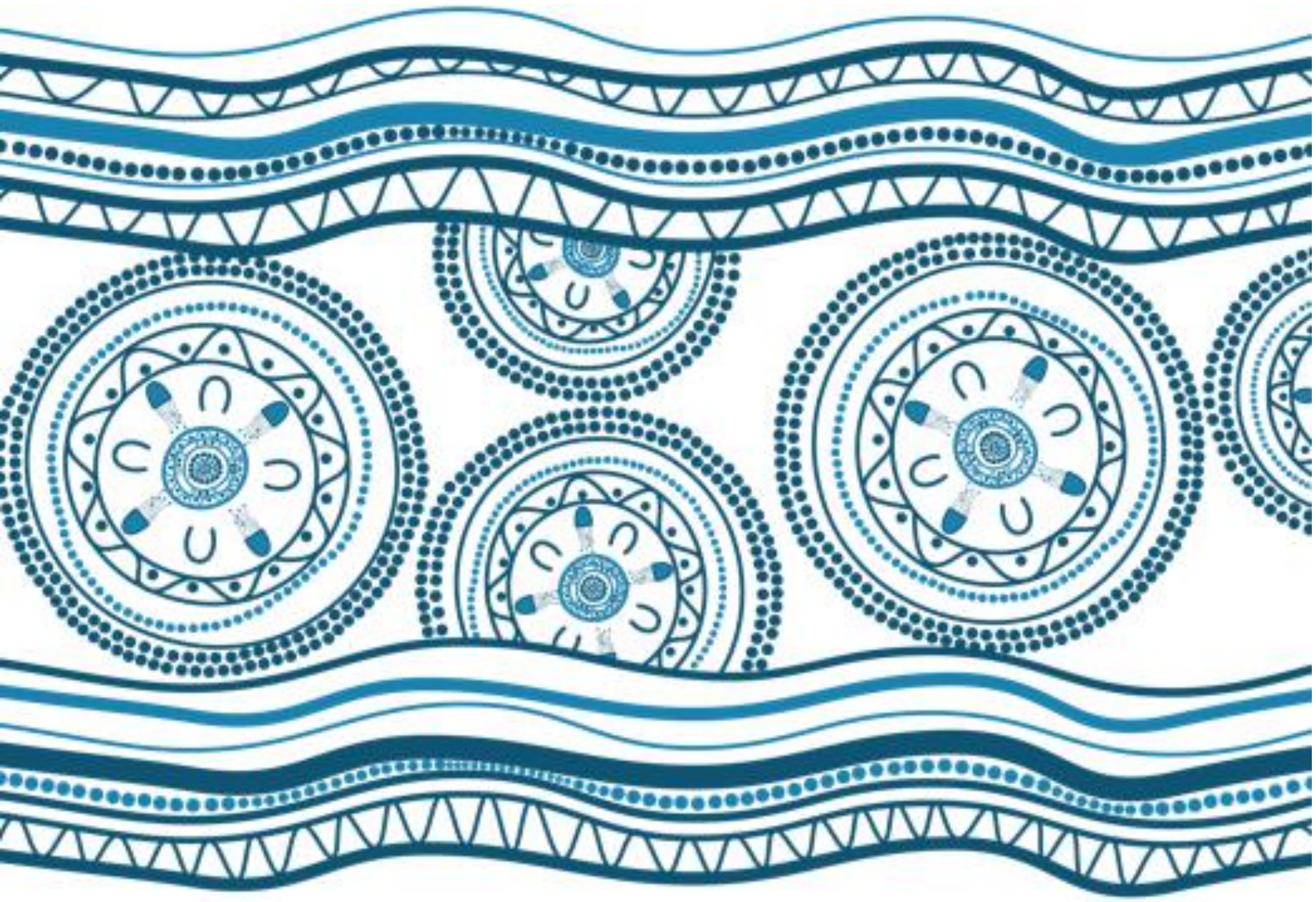
Appendix P

Underwater Noise Assessment



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Transport for NSW

Kamay Ferry Wharves Project

Underwater Noise Assessment

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Executive summary

This report assesses the underwater noise impacts predicted to occur from building and operating the Kamay Ferry Wharves (the project).

Approach and method

The assessment involved a literature review of underwater noise guidelines and criteria, the determination of underwater noise source levels, modelling the propagation (disperse) of underwater noise in Botany Bay, assessing the project's impacts, and defining mitigation and management measures.

Underwater noise is assessed using the following key criteria:

- Sound pressure level (SPL, L_p) is the average change in water pressure associated with underwater noise and is typically used to assess behavioural response.
- Peak pressure (PK, L_{pk}) is the maximum change in water pressure associated with underwater noise. This is also referred to a peak impulsive noise and is typically used to assess sudden shock and startle response health and welfare impacts.
- Sound exposure levels (SEL, $L_{E,24h}$) is the cumulative level of energy contained within underwater noise and is typically used to assess health and welfare impacts. This is also referred to as the "noise dose".

Sound and peak pressure levels are measured in decibels (dBs). They are typically reported against a standard reference value of 1 µPa (one micro pascal). This is different to sound levels in air which are reported using a reference value of 20 µPa. Because of this, and the fact that sound travels much slower in water than air the noise levels cannot be directly compared. For example, 100 dB of airborne noise is notable however it is a relatively low sound level underwater.

Underwater noise levels are commonly presented as a source level, which allows underwater noise levels to be compared against a common baseline. The source level is the noise level (relative to 1 µPa) normalised one metre from the source.

A key focus for the assessment was identifying relevant criteria above which there is an increased risk of the following underwater noise impacts:

- Temporary behaviour changes, the most common of which is simply avoiding or moving away from an area
- Temporary hearing loss
- Permanent hearing loss
- Injury or death.

Existing noise levels

Ambient underwater noise in Botany Bay is affected by a range of port, maritime, industrial, commercial, and recreational activities. The main underwater noise source is from the frequent movement of ships. This currently includes around nine vessel movements per day to or from Port Botany or the Kurnell Terminal Wharf. It is forecast that total vessel numbers associated with Port Botany are expected to grow by 45 per cent over the next 30 years (NSW Ports, 2015). There is also various subsea infrastructure under Botany Bay that potentially generates underwater noise.

Ambient noise levels around Australia coastal waters are around 120 dB (re: 1 µPa) (Government of South Australia, 2012). Ship-generated underwater noise is intermittent. It varies depending on the type and size of ship. Larger cargo ships and tankers generate noise up to a maximum of 209 dB (re: 1 µPa, Bowles and Graves, 2007).

While no baseline monitoring was carried out near the project areas, ambient underwater noise is likely to be influenced by shipping movements through the headlands. While ambient noise levels could vary as high as 190 dB (re: 1 µPa), this would only last for a short period while ships to pass through the area. The noise would also attenuate to around 120 to 150 dB (re: 1 µPa, Bowles and Graves, 2007).

Sensitive receivers

Underwater noise can impact marine mammals (whales, dolphins, porpoise, seals, and dugong), fish, sharks, rays, sea turtles, marine reptiles, birds, invertebrates, squid, and crustaceans. It can also affect divers and other recreational users. These are all ecological species that either inhabit or use Botany Bay. There is also a lot of human recreational in-water and on-water activity that takes place in the Bay around the year.

Criteria

The document most commonly used to set noise criteria (termed trigger levels) in Australia is the 2012 South Australia Underwater Piling Noise Guidelines. These were based on data developed by Southall *et al.* in 2007. However, Southall *et al.* updated their data in 2019 based on new scientific findings. The South Australia guidelines also do not include threshold criteria for certain species that are likely present in Botany Bay. Therefore, the approach taken in this study was to adopt the general procedures of the South Australian guidelines but to update the trigger levels based on the more-recent research.

By carrying out a review of the current literature, project specific criteria were developed. These criteria are the lowest noise levels where there may be an impact on marine species. Table ES1 summarises these criteria. Different frequency weighting functions are used to describe impacts to different species. This is because the frequency as well as the loudness of the noise affects species differently. Therefore, a range of values are provided below to cover impacts to different groups of animals).

Table ES1. Noise criteria summary (marine animal species)

Impacts	Impulsive (from piling)				Non-impulsive (from vessels)		
	Weighted Sound exposure (SEL 24hr, dB)	Unweighted Sound exposure (SEL 24hr, dB)	Sound pressure (SPL, dB)	Peak pressure (PK, dB)	Weighted Sound exposure (SEL 24hr, dB)	Unweighted Sound exposure (SEL 24hr, dB)	Sound Pressure Level (SPL, dB)
Behavioural response	-		160-175		-	-	120
Temporary hearing loss	140-189	-	-	196-226	153-200	204	-

Impacts	Impulsive (from piling)				Non-impulsive (from vessels)		
Permanent hearing loss	155-204	-	-	202-232	173-220	-	-
Physical injury	-	190-210	-	207-237	-	222	207-237

Human/divers can typically tolerate noise levels up to 145 dB SPL (recreational divers) to 170 dB SPL (trained professional divers). Of concern for human divers is not just behavioural impacts but also the potential injury that may occur if noise exposure results in a panic response. Above about 184 dB SPL the noise level may cause injury.

Modelling

Underwater noise modelling was carried out to predict how noise would propagate throughout Botany Bay. In summary, the modelling considered:

- How noise propagation is affected by water depth (bathymetry).
- How noise propagation is affected by change in (sound) speed as noise travels through the water column.
- How the harbour floor sediments would absorb or reflect the sound.

These parameters were included in an underwater noise model that was developed to predict how noise would propagate in Botany Bay. As with any modelling it predicts the real world. It cannot account for every factor in specific detail. Therefore, any model includes various assumptions and limitations. The key assumptions and limitations used in the underwater noise model were:

- Modelling the noise from a single point source because the construction boundary is sufficiently small not to affect the results.
- Using published typical source noise levels, which may vary from the actual source levels.
- Using representative average values for the seabed, sediment conditions and other physical conditions in Botany Bay because the modelling tools are currently not advanced enough to account for this. This means there may be some localised differences across parts of the Bay.
- Assuming each pile may be struck 600 times to determine the build-up of underwater noise over time. If the number of strikes is greater or lower this would affect the cumulative noise levels.

Impact assessment

In summary, the modelling predicted the following marine species impacts if no mitigation was introduced.

- Behaviour changes | **would** occur because of the piling works and construction vessel and operational ferry movements. The extent of the behavioural changes would depend on the scale and duration of the construction works, the species, the masking effect of other existing noise sources (as these were not included in the modelling), other behavioural pressures (e.g. presence of food sources, migration routes and how used (habituated) the species would be to noise.
- Temporary hearing loss | **would** only occur between **10 metres** and **330 metres** when piling (depending on the species). The impact **may** extend beyond this limit when the animal is

continuously exposed to piling noise. In this case the modelling predicts that these impacts could occur up to **2.25 km**.

- Permanent hearing loss | **would** occur within **100 metres** when piling. The impact **may** extend beyond this when the animal is continuously exposed to piling noise.
- Injury or death | **would not occur**.

In terms of humans, they are likely to hear the piling if they are in the water or diving in the Bay and no mitigation was introduced. Noise levels are predicted to be uncomfortably loud in most of the Bay during piling works. Within about **300 metres** of the works there is the potential for injury to human divers.

Mitigation measures

Underwater noise management is largely based on creating a series of management zones. In the case of the project three zones are recommended:

- **Zone 1** | where works would temporarily stop.
- **Zone 2** | where temporary work restrictions may be introduced depending on the species, planned work, whether the species was moving towards the piling works.
- **Zone 3** | where marine spotters would be used to observe marine mammals.

The final zones would be confirmed through carrying out specific monitoring onsite before starting piling. This is needed because the noise modelling included a range of assumptions meaning the extent of the impacts described above are likely a precautious upper limit. The zones may also be dynamic, meaning they could be adjusted depending on the species observed in the Bay at the time.

The fact that about a 75 metre exclusion zone would be introduced around the piling works limit the risk of underwater noise impacts on human in the water or diving. While there may still be the potential for impacts outside of this zone, these can be likely managed using mitigation.

Therefore, it should be possible reduce the zones and manage human impacts by introducing the following measures:

- Maintain minimum separation between construction vessels and marine mammals as per the NSW declared approach distances from the Biodiversity Conservation Regulation 2017.
- Where reasonable and feasible use bubble curtains to reduce the severity of the energy of the sounds caused by the driving of the piles.
- Use alternative methods during poor weather and visibility (e.g. sonar and radar).
- Carry out observations for 30 minutes before starting work in all zones.
- Have a slow-start process for the piling works that would last for 10 minutes.
- Implement a stand-by and shut down process.
- Prepare and maintain a compliance and siting report while piling takes place.
- Notify recreational user groups in the area and post notices at the key beaches warning people of the ongoing piling works so that can expect potential underwater noise.
- Aim to avoid piling at the weekend and during public holidays.

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Mitigation measures

Appendix G

Underwater noise level predictions (figures)

1 Introduction

The report describes the underwater noise impacts associated with the Kamay Ferry Wharves project (the project). It assesses both construction and operational impacts by:

- Carrying out a literature review.
- Determining underwater noise source levels.
- Modelling the propagation (spread) of underwater noise.
- Assessing potential impacts.
- Defining management and mitigation measures.

1.1 Project overview

Transport for New South Wales (Transport for NSW) is seeking approval to reinstate the ferry wharves at La Perouse and Kurnell in Botany Bay (the project) under Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) as State significant infrastructure (SSI).The project would allow for an alternative connection between La Perouse and Kurnell rather than by road. The primary purpose of this infrastructure would be to operate a public ferry to service visitors coming to the area and by the local community for cultural and recreational purposes. It would also provide supplementary temporary mooring for tourism-related commercial vessels and recreational boating.

The project provides opportunities for significant cultural and economic benefits to the local Aboriginal community by providing improved access to culturally significant sites. It is also expected to deliver wider community benefits on either side of Botany Bay. This may include investment opportunities in a ferry service and other new visitor/tourist experiences.

Key project features include:

- Two new wharves, one at La Perouse and one at Kurnell that would include:
  - Berth for ferries, to accommodate vessels up to 40 metres long.
  - Berth for recreational and commercial vessels, to accommodate vessels up to 20 metres long.
  - Sheltered waiting areas and associated furniture.
  - Additional space within the waiting areas to accommodate other users such as anglers and those using recreational vessels.
  - Signage and lighting.
- Landside paving, access ramps, seating, and landscaping at the entrance to the wharves.
- Reconfiguration of existing car parking areas at La Perouse.
- Reconfiguration of footpaths around the new car parking areas.
- Provision for bike racks at La Perouse.
- Installation of utilities to service the wharves.

It is anticipated to take up to 13 months to build the project, with work expected to start in early 2022. The two wharves would be built at the same time. A concept design has been developed for the project that forms the basis of this assessment. This underwater noise assessment supports the project's environmental impact statement (EIS). Figure 1 and Figure 2 show the proposed location of the ferry wharves. Figure 3 shows the path (route) for the ferries between both wharves.

Figure 1. Location of proposed ferry wharf at La Perouse

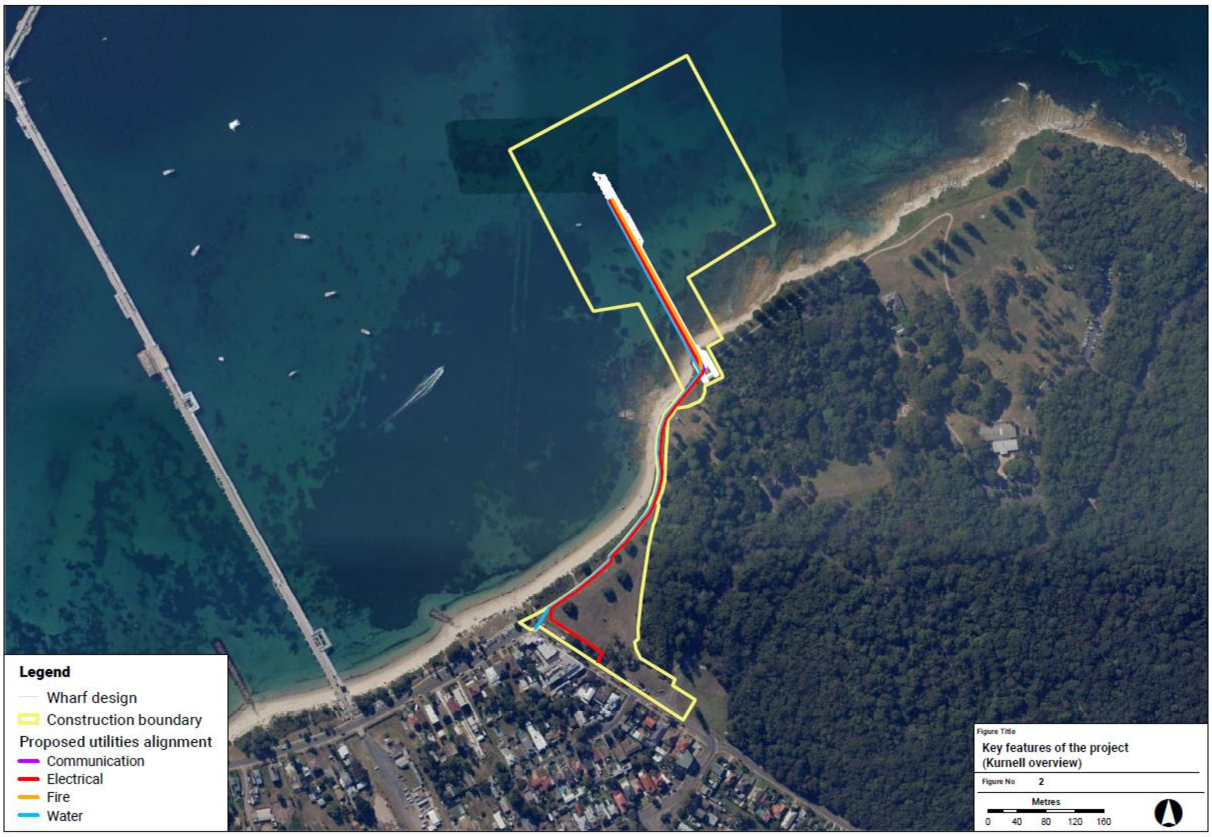

Figure 2. Location of proposed ferry wharf at Kurnell

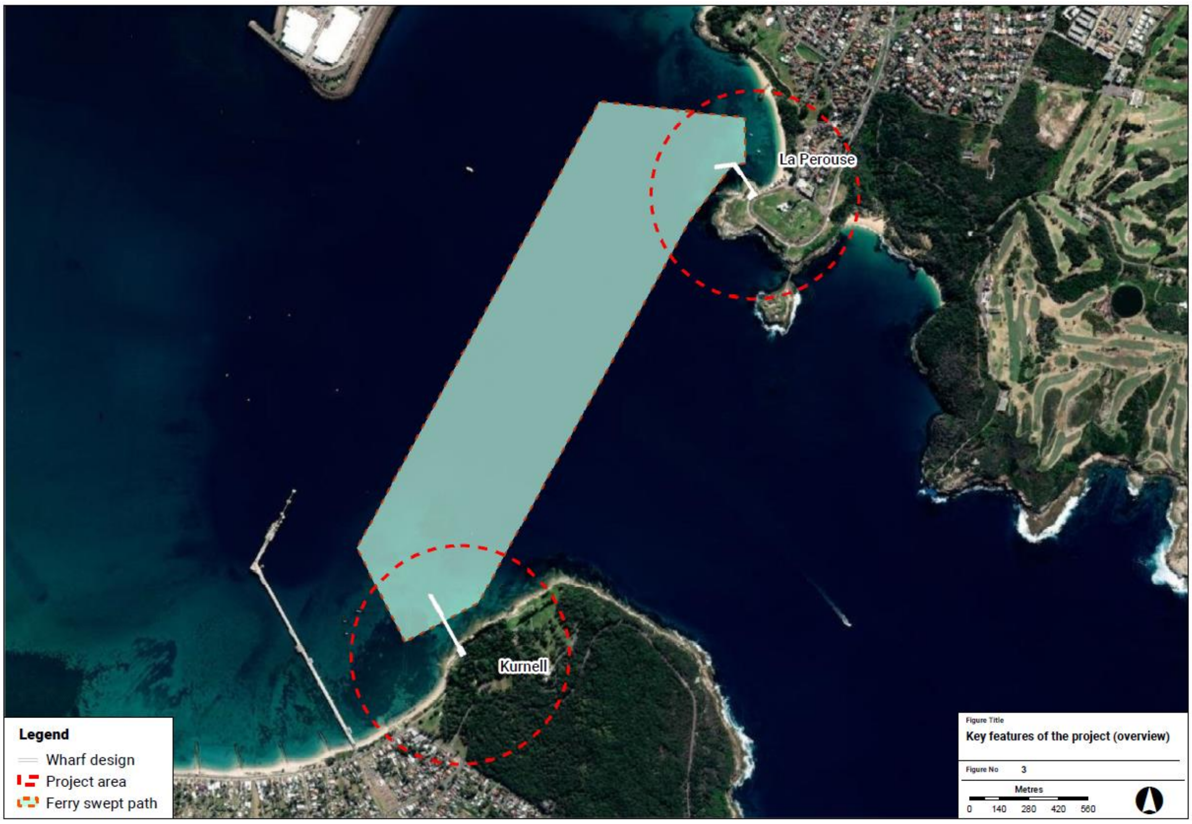

Figure 3. Swept ferry path between La Perouse and Kurnell

1.2 SEARs relevant to this assessment

Table 1 identifies the SEARs that are relevant to this technical assessment.

Table 1. SEARs for underwater noise

SEARs relevant to this technical report	Where addressed in this technical report
1. Assessment of key issues Key issue impacts are assessed objectively and thoroughly to provide confidence that the project will be constructed and operated within acceptable levels of impact.	
1. Biodiversity The project design considers all feasible measures to avoid and minimise impacts on terrestrial and aquatic biodiversity. Offsets and/or supplementary measures are assured which are equivalent to any residual impacts of project construction and operation.	
8. Water-based construction and vessel operation impacts on aquatic biodiversity, including:	Chapter 4 and Appendix B include the underwater noise criteria. Chapter 5 includes the results and Chapter 6 the mitigation measures.
(b) the nature and impact of underwater noise generating activities	
(c) proposed specific sound exposure and peak impulsive and continuous noise criteria for identified noise sensitive fauna.	Chapter 4, Appendix D and Appendix E.
6. Noise and vibration Construction noise and vibration (including airborne noise, ground-borne noise, and blasting) are effectively managed to minimise adverse impacts on acoustic amenity. Increases in noise emissions and vibration affecting nearby properties and other sensitive receivers during operation of the project are effectively managed to protect the amenity and well-being of the community.	
1. Land, water and underwater-based construction noise and vibration impacts of the project in accordance with relevant NSW noise and vibration guidelines. The assessment must include noise impacts of construction related traffic.	Chapter 4 and Appendix B include the underwater noise criteria. Chapter 5 includes the results and Chapter 6 the mitigation measures.
2. Operational noise impacts on the amenity of sensitive receivers, employees and visitors to the Kamay Botany Bay National Park, vessels approaching, mooring, and departing the infrastructure, and vehicular traffic.	

2 Existing environment

La Perouse and the Kurnell Peninsula are located south of the Sydney CBD. They define the northern and southern side of the entrance to Botany Bay. The Bay is sheltered and relatively shallow compared to the Sydney coastline. Various marine fauna inhabit or frequently visit the Bay. The Bay is also used for various on-water and in-water activities throughout the year.

2.1 Underwater noise sensitive receivers

Certain fauna (including humans) that are (potentially) present in Botany Bay may be impacted by underwater noise. The effects could be mild (e.g. avoiding areas) to serious (e.g. permanent hearing loss or death) depending on the species and the intensity and duration of the noise.

2.1.1 Marine fauna

Table 2 lists the noise-sensitive species that are recorded or may potentially occur in Botany Bay. These mainly focus on threatened species and those species that are recreationally fished in the area. Appendix H Marine Biodiversity Assessment Report of the EIS describes their ecological values in detail.

Table 2. Species potentially impacted by underwater noise

Group	Species
Cetaceans	Humpback whales Southern right whales
Sirenians	Dugong
Otariids	Australian fur seals New Zealand fur seals
Sea Turtles	Green sea turtles Loggerhead turtle
Fish	Black rockcod Sygnathiformes (pipefish, sea horses and sea dragons)
Sharks	Grey nurse sharks
Birds	Wandering and diving birds including various species of albatross Little blue penguin
Invertebrates	Calamari squid Crayfish

2.1.2 Human swimmers and divers

People swim, dive, recreationally/spear fish, snorkel, boat, kite surf, and carry out water sports in/on Botany Bay. This means people are regularly on or in the water refer to Appendix N Socioeconomic Impact Assessment Report of the EIS.

3 Policy and planning context

The assessment mainly focussed on the following guidelines and documents:

- Great Barrier Reef Underwater Noise Guideline Discussion and Options Paper (GBRMPA, 2017).
- Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act, Australian Government, 1999).
- EPBC Act Policy Statement 2.1 –Interaction between offshore seismic exploration and whales, Department of the Environment, Water, Heritage, and the Arts (Australian Government, 2008).
- Underwater Piling Noise Guidelines (Government of South Australia, 2012).
- International Standard ISO 18405 (2017) Underwater Acoustics – Terminology.

Appendix A and Appendix B list the other international standards and guidelines reviewed to help inform the assessment. This includes full references.

4 Assessment criteria

Appendix B provides a detailed review of the above guidelines. It was used to identify the impact assessment criteria summarised below where:

- Section 4.1 lists the criteria above which marine fauna and humans may be impacted by underwater noise.
- Section 4.2 lists the underwater noise levels that are expected to be generated by the project.
- Section 4.3 summarises the criteria adopted in the modelling.

4.1 Assessment criteria for noise sensitive receivers

Marine fauna and humans can experience the following underwater noise impacts in order of severity:

- Temporary behaviour changes, the most common of which is simply avoiding or moving away from an area
- Temporary hearing loss
- Permanent hearing loss
- Injury or death.

The exact noise levels (known as trigger levels) where impacts occur varies in the literature. The trigger levels also vary between species, and the impact depends on the length of time the underwater noise is generated.

ISO 18405 Underwater Acoustics – Terminology (ISO, 2017) introduces various terms to describe underwater noise impacts. There are three key terms used in this assessment:

- Sound pressure level (SPL, Lp) is the average change in water pressure associated with underwater noise and is typically used to assess behavioural response.
- Peak pressure (PK, Lpk) is the maximum change in water pressure associated with underwater noise. This is also referred to a peak impulsive noise and is typically used to assess sudden shock and startle response health and welfare impacts.
- Sound exposure levels (SEL, LE,24h) is the cumulative level of energy contained within underwater noise and is typically used to assess health and welfare impacts. This is also referred to as the “noise dose”.

Sound and peak pressure levels are measured in decibels (dBs). They are typically reported against a standard reference value of 1 µPa (one micro pascal). This is different to sound levels in air which are reported using a reference value of 20 µPa. Because of this, and the fact that sound travels much slower in water than air they cannot be directly compared. For example, 100 dB of airborne noise is notable however it is a relatively low sound level underwater.

Underwater noise is also reported as weighted and unweighed levels. The weightings were initially introduced by Southall *et al.* in 2007 and later updated to reflect more-recent research. Weighted levels are used because different species perceive and react to underwater noise frequencies differently. The different weighting functions account for the relative sensitivity of animals (or groups of animals) to noise and the frequency range over which they are sensitive to sound. In short, the by weighting the noise it provides a combined criterion. The weighting function is indicated in the parameter (e.g. there are species specific weightings as presented in Appendix E). Several trigger levels are presented only as weighted levels, while other trigger levels are based on unweighted levels.

4.1.1 Trigger levels

Marine species

The document generally used to set trigger levels for marine piling in Australia is the 2012 South Australia Underwater Piling Noise Guidelines. These were based on data developed by Southall *et al*. in 2007. However, Southall *et al.* updated their data in 2019 based on new scientific findings. The South Australia guidelines also do not include threshold criteria for certain species that are likely present in Botany Bay.

Therefore, various guidelines were used to define the trigger levels used in this assessment. Appendix B includes a full list and the detail of the references used to define the criteria.

Table 3 shows the weighted criteria adopted to assess the marine species impacts from piling while Table 4 shows the weighted criteria adopted to assess the impacts from shipping movements.

Table 3. Threshold noise criteria summary (impulsive piling noise)

Group	Behavioural response	Temporary hearing loss	Permanent hearing loss	Injury
	* unweighted	All measured as sound exposure levels ($L_{E,24h}$) unless otherwise stated		
Cetaceans (low frequency)	160 SPL	168	183	-
Cetaceans (mid frequency)		170	175	-
Cetaceans (high frequency)		140	155	-
Sirenians (dugong)		175	190	-
Otariids (seals)		188	203	-
Sea turtles	175 SEL	189	204	207
Fish (no swim bladder)	-	186	-	216-219
Fish (swim bladder | non-hearing)	-		-	203-210
Fish (swim bladder | hearing)	-		-	203-207
Fish (eggs/larvae)	-	-	-	210
Sharks	-	186	-	216-219
Birds (while diving)	*120 SPL	-	-	190 SPL
Invertebrates (squid)	*162 SEL	-	-	-
Invertebrates (crayfish)	202 PK	-	-	-
Humans (while diving)	*145 SPL	*167 SPL	-	184 SPL

Table 4. Threshold noise criteria summary (non-impulsive vessel noise)

Group	Behavioural response *unweighted	Temporary hearing loss All measured as sound exposure levels ($L_{E,24h}$) unless otherwise stated	Permanent hearing loss	Injury
Cetaceans (low frequency)	120 SPL	179	199	-
Cetaceans (mid frequency)		178	198	-
Cetaceans (high frequency)		153	173	-
Sirenians (dugong)		186	206	-
Otariids (seals)		199	219	-
Sea turtles		200		220
Fish (no swim bladder)	-	-	-	-
Fish (swim bladder | non-hearing)	-	-	-	-
Fish (swim bladder | hearing)	-	*158 SPL $_{12hrs}$	-	*170 SPL $_{48hrs}$
Fish (eggs/larvae)	-	-	-	-
Sharks	-	-	-	-
Birds (while diving)	*120 SPL	-	-	190 SPL
Invertebrates (squid)	*162 SEL	-	-	-
Invertebrates (crayfish)	202 PK	-	-	-
Humans (while diving)	*145 SPL	*167 SPL	-	184 SPL

Humans

Table 5 summarises how divers are impacted by underwater noise based on published information. This identifies that trained divers will be increasingly affected by noise up to 170 dB SPL above which noise is likely to be intolerably loud. Above 184dB SPL there is the risk of physical injury.

Table 5. Effects of underwater sound on humans

Received sound power level (dB)	Effect Source: Parvin, 2005
>184	Liver haemorrhage and soft tissue damage likely*
>170	Tolerance level for divers and swimmers. Sound causes lung and body vibration
148-157	The loudness and vibration levels become increasingly aversive. Some divers will contemplate aborting an open water dive.
140-148	A small number of divers rate the sound as “very severe”
136-140	The sound is clearly audible. Most divers tolerate the sound well with only “slight” aversion
130	Divers and swimmers able to detect body vibration
80-100	Auditory threshold

*Based on extrapolation from animal models of pressure-induced damage

4.2 Noise sources

There would be three major underwater noise sources associated with the project. During construction there is the need to pile the wharf foundations. This would generate impulsive noise for around eight months in Kurnell and La Perouse. The other noise source would be from construction vessels operating in the area for around 13 months. The final noise source would be the regular movement of ferries between La Perouse and Kurnell.

A review of the scientific literature has been carried out to determine appropriate source levels for the proposed piling works during construction and vessel movements during the project's construction and operation.

Appendix A and Appendix B provide the details of a literature review carried out to determine the noise levels generated from these activities. Table 6 and Table 7 below list the noise levels adopted in the assessment. Table 7 also shows the noise levels adopted for existing large commercial shipping that currently uses Botany Bay (presented for context).

Table 6. Piling, source levels for the project

Metric	Source level for 0.8 m diameter pile
Sound Pressure Level (multiple strikes)	222 dB re 1 µPa at 1m
Peak Pressure	232 dB re 1 µPa at 1m
Sound Exposure Level (1 strike)	206 dB re 1 µPa²-s at 1m

Table 7. Shipping, source levels for the project

Metric	Source sound exposure levels
Construction vessels	199 dB re 1 µPa²-s at 1m
Ferries	207 dB re 1 µPa²-s at 1m
Commercial shipping	209 dB re 1 µPa²-s at 1m

4.3 Modelling

Appendix D describes the various parameters used in the underwater noise model to assess how noise would propagate in Botany Bay. In summary, the modelling considered:

- How noise propagation is affected by water depth (bathymetry).
- How noise propagation is affected by change in (sound) speed as noise travels through the water column.
- How the harbour floor sediments would absorb or reflect the sound.

These parameters were included in an underwater noise model that was developed to predict how impulsive and continuous noise would propagate in Botany Bay. As with any modelling it predicts the real world. It cannot account for every factor in specific detail. Therefore, any model includes various assumptions and limitations. The key assumptions and limitations used in the underwater noise model were:

- Modelling the noise from a single point source because the construction boundary is sufficiently small not to affect the results.
- Using published typical source noise levels, which may vary from the actual source levels.
- Using representative average values for the seabed properties, underlying sediments, and other physical conditions in Botany Bay because the modelling tools are currently not advanced enough to account for the full variation in water depth and seafloor properties across the Bay. This means there may be some localised differences across parts of the Bay where the seabed differs from the typical seabed.
- Assuming each pile may be struck 600 times to determine the additive build-up of underwater noise over time. If the number of strikes is greater or lower this would affect the cumulative noise levels.

4.3.1 Ambient conditions

Ambient underwater noise in Botany Bay is affected by a range of port, maritime, industrial, commercial, and recreational activities. The main underwater noise source is from the frequent movement of ships. This currently includes around nine vessel movements per day to or from Port Botany or the Kurnell Terminal Wharf. It is forecast that total vessel numbers associated with Port Botany are expected to grow by 45 per cent over the next 30 years (NSW Ports, 2015). There is also various subsea infrastructure under Botany Bay that potentially generates underwater noise.

No baseline monitoring was carried out near the project areas because the assessment thresholds for both construction and operational noise are fixed absolute thresholds (e.g. fixed limits). They are not relative to the existing noise levels like the management levels defined for residential receivers in airborne noise assessment. The effect of considering existing ambient noise would be to only reduce the size of the predicted zones of impact (e.g. at distances far enough from the source that sound from the project activities is no longer audible against the ambient noise).

Ambient underwater noise is likely to be heavily influenced by shipping movements through the headlands and from vessel movements within Botany Bay. While ambient noise levels could be as high at 190 dB (re: 1 µPa) this would only last for a short period while ships to pass through the area. The noise would also attenuate to around 120 to 150 dB (re: 1 µPa, Bowles and Graves, 2007).

5 Impact assessment

This Chapter presents the predicted underwater noise impacts.

5.1 Marine species

For ease the following section reports the unweighted model predicted noise levels. The tables show the unweighted sound (and peak) pressures levels at set distances from the piling/vessels and the exposure levels (the amount of energy) at the same set distances. The tables report the results out to one kilometre. Appendix E confirms the predicted extent of the impacts, which extend out to 2.25 km in some instances.

A simple shading has been shown to show the predicted worst-case impact where:

- **Green shading** shows the potential for behavioural impacts.
- **Light orange** shading shows the potential for temporary hearing loss.
- **Dark orange** shading shows the potential for permanent hearing loss.

The predicted impacted species are also listed, noting that these are taken from Appendix E. They do not directly relate to the shading. They are provided to help simplify the reporting.

5.1.1 Piling

Table 8 shows the predicted maximum unweighted underwater noise levels at fixed distances from where the wharf piles would be installed. Appendix G shows graphs of the predicted piling noise levels.

Table 8. Maximum unweighted underwater noise levels from piling

Metrics	**Maximum noise level (dB) at specified distances from pile**				
	50 m	**100 m**	**300 m**	**500 m**	**1 km**
Sound Pressure Level (single strike)					
La Perouse	200	195	187	184	181
Kurnell	199	195	187	184	181
Model predicted impacts: *Behavioural response* | marine mammals, sea turtles, diving birds and humans.					
Peak Pressure Level (single strike)					
La Perouse	210	205	197	194	191
Kurnell	209	205	197	194	191
Model predicted impacts: *Permanent hearing loss* | (high frequency) cetaceans, sea turtles, fish and sharks					
Sound Exposure Level (single strike)					
La Perouse	184	179	171	168	165
Kurnell	183	179	171	168	165
Model predicted impacts: *Temporary hearing loss* | (low frequency) cetaceans					
Sound Exposure Level (cumulative strikes)					
La Perouse	214	208	201	198	195

Metrics	Maximum noise level (dB) at specified distances from pile				
	50 m	100 m	300 m	500 m	1 km
Kurnell	210	206	198	196	193
Model-predicted impacts: ***Permanent hearing loss*** | (low and high frequency) cetaceans, dugong, sea turtles, fish, sharks, and diving birds. ***Temporary hearing loss*** | (mid frequency) cetaceans, and seals.					

5.1.2 Construction vessels

Table 9 shows the predicted maximum unweighted underwater noise levels at fixed distances from where the construction vessels would be used. Appendix G shows graphs of the predicted piling noise levels.

Table 9. Maximum unweighted underwater noise levels from the construction vessels

Metrics	Maximum noise level (dB) at specified distances from pile				
	50 m	100 m	300 m	500 m	1 km
Sound Pressure Level					
La Perouse	137	133	129	127	124
Kurnell	136	133	128	126	124
Model-predicted impacts: ***Behavioural response*** | marine mammals and diving birds.					
Sound Exposure Level (one vessel)					
La Perouse	171	167	163	161	158
Kurnell	170	167	162	160	158

5.1.3 Operational ferries (at the wharves)

Table 10 shows the predicted maximum unweighted underwater noise levels at fixed distances from where the ferries would operate near the wharves. Appendix G shows graphs of the predicted piling noise levels.

Table 10. Maximum unweighted underwater noise levels from the operational ferries at the wharves

Metrics	Maximum noise level (dB) at specified distances from pile				
	50 m	100 m	300 m	500 m	1 km
Sound Pressure Level					
La Perouse	145	141	137	135	132
Kurnell	144	141	136	134	132
Model-predicted impacts: ***Behavioural response*** | marine mammals and diving birds.					
Sound Exposure Level (one vessel)					
La Perouse	179	175	171	169	166
Kurnell	178	175	170	168	166

5.1.4 Operational ferries (travelling between the wharves)

Table 11 shows the predicted maximum unweighted underwater noise levels at fixed distances from where the ferries would operate between the wharves. Appendix G shows graphs of the predicted piling noise levels.

Table 11. Maximum unweighted underwater noise levels from the ferries operating between the wharves

Metrics	Maximum noise level (dB) at specified distances from pile				
	50 m	100 m	300 m	500 m	1 km
Sound Pressure Level					
In transit	148	143	138	135	132
Model-predicted impacts: ***Behavioural response*** | marine mammals and diving birds.					
Sound Exposure Level (one vessel)					
In transit	182	177	172	169	166

5.2 Human impacts

In terms of humans, they are likely to hear the piling if they are in the water or diving in the Bay and no mitigation was introduced. The noise levels will become increasingly uncomfortable for distances closer to the piling to the point where divers are unlikely to wish to remain in the water. Even at levels below the tolerance limit, there is the potential that noise levels may result in indirect safety impacts for divers (particularly for inexperienced divers) if sudden noise levels result in a startle or panic reaction. This highlights the importance of effective community notification of piling and the need for a "soft start" regime so that noise levels do not suddenly increase. Within about 300 metres of the works there is the potential for physical injury to anyone in the water if no mitigation was introduced.

6 Mitigation measures

The guidelines in Chapter 3 have been used to define three zones to reduce underwater noise impacts.

- **Zone 1** | where work should stop.
- **Zone 2** | where work-restrictions (exclusions) should be introduced.
- **Zone 3** | where spotters would observe for noise-sensitive species entering the area.

The zones can only be confirmed once the final construction method is known and onsite monitoring is carried out to verify the noise propagation. This is to overcome the limitations in the modelling described in Section 4.3 above. The proposed zones below account for this uncertainty meaning they are conservative.

In some cases, the modelling predictions would result in a recommended exclusion zone that would be larger than the standard observation zones from the SA guidelines. In these cases, an observation zone 20 per cent larger than the exclusion zone has been defined.

6.1 Defining the zones

Zone 1 | stop work

The preliminary recommended stop-work zones are based on the predicted areas of impact from a single piling strike. While these distances are much smaller than the predicted impact areas from additive piling (refer to Chapter 5 above), they account for the fact that measures would be put in place before starting work to ensure no noise sensitive species were in the area (refer to section 6.2.1 below). This would minimise the risk for hearing loss or injury. Also, the slow start-up of works would allow species to move away from the noise source.

Zone 2 | work restrictions

The work restriction (exclusion) zones have been developed from the guidelines (refer to Chapter 4 above). They have been modified to consider the model-predicted distance where temporary or permanent hearing loss may occur from a single piling strike or temporary hearing loss may occur (in cetaceans, seals, dugong, and sea turtles) from multiple piling strikes(i.e. should an animal remain in the area for the duration of the piling works and not avoid the noise source). Appendix F explains how the zones have been modified.

Zone 3 | observations

It is only practical to include an observation zone for marine megafauna as these can be easily spotted as they need to come up for air every so often. It would not be feasible to observe other species, something recognised in the guidelines. The observation zones have been based on the recommended zones from the Guidelines or the size of the restriction/stop work zones; whichever is the greater.

Humans

Appendix E shows that humans may not be comfortable with the noise generated from piling anywhere in Botany Bay. However, there is an existing level of ambient noise already from the range of shipping and other activities. Also, the safety restrictions and exclusions around the construction boundary would prevent people from being in the water near the works (i.e. in the area where there is potential for injury). This would reduce the risk people suffering temporary or permanent hearing loss.

Activities

Exclusion and observation zones were defined for the piling works to manage the potential for temporary and permanent hearing loss.

Zones were not established to mitigate behavioural changes as these are temporary impacts where the response of an animal may be to move away from the noise source to a point of safety, and because other factors (e.g. feeding, predators/prey, migration routes) would also influence the animal's behaviour and may override any impacts from noise sources.

Exclusion and observation zones are not recommended for any shipping noise sources as they would only result in behavioural changes (refer to Chapter 5 above) and there is no predicted risk of direct injury to animals resulting from shipping noise.

6.2 Zones

Table 12 lists the maximum zones to be adopted when carrying out the piling works if no other mitigation was introduced. The upper zone limits show the default zone used as a worst-case. As noted above in Section 4.3, because the noise modelling includes a range of assumptions, the following zones are likely a precautious upper limit. They should be verified and adjusted onsite before starting the main piling works. They can also be adjusted depending on the species in the area at the time. For instance, the stop work zone could be as little as 10 metres if there are only seals in the area.

Table 12. Recommended observational and exclusion zones summary

<table>
<tr><th rowspan="2">Group</th><th>Zone 1
Stop work</th><th colspan="2">Zone 2
Restrict work</th><th colspan="2">Zone 3
Observations</th></tr>
<tr><th>Both locations</th><th>La Perouse</th><th>Kurnell</th><th>La Perouse</th><th>Kurnell</th></tr>
<tr><td>Upper zone limits</td><td>330 m</td><td>2.25 km</td><td>1.75 km</td><td>3 km</td><td>2 km</td></tr>
<tr><td>Cetaceans (low frequency)</td><td>240 m</td><td>2.25 km</td><td>1.75 km</td><td>3 km</td><td>2 km</td></tr>
<tr><td>Cetaceans (mid frequency)</td><td>10 m</td><td colspan="2">100 m</td><td colspan="2">1 km</td></tr>
<tr><td>Cetaceans (high frequency)</td><td>330 m</td><td colspan="2">1 km</td><td colspan="2">2 km</td></tr>
<tr><td>Sirenians (dugong)</td><td>15 m</td><td>500 m</td><td>300 m</td><td colspan="2">1.5 km</td></tr>
<tr><td>Otariids (seals)</td><td>10 m</td><td colspan="2">300 m</td><td colspan="2">1.5 km</td></tr>
<tr><td>Sea turtles</td><td>60 m</td><td>1 km</td><td>750 m</td><td colspan="2">2 km</td></tr>
<tr><td>Fish</td><td>60 m</td><td colspan="4">-</td></tr>
<tr><td>Birds</td><td>10 m</td><td colspan="4">-</td></tr>
</table>

6.2.1 Work-restrictions

The various guidelines in Chapter 3 provide practical management and mitigation measures for restricting work practices within the exclusion zones where piling is proposed. These are defined to protect marine mammals. Specifically:

Overall:

- Carry out initial monitoring in the area before starting work to verify the underwater noise levels and modify the zones.
- Maintain minimum separation between construction vessels and marine mammals as per the NSW declared approach distances from the Biodiversity Conservation Regulation 2017.
- Where reasonable and feasible use bubble curtains to reduce the severity of the energy of the sounds caused by the driving of the piles.
- Use alternative methods during poor weather and visibility (e.g. sonar and radar).
- Carry out observations for 30 minutes before starting work in all zones.
- Have a slow-start process for the piling works that would last for 10 minutes.
- Implement a stand-by and shut down process.
- Prepare and maintain a compliance and siting report while piling takes place.
- Notify the recreational user groups in the area and post notices at the key beaches warning people of the ongoing piling works so that can expect potential underwater noise.
- Aim to avoid piling at the weekend and during public holidays.

Zone 3 (Botany Bay) | observations

- Have a marine mammal spotter carry out regular inspections across Botany Bay over the duration of the project for noise-sensitive species.
- Ensure the spotters have the authority to restrict or stop work in the event of a possible risk.

Zone 2 (2.25 km from the piling) | potentially restrict work

- Reduce the piling rate and intensity in the area under the instruction of the marine spotter, relative to the species and its movement either towards or away from the piling work.
- If a noise-sensitive species is approaching Zone 1 then prepare to stop work.

Zone 1 (330 metres from the piling) | stop work

- Stop all piling and other boat movements in the area.
- Only restart work under the marine spotter’s authority.
- Restart under the a slow-start process described above.

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Appendix A

Policy context

A1 Australian context

The following Australian policy and planning documents were considered in this assessment:

- Great Barrier Reef Underwater Noise Guideline Discussion and Options Paper (GBRMPA, 2017)
- The Australian Environment Protection and Biodiversity Conservation Act 1999 (EPBC), including the Matters of National Environmental Significance (MNES)
- EPBC Act Policy Statement 2.1 –Interaction between offshore seismic exploration and whales, Department of the Environment, Water, Heritage and the Arts (2008)
- Government of South Australia Underwater Piling Noise Guidelines (2012).

A2 International

The following international underwater noise guidelines and documents were considered in this assessment:

- 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.)
- 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)
- 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)
- New Zealand 2013 Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations
- European Marine Strategy Framework Directive
- International Standard ISO 18405 (2017) Underwater Acoustics – Terminology.

Appendix B

Desktop review and criteria assessment

B1 Assessment criteria for noise sensitive receivers

B1.1 Assessment criteria for noise sensitive receivers

This assessment has used underwater noise criteria for measuring impacts of injury and behavioural changes to marine fauna and humans that are the most widely accepted and applied in Australia and internationally. The criteria adopted for this assessment have been presented using the terminology in ISO 18405 Underwater Acoustics – terminology (ISO, 2017).

The current resources utilised to determine the marine fauna and human swimmer/diver threshold criteria include but are not limited to those listed previously in Appendix A.

B1.2 Application of assessment criteria

The SA Underwater Piling Noise Guidelines have been the main resource and benchmark for determining underwater noise requirements for marine mammals in Australia since 2012. These guidelines were developed using the marine mammal frequency weighting and impact thresholds defined in Southall et al. (2007). However, these weighting functions and impact thresholds have been revised in Southall *et al.* (2019) considering subsequent scientific findings since 2007, with the update proposing revised noise exposure criteria to predict the onset of auditory effects in marine mammals. Southall *et al*. (2019) replaces Southall et al. (2007) as the most relevant criteria for assessment of injurious impacts on marine mammals.

The thresholds and weighting functions described in Southall *et al.* (2019) are in line with those stipulated in the US National Marine Fisheries Service (NMFS) Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (NMFS 2018). Southall et al. (2019) and NMFS (2018) do not include criteria for behavioural responses in marine mammals – to assess this the widely accepted thresholds applied by the US National Oceanic and Atmospheric Agency (NOAA) have been applied (NOAA, 2019).

The listed species likely to be present in the project study area include a range of marine fauna in addition to marine mammals, for which the SA Guidelines provide no recommendations. For this marine fauna, it is proposed to use criteria, guidelines and sound levels (referred to as 'thresholds') from literature. There is little known about the hearing of non-mammalian project specific marine fauna. The impact assessment proposes to use an approach which doesn't require an assessment of species-specific hearing and estimated thresholds, but rather conducts a robust assessment using applicable and justifiable thresholds commonly used and widely accepted in underwater noise impact assessments. This approach is described in Great Barrier Reef Underwater Noise Guideline Discussion and Options Paper (GBRMPA, 2017).

The Great Barrier Reef Marine Park Authority commissioned a guidance document, published in 2017 to inform the process of developing a guideline for considering and managing the impacts of anthropogenic underwater noise on the Great Barrier Reef's marine fauna. This document reviews current understanding of underwater noise and application. It also considered the technical approaches of how underwater noise should be appropriately measured and modelled. It provides a summary of best practice and internationally accepted methodologies. In addition, it reviews 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.

B1.3 Metrics

Due to the variable use of terminology in underwater acoustics there has been some ambiguity across different studies regarding effects on marine fauna. 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 B1.

Table B1. 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	SPLrms, SPLRMS	SPL	SPL (Lp)
Peak Pressure	SPLpk	PK	PK (Lpk)
Sound Exposure Level	SELcum	SEL24h	SEL24h (LE,24h)

B1.4 Marine mammals

The information currently available suggests a more refined understanding of hearing, hearing thresholds and behavioural responses. This increased knowledge also includes a better understanding of the auditory effects in marine mammals.
In addition, there has been a change in the approach of how hearing is represented, i.e. through weighting functions that are adjusted for the animal's frequency sensitivity.

Criteria for Temporary (TTS) and Permanent (PTS) threshold shifts have been better refined by the latest available literature and suggest different thresholds for peak, SEL and SPL that indicate potential for the onset of changes in hearing – i.e. the older criteria (including the Mmf and Mlf weightings) have generally been found to be over-conservative. For the most part, cetaceans have been referred to low, mid, and high frequency hearing (Table B2). 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. Cetaceans are divided into three categories as follows:

- Low-frequency cetaceans (LF): which consist of baleen whales such as humpback whales
- Mid-frequency cetaceans (MF): which consist of toothed whales except porpoises and river dolphins
- High-frequency cetaceans (HF): which consist of porpoises and river dolphins.

For the purposes of this review, it is considered extremely unlikely for high-frequency cetaceans to be present in the Botany Bay area, but they have been included for reference. Table B2 and Table B3 present behavioural and injury criteria for marine mammals for impulsive and continuous noise respectively. Note that in the following tables (and generally in this report, formatting is used to help differentiate criteria expressed in different underwater noise parameters – parameters for peak sound are presented in plain text, parameters for SPL are presented in underline and parameters for SEL (weighted or unweighted) are presented in bold.

Table B2 Commonly applied behavioural and injury criteria for marine mammals (Impulsive)

Effect	Low- frequency cetaceans	Mid-frequency cetaceans	High-frequency cetaceans	Sirenians	Otariid Pinnipeds
Behavioural Response	160 dB SPL re 1 µPa for impulsive noise, (NOAA,2019)				
TTS	213dB PK 168 dB SEL24hr (weighted)	224 dB PK 170 dB SEL 24hr (weighted)	196 dB PK 140 dB SEL 24hr (weighted)	220 dB PK 175 dB SEL24hr (weighted)	226 PK 188 dB SEL24hr (weighted)
PTS	219 dB PK 183 dB SEL24hr (weighted)	230 dB PK 185 dB SEL24hr (weighted)	202 dB PK 155 dB SEL24hr (weighted)	226 dB PK 190 dB SEL24hr (weighted)	232 PK 203 dB SEL24hr (weighted)
References	U.S. National Marine Fisheries Service (NMFS) criterion (NMFS 2018))				

Table B3. Commonly applied behavioural and injury criteria for marine mammals (non-impulsive /continuous noise) (TTS and PTS from Table AE-1, NMFS 2018)

Effect	Low- frequency cetaceans	Mid-frequency cetaceans	High-frequency cetaceans	Sirenians	Otariid Pinnipeds
Behavioural Response	120 dB SPL re 1 µPa for non-impulsive noise, (NOAA,2019)				
TTS	179 dB SEL24hr (weighted)	178 dB SEL 24hr (weighted)	153 dB SEL 24hr (weighted)	186 dB SEL24hr (weighted)	199 dB SEL24hr (weighted)
PTS	199 dB SEL24hr (weighted)	198 dB SEL24hr (weighted)	173 dB SEL24hr (weighted)	206 dB SEL24hr (weighted)	219 dB SEL24hr (weighted)
References	U.S. National Marine Fisheries Service (NMFS) criterion (NMFS 2018))				

B1.5 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. For some species or groups, absolute thresholds are not provided and instead the relative risk to the animal is provided as High, Moderate or Low based on the relative proximity of the animal to the sound source.

