Merimbula Sewage Treatment Plant Upgrade and Ocean Outfall

Appendix M

Underwater Noise Technical Report

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Client: Bega Valley Shire Council

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May 2021

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Executive summary

Bega Valley Shire Council (BVSC) is proposing an upgrade to the Merimbula Sewage Treatment Plant (STP) including a new ocean outfall in Merimbula Bay (the Project). The Project would be located between Merimbula and Pambula on Arthur Kaine Drive, within the Bega Valley Shire local government area (LGA). The Merimbula STP is bounded by the Pambula Merimbula Golf Club to the south, Merimbula Lake to the west, Merimbula Airport to the north and Arthur Kaine Drive to the east. The Merimbula STP is accessed via Arthur Kaine Drive, which links to Princes Highway to the west and providing direct access to Merimbula Airport in the north.

The Project would involve an upgrade of sewage treatment at the Merimbula STP and replacement of the existing beach face outfall and dunal exfiltration ponds with an ocean outfall in Merimbula Bay. Specifically, the Project would involve:

- upgrade of the STP to improve the quality of treated wastewater (including for beneficial re-use);
- decommissioning of the beach-face outfall, as well as an STP effluent pond;
- discontinuing the use of the dunal exfiltration ponds;
- installation of a secondary disposal mechanism - an ocean outfall pipeline about 3.5 km in length to convey treated wastewater to a submerged diffuser;
- installation of upgraded pumps; and
- continuation of the beneficial re-use irrigation scheme at the PMGC grounds and the Oaklands agricultural area, with treated wastewater of improved quality.

The Project area comprises the existing Merimbula STP site and ocean outfall alignment, as well as areas required for construction, including laydown areas within the adjacent Pambula Merimbula Golf Club grounds and on Merimbula Beach (with access via Pambula Beach).

The Project is aimed at reducing the environmental and health impacts of current operations, by providing a higher level of treatment and a superior mode of discharge/ dispersion of the treated wastewater via an ocean outfall in Merimbula Bay. The upgraded STP would be operated with the additional treatment processes which would improve the quality of the treated wastewater.

Hydroacoustics is the study and application of sound in water. The ocean is filled with a broad spectrum of both natural and anthropogenic sounds. Physical processes such as turbulence associated with tidal currents are a significant source of ambient noise up to about 100 Hertz (Hz). In addition to these natural sources, anthropogenic sources also contribute to underwater noise, shipping being the dominant source of low-frequency anthropogenic noise. The propagation of underwater noise is complex but is similar to the behaviour of noise propagating through air. The difference between noise propagation in air versus noise propagation in water is the media and defined boundaries that water creates in which noise travels through water, surface water, and the seafloor. These boundaries substantially affect noise propagation characteristics in water. Hydroacoustic sound is produced by natural sources underwater, such as snapping shrimp, lightning strikes, and breaking waves. Commercial vessels and recreational boats produce high levels of underwater sound.

Improved understanding of underwater sound and its potential to affect marine life along with an increase in anthropogenic (human) activity that introduces sound into the marine environment, has raised concerns about the potential impacts on marine organisms. While ambient background noise levels tend to be consistent and widespread across large areas of ocean, anthropogenic produced sounds often form localized noise sources. These localized noise sources, if sufficiently loud, may be detrimental to certain marine species under some circumstances. The degree of impact will be influenced by many factors, including the sound's persistence, amplitude and frequency, the distance between the sound source and marine life, and the sensitivity of marine life to the combination of these factors. Although sensitivity will vary between and, often to a lesser degree, within species of marine life, the outcome of these interactions may result in physical harm or behavioural changes.

Any anthropogenic noise could impact a marine mammal or fish if the sound falls within its audible or detectable range; noise disturbance can have a range of effects depending on the sound type or source level. Loud, intense noise sources have the potential to cause lethal physical non-auditory injury to marine mammals, while other noise sources can cause auditory damage or elicit behavioural responses (e.g. displacement and/or habitat exclusion).

This Underwater Noise Technical Report is one of a number of technical documents that forms part of the Environmental Impact Statement (EIS) for the Project. This assessment has been prepared to determine the predicted underwater noise levels that would be produced from the construction and operation of the offshore components of the Project (i.e. the offshore portion of the ocean outfall pipeline).

Underwater noise from construction and operation of the ocean outfall pipeline has been assessed against relevant criteria. For construction, a conservative approach was taken where the worst-case scenario was assumed for use in underwater noise modelling. Exclusion zones for permanent threshold shift (PTS), temporary threshold shift (TTS) and behavioural change were calculated with the noise model, and a summary of the impact on fish species against the applicable criteria has been provided. During operation, the Project is not expected to generate any notable underwater noise emissions. The results of this assessment have been used in the marine ecology assessment undertaken for the Project (refer **Chapter 11 Marine ecology** and **Appendix G** of the EIS).

1.0 Introduction

Bega Valley Shire Council (BVSC) is proposing an upgrade to the Merimbula Sewage Treatment Plant (STP) including a new ocean outfall in Merimbula Bay (the Project). The Project would be located between Merimbula and Pambula, within the Bega Valley Shire local government area (LGA) (refer **Figure 2-1**).

This report has been prepared to assess the potential underwater noise generated from construction and operation of the Project, and has been used to inform the Marine Ecology Assessment Report for the Project (refer **Appendix G** of the EIS).

1.1 Project overview

The Project would involve an upgrade of sewage treatment processes at the Merimbula STP, decommissioning of an existing effluent storage pond, and replacement of the existing beach-face outfall and dunal exfiltration ponds with an ocean outfall pipeline in Merimbula Bay.

When operational, the Project would involve continuation of the beneficial re-use irrigation scheme at the Pambula Merimbula Golf Club (PMGC) grounds and the nearby Oaklands agricultural area, with improved treated wastewater quality from the upgraded STP.

The Project would reduce the environmental and health impacts of the current operations, by providing a higher level of treatment and a superior mode of discharge/dispersion of the treated wastewater via the ocean outfall offshore in Merimbula Bay.

The Project is described in further detail in **Section 2.0**, and an overview of the Project area is provided in **Figure 2-1**. A full Project description is provided in the EIS (refer **Chapter 2 Project description**).

1.2 Purpose of this technical report

This technical report provides an underwater noise assessment of the Project and has been prepared to support the Environmental Impact Statement (EIS).

1.2.1 Structure of this report

This report is structured as follows:

- **Section 1.0**: Introduction – this section introduces the Project and this assessment.
- **Section 2.0**: Project description – this section provides a description of the existing operations, the proposed upgrade and construction activities with respect to underwater activities.
- **Section 3.0**: Existing environment – this section provides a description of the existing underwater noise environment within the study area.
- **Section 4.0**: Underwater noise sources and hydroacoustics – this section discusses the effects of underwater noise on marine mammals and fish.
- **Section 5.0**: Methodology – defines the study area and summarises the underwater noise exposure criteria used in this assessment.
- **Section 6.0**: Underwater construction noise assessment – this section provides the underwater noise assessment during construction and prediction of exclusion zones for appropriate marine fauna for different levels of impact.
- **Section 7.0**: Underwater noise assessment during operation – this section describes the operational impacts.
- **Section 8.0**: Mitigation and management measures – this section describes measures to address underwater noise impacts.
- **Section 9.0**: Conclusion – this section presents the conclusions of the assessment.

2.0 Project description

This chapter outlines the existing operations at the Merimbula STP and provides a summary of the Project description. A full Project description is provided in **Chapter 2 Project description** of the EIS.

The Project would be located between Merimbula and Pambula on Arthur Kaine Drive, within the Bega Valley LGA approximately 3.5 kilometres (km) south of the Merimbula town centre and 2.5 km north of Pambula village, as shown on **Figure 2-1**. The Merimbula STP is bounded by the PMGC to the south, Merimbula Lake to the west, Merimbula Airport to the north and Arthur Kaine Drive to the east. The Merimbula STP is accessed via Arthur Kaine Drive, which links to Princes Highway to the west and provides direct access to Merimbula Airport in the north.

2.1 Existing operations

The existing operations at the Merimbula STP consist of:

- sewage treatment at the Merimbula STP; and
- disposal of treated wastewater via:
  - a beach-face outfall;
  - dunal exfiltration ponds; and
  - a beneficial re-use scheme at the adjacent PMGC grounds, and at Oaklands agricultural area.

The STP is an intermittently decanted extended aeration (IDEA) activated sludge plant designed to serve an equivalent population of 15,500. The STP has a capacity to accommodate an average dry weather flow of up to 3.72 megalitres per day (ML/day) and a peak wet weather flow of seven times the average dry weather flow, or 26 ML/day. It handles an average of 790 megalitres (ML) of treated wastewater per year .

The current strategy for managing treated wastewater from the Merimbula STP comprises a combination of:

- beneficial re-use (the preferred disposal option): use of treated wastewater to irrigate the adjacent PMGC grounds and 'Oaklands' agricultural area (approximately 25% of annual treated wastewater), located on the Pambula River flats at South Pambula; and
- disposal: discharge of excess treated wastewater to the environment, via dunal exfiltration ponds located within the sand dunes east of the STP between the ocean and Merimbula Lake (approximately 25% of annual treated wastewater), or via the existing beach-face outfall east of the STP at Merimbula Beach (approximately 50% of annual treated wastewater).

2.2 The Project

The Project would involve:

- upgrade of the STP to improve the quality of treated wastewater (including for beneficial re-use);
- decommissioning of the beach-face outfall, as well as an STP effluent storage pond;
- discontinuing the use of the dunal exfiltration ponds;
- installation of a secondary disposal mechanism - an ocean outfall pipeline about 3.5 km in length to convey treated wastewater to a submerged diffuser;
- installation of upgraded pumps; and
- continuation of the beneficial re-use irrigation scheme at the PMGC grounds and nearby Oaklands agricultural area with treated wastewater of improved quality.

