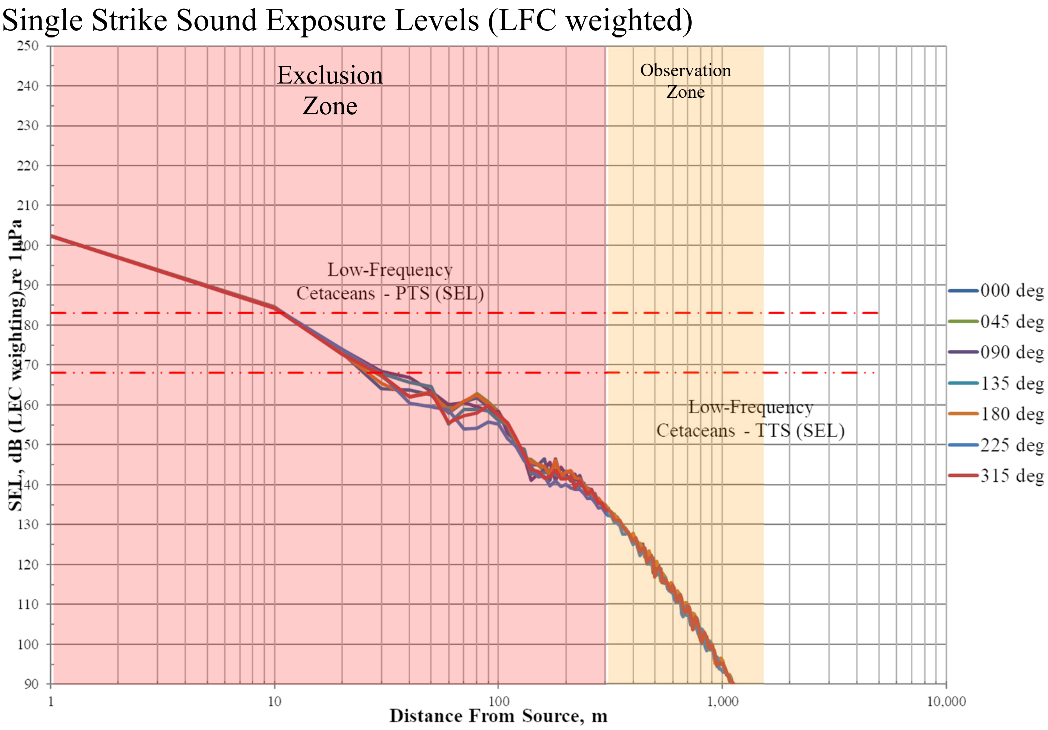
Peak Levels (dBht *Dugong dugon*)



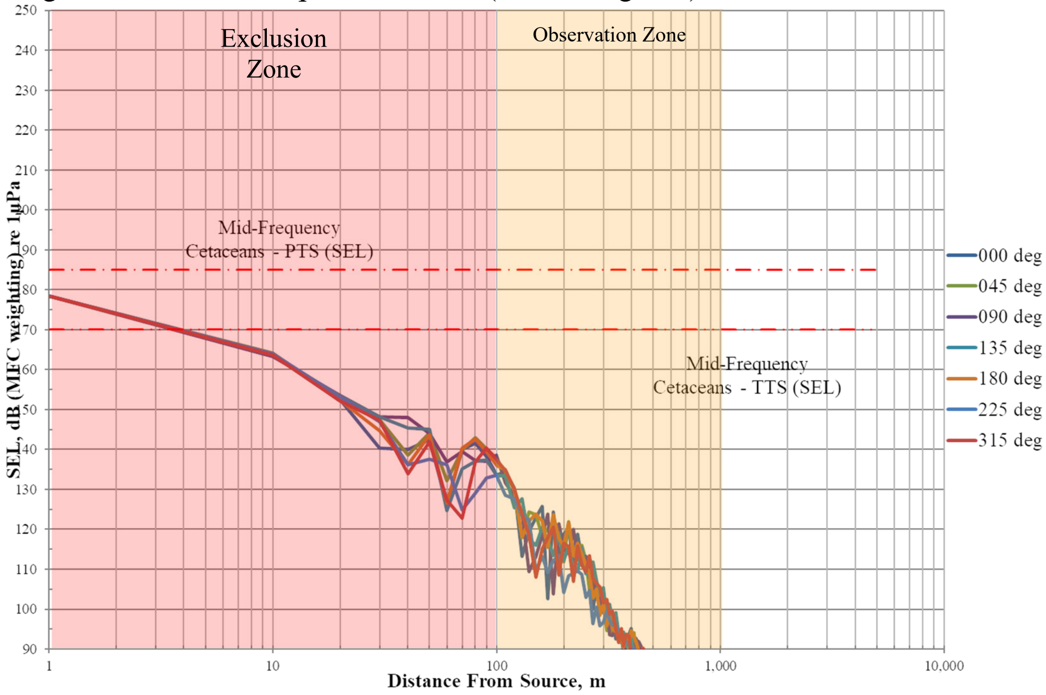
Sound Pressure Levels (rms) (Unweighted)