It is recommended that mitigation measures as described in Chapter 6 be considered to reduce likelihood of mortality (Table B4 and Table B5).

Table B4. Fish injury criteria due to impulsive sounds (e.g. pile driving), information reproduced from (Popper *et. al*. 2014).

Type of animal	Mortality and Potential mortal injury	Impairment Recoverable injury	TTS	Masking	Behaviour
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

Type of animal	Mortality and Potential mortal injury	Impairment Recoverable injury	TTS	Masking	Behaviour
Fish: Swim bladder not involved in hearing (particle motion detection)	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)	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 fish 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).

Table B5. Fish injury criteria due to shipping and continuous sounds, information reproduced from (Popper *et. al.* 2014).

Type of animal	Mortality and Potential mortal injury	Impairment Recoverable injury	TTS	Masking	Behaviour
Fish: No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB SPL (48 hours exposure) (equivalent to 222 dB SEL)	158 dB SPL (12 hours exposure) (equivalent to 204 dB SEL)	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Fish eggs and fish larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

SPL = rms sound pressure level dB re 1 µPa

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).

B1.6 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 sharks have been assumed to fall into a similar category as fish with no swim bladder (particle motion detection).

B1.7 Sea turtles

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 regarding pile driving (Table B6).

Additional criteria for sea turtles were sourced from Finneran et al 2017 and McCauley et al 2000 as summarised in Table B6 and Table B7.

Table B6. Sea turtle injury and behavioural criteria, impulsive sources (e.g. piling).

Mortality and Potential mortal injury	Impairment			Behaviour	Reference
	Recoverable injury	TTS	Masking		
207 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 SEL24hr (weighted) 232 dB PK	-	189 dB SEL24hr (weighted) 226 PK	-	-	Finneran et al. (2017)
-	-	-	-	175 dB SPL	McCauley et al (2000)

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).

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.

Table B7. Sea turtle injury and behavioural criteria, continuous sources (e.g. shipping)

Mortality and Potential mortal injury	Impairment			Behaviour	Reference
Recoverable injury		TTS	Masking		
(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low	Popper et at. 2014
PTS: 220 dB SEL24hr (weighted)	-	200 dB SEL24hr (weighted)	-		Finneran et al. (2017)

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).

B1.8 Birds

There is little information available on birds (while diving) as far as the impact on hearing and behaviour due to in water pile driving. In air, all avian species, including marine birds such as penguins, have excellent hearing abilities but the capabilities and thresholds for avian hearing underwater is poorly understood and defined (Johansen *et al.*, 2016, Sørensen *et al.*, 2019). It is currently understood that birds would be able to perceive the sound from pile driving underwater based on the hearing ranges and sensitivity of a number of preliminary studies of freshwater and marine birds (Crowell, 2016, Johansen *et al.*, 2016, Sørensen *et al.*, 2019).

Both Crowell (2016) and Johansen *et al* (2016) suggested 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). In the study completed by Sørensen *et al.* (2019) established behaviour responses to sound play back trials of stimulus sound levels ranging from 100 to 120 dB re 1 µPa. This study identified clear behavioural response and startle responses at 120 dB re 1 µPa. As such 120 dB re 1 µPa (RMS) is therefore applied as the behaviour response threshold.

There is data in the literature regarding hearing injury and mortality impacts to diving birds from a proximity explosion (Yelverton *et al.*, 1973) which has a different acoustic energy composition to pile driving. However as there is still a lack of understanding of the hearing and behavioural impacts of impulse noise on marine birds (diving) estimated thresholds (Table B8 below) have been based on data from explosions. This is expected to be conservative due to the shorter rise time of explosive sources compared to impact piling.

Table B8. Estimated thresholds for bird injury and behaviour.

Species	Injury to mortality	Behavioural response
Birds (diving)	190 dB SEL (Yelverton *et al.* 1973)	120 dB (dB re 1 µPa) (Sørensen *et al* 2019)

B1.9 Invertebrates

In the Marine Ecology Assessment Report, squid and crayfish were identified as a species of concern to the local recreational fisherman. As such Squid and crayfish were reviewed for potential impacts to under water noise (Table B9 below). They are referred to for discussion and general discussion on potential impacts.

B1.10 Cephalopods

Squid are within the Class Cephalopoda with also is inclusive of octopus and Cuttlefish. They are a soft bodies animal with limited “bony structures”. They do not have “ears” per se but sense the particle motion components of sound pressure waves moving through water (Mooney *et al*, 2012) via their statocyst structures. As such thresholds are based on behavioural responses which include escape responses, “inking” and agitated physiological behaviours. In 2012, Fewtrell and McCauley completed experiments on captive squid and determined behavioural responses to air gun sounds, at 162 dB re 1 µPa2 (per pulse SEL).

B1.11 Crustaceans

In crayfish, sound is received though a pair of statocysts organs in the cephalothorax, chordotonal organs associated with joints of antenna, legs and an array of internal and external hair like mechano-receptors (sensilla). Hearing is more in the form of particle motion where they detect changes in water movements associated with sound pressure waves and though vibrations (Svenja and Briffa, 2016). Responses of crayfish to impulsive sounds have a wide range of reactions and effects between species and individuals. In Payne *et al* (2007) it was concluded that 202 dB re 1 µPa was considered a suitable level to induces behaviour responses, without inducing mechano-sensory damage and or mortality.

Table B9. Invertebrate behaviour response thresholds

Invertebrate	Behavioural Response	Reference
Squid	162 per pulse SEL unweighted	Fewtrell & McCauley 2012
Crayfish (lobster)	202 dB re 1 µPa (Peak to Peak)	Payne et al. 2007

7.1.1 Humans

Parvin (2005) summarises criteria for human divers from various sources in the literature (Table B10 below) and recommends a threshold for behavioural impacts of 145 dB re 1 µPa (SPL) for low-frequency underwater noise.

Table B10. Summary of effects of low-frequency underwater sound on human divers

Received SPL	Effect
>184 dB	Liver haemorrhage and soft tissue damage likely*
>170 dB	Tolerance level for divers and swimmers. Sound causes lung and body vibration
148-157	The loudness and vibration levels become increasingly aversive. Some divers will contemplate aborting an open water dive.
140-148	A small number of divers rate the sound as “very severe”
136-140	The sound is clearly audible. Most divers tolerate the sound well with only “slight” aversion
130	Divers and swimmers able to detect body vibration
80-100	Auditory threshold

*Based on extrapolation from animal models of pressure-induced damage

The human underwater hearing threshold has been estimated anywhere from 70 dB re 1µPa to 120 dB re 1µPa with dizziness, vertigo and auditory changes noted from 167 dB re 1µPa (Parvin, 2005).

Although injury may not occur at these levels, the risk with pile driving and diving, particularly to recreation divers, is the potential panic response. The assessment completed by Parvin (2005) was completed on professional divers that are trained to deal with higher risk situations.

As such recreational divers exposed to a loud unexpected sound will have higher risk of incident than high risk trained professionals therefore the 145 dB re 1 µPa threshold is conservative and has been identified as a suitable level of protection for continuous and impulsive noise. The range of expected reaction from human divers ranges from the onset of severe reaction at ~145 dB SPL through to the tolerance level (i.e. near-total negative reaction) at ~170 dB SPL.

This level has also been applied as the accepted threshold level in similar applications in the Sydney region (Roads and Maritime Services, 2020 – Chapter 19 and Appendix I).

Appendix C

Noise sources

C1 Noise sources

A review of the scientific literature has been conducted to determine appropriate source levels for the proposed piling works during construction and vessel movements during operation of the project.

C1.1 Piling – project information

Different methods of piling are likely to be used depending on the ground conditions and further geotechnical investigation works. The following types of piles would potentially be used in each site.

- La Perouse:
- Bored piles, 600 mm diameter
- Screwed piles, 600 mm diameter
- Traditional driven piles, maximum 900 mm diameter
- Kurnell:
- Screwed piles, 600 mm diameter
- Traditional driven piles, maximum 900 mm diameter.

7.1.1.1 Piling – Literature review

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. Similarly, where a variety of piling methods are going to be used, a conservative approach has been followed where all piles have been assumed to be driven piles using impact piling.

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.* (2016), 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 10 m to source levels at 1m from the pile. (The assumption of spherical propagation close to the pile is considered a reasonable assumption provided that the water depth is greater than the propagation distance).

Figure C1 below, from Li and McPherson (2018), shows the modelled one third octave level of received signal with highest SEL at 10 m for 1.2 m 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 µPa2 s, which is equivalent to approximately 210 to 212 dB re 1 µPa2 s at 1m.

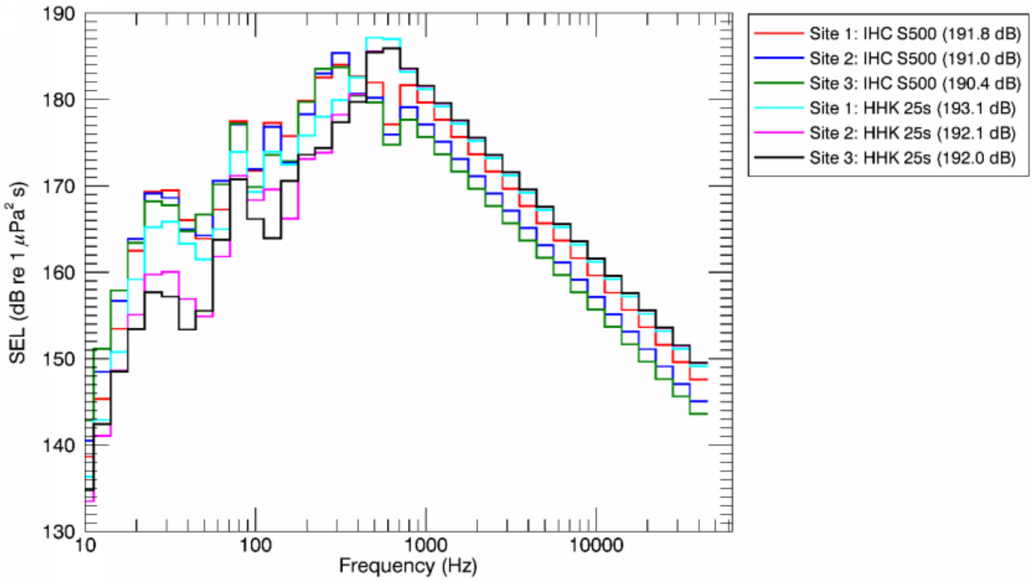

Figure C1. Modelled one third octave level of received signal with highest SEL at 10m for 1.2m diameter piles for two hammers and three sites, from (Li and McPherson, 2018).

Figure C1 and Figure C2 below, 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" (~0.8 m) or 24" (~0.6 m) 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 at 10 m was approximately 170-183 dB re 1 µPa2 s, and peak level at 10 m was approximately 200- 212 dB re 1 µPa.
The equivalent source levels are SEL at 1 m 190-203 dB re 1 µPa2 s, peak 220-232 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. Maximum SEL at 10m was approximately 171 dB re 1 µPa2 s and maximum peak at 10 m approximately 198 dB re 1 µPa.

The equivalent source levels are SEL at 1 m 191 dB re 1 µPa2 s and peak at 1m 218 dB re 1 µPa.

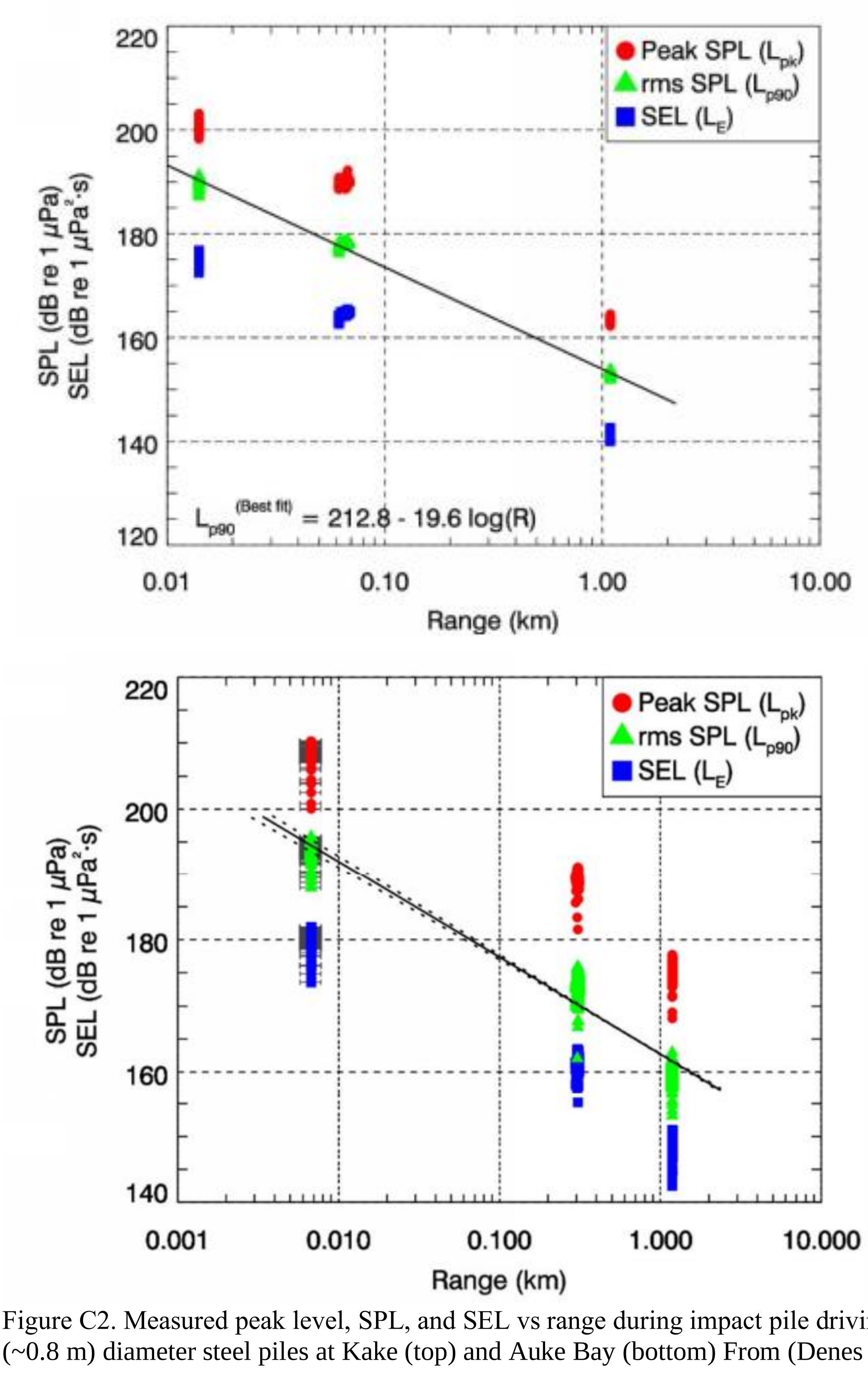

Figure C2. Measured peak level, SPL, and SEL vs range during impact pile driving for 30" (~0.8 m) diameter steel piles at Kake (top) and Auke Bay (bottom) From (Denes et al., 2016).

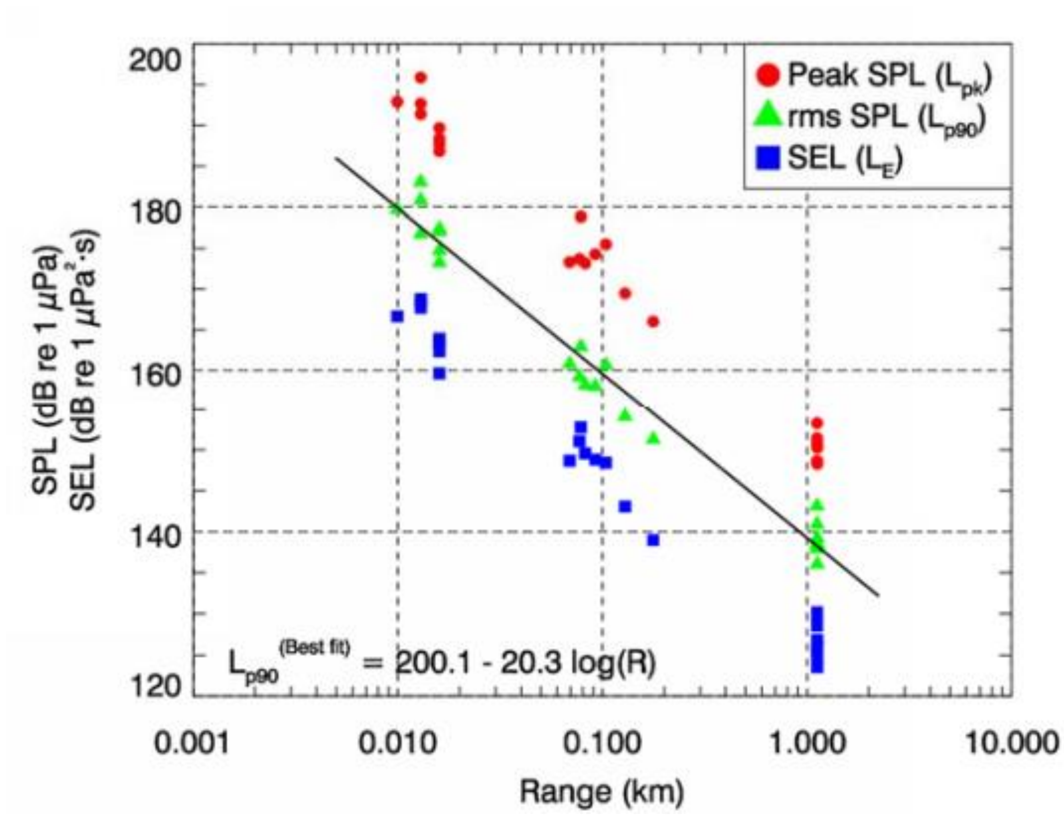

Figure C2: Measured peak level, SPL, and SEL vs range during impact pile driving for 24” (~0.6 m) diameter steel piles, Kodiak, from (Denes et al., 2016).

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 at 10 m for a 0.75 m diameter pile (~240 dB re 1 µPa at 1 m), and 200 dB re 1 µPa at 300 m for a 5 m 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 many 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 at 10 m and SEL at 10 m were:

- 0.6 m piles PK 203-207 dB re 1 µPa, SEL 177-180 dB re 1 µPa2 s
  (source levels of 223-227 dB re 1 µPa and 197-200 dB re 1 µPa2 s)
- 1.0 m piles PK 208-210 dB re 1 µPa, SEL 180-183 dB re 1 µPa2 s
  (source levels of 228-230 dB re 1 µPa and 200-203 dB re 1 µPa2 s)
- 2.4 m piles PK 220 dB re 1 µPa, SEL 195 dB re 1 µPa2 s
  (source levels of 240 dB re 1 µPa and 215 dB re 1 µPa2 s).

A peak level of 206 dB re 1 µPa at 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 at 10 m was on average 223 dB re 1 µPa and SEL at 10 m was 194 dB re 1 µPa2 s (source levels of 243 dB re 1 µPa and 214 dB re 1 µPa2 s).

Measurements of steel driven piles for temporary piles of 0.75 m diameter were presented in (Erbe, 2009). At the closest distance from the pile, 14 m, the recorded peak level was 207 dB re

1 µPa, and the SEL was 183 dB re 1 µPa2 s (source levels of 230 dB re 1 µPa and 206 dB re 1 µPa2 s respectively).

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).

Regarding spectrum, further to the spectrum shown in Figure C3 from (Li and McPherson, 2018) the predicted values from MacGillivray et al (2011) shows a roll-off of piling noise at frequencies below 100 Hz (Figure C3 below).

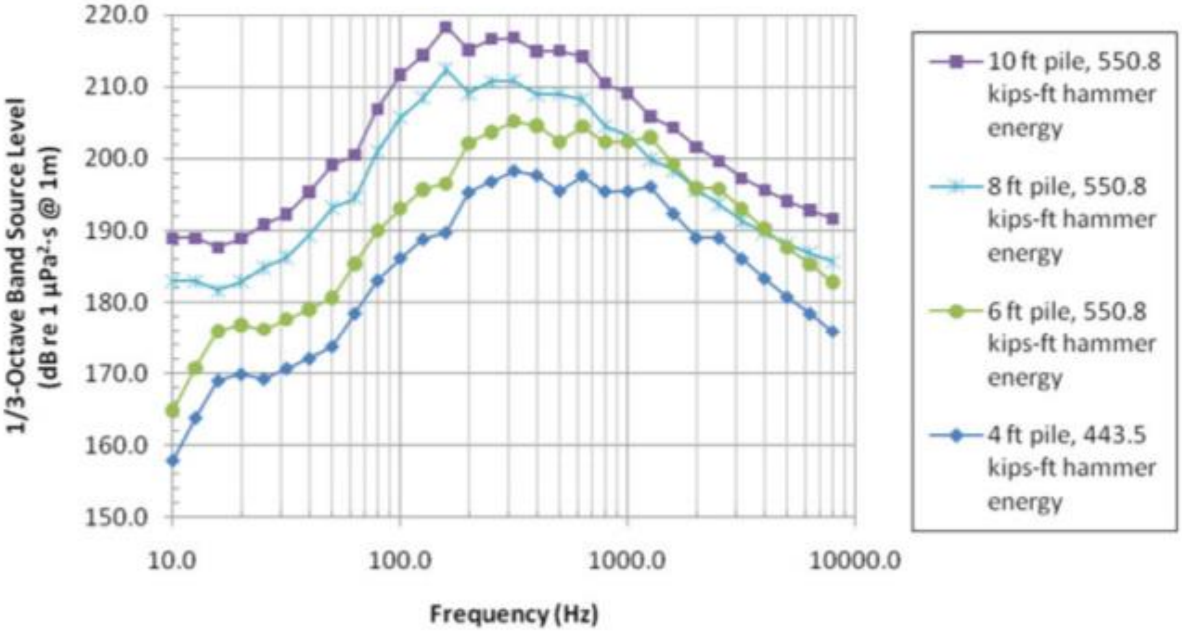

Figure C3: Predicted 1/3 octave band impact piling source levels for steel piles, from MacGillivray *et al* (2011)

The relevant piling levels found in the literature review for diameters up to 2.5 m are plotted in **Figure C4** and **Figure C5** below as a function of the pile diameter for the peak level and the SEL respectively. All values presented have been normalised to 1 m distance assuming spherical propagation. The vertical band shows the range of pile diameters to be used in the project, 0.6 m to 0.9 m.

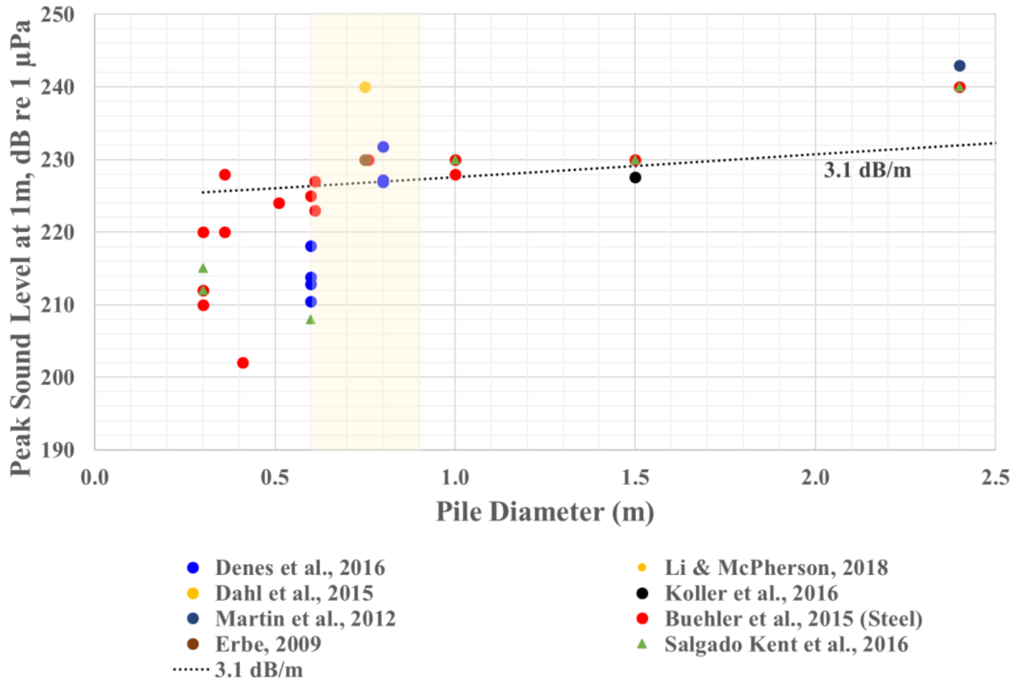

Figure C4. Comparison of peak piling levels vs pile diameter from literature normalised to 1 m assuming spherical propagation.

Where an interval of values is presented for a given pile diameter in the publication the maximum value is represented. A vertical cream colour band highlight the 0.6 m to 0.9 m diameter range, which represents the piles used in the project. 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).

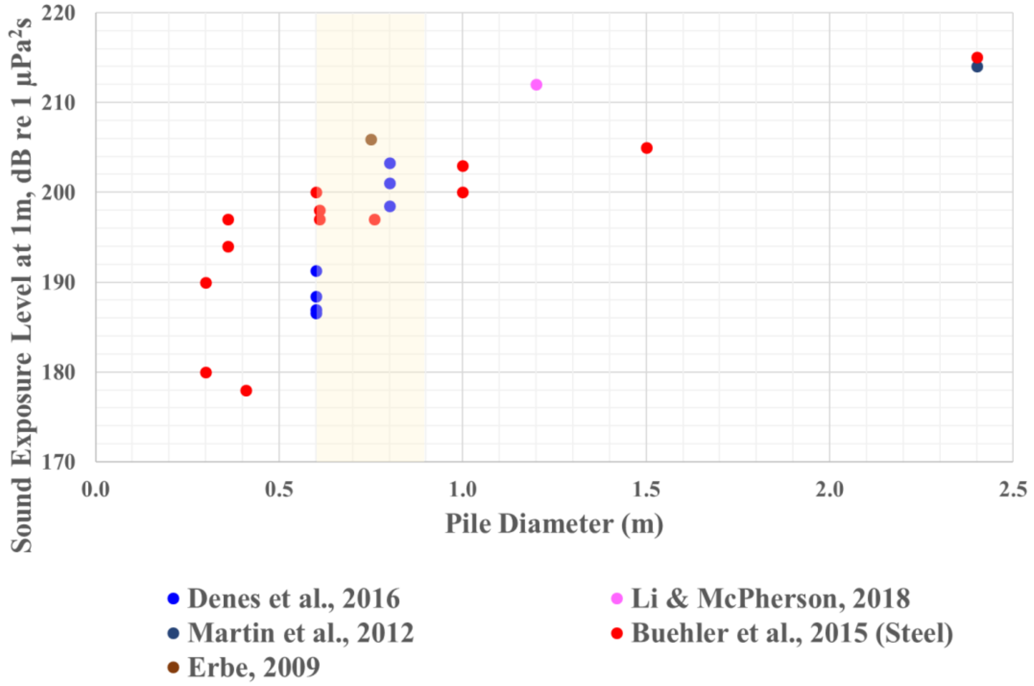

Figure C5. Comparison of SEL piling levels vs pile diameter from literature normalised to 1 m assuming spherical propagation.

Where an interval of values is presented for a given pile diameter in the publication the maximum value is represented. A vertical cream colour band highlight the 0.6 m to 0.9 m diameter range, which represents the piles used in the project.

C1.2 Project impact piling source levels

Peak and SEL source levels for the wharves piling have been set to be towards the upper end of the range for a 0.6-0.9m diameter driven pile as a conservative approach. The spectrum shape for the piles has been assumed based on the MacGillivray et al 2011 spectrum shapes for the 8ft pile (Table C1 below). Values for the 10 kHz 1/3 octave band 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.

Table C1. Piling source levels for the project

Metric	Source level for 0.9 m diameter pile
Sound Exposure Level (1 strike)	206 dB re 1 μPa2 s
Sound Pressure Level	222 dB re 1 μPa
Peak Pressure	232 dB re 1 μPa

The source spectra for the piling source levels are shown in Figure C6 below.

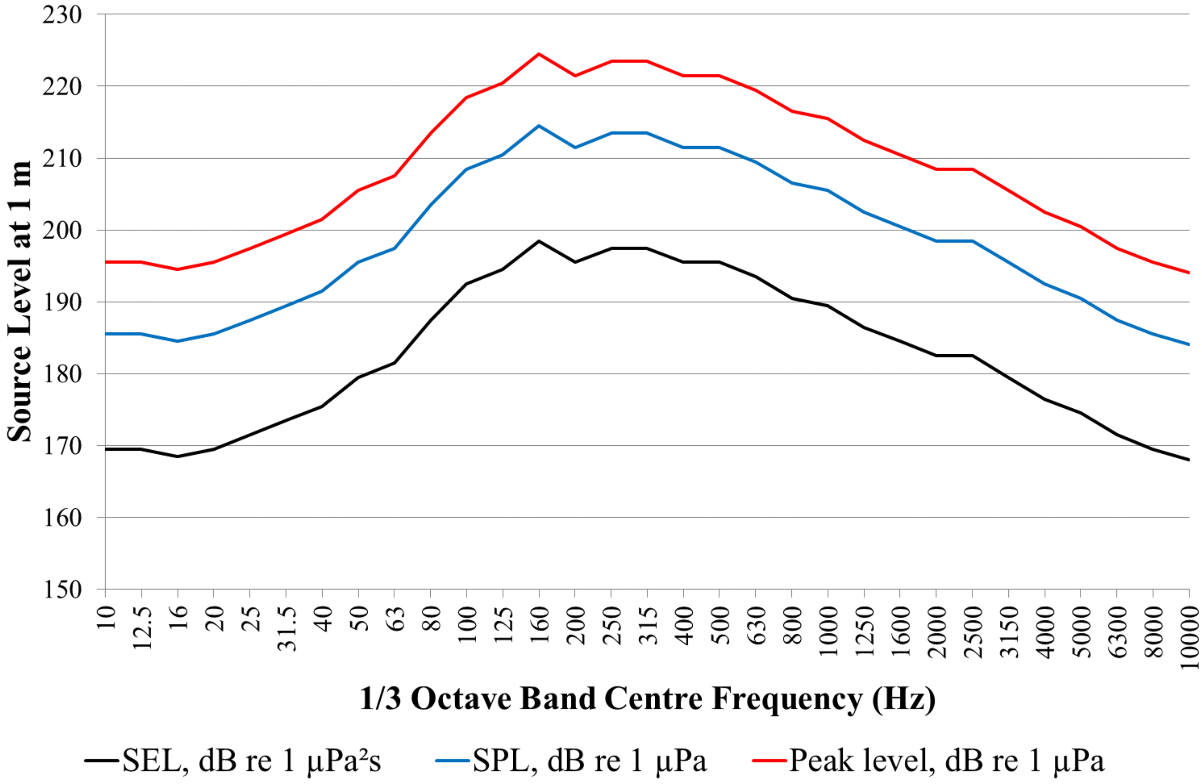

Figure C6. Spectrum for piling peak, SPL and SEL source levels at 1 m

These values are consistent with previous quoted piling source levels from recent literature and are conservative. Acknowledging the spread in the data in the literature shown in Figure C4 and Figure C5, it is recommended that early monitoring of actual piling levels within Botany Bay be conducted and if necessary, the predicted levels (and corresponding impact zones) updated.

For the piles used (0.6 – 0.9 m diameter) the number of strikes to drive each pile is assumed to be 600 (based on values cited in Buehler et al 2015 for piling up to 1 m diameter).

Noise from vibratory piling has not been assessed, as the potential physiological impacts are expected to be lower than those from impact pile driving (McCauley and Salgado Kent, 2008).

C2 Vessel noise

C2.1 Vessels – Project information

The wharves are designed to cater for small/medium ferries with a length overall (LOA) between ~15 – 40 m and are expected to carry up to 100 – 438 people. The following four vessels (Figure C7 to Figure C10 below) were identified as representative examples:

- Seacat One (LOA, 18m)
- Ocean Tracker (LOA 26m)
- Ocean Surface/Ocean Dreaming (LOA 30m)
- John Cadman II (LOA 39m).

Figure C7. Seacat One

Figure C8. Ocean Tracker

Figure C9. Ocean Surface/Ocean Dreaming

Figure C.10. John Cadman II

C2.2 Vessels – Literature review

Each type of vessel is characterised by a different acoustic signature which results from the combination on multiple factors such as the different sources of noise, where they are located, their spectrum, etc.

The main source of noise is typically the propeller and cavitation from the propeller when this occurs (Ross, 1976). The hull of the vessel can be excited resulting in vibration that radiates sound, and this could be the main source on noise on low power vessels, particularly those with a diesel engine firmly mounted (Abrahamsen, 2012). Additional noise can result from the mechanical equipment on board, but this is typically lower.

The image below from (MacGillivray, 2014) shows the source level of different vessels adjusted to 10 knot reference speed. Category 6 corresponds to small boats of 10-50 m LOA, which is the same length category as the proposed ferries to use the project wharves. The spectrum provided is equivalent to a source level of 172 dB re 1 µPa.

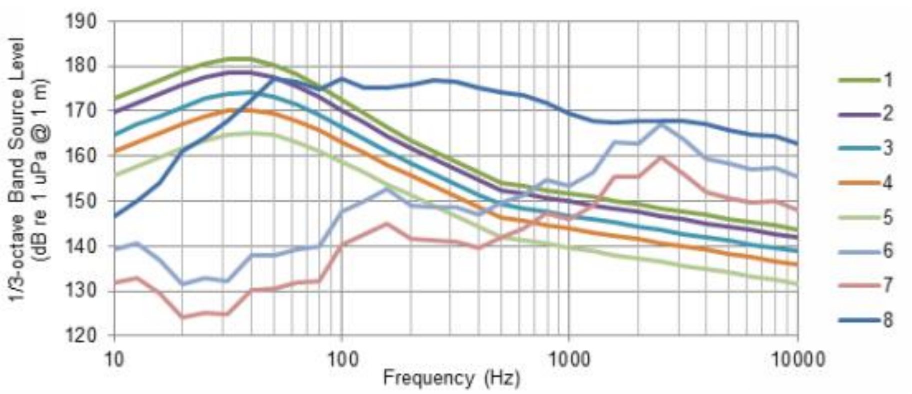

Figure C11. Source level of different vessels adjusted to 10 knot reference speed, from (MacGillivray, 2014)

The reported broadband source level produced by car ferries is 178-184 dB re 1 µPa @ 1m in (Salgado Kent *et al,* 2016) however these ferries are likely to be larger vessels than the vessels likely to use the project wharves. The estimated source level of large vehicular ferries (>100 m LOA) in (Bassett *et al.*, 2010) is 179 ± 4 dB at 1 m, which is consistent with the data from Salgado Kent et al, while data for 25 m Small Waterplane Area Twin Hull (SWATH) ferry with 2 inboard diesels was quoted as 166 dB re 1 µPa at 1 m (URS Australia, 2009).
For very large and powerful ferries, the source levels can be more than 200 dB re 1 µPa (Erbe *et*

al., 2019). The levels can vary by up to 40 dB for the same type of vessel depending on the design, speed, maintenance, etc. (Erbe *et al.*, 2019).

The values from MacGillivray 2014 are considered to be representative of the average vessel noise for vessels in the same length category as proposed for the project, noting also that the location of the measurements by (MacGillivray 2014) in the Great Barrier Reef means that vessels in this length category would likely include a proportion of tourist excursion vessels of similar size and construction to the ferries likely to be used for the project.

For ferries, the source level from (MacGillivray, 2014) of 173 dB re 1 µPa at 1m was used.

For small vessels associated with construction traffic, Category 7 vessels (up to 10 m length) with a source level of 165 dB re 1 µPa at 1 m have been used.

Botany Bay has significant existing commercial vessel traffic, and therefore vessel impacts from ferries will be operating between La Perouse and Kurnell must be placed into context of existing vessel traffic. Accordingly, the noise levels from existing commercial ships have also been modelled to assess the cumulative impact.

Hallett (2004) presented underwater noise data for merchant ships taken on entry/exit to the Port of Dampier and the Port of Gladstone and gives an average source level of 173 dB re 1 µPa at 1 m, with dominant frequencies 63-100 Hz (see Figure C12). The ships were mainly bulk carriers, with a tonnage range from 3500 to 201000 dwt, and vessel length from 89-320m.

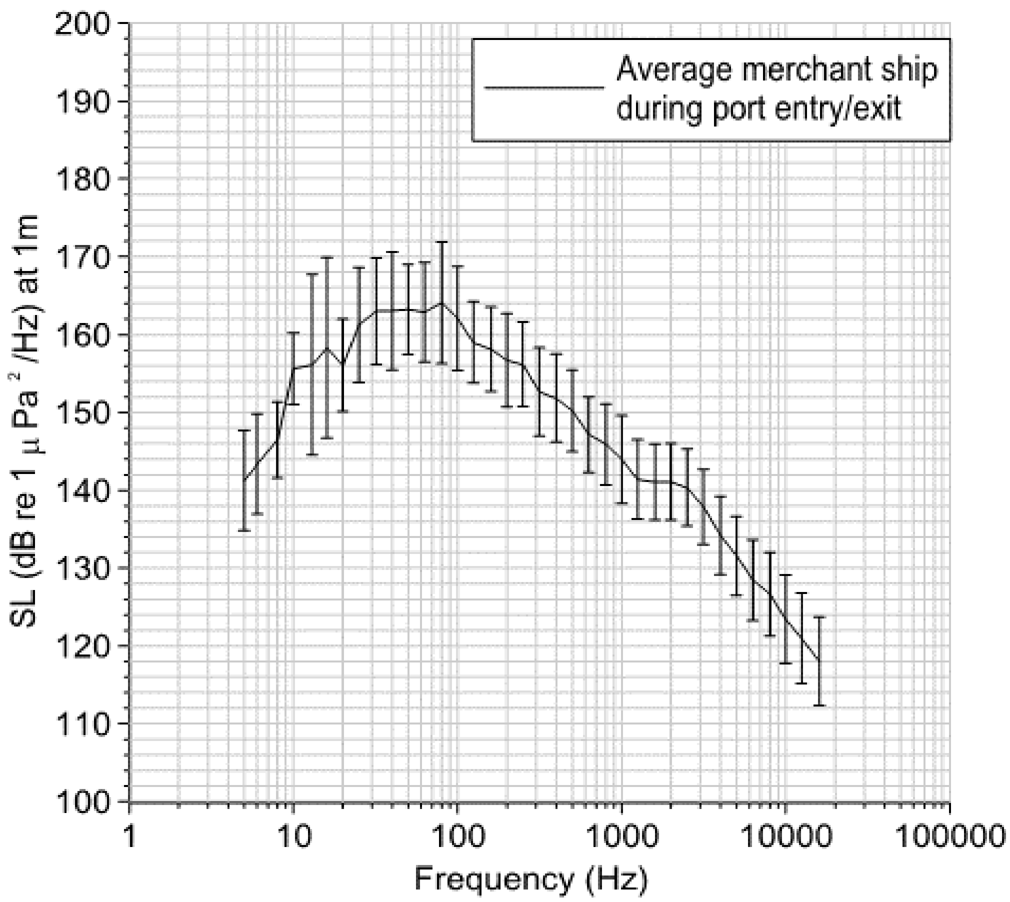

Figure C12. Average source level of bulk carriers entering/exiting port at mean speed of 10 knots, from Hallett (2004).

McKenna *et al.*, 2012 presents measurements of seven types of modern commercial ships in Santa Barbara Channel, California. The ship length ranged from 148-298 m and the displacement from 10,800 to 63,200 DWT.

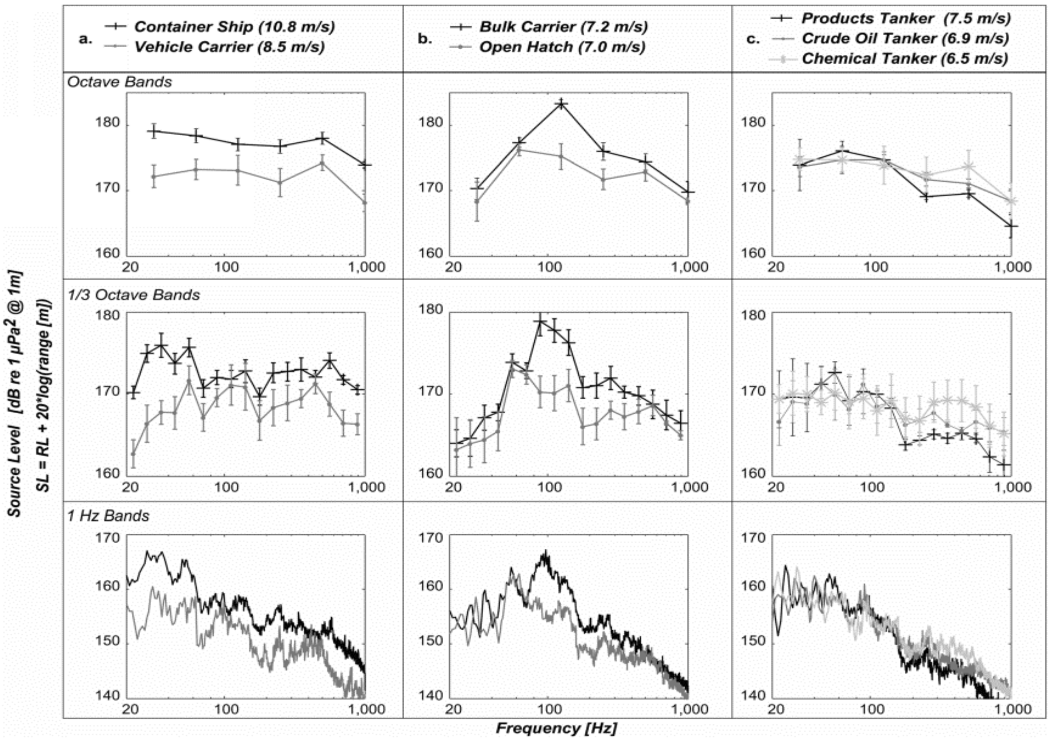

Figure C13. Ship source levels from (McKenna *et al.*, 2012)

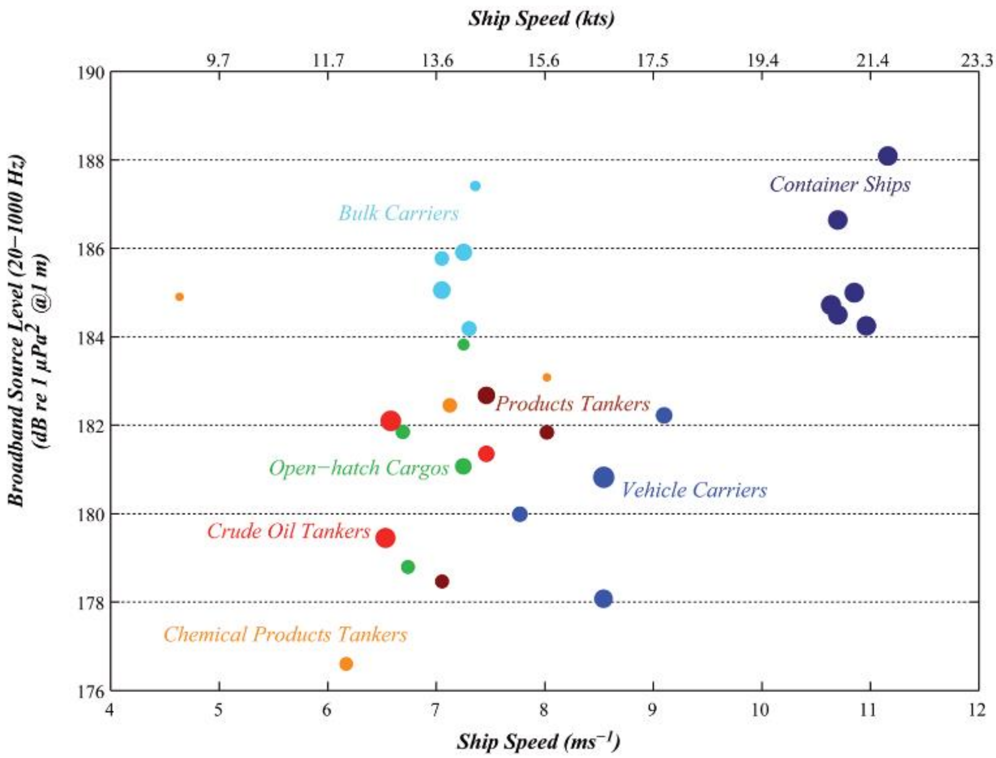

Figure C14. Relationship between ship type (colour), ship tonnage (size of bubbles), and ship speed on ship broadband source level (from McKenna et al 2012).

Comparison of the data from (Hallett 2004) for (mainly) bulk carriers at ~10 knots and the data from (McKenna *et al* 2012) in Figure C13 and Figure C14 above show a difference of ~10-15 dB in source level. This may be attributable to different speeds, different engine power settings (e.g. ships being potentially at full power when steaming in open water in (McKenna *et al* 2012) versus at lower power while exiting/entering port in (Hallett 2004), differences in tonnage of ship or even differences in the propagation assumptions used to back-calculate the source levels from the measured levels (distance not stated in (Hallett 2004); 3 km distance in (McKenna *et al*).

When normalised to the same speed (to 10 knots, using a 50 log relationship based on the Ross empirical model for predicting shipping underwater noise (Ross 1976)), the range of values from the McKenna et al dataset reduces to 169-178 dB re 1 µPa, with an average value of 174 dB re 1 µPa which is very similar to the average value from Hallett et al for the same average speed.

Figure C14 below presents the shipping noise spectra from Hallett and McKenna et al, normalised to 10 knots speed.

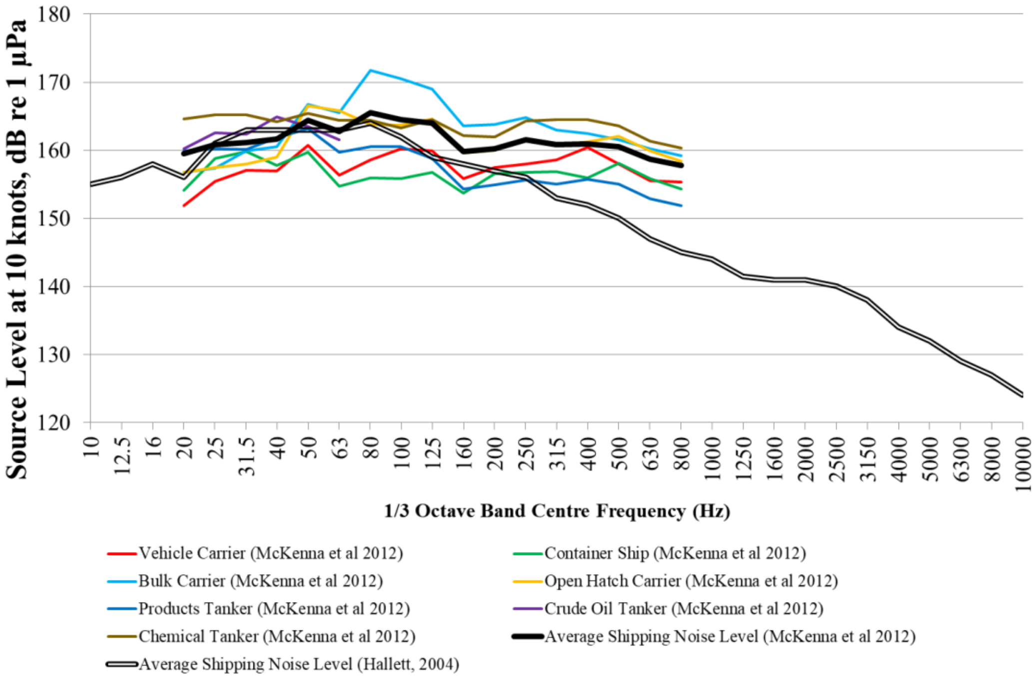

Figure C14. Shipping noise spectra from (McKenna *et al* 2012) normalised to 10 knot speed, compared with average spectrum from (Hallett *el al* 2004)

The average spectra are very similar up until 100 Hz (with the Bulk Carriers in the McKenna *et al* 2012 data having additional frequency content around 100 Hz), while above 100 Hz the McKenna et al data shows higher levels than the Hallett data. Although the Hallett data compares quite closely to typical shipping spectra, as a conservative assumption, the average of the McKenna et al and Hallett data has been used as the prediction spectrum (with the spectrum shape above 1000 Hz assumed to follow the spectrum shape from the Hallett data).

Figure C15 below shows the average commercial shipping spectrum (175 dB re 1 µPa at 1m) compared with the ferry source spectrum (173 dB re 1 µPa at 1m). Although the broadband noise level is very similar, the frequency content is very different and the smaller ferry vessels have significantly less low-frequency sound energy.

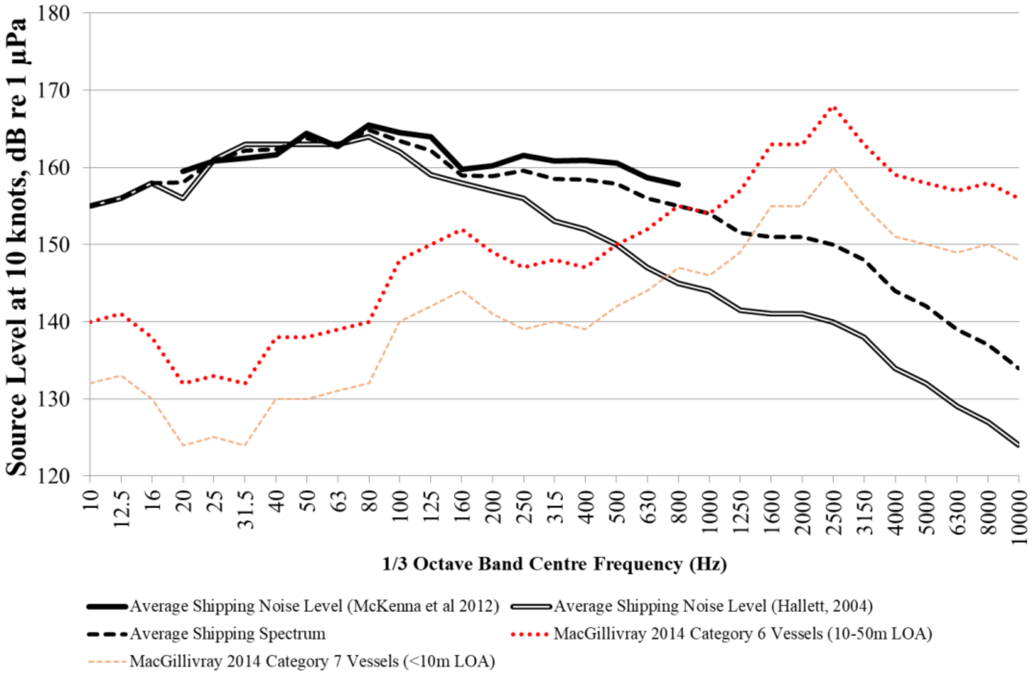

Figure C15. Average Commercial Shipping Spectrum (from Hallett 2004 and McKenna et al 2012) with ferry source spectrum (from MacGillivray 2014) overlaid.

C2.3 Project vessels source levels

The SEL spectrum for shipping has been assumed to be 34 dB higher than the SPL spectrum at the point of closest approach, based on the average relationship between SPL and SEL presented in McKenna et al 2012 for commercial shipping.

This assumption has been made for ferries, construction vessels and commercial shipping.

This results in the following shipping source levels (SEL):

- Ferries 207 dB re 1 µPa²-s
- Commercial Shipping 209 dB re 1 µPa²-s
- Construction vessels 199 dB re 1 µPa²-s

Appendix D

Noise modelling

D1 Noise modelling

This appendix describes the approach to noise modelling.

D1.1 Bathymetry

The bathymetry used for the underwater acoustic propagation modelling is shown on Figure D1 below. It was provided by Cardno and as described in (Cardno, 2020) the data was obtained from the NSW coastal area LIDAR survey for the Botany Bay, and from AUS charts 198 and 199 for the offshore region. The resolution of the data set is 50 m. Near the La Perouse and Kurnell project area the data was replaced by measurements taken for the project with a finer resolution of 0.5 m.