Upgrades to the STP and the ocean outfall would reduce the environmental and health risks and impacts of the current operations, by providing a higher level of treatment and a superior mode of discharge/ dispersion of the treated wastewater via an ocean outfall offshore in Merimbula Bay.

A summary of the proposed Project elements is provided in **Table 2-1**.

The Project area comprises the existing Merimbula STP site and the proposed outfall pipeline alignment. The Project construction areas would include areas within the Merimbula STP, temporary laydown areas on the adjacent PMGC grounds and on Merimbula Beach (with associated access from Pambula), as shown in **Figure 2-1**.

The EIS is based on a concept design for the Project. It is noted that during subsequent design stages, and subsequent to a design and construction contractor(s) being engaged, details of the Project may change or be refined (e.g. specific locations of some elements or infrastructure within the existing STP site; materials to be used in plant construction and technology).

Table 2-1 Project elements

Project element	Summary
STP upgrade	The STP upgrade would involve additional treatment processes incorporated into the existing STP site, including two stage poly aluminium chloride (PAC) dosing, ultraviolet (UV) disinfection, chlorine dosing and tertiary filtration (if required). The indicative physical layout of the proposed STP upgrade is shown in **Figure 2-2**. The new treatment processes would be incorporated into the following existing STP phases (refer **Chapter 2 Project description** for further information): *Phase two: secondary treatment* Addition of: • two stage PAC dosing for phosphorous removal. *Phase three: disinfection* A change to the existing disinfection (chlorine dosing) treatment, involving: • addition of UV treatment; • chlorine dosing would continue to be applied to treated wastewater, however wastewater would be divided into two separate streams: - wastewater to be beneficially re-used would be dosed with chlorine; and - wastewater to be discharged via the ocean outfall would no longer be subject to chlorine dosing; • the chlorine dosing proposed would involve installation of a new chlorine dosing unit (including two 920 kg drum storage of chlorine, and a new pump system). The chlorine dosing unit would be stored at a dedicated storage facility within the STP (either the existing chlorine storage shed would be upgraded to house the increased volume of chlorine required for the Project, or a new shed would be built on or near to the site of the existing shed); and • tertiary filtration could also be installed (if required).

Project element	Summary
	The Project would also require the following within the existing STP site: • a new storage tank and new chlorine contact tank; • installation of up to four additional pump stations: - ocean outfall pump station – to pump treated wastewater through the outfall pipeline; - storage tank pump station – to pump treated wastewater to the new storage tank; - chemical sludge pump station (if tertiary filters required) – to pump sludge and treated wastewater; and - pump station – to pump from wet weather overflow back into the STP treatment train. • installation of ancillary infrastructure (including new sheds/structures to house new treatment processes, above-ground storage tanks, pipes, pits, power supply and additional low voltage (LV) connection (including transformer, cabling and distribution board), control kiosks, a retaining wall and internal access roads); and • relocation and upgrade of utilities to accommodate the additional features proposed.
Existing STP effluent storage pond	The existing 17 ML effluent storage pond within the STP site would be decommissioned, including dewatering and sediment/sludge removal.
New ocean outfall pipeline and effluent diffuser, and associated pump station	<u>*Phase four: Disposal and beneficial re-use*</u> New additions would involve: • installation of a 3.5 km outfall pipeline – the pipeline would travel from the STP in an east-south-easterly direction to a location approximately 2.7 km offshore in Merimbula Bay; • the pipeline would involve two construction methods for different sections of the pipeline as follows: - 'Section one' – STP to a location beyond surf zone: underground trenchless drilling method (refer **Figure 2-3**); and - 'Section two' – Location beyond surf zone to offshore pipeline termination point: laying of pipeline on sea floor and covering with rock or concrete mattresses (refer **Figure 2-4**); • Section one of the pipeline (the onshore component) would be about 0.8 km and below ground. installation of the underground section would be via a trenchless method (e.g. horizontal direction drilling or direct drive tunnelling), followed by pipeline insertion via pulling or pushing; • Section two (the above ground section of the pipeline) would be installed via direct placement on the sea floor in 600 m to 800 m pipe lengths. This would also involve progressive protection and stabilisation works for the pipeline (e.g. potentially using concrete or rock mattresses) held together with ropes/ slings/ cables; • the terrestrial component of the outfall pipeline would be laid between about -9.3 m and -19.5 m AHD, with greater depth largely depending on the nature of the overlying sand dunes; • a multi-port pipeline diffuser would be located at the end of the pipeline at a depth of approximately 30 m; the diffuser would be approximately 80 m in length; • the pipeline would have an outer diameter of up to 450 mm (366 mm internal diameter) and consist of pipeline lengths welded together; • a transition riser may be required to connect the underground pipeline with the above ground section of pipeline on the sea floor (if required, the riser would be located beyond the surf zone); and • the pipeline would contain valves along its length for mitigating against air entrapment.

Project element	Summary
Existing exfiltration ponds	The existing exfiltration ponds within the adjacent sand dunes (east of the STP site) would cease to be used under the Project.
Existing beach-face outfall	The existing public beach-face outfall pipeline would be decommissioned. The exposed end of the outfall pipeline would be removed, and the remainder of the pipeline would remain in-situ (i.e. would remain buried underground).
Water use	The STP would continue to use potable town water for kitchen and amenities on site. Apart from these water inputs, the Project would not require any other ongoing water source during operation.
Construction	
Construction footprint	The construction footprint includes temporary compound and laydown areas as shown in **Figure 2-5**. The location of laydown areas would be confirmed during detailed design and would depend on the method and location/s proposed to be used for directional drilling by the construction contractor. Temporary construction laydown areas would be located: • within the STP site; • within a portion of the adjacent PMGC grounds; and on Merimbula Beach (if required, for pipe stringing and potentially an intermediate drill rig site for directional drilling). A total of approximately 2,800 square metres (m2) (or 0.28 hectares) of vegetation removal / trimming would be required in the following locations: • approximately 217 m^2 at the Pambula Beach access track; and • approximately 2,464 m^2 of regrowth scrub within the existing STP site and for construction access from the construction laydown area within the PMGC grounds; and • approximately 47 m^2 at the existing beach-face outfall pipeline (to be decommissioned).

Project element	Summary
Construction timing, hours and workforce	Pending Project approval, it is proposed to commence construction in 2022, with construction anticipated to be undertaken over a period of 24 months. Construction would be staged and there would be times when some construction stages overlap. Works would typically be limited to standard daytime hours, which include: • 7:00 am to 6:00 pm Monday to Friday; • 8:00 am to 1:00 pm Saturday; and • No work on Sundays, public holidays. Certain works may need to occur outside standard construction hours for the safety of workers, in accordance with transport licence requirements, or for constructability reasons. Activities to be carried out during out of hours periods may include oversized load deliveries and pipeline pulling as part of the directional drilling (which would need to be undertaken continuously until completed, which may take up to 48 hours). Construction works in Merimbula Bay could occur seven days a week to maximise works during favourable offshore weather conditions. Approval from BVSC would be required for any out of hours work and the affected community would be notified. Construction of the Project would require a workforce of around 20 workers, with peak construction periods requiring up to 30 workers.
Traffic, construction vehicle types and workforce	Construction traffic would indicatively comprise: • 5-10 heavy vehicles per day (e.g. truck and dogs); and • 10-20 light vehicles per day. Vehicles transporting machinery or oversized materials such as prefabricated units may be required from time to time, and oversized vehicles would require escort to and from site. The largest truck expected as part of construction is the directional drilling rig truck (the exact size would be confirmed by the construction contractor). The construction phase of the Project would require construction vehicles to transport materials and equipment along the existing road network to the construction compound/laydown areas at the Merimbula STP and PMGC grounds and, if required, at the Merimbula Beach laydown area via Pambula Beach. In facilitating these construction activities, various plant and equipment would be required, including:

Project element	Summary
	• small, medium and large excavators (3 tonne to 25 tonne) (tracked and wheeled); • compaction plant (e.g. roller/s, plate compactor); • grader; • bulldozer; • directional drilling rig truck and associated infrastructure (i.e. drilling fluid recovery and recovery unit); • pumps for dewatering (if required); • vacuum truck; • bobcat; • concrete trucks and pumps; • mobile cranes (e.g. franna crane, scissor lift, forklift); • semi-trailers and tipper truck; • telehandlers; • micro-piling rig (on barge); • water carts; • hand tools and welding equipment; • barges (e.g. 55 m and 73 m barges, jack-up barge) and tugs; • small, self-propelled vessel; • demolition saw, jackhammer, grinder; • generator/s, lighting tower; • forklift; • light vehicles and light trucks; and • heavy vehicles. The size of vehicles used for haulage would be consistent with the access route constraints, safety and any worksite constraints. Some construction activities (such as the delivery of precast sections) may require truck and trailer combinations or semi-trailers.
Access	Construction vehicles would access/egress the STP site via the following accesses: • Arthur Kane Drive, via either the northern end of the STP site, and/or the existing main STP entrance. Construction of the outfall pipeline would also utilise the following accesses: • Coraki Drive, Pambula (construction vehicles would enter the temporary beach access track from the end of Coraki Drive, before traversing the beach access track to the laydown area on Merimbula Beach); and • Port of Eden, Twofold Bay (barge/s would transport materials and equipment northward to the location of the proposed outfall pipeline alignment). Construction site accesses at Arthur Kaine Drive and Pambula Beach are shown in **Figure 2-5**. Construction materials and equipment could also be delivered to the Port of Eden using shipping containers, with construction vehicles expected to haul these containers to the construction sites via the Princes Highway.