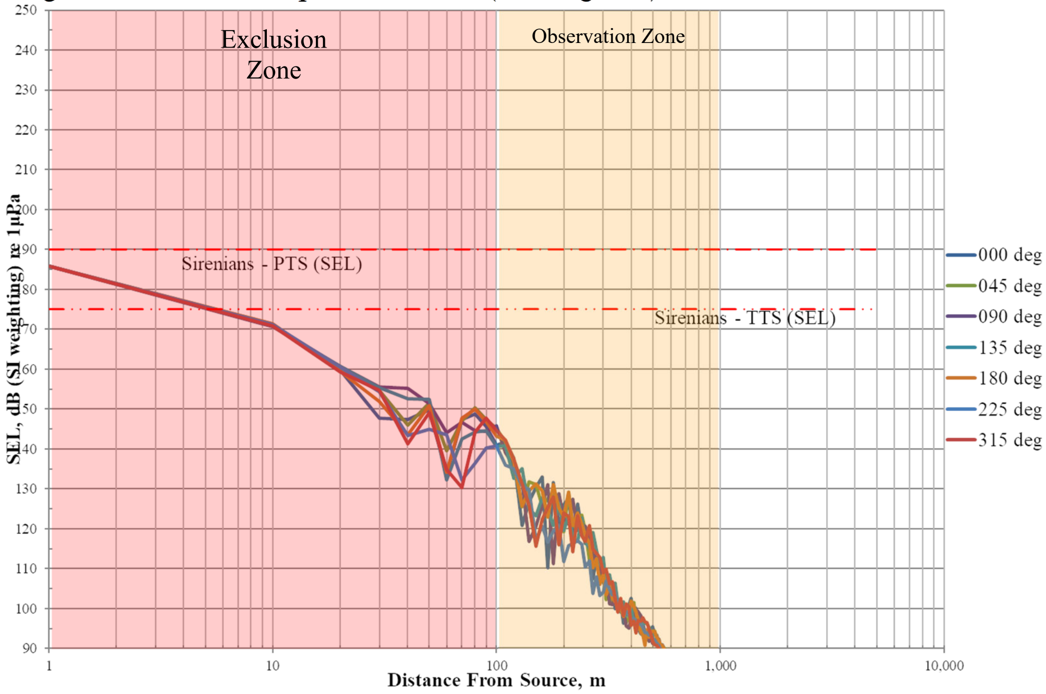

Single Strike Sound Exposure Levels (Unweighted)
Exclusion Zone
Observation Zone
Chelonians - Potential Mortal Injury (SEL)
Fish (Hearing Specialist) - Recoverable Injury (SEL)
Diving Birds - Injury (SEL)
Fish (Hearing Specialist) - TTS (SEL)
SEL, dB (No weighting) re 1μPa
Distance From Source, m
000 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