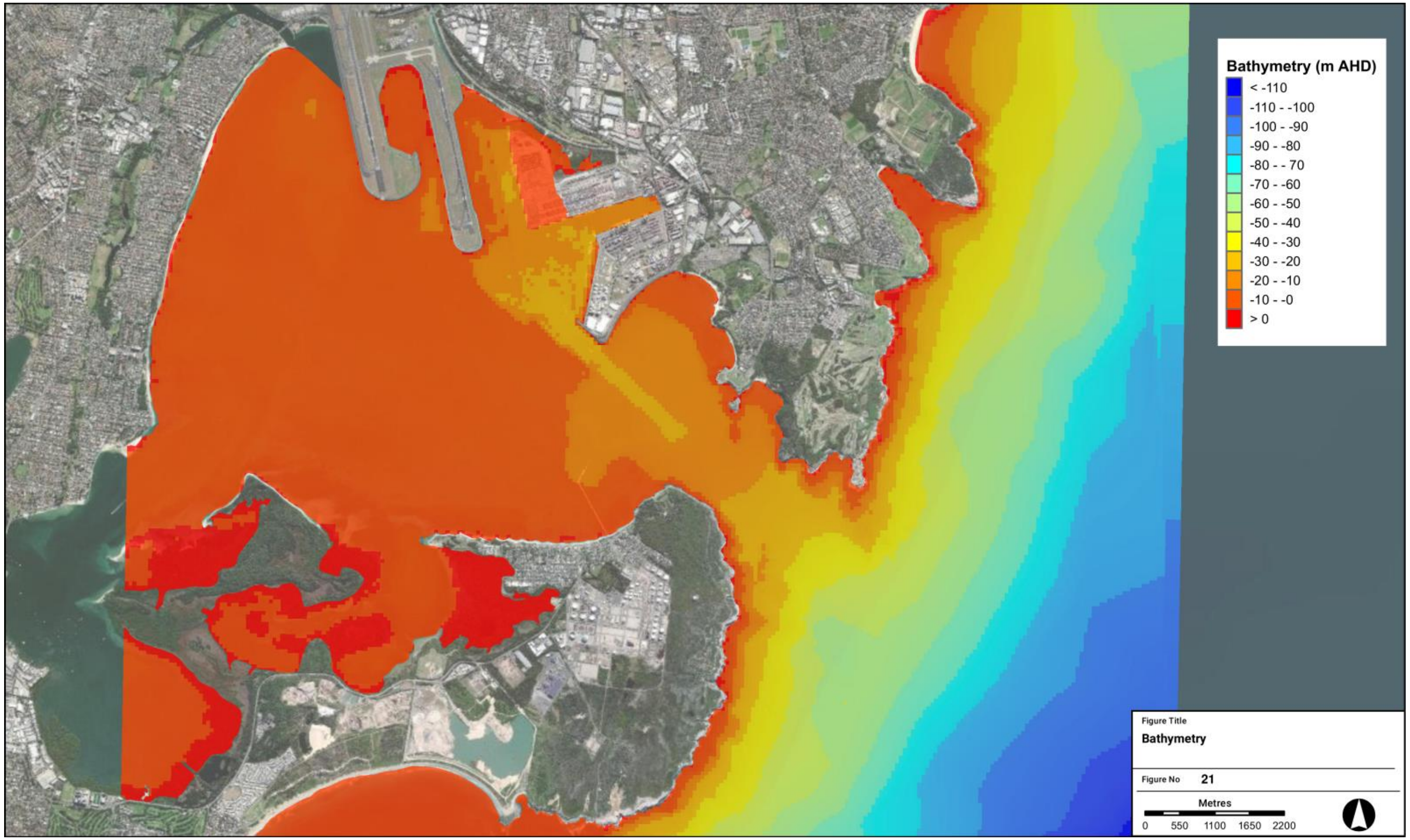

Figure D1. Bathymetry.

7.1.2 Water column

The average sound speed measured in the water column by Marine & Earth Sciences (MES, 2020) was 1528 m/s. A constant sound speed profile with this value was used for the propagation within the Bay, given the shallow waters. For the propagation outside the Bay, offshore, the sound speed profile was calculated from data from the World Ocean Atlas at a close location (Latitude -34° 1.8402' South, Longitude 151° 18.5202 East) and it is shown on Figure D2 below.

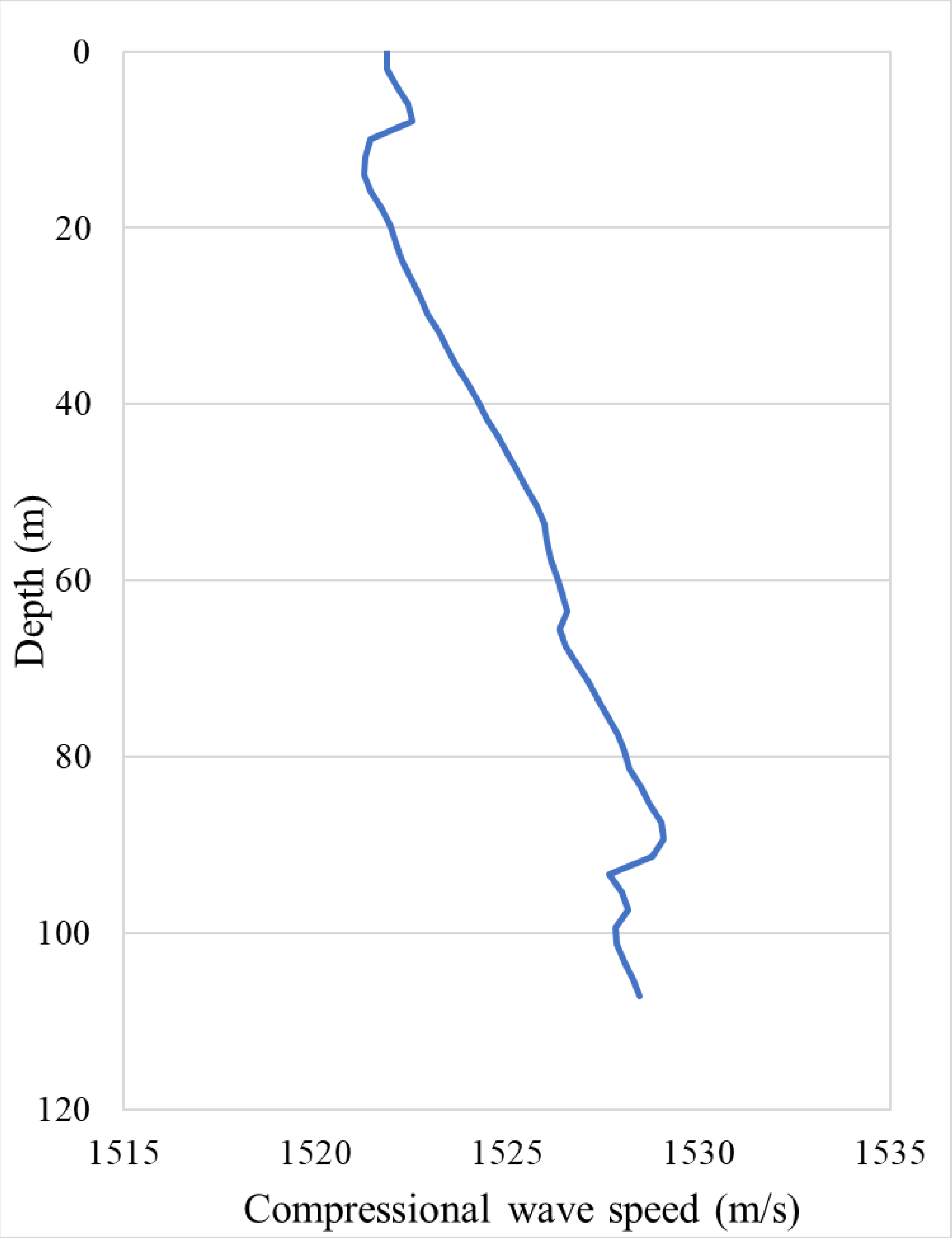

Figure D2. Sound speed profile for the offshore region.

7.1.3 Seafloor

For the underwater noise assessment model, a seafloor was assumed across the Bay and through the area offshore, consisting of three layers of constant thickness: sand, cemented calcarenite, and a limestone bedrock.

Sand was modelled as a fluid where the elastic properties were neglected given the small value of the compressional wave speed (Duncan *et al*, 2009). The presence of seagrass producing gas in coastal areas can significantly affect the sound propagation (Lee *et al.*, 2017) but the effect is difficult to quantify and has been neglected. Rocky reef outcrops, where present, were modelled as part of the calcarenite layer.

Table D1 below shows the different layers used in the model, from the water column to the sediments on the seabed. The thickness of each layer and their acoustic properties are included. Density is represented as ρ, cp and cs are the compressional and shear wave speed respectively, and αp and αs are the compressional and shear wave attenuation respectively. Acoustic parameters have been taken from (Koessler, 2017) and they are representative of typical sediments around Australia (Duncan *et al.*, 2009, 2013).

Table D2 below presents the complex densities for the calcarenite and limestone bedrock used in the fluid model approximation. Values were taken from (Koessler, 2017) where they proved to provide a sufficiently accurate reflection coefficient, except for some grazing angles where the predicted values are conservative.

Table D1. Layers and geoacoustic parameters for model

Layer	Thickness (m)	ρ (kg/m3)	cp (m/s)	cs (m/s)	αp (dB/λ)	αs (dB/λ)
Water column	N/A	1024	1528	N/A	0	N/A
Sand	3	1900	1700	N/A	0.7	N/A
Cemented calcarenite	2	2200	2600	1200	0.1	0.2
Limestone bedrock	N/A	2400	3200	1700	0.1	0.2

Table D2. Complex densities for fluid equivalent model

Layer	ρ (kg/m3)
Cemented calcarenite	1100 + 1500i
Limestone bedrock	3000 + 1500i

D2 Propagation modelling

D2.1 Propagation code

Modelling the noise propagation from underwater noise sources such as impact pile driving is a complex process and choosing a suitable sound propagation model is very important to obtain an accurate transmission loss.

There are many different models, which are typically classified based on what approximation they use to solve the wave equation.

Botany Bay is a shallow water, range dependent environment and with project noise sources such as pile driving and shipping being characterised by a low frequency spectrum, a model based on the parabolic equation approximation, like RAMGeo, would be the most suitable. Other models like SCOOTER (a wavenumber integration code), while stable and able to include fluid and elastic/solid layers for the seafloor, cannot include variations with depth (i.e. are range independent) and so have not been considered since they will be unable to model the variable depth within the shipping channel or noise propagation out to sea. Similarly, KRAKEN, a normal mode (NM) theory code was not considered. NM theory is very useful in shallow water scenarios when waveguide effects must be considered (Duncan *et al.*, 2009) but it is more suitable for range independent environments and the implementation of KRAKEN in AcTUP cannot handle range-dependent problems.

RAMGeo is a model based on the parabolic equation (PE) approximation that can deal well with range dependent environments and low frequency signals. It can include multiple fluid layers of sediments, and it was therefore the code used for the propagation modelling. Elastic/solid layers supporting shear waves cannot be included directly in RAMGeo, but each layer was modelled as an equivalent fluid where the effects of the shear waves are considered in the parameters corresponding to compressional waves (wave speed and attenuation), as described in Appendix D. While there is a modified PE model, RAMSGeo, that can handle elastic layers, it is typically unstable, and a test model of the Botany Bay bathymetry failed to converge and so an equivalent fluid model in RAMGeo was implemented instead.

D2.2 Source locations and transects

A total of three different source locations were used for the modelling. Two sources were used for the propagation modelling of the piling noise, one at Kurnell and one at La Perouse, each one along the proposed wharf. The changes on the wharves layouts after Concept design, being small, are not expected to cause a significant change on the sound propagation results obtained from the modelling with these sources, and therefore their location has not been changed.

For the propagation modelling of vessel noise a third source was also used located in mid-channel between La Perouse and Kurnell.

For all three sources the depth was set at 2 m. For the La Perouse and Kurnell sources this is approximately at the mid-point in the water column to represent noise radiating from the central section of the driven piles or from vessel propellers. For the source in the Channel the same depth was used to represent vessel noise from ferries. Note that a slightly deeper source location could be used to represent vessel noise from commercial shipping however the influence of the source depth on the predicted level is expected to be small, especially since commercial vessel shipping levels are only being modelled to provide context as to existing noise exposure within Botany Bay. The sources are listed in Table D3 below and shown on the map on Figure D3 below.

Table D3. Sources for propagation modelling

Source	Coordinates (X, Y) GDA94, MGA56	Use
La Perouse	336407.0214, 6237852.04	Impact pile driving and vessels noise
Kurnell	335296.9773, 6236165.687	Impact pile driving and vessels noise
Channel	335849.6422, 6237026.606	Vessels noise

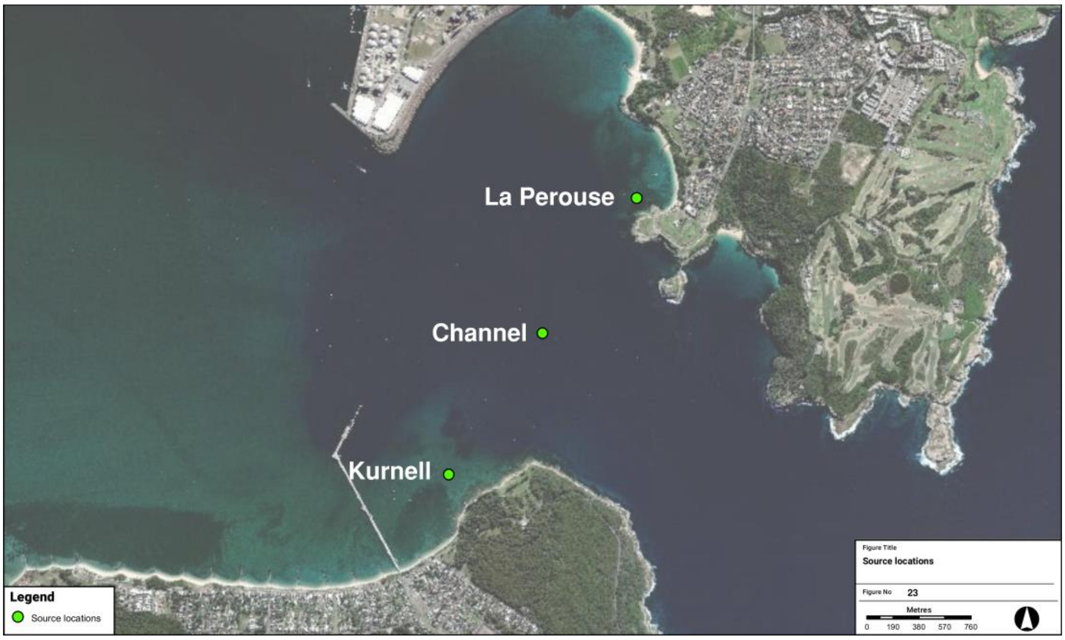

Figure D3. Source locations

For each source location a selection of transects was chosen in each case to assess the potential impact from the source to identified sensitive areas in all directions. The bathymetry transects were checked every five degrees and a representative selection was chosen – i.e. where adjacent transects were very similar in terms of depth to shore or bathymetry, one transect was selected as being representative of propagation conditions for several angles. This resulted in between 9 and 13 transects being used for each source The spatial distribution of the transects is shown in Figure D4 to Figure D6 below, and the bathymetry for each transect is shown in Figure D7 to Figure D9 below.

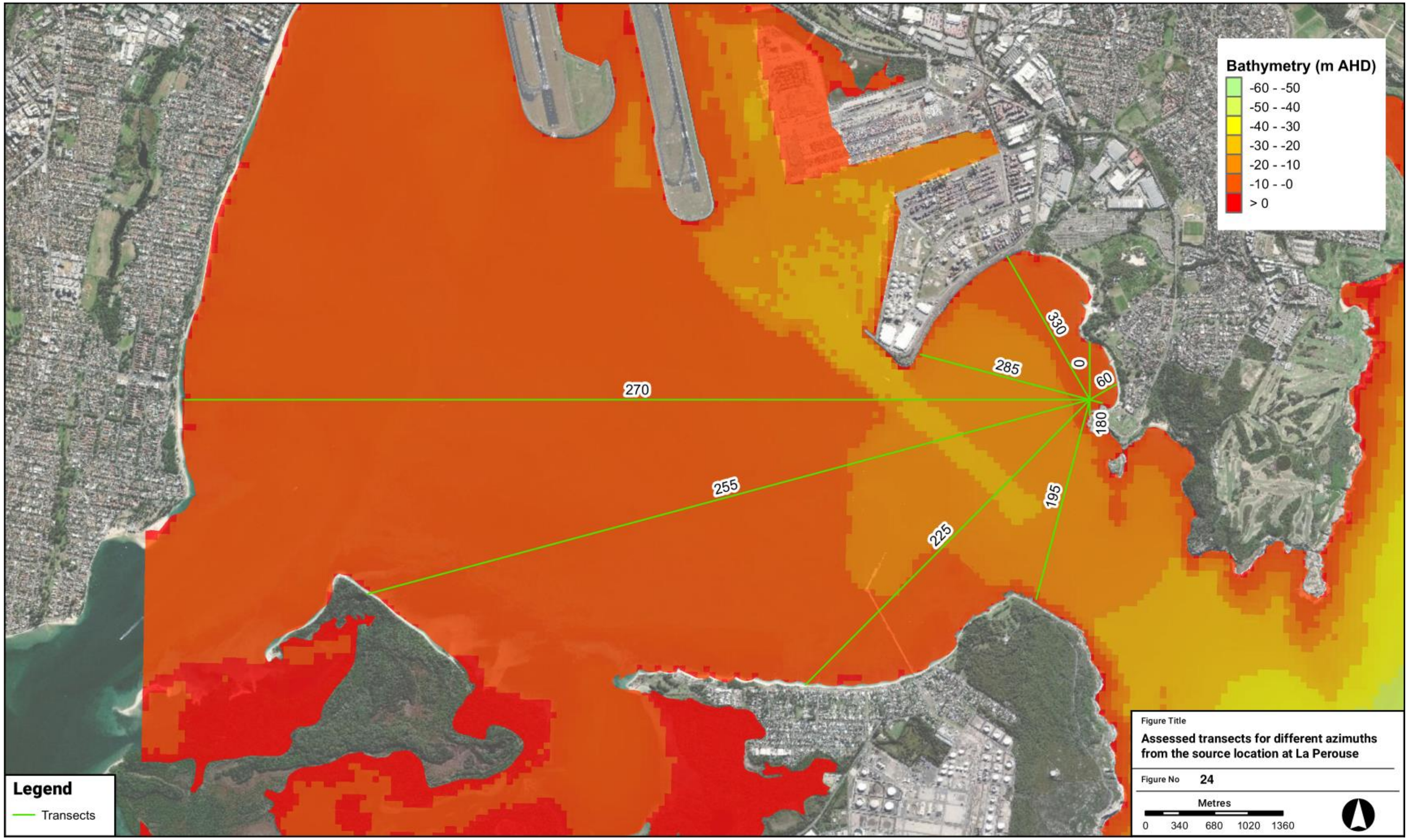

Figure D4. Assessed transects for different azimuths from the source location at La Perouse.

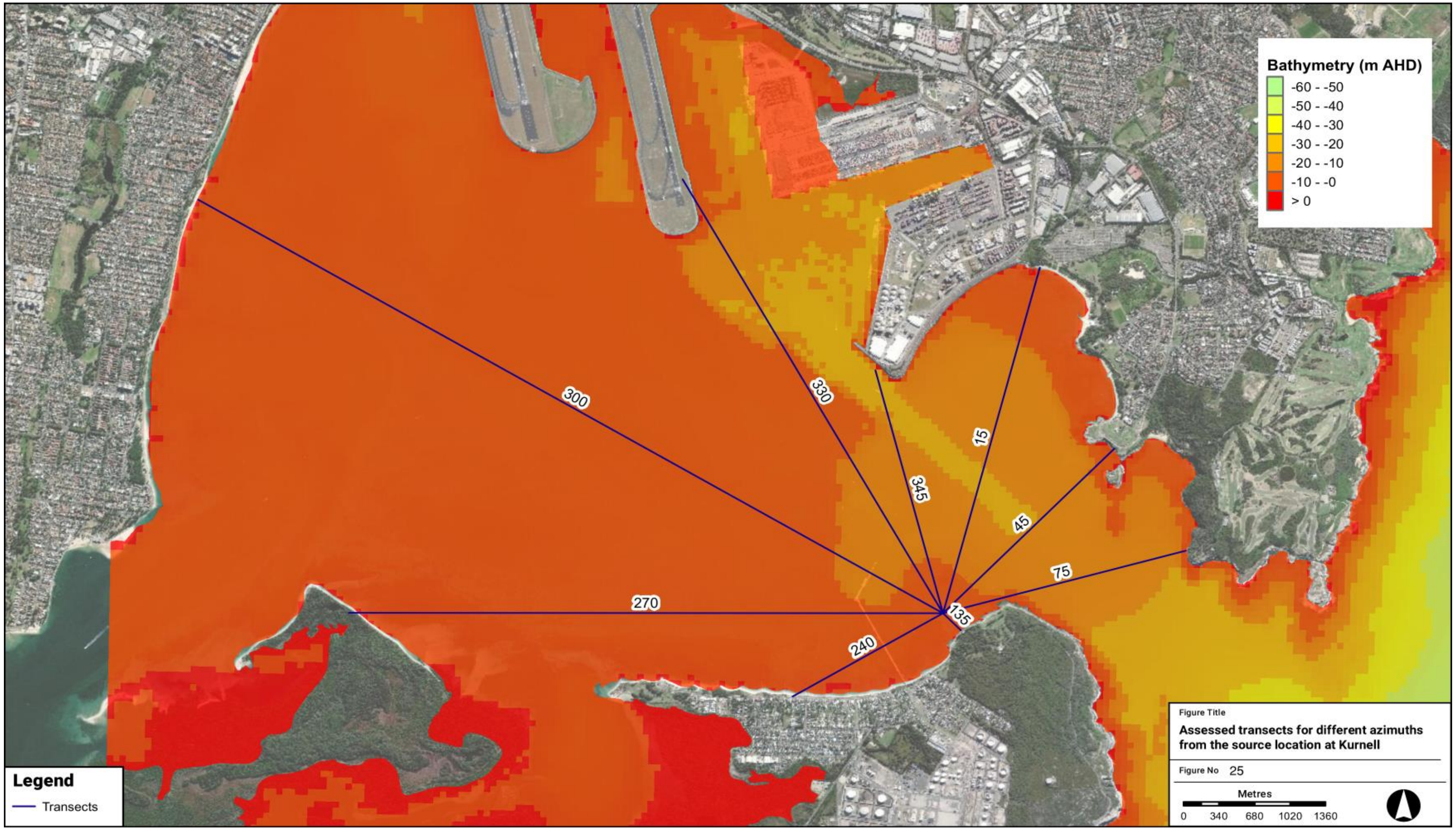

Figure D5. Assessed transects for different azimuths from the source location at Kurnell.

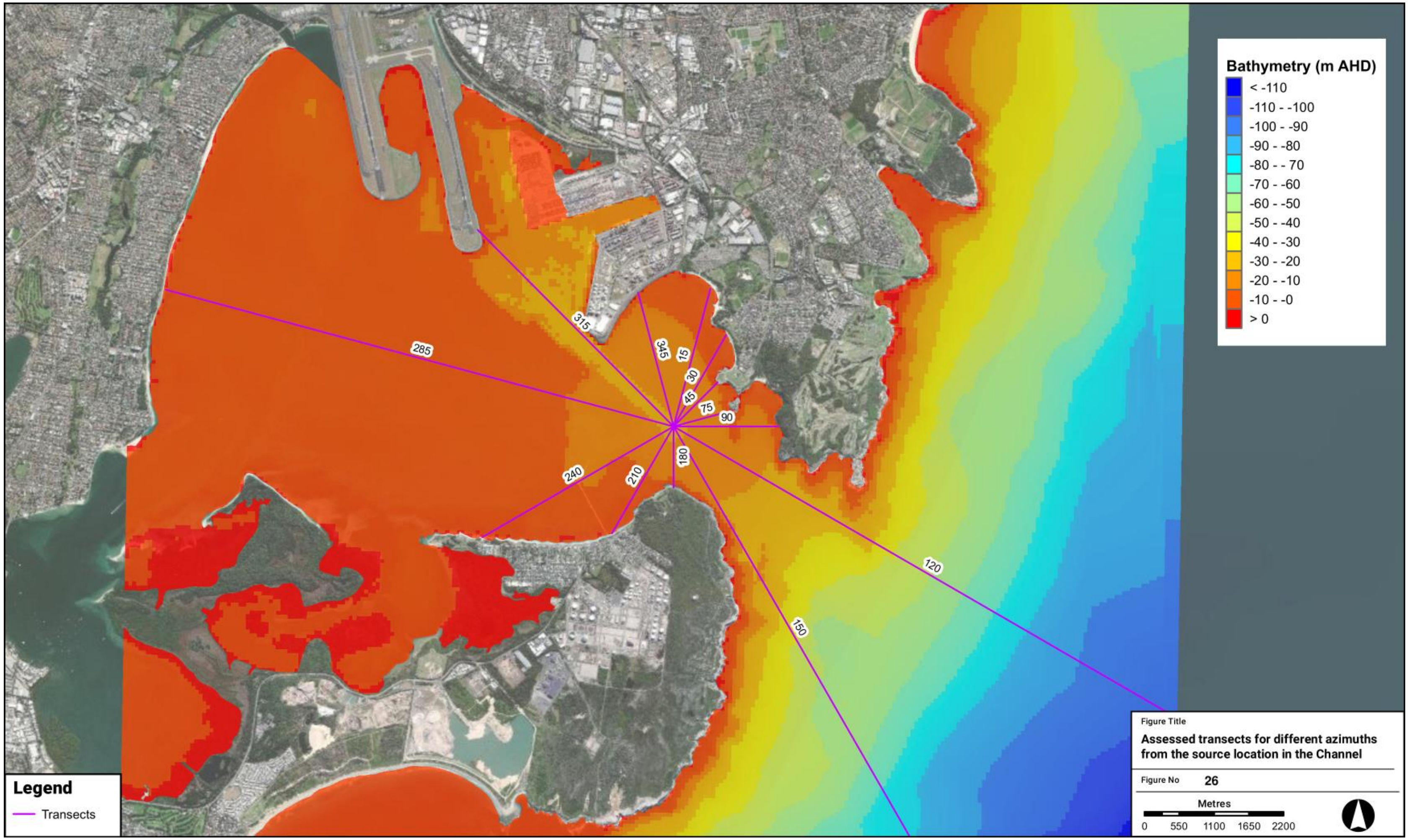

Figure D6. Assessed transects for different azimuths from the source location in the Channel.

The bathymetry for the transects selected for each source location is displayed on the figures below.

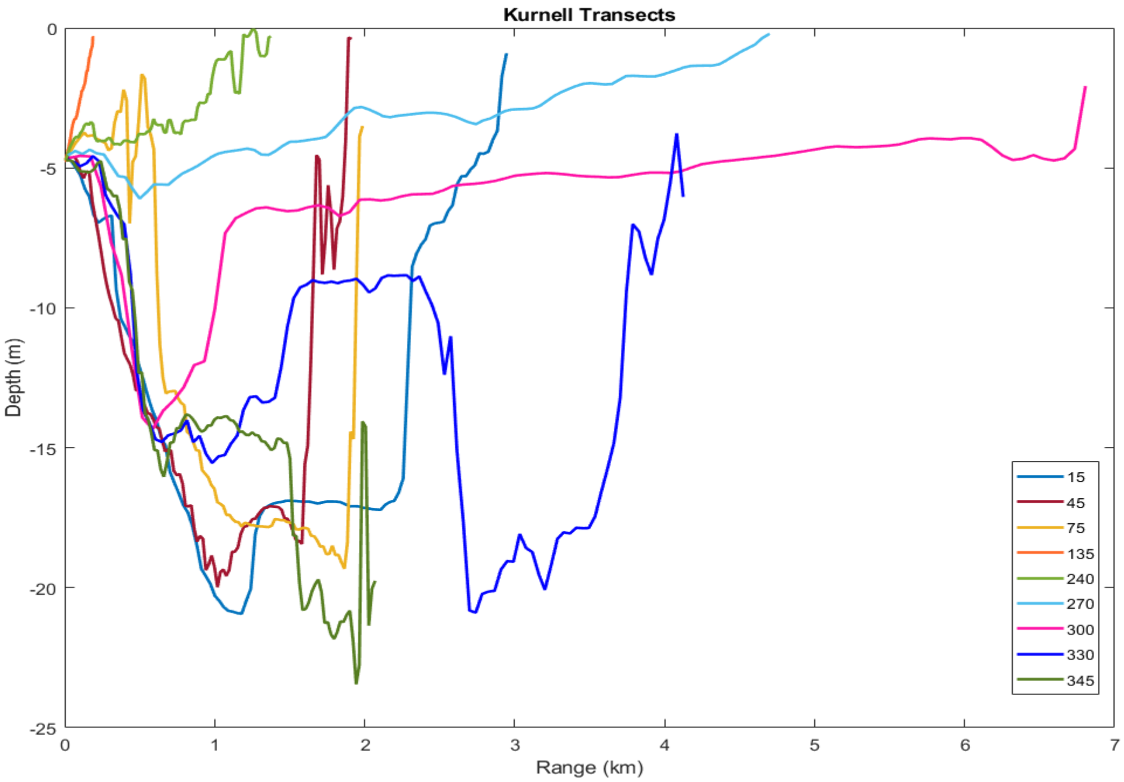

Figure D7. Bathymetry of assessed transects for different azimuths from the source location at Kurnell

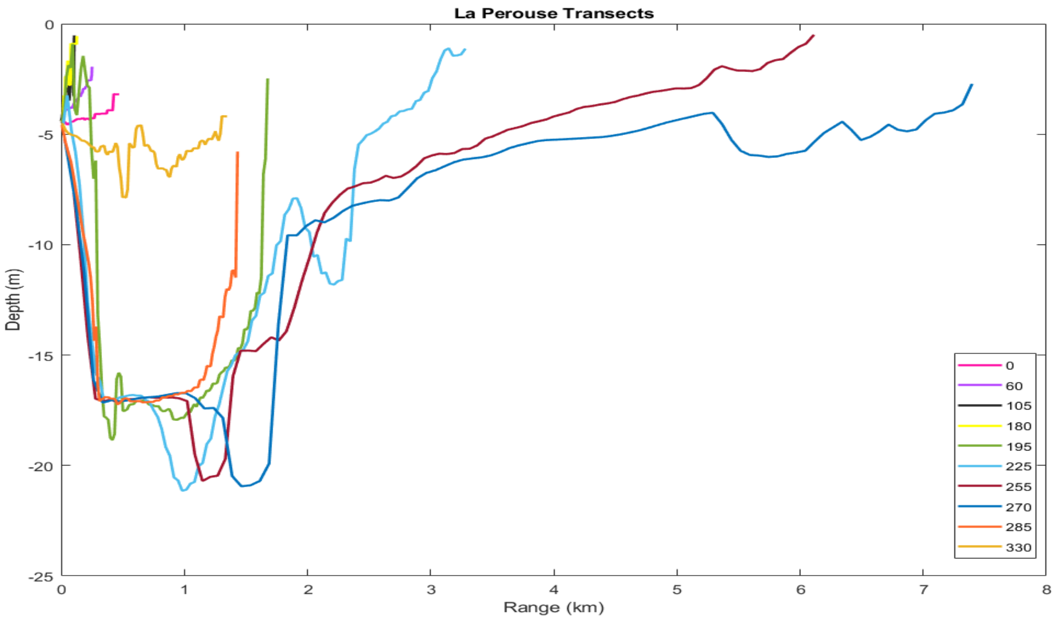

Figure D8. Bathymetry of assessed transects for different azimuths from the source location at La Perouse

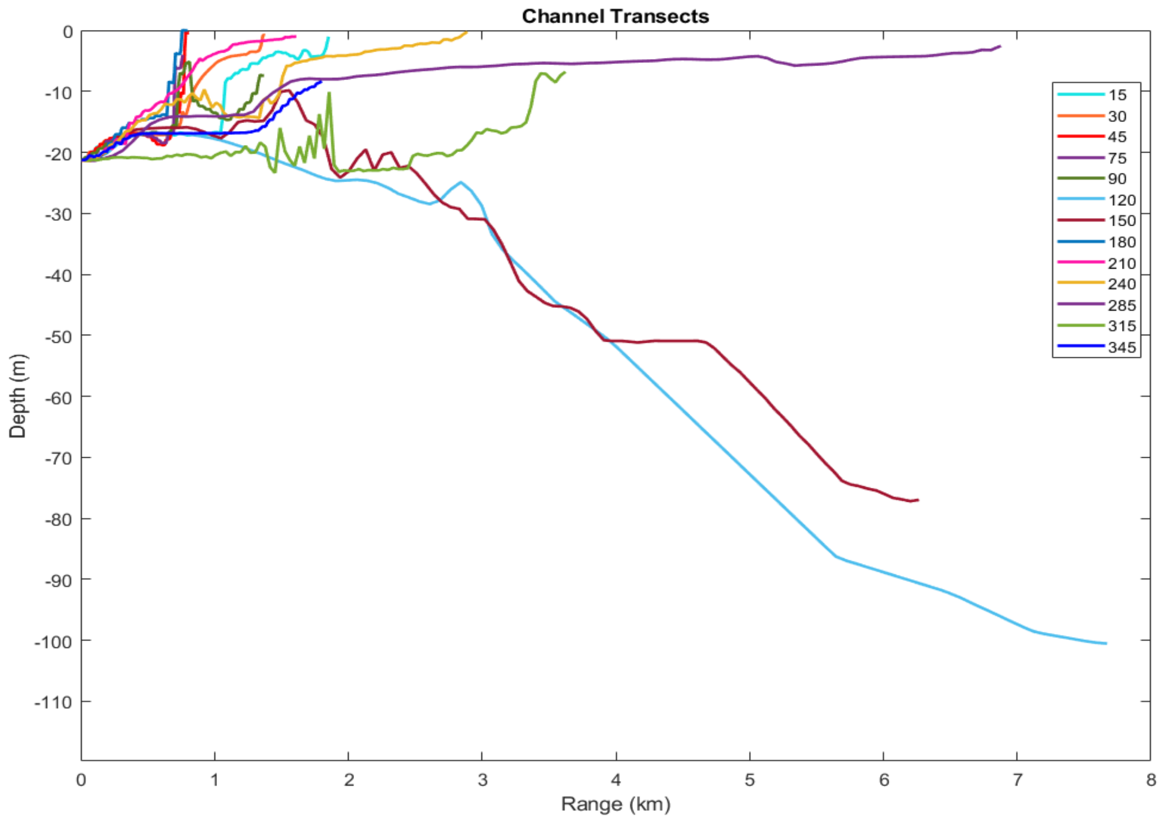

Figure D9. Bathymetry of assessed transects for different azimuths from the source location in the Channel

D2.3 Received levels

For each source location and azimuth RAMGeo was run to obtain the transfer function with transmission loss for frequencies between 10 Hz and 1000 Hz every 1/3 octave band, and for each range.

A shown in (Galindo Romero, 2017) the peak pressure level decays faster with distance than the SEL, which means that using the same TL obtained with the propagation model (RAMGeo in this case) would provide a good estimate for the SEL (if the environment is modelled accurately) because it is proportional to the signal energy, but it would overestimate the predicted peak pressure level. This is because the latter is more affected by changes in the environment. The difference between the predicted and actual level increases the further away from source. Given that the ranges modelled in this assessment are quite short by the standards of underwater acoustics, this effect has been neglected as a conservative approach, and the same TL was used to calculate SEL and the peak level with no further correction.

Once the transfer function was obtained it was combined with the source levels in Appendix C to obtain the predicted SEL and the peak level as a function of range.

In addition to the single strike levels, the cumulative SEL (denoted SELcum or SEL24hr) was calculated based upon the equation in (Popper et al., 2014):

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

This has been explained clearly in (Parnum et al., 2018) (emphasis added):

"SEL24h 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 SEL24h 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 SEL24h 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 (SEL24h) levels have been calculated with weighting functions to correct for hearing characteristics of each animal group. The more recent NMFS weighting functions LFC, MFC, HFC, OW, SI and TU (NMFS 2018), as described in Appendix E. In addition, unweighted levels have been presented for comparison to criteria for impacts on fish, sea turtles, invertebrates, human divers and (where applicable) marine birds (diving).

D2.4 Additional Assumptions and Limitations

- Single source locations have been used to model all piling and vessel sources. The variation in propagation conditions (and therefore received level) with source position over the extent of the wharf footprint is expected to be minor.
- Point sources have been used to model both piling and vessel noise sources. At close distances to the source this assumption may underestimate noise levels but results in acceptable error for distances greater than the largest dimension of the source or greater than the water depth.
- Source levels for both piling and vessel have been based on typical values from the literature. Actual source levels may be higher or lower than the modelled values. It is recommended that early monitoring of actual piling levels within Botany Bay be conducted and if necessary, the predicted levels (and corresponding impact zones) updated.
- Environmental conditions within Botany Bay and the entrance channel will have variable sound propagation conditions due to local changes in the bathymetry and changes in the seafloor properties. It is not practicable to model these variations using currently available underwater noise modelling techniques. The predicted noise levels are considered to be representative of average propagation conditions across the bay, however there may be local differences between the predicted and actual received noise levels due to fine-scale differences in sound propagation as the result of bathymetry or seafloor properties.
- Cumulative impacts from piling are assessed per pile based on 600 strikes per pile and assuming a single pile being driven at one time (i.e. no simultaneous construction at both La Perouse and Kurnell). If the cumulative number of strikes per day exceeds this (e.g. individual piles taking more blows to drive, or multiple piles being driven) then received levels will be higher than modelled.

Appendix E

Impact assessment

E1 Impact assessment

During the construction the main potential impact identified is impact pile driving, described below. The potential impacts associated with construction vessels will be significantly lower than the impact of the vessels operation, which is described in Appendix E due to the source levels for construction vessels being approximately 8 dB lower than ferries, however a summary of vessel impacts is included in Appendix E.

E1.1 Construction

Piling

The predicted underwater noise levels at set distances from the piling at each wharf are provided on Appendix E for La Perouse and Kurnell respectively, including predicted values at 100 metres and 300 metres distances (for use in determining size of the precautionary zones as per the SA Underwater Piling Noise Guidelines).

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

Table E1 and Table E2 below include a summary of the predicted distance at which impacts are expected (for single strike and from cumulative exposure to 600 pile strikes) for each species group. All impact zone distances are rounded up to the nearest 5 m (except for distances within 10 m of the pile).

Injury to marine fauna is predicted to occur within approximately 200 m of the pile from a single strike (depending on the species group), with cumulative impacts (i.e. if an animal were exposed to all pile strikes) extending out to approximately 2 km for permanent injury and 7 km (the extent of modelling) for temporary (recoverable) hearing injury. Behavioural impacts are predicted to occur out to approximately 7 km (the extend of modelling).

Impacts on human swimmers and divers are predicted to exceed the threshold of tolerance out to approximately 7 km (the extent of diving).

Table E1. Summary of impacts – Piling at La Perouse.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low- frequency)	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	219 dB PK and 183 dB SEL* (LFC weighted)	~30m single strike ~2050 m from 24-hour exposure.
		TTS	213 dB PK and 168 dB SEL* (LFC weighted)	~240 m from single strike > 7 km from 24-hour exposure.
	Behavioural Response		160 dB SPL	>7 km.
Cetaceans (Mid-frequency)	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	230 dB PK 185 dB SEL* (MFC weighted)	~1 m from single strike ~1 m from 24-hour exposure.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
		TTS	224 dB PK 170 dB SEL* (MFC weighted)	~10 m from single strike ~50 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Cetaceans (High-frequency)	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	202 dB PK 155 dB SEL* (HFC weighted)	~130 m from single strike ~110 m from 24-hour exposure.
		TTS	196 dB PK 140 dB SEL*(HFC weighted)	~330 m from single strike ~500 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Pinnipeds- Otariids	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	232 dB PK 203 dB SEL* (OW weighted)	~1 m from single strike ~1 m from 24-hour exposure.
		TTS	226 dB PK 188 dB SEL* (OW weighted)	~10 m from single strike. ~140 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Sirenians	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	226 dB PK 190 dB SEL* (SI weighted)	~15 m from single strike ~40 m from 24-hour exposure.
		TTS	220 dB PK 175 dB SEL* (SI weighted)	~10 m from single strike ~300 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Fish	Physical injury		207 dB PK 203 dB SEL* (unweighted)	~60 m from single strike ~160 m from 24-hour exposure
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	186 dB SEL* (unweighted)	~35 m from single strike ~3600 m from 24-hour exposure
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) High (F) Moderate
Sea Turtles	Physical injury		207 dB PK 210 dB SEL* (unweighted)	~60 m from single strike ~60 m from 24-hour exposure.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
	Auditory injury	PTS	232 dB PK 204 SEL* (TU weighted)	~1 m from single strike ~90 m from 24-hour exposure.
		TTS	226 dB PK 189 dB SEL* (TU weighted)	~10 m from single strike ~500 m from 24-hour exposure.
	Behavioural response		175 dB SPL (unweighted)	~3150 m from single strike.
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	~10 m from single strike ~1800m from 24-hour exposure.
	Auditory injury		N/A	N/A
	Behavioural response		120 dB SPL	>7 km.
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	>7 km.
		Onset of severe reaction	145 dB SPL	>7 km.

*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).

Table E2. Summary of impacts – Piling at Kurnell.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low- frequency)	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	219 dB PK and 183 dB SEL* (LFC weighted)	30m single strike ~1600 m from 24-hour exposure.
		TTS	213 dB PK and 168 dB SEL* (LFC weighted)	240 m from single strike > 7 km from 24-hour exposure.
	Behavioural Response		160 dB SPL	>7 km.
Cetaceans (Mid-frequency)	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	230 dB PK 185 dB SEL* (MFC weighted)	~1 m from single strike ~1 m from 24-hour exposure.
		TTS	224 dB PK 170 dB SEL* (MFC weighted)	~10 m from single strike ~50 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
	Physical injury		237 dB PK	< 1 m from pile.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (High-frequency)	Auditory injury	PTS	202 dB PK 155 dB SEL* (HFC weighted)	<130 m from single strike ~120 m from 24-hour exposure.
		TTS	196 dB PK 140 dB SEL*(HFC weighted)	~330 m from single strike ~600 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Pinnipeds-Otariids	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	232 dB PK 203 dB SEL* (OW weighted)	~1 m from single strike ~1 m from 24-hour exposure.
		TTS	226 dB PK 188 dB SEL* (OW weighted)	~10 m from single strike ~150 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Sirenians	Physical injury		237 dB PK	< 1 m from pile.
	Auditory injury	PTS	226 dB PK 190 dB SEL* (SI weighted)	~15 m from single strike ~80 m from 24-hour exposure.
		TTS	220 dB PK 175 dB SEL* (SI weighted)	~10 m from single strike ~120 m from 24-hour exposure.
	Behavioural response		160 dB SPL	>7 km.
Fish	Physical injury		207 dB PK 203 dB SEL* (unweighted)	~60 m from single strike ~180 m from 24-hour exposure.
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	186 dB SEL* (unweighted)	~35 m from single strike ~3800 m from 24-hour exposure.
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) High (F) Moderate
Sea Turtles	Physical injury		207 dB PK 210 dB SEL* (unweighted)	~60 m from single strike ~50 m from 24-hour exposure.
	Auditory injury	PTS	232 dB PK 204 SEL* (TU weighted)	~1 m from single strike ~80 m from 24-hour exposure.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
		TTS	226 dB PK 189 dB SEL* (TU weighted)	~10 m from single strike ~500 m from 24-hour exposure.
	Behavioural response		175 dB SPL (unweighted)	~3500 m from single strike
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	~10 m from single strike ~2100 m from 24-hour exposure.
	Auditory injury		No criteria provided	N/A
	Behavioural response		120 dB SPL	>7 km from single strike.
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	>7 km from single strike.
		Onset of severe reaction	145 dB SPL	>7 km 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).

Construction vessels

The predicted underwater noise levels at set distances from construction vessel traffic at each wharf are provided Appendix C.

Graphs with predicted construction vessel noise levels vs distance are included in Appendix CAppendix B.

Table E3 and Table E4 include a summary of the predicted distance at which impacts are expected for each species group. All impact zone distances are rounded up to the nearest 5 m (except for distances within 10 m of the source).

The predicted noise from the operation of construction vessels is above the threshold for behavioural impacts for marine mammals and diving birds for all source locations, with behavioural impacts expected to extend out to at approximately 2-2.5 km.

No temporary or permanent injury to marine fauna is predicted from construction vessel operation.

Human impacts are confined to a zone within approximately 30 m of the vessel within which a severe adverse reaction would be expected for recreational divers and swimmers.

Table E3. Summary of impacts – construction vessels at La Perouse.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low- frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	199 dB SEL* (LFC weighted)	< 1 m from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
		TTS	179 dB SEL* (LFC weighted)	< 1 m from vessel
	Behavioural Response		120 dB SPL	~1950 m from vessel
Cetaceans (Mid-frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	< 1 m from vessel.	< 1 m from vessel
		TTS	< 1 m from vessel.	< 1 m from vessel
	Behavioural response		120 dB SPL	~1950 m from vessel
Cetaceans (High frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	173 dB SEL* (HFC weighted)	< 1 m from vessel
		TTS	153 dB SEL* (HFC weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~1950 m from vessel
Pinnipeds- Otariids	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	219 dB SEL* (OW weighted)	< 1 m from vessel
		TTS	199 dB SEL* (OW weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~1950 m from vessel
Sirenians	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	206 dB SEL* (SI weighted)	< 1 m from vessel
		TTS	186 dB SEL* (SI weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~1950 m from vessel
Fish	Physical injury		222 dB SEL* (unweighted)	< 1 m from vessel
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	204 dB SEL* (unweighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Sea Turtles	Physical injury		No numerical criteria provided. Relative risk only	(N) Low (I) Low (F) Low
	Auditory injury	PTS	220 dB SEL* (TU weighted)	< 1 m from vessel
		TTS	200 dB SEL* (TU weighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	< 1 m from vessel
	Auditory injury		N/A	N/A
	Behavioural response		120 dB SPL	~1950 m from vessel
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	<1 m from vessel
		Onset of severe reaction	145 dB SPL	~ 30 m from vessel

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

Table E4. Summary of impacts – construction vessels at Kurnell.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low- frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	199 dB SEL* (LFC weighted)	< 1 m from vessel
		TTS	179 dB SEL* (LFC weighted)	< 1 m from vessel
	Behavioural Response		120 dB SPL	~2300 m from vessel
Cetaceans (Mid-frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	< 1 m from vessel.	< 1 m from vessel
		TTS	< 1 m from vessel.	< 1 m from vessel
	Behavioural response		120 dB SPL	~2300 m from vessel
	Physical injury		237 dB PK	< 1 m from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (High frequency)	Auditory injury	PTS	173 dB SEL* (HFC weighted)	< 1 m from vessel
		TTS	153 dB SEL* (HFC weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~2300 m from vessel
Pinnipeds- Otariids	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	219 dB SEL* (OW weighted)	< 1 m from vessel
		TTS	199 dB SEL* (OW weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~2300 m from vessel
Sirenians	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	206 dB SEL* (SI weighted)	< 1 m from vessel
		TTS	186 dB SEL* (SI weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~2300 m from vessel
Fish	Physical injury		222 dB SEL* (unweighted)	< 1 m from vessel
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	204 dB SEL* (unweighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Sea Turtles	Physical injury		No numerical criteria provided. Relative risk only	(N) Low (I) Low (F) Low
	Auditory injury	PTS	220 dB SEL* (TU weighted)	< 1 m from vessel
		TTS	200 dB SEL* (TU weighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	< 1 m from vessel
	Auditory injury		N/A	N/A
	Behavioural response		120 dB SPL	~2300 m from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Human divers/ swimmers	Behavioural response	Tolerance limit	170 dB SPL	<1 m from vessel
		Onset of severe reaction	145 dB SPL	~ 30 m from vessel

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

E1.2 Operation

The predicted underwater noise levels at set distances from vessel source at each wharf and from the middle of the channel are provided in Appendix G. Graphs with predicted shipping noise levels vs distance are included in Appendix G. Table E5 to Table E7 below include a summary of the predicted distance at which impacts are expected for each species group. All impact zone distances are rounded up to the nearest 5 m (except for distances within 10 m of the source) The predicted noise from the operation of the ferry vessels is above the threshold for behavioural impacts for marine mammals and diving birds for all source locations, with impacts expected to extend out to at least approximately ~7 km (the approximate limit of modelling).

- No temporary or permanent injury to marine fauna is predicted from ferry operation.
- Human impacts are confined to a zone within approximately 50 m of the vessel within which a severe adverse reaction would be expected for recreational divers and swimmers.
- Ferry noise is predicted to be lower than noise from existing shipping traffic and extend over a smaller zone of impact (in particular because the frequency content of the ferry noise has less low-frequency sound despite the broadband source level being similar).

This indicates that the operational impacts of the ferry movements associated with the project wharves would not be significant compared to the extensive existing commercial shipping movements to/from Port Botany. Similarly, noise from additional recreational vessels accessing the area to use the wharves (which would be smaller and, typically, quieter than ferries) would not be significant compared to the existing shipping traffic.

Table E5. Summary of impacts – ferry vessels at La Perouse.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	199 dB SEL* (LFC weighted)	< 1 m from vessel
		TTS	179 dB SEL* (LFC weighted)	< 1 m from vessel
	Behavioural Response		120 dB SPL	>7 km from vessel
	Physical injury		237 dB PK	< 1 m from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	**Injury**	**Thresholds**	**Threshold at distance**
Cetaceans (Mid frequency)	Auditory injury	PTS	< 1 m from vessel.	< 1 m from vessel
		TTS	< 1 m from vessel.	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Cetaceans (High frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	173 dB SEL* (HFC weighted)	< 1 m from vessel
		TTS	153 dB SEL* (HFC weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Pinnipeds- Otariids	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	219 dB SEL* (OW weighted)	< 1 m from vessel
		TTS	199 dB SEL* (OW weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Sirenians	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	206 dB SEL* (SI weighted)	< 1 m from vessel
		TTS	186 dB SEL* (SI weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Fish	Physical injury		222 dB SEL* (unweighted)	< 1 m from vessel
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	204 dB SEL* (unweighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Sea Turtles	Physical injury		No numerical criteria provided. Relative risk only	(N) Low (I) Low (F) Low
	Auditory injury	PTS	220 dB SEL* (TU weighted)	< 1 m from vessel
		TTS	200 dB SEL* (TU weighted)	< 1 m from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	< 1 m from vessel
	Auditory injury		N/A	N/A
	Behavioural response		120 dB SPL	>7 km from vessel
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	<1 m from vessel
		Onset of severe reaction	145 dB SPL	~ 50 m from vessel

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

Table E6. Summary of impacts – ferry vessels at Kurnell.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	199 dB SEL* (LFC weighted)	< 1 m from vessel
		TTS	179 dB SEL* (LFC weighted)	< 1 m from vessel
	Behavioural Response		120 dB SPL	>7 km from vessel
Cetaceans (Mid frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	< 1 m from vessel.	< 1 m from vessel
		TTS	< 1 m from vessel.	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Cetaceans (High frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	173 dB SEL* (HFC weighted)	< 1 m from vessel
		TTS	153 dB SEL* (HFC weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Pinnipeds- Otariids	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	219 dB SEL* (OW weighted)	< 1 m from vessel
		TTS	199 dB SEL* (OW weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Sirenians	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	206 dB SEL* (SI weighted)	< 1 m from vessel
		TTS	186 dB SEL* (SI weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	~2300 m from vessel
Fish	Physical injury		222 dB SEL* (unweighted)	< 1 m from vessel
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	204 dB SEL* (unweighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Sea Turtles	Physical injury		No numerical criteria provided. Relative risk only	(N) Low (I) Low (F) Low
	Auditory injury	PTS	220 dB SEL* (TU weighted)	< 1 m from vessel
		TTS	200 dB SEL* (TU weighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	< 1 m from vessel
	Auditory injury		N/A	N/A
	Behavioural response		120 dB SPL	>7 km from vessel
Human divers/ Swimmers	Behavioural response	Tolerance limit	170 dB SPL	<1 m from vessel
		Onset of severe reaction	145 dB SPL	~ 50 m from vessel

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

Table E7. Summary of impacts – ferry vessels in the channel.