2.3 Operational stage

The Project would be operated with the additional treatment processes which would improve the quality of the treated wastewater. Levels of total phosphorus, total suspended solids, biological oxygen demand, virus, bacteria and other pathogens would be managed to be within discharge limits. Treated wastewater would be tested for quality prior to discharge via the ocean outfall pipeline or via beneficial re-use offsite (to existing land application areas at the Oaklands agricultural area or the adjacent PMGC grounds). Maintenance activities for the STP and ocean outfall would also be undertaken and would continue until the STP is decommissioned or further upgraded in the future.

FIGURE 2-1: PROJECT AREA

Legend

Project area

Project area (temporary construction area)

Source: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

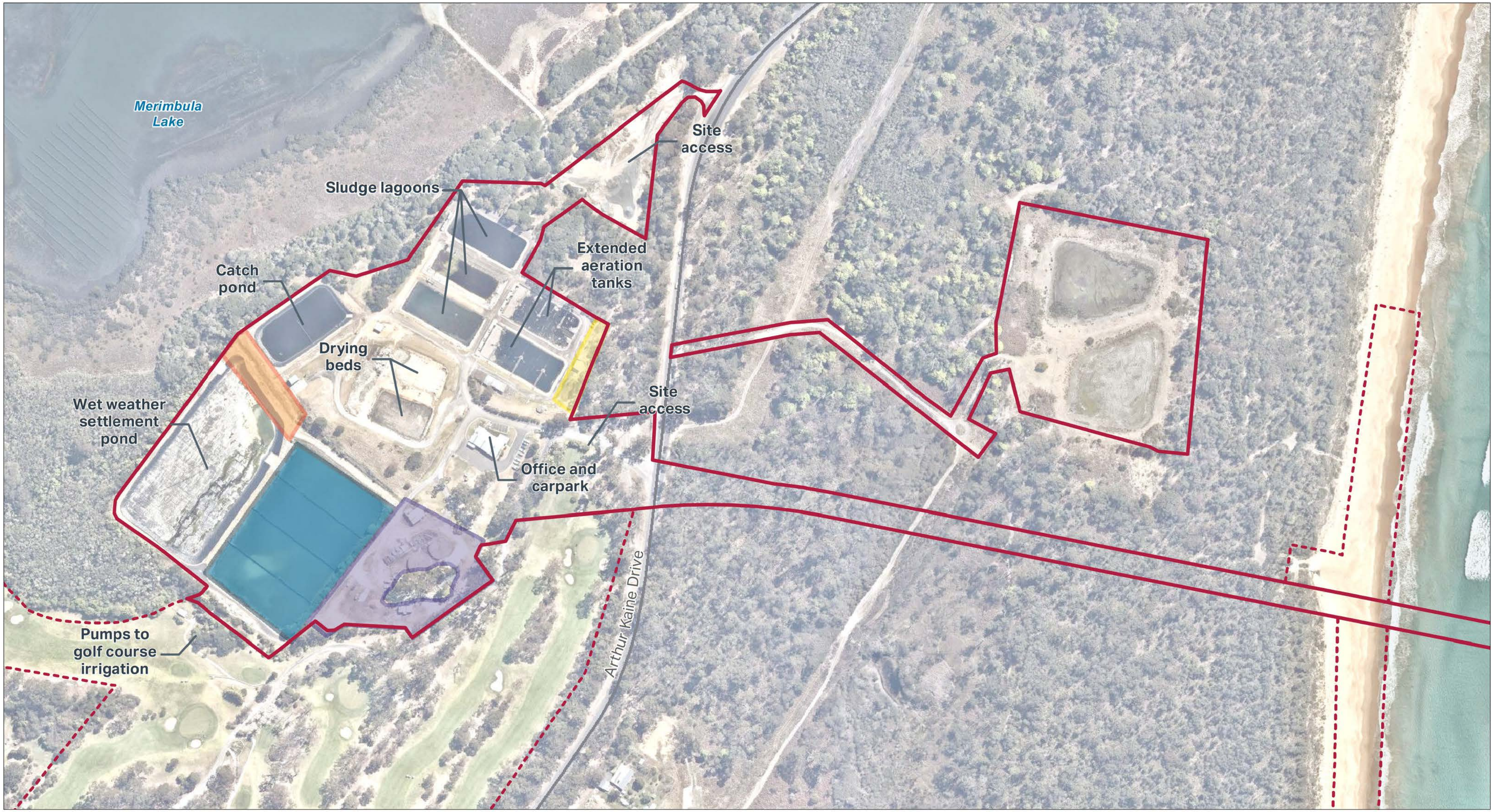

FIGURE 2-2: PROPOSED STP LAYOUT (INDICATIVE)

Legend

- Project area
- Project area (temporary construction area)

Proposed Project Upgrades

- PAC dosing, UV disinfection, tertiary treatment
- Pump stations, storage, chlorine disinfection
- PAC dosing (second unit)
- Effluent storage pond to be decommissioned

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Source: Nearmap, 2019

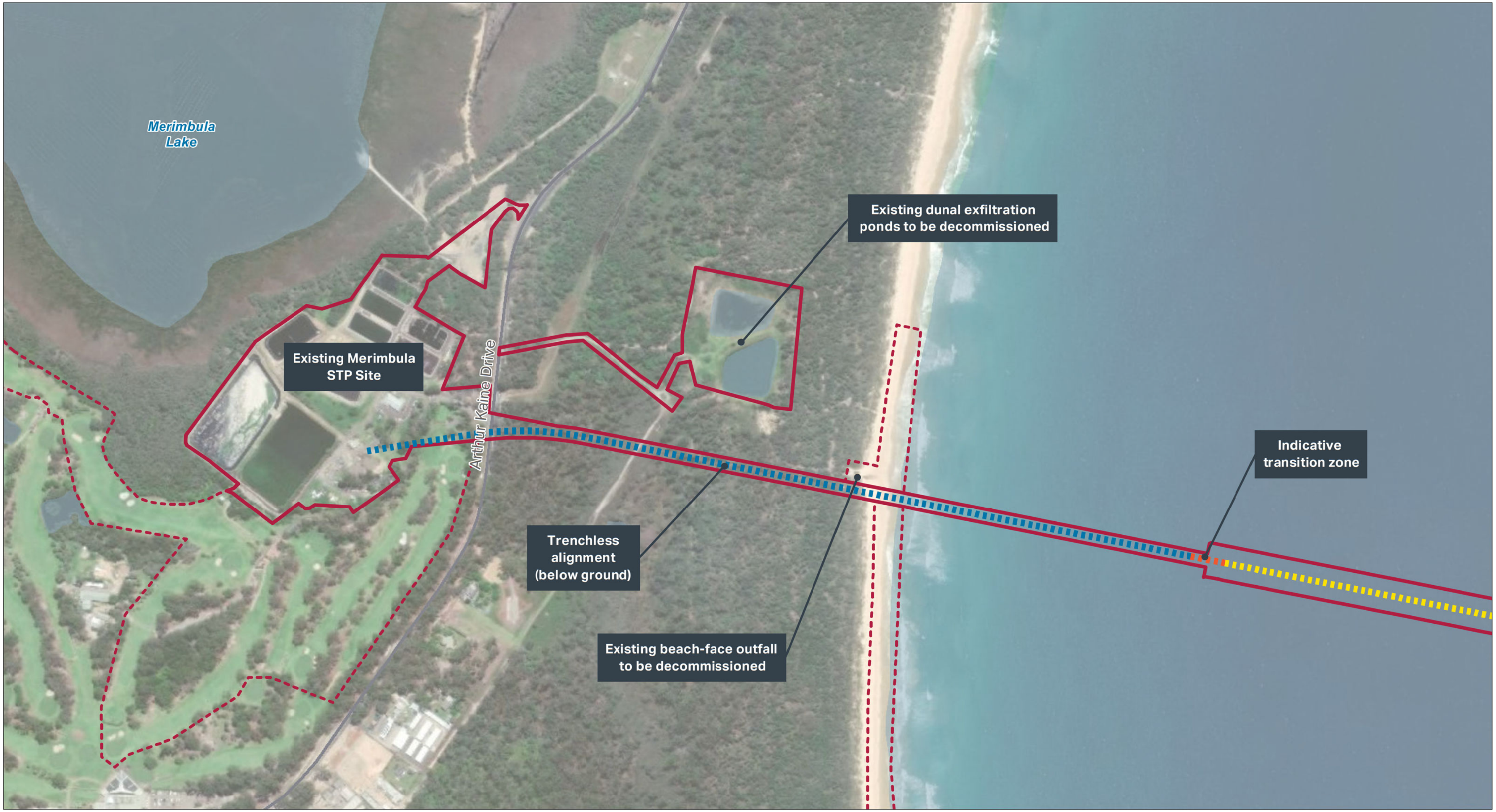

FIGURE 2-3: OCEAN OUTFALL PIPELINE - SECTION 1 (BELOW GROUND)

Legend

- Project area
- Project area (temporary construction area)
- Outfall pipeline – Section 1 (below ground)
- Transition Zone
- Outfall pipeline – Section 2 (above seafloor)

FIGURE 2-4 : OCEAN OUTFALL PIPELINE – SECTION 2 (ABOVE SEAFLOOR)

N

0 200 400 m

Legend

- Project area
- Project area (temporary construction area)
- Outfall pipeline – Section 1 (below ground)
- Transition Zone
- Outfall pipeline – Section 2 (above seafloor)
- Diffuser (above seafloor)

Source: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 2-5: CONSTRUCTION COMPOUND/LAYDOWN AREAS

Legend

- Project area
- Temporary project area for construction
- Construction access
- Construction compound/laydown area
- Construction laydown area and potential intermediate drilling site
- Construction laydown area at Pambula-Merimbula Golf Club grounds

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Source: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

3.0 Existing environment

3.1 Marine fauna

The Marine ecology assessment undertaken for the Project (refer **Chapter 11 Marine Ecology** and **Appendix G Marine Ecology Assessment**) provided a comprehensive review of marine fauna and the likelihood of occurrence in the Project area. A summary of the marine fauna considered likely to be found around the Project area is in **Table 3-1**.