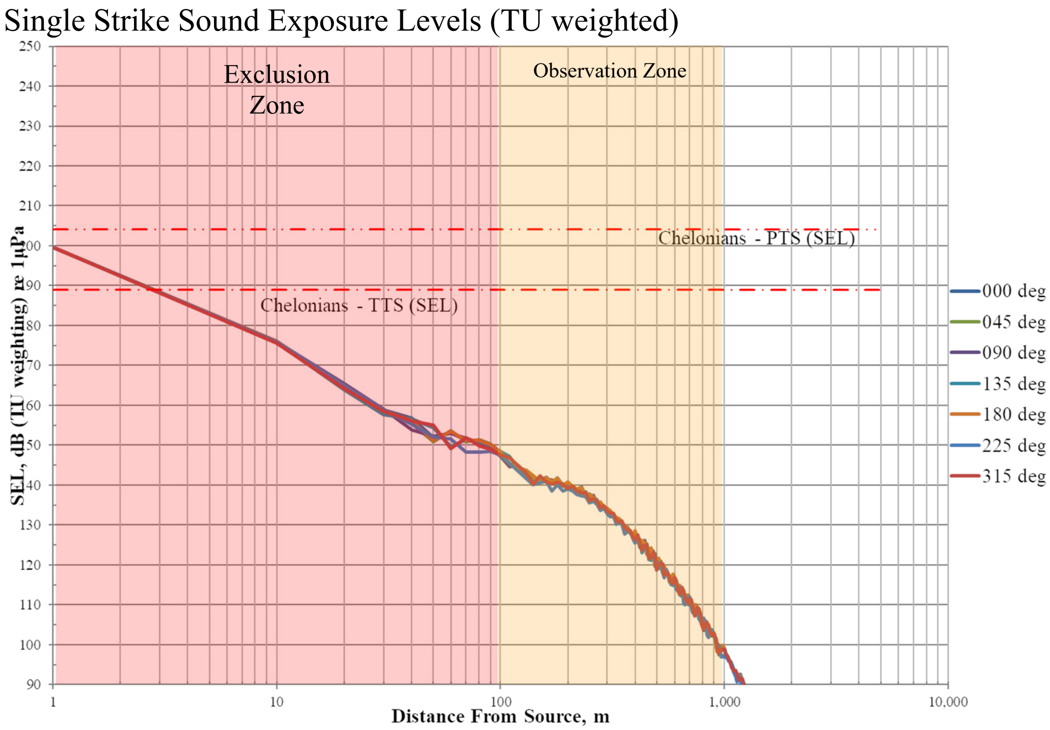

Single Strike Sound Exposure Levels (LFC weighted)
Exclusion Zone
Observation Zone
Low-Frequency Cetaceans - PTS (SEL)
Low-Frequency Cetaceans - TTS (SEL)
SEL, dB (LFC weighting) re 1μPa
Distance From Source, m
000 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

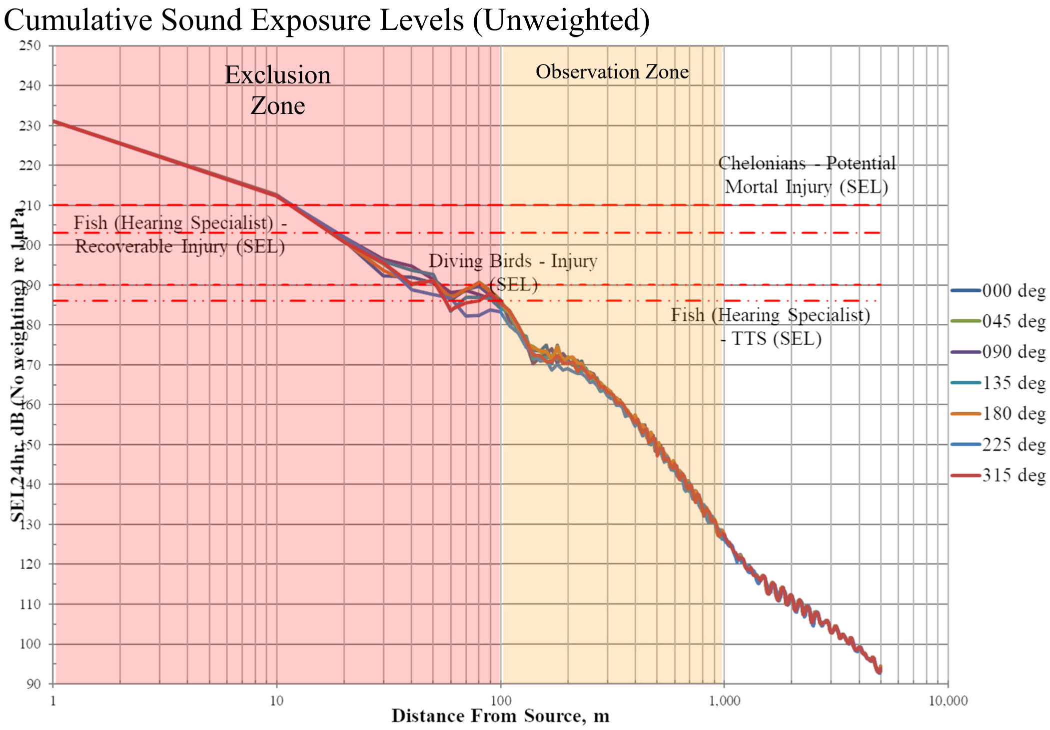
Single Strike Sound Exposure Levels (MFC weighted)