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	Injury	Thresholds	Threshold at distance
Cetaceans (Low frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	199 dB SEL* (LFC weighted)	< 1 m from vessel
		TTS	179 dB SEL* (LFC weighted)	< 1 m from vessel
	Behavioural Response		120 dB SPL	>7 km from vessel
Cetaceans (Mid frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	< 1 m from vessel.	< 1 m from vessel
		TTS	< 1 m from vessel.	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Cetaceans (High frequency)	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	173 dB SEL* (HFC weighted)	< 1 m from vessel
		TTS	153 dB SEL* (HFC weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Pinnipeds- Otariids	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	219 dB SEL* (OW weighted)	< 1 m from vessel
		TTS	199 dB SEL* (OW weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Sirenians	Physical injury		237 dB PK	< 1 m from vessel
	Auditory injury	PTS	206 dB SEL* (SI weighted)	< 1 m from vessel
		TTS	186 dB SEL* (SI weighted)	< 1 m from vessel
	Behavioural response		120 dB SPL	>7 km from vessel
Fish	Physical injury		222 dB SEL* (unweighted)	< 1 m from vessel
	Auditory Injury	PTS	No criteria provided	N/A
		TTS	204 dB SEL* (unweighted)	< 1 m from vessel

Fauna group	Impact Thresholds and Distance of Greatest Impact			
	Impact	**Injury**	**Thresholds**	**Threshold at distance**
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Sea Turtles	Physical injury		No numerical criteria provided. Relative risk only	(N) Low (I) Low (F) Low
	Auditory injury	PTS	220 dB SEL* (TU weighted)	< 1 m from vessel
		TTS	200 dB SEL* (TU weighted)	< 1 m from vessel
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) Moderate (F) Low
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	< 1 m from vessel
	Auditory injury		N/A	N/A
	Behavioural response		120 dB SPL	>7 km from vessel
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	<1 m from vessel
		Onset of severe reaction	145 dB SPL	~ 50 m from vessel

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

E1.3 Impacts at set distances

The following tables list the impacts at set distances from the works.

E1.3.1 Construction

Piling at La Perouse

The predicted underwater noise levels at set distances from the piling at La Perouse wharf are provided on the table below. The maximum value from each direction has been shown for each distance. Values that are above behavioural response thresholds have been formatted in underline. Values that are above damage (TTS or PTS) criteria are formatted in **bold** (for TTS) or ***bold italic*** (for PTS).

Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E8. Updated underwater noise level prediction from pile driving at La Perouse

Metrics	Maximum Level at specified distances from pile				
	50m	100m	300m	500m	1km
Sound Pressure Level (SPL) dB re 1 µPa (rms) | single strike					
Unweighted	200*	195*	187*	184*	181*
Peak (PK) dB re 1 µPa se | single strike					
Unweighted	***210****	***205****	**197****	194	191
Sound Exposure Level (SEL) dB re 1 µPa²·s | single strike (not cumulative)					
Unweighted	184	179	171	168	165
Cetaceans Low frequency (LFC)	**182**	**176**	166	161	158
Cetaceans Mid frequency (MFC)	144	137	129	121	118
Cetaceans High frequency (HFC)	135	128	120	112	108
Pinnipeds – Otariid (OW)	170	162	154	147	143
Sirenians (SI)	161	155	147	136	130
Chelonians (TU)	182	176	167	162	158
Cumulative Sound Exposure Level (SEL24hrs) (SELss+10log10(N)) dB re 1 µPa²·s | N= 600 strikes^					
Unweighted	***214****	***208****	***201****	***198****	***195****
Cetaceans Low frequency (LFC)	***212***	***205***	***196***	***191***	***187***
Cetaceans Mid frequency (MFC)	**174**	167	158	151	147
Cetaceans High frequency (HFC)	***165***	***158***	**150**	**141**	137
Pinnipeds – Otariid (OW)	**199**	**192**	184	177	173
Sirenians (SI)	***191***	**185**	**177**	166	159
Chelonians (TU)	***211***	***205***	**197**	**191**	187

* Exceeding the behavioural threshold for marine mammals, chelonians, humans and birds
**Exceeding the TTS (and PTS at <150m) threshold for high-frequency cetaceans and the injury threshold for fish and chelonians (<70m)
***Exceeding the injury threshold for chelonians (<80m), fish (<120m), diving birds (<2400m) if animals are exposed to all 600 pile strikes
^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.

Piling at Kurnell

The predicted underwater noise levels at set distances from the piling at La Perouse wharf are provided on the table below. The maximum value from each direction has been shown for each distance. Values that are above behavioural response thresholds have been formatted in underline. Values that are above damage (TTS or PTS) criteria are formatted in **bold** (for TTS) or ***bold italic*** (for PTS). Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E9. Underwater noise level prediction from pile driving at Kurnell

Metrics	Maximum Level at specified distances from pile				
	50m	100m	300m	500m	1km
Sound Pressure Level (SPL) dB re 1 µPa (rms) | single strike					
Unweighted	199*	195*	187*	184*	181*
Peak (PK) dB re 1 µPa | single strike					
Unweighted	209**	205**	197**	194	191
Sound Exposure Level (SEL) dB re 1 µPa²·s | single strike (not cumulative)					
Unweighted	183	179	171	168	165
Cetaceans Low frequency (LFC)	**180**	**176**	165	161	158
Cetaceans Mid frequency (MFC)	143	137	129	122	118
Cetaceans High frequency (HFC)	134	129	120	113	109
Pinnipeds – Otariid (OW)	168	163	154	148	143
Sirenians (SI)	151	146	137	131	126
Chelonians (TU)	180	176	165	161	158
Cumulative Sound Exposure Level (SEL24hrs) (SELss+10log10(N)) dB re 1 µPa²·s | N= 600 strikes^					
Unweighted	210***	206***	198***	196***	193***
Cetaceans Low frequency (LFC)	***208***	***203***	***193***	***189***	***185***
Cetaceans Mid frequency (MFC)	**170**	166	156	150	146
Cetaceans High frequency (HFC)	***164***	***157***	**147**	**141**	137
Pinnipeds – Otariid (OW)	**195**	**191**	182	175	171
Sirenians (SI)	**179**	**174**	164	158	154
Chelonians (TU)	***208***	***203***	**193**	**189**	186

* Exceeding the behavioural threshold for marine mammals, chelonians, humans and birds
**Exceeding the TTS (and PTS at <150m) threshold for high-frequency cetaceans and the injury threshold for fish and chelonians (<70m)
***Exceeding the injury threshold for chelonians (<80m), fish (<120m), diving birds (<2400m) if animals are exposed to all 600 pile strikes
^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.

Construction vessels at La Perouse

The predicted underwater noise levels at set distances from vessels at La Perouse wharf are provided on the table below. The maximum value from each direction has been shown for each distance. Values that are above behavioural response thresholds have been formatted in underline. Values that are above damage (TTS) criteria are formatted in **bold**.

Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E10. Underwater noise level prediction from construction vessels at La Perouse

Metrics	Sound Level dB at specified distances from vessel				
	50m	100m	300m	500m	1km
SPL dB re 1 µPa (rms)					
Unweighted	137*	133*	129*	127*	124*
Sound Exposure Level (SEL) dB re 1 µPa²·s | 1 vessel pass-by					
Unweighted	171	167	163	161	158
Cetaceans Low frequency (LFC)	165	159	152	149	146
Cetaceans Mid frequency (MFC)	132	126	118	110	106
Cetaceans High frequency (HFC)	123	117	110	100	96
Chelonians (TU)	162	157	151	149	146
Pinnipeds – Otariid (OW)	157	151	143	135	132
Sirenians (SI)	140	134	126	117	113

*Exceeding behavioural impact threshold for marine mammals and birds

Construction vessels at Kurnell

The predicted underwater noise levels at set distances from vessels at Kurnell wharf are provided on the table below. The maximum value from each direction has been shown for each distance. Values that are above behavioural response thresholds have been formatted in underline. Values that are above damage (TTS) criteria are formatted in bold.

Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E11. Underwater noise level prediction from construction vessels at Kurnell

Metrics	Sound Level dB at specified distances from vessel				
	50m	100m	300m	500m	1km
SPL dB re 1 µPa (rms)					
Unweighted	136*	133*	128*	126*	124*
Sound Exposure Level (SEL) dB re 1 µPa²·s 1 vessel pass-by					
Unweighted	170	167	162	160	158
Cetaceans Low frequency (LFC)	164	159	152	149	146
Cetaceans Mid frequency (MFC)	132	127	118	112	108
Cetaceans High frequency (HFC)	124	118	109	103	99
Chelonians (TU)	161	157	150	149	146
Pinnipeds – Otariid (OW)	157	151	143	137	133
Sirenians (SI)	141	135	126	120	116

*Exceeding behavioural impact threshold for marine mammals and birds

E1.3.2 Operation

Ferry vessels at La Perouse

The predicted underwater noise levels at set distances from vessels at La Perouse wharf are provided on the table below. The maximum value from each direction has been shown for each distance. Values that are above behavioural response thresholds have been formatted in underline. Values that are above damage (TTS) criteria are formatted in **bold.**

Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E12. Underwater noise level prediction from ferry vessels at La Perouse

Metrics	Sound Level dB at specified distances from vessel				
	50m	100m	300m	500m	1km
SPL dB re 1 µPa (rms)					
Unweighted	145*	141*	137*	135*	132*
Sound Exposure Level (SEL) dB re 1 µPa²·s | 1 vessel pass-by					

Metrics	Sound Level dB at specified distances from vessel				
	50m	**100m**	**300m**	**500m**	**1km**
Unweighted	179	175	171	169	166
Cetaceans Low frequency (LFC)	173	167	160	157	154
Cetaceans Mid frequency (MFC)	140	134	126	118	114
Cetaceans High frequency (HFC)	131	125	118	108	104
Chelonians (TU)	170	165	159	157	154
Pinnipeds – Otariid (OW)	165	159	151	143	140
Sirenians (SI)	148	142	134	125	121

*Exceeding behavioural impact threshold for marine mammals and birds

Ferry vessels at Kurnell

The predicted underwater noise levels at set distances from vessels at Kurnell wharf are provided on the table below. The maximum value from each direction has been shown for each distance. 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.**

Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E13. Underwater noise level prediction from ferry vessels at Kurnell

Metrics	Sound Level dB at specified distances from vessel				
	50m	100m	300m	500m	1km
SPL dB re 1 µPa (rms)					
Unweighted	<u>144*</u>	<u>141*</u>	<u>136*</u>	<u>134*</u>	<u>132*</u>
Sound Exposure Level (SEL) dB re 1 µPa²·s | 1 vessel pass-by					
Unweighted	178	175	170	168	166
Cetaceans Low frequency (LFC)	172	167	160	157	154
Cetaceans Mid frequency (MFC)	140	135	126	120	116
Cetaceans High frequency (HFC)	132	126	117	111	107
Chelonians (TU)	169	165	158	157	154
Pinnipeds – Otariid (OW)	165	159	151	145	141
Sirenians (SI)	149	143	134	128	124

*Exceeding behavioural impact threshold for marine mammals and birds

Ferry vessels in the Channel

The predicted underwater noise levels at set distances from vessels in the channel are provided on the table below. The maximum value from each direction has been shown for each distance. 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.**

Note that impacts to fish, birds and human divers are described using unweighted sound levels while impacts to marine mammals and turtles are described using a combination of weighted and unweighted sound levels.

Table E14. Underwater noise level prediction from ferry vessels in the channel

Metrics	Sound Level dB at specified distances from vessel				
	50m	100m	300m	500m	1km
SPL dB re 1 µPa (rms)					
Unweighted	148*	143*	138*	135*	132*
Sound Exposure Level (SEL) dB re 1 µPa²·s, | 1 vessel pass-by					
Unweighted	182	177	172	169	166
Cetaceans Low frequency (LFC)	167	167	161	159	154
Cetaceans Mid frequency (MFC)	128	129	126	123	119
Cetaceans High frequency (HFC)	118	119	117	114	110
Chelonians (TU)	167	166	160	158	154
Pinnipeds – Otariid (OW)	153	154	151	147	144
Sirenians (SI)	136	137	134	131	127

*Exceeding behavioural impact threshold for marine mammals and birds

**Exceeding behaviour impact threshold for chelonians

Appendix F

Mitigation measures

F1 Mitigation measures

This appendix considers the recomended mitigation measures.

F1.1 Construction

Recommended precautionary zones (i.e. observation and exclusion zones) have been defined. These safety zones should be reviewed once detailed planning for construction commences and in response to actual monitoring of received underwater noise levels.

Shut-down zones apply in a straight line from the sound source – i.e. areas of the approach to Botany Bay which do not have line-of-sight to the piling source would not be considered to be part of the shut-down zones even if within the recommended distances.

The observation zone would be developed based on:

- The recommended observation zone from the SA Underwater Piling Noise Guidelines (with modifications to use the Phase 3 weighting functions in place of the M-weightings as described further in Appendix E),
- ~20% larger than the exclusion zone, where the exclusion zone would otherwise be larger than the recommended observation zone from the Guidelines.

It should be noted that the zone of expected behavioural impacts is generally much larger than the recommended observation zone, which this means that animals that enter the observation zone may potentially experience an avoidance reaction and turn away from the pile, decreasing the probability that animals will enter the zone where actual injury to the animal could occur.

The EPCB Act Policy Statement 2.1 (Department of the Environment, Water, Heritage and the Arts, 2008) notes that "*it is likely that whales in the vicinity of seismic surveying will avoid the immediate area due to an aversive response to the sound. This aversion is relied upon as a form of mitigation to prevent whales from approaching or being approached closely enough to cause acoustic injury from intense or prolonged sound exposure*.". This aversion may also occur for piling which is similarly a low-frequency dominant impulsive sound source.

The exclusion zone would be developed based on:

- The predicted distance at which any injury (i.e. TTS, PTS) would occur from a single pile strike (either peak or single strike SEL)
- For cetaceans, pinnipeds, sirenians or chelonians: the predicted distance at which TTS may occur from cumulative piling (SEL24hr)
- The recommended exclusion zone from the SA Underwater Piling Noise Guidelines (with modifications to use the Phase 3 weighting functions in place of the M-weightings as described further in Appendix E).

This approach is essentially defining the exclusion zone as including the area within which instantaneous injury to an animal would be expected from a single pile strike, plus the area in which it would be possible for an animal to experience cumulative injury in the (unlikely) event that the animal remains within the exclusion zone for all piling strikes.

Marine megafauna has 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.

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 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. Safety zones for humans are not provided since there are no impact thresholds for injury to humans available. Impacts to humans are described based on behavioural impacts and will be managed via beach closures, restrictions on diving etc.
Because the modelling has only considered discrete 'slices' of bathymetry, and accounting for the degree of variation in the source levels, a conservative approach has been adopted to determine precautionary zones so that any changes in bathymetry that may occur at azimuth angles other than those modelled do not make the precautionary zones inadequate. A safety factor of 10% has been applied in determining precautionary zones (which are rounded up to the nearest 10 m).

F1.1.1 Protection zone

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/HFC/OW/SI/TU weightings 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, precautionary 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, precautionary zones of 300 m (exclusion) / 1.5 km (observation) would apply.
- Where the weighted SELss > 150 dB at 300 m, precautionary zones of 1 km (exclusion) / 2 km (observation) would apply.

However, because of the changes from the M-weightings in Southall et al 2007 to the new NMFS (LFC etc) weightings, the threshold values (i.e. the 150 dB weighted SELss) from the SA Piling Guidelines need to be updated to reflect the latest scientific understanding of the sensitivity of marine mammals.
The threshold for PTS impacts from (Southall *et al* 2007) was 198 dB SEL M-weighted for cetaceans and 186 dB SEL Mpw weighted for pinnipeds. However, the latest NMFS / Finneran et al 2017 Phase 3 weightings do not have the same threshold values for each cetacean group, as shown below in Table F1 below.

Table F1. Comparison of Phase 1 (original data 2010) (M-weighting) and Phase 3 (original data 2016) thresholds for PTS, dB SEL (weighted)

Species Group	Original data 2010	Revised data 2016
Low-Frequency Cetaceans	198 dB Mlf	183 dB LFC
Mid-Frequency Cetaceans	198 dB Mmf	185 dB MFC
High-Frequency Cetaceans	198 dB Mhf	155 dB HFC
Pinnipeds (Otariid)	186 dB Mpw	203 dB OW
Sirenians	No threshold provided	190 dB SI
Chelonians	No threshold provided	204 dB OW

This means that the 150 dB threshold value from the Guidelines is not valid for use with the newer Phase 3 weightings.

In place of the 150 dB weighted SEL value, from the Guidelines, a threshold of 48 dB below the PTS threshold (i.e. an equivalent level below the PTS threshold) has been used to determine the recommended exclusion zones.

The predicted single strike SEL values for piling at La Perouse and Kurnell are presented in Table F2 and Table F3 respectively, colour-coded to show the applicable category.

Table F2. Predicted weighted single strike SEL levels at 100 m and 300 m distance from piling at Kurnell.

Species Group	Weighted SELss Level at 100 m relative to PTS threshold	Weighted SELss Level at 300 m relative to PTS threshold
Low-Frequency Cetaceans	-7 dB	-18 dB
Mid-Frequency Cetaceans	-48 dB	-56 dB
High-Frequency Cetaceans	-11 dB	-20 dB
Pinnipeds – Otariid	-40 dB	-49 dB
Sirenians	-44 dB	-53 dB
Chelonians	-28 dB	-39 dB

Table F3. Predicted weighted single strike SEL levels at 100 m and 300 m distance from piling at La Perouse.

Species Group	Weighted SELss Level at 100 m	Weighted SELss Level at 300 m
Low-Frequency Cetaceans	-7 dB	-17 dB
Mid-Frequency Cetaceans	-48 dB	-56 dB
High-Frequency Cetaceans	-12 dB	-20 dB
Pinnipeds – Otariid	-41 dB	-49 dB
Sirenians	-35 dB	-43 dB
Chelonians	-28 dB	-37 dB

Because of the three categories, there can be significant increases in the size of the zone in cases where noise levels are just above a threshold. In these cases, the recommended zones have been modified based on the predicted zones of impact.

Appendix E presents the recommended exclusion zones from the SA Underwater Piling guidelines (as modified above) compared with the predicted zones of impact. In general, the modified SA Underwater Piling Guideline exclusion zones are more conservative (larger) than the distance at which cumulative temporary hearing damage would be expected, with the exception of low-frequency cetaceans where the recommended exclusion zone is actually smaller than the zone within which cumulative permanent hearing damage is predicted. For some animals (sirenians, chelonians) the SA Guideline exclusion zones are considered to be over-conservative since the exclusion zone is more than twice the size of the predicted cumulative zone of impact – which is itself conservative because the cumulative impact zones assume that animals are stationary and make no attempt to avoid the noise source.

Accordingly, for some species/locations the size of the exclusion zone is recommended to be adjusted compared to the SA Guideline to better reflect the predicted zones of impact.

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 4.3. The observation and exclusion zones are summarised in Table F4 and Table F5 below.

As discussed previously, no precautionary zones are defined for fish, diving birds or humans however the typical impact zones have been provided for context.

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

Table F4. Recommended observational and exclusion zones summary– Piling at La Perouse.

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
Cetaceans (Low- frequency)	Physical injury		237 dB PK	< 1 m from pile.	1000 m	2000 m	2250 m	3000 m	The SA Guideline shut-down zone is smaller than the distance at which cumulative permanent or temporary hearing damage may occur if an animal is exposed to all pile strikes. Setting the shut-down zone as the size of the zone where permanent injury could occur (with an appropriate safety factor) is recommended. Setting the shut-down zone based on the zone of temporary (recoverable) injury is not considered reasonable since it would result in the entirety of Botany Bay being the shut-down zone.
	Auditory injury	PTS	219 dB PK and 183 dB SEL* (LFC weighted)	~30m single strike ~2050 m from 24-hour exposure.					
		TTS	213 dB PK and 168 dB SEL* (LFC weighted)	~240 m from single strike > 7 km from 24-hour exposure.					
	Behavioural Response		160 dB SPL	>7 km.					
Cetaceans (Mid-frequency)	Physical injury		237 dB PK	< 1 m from pile.	100 m	1000 m	100 m	1000 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
	Auditory injury	PTS	230 dB PK 185 dB SEL* (MFC weighted)	~1 m from single strike ~1 m from 24-hour exposure.					

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
		TTS	224 dB PK 170 dB SEL* (MFC weighted)	~10 m from single strike ~50 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					
Cetaceans (High-frequency)	Physical injury		237 dB PK	< 1 m from pile.	1000 m	2000 m	1000 m	2000 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
	Auditory injury	PTS	202 dB PK 155 dB SEL* (HFC weighted)	~130 m from single strike ~110 m from 24-hour exposure.					
		TTS	196 dB PK 140 dB SEL*(HFC weighted)	~330 m from single strike ~500 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					
Pinnipeds-Otariids	Physical injury		237 dB PK	< 1 m from pile.	300 m	1500 m	300 m	1500 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative
	Auditory injury	PTS	232 dB PK	~1 m from single strike					

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
			203 dB SEL* (OW weighted)	~1 m from 24-hour exposure.					temporary injury is predicted to occur. Shut down zone is conservative.
		TTS	226 dB PK 188 dB SEL* (OW weighted)	~10 m from single strike ~140 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					
Sirenians	Physical injury		237 dB PK	< 1 m from pile.	1000 m	2000 m	500 m	1500 m	SA Piling Guideline shut-down zone is more than twice the size of the distance at which cumulative temporary injury is predicted to occur. SA Guidelines shut down zone is considered over-conservative.
	Auditory injury	PTS	226 dB PK 190 dB SEL* (SI weighted)	~15 m from single strike ~40 m from 24-hour exposure.					
		TTS	220 dB PK 175 dB SEL* (SI weighted)	~10 m from single strike ~300 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
Fish	Physical injury		207 dB PK 203 dB SEL* (unweighted)	~60 m from single strike ~160 m from 24-hour exposure.	N/A	N/A	N/A	N/A	N/A
	Auditory Injury	PTS	No criteria provided	N/A					
		TTS	186 dB SEL* (unweighted)	~35 m from single strike ~3600 m from 24-hour exposure.					
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) High (F) Moderate					
Sea Turtles	Physical injury		207 dB PK 210 dB SEL* (unweighted)	~60 m from single strike ~60 m from 24-hour exposure.	1000 m	2000 m	1000 m	2000 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
	Auditory injury	PTS	232 dB PK 204 SEL* (TU weighted)	~1 m from single strike ~90 m from 24-hour exposure.					

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
		TTS	226 dB PK 189 dB SEL* (TU weighted)	~10 m from single strike ~500 m from 24-hour exposure.					
	Behavioural response		175 dB SPL (unweighted)	~3150 m from single strike.					
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	~10 m from single strike ~1800m from 24-hour exposure.	N/A	N/A	N/A	N/A	N/A
	Auditory injury		N/A	N/A					
	Behavioural response		120 dB SPL	>7 km.					
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	>7 km.	N/A	N/A	N/A	N/A	N/A
		Onset of severe reaction	145 dB SPL	>7 km.					

*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).

Table F5. Recommended observational and exclusion zones summary – Piling at Kurnell.

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
Cetaceans (Low- frequency)	Physical injury		237 dB PK	< 1 m from pile.	1000 m	2000 m	1750 m	2000 m	The SA Guideline shut-down zone is smaller than the distance at which cumulative permanent or temporary hearing damage may occur if an animal is exposed to all pile strikes. Setting the shut-down zone as the size of the zone where permanent injury could occur (with an appropriate safety factor) is recommended. Setting the shut-down zone based on the zone of temporary (recoverable) injury is not considered reasonable since it would result in the entirety of Botany Bay being the shut-down zone.
	Auditory injury	PTS	219 dB PK and 183 dB SEL* (LFC weighted)	30m single strike ~1600 m from 24-hour exposure.					
		TTS	213 dB PK and 168 dB SEL* (LFC weighted)	240 m from single strike > 7 km from 24-hour exposure.					
	Behavioural Response		160 dB SPL	>7 km.					
Cetaceans (Mid-frequency)	Physical injury		237 dB PK	< 1 m from pile.	100 m	1000 m	100 m	1000 m	SA Piling Guideline shut-down zone is approximately twice the size of

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
	Auditory injury	PTS	230 dB PK 185 dB SEL* (MFC weighted)	~1 m from single strike ~1 m from 24-hour exposure.					the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
		TTS	224 dB PK 170 dB SEL* (MFC weighted)	~10 m from single strike ~50 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					
Cetaceans (High-frequency)	Physical injury		237 dB PK	< 1 m from pile.	1000 m	2000 m	1000m	2000m	SA Piling Guideline shut-down zone is almost twice the size of the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
	Auditory injury	PTS	202 dB PK 155 dB SEL* (HFC weighted)	<130 m from single strike ~120 m from 24-hour exposure.					
		TTS	196 dB PK 140 dB SEL*(HFC weighted)	~330 m from single strike ~600 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
Pinnipeds-Otariids	Physical injury		237 dB PK	< 1 m from pile.	300 m	1500 m	300 m	1500 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
	Auditory injury	PTS	232 dB PK 203 dB SEL* (OW weighted)	~1 m from single strike ~1 m from 24-hour exposure.					
		TTS	226 dB PK 188 dB SEL* (OW weighted)	~10 m from single strike ~150 m from 24-hour exposure.					
	Behavioural response		160 dB SPL	>7 km.					
Sirenians	Physical injury		237 dB PK	< 1 m from pile.	300 m	1500 m	300 m	1500 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative temporary injury is predicted to occur. Shut down zone is conservative.
	Auditory injury	PTS	226 dB PK 190 dB SEL* (SI weighted)	~15 m from single strike ~80 m from 24-hour exposure.					
		TTS	220 dB PK 175 dB SEL* (SI weighted)	~10 m from single strike ~120 m from 24-hour exposure.					

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
	Behavioural response		160 dB SPL	>7 km.					
Fish	Physical injury		207 dB PK 203 dB SEL* (unweighted)	~60 m from single strike ~180 m from 24-hour exposure.	N/A	N/A	N/A	N/A	N/A
	Auditory Injury	PTS	No criteria provided	N/A					
		TTS	186 dB SEL* (unweighted)	~35 m from single strike ~3800 m from 24-hour exposure.					
	Behavioural response		No numerical criteria provided. Relative risk only	(N) High (I) High (F) Moderate					
Sea Turtles	Physical injury		207 dB PK 210 dB SEL* (unweighted)	~60 m from single strike ~50 m from 24-hour exposure.	1000 m	2000 m	750 m	2000 m	SA Piling Guideline shut-down zone is approximately twice the size of the distance at which cumulative temporary injury is predicted to occur.

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
	Auditory injury	PTS	232 dB PK 204 SEL* (TU weighted)	~1 m from single strike ~80 m from 24-hour exposure.					Shut down zone is conservative.
		TTS	226 dB PK 189 dB SEL* (TU weighted)	~10 m from single strike. ~500 m from 24-hour exposure.					
	Behavioural response		175 dB SPL (unweighted)	~3500 m from single strike.					
Birds (diving)	Physical injury		190 dB SEL* (unweighted)	~10 m from single strike ~2100 m from 24-hour exposure.	N/A	N/A	N/A	N/A	N/A
	Auditory injury		No criteria provided	N/A					
	Behavioural response		120 dB SPL	>7 km from single strike.					
Human divers / Swimmers	Behavioural response	Tolerance limit	170 dB SPL	>7 km from single strike.	N/A	N/A	N/A	N/A	N/A

Fauna group	Impact Thresholds and Distance of Greatest Impact				Standard SA Guideline Safety Zones		Recommended safety zones		Rationale
	Impact	Injury	Thresholds	Threshold at distance	Shut down zone (m)	Observation zone (m)	Shut down zone (m)	Observation zone (m)	
		Onset of severe reaction	145 dB SPL	>7 km 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).

F1.1.2 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:

- Precautionary zones, including observation and exclusion zones (sized by comparing expected received noise levels with defined noise exposure thresholds). Note that a modified procedure is proposed for this project based on the obsolete nature of the criteria used to set the thresholds in the Guidelines
- 30-minute pre-start-up visual observations
- 10-minute soft-start procedures
- Standby and shut-down procedures
- Compliance and sighting reports.

Although the standard thresholds from the SA Piling Guidelines are based on the outdated Mmf and Mlf parameters, the overall framework for management and mitigation from the Guidelines is considered reasonable – albeit with precautionary zones modified to be calculated on the basis of more-recent LFC, MFC etc parameters as discussed above in Appendix E.

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 precautionary zones
- Use of qualified marine mammal observers
- Operational procedures during night-time or poor visibility
- Passive acoustic monitoring
- Bubble curtains to reduce the severity of the energy of the sounds caused by the driving of the piles
- Maintaining minimum separation between construction vessels and marine mammals as per the NSW declared approach distances from the Biodiversity Conservation Regulation 2017 (NSW) Division 2.1.

F1.1.3 Management and mitigation measures for human swimmers and divers

The predicted noise level within the entire project study area is predicted to exceed the threshold for behavioural impacts to human swimmers and divers. Noise from a single pile strike is predicted to exceed the 145 dB re 1 µPa recommended threshold and the 170 dB re 1 µPa “tolerance limit” across to the opposite side of Botany Bay. This indicates that piling noise is likely to be extremely unpleasant for any swimmers or divers exposed to the noise level and severe avoidance reactions (including startle reactions) may be expected, with divers and swimmers unlikely to want to remain in the water while exposed to the noise.

This is based on worst case modelling assuming line of sight (i.e. straight line from source to swimmer with no intervening terrain) and no mitigation or source controls, however the preliminary mitigation recommendation would be to restrict swimming and diving within Botany Bay (including the channel out to Cape Banks / Cape Solander) when piling works are being conducted.

It is recommended that monitoring of actual underwater noise levels be conducted at the commencement of piling works at each site to determine the actual received level at each swimming/diving location (particularly locations that do not have line-of-sight to the piling rig where prediction is less accurate), and to refine whether restrictions on swimming/diving need to be maintained for each site.

To avoid significant disruptions to the community's ability to engage in recreational swimming and diving within Botany Bay/Cape Banks/Cape Solander for the duration of piling works (up to ~6 months) it is recommended that piling works be scheduled to provide periods in which recreational swimming or diving can be conducted, e.g.

- No works on weekends or public holidays
- No works during school holidays.

F1.2 Operation

Given the limited operational impacts (refer to Appendix E) no specific mitigation measures are proposed. The normal safety measures would apply to avoid people swimming or diving near the ferries and other commercial vessels.

Appendix G

Underwater noise level predictions (figures)

G1 Piling at La Perouse

Predicted underwater noise levels from piling at La Perouse are presented in the figures below. Each colour represents an azimuth.

G1.1.1 Sound Pressure Level

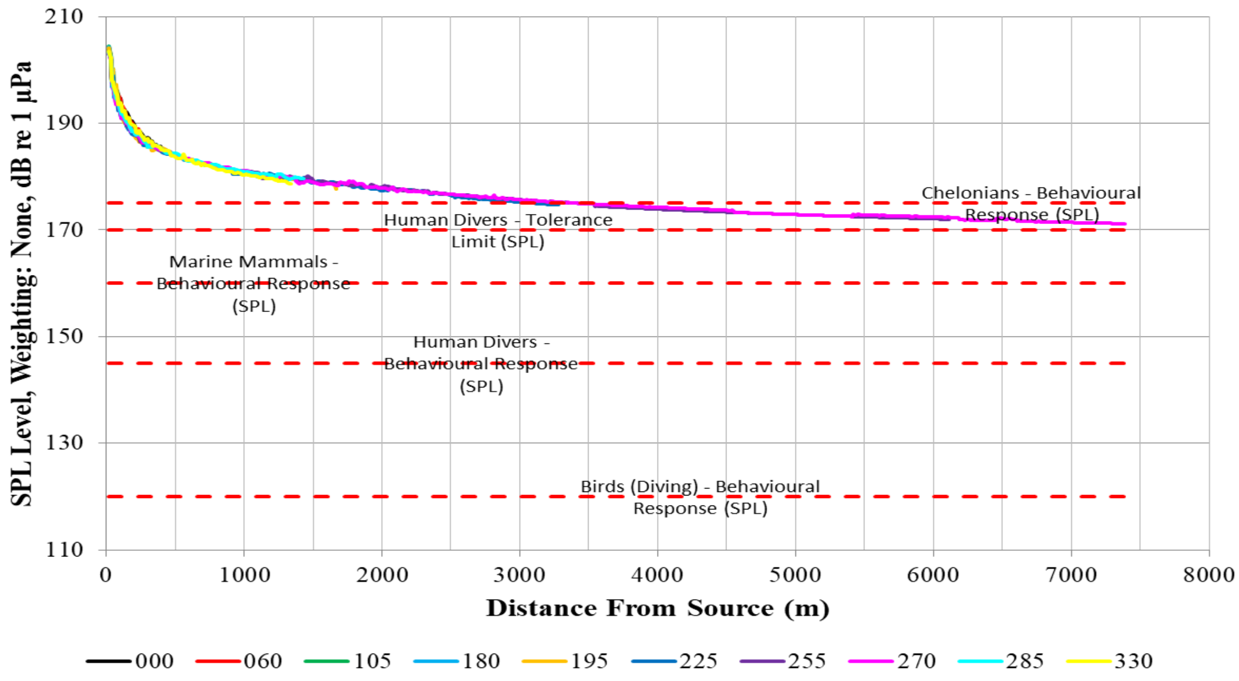

Figure G1. SPL from 0.9m Diameter Impact Piling at La Perouse, Unweighted

G1.1.2 Peak Level

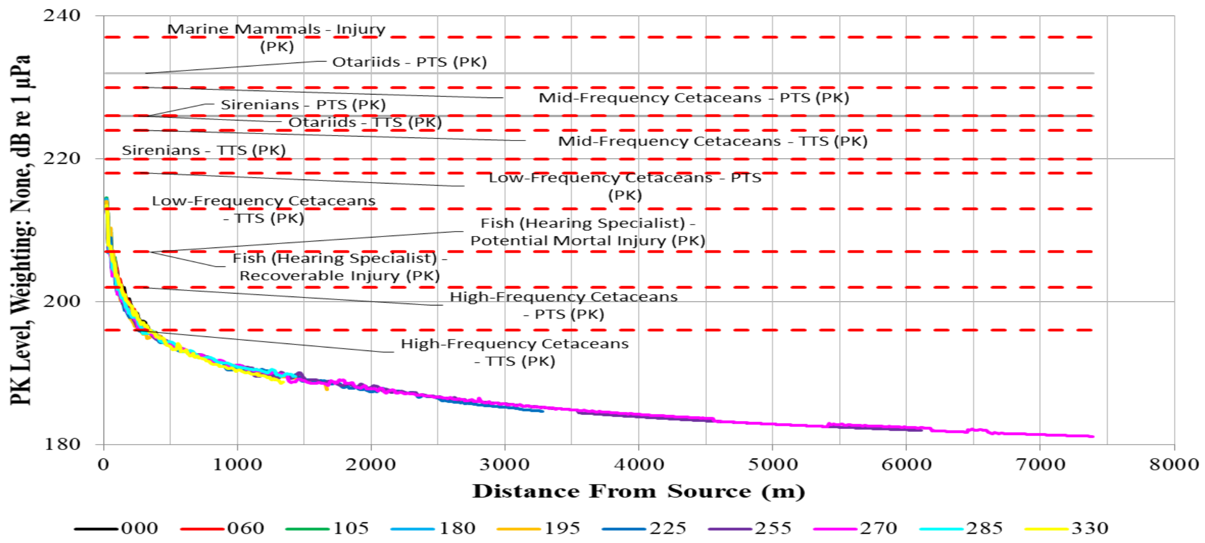

Figure G2. Peak Level from 0.9m Diameter Impact Piling at La Perouse, Unweighted

G1.1.3 Sound Exposure Level (Single Strike)

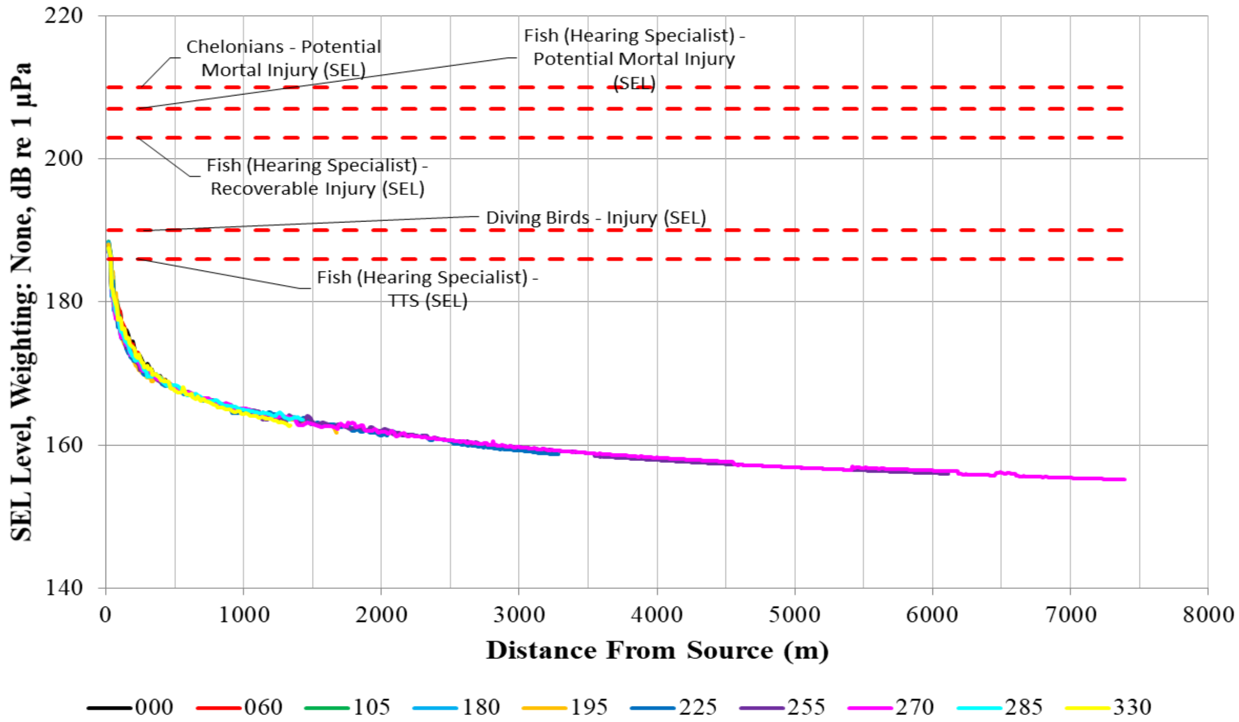

Figure G3. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, Unweighted

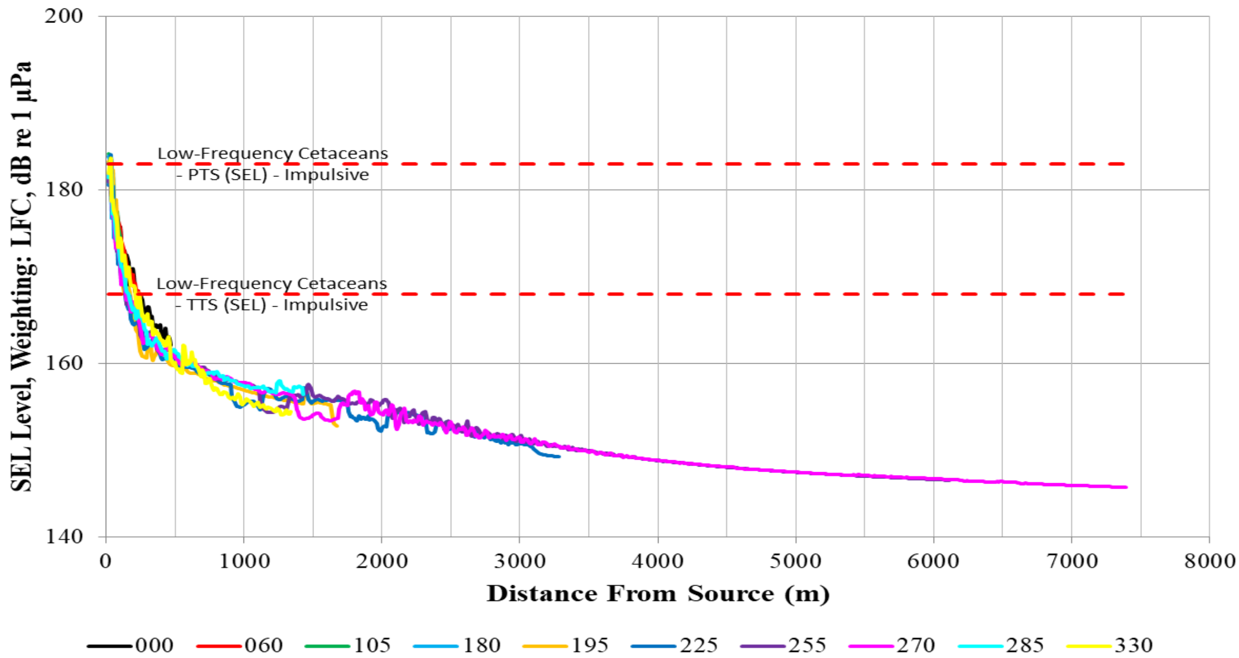

Figure G4. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, LFC Weighted

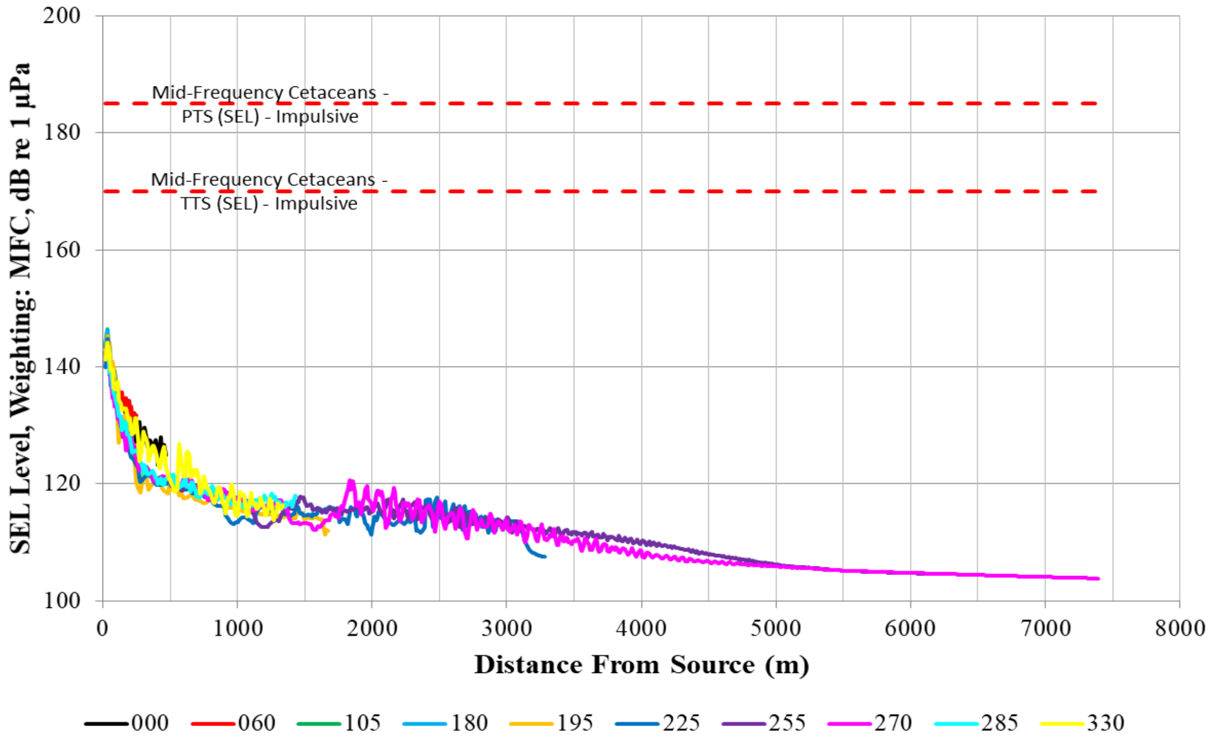

Figure G5. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, MFC Weighted

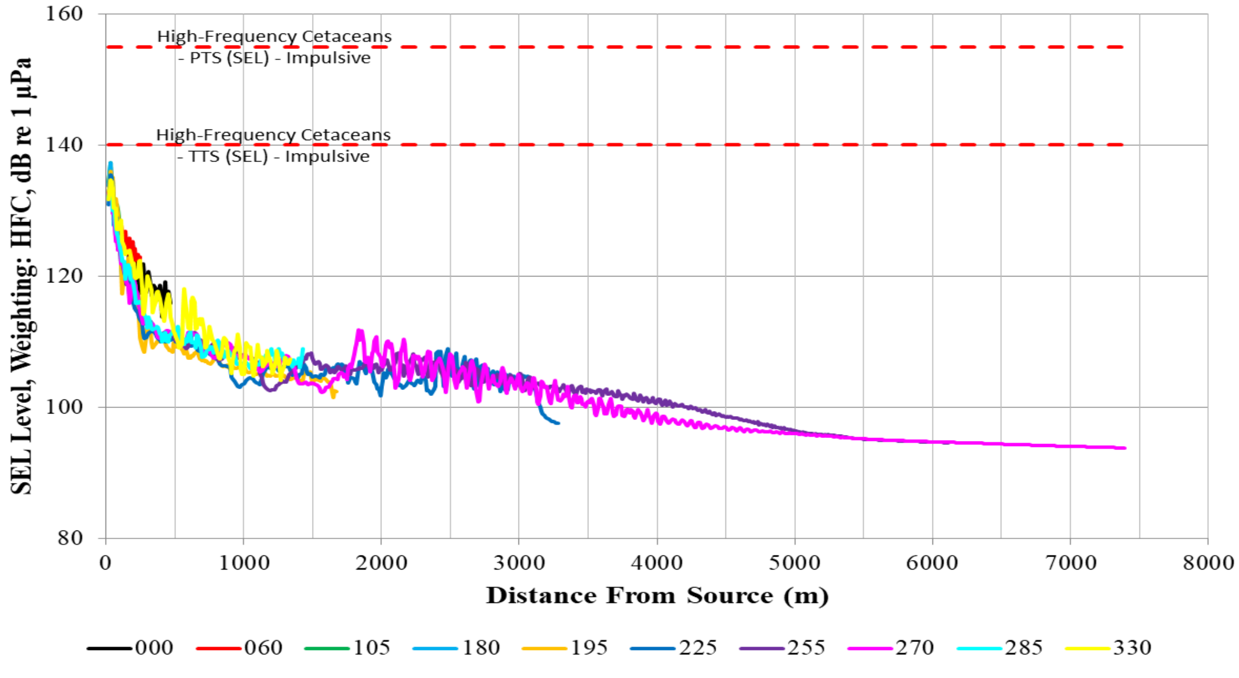

Figure G6. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, HFC Weighted

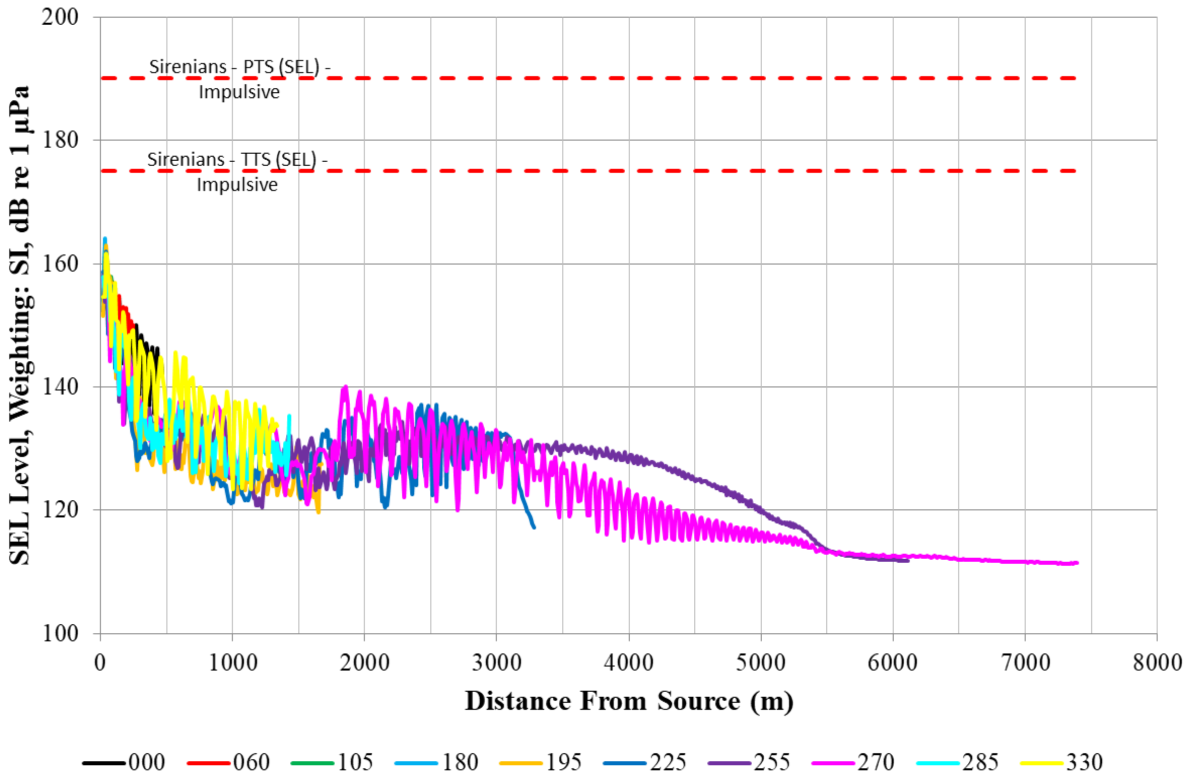

Figure G7. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, TU Weighted

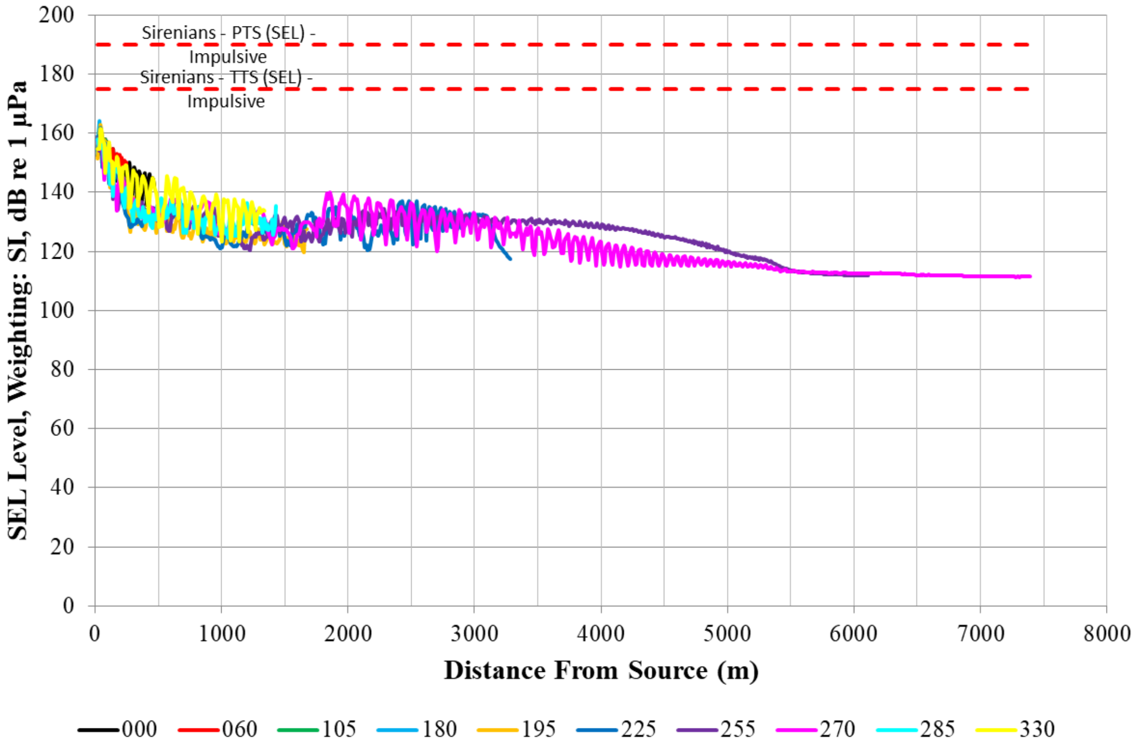

Figure G8. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, SI Weighted

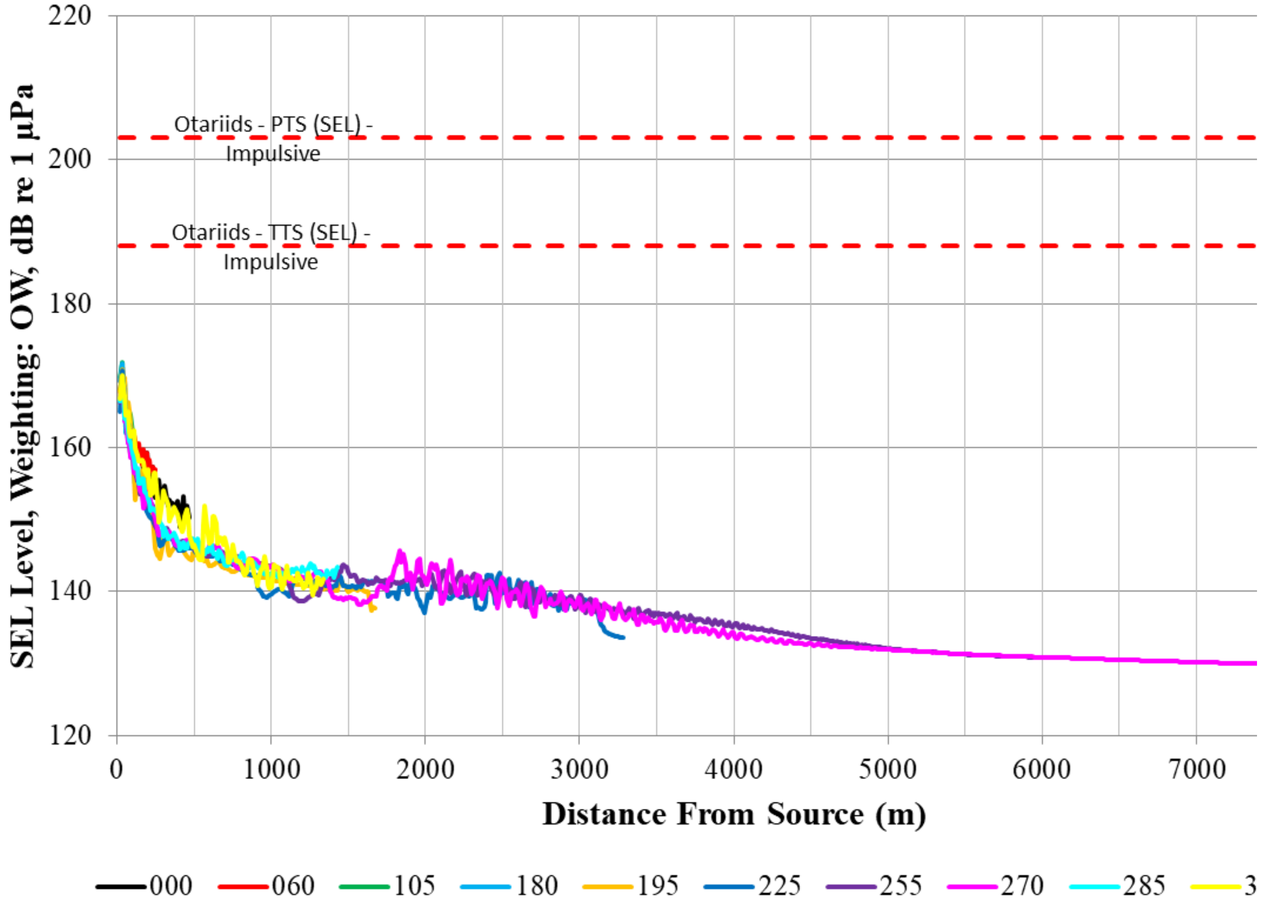

Figure G9. SEL (Single Strike) from 0.9m Diameter Impact Piling at La Perouse, OW Weighted