Weighting groups for each species are classified according to the criteria set out in **Section 5.0**.

Table 3-1 Marine fauna around the Project area

Species name	Common name	Likelihood of occurrence[2]	Auditory weighting function[1]
Eubalaena australis	Southern right whale	High	LF
Megaptera novaeangliae	Humpback whale	High	LF
Orcinus orca	Killer Whale (Orca)	Moderate	HF
Delphinus delphis	Common Dolphin	High	HF
Tursiops truncatus	Bottlenose Dolphin	High	HF
Arctocephalus forsteri	New Zealand fur-seal	High	OCW
Arctocephalus pusillus	Australian fur-seal	High	OCW
Epinephelus daemelii	Black cod	Moderate	Fish – swim bladder involved in hearing
Thunnus macocoyii	Southern bluefin tuna	High	Fish – swim bladder involved in hearing
Syngnathiformes	Seahorses, pipefish, pipehorses, sea moths	Moderate	Fish – swim bladder involved in hearing

Notes:

1 *LF – low frequency; HF – high frequency; OCW - Other marine carnivores in water.*

2 *See section 13.3 of Appendix G Marine Ecology Technical Report.*

It should be noted that the likelihood of occurrence ratings are based on a set of pre-determined criteria (refer to **Chapter 11 Marine Ecology** and Section 13 of **Appendix G**) and as such some species may be classified as having a high to moderate likelihood of occurrence, due to a small number of previous recorded sightings in the area. However, despite the high to moderate rating, there are a number of species where the frequency of occurrence is very low and therefore the likelihood of encountering these species during project construction are considered rare, these include:

- Southern right whale - Smith (2001) has estimated the total number of southern right whales now visiting NSW in any one year to be less than ten. There are several records of the species occurring within Merimbula Bay with the most recent sighting in 2016. For the most part, sighting a southern right whale in Merimbula Bay could be considered a rare occurrence.
- Killer whale - The last sighting of a killer whale in the region was Twofold Bay in 2015, therefore this species is not expected to be a regular visitor to the Project area.
- Black cod - With only four confirmed sightings since 1972, the occurrence of a local viable population of black cod in the BVSC region can be considered rare, however suitable habitat is present within the Project area.
- Southern bluefin tuna - The species is usually observed in deep offshore waters along the continental shelf and rarely sighted within Merimbula Bay. However, in January 2018, a solitary Southern bluefin tuna was observed in the Pambula broadwater likely having followed baitfish up the river (Merimbula News Weekly, 16 January 2018).

A precautionary approach has been applied to the underwater noise assessment, to include all species determined as having a high or moderate likelihood of occurrence despite a low frequency of occurrence (as detailed above).

4.0 Underwater noise sources and hydroacoustics

4.1 Hydroacoustics

Hydroacoustics is the study and application of sound in water. The ocean is filled with a broad spectrum of both natural and anthropogenic sounds. **Table 4-1** lists a few of these noise sources. Physical processes such as turbulence associated with tidal currents are a significant source of ambient noise up to about 100 Hertz (Hz). In addition to these natural sources, anthropogenic sources also contribute to underwater noise, shipping being the dominant source of low-frequency anthropogenic noise.

Table 4-1 Natural and anthropogenic noise comparison

Noise Source	Maximum Source Level (Decibels (dB), Root Mean Square (RMS))
Underwater earthquake	272 dB
Seafloor volcano eruption	255+ dB
Lightning strike on sea surface	250 dB
Fin Whale	200 dB (avg. 155-186)
Container ship	198 dB
General commercial shipping	160-190 dB
Humpback whale	192 dB (avg. 175-190)
Supertanker	190 dB
Blue whale	188 dB (avg. 145-172)
Right whale	187 dB (avg. 172-185)
Open ocean ambient noise	72-100 dB

Source: Adapted from Heathershaw et al., 2001

Acoustics is defined as the physics of sound while the sub-discipline of hydroacoustics is defined as the physics of sound in water. In acoustics in general, the fundamental scientific model consists of a sound source, a receiver, and the propagation path between the two. The loudness of the sound source and obstructions or atmospheric factors affecting the propagation path to the receiver determines the sound level and characteristics of the sound (noise) perceived by the receiver.

Sound typically is described by pitch and loudness. Pitch is the height or depth of a tone or sound, depending on the relative rapidity (frequency) of the vibrations by which it is produced. Loudness is the intensity of sound waves combined with the reception characteristics of the auditory system. Intensity may be compared with the height of an ocean wave because it is a measure of the amplitude of the sound wave. Acoustics addresses primarily the propagation and control of sound.

In addition to the concepts of pitch and loudness, several noise measurement scales are used to describe the sound. A decibel (dB) is a unit of measurement describing the amplitude of sound; a dB is equal to 20 times the logarithm to base 10 of the ratio of the pressure of the sound measured to the reference pressure. For underwater sounds, a reference pressure of 1 micro pascal (μPa) is commonly used to describe sounds in terms of decibels. Therefore, 0 dB on the decibel scale would be a measure of a sound pressure of 1 μPa. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, and 30 decibels is 1,000 times more intense and so forth.

The number of sound pressure peaks traveling past a given point in a single second is referred to as the frequency, expressed in cycles per second or Hertz (Hz). The amplitude of pressure waves generated by a sound source determines the perceived loudness of that source. Sound pressure amplitude is measured in µPa. One µPa is approximately one hundred billionths (0.00000000001) of normal atmospheric pressure. Sound pressure amplitudes for different kinds of environments can range from less than 100 µPa to 100,000,000 µPa. Because of this huge range of values, sound is rarely expressed in terms of pressure. Instead, a logarithmic scale is used to describe sound pressure level (SPL) in terms of dB. Sound intensity for underwater applications is typically expressed in dB referenced to 1 µPa.

The primary sound level metrics for impulsive sound sources are peak sound pressure level (peak SPL), root mean square sound pressure level (RMS SPL), and sound exposure level (SEL). These metrics for underwater sound are calculated on a logarithmic scale relative to a standard reference pressure of 1 µPa (equal to 10-6 Pa or 10-11 bar) expressed in decibels (dB). The peak pressure is the highest absolute value of the measured waveform and can be a negative or positive pressure peak. The RMS SPL level is determined by analysing the waveform and computing the average of the squared pressures over the time that makes up that portion of the waveform containing the vast majority of the sound energy (Richardson et al., 1995). SEL is an acoustic metric that provides an indication of the amount of acoustical energy contained in a sound event. Typically, SEL is measured for a single strike and a cumulative condition.

4.2 Hydroacoustic parameters

Underwater sound source levels are defined as the SPL at a reference distance of 1metre (m) from the point source (dB re 1 µPa at 1m). Depending upon the type of source, whether impulsive or constant, a variety of acoustic metrics[1] can be used to describe the sound source:

- Peak - The highest weighted or un-weighted instantaneous peak to peak noise level from an event.
- RMS (root mean square) - This is the square of the amplitude at each instant of a time-varying sound, averaged over the period of interest and the square root taken. There is a direct relationship between the RMS and the energy of the sound for non-impulsive sources.
- SEL (Sound Exposure Level, L_{ZE}) - Defined as the mean square sound pressure of an event normalized to a standard time interval, i.e. one second. It is a useful way of comparing the 'sound energy' of different sound events and sources of varying durations. SEL is the constant sound level in one second, which has the same amount of acoustic energy as the original time-varying sound (i.e., the total energy of an event). SEL is calculated by summing the cumulative pressure squared over the time of the event.
- SEL_{cum} (Cumulative Sound Exposure Level, $L_{E,24h}$) - This considers both the received level and the duration of the exposure. In contrast to SEL (time period of 1 second), the SEL_{cum} accounts for the accumulated exposure over the duration of the activity within a 24-hour period (although SEL_{cum} can be for shorter periods). It is intended for individual activities / sources, rather than a general accumulation of all sources. For impulsive sources the SEL_{cum} considers the number of events.

The propagation of underwater noise is complex but is similar to the behaviour of noise propagating through air. The difference between noise propagation in air versus noise propagation in water is the media in which noise travels through and defined boundaries that water creates (e.g. water, surface water, and seafloor). These boundaries substantially affect noise propagation characteristics in water.

[1] Metrics have been notated according to ISO 18405:2017 Underwater acoustics -- Terminology

Hydroacoustic sound is produced by natural sources underwater, such as snapping shrimp, lightning strikes, and breaking waves. Commercial vessels and recreational boats produce high levels of underwater sound. Large tankers and naval vessels produce up to 198 dB, depth sounders can produce up to 180 dB, and commercial sonar operates in a range of 150 to 215 dB. Even small boats with large outboard motors can produce sound pressure levels in excess of 175 dB. **Table 4-1** provides ambient sound level data for various noise sources. In terms of hydroacoustics, these sounds are described by the RMS.

Another measure of the pressure waveform that can be used to describe the pulse is the sound energy itself. The total sound energy in the pulse is referred to in many ways, such as the "total energy flux" (Finerran et al., 2002). The "total energy flux" is equivalent to the unweighted SEL for a plane wave propagating in a free field, a common unit of sound energy used in airborne acoustics to describe short-duration events, referred to as dB re 1µPa2-sec. Peak pressures and RMS sound pressure levels are expressed in dB re 1 µPa. The total sound energy in an impulse accumulates over the duration of that pulse. A common unit of total sound energy used in underwater acoustics to describe short-duration events is SEL. Typically, peak intensity, RMS, and SEL are used by resource agencies to assess the effects of underwater noise on marine mammals and fish.