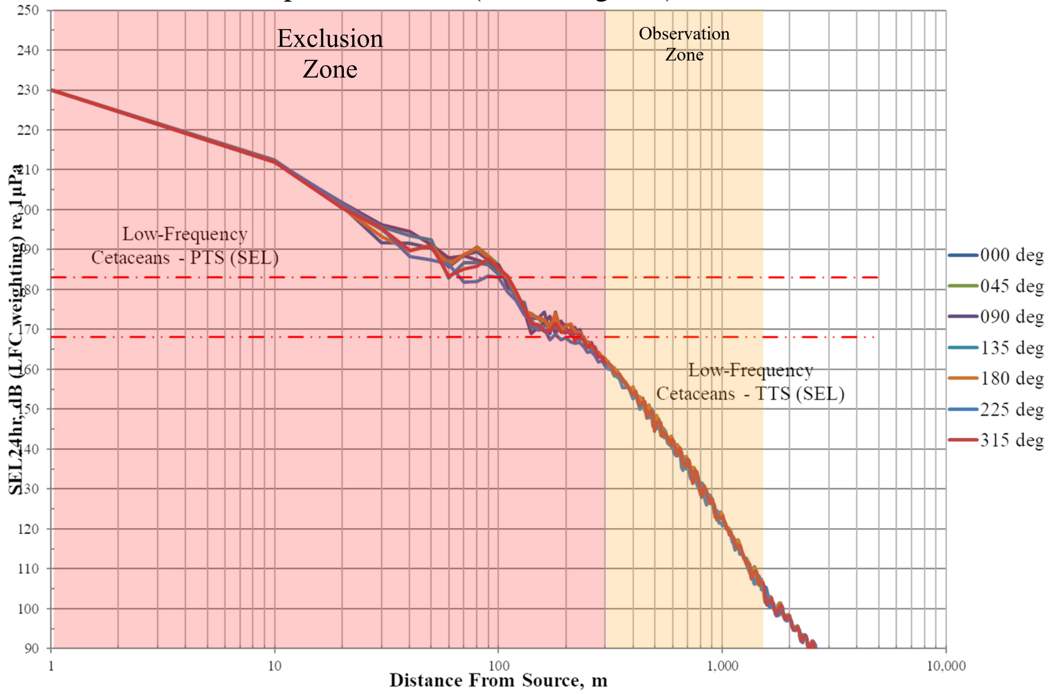
Single Strike Sound Exposure Levels (SI weighted)



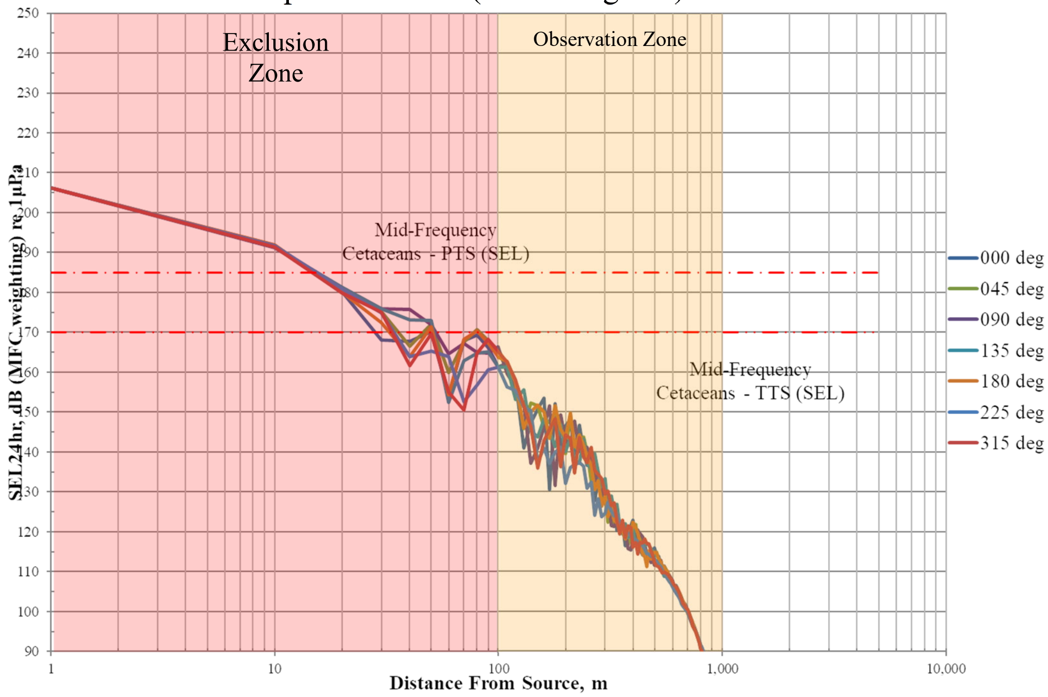

Single Strike Sound Exposure Levels (TU weighted)
Exclusion Zone
Observation Zone
Chelonians - PTS (SEL)
Chelonians - TTS (SEL)
SEL, dB (TU weighting) re 1µPa
Distance From Source, m
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
1
10
100
1,000
10,000
000 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg


Cumulative Sound Exposure Levels (Unweighted)
Exclusion Zone
Observation Zone
Chelonians - Potential Mortal Injury (SEL)
Fish (Hearing Specialist) - Recoverable Injury (SEL)
Diving Birds - Injury (SEL)
Fish (Hearing Specialist) - TTS (SEL)
SEL24hr, dB (No weighting) re 1µPa
Distance From Source, m
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
1
10
100
1,000
10,000
000 deg
045 deg
090 deg
135 deg
180 deg
225 deg
315 deg