G1.2 Sound Exposure Level (Cumulative)

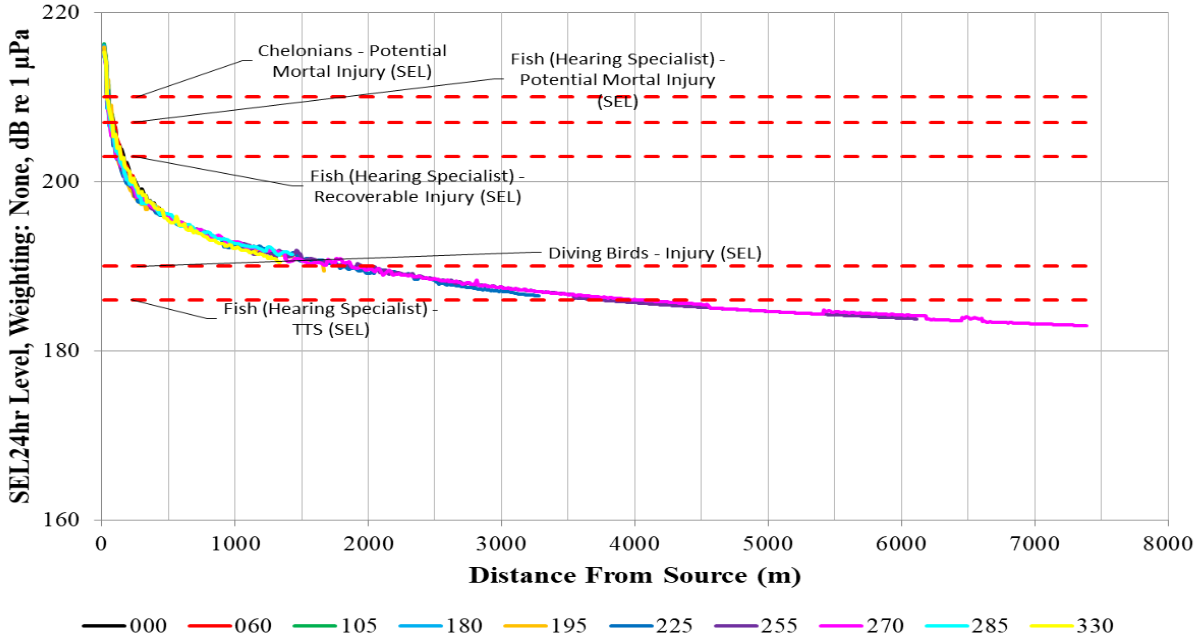

Figure G10. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, Unweighted

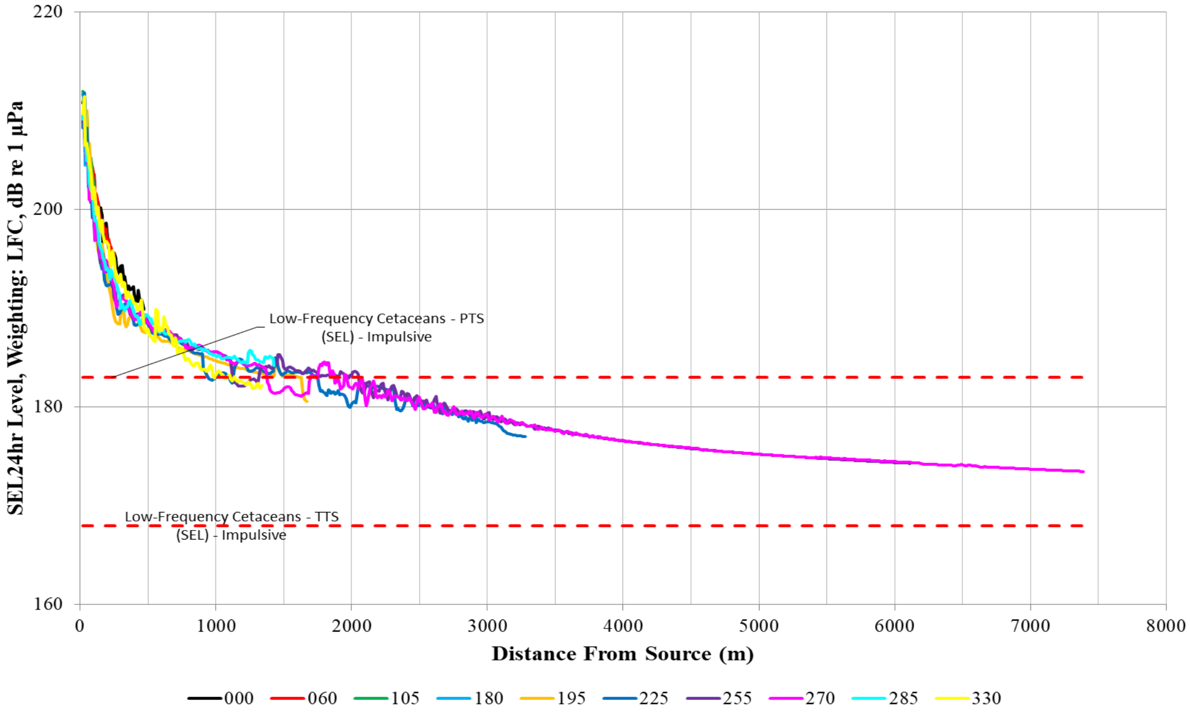

Figure G11. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, LFC Weighted

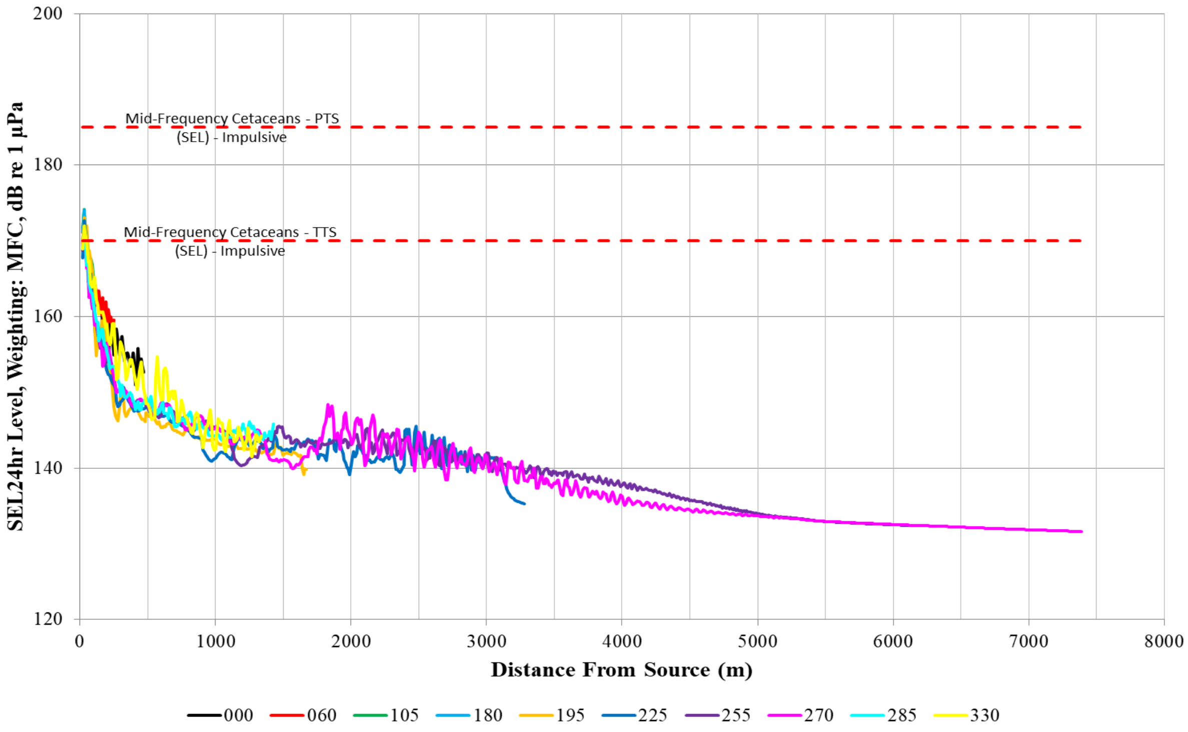

Figure G12. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, MFC Weighted

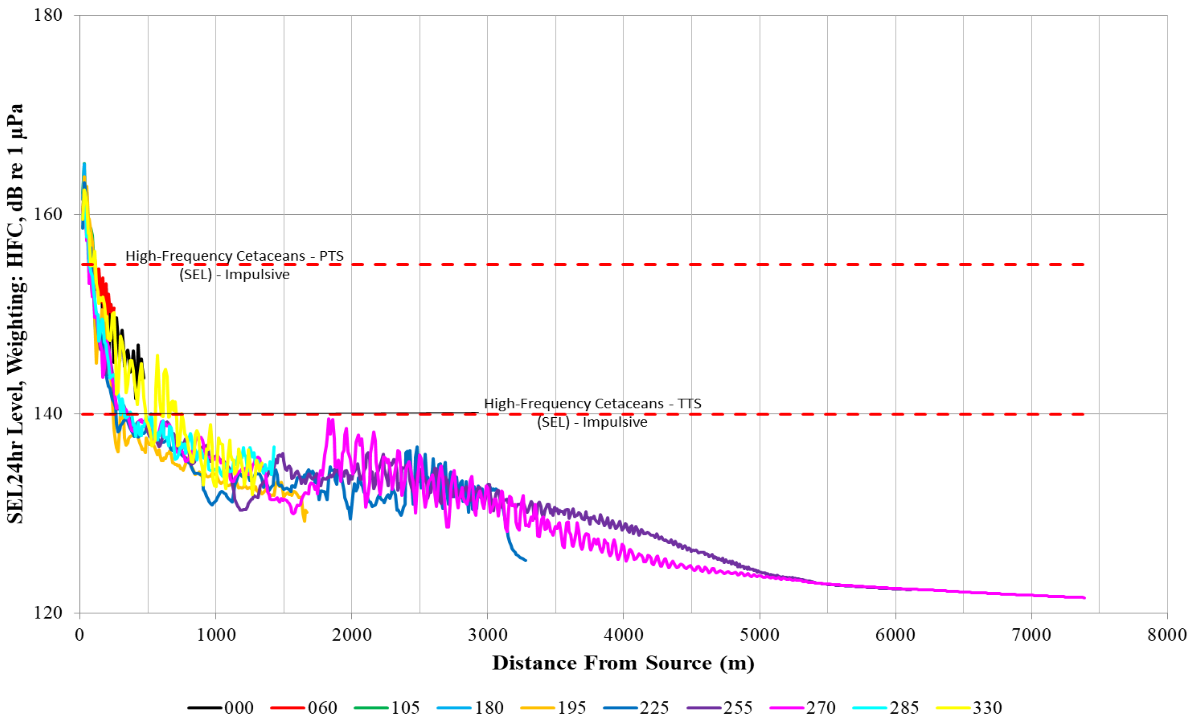

Figure G13. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, HFC Weighted

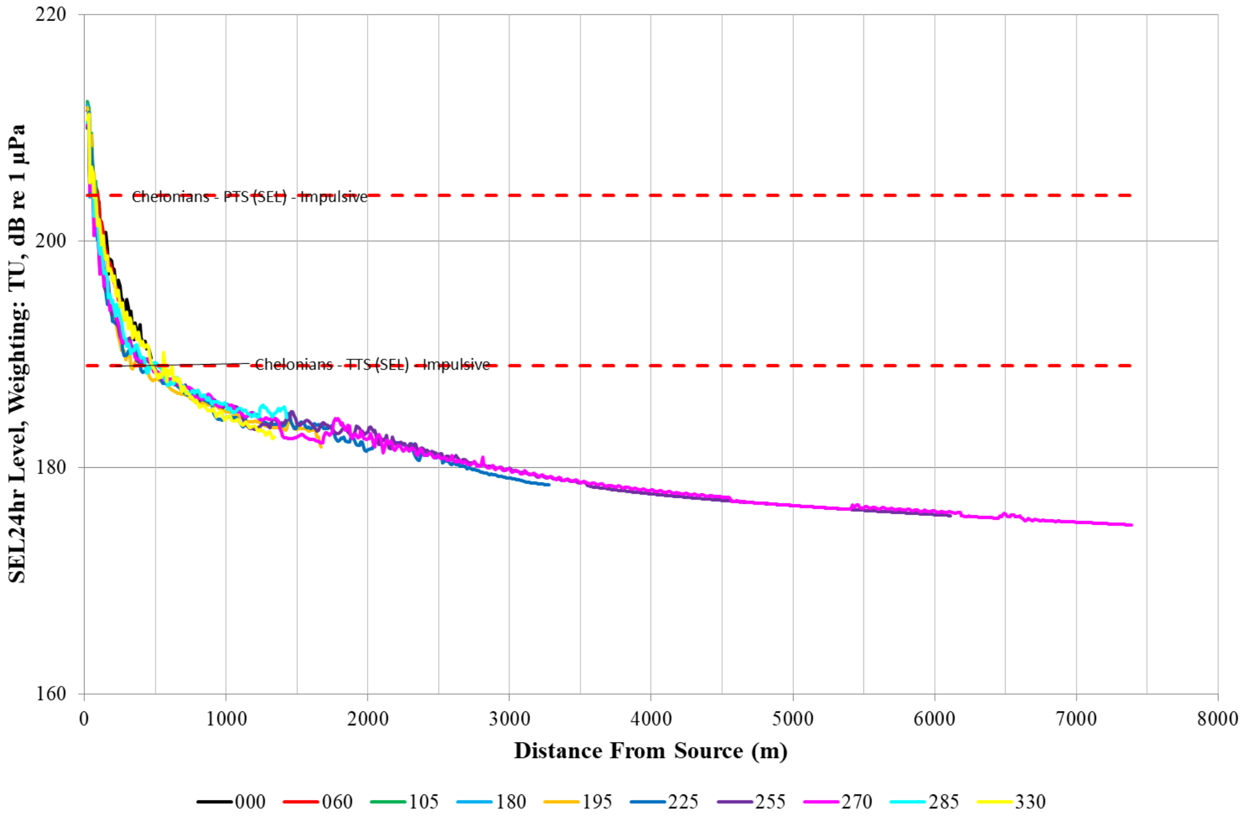

Figure G14. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, TU Weighted

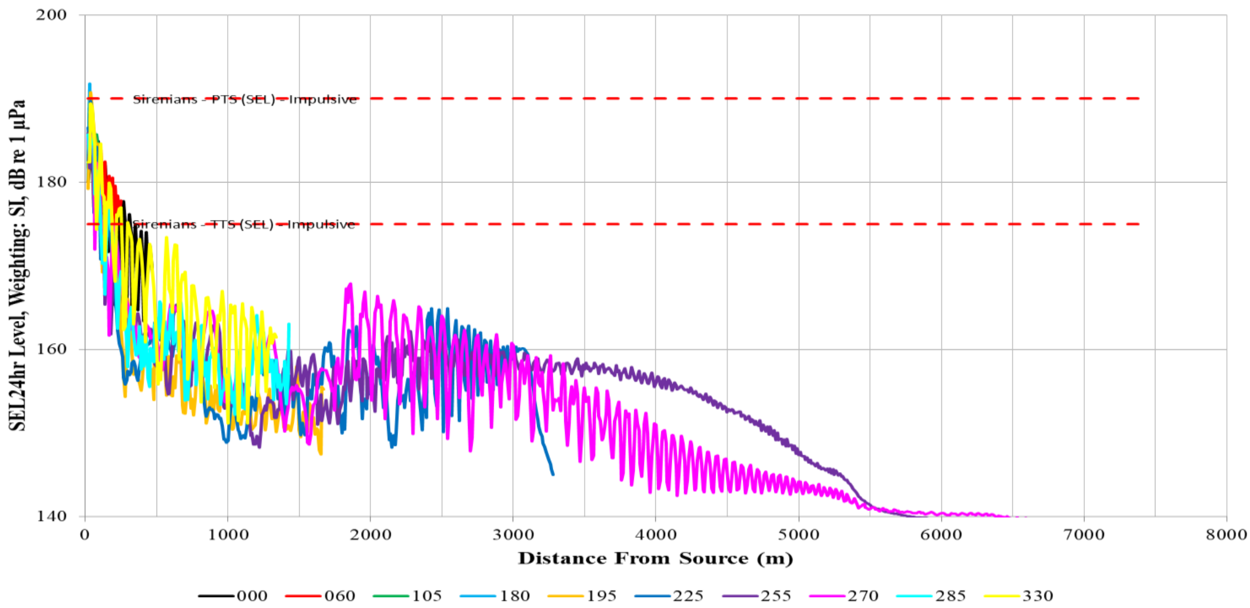

Figure G15. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, SI Weighted

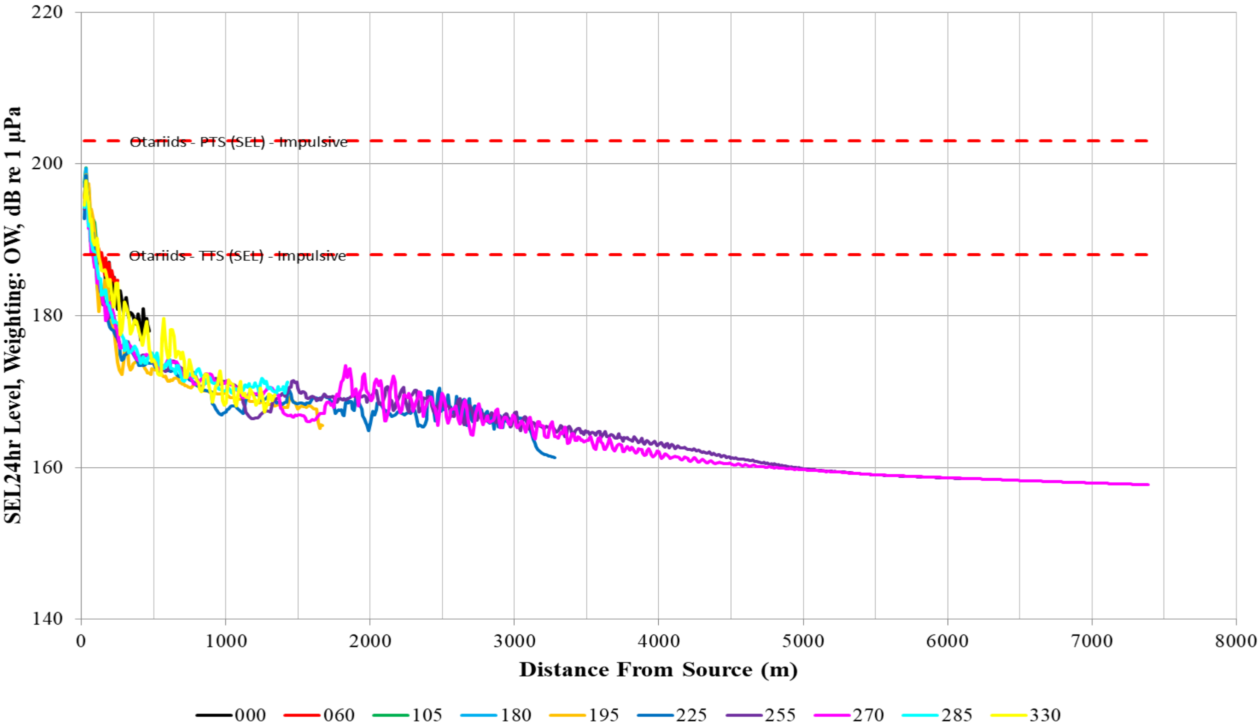

Figure G16. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at La Perouse, OW Weighted

G2 Piling at Kurnell

Predicted underwater noise levels from piling at Kurnell are presented in the figures below. Each colour represents an azimuth transect.

G2.1 Sound Pressure Level

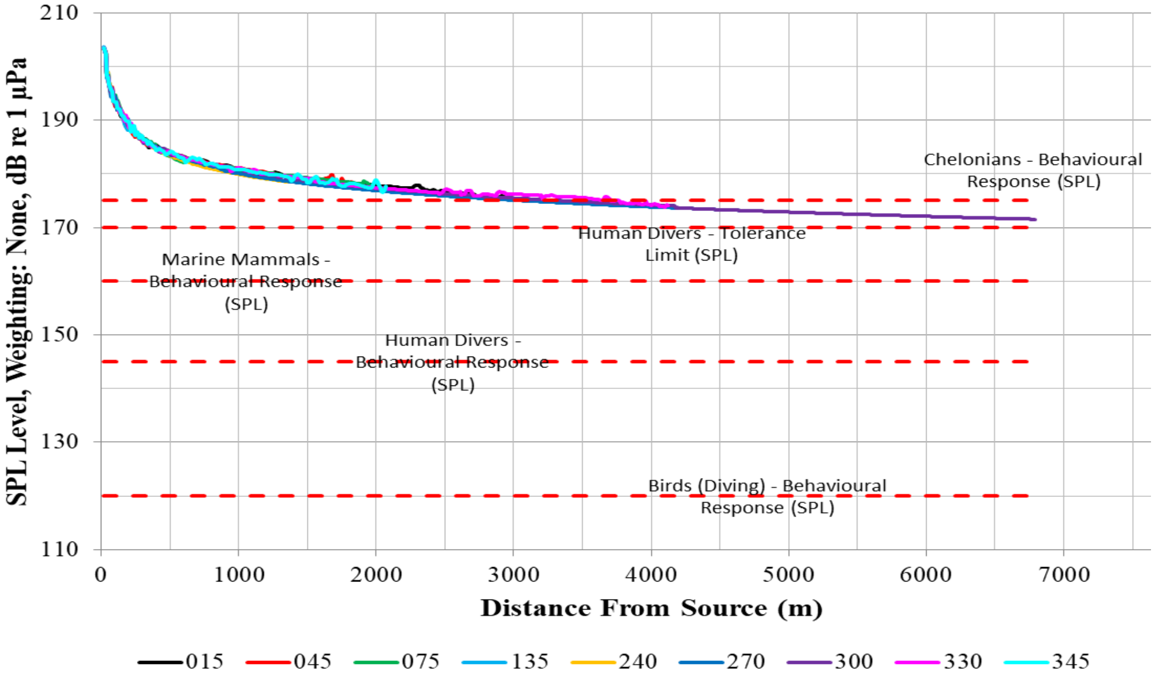

Figure G17. SPL from 0.9m Diameter Impact Piling at Kurnell, Unweighted

G2.2 Peak Level

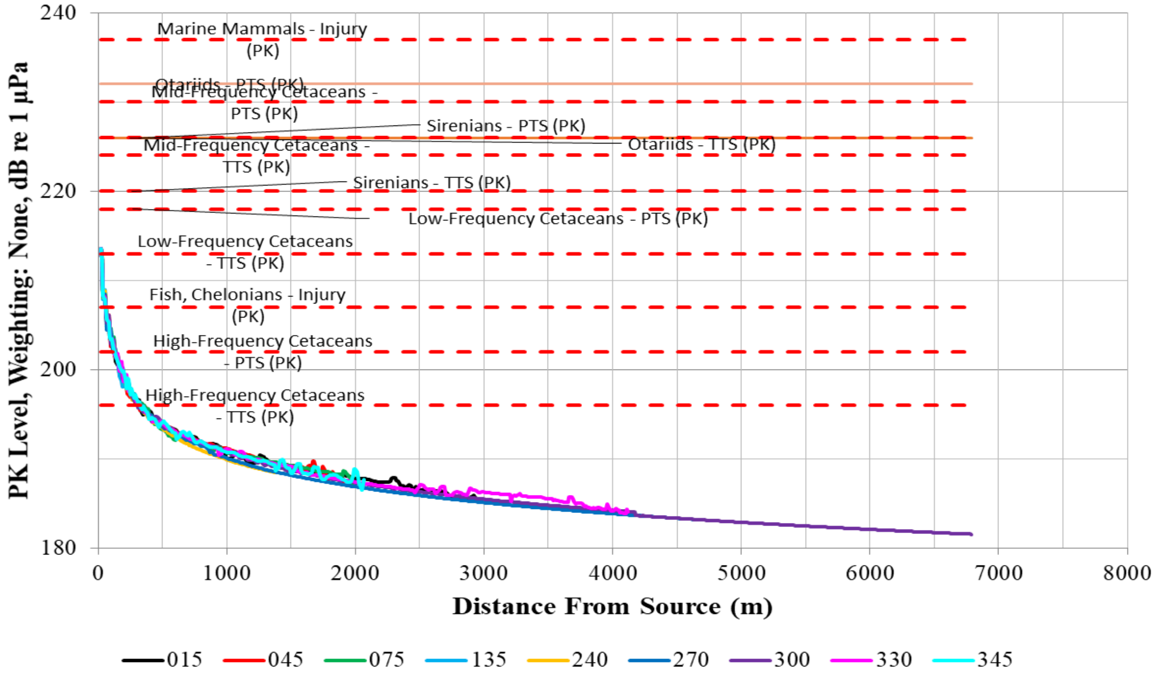

Figure G18. Peak Level from 0.9m Diameter Impact Piling at Kurnell, Unweighted

G2.3 Sound Exposure Level (Single Strike)

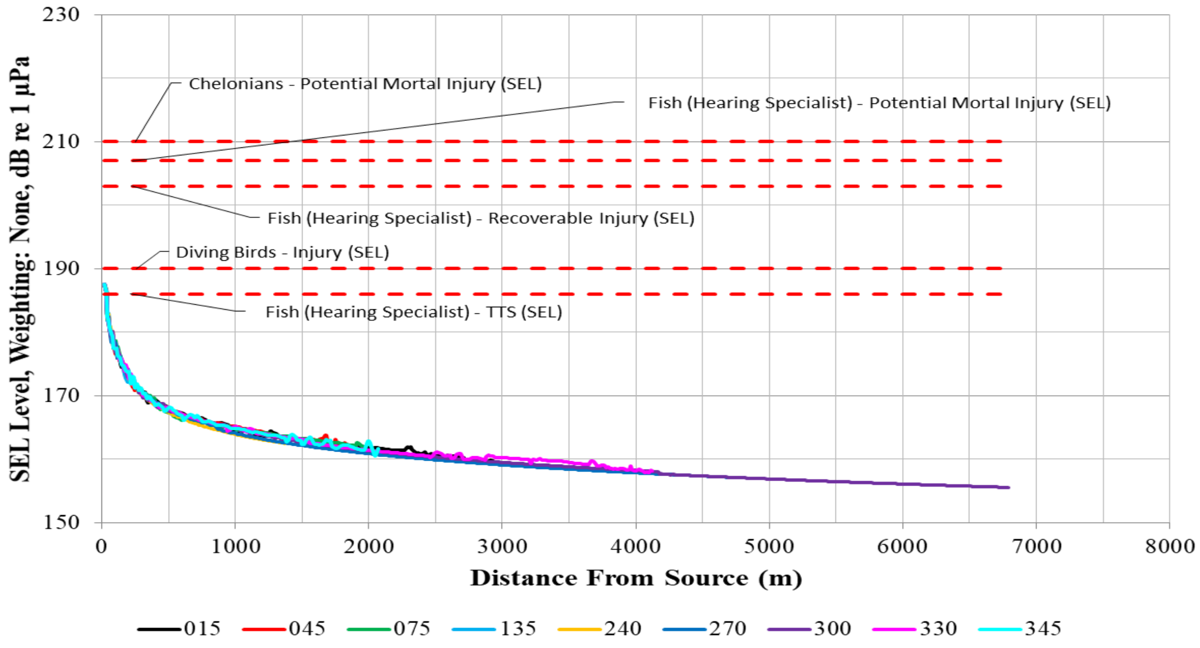

Figure G19. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, Unweighted

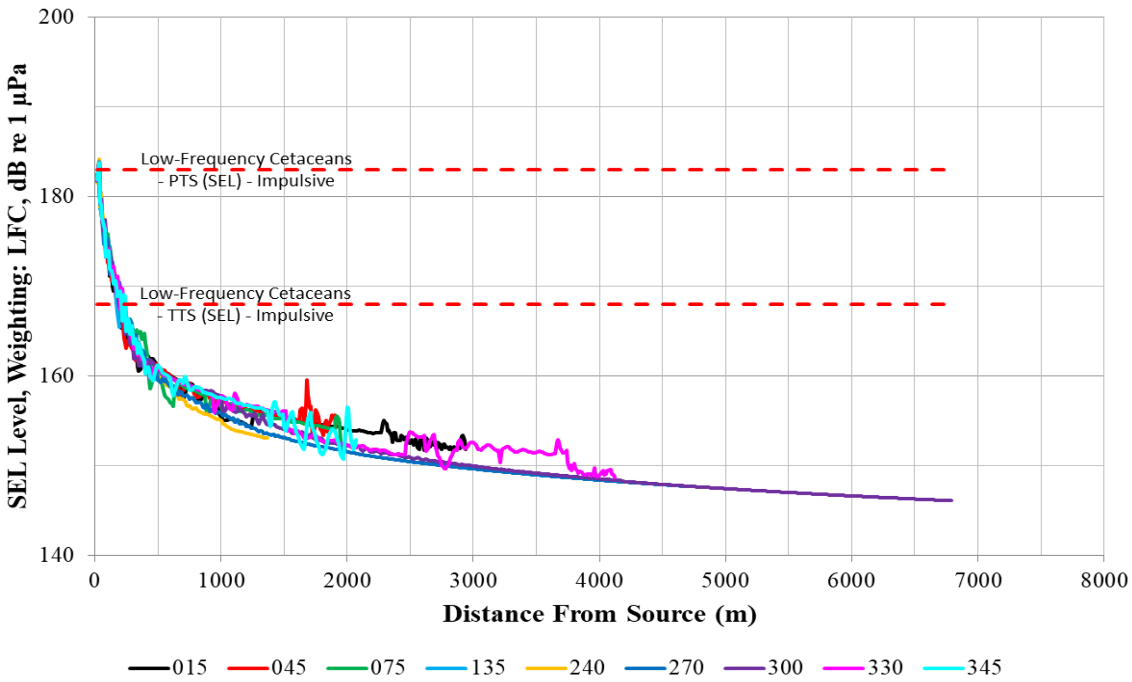

Figure G20. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, LFC Weighted

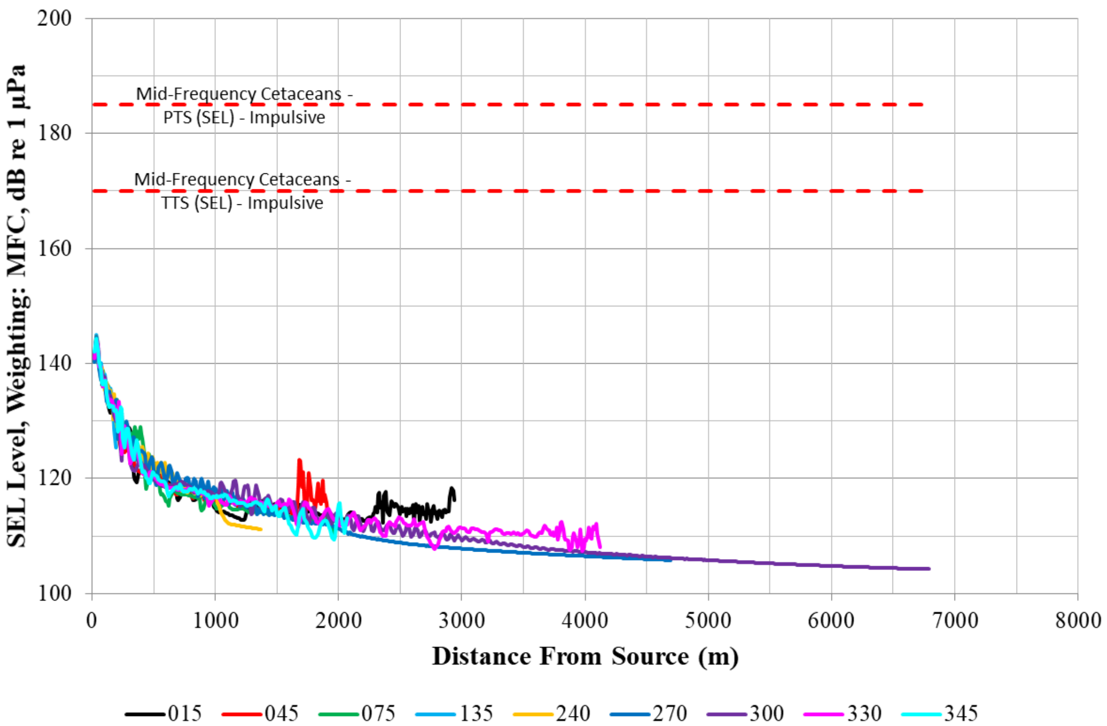

Figure G21. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, MFC Weighted

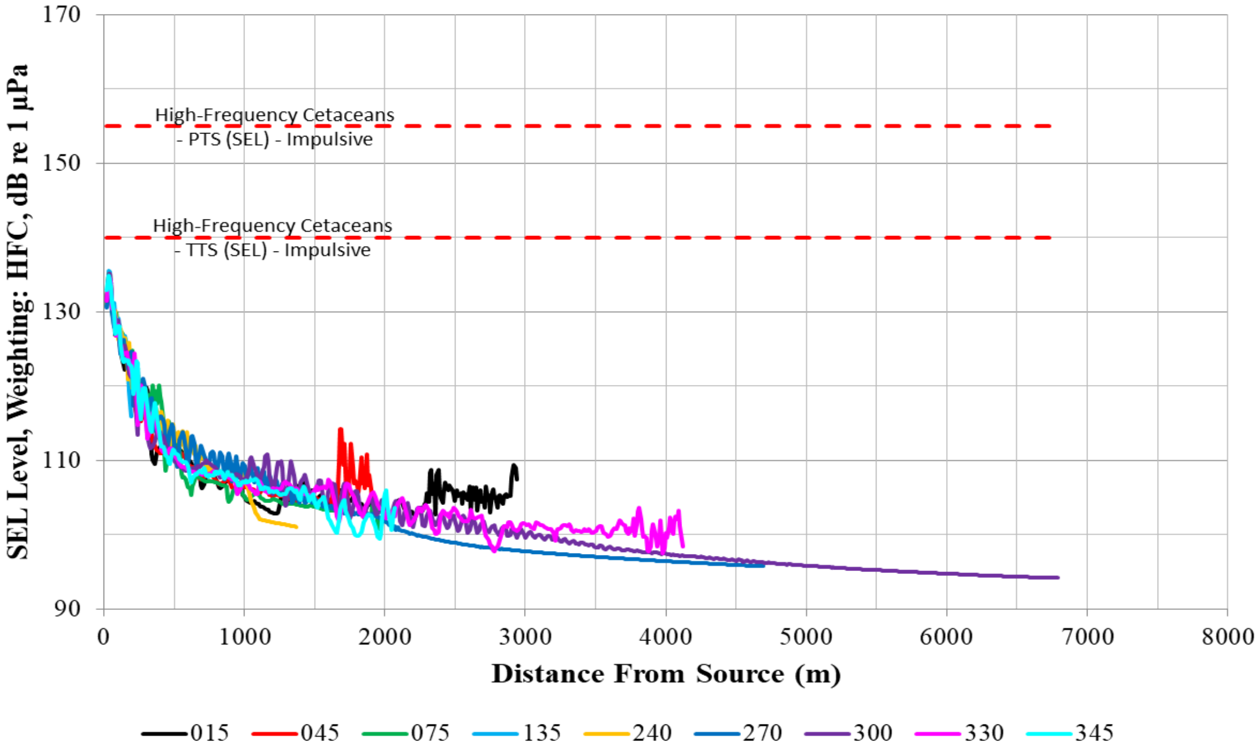

Figure G22. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, HFC Weighted

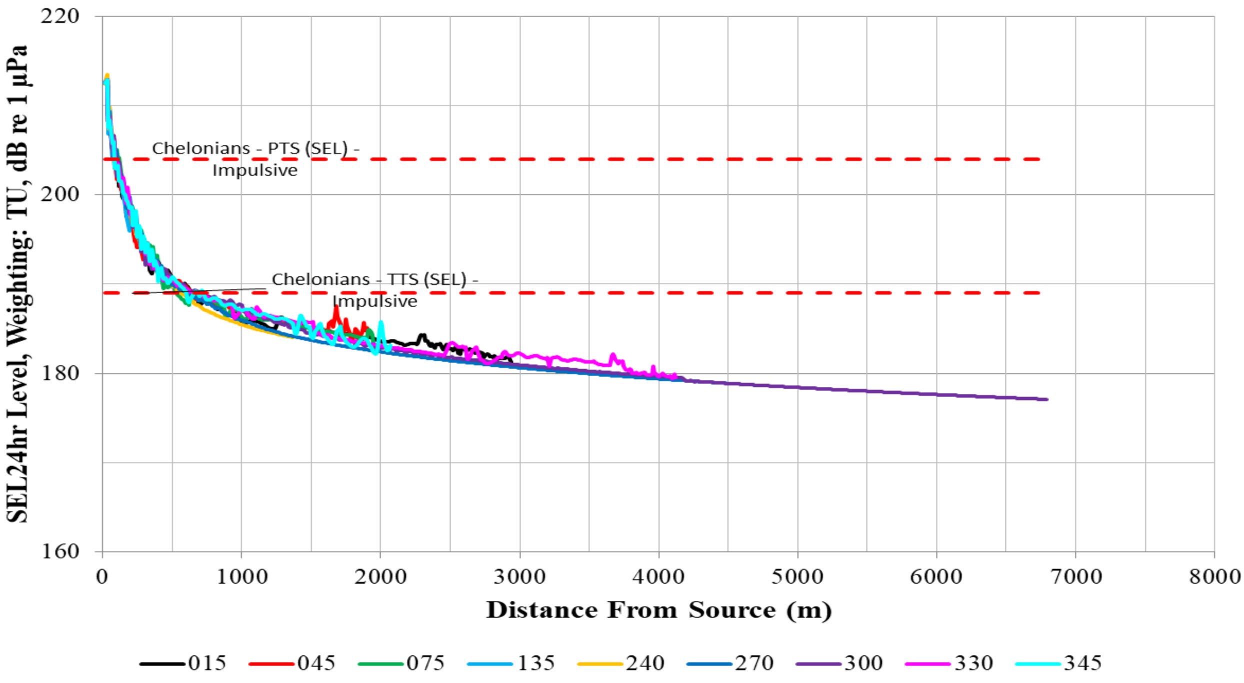

Figure G23. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, TU Weighted

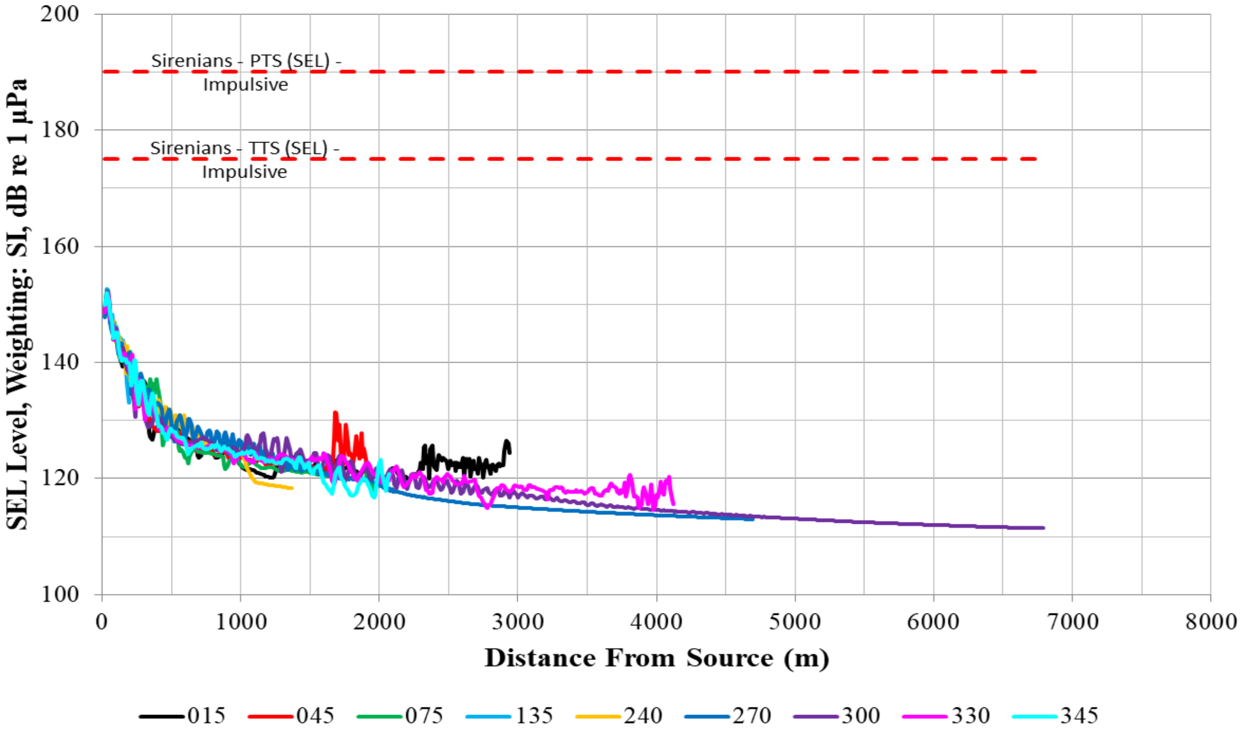

Figure G24. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, SI Weighted

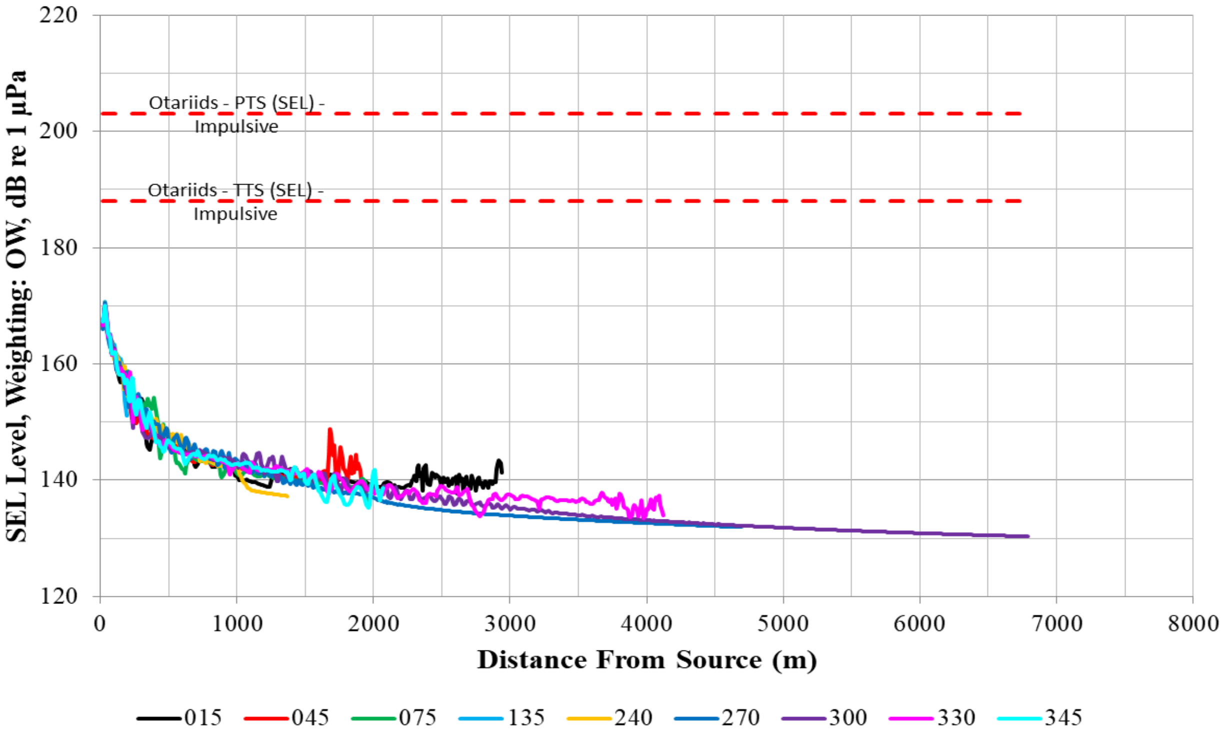

Figure G25. SEL (Single Strike) from 0.9m Diameter Impact Piling at Kurnell, OW Weighted

G2.4 Sound Exposure Level (Cumulative)