4.3 Effects of hydroacoustic noise

Improved understanding of underwater sound and its potential to affect marine life along with an increase in anthropogenic (human) activity that introduces sound into the marine environment has raised concerns about the potential impacts on marine organisms. Anthropogenic underwater sounds have increased steadily in many regions of the global marine environment over the past decades due to increased shipping, fishing, recreation and oil and gas activity. For example, over the past 75 years the number of global merchant ships may have tripled, and in deep water it has been suggested that background noise seems to be growing by around three to five decibels per decade in the sound frequency band occupied by commercial ships (Jasny et al., 2005).

However, the potential negative impacts on marine species related to rising levels of anthropogenic underwater sound are not well understood. Knowledge of the impacts of underwater sound on marine species is complicated by a number of factors, including:

- difficulties associated with working with large marine organisms;
- differences between species and individual variability within a species;
- separation of responses to natural sounds (e.g. waves, wind, precipitation, lightning calls from other marine organisms, and other causes);
- challenges with consistently measuring underwater sounds; and
- an incomplete understanding of which aspects of sound (frequency, rise time, sound pressure level, sound energy level, and others) are important.

While ambient background noise levels tend to be consistent and widespread across large areas of ocean, anthropogenic produced sounds often form localized noise sources. These localized noise sources, if sufficiently loud, may be detrimental to certain marine species under some circumstances. The degree of impact will be influenced by many factors, including the sound's persistence, amplitude and frequency, the distance between the sound source and marine life, and the sensitivity of marine life to the combination of these factors. Although sensitivity will vary between and, often to a lesser degree, within species of marine life, the outcome of these interactions may result in physical harm or behavioural changes.

4.4 Hearing sensitivities of marine mammals

The hearing ability of marine mammals is commonly described using audiograms; this is a plot of the hearing sensitivity of a species at different frequencies, which indicates the range of frequencies detectable by a species and can highlight where hearing is most sensitive. The hearing threshold can be defined as the received sound level in the vicinity of the ear that is just audible to an animal. Hearing thresholds depend on the frequency of the sounds and can vary strongly across species. An audiogram displays the hearing threshold as a function of frequency. A lower sound pressure level value on an audiogram display reflects a lower hearing threshold at a given frequency and hence a higher auditory sensitivity (this means that even a very weak sound could still be audible to the animal). Audiograms in mammals are typically U-shaped reflecting the fact that hearing sensitivity declines towards the edge of the hearing range.

Audiograms are typically derived experimentally and can be based on behavioural or electrophysiological responses to tonal sound stimuli. Studies on the hearing sensitivity in marine mammals are usually carried out on captive animals and as a consequence, audiograms are unavailable for the majority of species. Furthermore, audiograms have been calculated for a limited number of individual animals and consequently may not capture the variation in auditory ranges or most sensitive frequencies across the entire species. However, despite the lack of data on the hearing sensitivities of many marine mammals at the species level, it is possible to make some generalizations about higher taxonomic levels.

In assessing the potential for behavioural impacts from exposure to a noise source, sensation levels are commonly used in combination with a reference threshold (e.g. an audiogram). The sensation level is the sound pressure level by which a stimulus exceeds the hearing threshold. Equal sensation levels can be expected to roughly cause similar loudness perception. Using sensation levels in calculations can be expected to be comparable to A-weighting procedures used in humans (dBA).

To assess zones of behavioural avoidance, the level of sound weighted by a species (or species group composite) audiogram can be investigated to determine how an animal might be perceived and be impacted by exposure to a noise source.

4.5 Impacts of noise on marine mammals

Marine mammals spend most, or all, of their lives at sea, and the majority of that time is spent submerged. Sound propagates efficiently through the water and marine mammals rely on the use of sound to communicate with other animals, for predator avoidance, mate selection, and social interactions (Janik, 2009; Rendell and Whitehead, 2004; Schulz et al., 2008). Additionally, most odontocete (toothed whales, dolphins, and porpoises) species produce echolocation clicks for orientation, navigation, and to detect prey (Au et al., 2004; Hastie et al., 2006; Madsen et al., 2005a; Madsen et al., 2005b). Coupled with this, they have an acute sense of hearing with high sensitivity over a wide frequency range (Southall et al., 2007). This reliance on sound in their general ecology makes marine mammals particularly vulnerable to the effects of underwater noise.

Any anthropogenic noise could impact a marine mammal if the sound falls within its audible range; noise disturbance can have a range of effects depending on the sound type or source level. Loud, intense noise sources such as explosions have the potential to cause lethal physical non-auditory injury to marine mammals, while other noise sources can cause auditory damage or elicit behavioural responses (e.g. displacement and/or habitat exclusion) (Richardson et al., 1995).

4.5.1 Behavioural response

The zone of behavioural response is defined as the region surrounding the sound source within which a marine mammal exhibits an observable response (Richardson et al., 1995). While the physical process of detecting or being damaged by a sound can be predicted from a combination of empirical studies and acoustic models, this is generally not the case for behavioural responses. The reactions of an individual animal to a particular stimulus will be impacted by many factors, including life-history stage, nutritional state (hungry or satiated), behavioural state (foraging, resting, migrating, etc.), reproductive state (pregnant, lactating, juvenile, mature), location, and conditioning from previous exposure history.

Previous studies have documented changes in the distribution and behaviour of marine mammals when they are exposed to acoustic stimuli. Studies have investigated reactions to a variety of noise sources, including vessel traffic, seismic exploration, and construction noise. For many free-ranging marine mammals, behavioural responses to acoustic stimuli can be challenging to observe, and precise measurement of received sound levels can be difficult to obtain. Furthermore, interpretation of the biological consequences of the observed results is limited by uncertainty as to what constitutes a meaningful response at the individual-, population- and species-level. Short-term behavioural responses may become biologically significant if animals are exposed for sustained periods of time (Bejder et al., 2006). For these reasons, caution should be exercised when assessing the potential for behavioural disturbance.

4.5.2 Auditory injury

Hearing damage results in a loss of sensitivity and occurs first as a short-term shift in the hearing threshold that is recovered from, referred to as a temporary threshold shift (TTS) in hearing. If the sound exposures are of high- or moderate-intensity over a long temporal period, then the threshold shift can be permanent. This is called a permanent threshold shift (PTS), whereby hearing is damaged permanently. There is also the potential for exposure to very loud sounds to cause non-auditory tissue damage, which can be fatal. For impulsive sounds, the intensity, rise time, pulse duration, pulse repetition rate, and duration of exposure can all affect the timing and extent of TTS and PTS (Richardson et al., 1995). Cumulative sound exposure levels (SELcum) have been used to predict the onset of auditory injury (Southall et al., 2007) and have been used in this assessment to determine the potential auditory impacts of marine species being exposed to sounds generated by project activities. It is a measure of the total sound energy to which an animal is exposed over a given time period. Given that SELcum is expressed as a logarithmic function, it does not increase linearly with time and most of the noise dose occurs at the start of the exposure, beyond which the SEL effectively approaches an asymptote. However, it should be considered that studies of TTS in marine mammals all used small sample sizes (i.e. low number of individuals tested) in a controlled, captive setting in investigating the practical potential for TTS/PTS, and the patterns observed in captivity may be different in the marine environment and vary between individuals impacted.

Although noise exposure criteria for auditory injury ideally should be based on exposures empirically shown to produce PTS-onset, no experiments to directly determine the threshold for PTS have been performed on marine mammals. PTS is therefore estimated from the rate at which the degree of TTS increases with increasing sound exposure levels (Southall et al., 2007).

4.6 Marine mammals and noise frequency

The potential for anthropogenic noise to impact marine species depends on how well the species can hear the sounds produced. Noises are less likely to disturb animals if they are at frequencies that the animal cannot hear well. For low-level sound, frequency weighting based on audiograms may be applied to weigh the importance of sound levels at particular frequencies in a manner reflective of the receiver’s sensitivity to those frequencies (Nedwell et al., 2007).

Based on a review of literature on marine mammal hearing and physiological and behavioural responses to anthropogenic sound, Southall et al. (2007) proposed standard frequency-weighting functions (referred to as M-weighting functions), for five functional hearing groups of marine mammals. These are shown on **Figure 4-1** and include:

- low-frequency cetaceans: include mysticetes (baleen whales);
- mid-frequency cetaceans: include some odontocetes (toothed whales);
- high-frequency – include odontocetes (i.e., porpoises, river dolphins, and the genera Kogia and Cephalorhynchus);
- pinnipeds (i.e., seals, sea lions, and walruses) listening in water; and
- pinnipeds listening in air.

The amount of discount applied by M-weighting functions for less-audible frequencies is less than that indicated by the corresponding threshold-audiograms for member species of these hearing groups. The rationale for applying a smaller discount than suggested by audiograms is due in part to an observed characteristic of mammalian hearing that perceived equal loudness curves increasingly have less rapid roll-off outside the most sensitive hearing frequency range as sound levels increase. This is why C-weighting curves for humans, used for assessing loud sounds such as blasts, are flatter than A-weighting curves, used for quiet to mid-level sounds. Additionally, out-of-band frequencies, though less audible, can still cause physical injury if pressure levels are sufficiently high. The M-weighting functions, therefore, are primarily intended to be applied at high sound levels where impacts such as temporary or permanent hearing threshold shifts may occur. The use of M-weighting should be considered precautionary (in the sense of overestimating the potential for impact) when applied to lower-level impacts such as the onset of behavioural response. **Table 4-2** shows the decibel frequency weighting of the four underwater M-weighting functions. M-weighting is a generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths and appropriate in characterising auditory effects of strong sounds.