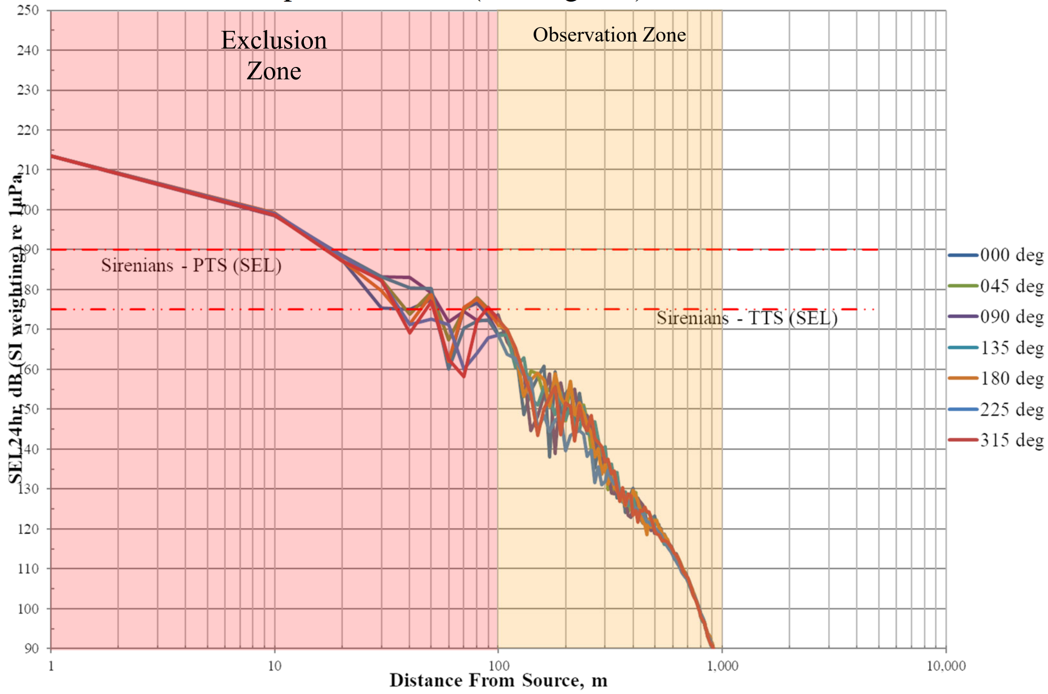
Cumulative Sound Exposure Levels (LFC weighted)



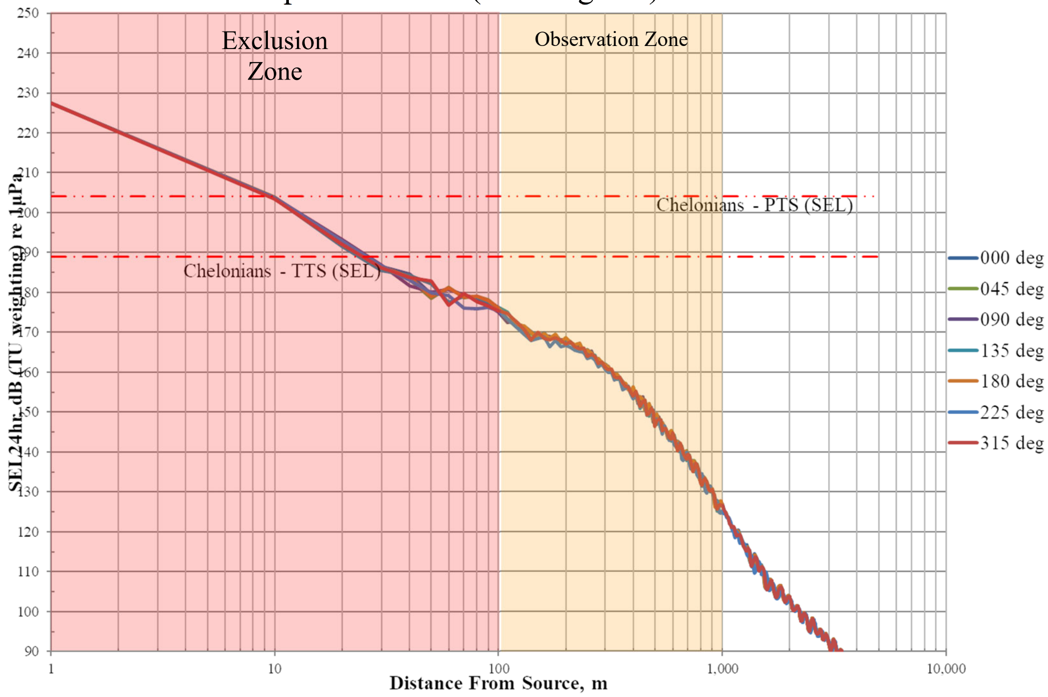
Cumulative Sound Exposure Levels (MFC weighted)