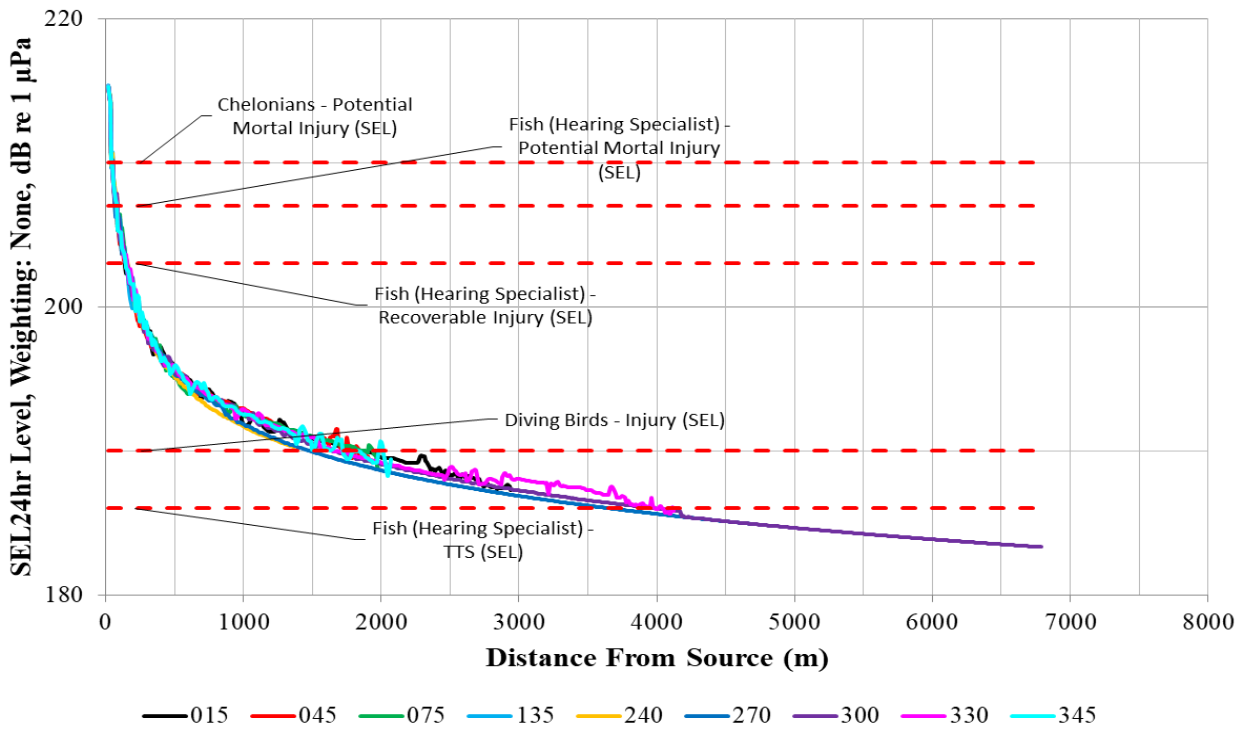

Figure G26. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, Unweighted

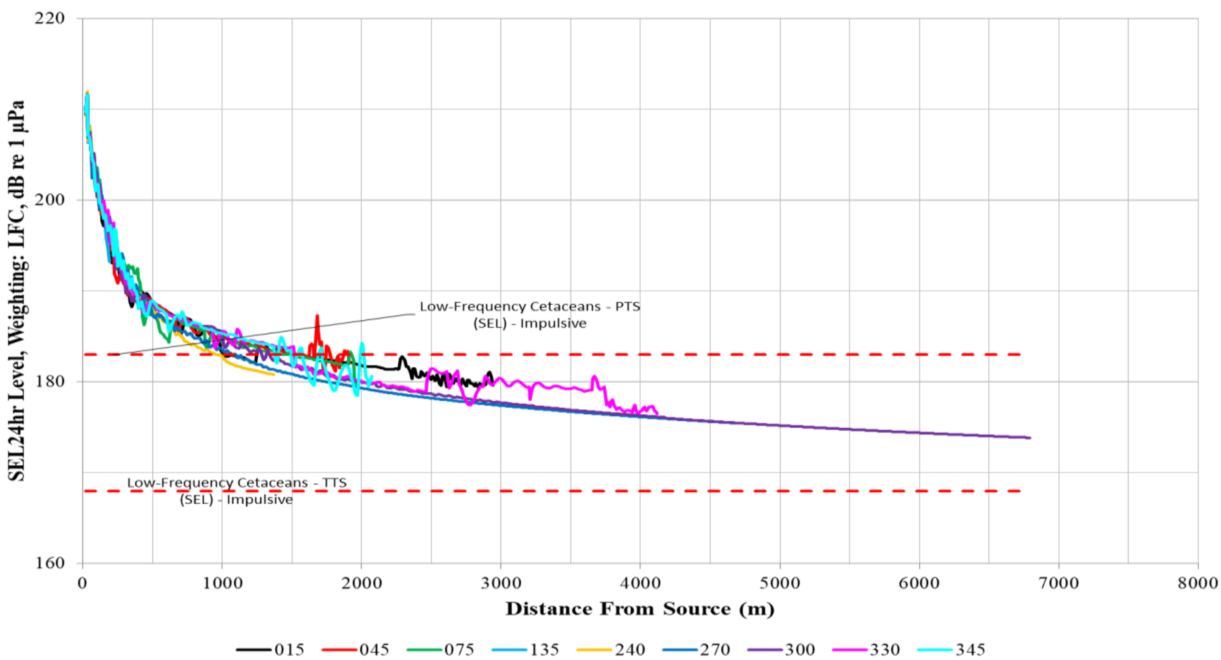

Figure G27. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, LFC Weighted

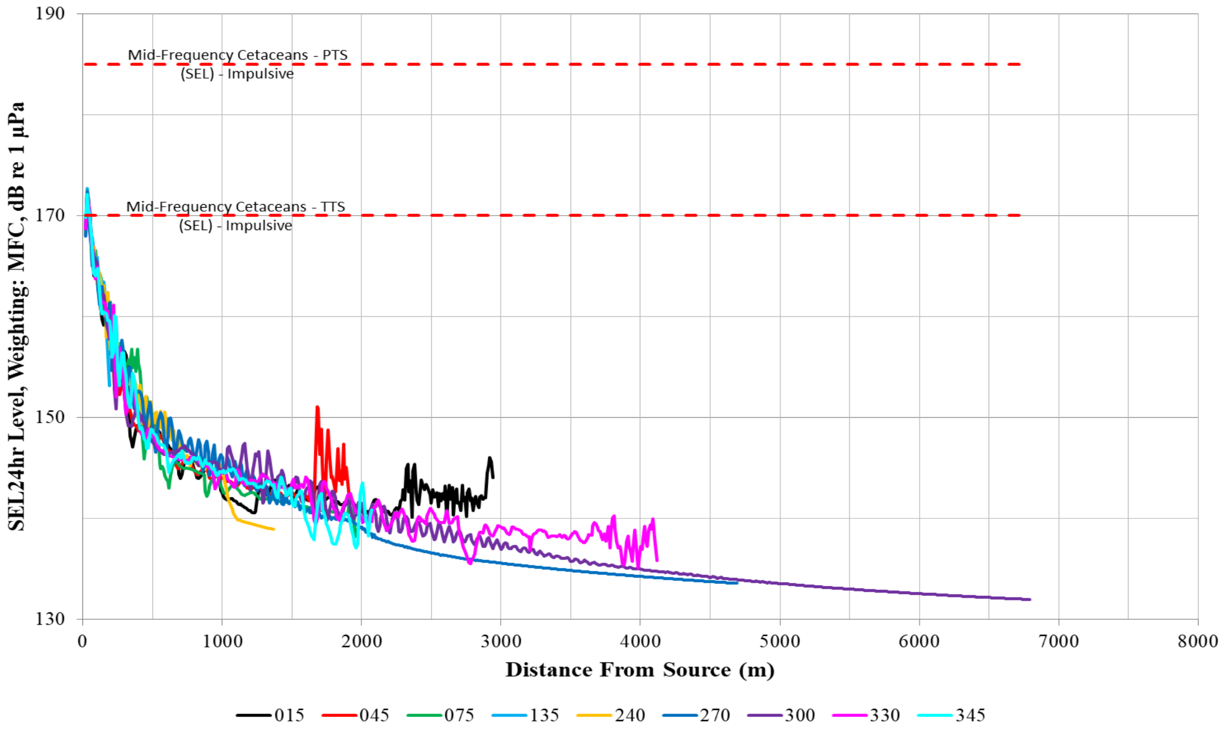

Figure G28. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, MFC Weighted

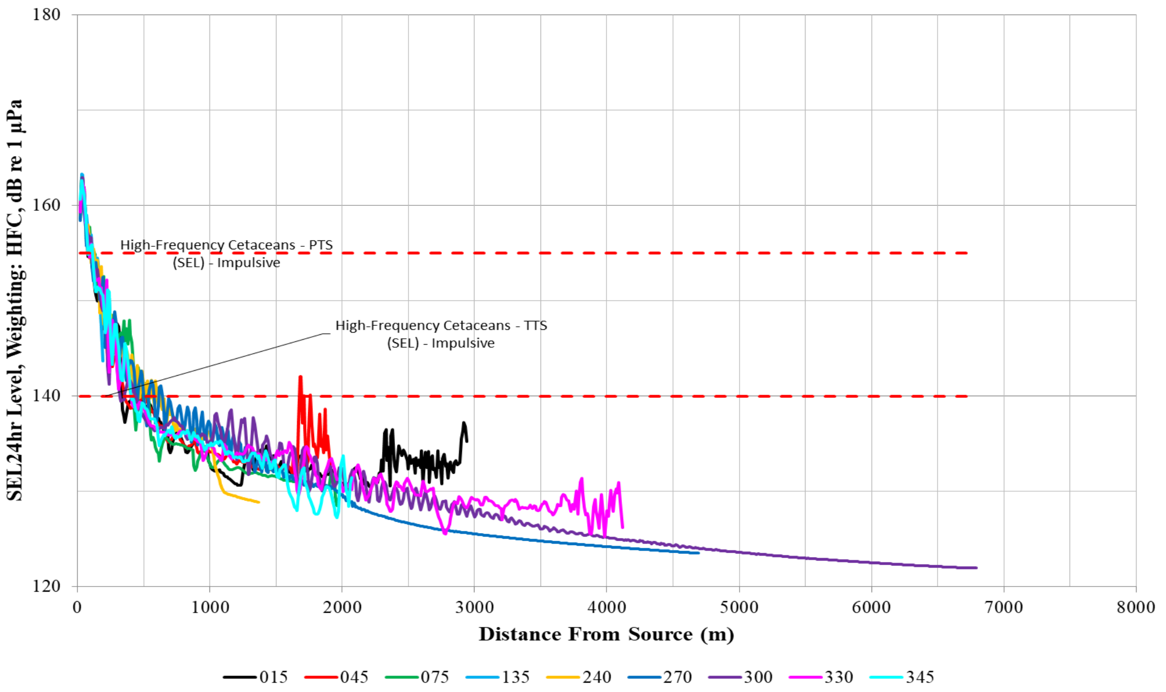

Figure G29. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, HFC Weighted

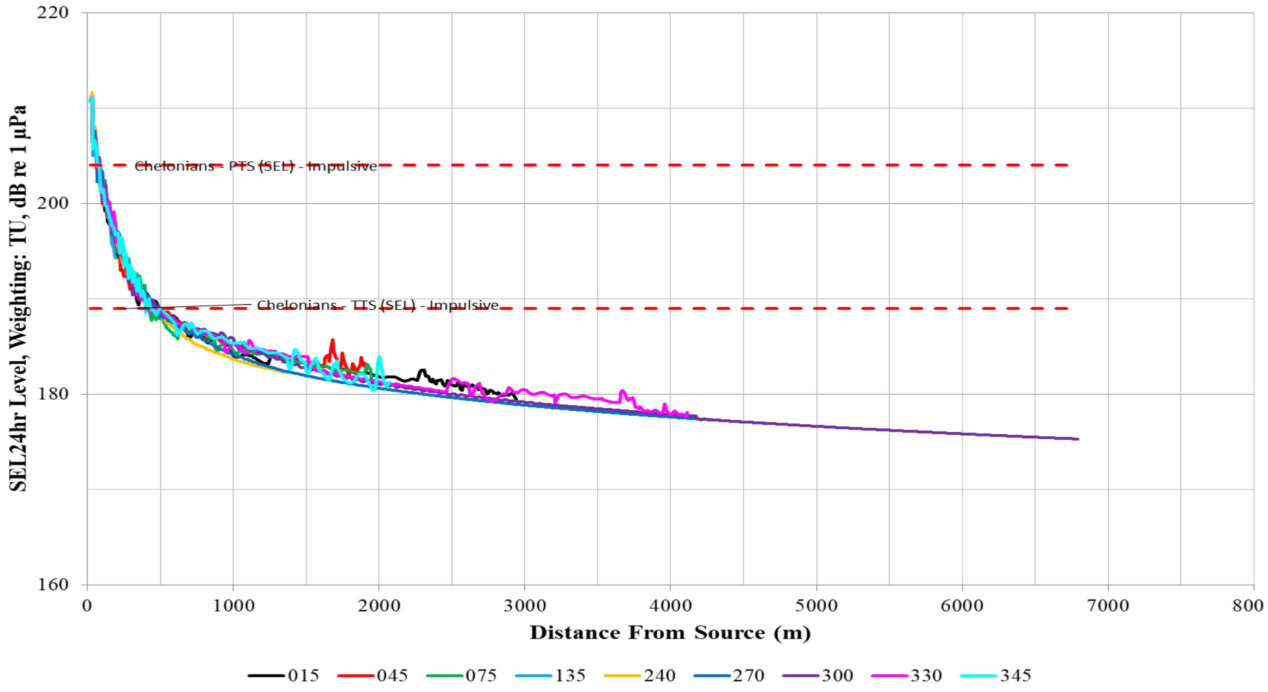

Figure G30. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, TU Weighted

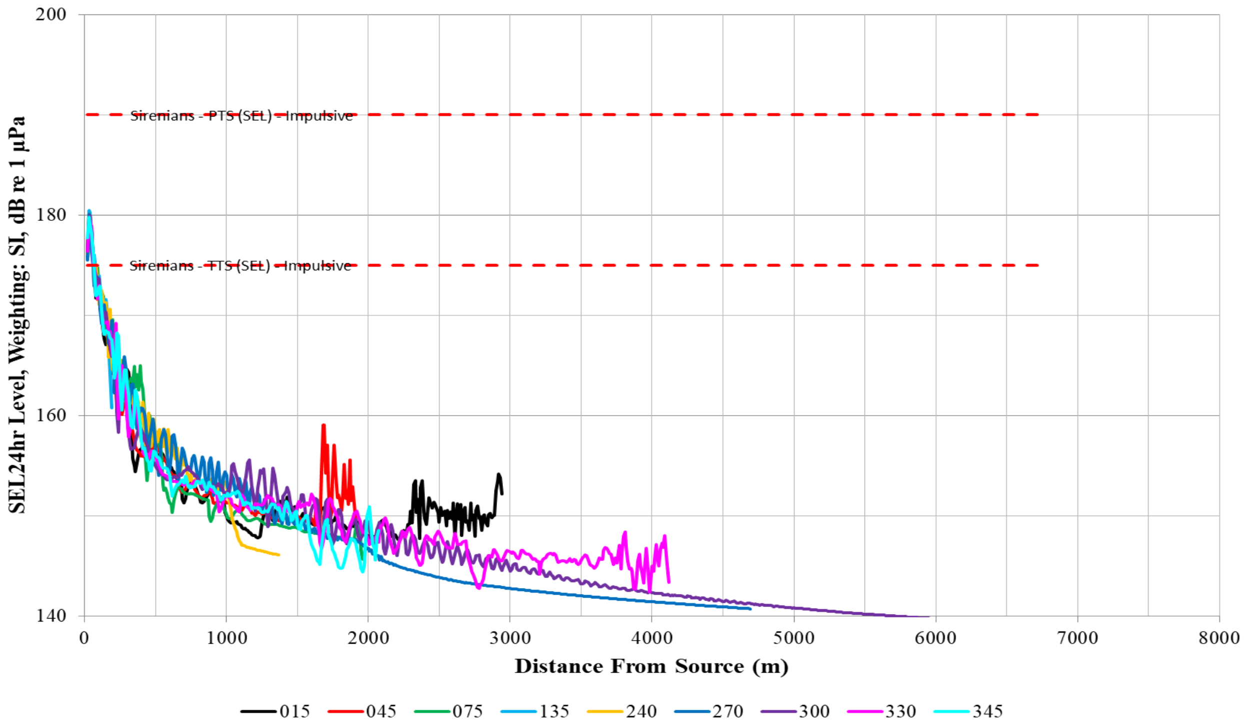

Figure G31. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, SI Weighted

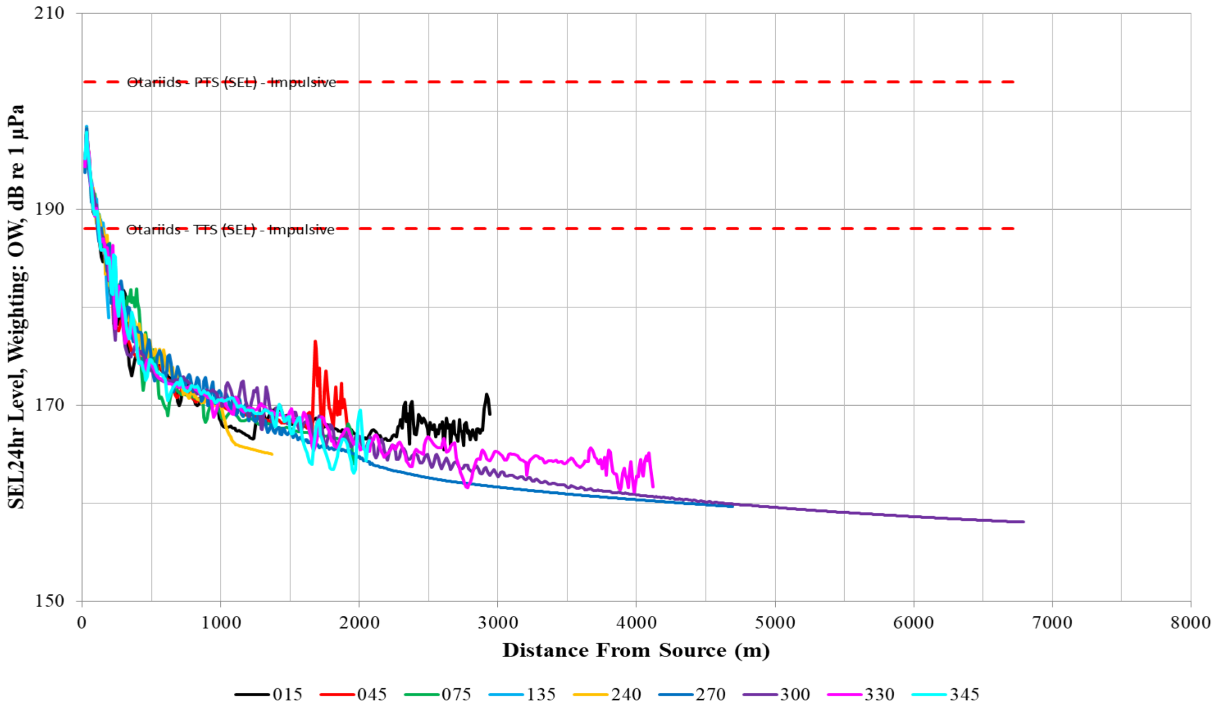

Figure G32. SEL (Cumulative, 600 strikes) from 0.9m Diameter Impact Piling at Kurnell, OW Weighted

G3 Vessels at La Perouse

Predicted underwater noise levels from vessels at La Perouse are presented in the figures below. Each colour represents an azimuth.