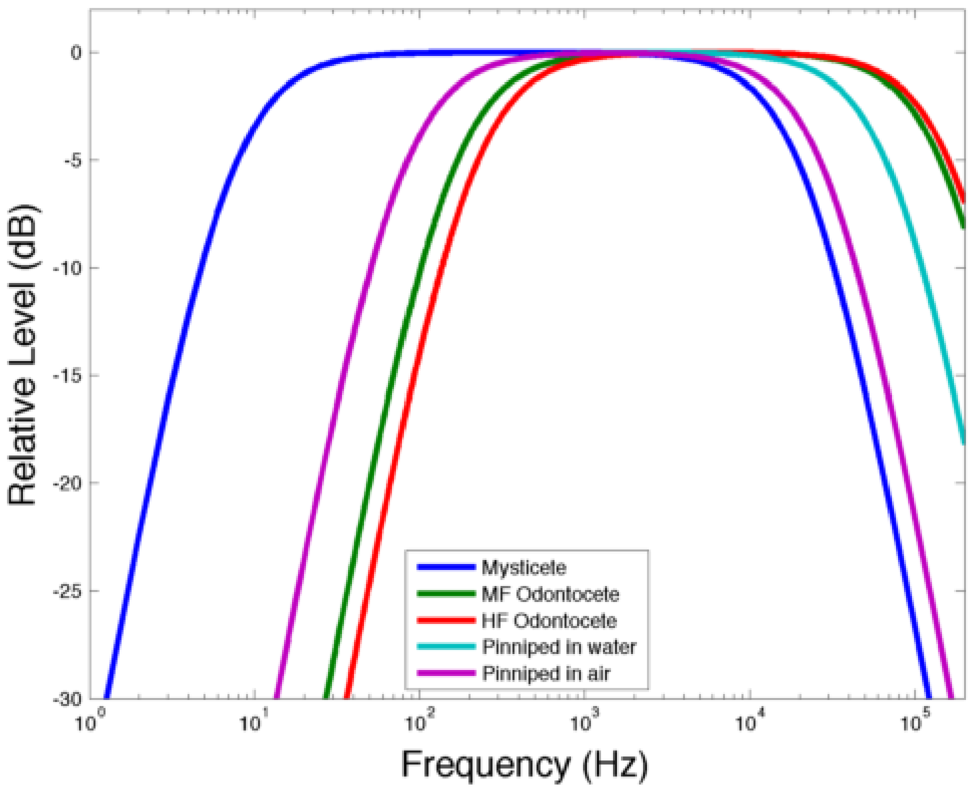

Figure 4-1 Standard M-weighting functions for the low-, and mid-, and high-frequency cetacean, and pinnipeds in water functional marine mammal hearing groups

Source: Southall et al., 2007.

The M-weighting functions have unity gain (0 dB) through the pass band and their high and low frequency roll-offs are approximately –12 dB per octave. The amplitude response in the frequency domain of the M-weighting functions is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{f_{lo}^2}{f^2}\right)\left(1+\frac{f^2}{f_{hi}^2}\right)\right]$$

The roll-off and passband of these functions are controlled by the parameters f_{lo} and f_{hi}; the estimated upper and lower hearing limits specific to each functional hearing group (refer **Table 4-2**).

Table 4-2 Low and high frequency cut-off parameters of the M-weighting functions for each marine mammal functional hearing group

Functional hearing group	f_{lo} (Hz)	f_{hi} (Hz)
Low-frequency cetaceans	7	22,000
Mid-frequency cetaceans	150	160,000
High-frequency cetaceans	200	180,000
Pinnipeds in water	75	75,000

4.7 Fish species

The way fish perceive noise can be categorized as “generalists” (e.g. trout) and “specialists” (e.g. herring). Generalists detect noise directly in the inner ear and by sound energy from the swim bladder (gas-filled structure). Specialists have evolved several mechanisms to detect noise coupled with the swim bladder. Sound waves, or noise, stimulate the swim bladder which in turn re-radiates noise energy by exciting the adjacent particles that are detectable by the inner ear. Specialists have increased hearing sensitivity and thus, are more susceptible to elevated noise levels (Caltrans, 2015). Potential effects on fish from anthropogenic sounds can include both behavioural responses (Hawkins et al., 2014) and auditory injury (Hastings, 1998; Hastings and Popper, 2005).

5.0 Methodology

5.1 Study area

The study area considered for this assessment includes the offshore section of the proposed outfall pipeline alignment and an area that encompasses distances from the source of underwater noise generating sources as they relate to impact thresholds for relevant marine fauna species.

5.2 Underwater noise exposure criteria

5.2.1 Marine mammals

Standard criteria for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals are presented in a study on marine mammal noise exposure criteria prepared by Southall et al (2019)[2].

In this study, marine mammals are classified into frequency weighting groups, dependant on estimated audiograms. Temporary threshold shift (TTS) and permanent threshold shift (PTS) criteria are then presented for each frequency weighting group.

Widely accepted criteria for behavioural changes in marine mammals are presented in NMFS 2013[3], i.e. 120 dB re 1 µPa^2 RMS for non-impulsive noise sources.

Based on the marine fauna identified in the Project area in **Section 3.1**, underwater criteria used in this assessment are presented in **Table 5-1**.

Table 5-1 Marine mammal underwater noise criteria

Marine mammal hearing group	Permanent threshold shift, dB re 1 µPa^{2}s SEL_{cum} 24hr, weighted	Temporary threshold shift, dB re 1 µPa^{2}s SEL_{cum} 24hr, weighted	Behavioural change, dB re 1 µPa^2 RMS SPL, unweighted
Low-frequency cetaceans (LF) - whales	199	179	120
High-frequency cetaceans (HF) - dolphins	198	178	120
Other marine carnivores in water (OCW) - seals	219	199	120

It is noted that the naming of some of the frequency weighting groups in Southall et al (2019) differs to widely used frequency weighting groups in past studies, e.g. NMFS (2016)[4]. Between these studies, the same weighting functions are applied between the HF group in Southall et al (2019) and the MF group in NMFS (2016), despite the difference in naming. Other naming of frequency weighting groups between the two studies remains consistent.

[2] Southall, B., Finneran, J., Reichmuth, C., Nachtigall, P., Ketten, D., Bowles, A., Ellison, W., Nowacek, D. and Tyack, P., 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals, 45(2), pp.125-232. https://www.aquaticmammalsjournal.org/index.php?option=com_content&view=article&id=1886:marine-mammal-noise-exposure-criteria-updated-scientific-recommendations-for-residual-hearing-effects&catid=174&Itemid=326

[3] National Marine Fisheries Services (NMFS), 2013, Marine mammals: Interim Sound Threshold Guidance (webpage), National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce., http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html

[4] National Marine Fisheries Services (NMFS), 2016, Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-55, 178 pp.

5.2.2 Fish species

Popper et al[5] presents noise criteria for shipping and continuous sounds on fish. **Table 5-2** sets out criteria for injury, impairment and behaviour change for fish from continuous noise sources.

Table 5-2 Noise criteria for fish (Source: Popper et al, 2014)

Type of Animal	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
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 is 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) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB rms for 48 h	158 dB rms for 12 h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low

Notes: RMS sound pressure levels 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).

Source: Popper et al (2014): Table 7.7 Shipping and continuous sounds. For the most part, data in this table are based on knowing that fish will respond to sounds and their hearing sensitivity, but, as discussed in the text, there are no data on exposure or received levels that enable guideline numbers to be provided.

Fish species are grouped according to the biological mechanism used for hearing:

- fish – no swim bladder;
- fish – swim bladder is not involved in hearing; and
- fish – swim bladder is involved in hearing.

For the study the criteria proposed for fish species is the 'fish - swim bladder involved in hearing', as it is the most stringent for all scenarios and represents a conservative approach. Noise impacts on fish in the Project area have therefore been assessed according to the 'fish – swim bladder involved in hearing' criteria.

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[5] Popper A. N., Hawkins A. D., Fay R. R., Mann D. A., Bartol S., Carlson T. J., Coombs S., Ellison W. T., Gentry R. L., Halworsen M. B., Lokkeborg S., Rogers P. H., Southall B. L., Zeddies D. G. and Tavolga W. N., 2014, ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. https://link.springer.com/book/10.1007%2F978-3-319-06659-2

Criteria for mortality/potential mortal injury, masking and behavioural changes are classified according to distance from the noise sources. Three groupings of distances are proposed in Popper et al (2014) – near, intermediate, and far, and shown in **Table 5-3**. Exact distances are not provided as the effects will vary depending on site-specific conditions, however the distance groupings can generally be classified according to the following:

- near: within tens of metres of the sound source;
- intermediate: within hundreds of metres of the sound source; and
- far: within thousands of metres of the sound source.

Criteria for recoverable injury and TTS are expressed in terms of exposure to RMS noise levels over a given time period.

Table 5-3 Criteria for noise effects on fish species (source: Popper et al, 2014 – Table 7.7)

Type of animal	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS[5]	Masking	
Fish: swim bladder involved in hearing (primarily pressure detection)	(Near[1]) Low (Intermediate[2]) Low (Far[3]) Low	170 dB rms[4] for 48 hr	158 dB rms for 12 hr	(Near) High (Intermediate) High (Far) High	(Near) High (Intermediate) Moderate (Far) Low

Notes:

1. near: within tens of metres of the sound source.

2. intermediate: within hundreds of metres of the sound source.

3. far: within thousands of metres of the sound source.

4. rms – root mean square

5. Temporary Threshold Shift (TTS) – short term reversible hearing.

6.0 Underwater noise levels during construction of the outfall pipeline

6.1 Construction activities

6.1.1 Description of construction activities taking place

The pipeline would extend approximately 2.7 km offshore in Merimbula Bay. The pipeline would be constructed via underground trenchless drilling out to approximately 150 m from the shore, after which the remaining length will be laid on the seabed via barges. The pipeline would be anchored down by rocks or concrete mattresses.