Cumulative Sound Exposure Levels (SI weighted)



Cumulative Sound Exposure Levels (TU weighted)



Appendix B

Peer Review Comments

MARSHALL DAY Acoustics

Marshall Day Acoustics Pty Ltd
ABN: 53 470 077 191
6/448 Roberts Road
Subiaco WA 6008
Australia
T: +618 9779 9700
www.marshallday.com

23 September 2019

Arup
Level 4 108 Wickham Street
Fortitude Valley QLD 4006

Attention: Cameron Hough

Dear Cameron

PORT OF CAIRNS - UNDERWATER NOISE REPORT PEER REVIEW

Marshall Day Acoustics has conducted a peer review of an underwater noise assessment carried out by Arup for the Cairns Shipping and Development Project (CSDP). The CSDP involves widening and deepening of the Cairns Shipping Channel and improvement of navigation and wharf facilities. Some CSDP construction activities will generate noise in the underwater environment and these activities were assessed by Arup in the draft Environment Impact Statement (EIS), as part of the project approval process.

The CSDP was granted approval by the Department of Environment and Energy under the EPBC Act in 2017. The approval included conditions that specifically related to piling activities. The Arup report that is the subject of this peer review has been prepared to address these conditions.

Presented below are details of the scope of the peer review and documentation that has been considered in the review. Review comments and recommendations are provided in Appendix A.

Documents

For following documents have been referred to as part of this review:

Document title	Date	Description	Document short name
Draft: Environmental Impact Statement Appendix D.7 Noise and Vibration Technical Report	November 2014	Comprehensive noise and vibration assessment report prepared for the draft EIS. The report includes assessment of various underwater noise sources, not just piling noise.	Draft EIS noise report 2014
Cairns Shipping Development Project Revised Draft Environmental Impact Statement Chapter B10: Noise and Vibration	July 2017	Noise and vibration assessment based on a revised project proposal. The underwater noise component was not updated as part of the revised draft EIS.	Chapter B10 2017
Ports North Cairns Shipping Development Project Piling Underwater Noise Report R01 draft issue	13 August 2019	Updated piling assessment prepared to address specific EBPC approval conditions and required to be peer reviewed. The report does not address all underwater noise sources. The report makes reference to the Draft EIS noise report 2014 and has only update selected aspects of the 2014 assessment.	Piling report 2019

Scope of review

The key focus of this review has been on the method used to determine zone distances outlined in the Piling report 2019. This includes the noise source data, noise criteria, and the modelling method

Certified System ISO 9001

and inputs. To the extent that is has been necessary, reference has been made to the Draft EIS noise report 2014 and Chapter B10 2017 but these reports are not considered to be part of this peer review.

The peer review has broadly considered the modelling noise predications, however independent modelling has not been carried out to validate the results

This review does not address assumptions regarding the types of marine fauna likely to be present in the study area at the time of piling operations, the potential effects of noise on marine fauna or response behaviours.

Review comments

Review comments and recommendations are provided in Appendix A. In summary, the key points are:

- The assessment criteria are generally suitable
- Clarification is required on several modelling inputs and piling methodology assumptions, such as, the representative number of strikes assumed per driven pile
- The management approach is generally suitable

We trust this information is satisfactory. If you have any further questions, please do not hesitate to contact us.