G3.1 Ferries

G3.1.1 Sound Pressure Level

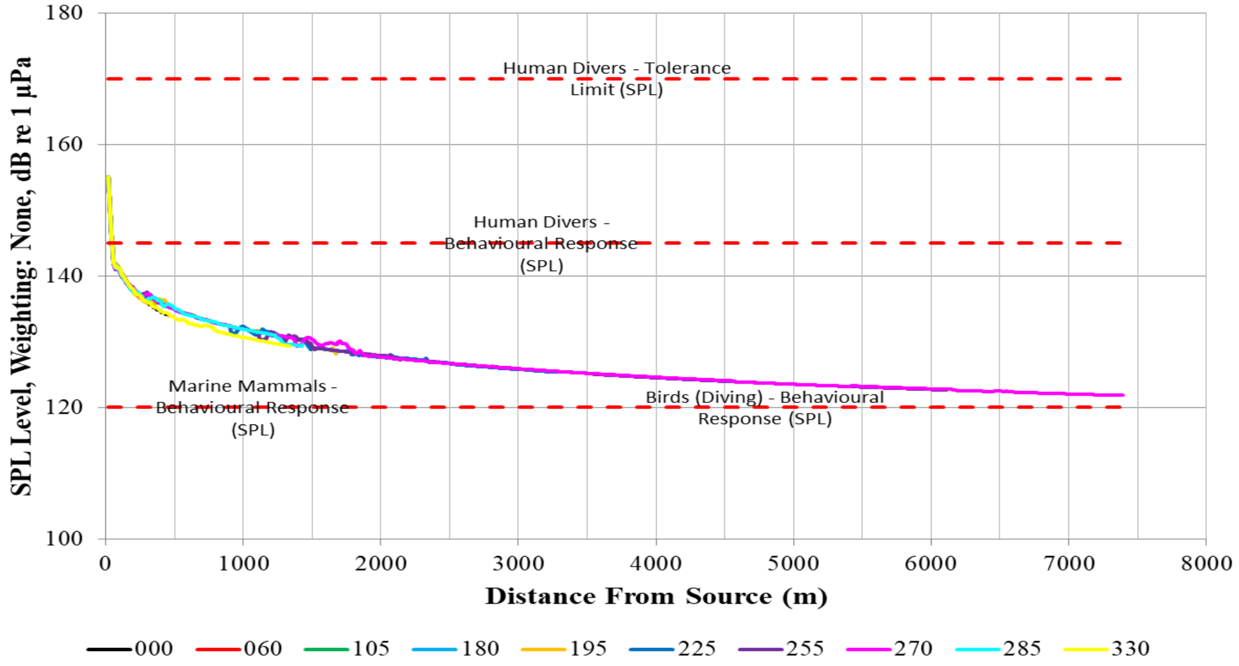

Figure G33. SPL from Ferries at La Perouse, Unweighted

G3.1.2 Sound Exposure Level

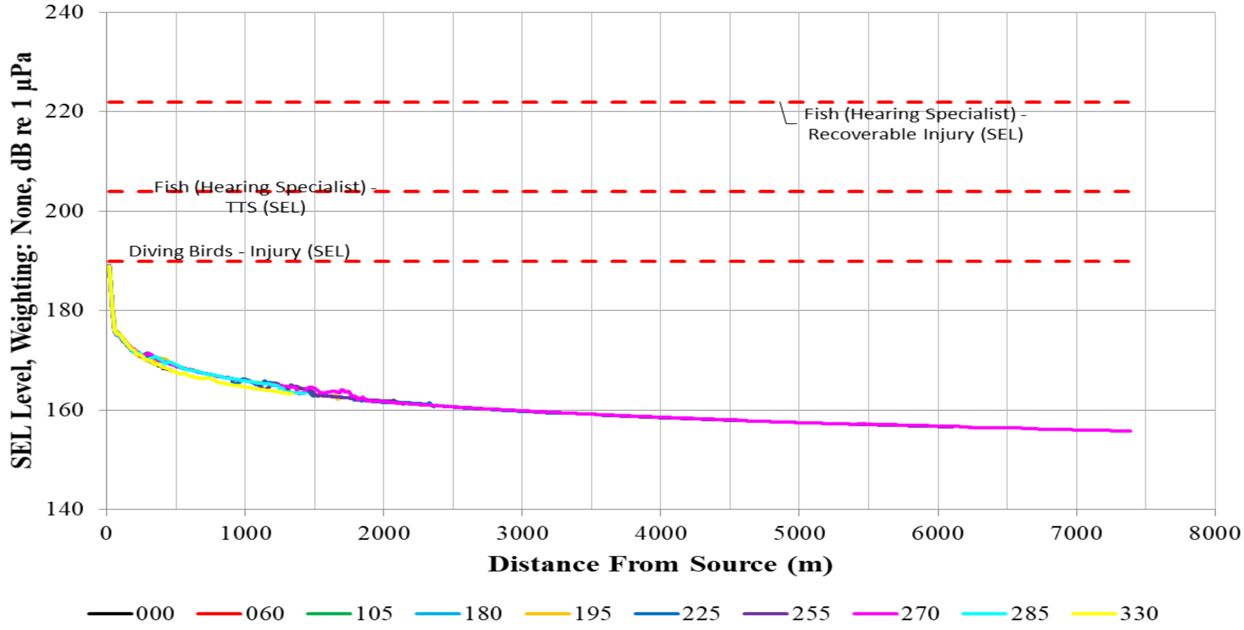

Figure G34. SEL from Ferries at La Perouse, Unweighted

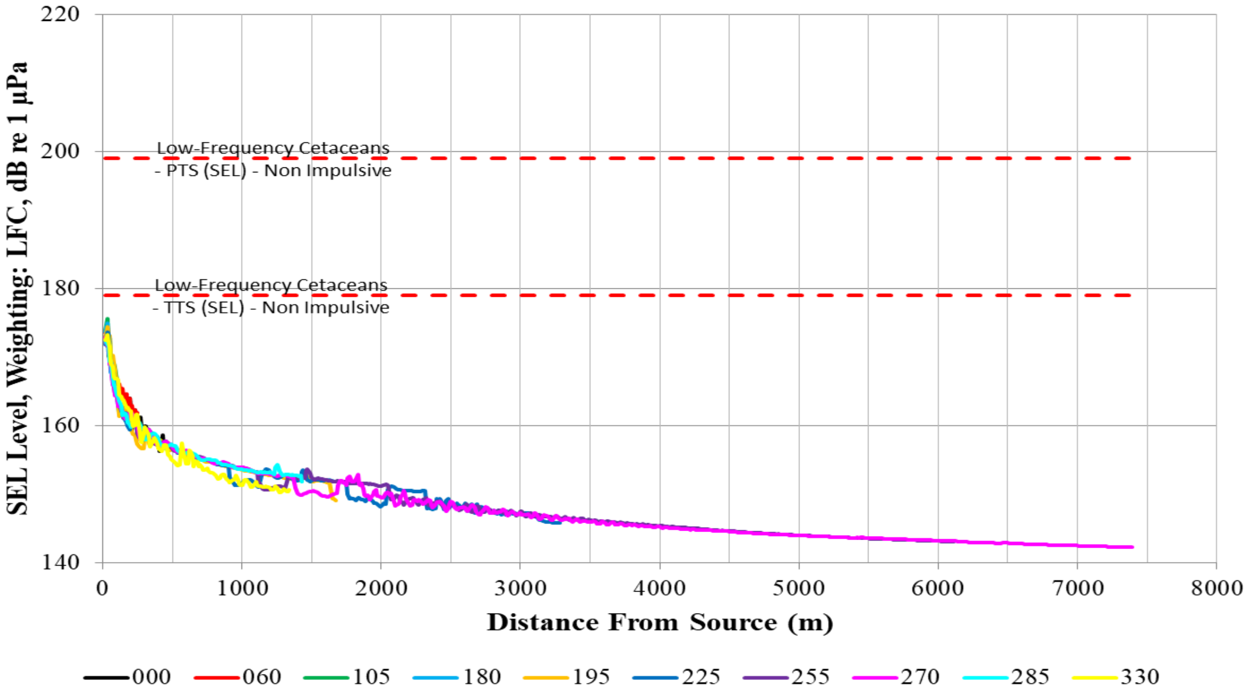

Figure G35. SEL from Ferries at La Perouse, LFC Weighted

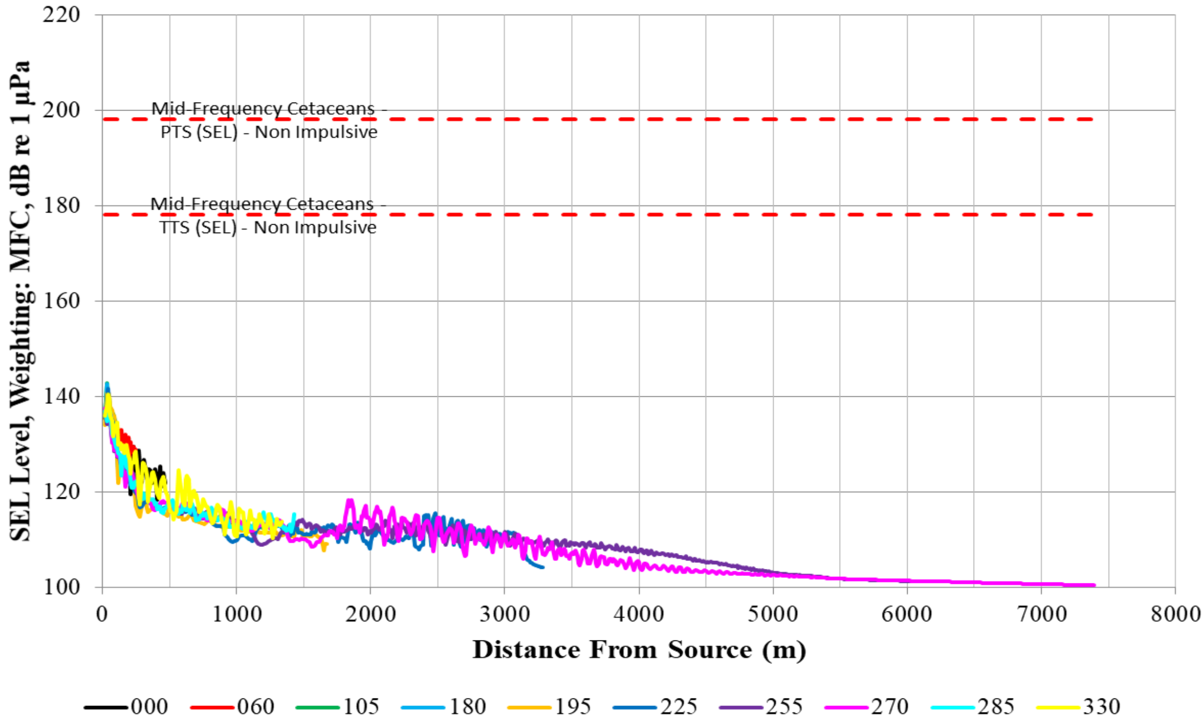

Figure G36. SEL from Ferries at La Perouse, MFC Weighted

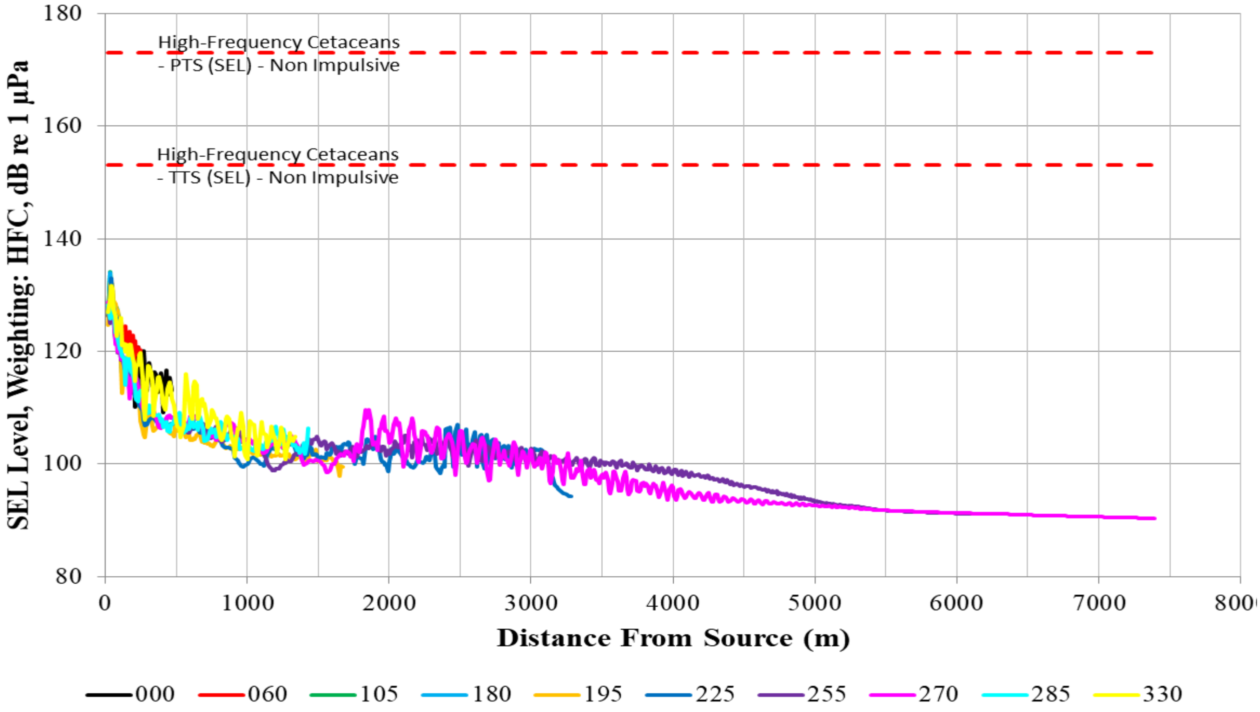

Figure G37. SEL from Ferries at La Perouse, HFC Weighted

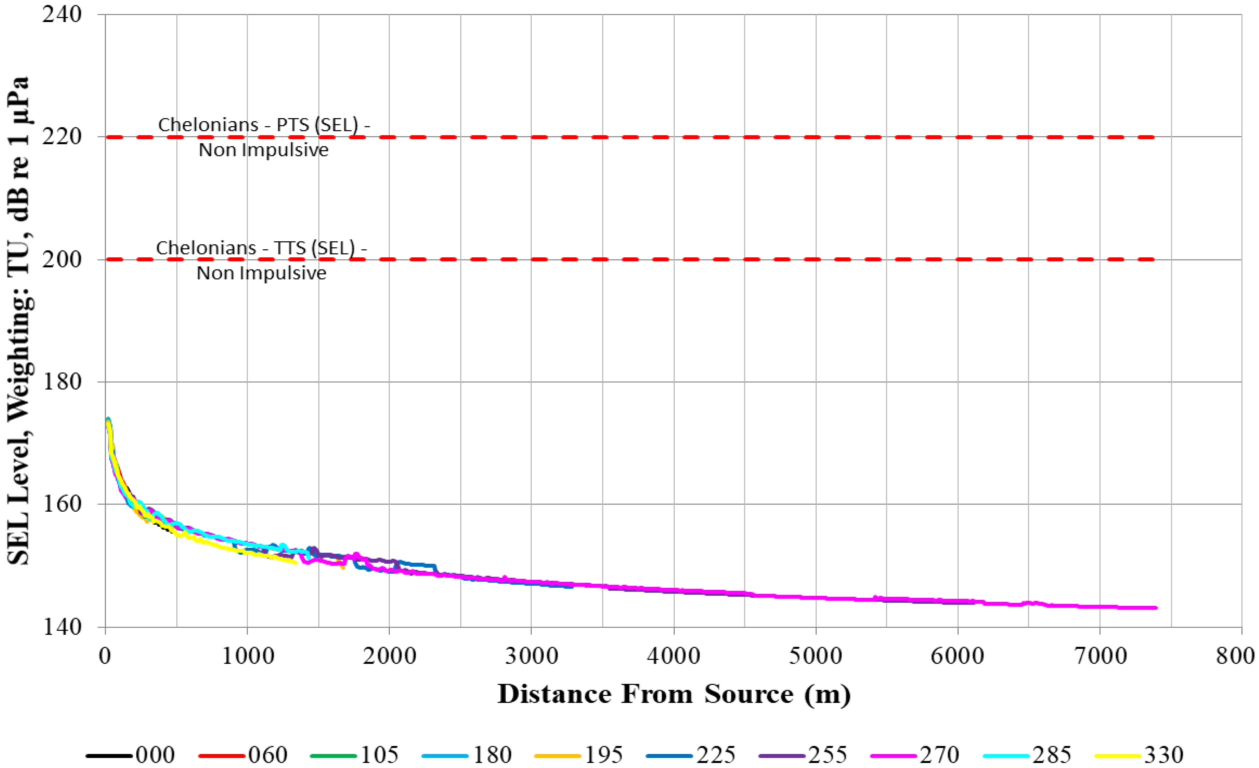

Figure G38. SEL from Ferries at La Perouse, TU Weighted

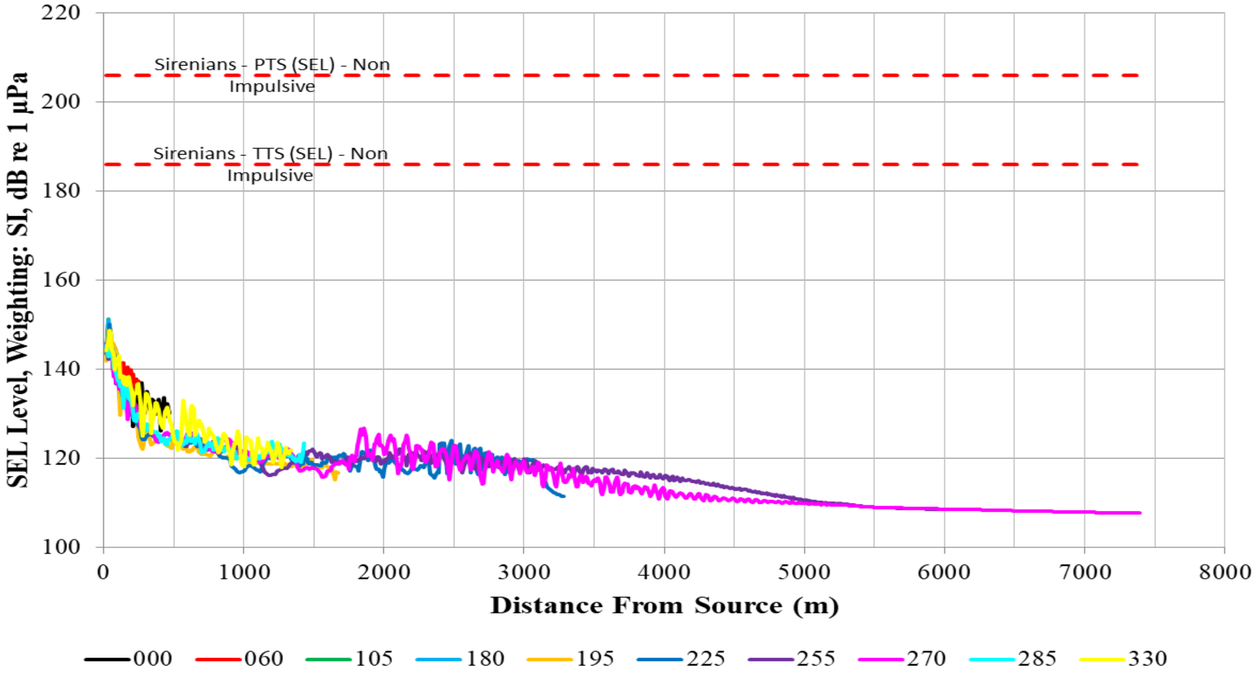

Figure G39. SEL from Ferries at La Perouse, SI Weighted

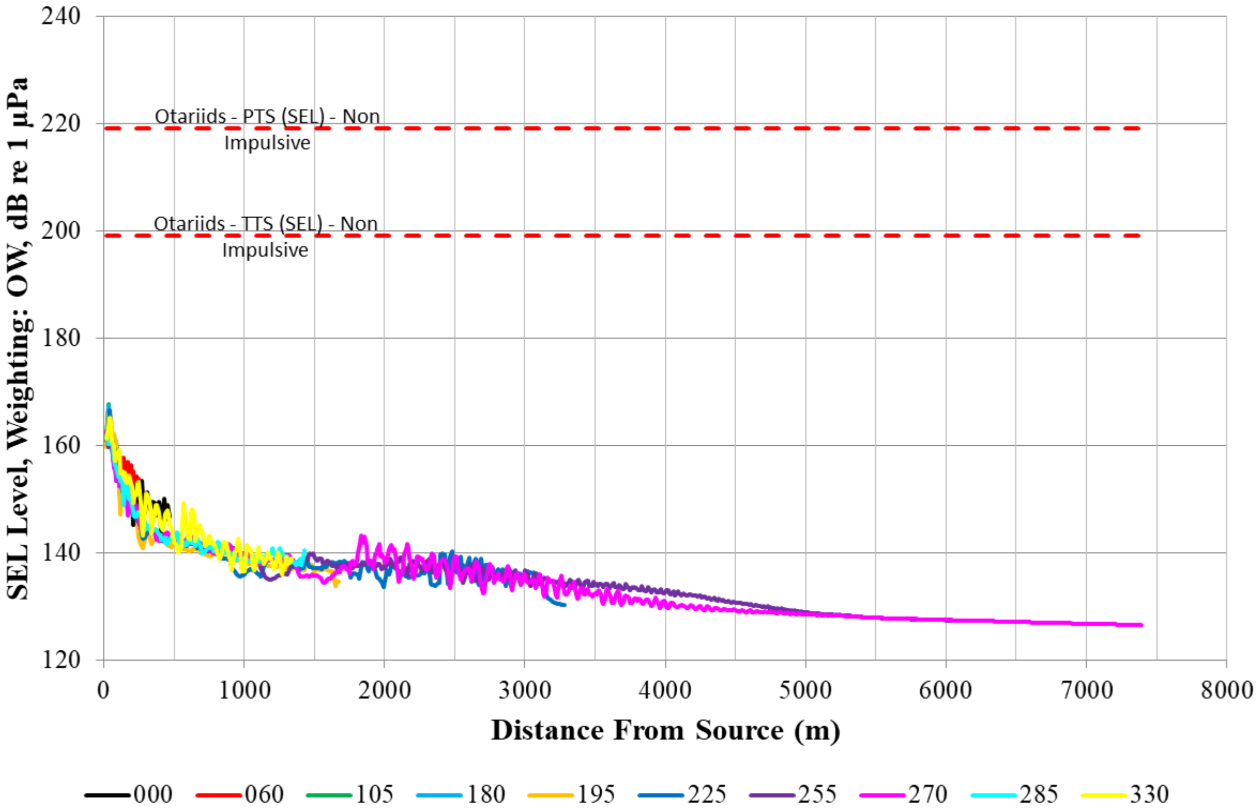

Figure G40. SEL from Ferries at La Perouse, OW Weighted

G3.2 Construction Vessels

G3.2.1 Sound Pressure Level

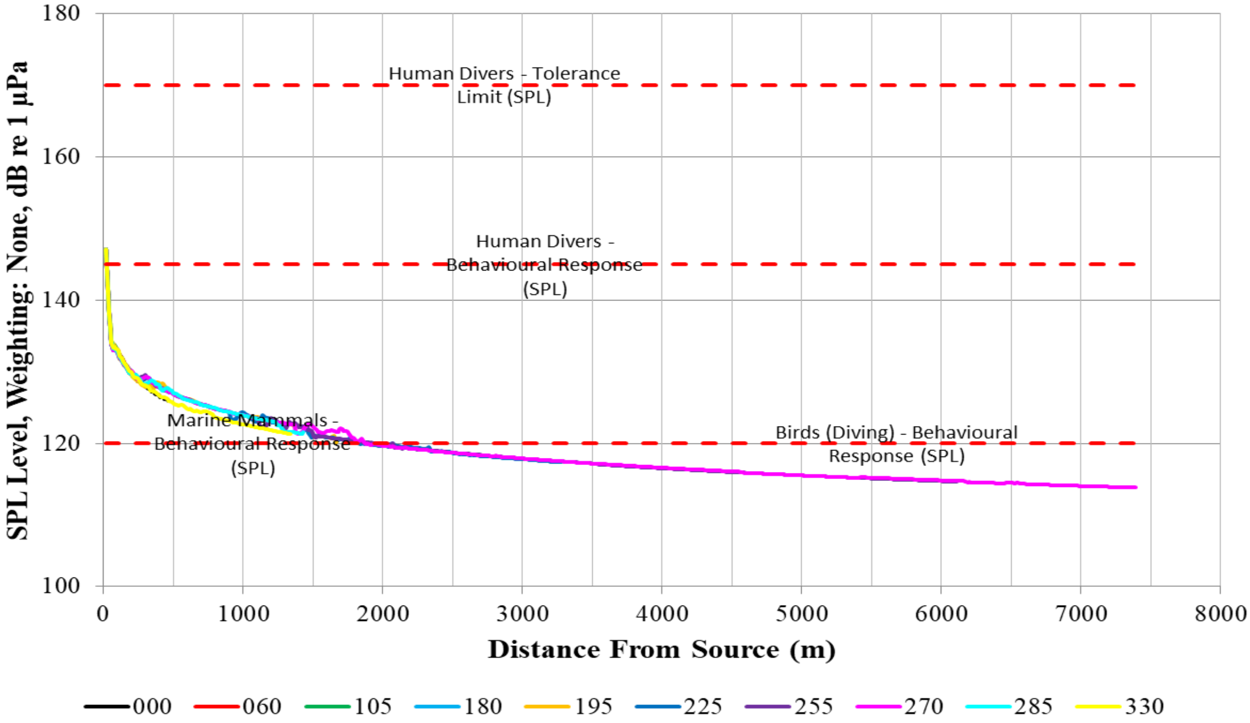

Figure G41. SPL from Construction Vessels at La Perouse, Unweighted

G3.2.2 Sound Exposure Level

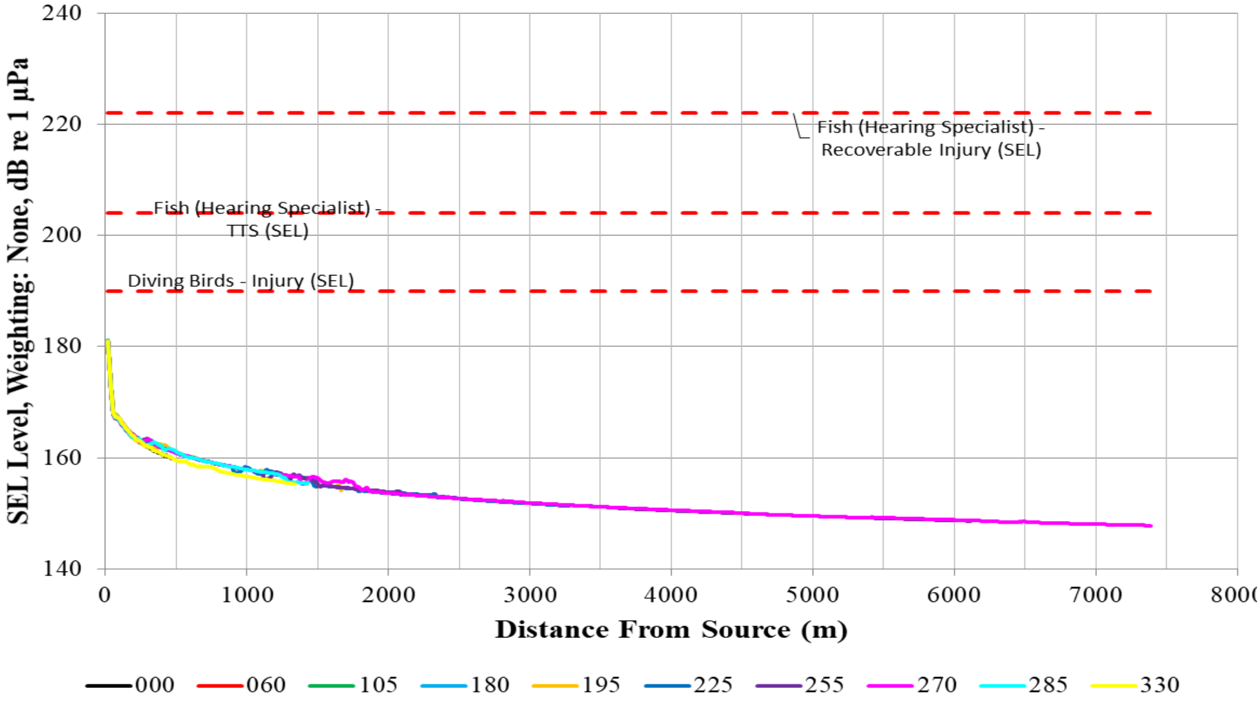

Figure G42. SEL from Construction Vessels at La Perouse, Unweighted

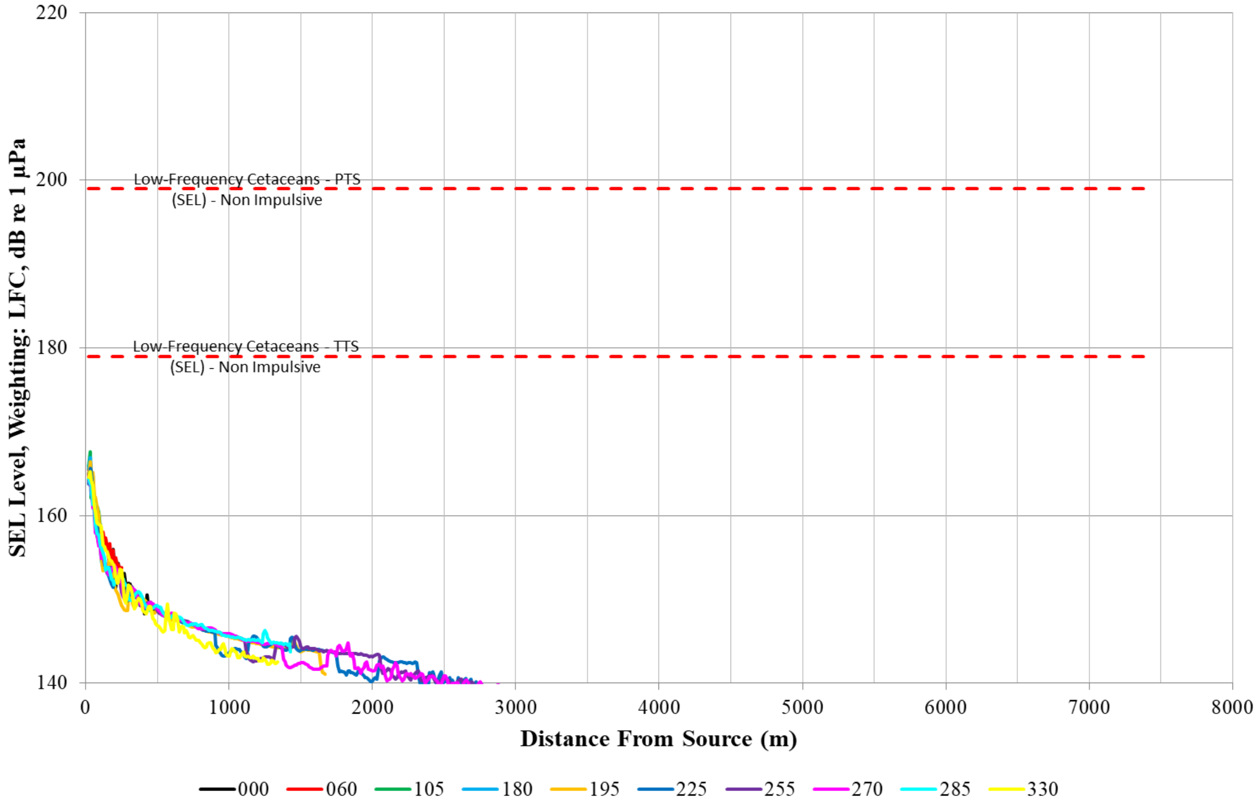

Figure G43. SEL from Construction Vessels at La Perouse, LFC Weighted

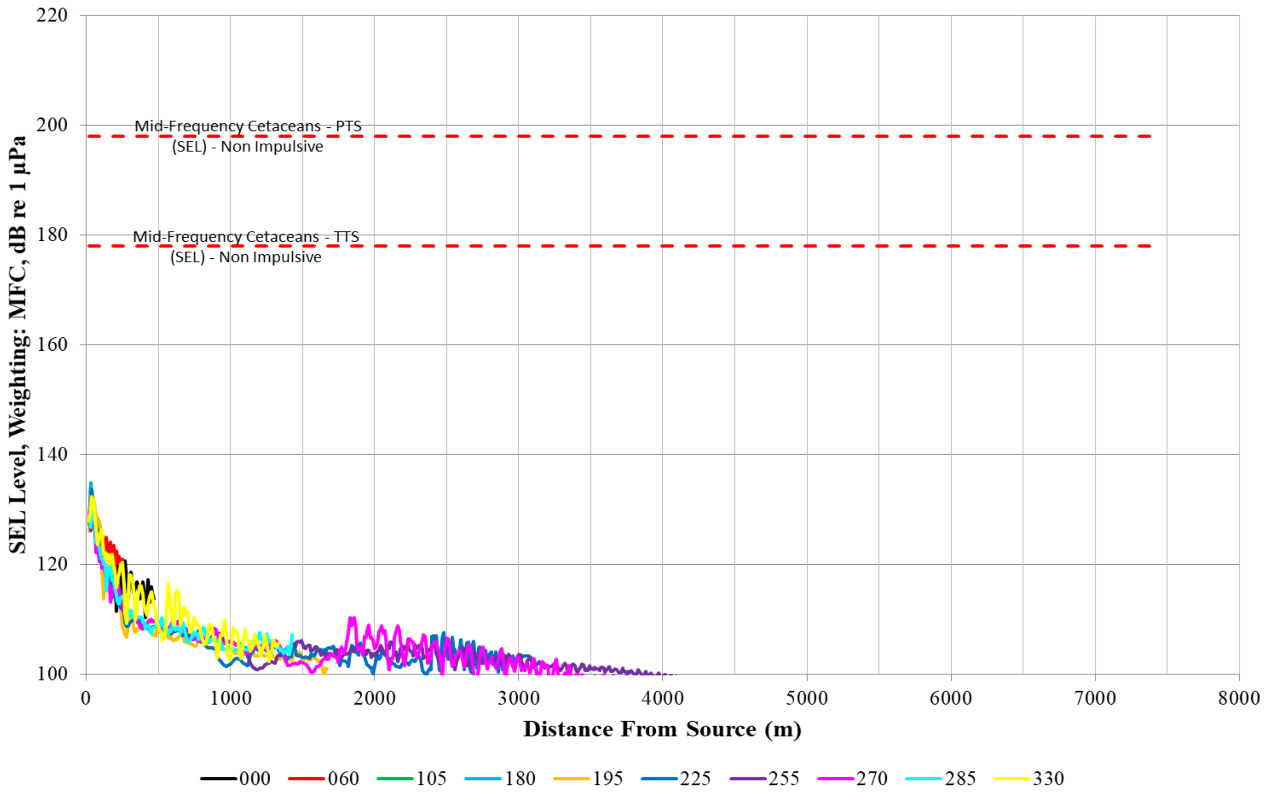

Figure G44. SEL from Construction Vessels at La Perouse, MFC Weighted

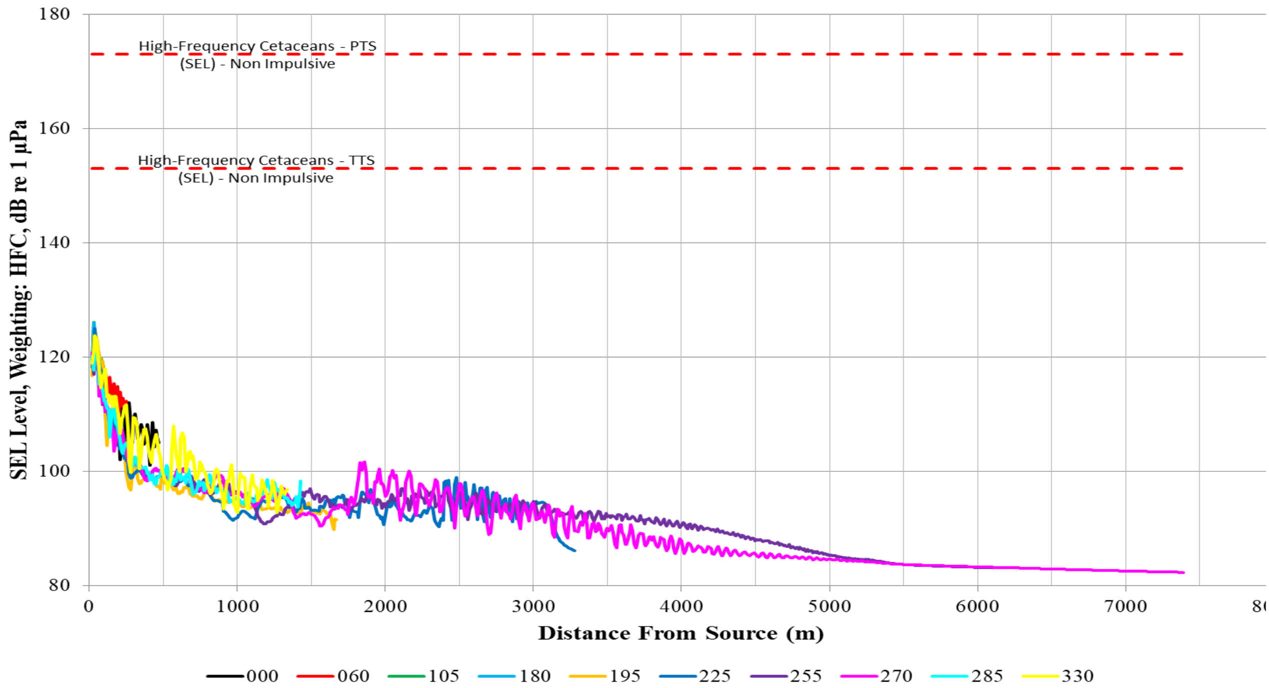

Figure G45. SEL from Construction Vessels at La Perouse, HFC Weighted

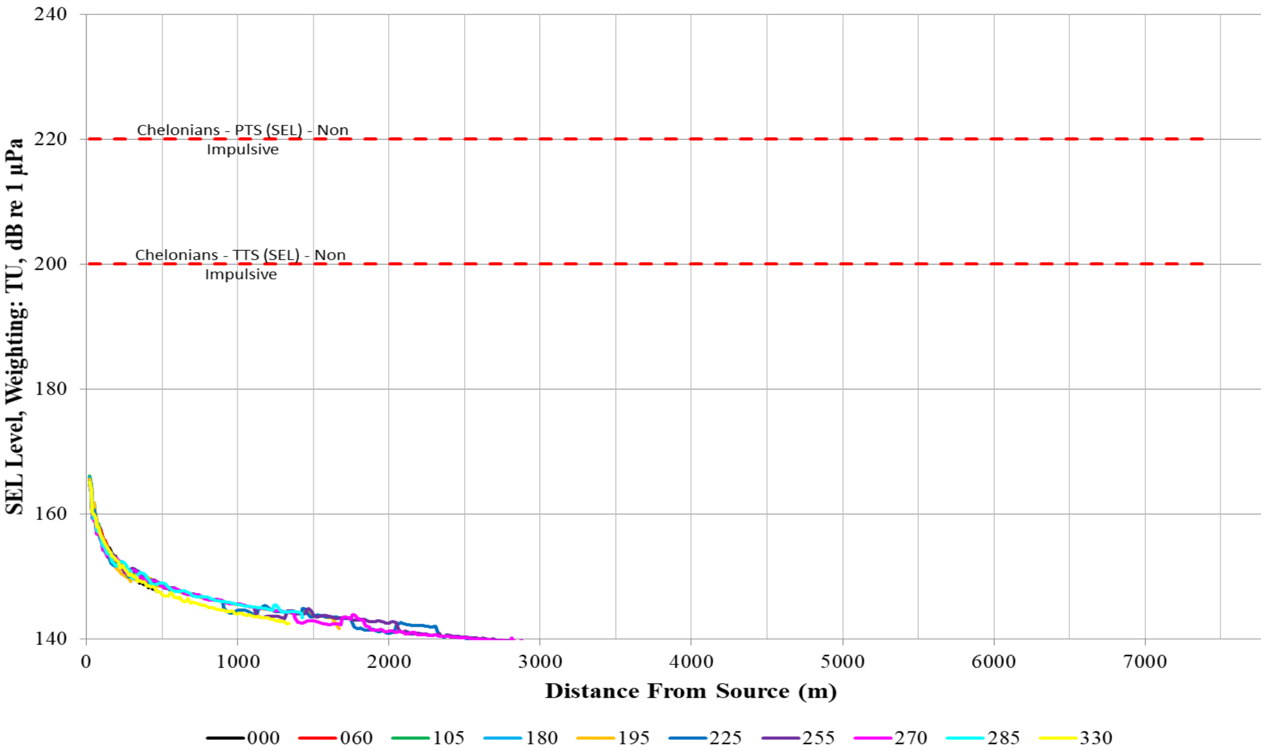

Figure G46. SEL from Construction Vessels at La Perouse, TU Weighted

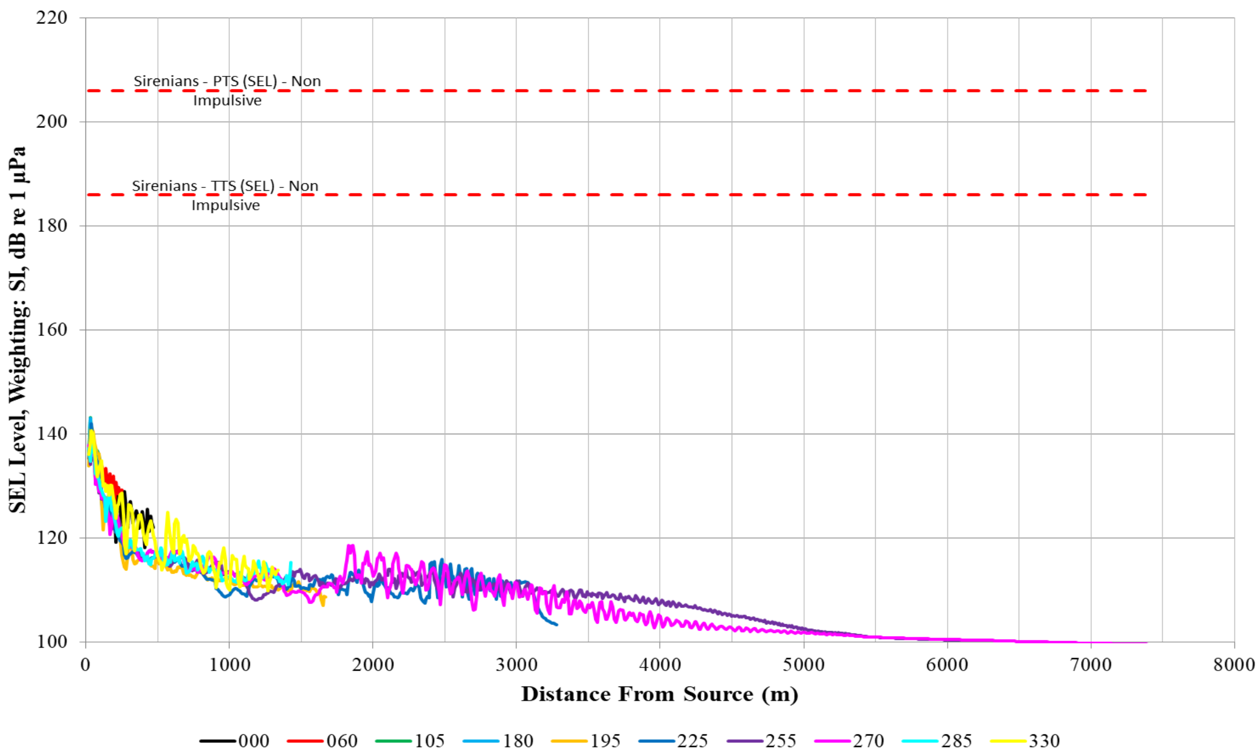

Figure G47. SEL from Construction Vessels at La Perouse, SI Weighted

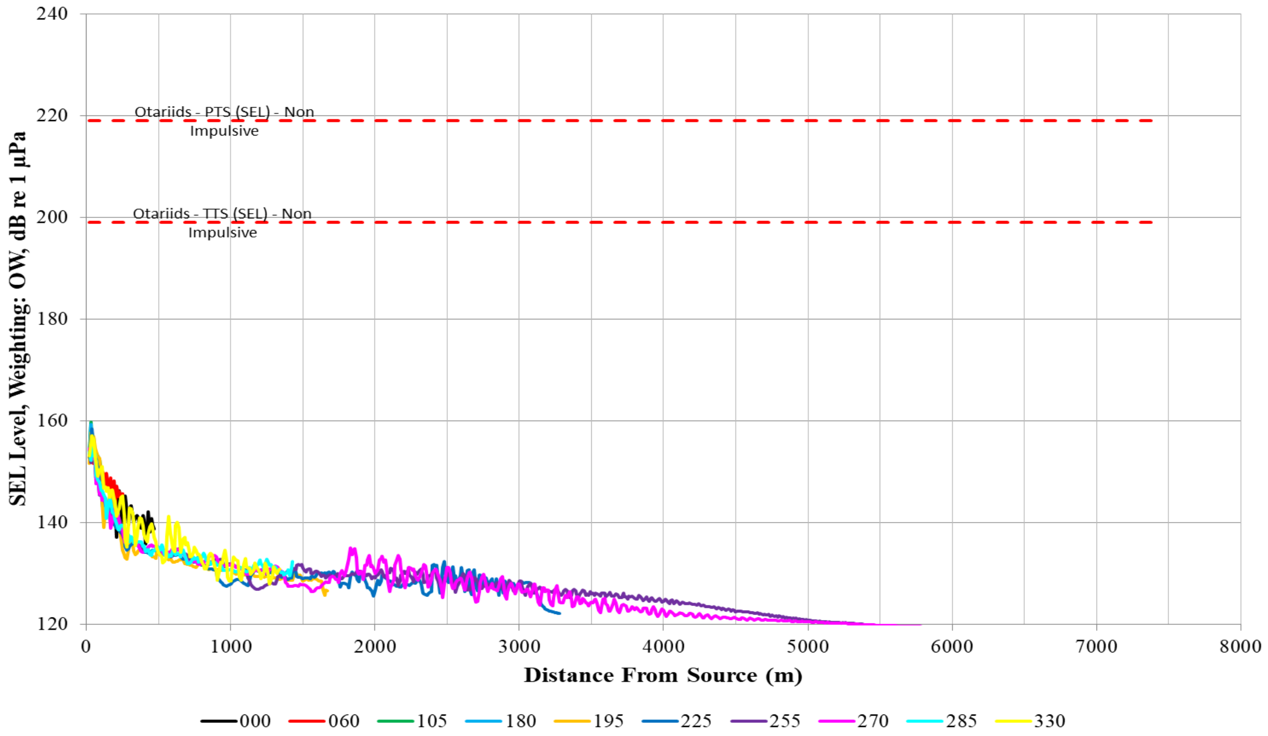

Figure G48. SEL from Construction Vessels at La Perouse, OW Weighted

G4 Vessels at Kurnell

G4.1 Ferries

Predicted underwater noise levels from vessels at Kurnell are presented in the figures below. Each colour represents an azimuth.

G4.1.1 Sound Pressure Level

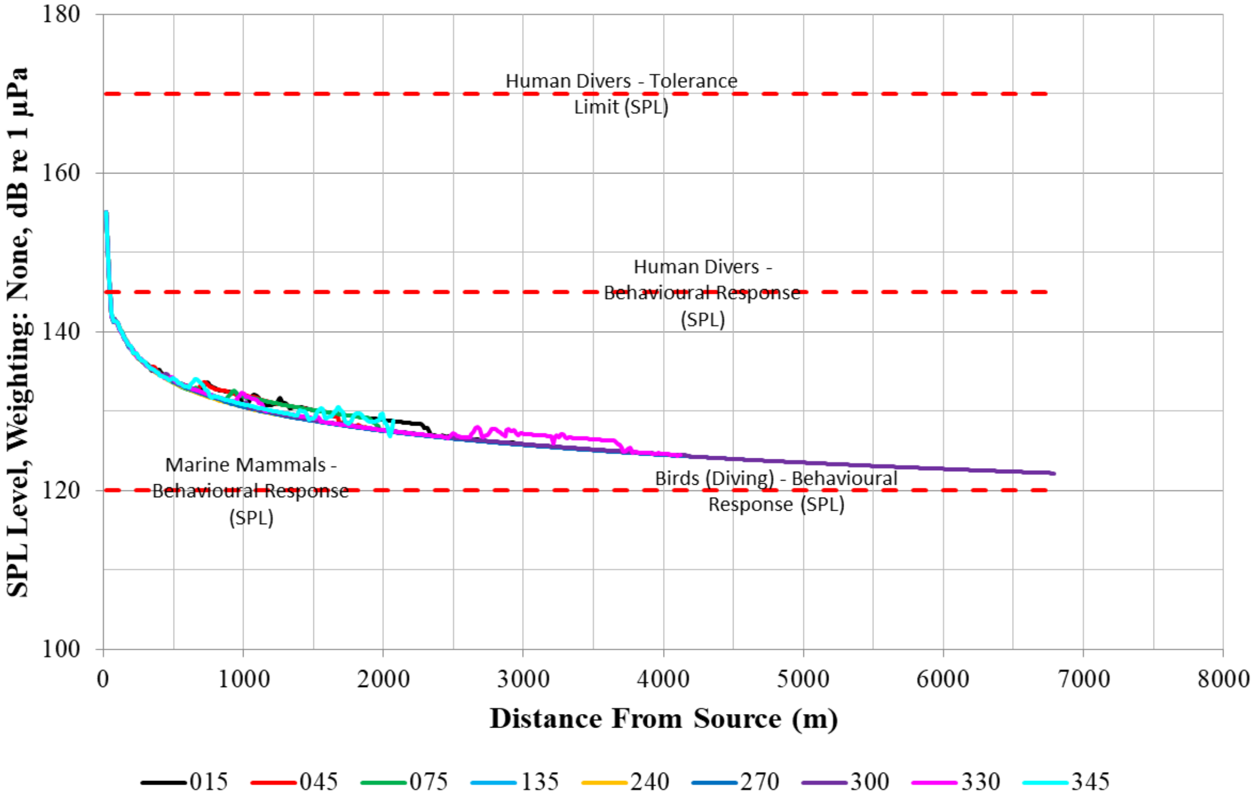

Figure G49. SPL from Ferries at Kurnell, Unweighted

G4.1.2 Sound Exposure Level

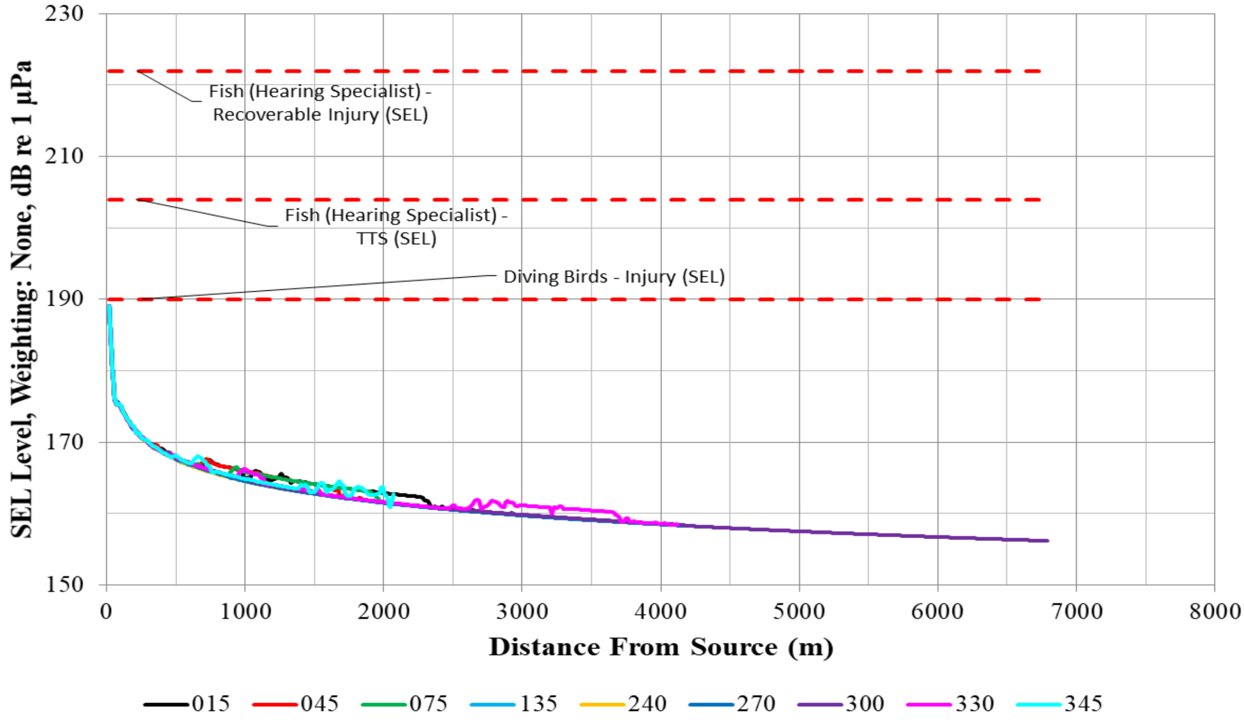

Figure G50. SEL from Ferries at Kurnell, Unweighted

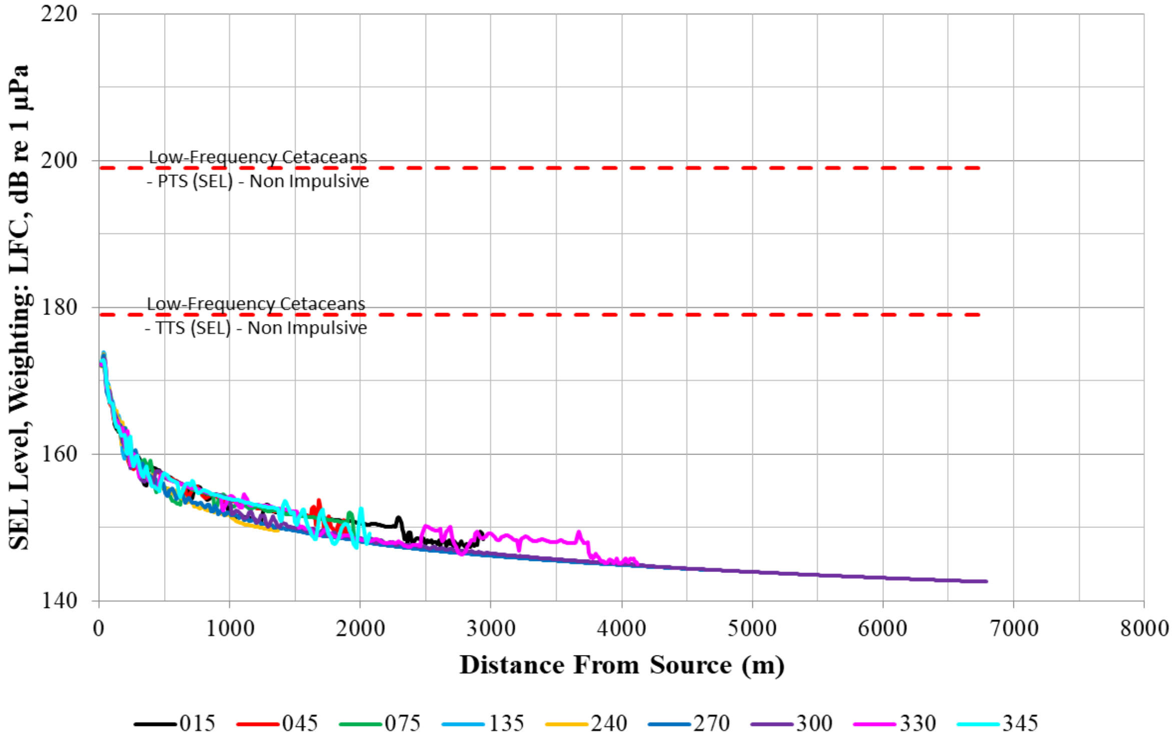

Figure G51. SEL from Ferries at Kurnell, LFC Weighted

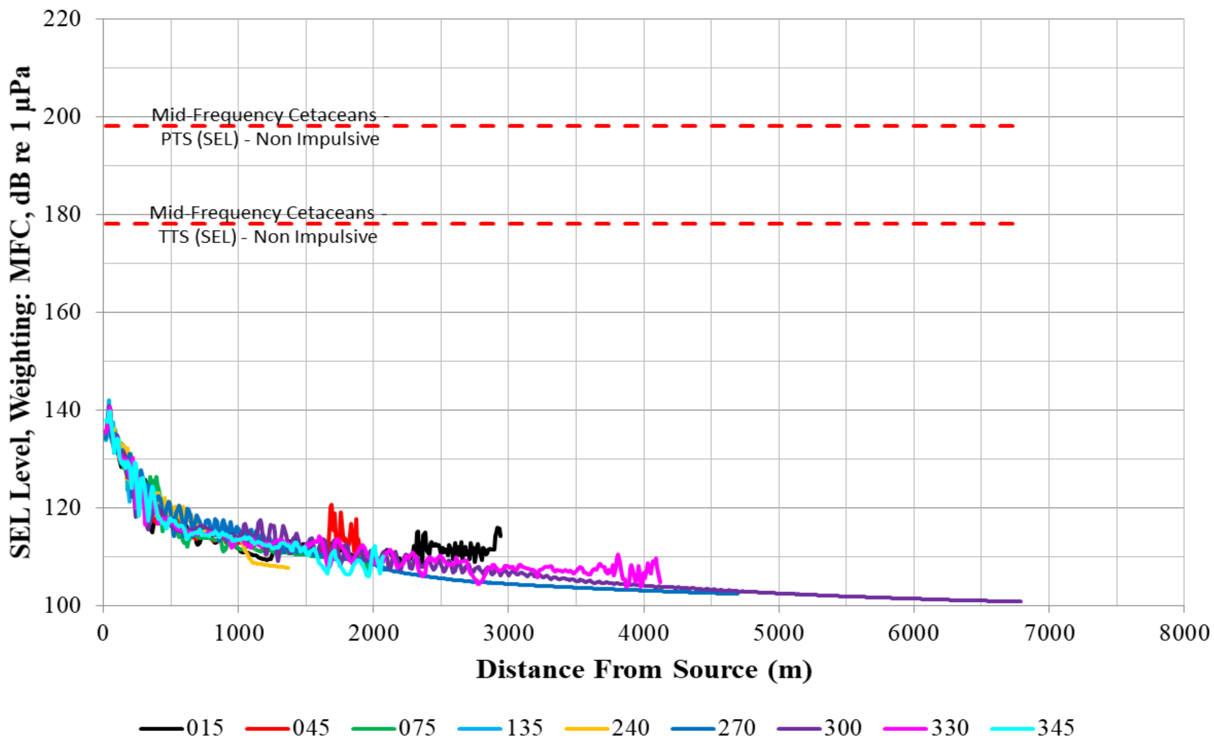

Figure G52. SEL from Ferries at Kurnell, MFC Weighted

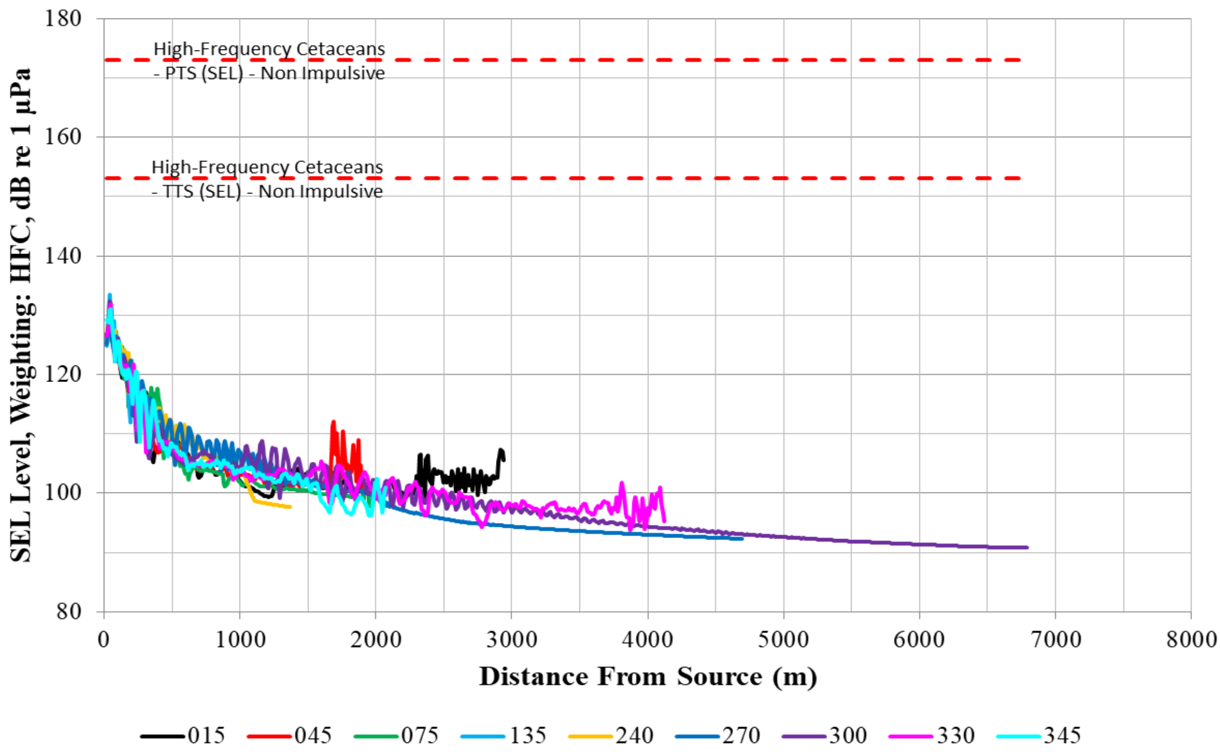

Figure G53. SEL from Ferries at Kurnell, HFC Weighted

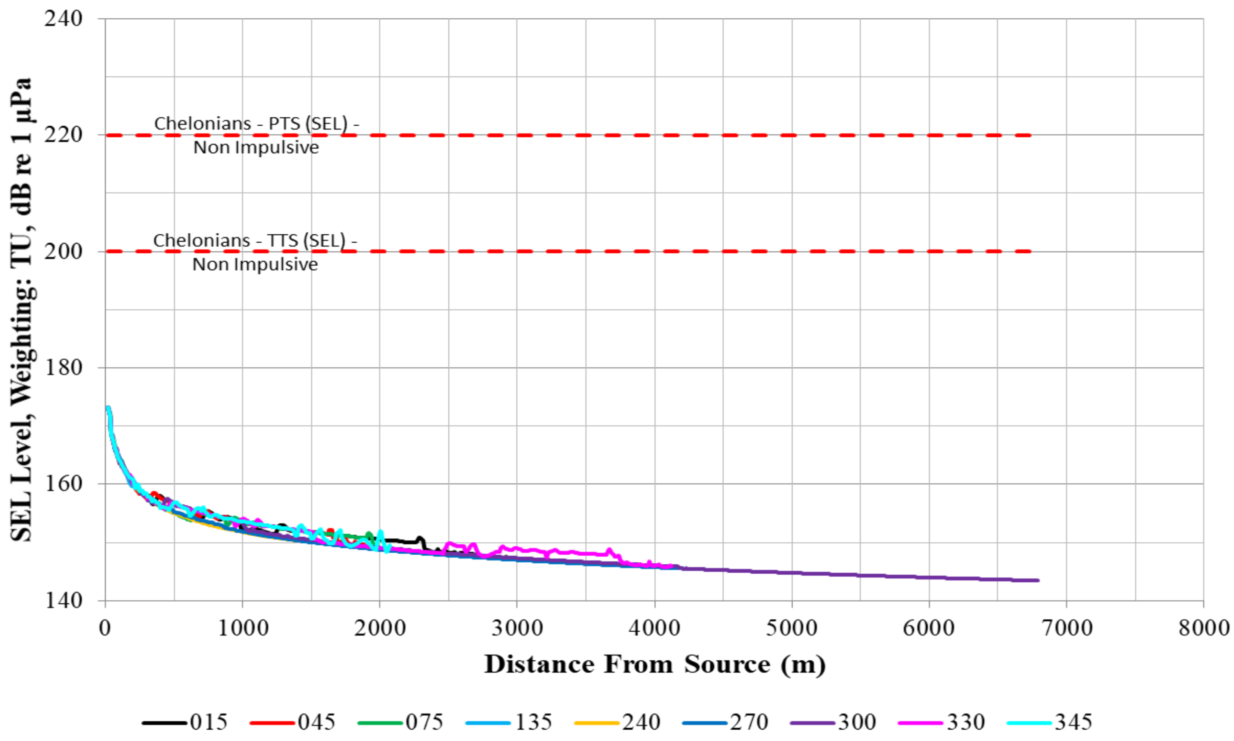

Figure G54. SEL from Ferries at Kurnell, TU Weighted

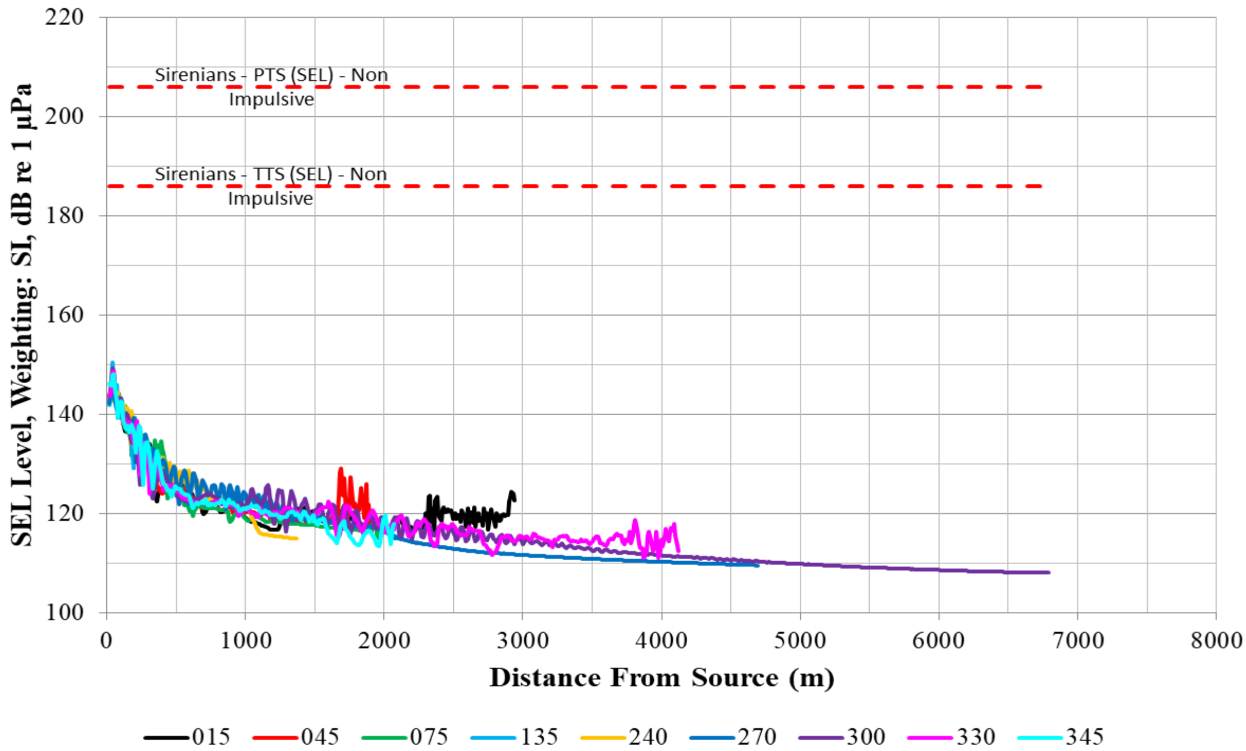

Figure G55. SEL from Ferries at Kurnell, SI Weighted

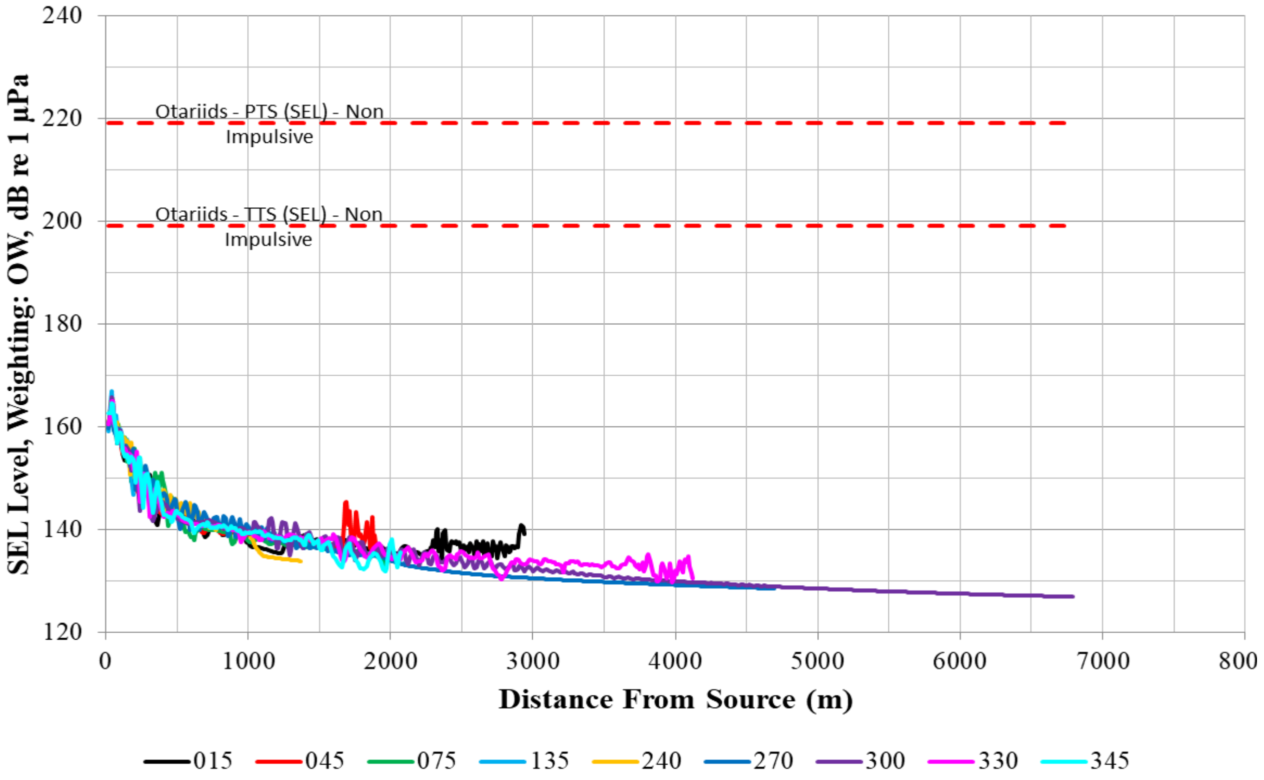

Figure G56. SEL from Ferries at Kurnell, OW Weighted

G4.2 Construction Vessels

G4.2.1 Sound Pressure Level

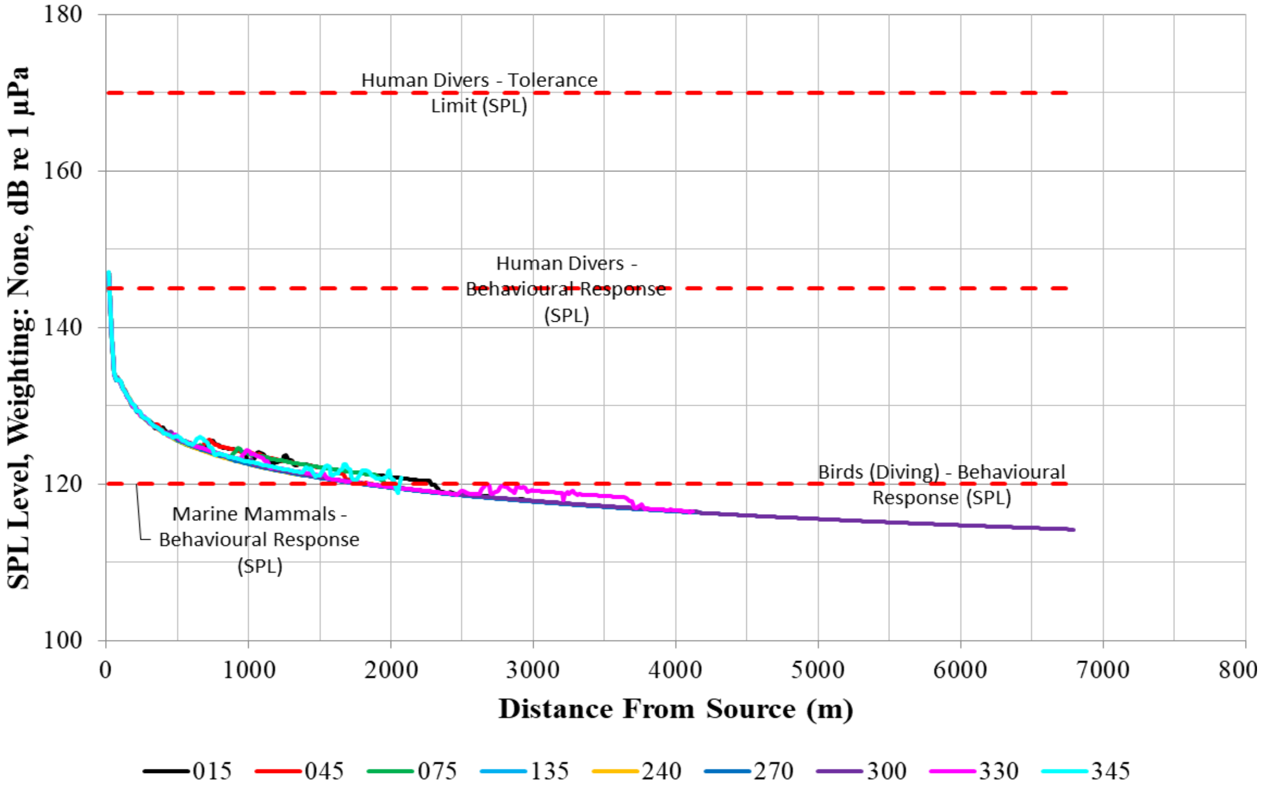

Figure G57. SPL from Construction Vessels at Kurnell, Unweighted

G4.2.2 Sound Exposure Level

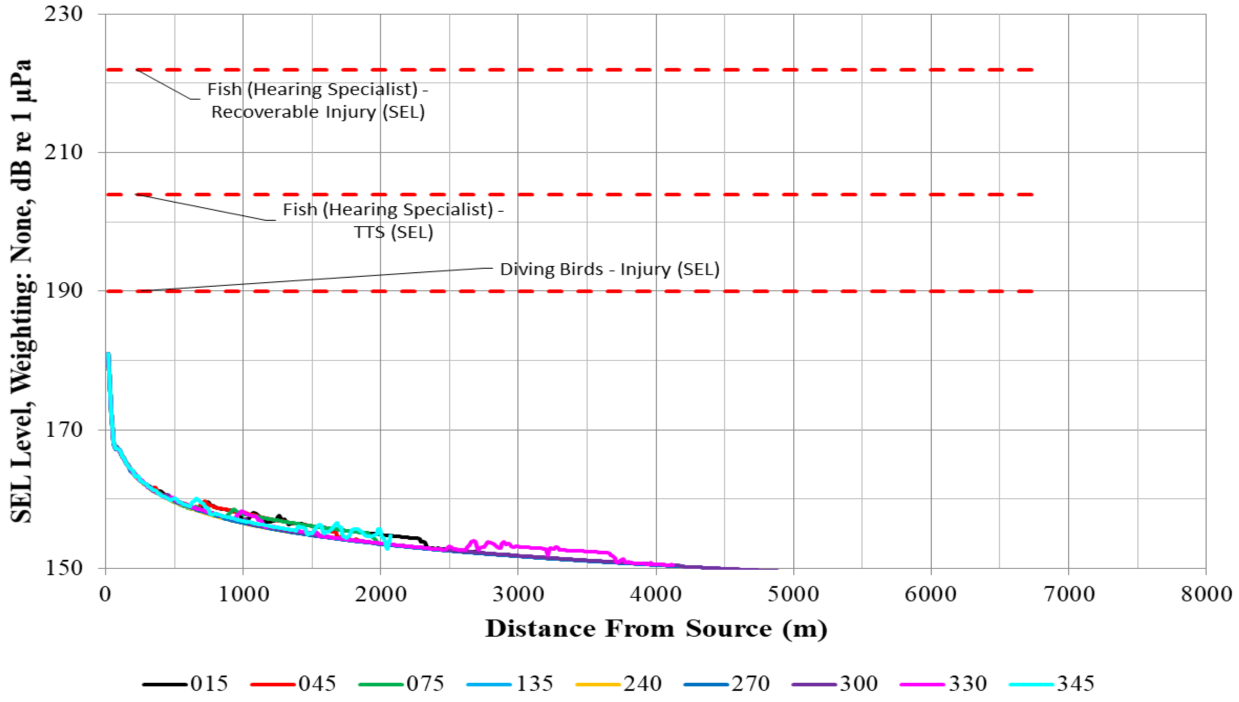

Figure G58. SEL from Construction Vessels at Kurnell, Unweighted

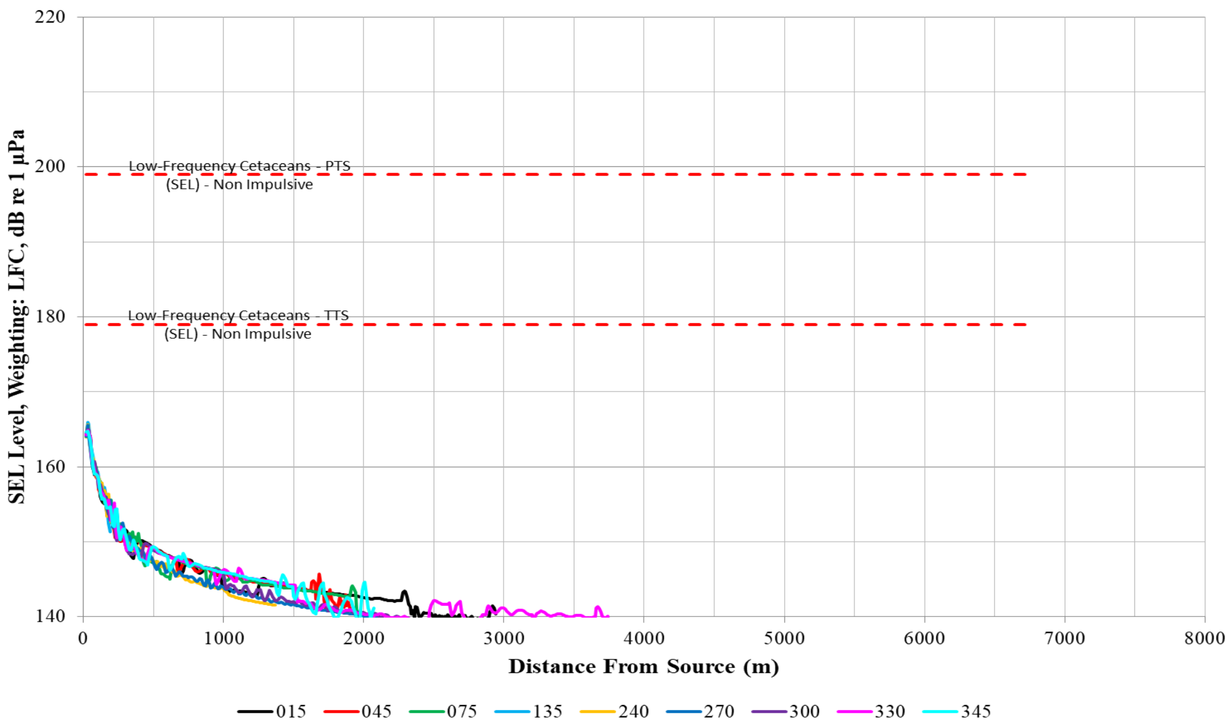

Figure G59. SEL from Construction Vessels at Kurnell, LFC Weighted

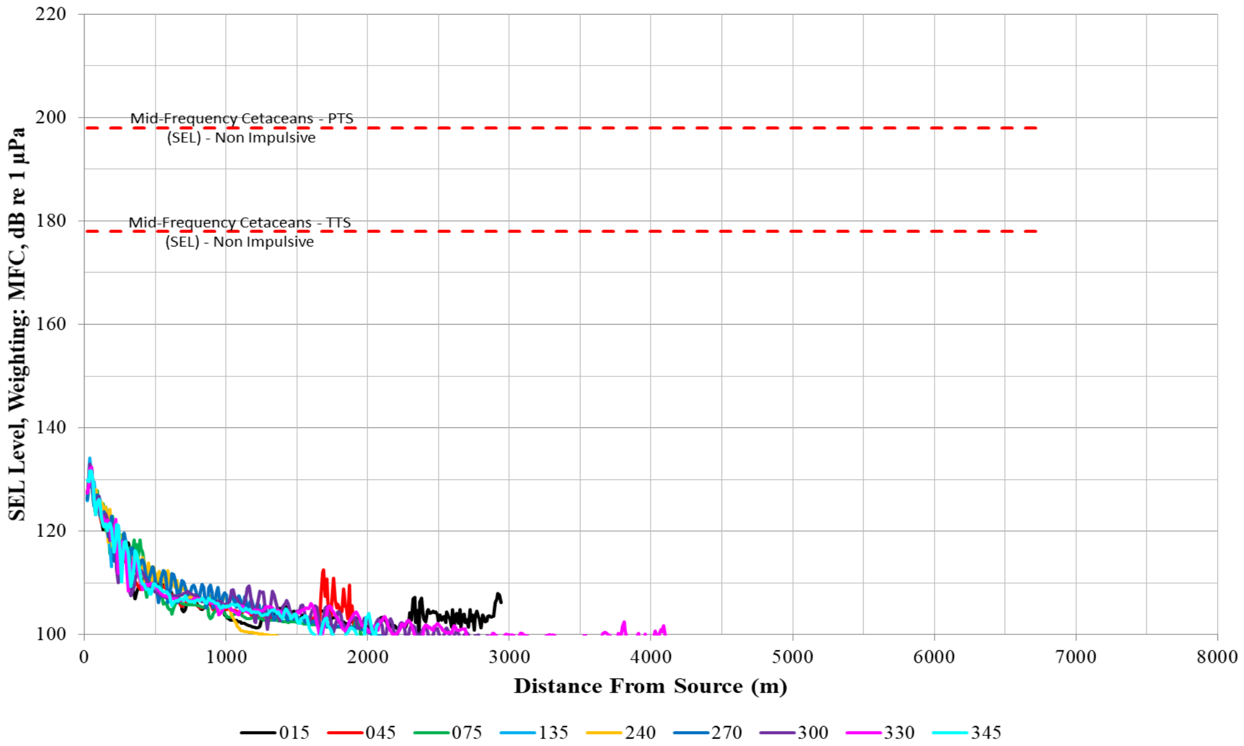

Figure G60. SEL from Construction Vessels at Kurnell, MFC Weighted

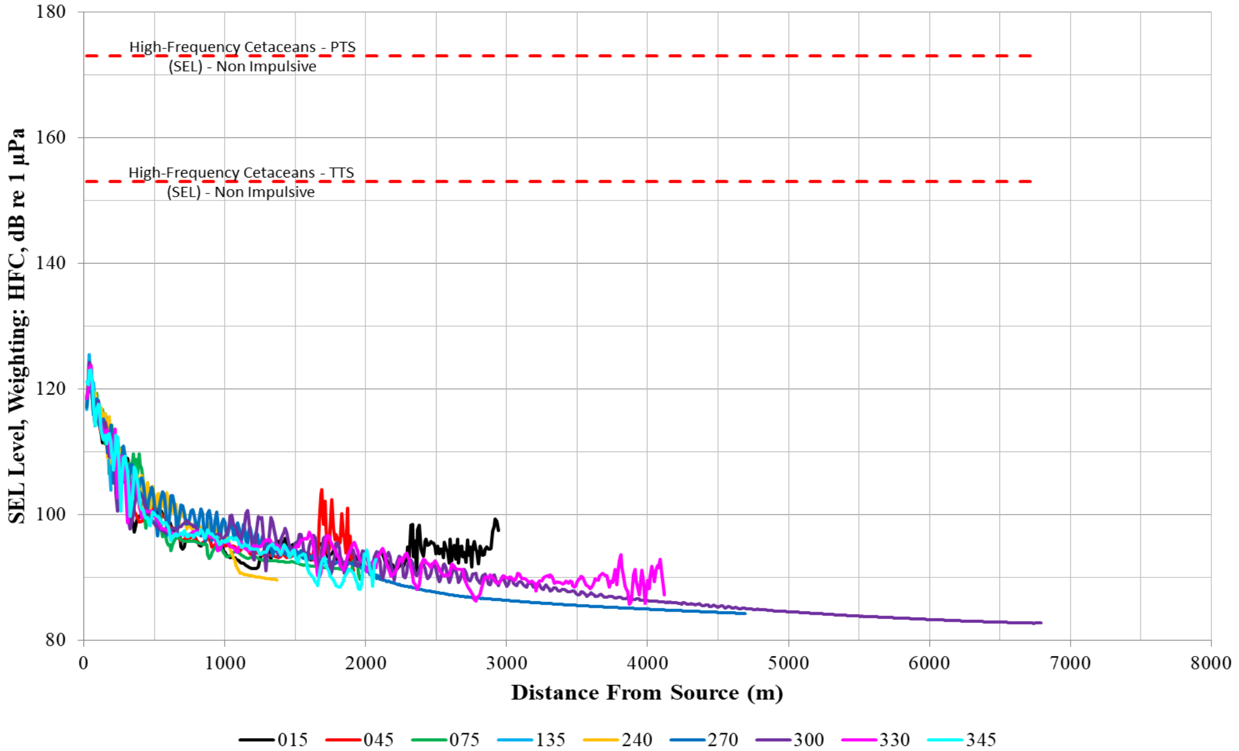

Figure G61. SEL from Construction Vessels at Kurnell, HFC Weighted

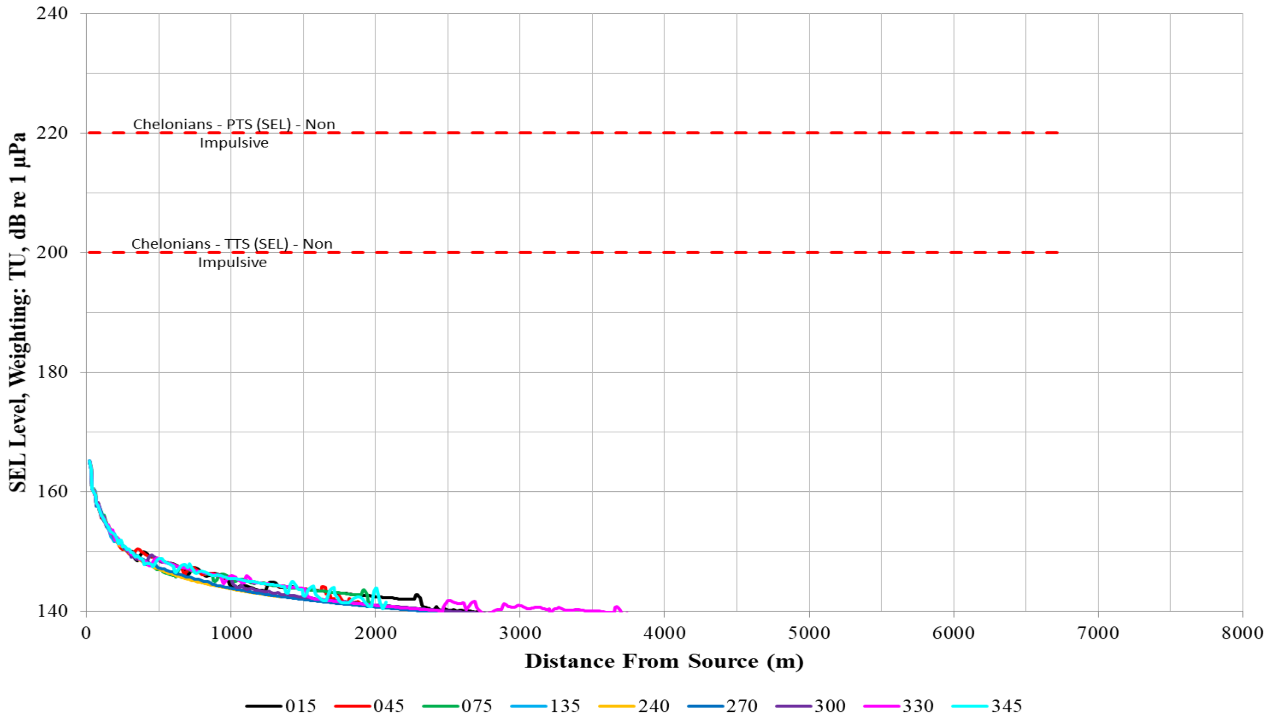

Figure G62. SEL from Construction Vessels at Kurnell, TU Weighted

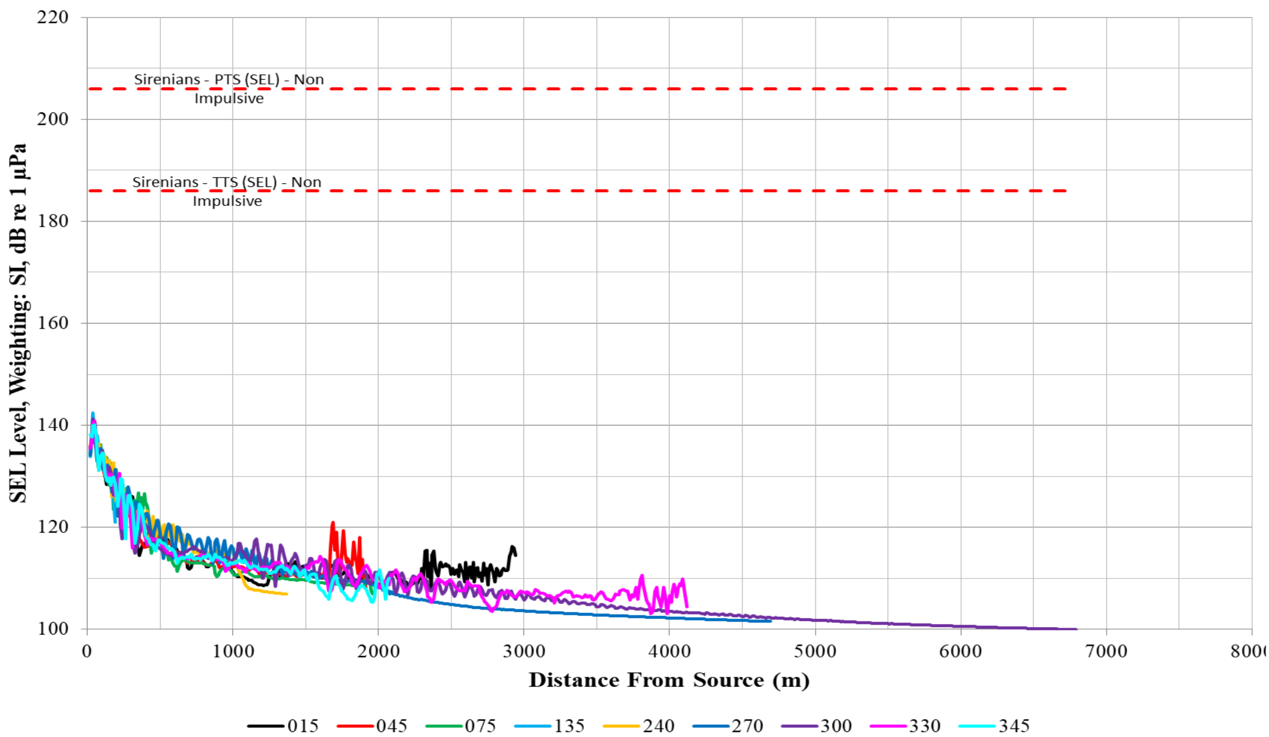

Figure G63. SEL from Construction Vessels at Kurnell, SI Weighted

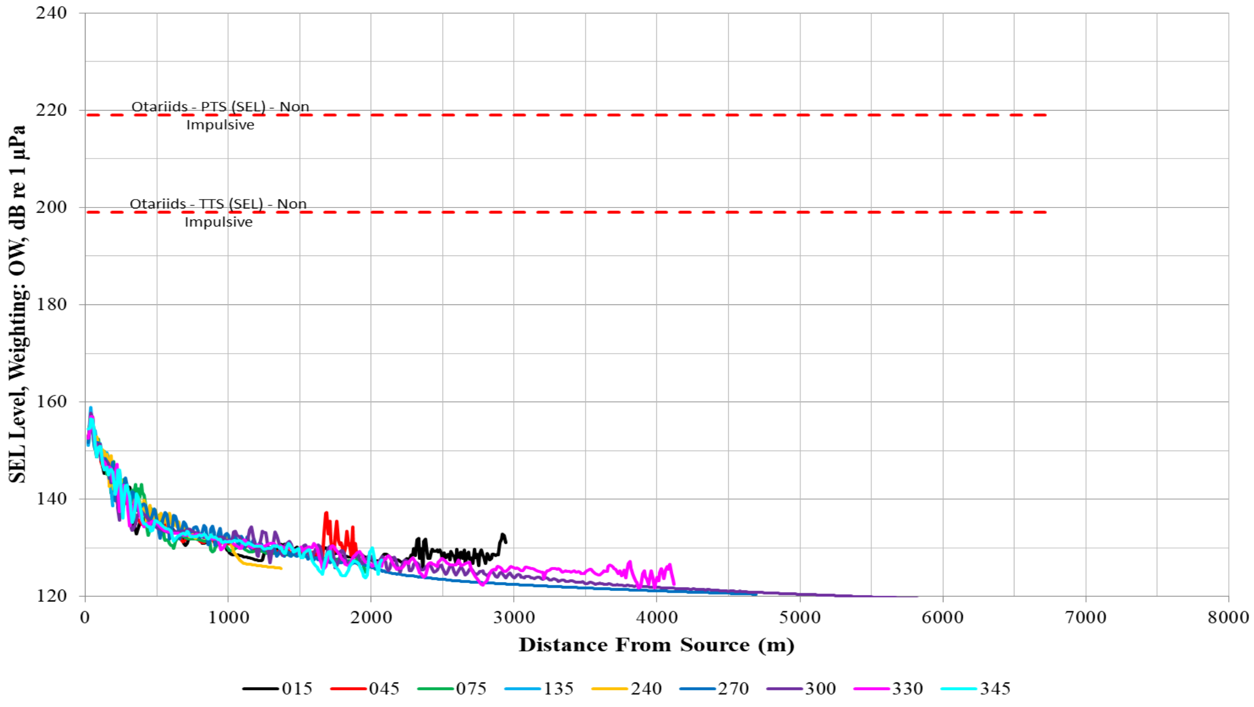

Figure G64. SEL from Construction Vessels at Kurnell, OW Weighted

G5 Vessels in the Channel

Predicted underwater noise levels from vessels in the channel are presented in the figures below. Each colour represents an azimuth.