Only those construction stages that would contribute to underwater noise emissions have been considered in this assessment (note that other land-based construction activities have been considered in the noise and vibration impact assessment for airborne noise, provided in **Appendix L** of the EIS). Project construction stages are shown in **Table 6-1**.

Table 6-1 Project construction stages

Stage	Description of activities	Noise emitting plant/equipment involved	Duration	Timing[1]
Stage 5 – Directional drilling and pulling	Stage 5, Option D - Offshore based drilling rig: • barge to site from Port Eden. • establishment of drilling rig approx. 150 metres offshore, past the surf zone (i.e. where the underground section of the pipeline would emerge and join to the aboveground section of pipeline on the sea floor). Drilling would be in an eastbound direction. Pipe strings would be located on land-side on Merimbula Beach/or at STP/golf course site. • mobilisation of drill rig and equipment/machinery to site from Port Eden, including drilling fluid recycling unit set up • directional drilling and pulling (pulling would likely be done continuously over 48 hours and therefore involve 'out of standard hours' work).	• directional drill rig on jack up barge • drilling fluid recycling unit on barge • hand tools / welding gear • generators	2.5 months, up to 4.5 months depending on drilling method/ locations used	Standard construction hours, plus out of hours work (evening and night-time work) for pulling (i.e. 48 hours or more continuous)

Stage	Description of activities	Noise emitting plant/equipment involved	Duration	Timing[1]
Stage 6A - Offshore Pipeline riser/exit works	• barge to offshore location • install pipeline riser (if required) in seabed at end of directionally drilled pipeline section using micro-piling • install exit casing and/or exit pit or a temporary exit mound on the seabed at the riser to prevent drilling fluid blow out	• welding gear/hand tools • jack-up barge (only required for exit casing (or if drill rig operation is marine based)) • micro-piling rig on barge • 73 m barge • 55 m supply barge Anchor handling tug supply (AHTS) vessel • excavator • drill rig	3 months	Standard construction hours and out of hours work (evening and night-time works)
Stage 6C[2] - Lay pipe strings for above ground offshore section	• float out and progressively sink pipe strings for above ground offshore section, including: - loading 400-500 m pipe lengths onto 73 m barge at Port Eden or beach laydown area - tow out to installation location - progressively lower pipe strings to seabed	• 73 m barge with crane/pipe handler to lower pipe • 2 x small self-propelled vessels to assist • excavator with attachment (to load pipes onto barge)	1 month	Up to 24 hours
Stage 6D[2] - Cover above-ground offshore pipeline	• covering offshore pipeline using barges to lower rock or concrete mattresses to cover pipeline • an anchored vessel such as a small barge would act as the target vessel for the rock barges to tie up alongside and dump rock into a chute fixed to the target vessel	• 73 m barge • 55 m barge • anchored vessel / small barge	1 month	Up to 24 hours

Stage	Description of activities	Noise emitting plant/equipment involved	Duration	Timing[1]
Stage 6E[2] - Diffuser works	• float diffuser out to offshore location, sink it, cover/protect it	• 73 m barge • 55 m barge • anchored vessel / small barge	<1 month	Up to 24 hours
Stage 7 - Commissioning (all new components)	• operating pump stations • operating new STP components • pipeline pigging • barge operation	• hand tools • barge (up to 120 ft) with tug or self-propelled dive vessel	2 to 5 months	Standard construction hours

Notes:

1: Certain works may need to occur outside standard daytime hours for the safety of workers and in accordance with transport licence requirements. Activities to be carried out during these periods may include oversized load deliveries. Approval would be required for any out of hours work and the affected community would be notified.

2: Marine work in Stages 6C, 6D and 6E may require extended hours and weekend work to take advantage of favourable conditions.

6.1.2 Construction noise sources considered in underwater noise model

Only those construction plant / equipment that would contribute to underwater noise emissions have been considered in the underwater noise modelling. For rock dumping/placement of concrete mattresses, the UK Department of Energy and Climate Change (DECC) report references a study by Nedwell and Edwards (2004) where sound from rock placement for pipeline protection was measured. This study observed that noise was dominated by the vessel and not by rock dumping activities. For the purposes of this assessment, it is assumed that this would also be the case if the pipeline was anchored via rock or concrete mattresses.

Source levels for the 73 m barge, 55 m barge and anchor handling tug supply barges were taken from a report for the UK Department of Energy and Climate Change (DECC) compiling underwater sound source levels from oil and gas activities[6].

A summary of the noise sources used in the underwater noise model is provided in **Table 6-2**. This combination of noise sources is a worst-case scenario and considered conservative (i.e. represents the loudest sound power levels that would be experienced at any one time with respect to the construction stages described in **Table 6-1** above).

Table 6-2 Noise sources used in underwater noise model (worst case total sound power level)

Noise source	Activity	Depth	Reference
Directional drilling, micro piling	Drilling	Seafloor	Hannay et al. 2004
73 m barge	Supporting operations	Near surface	McCauley 1998
55 m barge	Supporting operations	Near surface	Patterson et al. 2007
Anchor handling tug supply barge	Performing anchor pull	Near surface	Hannay et al. 2004

[6] Review and Assessment of Underwater Sound Produced from Oil and Gas Sound Activities and Potential Reporting Requirements under the Marine Strategy Framework Directive. 2011. Genesis Oil and Gas Consultants report for the Department of Energy and Climate Change.

Due to a scarcity of data available for underground drilling activities and micro-piling activities, noise data for drilling in the context of oil and gas activities was used in the noise model as an approximation. This is a conservative approach as it is not expected that noise levels from micro-piling and underground drilling in this Project would exceed those for drilling in the context of oil and gas projects and activities.

6.2 Modelling and software

Underwater sound levels were modelled using the commercially available software package, dBSea version 2.2.5. The dBSea program models three-dimensional transmission losses along evenly distributed radial transects from the sound source (so-called N×2D modelling). The propagation methodology consists of a set of algorithms that calculates transmission loss based on a range of factors, including:

- distance between the source and receiver;
- basic ocean parameters, including depth and bathymetry;
- geoacoustic properties of sediment type; and
- temperature-depth sound speed profile (SSP).

The computational complexity of the model depends upon the number of transects and the spacing between calculation points. Between individual transects and calculation points, dBSea interpolates the results to enable sound level contours to be produced.

6.2.1 Solver settings

The modelling was performed using two available dBSea algorithms: a low-frequency acoustic algorithm based on modes, followed by a high frequency ray tracing algorithm. The crossover frequency was set at the default of 500 Hz with the overall modelling frequency bandwidth set from 12.5 Hz to 10 kHz.

Although the hearing range of cetaceans extends above this range, sound energy associated with the activities are expected to be predominantly within this frequency range and significantly lower at higher frequencies. In addition, sound attenuation increases with frequency. Considering these factors, propagation of higher frequency sound is not considered to be significant.

The dBSeaModes solver first calculates normal modes for specified water depths based on SSP and sediment properties, then calculates the sound field based on coupling between the calculated modes across the interfaces. dBSeaModes is suitable for low frequency sound sources in shallow water.

The ray solver algorithm forms a solution by tracing rays from the source out into the sound field. Rays leave the source covering a range of angles, and the sound level at each point in the receiving field is calculated by summing the components from each individual ray. dBSeaRay is suitable for high frequency sound sources.

6.2.2 Bathymetry

Bathymetry contours in the local area around the outfall pipeline were provided by the project team. Bathymetry contours at a resolution of 50 m for deep-water areas 30 km from the coastline were obtained from an Australian government database[7].

The two bathymetry sources were combined, and contours between the two datasets were interpolated. This bathymetry dataset was then used in the dBSea underwater noise model.

6.2.3 Seabed

A geophysics report was prepared by Marine & Earth Sciences[8]. The report identified fine to medium-grained uncemented sediments for the first two metres below the seabed along the pipeline alignment. Below this, loose to dense unconsolidated sediment was identified. No borehole data was available.

[7] 50 m Multibeam Dataset of Australia 2018, Commonwealth of Australia (Geoscience Australia), https://data.gov.au/dataset/ds-ga-e07f5621-3f99-441a-9580-c27a72de24d4/details?q=
[8] "Phase 2 – Merimbula Ocean Outfall Project – Geophysical Study", prepared by Marine & Earth Sciences, September 2019

Based on the data available, the seabed was modelled as sand with infinite thickness. Because sand is reflective in shallow water, this is considered to be a conservative approach.

6.2.4 Other modelling parameters

Default values for salinity (35 parts per thousand (ppt)), temperature (8°C) and SSP (constant 1,500 metres per second (m/s) to depth) were assumed as no detailed information for these parameters was available. Assumption of these values are reasonable given the shallow water depth in the Project area. Modelling results

6.2.5 Safety / Exclusion zones for marine fauna

The criteria presented in **Section 5.1** and the underwater noise sources presented in **Section 6.1.2** were used in the underwater noise model, which subsequently generates exclusion zones for marine fauna.

Table 6-3 shows the distance at which the threshold level for specific hearing groups would be met. These distances inform the appropriate safety / exclusion zones for PTS, and TTS and potential behavioural change that should be implemented as part of mitigation measures.

Table 6-3 Summary of PTS and TTS zones for marine mammals

Species weighting group	Permanent threshold shift (PTS) exclusion zone	Temporary threshold shift (TTS) observation	Behavioural change zone
Low-frequency (LF)	170 m	2.3 km	16 km
High-frequency (HF)	N/A	85 m	16 km
Other marine carnivores in water (OCW)	N/A	70 m	16 km

The results show for species in the low-frequency range (humpback and southern right whales), Project noise would be above the PTS threshold within 170 m of Project activities; the TTS threshold would be exceeded within 2.3 km and the behavioural threshold would be exceeded within 16 km. For species in the high-frequency range (common and bottlenose dolphins and killer whales), Project noise would not exceed the PTS threshold and the TTS threshold would be exceeded within 85 m and the behavioural threshold within 16 km. Also, for other marine carnivores in water (Australian and New Zealand fur seals), Project noise would not exceed the PTS threshold and the TTS threshold would be exceeded within 70 m and the behavioural threshold within 16 km.