Yours sincerely

MARSHALL DAY ACOUSTICS PTY LTD

Ben Wilson

Associate

Enclosed: Appendix A – Review comments

APPENDIX A REVIEW COMMENTS

Report section	Description	MDA comment	Recommendation or action
1	Introduction	The introduction outlines the reasons for the peer review being carried out, but does not state clearly that the scope of the updated assessment is limited to piling noise only. We note that it does not include other noise sources that were previously included in the Draft EIS noise report 2014, for example noise associated with dredging.	Comment only.
2.1	Project description	It would be helpful for the reader to include a site plan showing high level information regarding the project study area and piling activating locations. While this information may exist in other documentation, it would be appropriate to include within this section of the report also.	Include a site plan show piling activity locations.
2.3	Piling details	No information is provided on the length of the piles. Driven depth is only provided for the Navigational Aids piles but not the Wharf piles. This information would be helpful for reviewing the source heights in the noise model and assumptions regarding the number of strikes needed. Further comments regarding pile strike rate and other related model input are provided below for report sections 5.1 and 5.3.	Provide pile length details if available and details on the piling approach (e.g. the piles will be impact/vibro driven to depth or driven to refusal/seal and drilled out.)
2.3	Piling details	It is noted that piling rate for Wharf #6 may be more than 1 per day but predictions for cumulative SEL are based on 1 per day.	Clarify if more than 1 pile per day is expected. If it is, the cumulative SEL levels should be updated to reflect expected number of strikes from the total number of piles driven per day.
2.3	Piling details	The Piling report 2019 mentions that both impact piling and vibro piling would be used. While noise from vibro piling is typically much lower than impact piling, the continuous nature of the source can still have effects on marine fauna (e.g. masking/communication space). Vibro piling can result in appreciable cumulative noise levels if the vibro hammer is operated for long periods (as has been our experience on a number of marine piling projects). Some commentary regarding these effects would be appropriate in the report.	Provide commentary regarding the possible effect from vibro piling.
4.1-4.2	Literature Review - Relevant Legislation and Policy	This section lists selected documents however it does not provide any commentary on the relevance of these documents to the current assessment. We would expect a literature review to include this for context. Some commentary is provided in section 4.2 regarding the *Great Barrier Reef Underwater Noise Guideline and Options Paper* but no details are provided on how this has been applied in the assessment. From our reading of that paper, it seems that selected aspects of the have been applied, but not all.	Explanation of how each document relates to the assessment would be helpful for the reader.

Report section	Description	MDA comment	Recommendation or action
4.4	Source Levels for Marine Piling	This section presents a range of data for piling source noise levels for different pile diameter sizes. To determine the source levels for the assessment the same approach has been used as in the Draft EIS noise report 2014 (measured levels for 5 m piles, adjusted down for smaller pile diameters, based on a linear relationship). A 10dB safety factor has been added to the derived levels. The approach used results in piling source noise levels that could be considered to be at the upper end of the range for the respective pile sizes. The inclusion of a 10dB safety factor seems unnecessarily high given the impact such a factor could have on zone distances. If there were particular concerns about the linear relationship method of noise level derivation, some commentary should be provided and the 10dB adjustment justified. While we would typically encourage the use of a conservative approach, in this case the levels could be considered unrealistic when compared to source levels measured from similar piling operations and could result in management zone distance that are greater than necessary. Provisions for early monitoring have been recommended in the report so piling noise levels could be confirmed at that stage and zones adjusted accordingly. We broadly agree with the statement that levels roll-off at frequencies below 100 Hz and consider the spectra used in the assessment to be suitable.	Reconsider piling source levels.
5.1	Assumptions and Limitations	This section outlines some details used in the predication model but references the Draft EIS noise report 2014 for others. A concise summary of all model inputs would be beneficial for the reader to clearly understand the assumptions and input used in the model.	Consolidate all model inputs into the Piling report 2019
5.1	Source locations	The assessment makes reference to the Draft EIS noise report 2014 for source locations however that report does not specifically state location coordinates. The only information provided regarding the source locations in the Draft EIS noise report 2014 is the site plan in Figure D7.7.6.1a.	Provide source location coordinates
5.1	Bathymetry	The assessment makes reference to the Draft EIS noise report 2014 for bathymetry information. That report states that 'Bathymetry data was obtained from the Geoscience Australia 250 m electronic bathymetry grid.' Our understanding is that the Geoscience data would not provide sufficient depth resolution for modelling purposes for the wharf area and shipping channel. The results suggest that additional bathymetry data has been used (plots in Figure D7.7.6.1a. appear to show detailed bathymetry was available) but no details are provided.	Clarify data sets used for bathymetry.
5.1	Sound speed profile	The assessment makes reference to the Draft EIS noise report 2014 for SSP information. Data from the World Ocean Database has been used and the information provided is considered suitable. SPP is unlikely to have a significant effect of the predictions in shallow water.	Comment only
5.1	Source depths	Source depths are defined the Draft EIS noise report 2014 and are considered appropriate	Comment only