G5.1 Ferries

G5.1.1 Sound Pressure Level

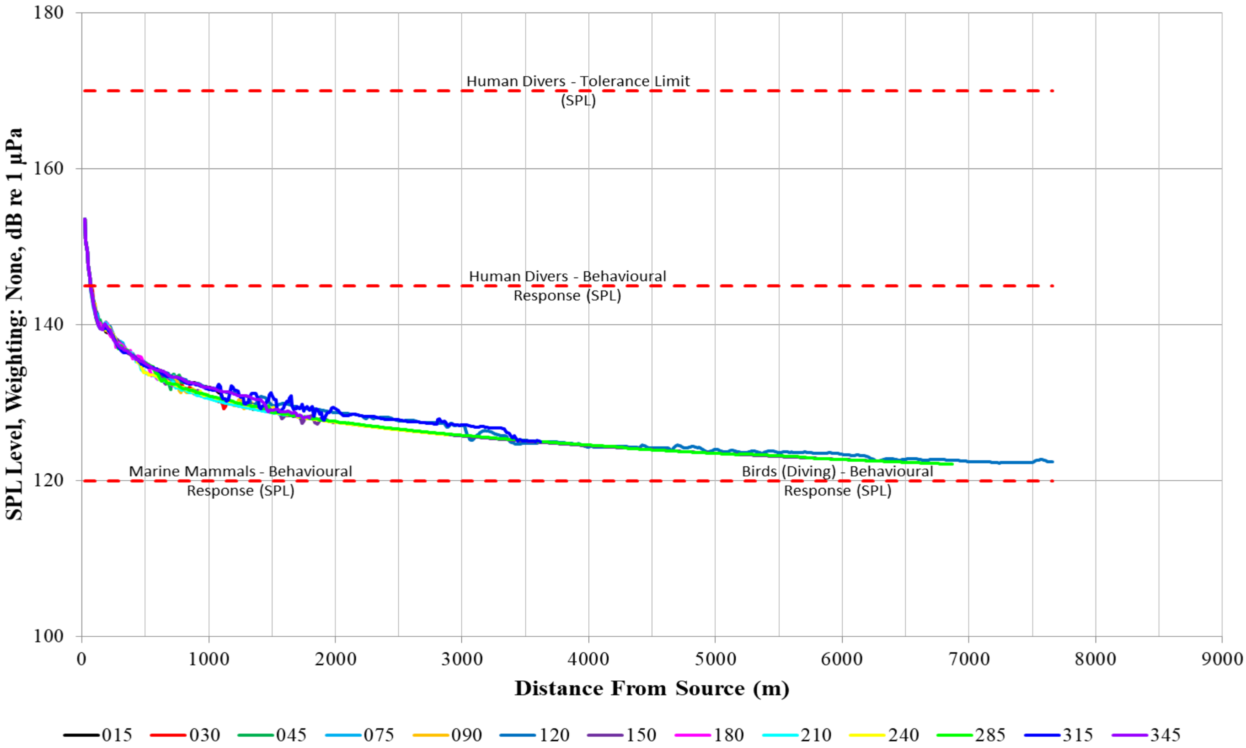

Figure G65. SPL from Ferries in the channel, Unweighted

G5.1.2 Sound Exposure Level

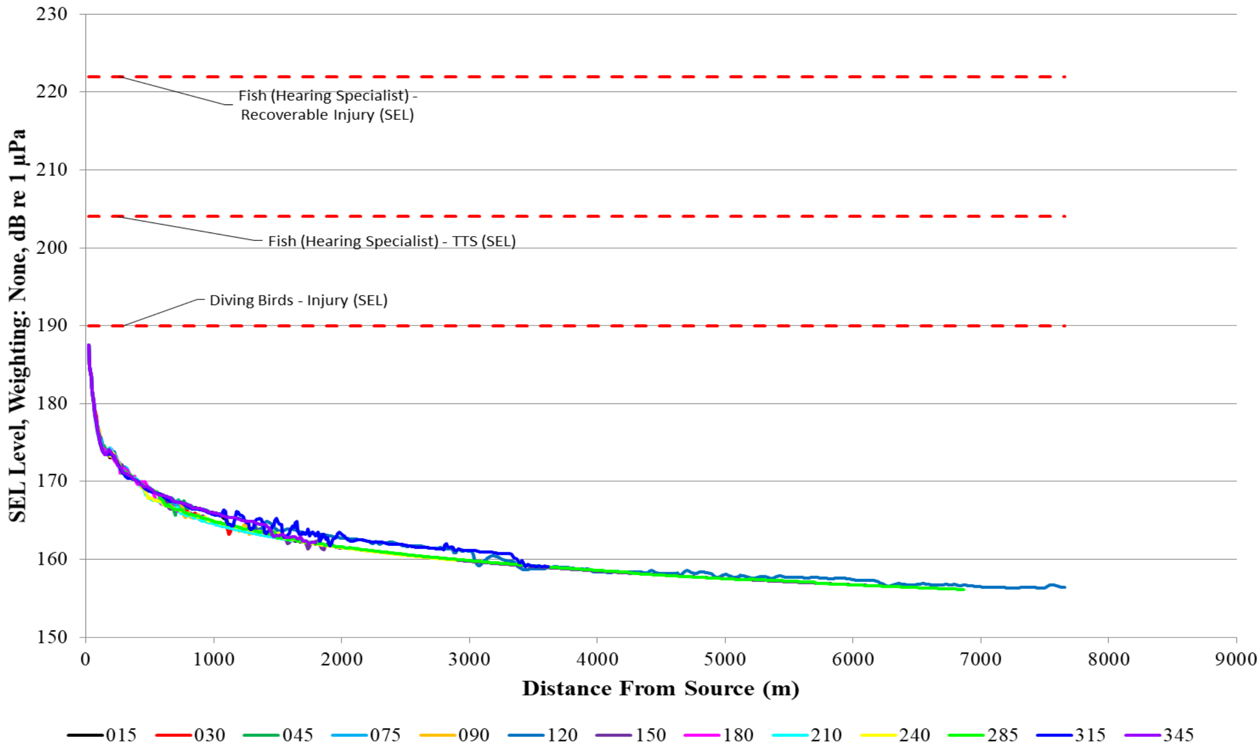

Figure G66. SEL from Ferries in the channel, Unweighted

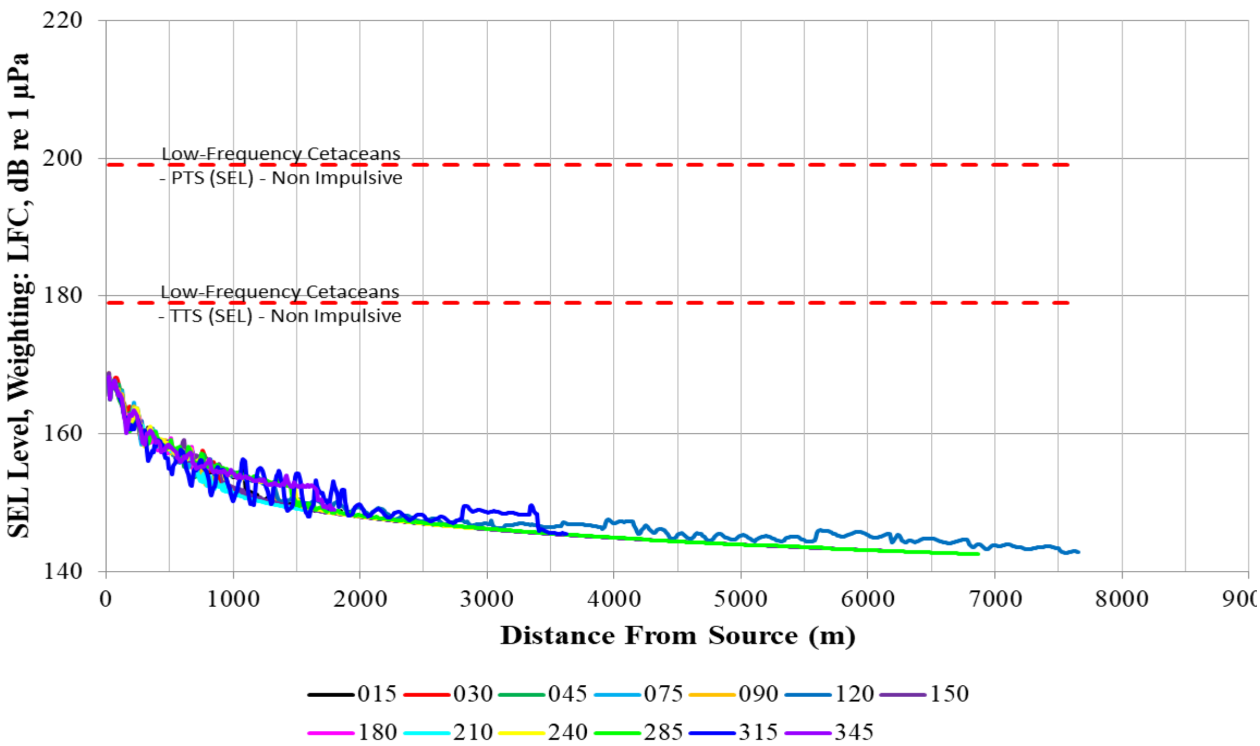

Figure G67. SEL from Ferries in the channel, LFC Weighted

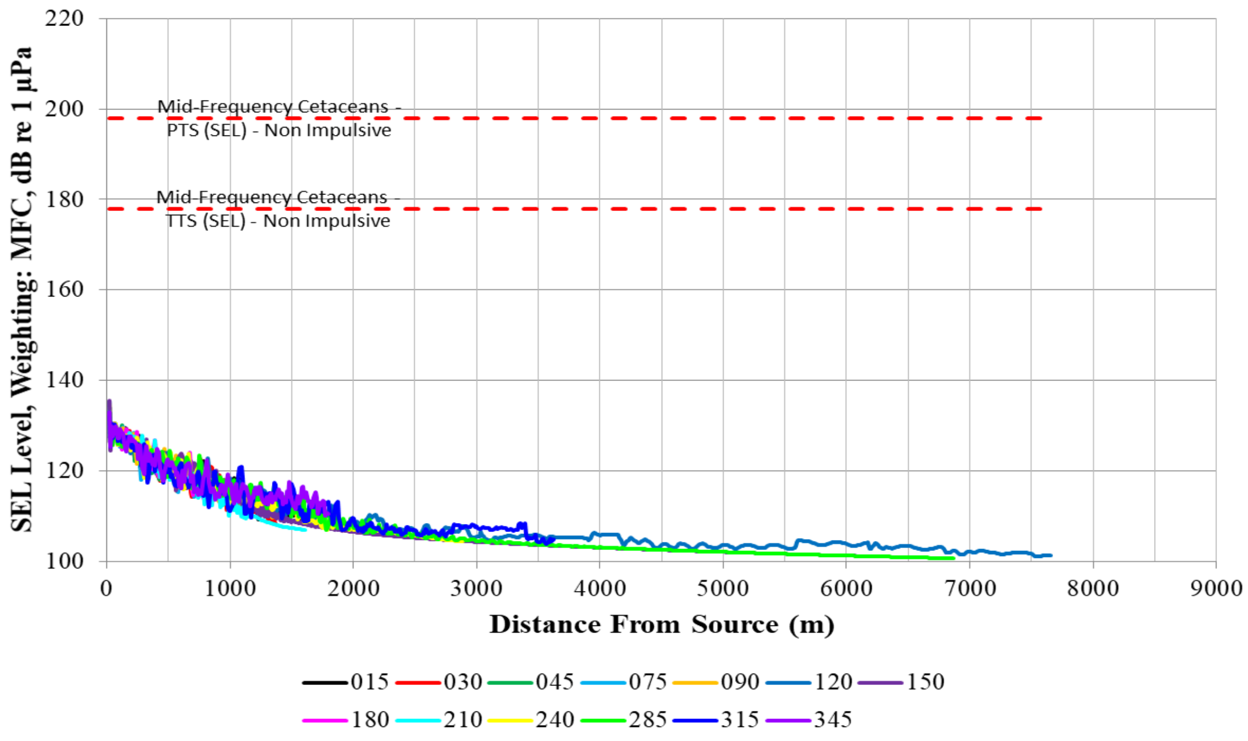

Figure G68. SEL from Ferries in the channel, MFC Weighted

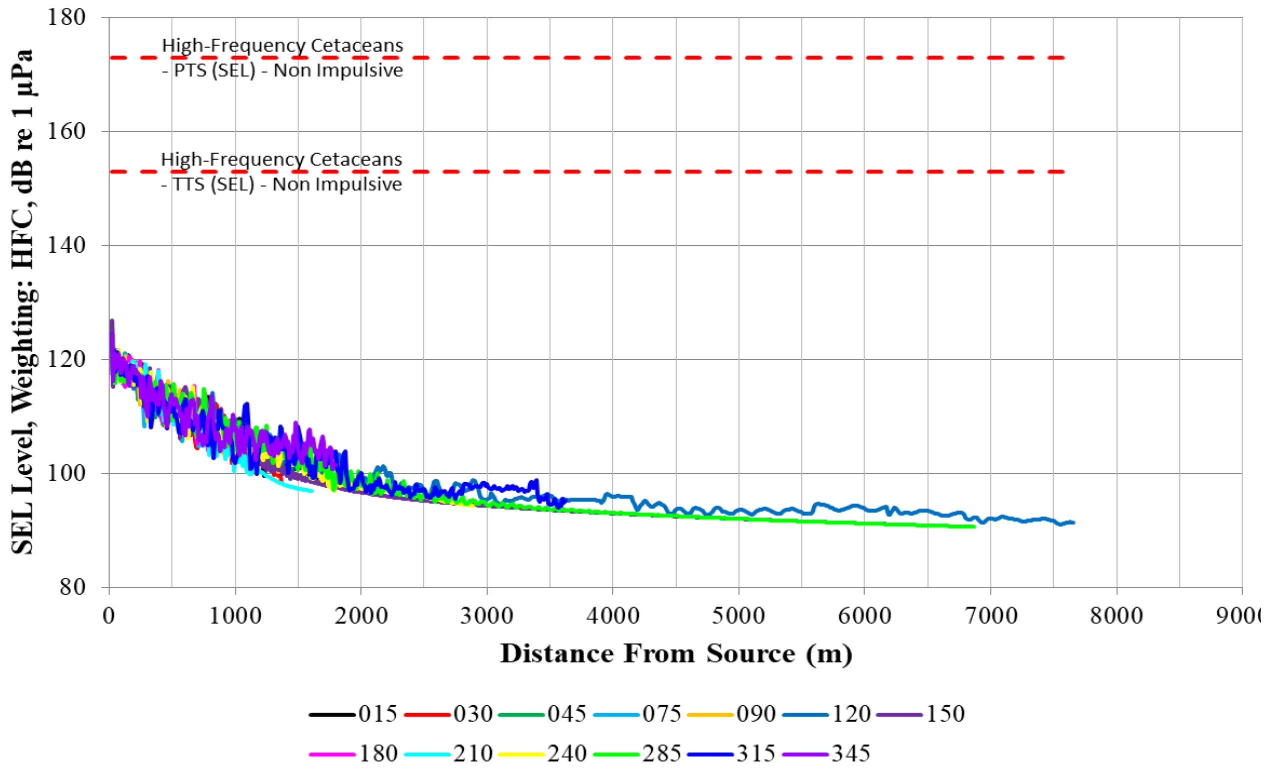

Figure G69. SEL from Ferries in the channel, HFC Weighted

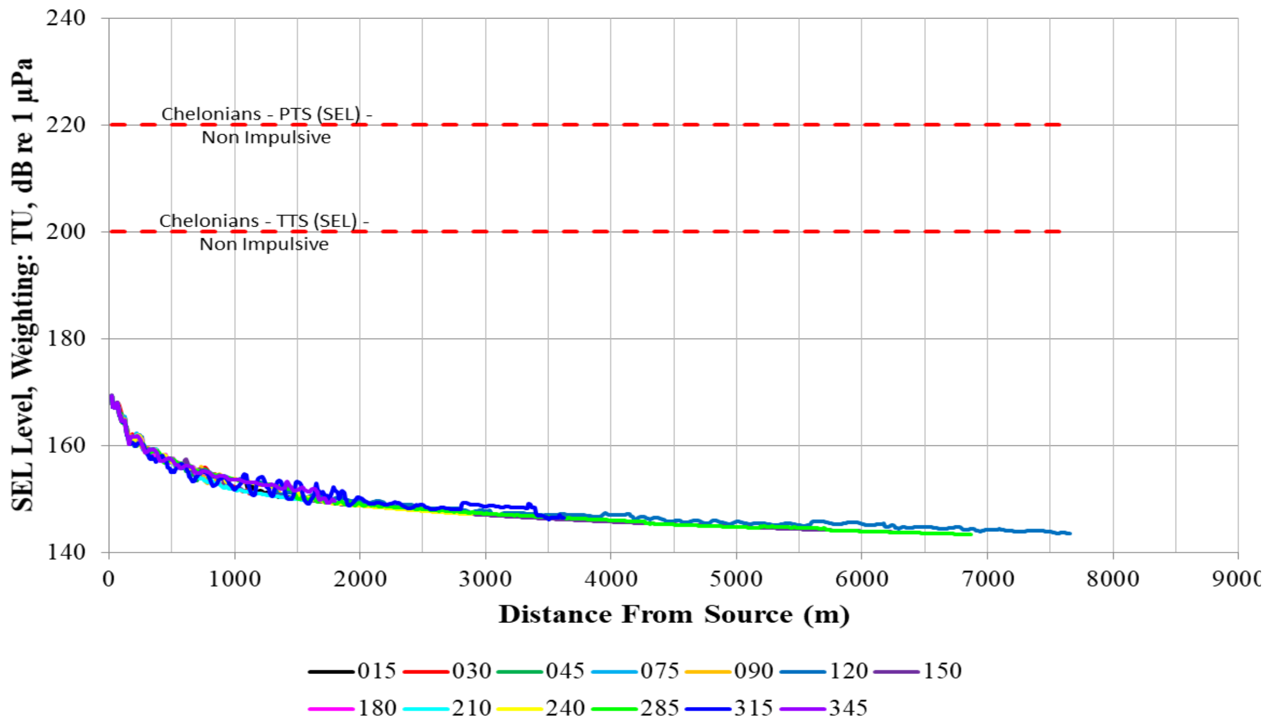

Figure G70. SEL from Ferries in the channel, TU Weighted

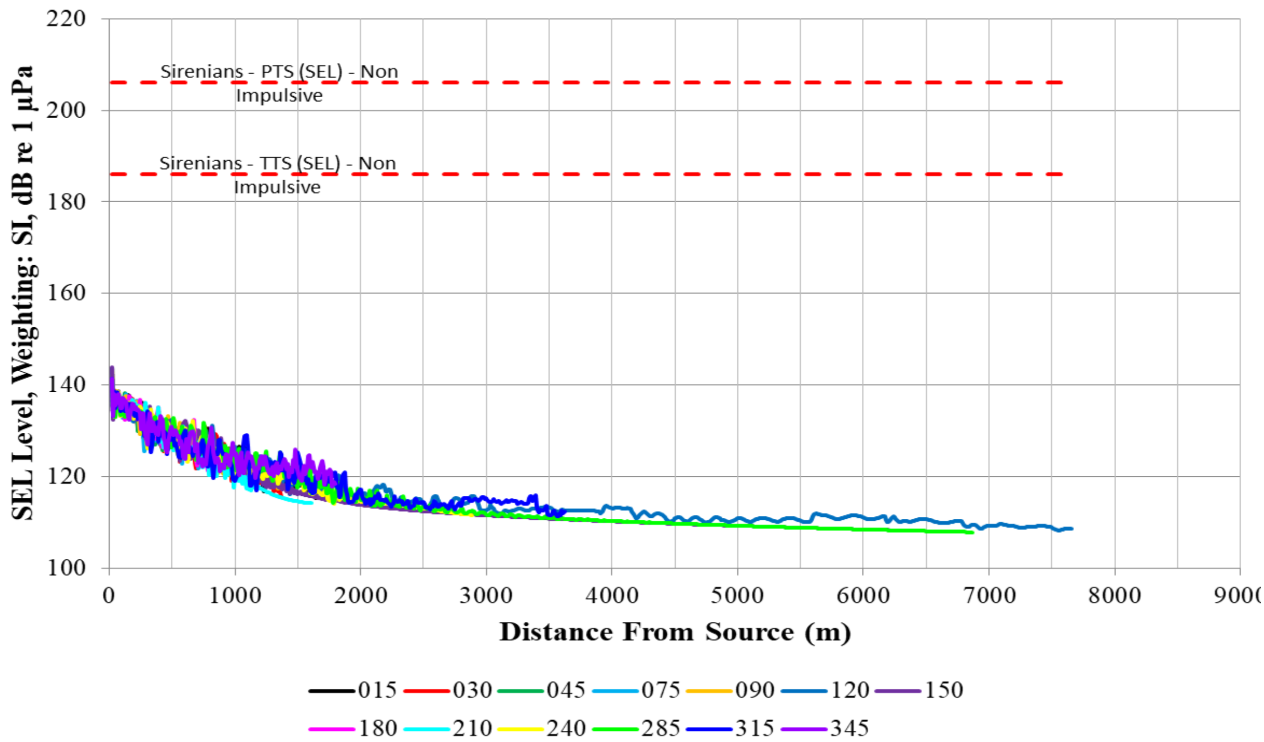

Figure G71. SEL from Ferries in the channel, SI Weighted

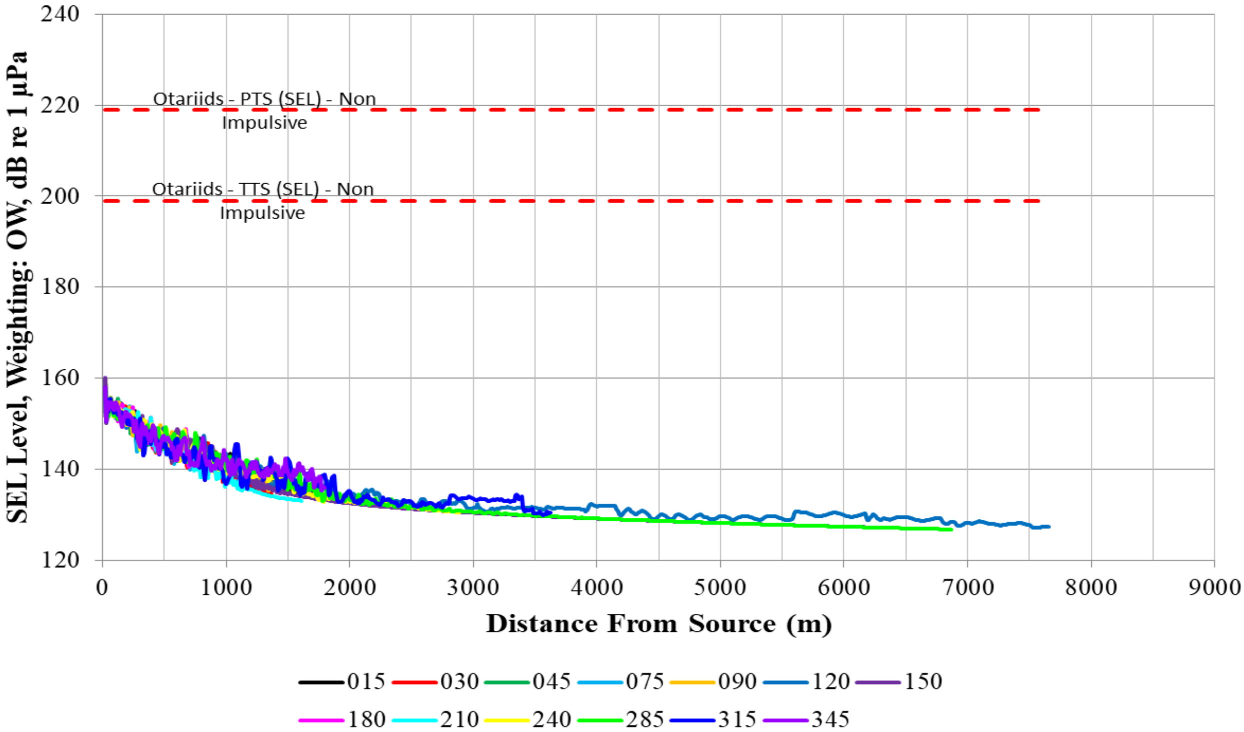

Figure G72. SEL from Ferries in the channel, OW Weighted

G5.2 Commercial Shipping

G5.2.1 Sound Pressure Level

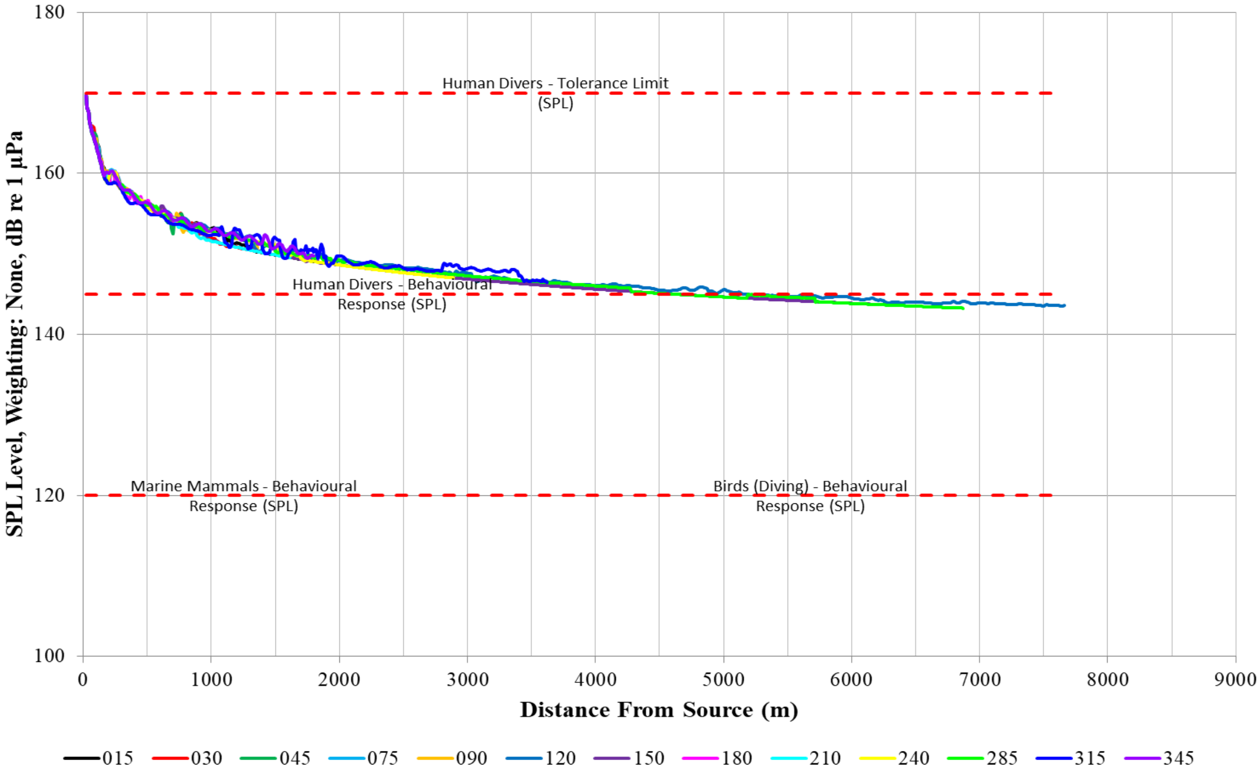

Figure G73. SPL from Commercial Shipping in the channel, Unweighted

G5.2.2 Sound Exposure Level

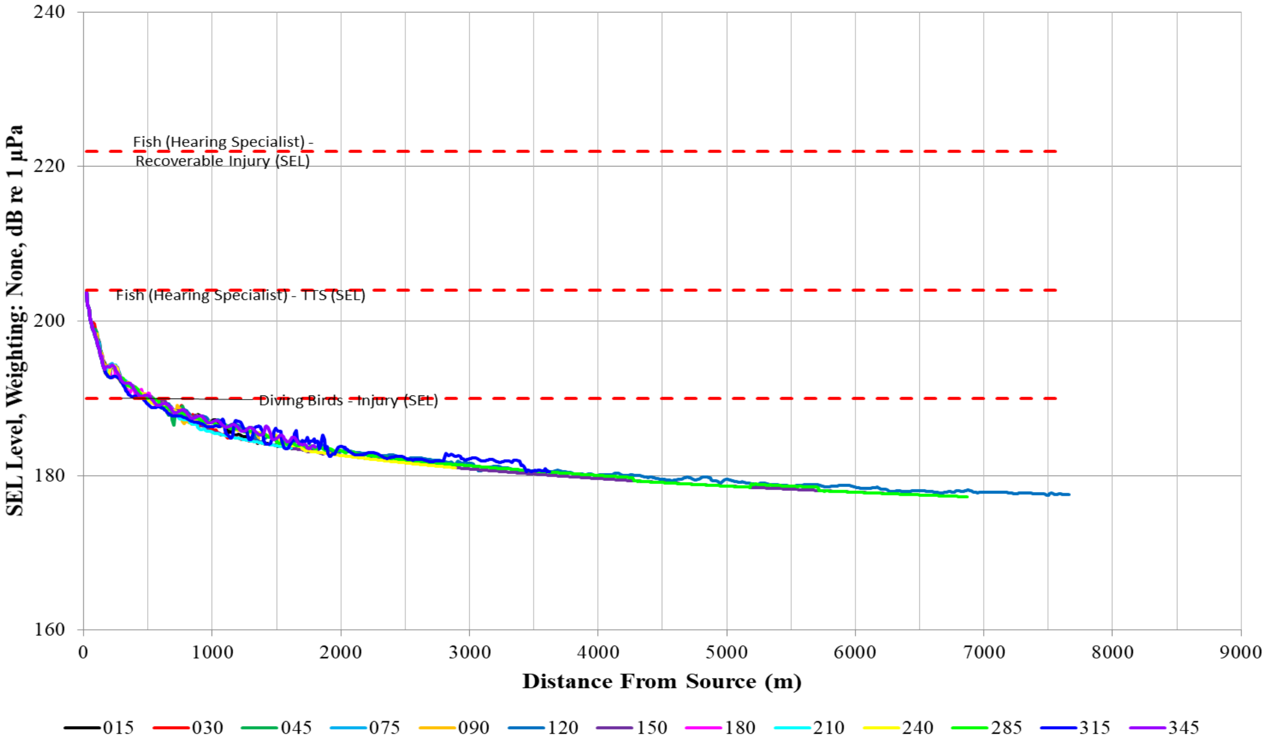

Figure G74. SEL from Commercial Shipping in the channel, Unweighted

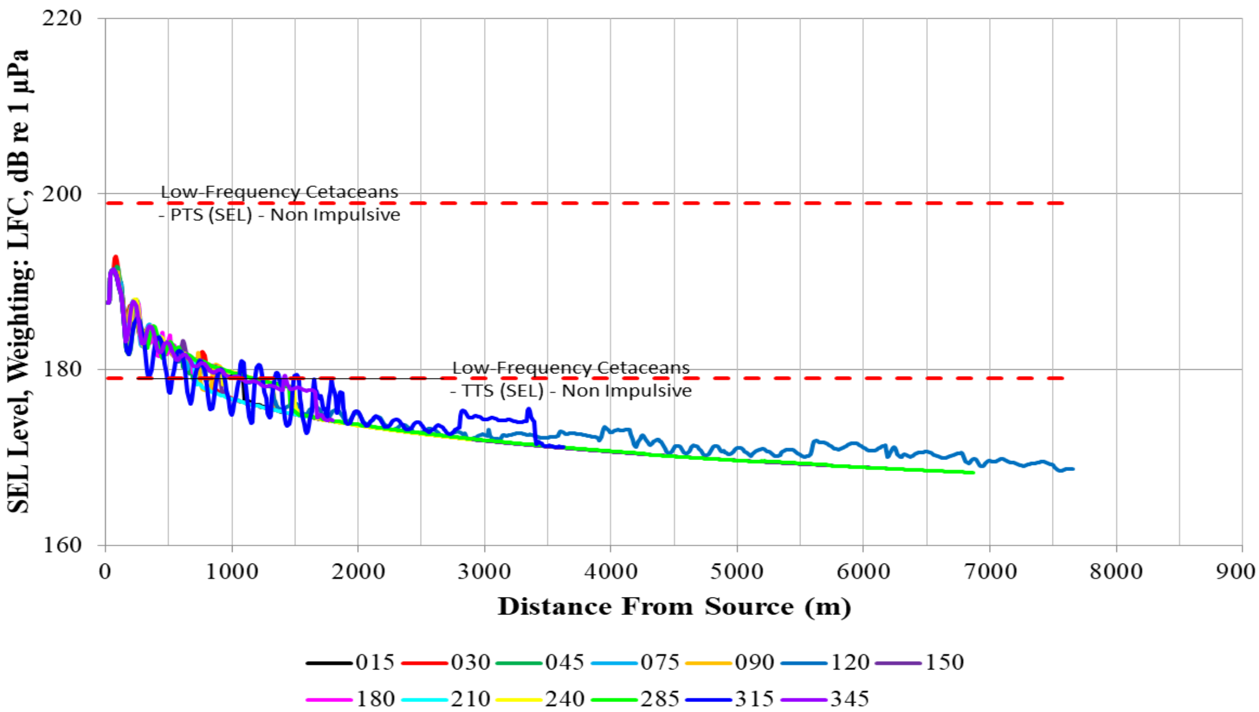

Figure G75. SEL from Commercial Shipping in the channel, LFC Weighted

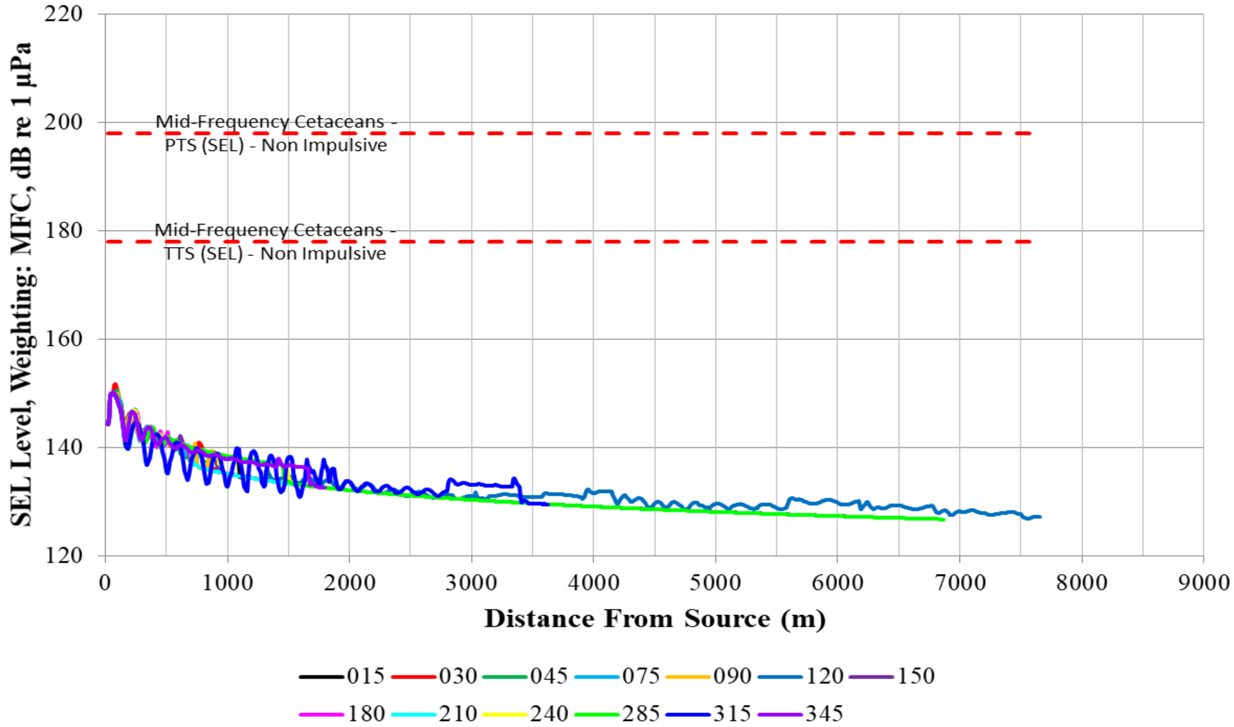

Figure G76. SEL from Commercial Shipping in the channel, MFC Weighted

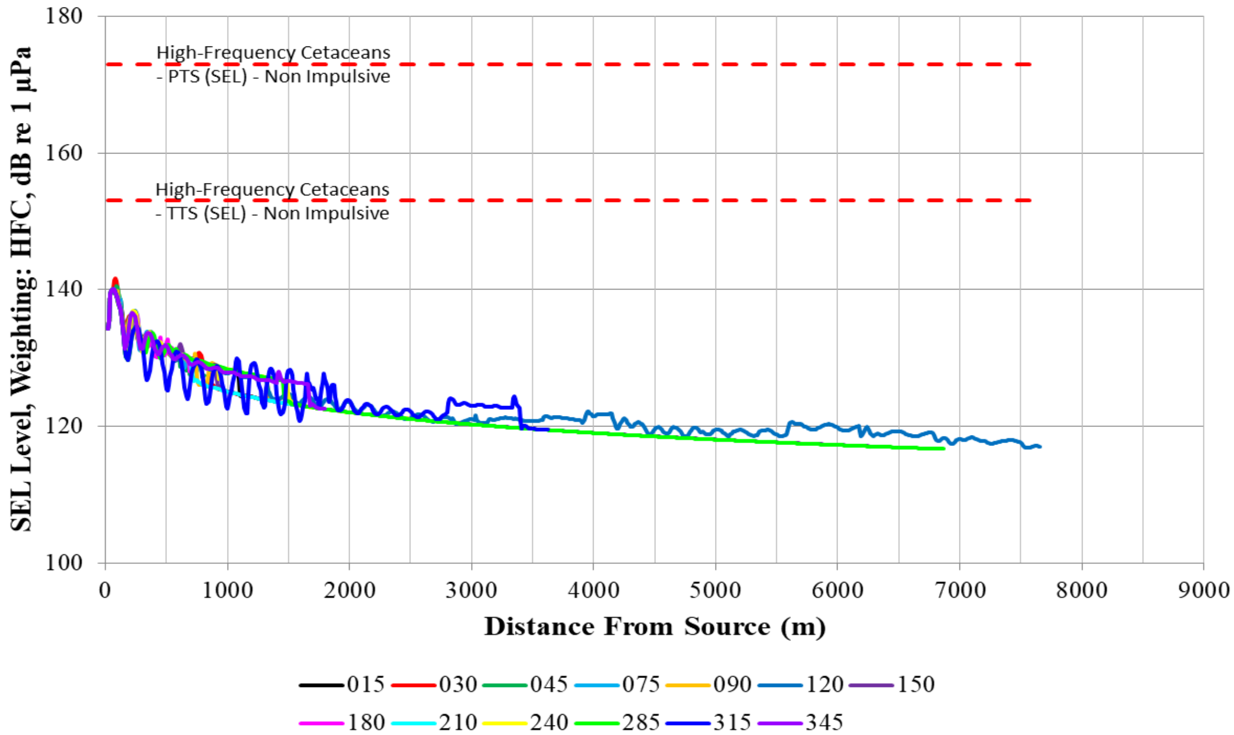

Figure G77. SEL from Commercial Shipping in the channel, HFC Weighted

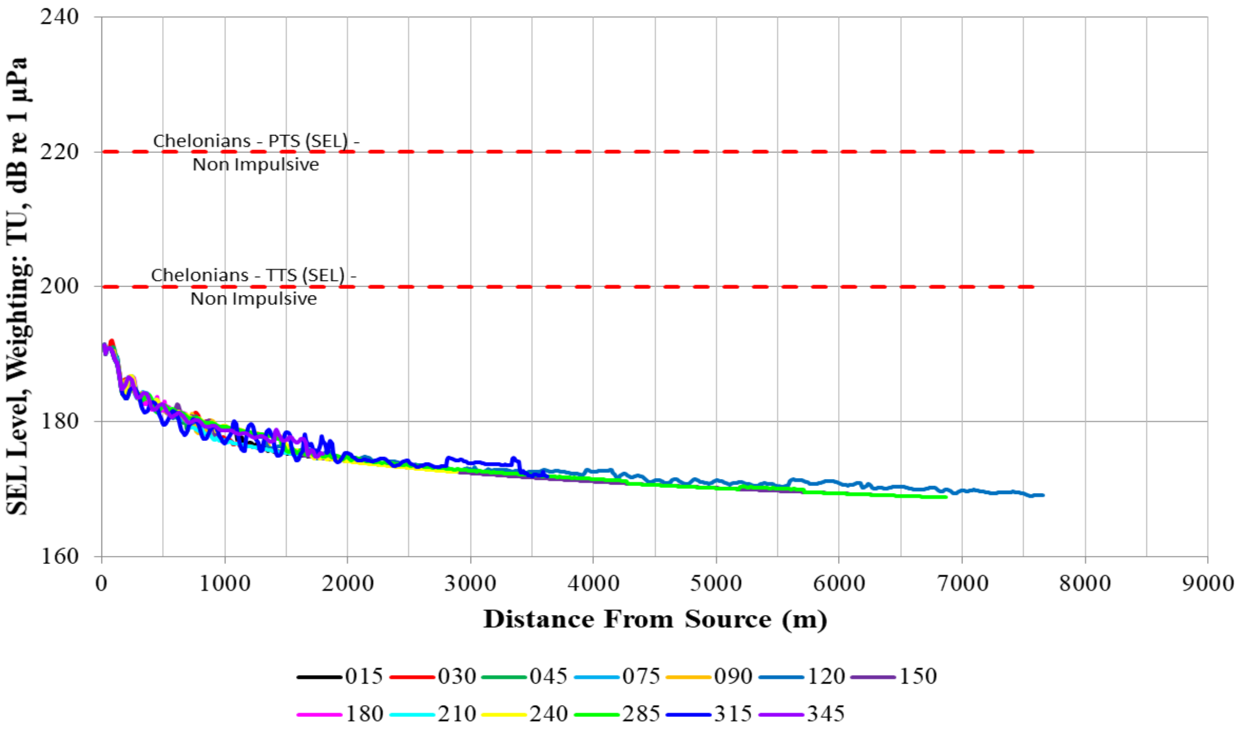

Figure G78. SEL from Commercial Shipping in the channel, TU Weighted

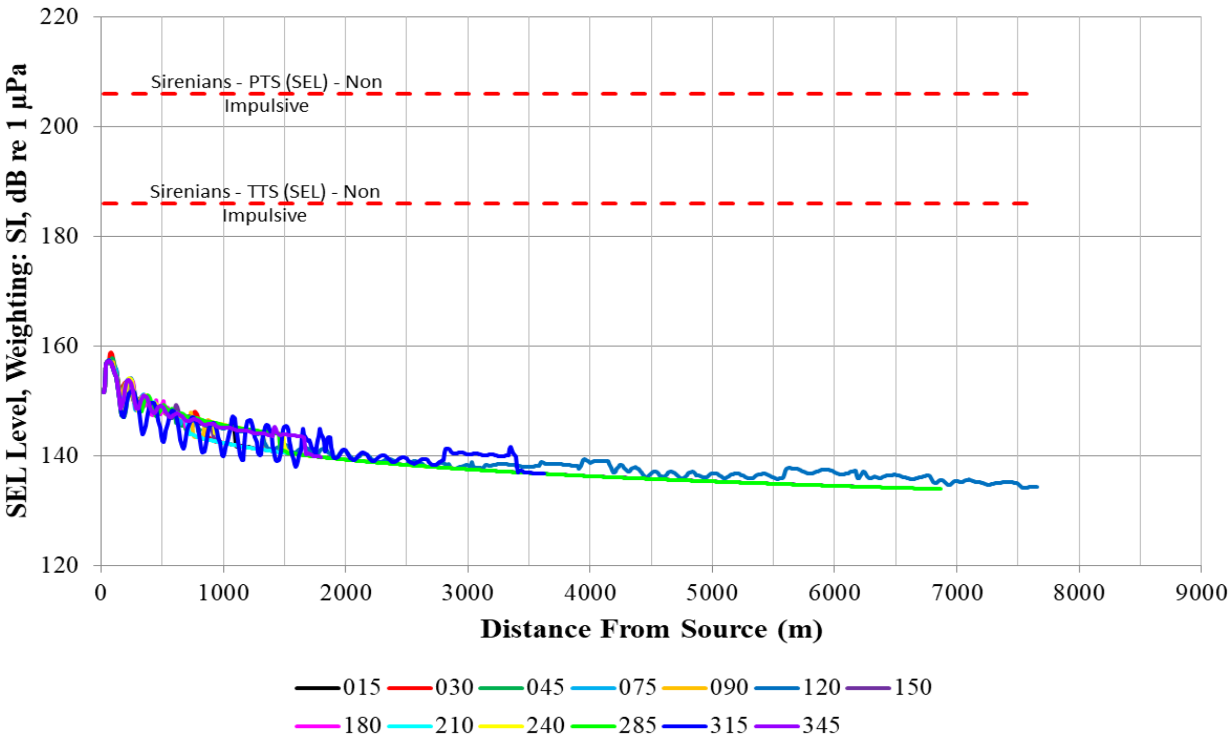

Figure G79. SEL from Commercial Shipping in the channel, SI Weighted

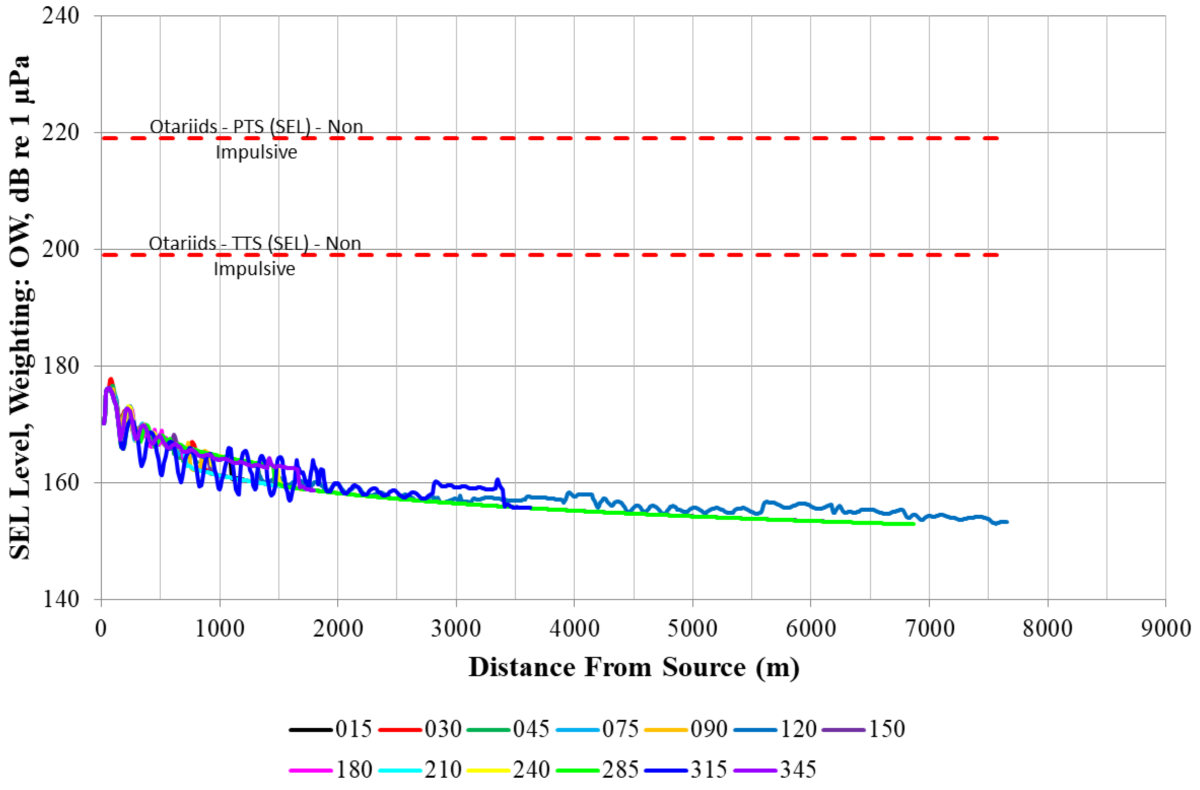

Figure G80. SEL from Commercial Shipping in the channel, OW Weighted