The zones of potential noise impact for TTS and PTS auditory response are shown as distance radii modelled from source noise at the end of the diffuser structure and illustrated in **Appendix A.** These distance radii apply to construction activities occurring along the entire 2.7 km pipeline, not just the end of diffuser and represent the following safety and exclusion zones:

- **Zone of potential hearing injury (Exclusion zone)** – An exclusion zone is based on the threshold for PTS onset. If a LF cetacean (southern right and humpback whales) is observed swimming towards or within the designated exclusion zone, work would immediately cease, until the animal has cleared the area. Potential for physiological impact such as PTS to LF cetaceans is modelled to potentially occur within a 170 m radius of the noise source. This exclusion zone would only be applicable during the period LF cetaceans are likely to be encountered in the Project area (June to November). PTS thresholds for HF cetaceans and other marine carnivores are not anticipated to be exceeded as result of the Project. Therefore, for works undertaken outside of June to November each year, no exclusion zone would be required.

- **Zone of potential responsiveness (Safety zone)** – A safety zone is based on the threshold for TTS onset. For LF cetaceans this zone is 2.3 km. Outside of the LF cetacean occurrence (June to November), the safety zone would be a conservative 500 m. If a marine mammal is observed swimming within the safety zone it's behaviour and direction of travel would be monitored, and if seen swimming into the exclusion zone work would be ceased (when it is safe to do so) until the animal is clear of the exclusion zone. For HF cetaceans (dolphins) and other marine carnivores (seals), behaviour within this zone would be monitored and recorded, no shut down of activities would be required.

6.2.6 Impact on fish

A summary of the impact on fish species against the relevant criteria set out in **Section 5.2.2** is provided in **Table 6-4**.

Table 6-4 Summary of impacts on fish species

Mortality and potential mortal injury	Impairment			Behaviour
	Recoverable injury	TTS	Masking	
Near: Low risk Intermediate: Low risk Far: Low risk	110m zone	120m zone	Near: High risk Intermediate: High risk Far: High risk	Near: High risk Intermediate: Moderate risk Far: Low risk

As shown in **Table 6-4**, above, for fish species, Project noise would be above the recoverable injury threshold within 110 m from the noise sources of Project activities; and the TTS threshold would be exceeded within 120 m. These thresholds have been used to inform the marine ecology assessment and associated mitigation measures (refer **Appendix G** of the EIS (management and mitigation measures are presented in Section 15)).

7.0 Underwater noise levels during operation of the outfall pipeline

During operation, a pump would be used to push wastewater down the pipeline, however this would not be located underwater, and would be located at the eastern extent of the pipeline within the STP site. The pump would also be within a housing designed for noise mitigation. For these reasons the ocean outfall pump is not expected to generate any notable underwater noise emissions during operation of the ocean outfall, and there is not expected to be any other underwater noise emissions generated during typical operation of the Project.

Maintenance activities for the ocean outfall pipeline would include monitoring, inspections, cleaning and repairs as required, including:

- measurement and recording pipeline flow and hydraulic head;
- underwater visual inspections by divers and/or remote operated vehicles (ROV) periodically and as required (e.g. annually);
- cleaning accumulated sediment/grease and/or other impediments by periodically flushing (increasing flow through the pipeline) and/or pigging, and/or physically removing marine organisms growing/accumulating around the diffuser (e.g. barnacles); and
- corrosion repairs by divers (e.g. physically removing corrosion/strengthening or replacing any components subject to corrosion such as fasteners, joints, fittings or anchors).

Maintenance activities for the ocean outfall pipeline would be periodic only (e.g. annually or bi-annually; and less than every 5 year intervals), and undertaken over small periods of time (typically hours or days). These activities may generate minor underwater noise emissions at times (e.g. from a single vessel accessing the ocean outfall pipeline, use of remote operated vehicle/s, or use of hand held tools for corrosion repairs). Underwater noise impacts from periodic maintenance activities are expected to be negligible to minor.

8.0 Mitigation and management measures

The results of this underwater noise assessment have been used in the marine ecology assessment undertaken for the Project. Associated mitigation and management measures for marine ecology are found in Section 15 of **Appendix G Marine ecology assessment** of the EIS. General underwater noise mitigation measures are recommended bel The approach to managing potential impacts related to underwater noise is described below.

8.1.1 Performance outcomes

The underwater noise performance outcome for the Project is as follows:

- safety zones are implemented during construction to mitigate hearing injury to marine mammals.

The Project would be designed, constructed and operated to achieve this performance outcome.

8.2 Mitigation and management measures

Table 8-1 presents the mitigation and management measures which should be implemented as part of the Project.

Table 8-1 Mitigation and management measures

ID	Mitigation and management measure	Applicable location(s)
Construction		
NVU1	A CNVMP would be prepared as part of the CEMP and would include measures for minimising underwater noise emissions. The CNVMP should include general feasible and reasonable work practices as identified in 'Section 6 Work practices' of the *Interim Construction Noise Guideline* (ICNG) (Department of Environment and Climate Change (DECC), 2009). The CNVMP would include the following measures as a minimum: • undertake works during standard construction hours where practicable; • works undertaken between June and November during the whale migration period (Southern Right and Humpback Whale southern migrations) would be avoided where possible, or otherwise minimised; if work is required within this period adopt a safety shut-down zone of 170 m and a safety watch zone of 2.3 km where work activity would either be temporarily halted or varied in event that a LF cetacean occurs within these zones; • Works undertaken outside of June to November, will implement a safety watch zone of 500 m where marine mammals (dolphins and seals) will be observed and recorded (no shut down zone is required); • vessels are to have a trained marine mammal observer onboard during all underwater noise generation activities, to record observations of when a cetacean or pinniped enters the 2.3 km safety watch zone. All marine fauna sightings are to be recorded; • prior to commencing noise disturbance activities, the watch zone is to be clear of marine mammals for a period of at least 10 minutes; • all injured marine mammals should be immediately reported to ORRCA (02 94153333) and National Parks and Wildlife Service Merimbula office (02 64955000); and • implement vessel speed limits to reduce vessel noise.	Merimbula Bay / Section 2 of the ocean outfall pipeline (i.e. offshore section)

9.0 Conclusion

This underwater noise (hydroacoustic) assessment has been prepared to determine the predicted underwater noise levels that would be produced from the construction and operation of the offshore components of the Project (i.e. the offshore portion of the ocean outfall pipeline). The results of this assessment have also been used in the marine ecology assessment undertaken for the Project (refer **Chapter 11** and **Appendix G** of the EIS). For construction, a conservative approach was taken where the worst-case scenario was assumed for use in underwater noise modelling. Exclusion zones for permanent threshold shift (PTS), temporary threshold shift (TTS) and behavioural change were calculated with the noise model, and a summary of the impact on fish species against the applicable criteria has been provided. During operation, the Project is not expected to generate any notable underwater noise emissions.

Based on the modelling outputs:

- the largest predicted observation zone for temporary threshold shift is for marine mammals in the low-frequency weighting group and will extend up to 2.3 km from the offshore pipeline construction works. This is reduced to a conservative 500 m for high frequency cetaceans and other marine carnivores in water;
- the only predicted exclusion zone for permanent threshold shift is for marine mammals in the low-frequency weighting group and will extend up to 170 m from the offshore pipeline construction works. No exclusion zone is required for high frequency cetaceans or other marine carnivores in water;
- behavioural changes to marine species may occur up to 16 km from the offshore pipeline construction works; and
- general mitigation measures to reduce underwater noise emissions should be included in the CNVMP for the Project.

With the implementation of mitigation measures, the impact of underwater noise on sensitive marine receptors is considered to be low.

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11.0 Glossary and abbreviations

Term	Description
AHTS	Anchor handling tug supply
μPa	Micro pascal
dB	decibel
dBA	a-weighted decibel
DECC	Department of Energy and Climate Change
EIS	Environmental Impact Statement
HF	High frequency
Hz	Hertz
LF	Low frequency
LGA	Local government area
NMFS	National Marine Fisheries Service
OCW	Other marine carnivores in water
PAC	Poly Aluminium Chloride
PTS	Permanent threshold shift
RMS	Root mean square
RMSSPL	Root mean square sound pressure level
SEL	Sound exposure level
SEL_{cum}	Cumulative Sound Exposure Level
SPL	SPL – sound pressure level
SSP	SSP – sound speed profile
STP	Sewage treatment plant
TTS	Temporary threshold shift
UV	Ultraviolet

Appendix A

Exclusion Zone Maps

AECOM

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- Low Frequency TTS
- Low Frequency PTS
- High Frequency TTS
- Other Marine Carnivores in Water TTS

SHEET TITLE

Temporary and Permanent Threshold Shift Exclusion Zones

PROJECT

Merimbula Ocean Outfall

CLIENT

Bega Valley Shire Council

PROJECT NUMBER

60541653

DATE

28/10/2020

Sheet number

1

SPATIAL REFERENCE

1:20,000 (A3 size)

0 0.1 0.2 0.4 0.6 Kilometers

Map features depicted in terms of GDA 1994 MGA Zone 55 coordinate system

PROJECT MANAGEMENT

Approved		Date	28/10/2020
Checked		Date	28/10/2020
Designed		Date	28/10/2020
Drawn		Date	28/10/2020

Service Layer Credits: Hybrid Reference Layer: Vicmap, Esri, HERE, Garmin, METI/NASA, USGS
World Imagery: Maxar