Report section	Description	MDA comment	Recommendation or action
5.1	Receptor depth	Receptor depths are defined the Draft EIS noise report 2014. 3 m has been used for all predications. Typically, it would be appropriate to use a 'maximum over depth' approach in order to determine the maximum level within the water column at any one location. A specific receptor height is generally not specified unless a marine ecologist can advise on the likely depth of a given species. .	Confirm that the 3m receptor height is representative of the highest underwater noise levels in the water column, or that the species of interest are likely to be at this depth.
5.1	Pile strikes	The Piling report 2019 has assumed 200 pile strikes within a 24-hour period and claims this is considered to be a conservative assumption. While the number of strikes will be dependent on the outcomes of a driveability assessment, we consider that this number is not conservative and could in fact be at the lower end of the likely range. The CALTRANS document[1] provides typical strike data for various pile sizes and types. For 40-inch (~100cm) piles, 600 strikes are listed as typical. We have generally found this to be a good upper estimate for nearshore piling projects we have monitored. If this number were to be used in the assessment, predicted levels would be around 5dB higher.	Given the potential significant effect on level predications, we recommend that further details be provided to support the assumed number of pile strikes.
5.1	Sediment type	The Draft EIS noise report 2014 does not include details of the seafloor properties used in the model. A general comment is made that refers to 'rock substrate' but no details are provided of sediment layers. The seafloor properties can have a significant impact on sound propagation in shallow water and therefore this information is key to the modelling outcomes and should be reported	Provide details of the seafloor properties used in the noise model
5.1	Solver details	The Draft EIS noise report 2014 does not include details of the propagation solvers and solver parameters used in the modelling. The selection of solver type can have a significant effect on the predication and so it is important that an appropriate solver type is used to match the modelled scenario. While an appropriate solver may have been used, the details have not been provided.	Provide details of the solve type used in the noise model
5.2.1	Updated Assessment Criteria - Marine mammals (cetaceans, dugongs, and other)	The Arup 2019 notes that threshold criteria for cetaceans has been revised since the Draft EIS noise report 2014 and the new criteria from NMFS 2018 (NOAA 2018) are considered appropriate for this assessment.	Comment only
5.2.2/3	Updated Assessment Criteria - Fish (including eggs and larvae) / Sea Turtles	The updated threshold criteria for fish and sea turtle (from Popper 2014) is considered the appropriate for this assessment.	Comment only

[1] Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish, November 2015

Report section	Description	MDA comment	Recommendation or action
5.2.4	Birds	We note the inclusion for threshold criteria for birds but would not consider assessment of underwater noise impacts for birds to necessary in this case.	Comment only
5.3	Updated Underwater Noise Predictions	The report provides commentary regarding the conservative nature of using 24 hr cumulative sound exposure levels on the basis that animals are unlikely to stay in a noisy environment and uses this to explain that 200 pile strikes is conservative. While there a logic to this argument, we would consider it more appropriate to state the likely number of strikes, based on the piling requirements, and then separately provide commentary on why this might result in conservative predictions.	Reconsider the pile strike requirements or present results based on a range
5.3	Table 7 & 8 results	The results presented show propagation losses that appear to be unusually high. A propagation loss relationship of 15xlog(distance) is often used as a rough guide for underwater noise propagation loss. The results presented in the Piling report 2019 show propagation loss relationships that significantly higher than this and require checking and some explanation.	We recommend that modelling predications be reviewed to confirm inputs and assumptions are correct. If the propagation losses are found to be correct, we suggest that some explanation is provided as to why they are high.

Report section	Description	MDA comment	Recommendation or action
5.4	Recommended Safety Zones	The approach to setting the management zone seems overly complicated. Several methods have been used to determine zones for different species types and then the most stringent zone selected for management purposes. Two zone types are used; *exclusion/shutdown zone* and *observation zone*. A nominal 10% safety factor has been applied to the management zones determined based on TTS, but not to the zones determined in using the SA Guidelines[2]. It is not clear why a combination approach has been used. The SA Guidelines were used in the Arup 2014, however the Piling report 2019 acknowledges that the weightings referred to in the SA Guidelines are outdated and updated behavioural and injury criteria have been determined based on more recent research. While there may be a desire to maintain consistency with the Arup 2014, the approach does end up being unnecessarily complicated in our view. Notwithstanding the above comments regarding complexity, the zones determined do seem to be correct, based on the predicted levels that have been reported. It is noted that the SA Guidelines have been used for sirenians and chelonians although species from these groups are not specifically covered by the SA Guidelines. In the event that predications are revised (either to address concerns raised in this peer review or following early noise monitoring) we would recommend consideration be given to a more simplified approach to determine the shutdown zones for marine mammals and sea turtles based on the SEL_{24hr} TTS criteria, as is commonly used for similar piling projects. Given the concerns raised in this review regarding propagation losses and pile strike rates, there is a risk that the predicated levels are not representative and higher levels are possible. If predicated levels were to increase (or determined during early monitoring), this could have a significant impact on the zone distances.	In the event that predications are revised (either to address concerns raised in this peer review or following early noise monitoring) we would recommend consideration be given to a more simplified approach to determine the shutdown zones for marine mammals and sea turtles based on the SEL_{24hr} TTS criteria, as is commonly used for similar piling projects.
5.4.1	Additional management and mitigation recommendations	The recommendations for mitigation are generally considered appropriate. In addition to the items listed, we would recommend including the following options: • Use a wooden (preferable) or plastic dolly for the steel piles Given the concerns raised above regarding the accuracy of the predication, we would strongly recommend that noise monitoring be carried out to confirm actual piling noise levels and adjust zoning requirements if necessary.	Comment only.

[2] South Australian Department of Planning, Transport and Infrastructure (DPTI), South Australia Pile Driving Guidelines, November 2012, Document: # 4785592